Original Article

The Lisbon Agreement on femoroacetabular impingement imaging. Part 2: general issues, parameters, and reporting

ABSTRACT

Aims: Imaging assessment for the clinical management of femoroacetabular impingement (FAI) syndrome is controversial because of a paucity of evidence-based guidance and notable variability among practitioners. Hence, expert consensus is needed, because standardised imaging assessment is critical for clinical practice and research. We aimed to establish expert-based statements on FAI imaging by using the formal methods of consensus-building. This is the second part of a three-part consensus series, and focuses on 'General issues' and 'Parameters and reporting'.

Methods: The Delphi method was used to formally derive consensus among 30 panel members from 13 countries. Forty-four questions were agreed upon, and relevant seminal literature was circulated and classified in major topics ('General issues', 'Parameters and reporting', 'Radiographic assessment', 'Magnetic resonance imaging (MRI)' and 'Ultrasound') to produce answering statements. The level of evidence was noted for all statements, and panel members were asked to score their level of agreement (0–10). Either 'group consensus', 'group agreement', or 'no agreement' was achieved.

Results: Forty-seven statements were generated and group consensus was reached for 45. Twenty-five statements pertaining to 'General issues' (nine addressing diagnosis, differential diagnosis and postoperative imaging) and 'Parameters and reporting' (16 addressing femoral/acetabular parameters) were produced.

Conclusions: The first international Delphi-based consensus on FAI imaging was developed. The available evidence was reviewed critically, recommended criteria for diagnostic imaging highlighted, and the roles of different imaging parameters assessed. The resulting statements can serve as a tool for practitioners working with hip-related pain to reduce clinical variability and guide further research for FAI management.

Key points

- Radiographic evaluation (anteroposterior radiograph of the pelvis and a lateral view of the hip, preferably a Dunn 45° view) with a reproducible methodology is the cornerstone of hip-imaging assessment and minimum imaging study that should be performed when assessing adult patients for FAI.
- In selected cases, cross-sectional imaging is warranted because MRI with a dedicated protocol is the 'gold standard' imaging modality for the comprehensive evaluation, differential diagnoses assessment, and surgical planning of FAI.
- For acetabular morphology, coverage (centre-edge angle of Wiberg and acetabular index) and version (crossover, posterior wall, and ischial spine signs) should be assessed routinely. On the femoral side, the morphology of the head–neck junction (alpha angle and offset), neck morphology (neck-shaft angle) and torsion (antetorsion angle) should be assessed routinely.

Clinical Relevance

- Imaging assessment for FAI is unstandardised because of a paucity of evidence-based guidance and lack of consensus among experts on which imaging modalities, diagnostic criteria, and parameters should be used/assessed routinely. This Delphi-based consensus, aims to establish evidence-based statements/recommendations on the imaging diagnosis, parameters, differential diagnosis, and postoperative imaging of FAI.
- Thorough analyses of imaging parameters are paramount to identify osseous morphologies consistent with FAI and to exclude other structural disorders. MRI allows for further characterisation of hip morphology and chondro-labral disease, as well as evaluation of differential diagnoses. The resulting consensus can serve as a tool to reduce variability in clinical practice and guide further research for FAI management.

Keywords

Hip; Femoroacetabular impingement; Diagnostic imaging; Orthopaedics; Guideline

Abbreviations

3D - three dimensional

α° - alpha angle

AI - acetabular index

AF - acetabular fossa

AP - anteroposterior

AW- anterior wall

CEA - centre-edge angle

COS - cross-over sign

CT - computed tomography

CTA - CT arthrography

dMRA - direct MR arthrography

ESSR - European Society of Musculoskeletal Radiology

FAI - femoroacetabular impingement

FAIS - femoroacetabular impingement syndrome

FH - femoral head

FHN - femoral head-neck

FO - femoral head-neck offset

FOV - field-of-view

FT- femoral torsion

HPS - hip preservation surgery

ISS - ischial spine sign

L-CEA - Lateral centre-edge angle

MRI - magnetic resonance imaging

MRA - magnetic resonance arthrography

NSA- neck-shaft angle

OA - osteoarthritis

PWS - posterior wall sign

RefInt - reference intervals

W-CEA - centre-edge angle of Wiberg

INTRODUCTION

Femoroacetabular impingement (FAI) is a motion-related clinical disorder associated with a triad of groin/hip pain, signs of limited motion, and characteristic imaging findings[1–3]. It results from a conflicting contact between the proximal femur and the acetabular rim[1,4]. FAI has been associated with pain, functional impairment and can, ultimately, lead to premature osteoarthritis of the hip[5]. However, it is imperative to understand that FAI is a dynamic phenomenon and not a static imaging diagnosis. Characteristic osseous morphologies (Cam/Pincer) are necessary to diagnose FAI[3], but many individuals with these morphologies are asymptomatic[4,6], which warrants caution if interpreting imaging studies[7].

Hip pain and FAI remain controversial in terms of 'true' incidence, diagnosis, prognosis and management[2–4]. There is no consensus regarding the preoperative diagnostic assessment and case definition of FAI. However, several research groups have put forth guidelines to better define FAI and to facilitate diagnosis and treatment[2,3].

Imaging is a pivotal part of the diagnostic workup for FAI. The ultimate goals of imaging are diagnosing hip morphology, detecting osteoarthritis signs, appreciating associated soft-tissue damage, and assessment of differential diagnoses[3,8,9]. Accordingly, different imaging methods, along with a multitude of imaging parameters,[8,10] are used in clinical practice. Previous work has reinforced the importance of radiographs on the initial assessment of FAI, and advocated the use of cross-sectional imaging to further assess hip morphology as well as cartilage and labral lesions[3,8,11].

With regard to imaging parameters, the alpha angle (α°) and femoral torsion (FT), two of the most commonly cited quantitative parameters of the femur[12], are controversial mainly owing to their proposed thresholds and methods of assessment[10,13,14]. On the acetabular side, evaluating version and coverage on radiographs has been reported to have limited reliability[15–17], with potential repercussions on patient care. Given the multitude of signs and evolving concepts used in hip-preservation imaging, choosing which imaging parameters and criteria to use can be challenging.

Imaging assessment for FAI is unstandardised because of a paucity of evidence-based guidance. There is no consensus among experts on which imaging modalities, diagnostic criteria, and parameters should be assessed routinely[8,18]. The aim of this Delphi-based consensus is to establish evidence-based statements using formal methods of consensus-building among an expert group. The current work, which belongs to a three-part series, presents recommendations on the imaging diagnosis, parameters, differential diagnosis, and postoperative imaging of FAI.

METHODS

Given the paucity of high-level evidence for assessment of FAI-related imaging, clinical consensus is lacking. Accordingly, collecting experts' opinions using formal methods of consensus development, such as the Delphi method, is an acceptable way of creating practice recommendations[19,20]. This method involves a sequence of discussion rounds to determine experts' opinions on controversial topics, drafted on the basis of the existing literature to produce a final consensus agreement.

This consensus is a part of a collaborative project aimed at establishing expert-based statements on FAI imaging. Full details of the Delphi method, including (1) participants, (2) consensus method, (3) literature review, (4) drafting of statements and level of evidence, (5) final scoring, (6) data analyses, and (7) paper drafting are reported as Supplementary Material. Evidence levels set by the Oxford Centre for Evidence-based Medicine were applied[21].

Briefly, after project conception (VVM, MOC, and PDA), the process was started with a first meeting during the European Society of Musculoskeletal Radiology (ESSR) 2018 congress in Amsterdam (the Netherlands). This was followed by four Delphi rounds, culminating in an open meeting at ESSR 2019 held in Lisbon (Portugal), giving rise to the 'Lisbon agreement on FAI imaging'.

Following the first overview paper ('The Lisbon Agreement on femoroacetabular impingement imaging. Part 1: overview' by Mascarenhas et al., submitted in December 2019 to *European Radiology*), two additional detailed manuscripts address and discuss all produced statements (Part 2 and Part 3). This manuscript corresponds to Part 2 of the consensus, focusing on 'General issues, parameters and reporting'.

Approval of the study protocol by our Institutional Review Board was not required because patients were not involved.

RESULTS AND DISCUSSION

Delphi process

Thirty panellists comprised (21 musculoskeletal radiologists and 9 orthopaedic surgeons) this consensus initiative. Nineteen (90.4%) of the radiologists had more than 10 years of experience of musculoskeletal imaging, and 18 had special dedication and/or expertise in hip imaging. All orthopaedic surgeons had more than 10 years of experience in hip-preservation surgery (HPS). Twenty-six participants (6 orthopaedic surgeons and 20 radiologists) completed all survey rounds.

Forty-seven statements were generated and distributed among the topics 'General issues' (9 statements) (Table 1), 'Parameters and reporting' (16) (Table 2), 'Radiographic assessment' (8), 'Magnetic resonance imaging (MRI) evaluation' (12) and 'Ultrasound' (2). At the end of the Delphi process, 'group consensus' was obtained for 45 statements. In the following paragraphs, we present the statements concerning Part 2, followed by a summary of the panel's discussions.

Statements and recommendations

The pathway for the imaging management and assessment of suspected FAI (Figure 1), along with statements on the diagnosis, differential diagnoses and postoperative imaging of FAI (Table 1), were put forth by the panel.

TABLE 1. Statements on diagnosis, differential diagnosis, and post-operative imaging of femoroacetabular impingement (FAI) with evidence levels. The listed levels of agreement represent the percentage of votes ≥8 on a 0-10 scale. All listed statements obtained group consensus. AP: anteroposterior. COS: crossover sign. CT: computed tomography. CTA: CT arthrography. FHN: femoral head-neck. IQR: interquartile range. ISS: ischial spine sign. LOE: Level of evidence. MRI: magnetic resonance imaging. MRA: MR arthrography. PWS: posterior wall sign. Q1: 1st quartile. Q3: 3rd quartile. T: Tesla. W-CEA: Wiberg centre-edge angle.

Type of statement	Statement	LOE	Median IQR (Q1-Q3) Level of agreement
DIAGNOSIS			
How should imaging studies in an asymptomatic hip with FAI-related morphology be reported?			
Diagnosis	The radiologist should not state that abnormal signs and parameters are indicative of FAI in an asymptomatic patient.	5	**10** **0 (10-10)** **96%**
What should be the minimal acceptable imaging to support the clinical diagnosis of FAI?			
Diagnosis	An AP radiograph of the pelvis and a lateral view of the hip are the minimum imaging studies that should be performed when assessing patients for FAI.	4	**10** **0 (10-10)** **96%**
PINCER AND CAM CRITERIA			
What are the imaging criteria for defining Cam morphology?			
Interpretation	The main imaging criterion for defining Cam morphology is an alpha angle >60° at any location around the anterosuperior FHN junction. Other measurements are used to a lesser extent, such as the head-neck offset and offset ratio.	2	**10** **1.5 (8.5-10)** **96%**
	For defining Cam morphology in a research setting (regardless of the symptomatic state), the following criteria may be used: a) Osseous convexity of the FHN junction OR b) Alpha angle ≥ 60° OR c) FHN offset < 8 mm AND FHN offset ratio ≤ 0.15	5	**9** **1 (9-10)** **96%**
What are the imaging criteria for defining Pincer morphology?			
Interpretation	Pincer morphology can be due to acetabular retroversion and/or overcoverage. Criteria for retroversion on imaging are a cross-over sign, posterior wall sign, or ischial spine sign. Overcoverage is indicated by *protrusio acetabuli*, W-CEA ≥ 40° or acetabular index < 0°.	4	**10** **1.5 (8.5-10)** **100%**
	For defining Pincer morphology in a research setting (regardless of the symptomatic state), the following criteria may be used: a) **Global Pincer**: - Protrusio acetabuli OR W-CEA ≥ 40° - W-CEA ≥ 35° AND acetabular index < 0° - Positive COS AND PWS AND ISS (global retroversion) b) **Focal Pincer**: Positive COS OR Cranial acetabular version < 0°	5	**9,5** **1 (9-10)** **100%**
DIFFERENTIAL DIAGNOSIS			
Should we be more comprehensive in looking for other extra-articular causes of pain?			
Diagnosis	Potential extra-articular sources of hip pain should always be sought clinically when assessing patients with FAI; in selected cases, cross-sectional imaging is warranted.	3	**10** **0.25 (9.75-10)** **100%**
POST-OPERATIVE IMAGING			
How should the postoperative FAI patient be imaged?			
Post-operative	Radiographs are the initial imaging modality for evaluating symptoms following FAI surgery. MRI, MRA and, occasionally, CT (or CTA), should be used if the symptoms are not explained by the radiographs and/or if further anatomical information is desired.	5	**10** **0.25 (9.75-10)** **93%**
Post-operative control: which imaging outcome measures should be used to assess surgical treatment for FAI?			
Post-operative	Following FAI surgery, the underlying Cam-type and/or Pincer-type morphology, as well as the potential radiographic progression of hip osteoarthritis, should be assessed appropriately.	3	**9** **2 (8-10)** **93%**

* level of evidence 5 represents expert opinion

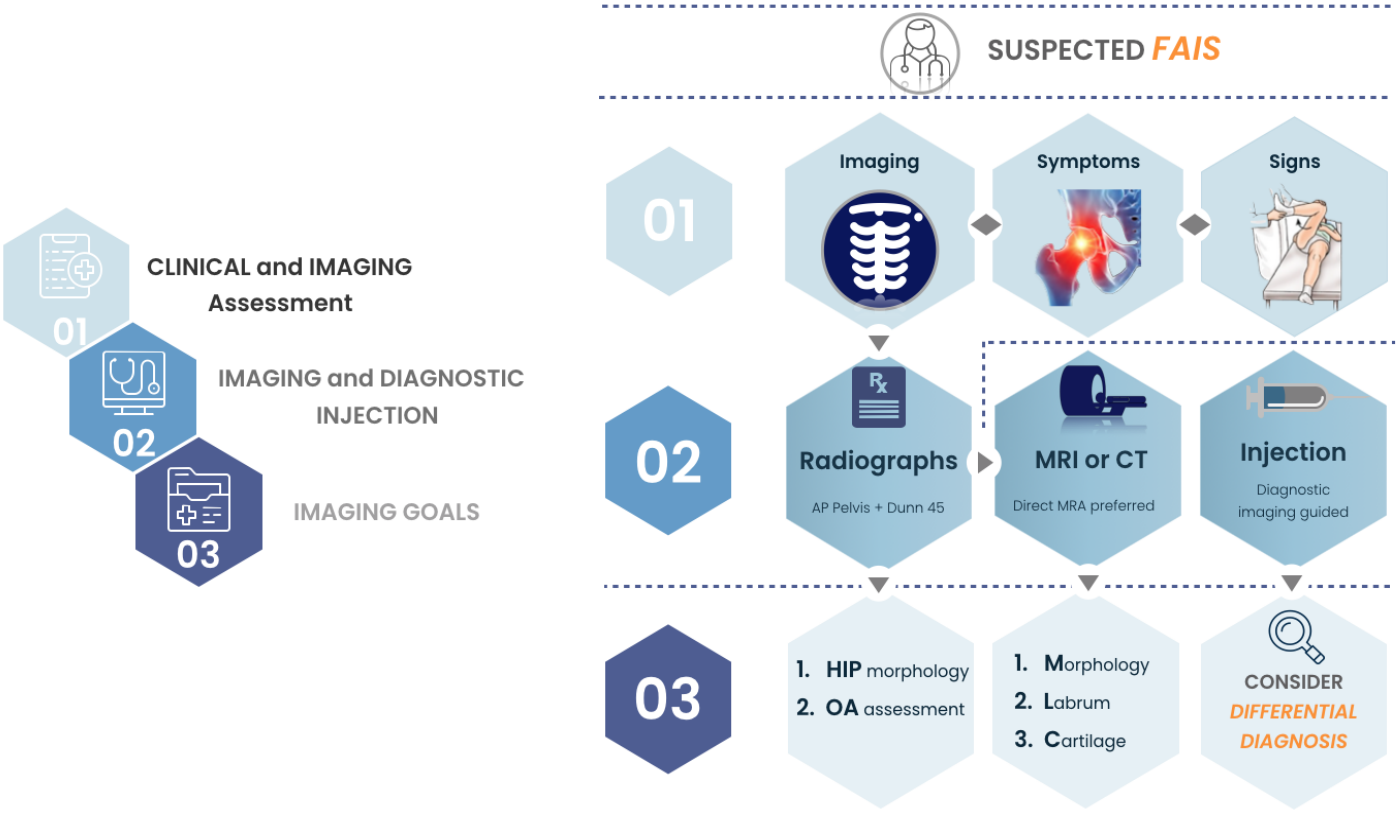


FIGURE 1. Pathway for the imaging management and assessment of femoroacetabular impingement syndrome (FAIS). An AP pelvis radiograph and a lateral femoral neck view of the symptomatic hip should be initially performed to assess pelvis and hip morphology (namely identify Cam or Pincer morphologies). Frequently, if exclusion of other causes of hip pain or if further assessment of hip morphology and associated cartilage/labral lesions is warranted, cross-sectional imaging is appropriate to thoroughly appreciate differential diagnosis. In doubtful cases, diagnostic hip injections may be necessary to confirm the hip as the source of pain. OA: osteoarthritis.

1. DIAGNOSES and IMAGING

Statement: *An anteroposterior radiograph of the pelvis and a lateral view of the hip are the minimum imaging studies that should be performed when assessing patients for FAI.*

Radiographs should be used as first-line assessment of suspected FAI because they allow an overall evaluation of the pelvis and hips, as well as exclusion of other causes of symptoms[3,8,22]. Conjointly, radiographs and MRI are the preferred imaging modalities used to characterise hip

pathomorphology and treatment planning[8,10,22].

For an initial diagnostic approach, standard imaging should include two radiographs: an anteroposterior (AP) view of the pelvis and a lateral view of the hip[3,8,10]. The shape and orientation of the acetabulum may be assessed on the AP radiograph, though the morphology of the proximal femur is best assessed on the orthogonal view of the femoral neck[3,8,11,23] (Figure 2). Femoral head-neck (FHN) asphericity in hips with FAI is most often localised in the anterosuperior region[6,9,24]. Although not accepted unanimously, these asphericities are usually best shown with a Dunn 45° view (hips in 45° of flexion and 20° of abduction)[25–27].

FAI syndrome is a dynamic phenomenon in which a structurally predisposed hip with minimal activity may become symptomatic and, conversely, a structurally normal hip may become symptomatic only with extreme activity[2,22]. Accordingly, in clinical practice, providing definite criteria to establish the diagnosis of FAI is challenging. However, in research and clinical-trial settings, specific group classification using imaging criteria is important to establish homogeneous study groups. Accordingly, based on published evidence and panel consensus, Pincer and Cam criteria are suggested (Table 2).

a) CAM criteria

Statement: *The main imaging criterion for defining Cam morphology is an alpha angle >60° at any location around the anterosuperior FHN junction. Other measurements are used to a lesser extent, such as the head-neck offset and offset ratio.*

Statement: *A threshold of 60° is recommended for the alpha angle because higher values are reported to be clinically more relevant. An anterior femoral offset <8 mm may be regarded as 'abnormal'.*

Since the original description of the α°[12], there has been much debate regarding its thresholds, though current evidence suggests that the α° should be defined according to the FHN location and sex[3,6,13,24]. Based on cross-sectional studies (comparing asymptomatic individuals with Cam-type FAI patients) and on the natural course of FAI (short- and mid-term osteoarthritis progression in symptomatic hips with an α° >60°), an α° threshold of 60° may be recommended (at any location)[6,24,28,29]. Furthermore, recent research suggests that a Cam morphology with α° measurements above 57°–60° at the 1:30- to 2-o'clock position is probably symptomatic. Using

this threshold would optimise discriminative power while favouring specificity[29,30]. Nevertheless, caution is recommended because several patients with Cam morphology have signs of impingement with an α° <60°, whereas others above that cut-off value will remain asymptomatic[4,13,30]. Considering that substantial overlap exists, additional clinical and imaging variables should be investigated, such as combination with certain anatomical factors (e.g. decreased FT, acetabular morphology, spinopelvic parameters), sex and athletic performance[4,30,31]. Other measurements are used to a lesser extent, such as the FHN offset (FO) and offset ratio[32–35]. Only limited data exist for the anterior FO, although a value of <8 mm has been reported as 'abnormal'[32,34,36]

b) PINCER criteria

Statement: *Pincer morphology can be due to acetabular retroversion and/or overcoverage. Criteria for retroversion on imaging are a crossover sign, posterior wall sign, or ischial spine sign. Overcoverage is indicated by protrusio acetabuli, W-CEA ≥40° or acetabular index <0°.*

Imaging signs of Pincer morphology include markers of increased acetabular coverage and of abnormal acetabular version. Caution is warranted when interpreting radiographs because pelvic tilt and rotation are known to affect some of these parameters (particularly AP coverage and retroversion)[37]. Although generally supported by the literature[38] and by this panel, further research is needed to define more precisely the value of radiographic signs in the diagnosis of Pincer morphologies, as well as the clinical relevance of cross-sectional imaging in this setting.

TABLE 2. Criteria proposed by the panel for classifying Pincer and Cam morphology in a research/clinical trial setting (regardless of the symptomatic state). FHN: femoral head-neck. W-CEA: Wiberg centre-edge angle. COS: cross-over sign.

<table>
<tr><th colspan="3">IMAGING CLASSIFICATION CRITERIA for hip morphology</th></tr>
<tr><th rowspan="2">Cam morphology</th><th colspan="2">Pincer Morphology</th></tr>
<tr><th>GLOBAL PINCER+</th><th>FOCAL PINCER+,‡</th></tr>
<tr><td rowspan="2">Osseous convexity of the FHN junction*
OR
Alpha angle ≥ 60°*
OR
FHN offset < 8 mm AND FHN offset ratio ≤ 0.15**</td><td>Protrusio acetabuli
OR
W-CEA ≥ 40°
OR
W-CEA ≥ 35° AND acetabular index < 0°</td><td rowspan="2">Positive COS++
OR
Cranial acetabular version < 0° +++</td></tr>
<tr><td>Positive COS
AND
Posterior Wall Sign
AND
Ischial Spine Sign
(Global RETROVERSION)</td></tr>
</table>

** at any location around the FHN junction. Evaluation using radiography (preferably assessed by an AP Pelvis and Dunn 45°), CT or MRI (with radial imaging/reformats).*

*** usually used at an anterior location around the FHN junction (3 o´clock). Evidence is scarce to support its use in other FHN locations. Evaluation using radiography (preferably assessed by a cross-table view), CT or MRI (with radial imaging/reformats).*

‡ corresponding to cranial retroversion in non-dysplastic hips.

+ evaluation of standardized AP pelvic radiographic images is required.

++ confirmation of the presence of acetabular retroversion using CT or MRI may be recommended due to false positive COS in pelvic radiographs.

+++ evaluation using MRI or CT (adequately centred and corrected for tilt on the coronal plane and rotation in the axial plane).

2. DIFFERENTIAL DIAGNOSES

Statement: *Potential extra-articular sources of hip pain should always be sought clinically when assessing patients with FAI; in selected cases, cross-sectional imaging is warranted.*

The need for advanced cross-sectional imaging to diagnose FAI has, paradoxically, been challenged[39]. However, comprehensive imaging is crucial to assess intra- and extra-articular disease[30] as well as for surgical planning. Interestingly, a significant prevalence of sacroiliac and pubic symphysis abnormalities has been reported on imaging in FAI patients. Considering that several conditions can mimic and/or frequently coexist with FAI, if other potential causes of hip pain are not considered, patients may fail to improve after surgery or conservative treatment[40–42] (Table 3). Diagnostic injections may prove useful to confirm the hip as the source of symptoms[43] (Figure 1).

TABLE 3. Differential diagnosis of FAI-related pain: an overview of possible causes of intra-articular and extra-articular causes of hip pain.

INTRA-ARTICULAR	PERI-ARTICULAR	MIMICKERS
FAI	**Muscle and Tendon-related pathology** -Iliopsoas related-pathology -Iliotibial band injury -Other	**Axial skeletal pathology** -Lumbar spine pathology -Sacroiliac joint pathology -Spondyloarthropathies
Instability and Microinstability		
Osteoarthritis	**Stress fracture** -Femoral neck or Acetabulum -Pubic ramus	**Pubic-related pathology** -Groin pain in athletes -Osteitis pubis
Non-FAI related -Chondrolabral injuries -Loose bodies -Ligamentum teres pathology -Capsular laxity	**Greater trochanteric pain syndrome** -Gluteus medius or minimus pathology -Trochanteric bursitis	**Neurological** disorders and Nerve entrapment -Obturator -Ilioinguinal -Genitofemoral -Iliohypogastric
Developmental disorders -Acetabular dysplasia -Slipped capital femoral epiphysis -Perthes' disease	**Apophysitis or avulsion fracture** -Anterior superior iliac spine -Anterior inferior iliac spine -Pubic bone	**Hernia** -femoral or inguinal -Posthernioplasty
Avascular necrosis/transient osteoporosis of the femoral head	**Extra-articular impingement** -External/internal snapping hip -Trochanteric-pelvic impingement -Deep gluteal syndrome -Pectineo-foveal impingement -Ischiofemoral impingement -Subspine impingement	**Intra-abdominal/pelvic abnormality** -Gynaecological conditions -Prostatitis/Urinary tract infections/Kidney stone -Appendicitis/Diverticulitis
Arthritis (reactive or infectious)		**Tumors** and pseudotumors of the hip and pelvis

Statement: *The radiologist should not state that abnormal signs and parameters are indicative of FAI in an asymptomatic patient.*

Although FAI-associated morphologies may be mentioned in the radiological report, interpretation should be undertaken in conjunction with the clinical history and physical examination[4,6,44]. Similarly, deviations from currently accepted reference intervals (RefInts) in the morphological evaluation of the hip in asymptomatic individuals (or with unknown clinical status) should be handled with caution. Most imaging parameters classically related to FAI are present in a large proportion of asymptomatic individuals, suggesting that currently accepted thresholds may need to be redefined[4,6,24,30].

3. PARAMETERS AND REPORTING

The recommended imaging parameters of the hip/pelvis to be assessed in a patient with suspected FAI (Figure 2) and corresponding consensus statements were put forth by the panel (Tables 4 and 5).

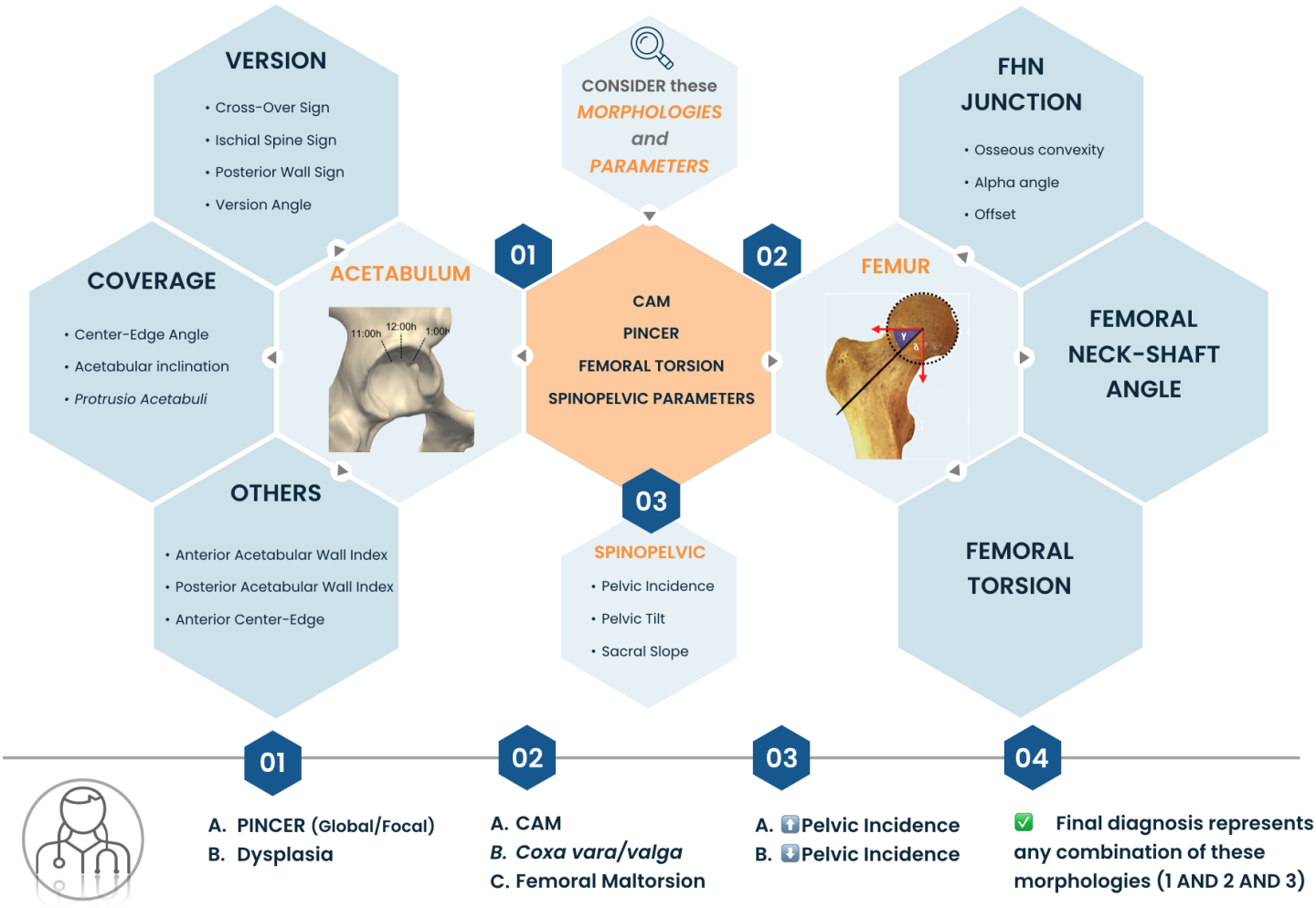


FIGURE 2. Parameters for the imaging assessment of the hip and pelvis in a patient with hip pain and suspected femoroacetabular impingement (FAI). Evaluating different features, namely (1) acetabular (coverage, version), (2) femoral (FHN junction, femoral neck-shaft angle, and femoral torsion), and (3) spinopelvic (pelvic incidence, pelvic tilt, and sacral slope) parameters, allows to define different pathomorphologies (bottom line). Ultimately, any combination of these morphologies maybe present (4), reflecting impingement, instability and/or microinstability. FHN: femoral head-neck.

TABLE 4. Statements on imaging parameters used in the assessment of femoroacetabular impingement (FAI) with evidence levels. The listed levels of agreement represent the percentage of votes ≥8 on a 0-10 scale. All listed statements obtained group consensus. AP: anteroposterior. CEA: centre-edge angle. CT: computed tomography. FHN: femoral head-neck. IQR: interquartile range. LOE: level of evidence. MRI: magnetic resonance imaging. NSA: neck-shaft angle. Q1: 1st quartile. Q3: 3rd quartile. T: tesla. W-CEA: Wiberg centre-edge angle.

Type of statement	Statement	LOE	Median IQR (Q1-Q3) Level of agreement
FEMORAL NECK-SHAFT ANGLE			
Which modality should be used for measurements?			
Technique	A standardised AP radiograph of the pelvis, or CT and/or MRI in the coronal femoral neck plane should be used for measuring the neck-shaft angle.	3	**10** **1 (9-10)** **100%**
Which reference values define normal neck-shaft angle (NSA) and coxa valga/vara?			
Interpretation	The classic reference range for a 'normal' NSA (derived from radiographs) is 120-135°, for *coxa vara is* <120°and for *coxa valga* is >135°. On CT, the reference NSA range is 120-140°.	3	**10** **1 (9-10)** **96%**
FEMORAL HEAD-NECK JUNCTION			
Which modality should be used to assess the configuration of the FHN junction?			
Technique	Radial MRI or CT are the most accurate imaging modalities for assessing the femoral head-neck junction. Radiographs, although less precise, may also be used to depict Cam morphology.	3	**10** **0 (10-10)** **100%**
Which parameters should be used to assess the FHN junction?			
Interpretation	The alpha angle is convenient to assess the FHN junction but has limited discriminatory power. Femoral offset is another useful parameter, but is less well established.	3	**10** **0.5 (9.5-10)** **100%**
Which reference values should be used for these parameters?			
Interpretation	A threshold of 60° is recommended for the alpha angle because higher values are reported to be clinically more relevant. An anterior femoral offset <8mm may be regarded as 'abnormal'.	4	**10** **2 (8-10)** **96%**
FEMORAL TORSION			
Which imaging modality should be used to perform measurements of femoral torsion?			
Technique	CT or MRI are the recommend imaging modalities for measurement of femoral torsion.	2	**10** **0 (10-10)** **100%**
Does it matter which method of measurement we use in the assessment of femoral torsion? If yes, which one should be used?			
Technique	Several methods of measurement of femoral torsion have been reported, resulting in different reference intervals. There is insufficient evidence to support a single method over the others.	3	**10** **0 (10-10)** **100%**
What are the reference values for normal femoral torsion?			
Interpretation	The normal femoral antetorsion in adults should be ~3° with a standard deviation of ~10° using the method of Reikeras et al.	2	**9,5** **1** **100%**
ACETABULAR COVERAGE			
Which should be the primary modality for assessing acetabular coverage?			
Technique	An AP radiograph of the pelvis should be the first-line modality for assessing acetabular coverage.	3	**10** **0 (10-10)**

			100%
Which measurements should be routinely performed for the assessment of acetabular coverage?			
Interpretation	The centre-edge angle of Wiberg and the acetabular index should be assessed routinely in the evaluation of acetabular coverage.	4	**10** **0 (10-10)** **89%**
How should the measurement of lateral centre-edge angle be performed?			
Interpretation	The CEA on AP radiographs of the pelvis is measured by using the centre of the femoral head and two distinct landmarks at the lateral acetabular roof: the outer edge of the acetabular sourcil, or the most lateral aspect of the bony acetabulum. The CEA values obtained by using these two landmarks often are not identical, and represent different areas of coverage in the 3D geometry of the acetabulum.	4	**10** **1.25 (8.75-10)** **93%**
What are the reference values for acetabular coverage based on the lateral centre-edge angle and acetabular index?			
Interpretation	For the W-CEA, the classical radiographic-based reference intervals are <20° for undercoverage, 20-25° for borderline undercoverage, 25-39° for normal coverage, and ≥40° for overcoverage. An acetabular index of <0° on an AP radiograph of the pelvis is classically accepted as overcoverage, whereas a value >13° represents undercoverage.	4	**10** **1 (9-10)** **96%**
Should the anterior and posterior acetabular coverage be reported on an AP pelvic radiograph?			
Interpretation	There is insufficient evidence to recommend the routine reporting of posterior and anterior acetabular coverage in clinical practice, though they may be relevant in specific clinical situations, such as in specialised hip-preserving units and in research settings.	4	**9** **1 (9-10)** **96%**
ACETABULAR VERSION			
Which modality should be used to perform measurements of acetabular version?			
Technique	An AP radiograph of the pelvis should be used for the initial assessment of acetabular version. However, CT or MRI should be considered if clinical and radiographic evaluations are suggestive of acetabular malversion.	4	**9.5** **2 (8-10)** **100%**
Which signs should be routinely sought when assessing acetabular version?			
Interpretation	On an AP radiograph of the pelvis, the cross-over sign should be routinely assessed. The posterior wall sign and the ischial spine sign should also be assessed.	4	**10** **0.25 (9.75-10)** **93%**
How should abnormal acetabular version be described?			
Interpretation	An isolated positive cross-over sign is an indication of focal cranial retroversion whereas a positive cross-over sign combined with a posterior wall sign and ischial spine sign is an indication of global retroversion.	3	**10** **1.25 (8.75-10)** **96%**

A) FEMUR

The most commonly described parameters to evaluate femoral morphology can be divided according to the main features that they assess: joint congruency, femoral head (FH) sphericity and other important parameters, such as neck orientation in the coronal (neck-shaft angle (NSA)) and axial (torsion) planes (Figure 3 and Supplemental Table 1).

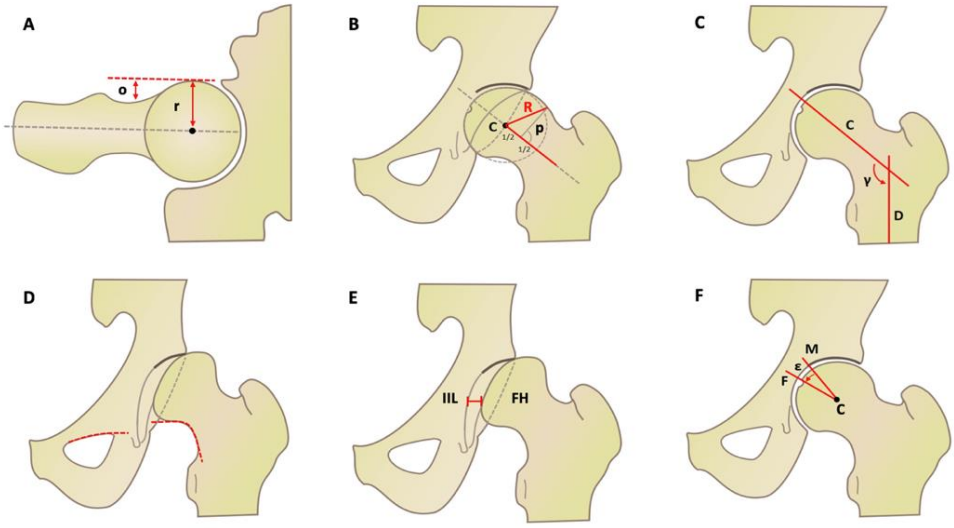


FIGURE 3. Imaging parameters to describe femoral morphology. See Supplemental Table 1 for definitions. A) offset and offset ratio, B) triangular index, C) neck-shaft angle or centrum collum diaphyseal (CCD) angle, D) Shenton's line, E) lateralization of femoral head, and F) fovea angle delta.

a1) NECK-SHAFT ANGLE

Statement: *A standardised AP radiograph of the pelvis or, CT and/or MRI in the coronal femoral neck plane should be used for measuring the neck-shaft angle.*

Statement: *The classic reference range for a 'normal' NSA derived from radiographs is 120–135°, for coxa vara is <120°, and for coxa valga is >135°. On CT, the reference NSA range is 120–140°.*

Radiographs remain the clinical/research standard for evaluation of the NSA. However, a generally accepted measurement method is lacking[45] (Supplemental Figure 1) because hip rotation and femoral torsion are known to influence NSA assessment. Accordingly, published RefInts vary widely depending on differences on the measurement methods and rotation correction used[45] (Supplemental Table 2) and, to a small extent, with age (values decrease with age) and sex (higher mean values have been observed in females)[45,46].

CT coronal reformats of the proximal femur or coronal oblique MRI in the femoral-neck plane allow correct anatomical measurement of the NSA. In a recent series of 800 asymptomatic hips, Boese et al. reported CT-based positionally corrected NSA mean values of 130°±5.9°. The difference between corrected/non-corrected measurements in that study was ~3°[46]. Mascarenhas et al. reported a CT-based 95% RefInts of 120–141° in 1111 asymptomatic hips[6].

a2) FEMORAL HEAD-NECK JUNCTION

Statement: *Radial MRI or CT are the most accurate imaging modalities for assessing the femoral head–neck junction. Radiographs, although less precise, may also be used to depict Cam morphology.*

Statement: *The alpha angle is convenient to assess the FHN junction but has limited discriminatory power. Femoral offset is another useful parameter, but is less well established.*

Cam morphology corresponds to an asphericity of the FHN junction, most commonly at an anterosuperior location (1–2 o'clock on the clock face) and is usually assessed by measuring the α°[3,12]. Importantly, Cam morphology has been detected in all populations, although few scholars have used the same case definitions, whereas other researchers have used different definitions inconsistently for males/females[4,8], employed various imaging modalities, or measured the α° at different FHN positions[4,6,13,29].

The α° and FO describe different features of the FHN junction. The α° reflects the proximal aspect of the asphericity, whereas the FO describes the width of the femoral neck relative to the FH[8,10,34,47] (Figure 4 and Supplemental Figure 2). Although these parameters are useful to quantify the morphology of the FHN junction, caution is warranted when using them in routine clinical practice. The α° is controversial due to its moderate reproducibility, moderate

discriminative ability, and lack of conclusive data on 'ideal' threshold values[8,18,30] (Supplemental Table 3 and 4).

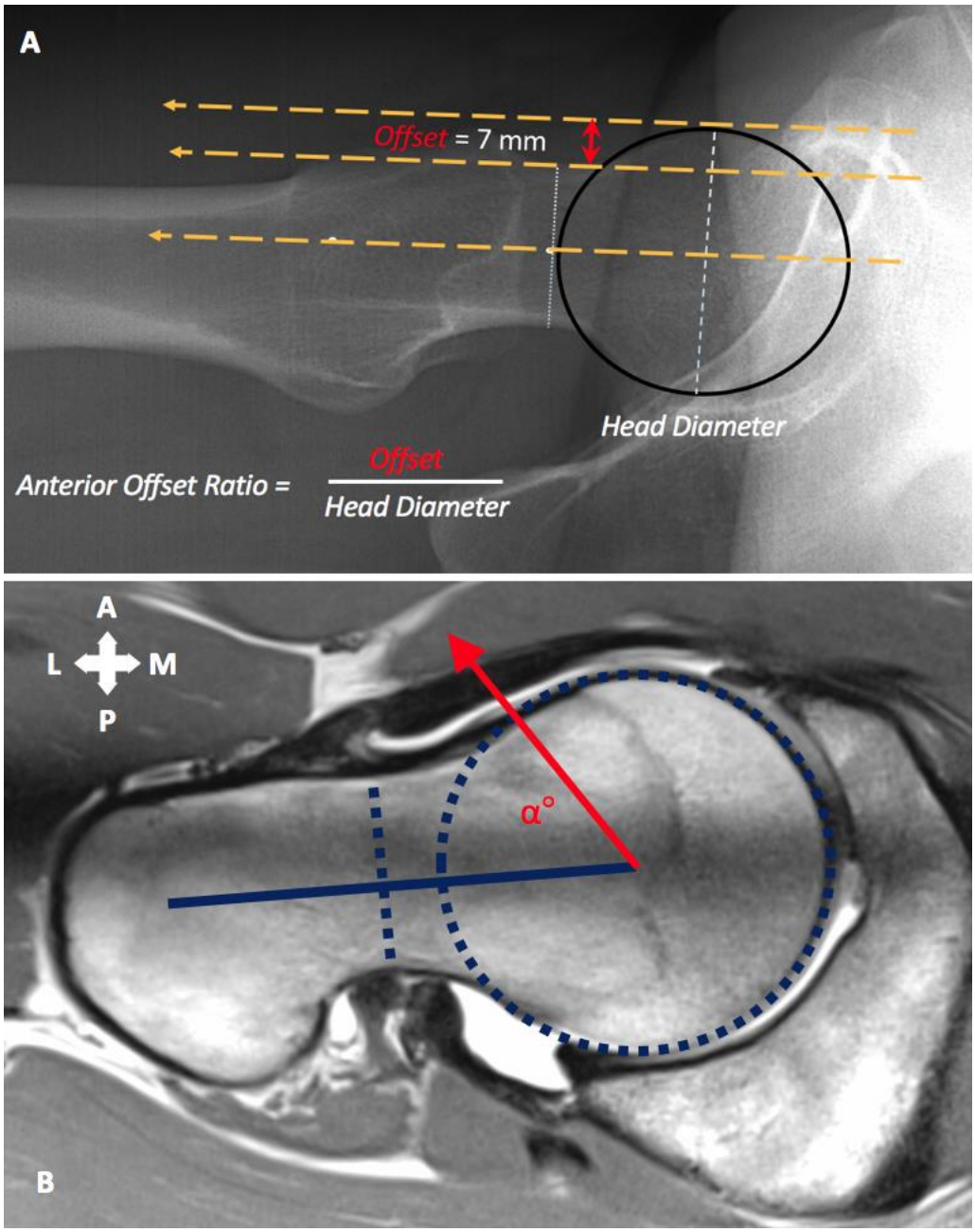


FIGURE 4. (A) Right hip cross-table lateral view. To calculate the offset, three parallel lines are drawn: the first line passes through the centre of the long axis of the femoral neck; the second line, through the anterior aspect of the femoral neck; and the third line, through the anterior aspect of the femoral head. The head-neck offset is calculated by measuring the distance between the second and third lines. **(B)** Alpha angle measurement in a right hip MRI arthrogram, according to method 1 originally described by Nötzli in an arthro-MRI examination (also known as '3-point method'): place a circle adjusted over the

contour of the femoral head (dotted blue circle). The femoral neck axis (FNA) is defined as a line passing through the femoral head centre (FHC) and the centre of the neck (FNC) at its narrowest point (i.e. place a circle [not shown] with its corresponding diameter [dotted blue line] at the shortest possible distance between the anterior [ventral] and posterior [dorsal] outline of the femoral neck). Next, a line is drawn connecting the centre of these two circles. Then, a line is drawn connecting the FHC to the point where the contour of the femoral head or head-neck junction first exited the femoral head circle. The alpha angle is the angle formed by these two lines. A: Anterior. P: Posterior. M: Medial. L: Lateral.

a3) FEMORAL TORSION

Statement: *CT or MRI are the recommend imaging modalities for measurement of femoral torsion.*

CT and MRI are the most commonly used modalities to assess FT because they are validated and, in general, considered to provide accurate and reliable measurements[48,49]. MRI may be preferred to avoid radiation exposure. Biplanar radiographs with three-dimensional (3D) modelling are an alternative to cross-sectional imaging, and provide comparable results to those obtained with CT/MRI[50,51]. Analysis of 3D datasets holds promise to become a more accurate method of FT quantification[52].

Statement: *Several methods of measurement of femoral torsion have been reported, resulting in different reference intervals. There is insufficient evidence to support a single method over the others.*

The methods for assessing FT differ mainly in the definition of the centre of the neck and proximal femoral axis, which yields different values[49,53,54]. Although none of the methods seem superior, it is imperative to use the same method consistently if results are to be comparable (Figure 5).

Statement: *The normal femoral antetorsion in adults should be ~13° with a standard deviation of ~10° using the method of Reikeras et al.*

The reported RefInts of FT vary significantly. A multitude of reasons may explain such variation, but the measurement method employed accounts largely for the discrepant values. In a study comparing different measurement methods, mean values ranged from 11.4±7.4° to 22.4±6.8°[53]. Thus, distinct RefInts should be considered according to the method used. Sutter et al. reported

a mean value of 12.8±10.1° in asymptomatic adults using MRI based on the method of Reikeras and colleagues[48]. Other authors have obtained similar results using an equivalent methodology (Supplemental Table 5).

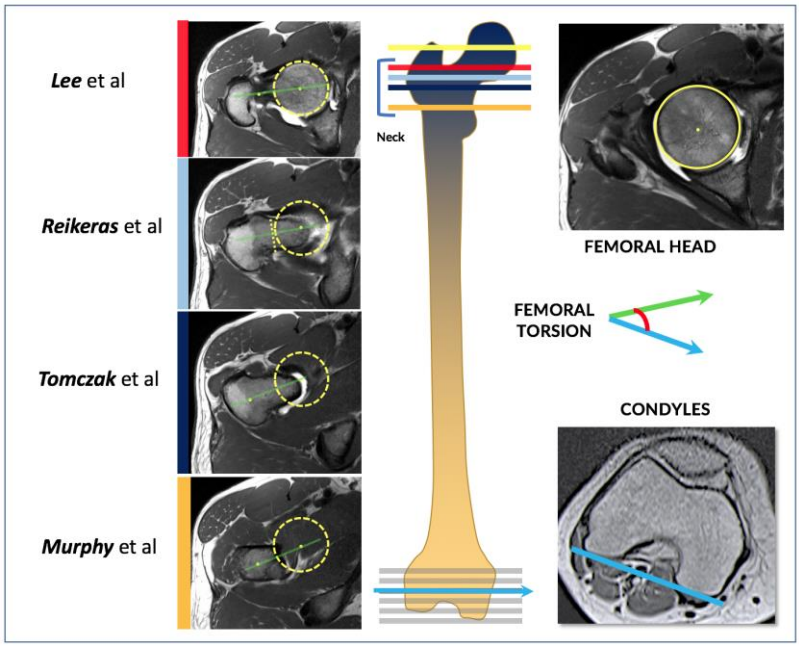


FIGURE 5. Assessment of femoral torsion on cross-sectional imaging (selected methods represented; not comprehensive). On consecutive strict axial images over the proximal femur, determine the femoral head centre (FHC) (yellow circle and yellow line). Defining the femoral neck axis (green line) can be obtained by several methods. **Lee** (**red bar**): A line is drawn on the first image on which the FHC can be connected with the most cephalic junction of the greater trochanter and the femoral neck; **Reikeras** (**light blue bar**): A line connecting the FHC with the femoral neck centre is drawn on an image where the anterior and posterior cortices run parallel to each other. **Tomczak** (**dark blue bar**): The FHC is connected with the centre of the greater trochanter at the base of the femoral neck. **Murphy** (**orange bar**): the FHC is connected with the centre of the base of the femoral neck directly superior to the lesser trochanter. Then, over the distal femur, draw a tangent to the posterior aspect of the femoral condyles (blue line; choosing the slice where the condyles are more prominent). The angle between both lines represents the femoral version. Although some of these reference points are located on different adjacent slices, modern workstations should allow drawing and modifying a line across multiple images in one series or, alternatively, different slices can be superimposed on a single image with the help of post-processing software.

B) ACETABULUM

Overall, the most commonly described parameters to assess acetabular morphology can be divided according to the main features that they measure: depth, coverage or orientation (Figure 6 and Supplemental Table 6).

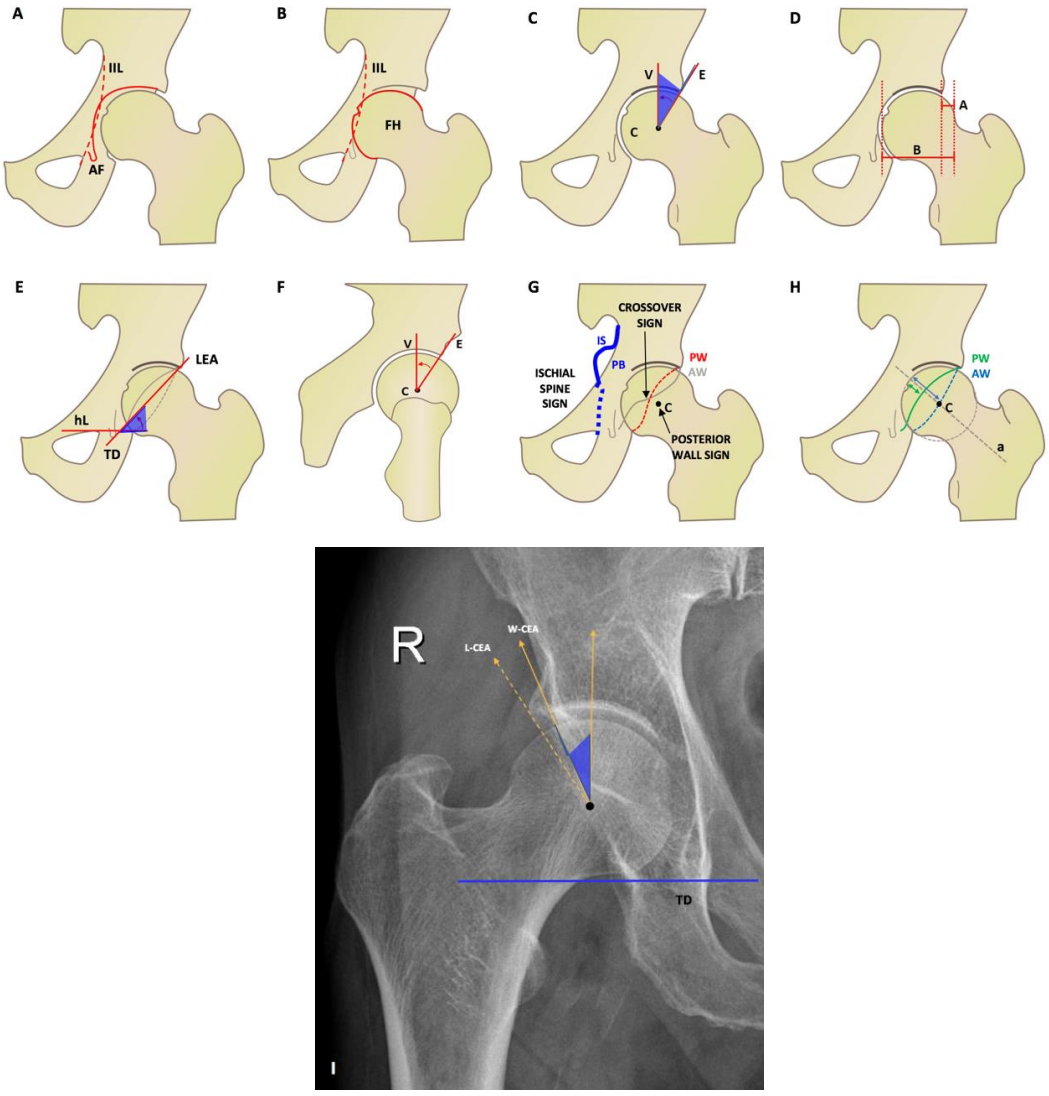


FIGURE 6. Imaging parameters to describe acetabular morphology. (A) *Coxa profunda*. (B) *Protrusio acetabuli*. (C) Centre-edge angle (CEA). The Wiberg-CEA (WCEA) is formed between a vertical line crossing the centre of the femoral head, perpendicular to the horizontal line uniting the inferior margins of both teardrops, and a line connecting the centre of the femoral head to the lateral margin of the acetabular bone dense area (known as the acetabular sourcil). The lateral CEA (L-CEA) is formed between the vertical line described and a line connecting the centre of the femoral head to the far lateral margin of the acetabulum. (D) extrusion index. (E) Sharp angle. (F) anterior centre-edge angle. (G) posterior wall sign, ischial spine sign and crossover sign. (H) anterior and posterior acetabular wall index. (I) The W-CEA should

be distinguished from the L-CEA, as the most lateral point to consider would be the lateral end of the sourcil (W-CEA) rather than the most lateral rim of the acetabulum (L-CEA). Frequently, these two reference points might coincide. See supplemental Table 6 for definition of the most relevant parameters. IIL, ilioischial line; AF, acetabular fossa; FH, femoral head; V, vertical; E, edge; C, centre; B, diameter of the femoral head; A, extrusion in millimetres; hL, horizontal axis; TD, tear drop; IS, ischial spine; PB, pelvic brim; PW, posterior wall; AW, anterior wall; a, neck axis.

b1) COVERAGE

Statement: *An AP radiograph of the pelvis should be the first-line modality for assessing acetabular coverage.*

Statement: *The centre-edge angle of Wiberg and the acetabular index should be assessed routinely in the evaluation of acetabular coverage.*

An AP radiograph of the pelvis should be the initial examination for assessing acetabular coverage. However, cross-sectional imaging may also be used because it provides similar measurements for most parameters[55,56]. Conflicting reports exist regarding the effect of pelvic positioning on radiographic parameters of coverage, although tilt and rotation seem to mainly influence the radiographic signs of acetabular retroversion[37,57].

The centre-edge angle of Wiberg (W-CEA) and acetabular index (AI) are the most often used parameters of superior-lateral coverage[58,59]. Anterior and posterior acetabular coverage may be quantified using anterior-wall and posterior-wall indices[60]. Other parameters, such as the anterior centre-edge angle, extrusion index, or Sharp angle, are used less frequently[6,24,61]. *Protrusio acetabuli* should always be noted because it is a clinically relevant condition[62].

Statement: *The centre-edge angle (CEA) on AP radiographs of the pelvis is measured using the centre of the femoral head and two distinct landmarks at the lateral acetabular roof: the outer edge of the acetabular sourcil, or the most lateral aspect of the bony acetabulum. The CEA values obtained using these two landmarks often are not identical, and represent different areas of coverage in the 3D geometry of the acetabulum.*

On an AP radiograph of the pelvis, two types of CEA should be distinguished and stated clearly: the sourcil-edge CEA (W-CEA), which represents anterosuperior coverage, and the bone-edge

or lateral CEA (L-CEA), which represents superolateral coverage[59,63] (Figure 6i). They are both useful and complimentary for assessing acetabular coverage.

Statement: *For the CEA of Wiberg, the classical radiographic-based reference intervals are <20° for undercoverage, 20–25° for borderline undercoverage, 25–39° for normal coverage, and ≥40° for overcoverage. An acetabular index of <0° on an AP radiograph of the pelvis is classically accepted as overcoverage, whereas a value >13° represents undercoverage.*

The cut-off values for the W-CEA reported originally by Wiberg[64] have been considered the RefInt values, and are recommended by this consensus group.

A recent large population-based study[65] and other studies (Supplemental Table 7) reported RefInts for the W-CEA and AI which are significantly broader compared with the classical thresholds. Interestingly, if these updated RefInts were to be used, many hips considered 'pathologic' using the classical RefInt would now be classified as 'normal'. This observation strongly suggests the need to update the thresholds used in the classification of lateral acetabular coverage based, for example, on the natural course of the disease.

Statement: *There is insufficient evidence to recommend the routine reporting of posterior and anterior acetabular coverage in clinical practice, though they may be relevant in specific clinical situations, such as in specialised hip-preservation units and in research settings.*

On an AP radiograph of the pelvis, anterior and posterior acetabular coverage corresponds to the overlap of the anterior and posterior acetabular walls with the FH. It may be quantified by the percentage of the FH covered by each wall[61] or by anterior wall/posterior wall indices[60] (Supplemental Table 6).

b2) VERSION

Statement: *An AP radiograph of the pelvis should be used for the initial assessment of acetabular version. However, CT or MRI should be considered if clinical and radiographic evaluations are suggestive of acetabular malversion.*

Statement: *On an AP radiograph of the pelvis, the cross-over sign should be assessed routinely. The posterior wall sign and the ischial spine sign should also be assessed.*

Statement: *An isolated positive cross-over sign is an indication of focal cranial retroversion, whereas a positive cross-over sign combined with a posterior wall sign and ischial spine sign is an indication of global retroversion.*

Assessment of acetabular version with an AP radiograph of the pelvis[38] is paramount because surgical planning for correcting abnormal version is usually based on radiographic retroversion[66,67]. Nevertheless, measurements of acetabular version on radiographs have been reported to be less reliable compared with those obtained using cross-sectional/3D imaging[16,17], which may quantify individual acetabular morphologies more accurately. Limitations in radiographic evaluation are mainly inherent to the imaging modality and pelvic tilt[17].

The cross-over sign, posterior wall sign, and ischial spine sign (Figure 6) should be assessed because there is evidence that, depending on the presence of different signs and degree of acetabular retroversion, different surgical approaches may be considered. Accordingly, in contrast to cranial acetabular retroversion, patients with a global retroversion may benefit from pelvic reorientation instead of trimming of the acetabular rim[68].

Caution is warranted because: (a) these radiographic signs are commonly present among asymptomatic individuals;[69] (b) their accuracy *per se* is questionable[17,38,69]. Although the clinical added value of advanced imaging remains to be established, it should be considered when clinical and radiographs findings are consistent with Pincer FAI and retroversion.

TABLE 5. Overview of most relevant femoral and acetabular parameters, notes and recommendations for research and clinical practice (refer to text for details). COS: Cross-over sign; CT: computed tomography; FHN: femoral head-neck junction; L-CEA: Lateral centre-edge angle; MRI: Magnetic Resonance Imaging; W-CEA: Wiberg centre-edge angle.

PARAMETER	MEASUREMENT VALUES TO CONSIDER	PREFERRED MEASUREMENT METHOD	NOTES and RECCOMENDATIONS
ALPHA ANGLE	▸ >60° indicates Cam morphology (at any location around the anterosuperior FHN junction)	▸ Radial imaging ▸ AP pelvic radiograph and Dunn 45 view	▸ State measurement location ▸ Measure and report where maximal deformity is noted around the FHN junction

NECK-SHAFT ANGLE	▸ AP Pelvic radiograph: 120-135° ▸ CT: 120-140°	▸ AP pelvic radiograph ▸ CT and/or MRI in the coronal femoral neck plane	▸ Hip rotation and femoral torsion influence assessment ▸ Vary with sex and age
FEMORAL TORSION	▸ 13±10° (Reikeras method)	▸ CT or MRI	▸ Clearly define measurement method
W-CEA	▸ <20°: undercoverage ▸ 20-25°: *borderline* undercoverage ▸ 25-39°: normal coverage ▸ ≥40°: overcoverage	▸ AP pelvic radiograph	▸ Clearly define whether W-CEA or L-CEA is measured ▸ Represents superior and lateral coverage
ACETABULAR INDEX	▸ >13°: undercoverage ▸ <0°: overcoverage	▸ AP pelvic radiograph	▸ Represents superior and lateral coverage
PROTRUSIO ACETABULI	▸ present or absent	▸ AP pelvic radiograph	▸ Represent a qualitative sign of gobal overcoverage ▸ Always pathological
CROSS-OVER SIGN **POSTERIOR WALL SIGN** **ISCHIAL SPINE SIGN**	▸ present or absent	▸ AP pelvic radiograph	▸ Represent qualitative signs of version ▸ COS indicative of Focal Pincer (acetabular retroversion) ▸ When all signs are present indicative of Global Pincer (global retroversion)
ACETABULAR VERSION	▸ Cranial version < 0°: Focal retroversion	▸ CT or MRI	▸ Clearly define measurement method ▸ Indicative of Focal Pincer (acetabular retroversion)

4. POSTOPERATIVE IMAGING

Statement: *Radiographs are the initial imaging modality for evaluating symptoms following FAI surgery. MRI, MRA and, occasionally, CT (or CTA), should be used if the symptoms are not explained by the radiographs and/or if further anatomical information is desired.*

Radiographs (AP pelvis and a lateral hip view) are obtained routinely after HPS and as follow-up imaging. They are useful for assessment of bone morphology (residual deformities and/or bone over-resection) and to assess heterotopic ossification[70,71]. In cases of persistent hip pain (i.e. 6 months after surgery), MRI or magnetic resonance arthrography (MRA) should be considered[70,71] to evaluate the surgical repair and to exclude complications. Unilateral high-resolution (1.5 T or 3 T) MRI or MRA should be undertaken, and their data should be compared with preoperative examinations. CT is particularly useful to evaluate: (i) delayed or non-union after periacetabular or trochanteric osteotomy; (ii) osteochondroplasty (over- or under-resection); (iii) complications such as fractures or heterotopic ossification[71].

Although ultrasound is rarely used, it might be helpful to diagnose fluid collections, effusion, deep venous thrombosis, as well as for image-guided aspiration[71].

Statement: *Following FAI surgery, the underlying Cam-type and/or Pincer-type morphology, as well as the potential radiographic progression of hip osteoarthritis, should be assessed appropriately.*

Recommended imaging outcome measures to evaluate postoperative results are the: (i) α° and FO for Cam correction; (ii) W-CEA, AI and crossover sign for Pincer correction[62]; (iii) radiographic progression of osteoarthritis. Furthermore, clinical correlation with patient-reported outcome measures is suggested[3].

CONCLUSIONS

Standardised plain radiographs, including AP pelvis and a Dunn 45° view, are the initial imaging diagnostic tools for assessment of hip pain and FAI. Thorough analyses of imaging parameters are paramount to identify osseous morphologies consistent with FAI and to exclude other structural disorders. MRI allows for further characterisation of hip morphology and chondro-labral disease, as well as evaluation of differential diagnoses.

The first Delphi-based consensus for imaging of FAI was developed. The panel critically reviewed the available evidence, imaging parameters, classification criteria, and recommended pathways for diagnostic work-up. The resulting consensus can serve as a tool to reduce variability in clinical practice and guide further research for FAI management.

REFERENCES

1. **Ganz R, Parvizi J, Beck M, Leunig M, Nötzli H, Siebenrock KA**. Femoroacetabular impingement: a cause for osteoarthritis of the hip. *Clin Orthop Relat Res* 2003;(417):112–120.

2. **Nepple JJ, Prather H, Trousdale RT, Clohisy JC, Beaulé PE, Glyn-Jones S, et al.** Clinical diagnosis of femoroacetabular impingement. *J Am Acad Orthop Surg* 2013;21 Suppl 1:S16–9.

3. **Griffin DR, Dickenson EJ, O'Donnell J, Agricola R, Awan T, Beck M, et al.** The Warwick Agreement on femoroacetabular impingement syndrome (FAI syndrome): an international consensus statement. *British Journal of Sports Medicine* 2016;50(19):1169–1176.

4. **Mascarenhas VV, Rego PA, Dantas P, Morais F, McWilliams J, Collado D, et al.** Imaging prevalence of femoroacetabular impingement in symptomatic patients, athletes, and asymptomatic individuals: A systematic review. *European Journal of Radiology* 2016;85(1):73–95.

5. **Agricola R, Heijboer MP, Bierma-Zeinstra SMA, Verhaar JAN, Weinans H, Waarsing JH**. Cam impingement causes osteoarthritis of the hip: a nationwide prospective cohort study (CHECK). *Ann Rheum Dis* 2013;72(6):918–923.

6. **Mascarenhas VV, Rego PA, Dantas P, Castro M, Jans L, Marques RM, et al.** 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* 2018;28(4):1609–1624.

7. **Palmer WE**. Femoroacetabular Impingement: Caution Is Warranted in Making Imaging-based Assumptions and Diagnoses. *Radiology* 2010;257(1):4–7.

8. **Mascarenhas VV, Ayeni OR, Egund N, Jurik AG, Caetano A, Castro M, et al.** Imaging Methodology for Hip Preservation: Techniques, Parameters, and Thresholds. *Semin Musculoskelet Radiol* 2019;23(03):197–226.

9. **Pfirrmann CWA, Mengiardi B, Dora C, Kalberer F, Zanetti M, Hodler J**. Cam and Pincer Femoroacetabular Impingement: Characteristic MR Arthrographic Findings in 50 Patients. *Radiology* 2006;240(3):778–785.

10. **Tannast M, Siebenrock KA, Anderson SE**. Femoroacetabular impingement: radiographic diagnosis--what the radiologist should know. *AJR Am J Roentgenol* 2007;188(6):1540–1552.

11. **Dudda M, Albers C, Mamisch TC, Werlen S, Beck M**. Do Normal Radiographs Exclude Asphericity of the Femoral Head-Neck Junction? *Clin Orthop Relat Res* 2008;467(3):651–659.

12. **Nötzli HP, Wyss TF, Stoecklin CH, Schmid MR, Treiber K, Hodler J**. The contour of the femoral head-neck junction as a predictor for the risk of anterior impingement. *Journal of Bone and Joint Surgery - British Volume* 2002;84(4):556–560.

13. **Sutter R, Dietrich TJ, Zingg PO, Pfirrmann CWA**. How useful is the alpha angle for discriminating between symptomatic patients with cam-type femoroacetabular impingement and asymptomatic volunteers? *Radiology* 2012;264(2):514–521.

14. **Lerch TD, Todorski IAS, Steppacher SD, Schmaranzer F, Werlen SF, Siebenrock KA, et al.** 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* 2017;417(1):036354651772698.

15. **Zaltz I, Kelly BT, Hetsroni I, Bedi A**. The Crossover Sign Overestimates Acetabular Retroversion. *Clin Orthop Relat Res* 2012;471(8):2463–2470.

16. **Larson CM, Moreau-Gaudry A, Kelly BT, Thomas Byrd JW, Tonetti J, Lavallee S, et al.** Are Normal Hips Being Labeled as Pathologic? A CT-based Method for Defining Normal Acetabular Coverage. *Clin Orthop Relat Res* 2014;473(4):1247–1254.

17. **Wassilew GI, Heller MO, Diederichs G, Janz V, Wenzl M, Perka C**. Standardized AP radiographs do not provide reliable diagnostic measures for the assessment of acetabular retroversion. *J Orthop Res* 2012;30(9):1369–1376.

18. **Kassarjian A**. Hip Hype: FAI Syndrome, Amara's Law, and the Hype Cycle. *Semin Musculoskelet Radiol* 2019.

19. **Steurer J**. The Delphi method: an efficient procedure to generate knowledge. *Skeletal Radiol* 2011;40(8):959–961.

20. **McMillan SS, King M, Tully MP**. How to use the nominal group and Delphi techniques. *Int J Clin Pharm* 2016;38(3):655–662.

21. **No authors listed.** OCEBM Levels of Evidence. The Oxford 2011 levels of evidence. 2011 Mar.

22. **Sutter R, Pfirrmann CWA**. Update on Femoroacetabular Impingement: What Is New, and How Should We Assess It? *Semin Musculoskelet Radiol* 2017;21(5):518–528.

23. **Atkins PR, Shin Y, Agrawal P, Elhabian SY, Whitaker RT, Weiss JA, et al.** Which Two-dimensional Radiographic Measurements of Cam Femoroacetabular Impingement Best Describe the Three-dimensional Shape of the Proximal Femur? *Clin Orthop Relat Res* 2018;:1.

24. **Mascarenhas VV, rego P, Dantas P, Gaspar A, Soldado F, Consciência JG**. 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* 2017;27(5):2011–2023.

25. **Domayer SE, Ziebarth K, Chan J, Bixby S, Mamisch TC, Kim YJ**. Femoroacetabular cam-type impingement: diagnostic sensitivity and specificity of radiographic views compared to radial MRI. *European Journal of Radiology* 2011;80(3):805–810.

26. **Meyer DC, Beck M, Ellis T, Ganz R, Leunig M**. Comparison of Six Radiographic Projections to Assess Femoral Head/Neck Asphericity. *Clin Orthop Relat Res*

2006;PAP.

27. **Saito M, Tsukada S, Yoshida K, Okada Y, Tasaki A**. 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* Springer Berlin Heidelberg, 2016;:1–7.

28. **Agricola R, Waarsing JH, Thomas GE, Carr AJ, Reijman M, Bierma-Zeinstra SMA, et al.** Cam impingement: defining the presence of a cam deformity by the alpha angle: data from the CHECK cohort and Chingford cohort. *Osteoarthritis and cartilage / OARS, Osteoarthritis Research Society* 2014;22(2):218–225.

29. **Golfam M, Di Primio LA, Beaulé PE, Hack K, Schweitzer ME**. Alpha Angle Measurements in Healthy Adult Volunteers Vary Depending on the MRI Plane Acquisition Used. *The American Journal of Sports Medicine* 2017;45(3):620–626.

30. **Mascarenhas VV, Rego PA, Dantas P, Caetano AP, Jans L, Sutter R, et al.** 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* 2018;46(13):3097–3110.

31. **Beaulé PE, Grammatopoulos G, Speirs A, Ng G, Carsen S, Frei H, et al.** Unravelling the Hip Pistol Grip / CAM Deformity: Origins to Joint Degeneration. *J Orthop Res* 2018.

32. **Eijer H, Leunig M, Mahomed N, Ganz R**. Cross-table lateral radiographs for screening of anterior femoral head-neck offset in patients with femoro-acetabular impingement

. *Hip Int* 2001;11(1):37–41.

33. **Fraitzl CR, Kappe T, Pennekamp F, Reichel H, Billich C**. Femoral head-neck offset measurements in 339 subjects: distribution and implications for femoroacetabular impingement. *Knee Surg Sports Traumatol Arthrosc* 2012;21(5):1212–1217.

34. **Ehrmann C, Rosskopf AB, Pfirrmann CWA, Sutter R**. Beyond the alpha angle: Alternative measurements for quantifying cam-type deformities in femoroacetabular impingement. *J Magn Reson Imaging* 2015;:n/a–n/a.

35. **Pollard TCB, Villar RN, Norton MR, Fern ED, Williams MR, Simpson DJ, et al.** Femoroacetabular impingement and classification of the cam deformity: the reference interval in normal hips. *Acta Orthop* 2010;81(1):134–141.

36. **Kang ACL, Gooding AJ, Coates MH, Goh TD, Armour P, Rietveld J**. Computed Tomography Assessment of Hip Joints in Asymptomatic Individuals in Relation to Femoroacetabular Impingement. *The American Journal of Sports Medicine* 2010;38(6):1160–1165.

37. **Tannast M, Fritsch S, Zheng G, Siebenrock KA, Steppacher SD**. Which Radiographic Hip Parameters Do Not Have to Be Corrected for Pelvic Rotation and Tilt? *Clin Orthop Relat Res* 2014.

38. **Rhee C, Le Francois T, Byrd JWT, Glazebrook M, Wong I**. Radiographic Diagnosis of Pincer-Type Femoroacetabular Impingement: A Systematic Review. *Orthopaedic Journal of Sports Medicine* 2017;5(5):232596711770830.

39. **Cunningham DJ, Paranjape CS, Harris JD, Nho SJ, Olson SA, Mather RC III**. Advanced Imaging Adds Little Value in the Diagnosis of Femoroacetabular Impingement Syndrome. *The Journal of Bone and Joint Surgery* 2017;99(24):e133.

40. **Krishnamoorthy VP, Beck EC, Kunze KN, Cancienne JM, Krivicich LM, Suppauksorn S, et al.** Radiographic Prevalence of Sacroiliac Joint Abnormalities and Clinical Outcomes in Patients With Femoroacetabular Impingement Syndrome. *Arthroscopy* 2019;35(9):2598–2605.e1.

41. **Krishnamoorthy VP, Kunze KN, Beck EC, Cancienne JM, O'Keefe LS, Ayeni OR, et al.** Radiographic Prevalence of Symphysis Pubis Abnormalities and Clinical Outcomes in Patients With Femoroacetabular Impingement Syndrome. *The American Journal of Sports Medicine* 2019;47(6):1467–1472.

42. **Tibor LM, Sekiya JK**. Differential diagnosis of pain around the hip joint. *Arthroscopy* 2008;24(12):1407–1421.

43. **Khan W, Khan M, Alradwan H, Williams R, Simunovic N, ayeni OR**. Utility of Intra-articular Hip Injections for Femoroacetabular Impingement: A Systematic Review. *Orthopaedic Journal of Sports Medicine* 2015;3(9).

44. **Frank JM, Harris JD, Erickson BJ, Slikker W, Bush-Joseph CA, Salata MJ, et al.** Prevalence of Femoroacetabular Impingement Imaging Findings in Asymptomatic Volunteers: A Systematic Review. *Arthroscopy* 2015;31(6):1199–1204.

45. **Boese CK, Dargel J, Oppermann J, Eysel P, Scheyerer MJ, Bredow J, et al.** The femoral neck-shaft angle on plain radiographs: a systematic review. *Skeletal Radiol* 2015;45(1):19–28.

46. **Boese CK, Jostmeier J, Oppermann J, Dargel J, Chang D-H, Eysel P, et al.** The neck shaft angle: CT reference values of 800 adult hips. *Skeletal Radiol* 2015;45(4):455–463.

47. **Ganz R, Leunig M, Leunig-Ganz K, Harris WH**. The Etiology of Osteoarthritis of the Hip. *Clin Orthop Relat Res* 2008;466(2):264–272.

48. **Sutter R, Dietrich TJ, Zingg PO, Pfirrmann CWA**. Femoral antetorsion: comparing asymptomatic volunteers and patients with femoroacetabular impingement. *Radiology* 2012;263(2):475–483.

49. **Tomczak RJ, Guenther KP, Rieber A, Mergo P, Ros PR, Brambs HJ**. MR imaging measurement of the femoral antetorsional angle as a new technique: comparison with CT in children and adults. *American Journal of Roentgenology* 1997;168(3):791–794.

50. **Rosskopf AB, Ramseier LE, Sutter R, Pfirrmann CWA, Buck FM**. Femoral and tibial torsion measurement in children and adolescents: comparison of 3D models based on low-dose biplanar radiography and low-dose CT. *AJR Am J Roentgenol* 2014;202(3):W285–91.

51. **Rosskopf AB, Buck FM, Pfirrmann CWA, Ramseier LE**. Femoral and tibial torsion measurements in children and adolescents: comparison of MRI and 3D models based on low-dose biplanar radiographs. *Skeletal Radiol* 2017;46(4):469–476.

52. **Hartel MJ, Petersik A, Schmidt A, Kendoff D, Nüchtern J, Rueger JM, et al.** Determination of Femoral Neck Angle and Torsion Angle Utilizing a Novel Three-Dimensional Modeling and Analytical Technology Based on CT Datasets. Alberich-Bayarri A, ed. *PLoS ONE* 2016;11(3):e0149480.

53. **Kaiser P, Attal R, Kammerer M, Thauerer M, Hamberger L, Mayr R, et al.** Significant differences in femoral torsion values depending on the CT measurement technique. *Arch Orthop Trauma Surg* Springer Berlin Heidelberg, 2016;136(9):1259–1264.

54. **Sutter R, Dietrich TJ, Zingg PO, Pfirrmann CWA**. Assessment of Femoral Antetorsion With MRI: Comparison of Oblique Measurements to Standard Transverse Measurements. *AJR Am J Roentgenol* 2015;205(1):130–135.

55. **Stelzeneder D, Hingsammer A, Bixby SD, Kim Y-J**. Can Radiographic Morphometric Parameters for the Hip Be Assessed on MRI? *Clin Orthop Relat Res* 2012;471(3):989–999.

56. **Air ME, Harrison JR, Nguyen JT, Kelly BT, Bogner EA, Moley PJ**. Correlation of Measurements of the Prearthritic Hip Between Plain Radiography and Computed Tomography. *PM R* 2019;11(2):158–166.

57. **Jackson TJ, Estess AA, Adamson GJ**. Supine and Standing AP Pelvis Radiographs in the Evaluation of Pincer Femoroacetabular Impingement. *Clin Orthop Relat Res* Springer US, 2016;474(7):1692–1696.

58. **Werner CML, Ramseier LE, Ruckstuhl T, Stromberg J, Copeland CE, Turen CH, et al.** Normal values of Wiberg's lateral center-edge angle and Lequesne's acetabular index–a coxometric update. *Skeletal Radiol* 2012.

59. **Wylie JD, Kapron AL, Peters CL, Aoki SK, Maak TG**. Relationship Between the Lateral Center-Edge Angle and 3-Dimensional Acetabular Coverage. *Orthopaedic Journal of Sports Medicine* 2017;5(4):2325967117700589.

60. **Siebenrock KA, Kistler L, Schwab JM, Büchler L, Tannast M**. The acetabular wall index for assessing anteroposterior femoral head coverage in symptomatic patients. *Clin Orthop Relat Res* 2012;470(12):3355–3360.

61. **Tannast M, Hanke MS, Zheng G, Steppacher SD, Siebenrock KA**. What are the radiographic reference values for acetabular under- and overcoverage? *Clin Orthop Relat Res* 2015;473(4):1234–1246.

62. **Hanke MS, Steppacher SD, Anwander H, Werlen S, Siebenrock KA, Tannast M**. What MRI Findings Predict Failure 10 Years After Surgery for Femoroacetabular Impingement? *Clin Orthop Relat Res* Springer US, 2016;:1–16.

63. **Mittal A, Bomar JD, Jeffords ME, Huang M-T, Wenger DR, Upasani VV**. Defining the lateral edge of the femoroacetabular articulation: correlation analysis between radiographs and computed tomography. *J Child Orthop* Springer Berlin Heidelberg, 2016;:1–6.

64. **Wiberg G**. *Studies on Dysplastic Acetabula and Congenital Subluxation of the Hip Joint: With Special Reference to the Complication of Osteo-arthritis*. Karolinska Institutet, Orthopedic Clinic, 1939.

65. **Laborie LB, Engesæter IØ, Lehmann TG, Sera F, Dezateux C, Engesæter LB, et al.** Radiographic measurements of hip dysplasia at skeletal maturity—new reference intervals based on 2,038 19-year-old Norwegians. *Skeletal Radiol* 2013;42(7):925–935.

66. **Siebenrock KA, Schaller C, Tannast M, Keel M, Büchler L**. Anteverting periacetabular osteotomy for symptomatic acetabular retroversion: results at ten years. *J Bone Joint Surg Am* 2014;96(21):1785–1792.

67. **Hartigan DE, Perets I, Walsh JP, Close MR, Domb BG**. Clinical Outcomes of Hip Arthroscopy in Radiographically Diagnosed Retroverted Acetabula. *The American Journal of Sports Medicine* 2016;44(10):2531–2536.

68. **Wall PDH, Brown JS, Parsons N, Buchbinder R, Costa ML, Griffin D**. Surgery for treating hip impingement (femoroacetabular impingement) (Review). *Cochrane Database Syst Rev* 2014;9:CD010796.

69. **Bensler S, Dietrich TJ, Zubler V, Pfirrmann CWA, Sutter R**. Pincer-type MRI morphology seen in over a third of asymptomatic healthy volunteers without femoroacetabular impingement. *J Magn Reson Imaging* 2019;49(5):1296–1303.

70. **Li AE, Jawetz ST, Greditzer HG, Burge AJ, Nawabi DH, Potter HG**. MRI Evaluation of Femoroacetabular Impingement After Hip Preservation Surgery. *AJR Am J Roentgenol* 2016;207(2):392–400.

71. **Dietrich TJ, Grob K, Kim C-HO**. Postoperative Imaging after Impingement Surgery. *Semin Musculoskelet Radiol* 2017;21(5):529–538.

SUPPLEMENTAL FIGURES AND TABLES

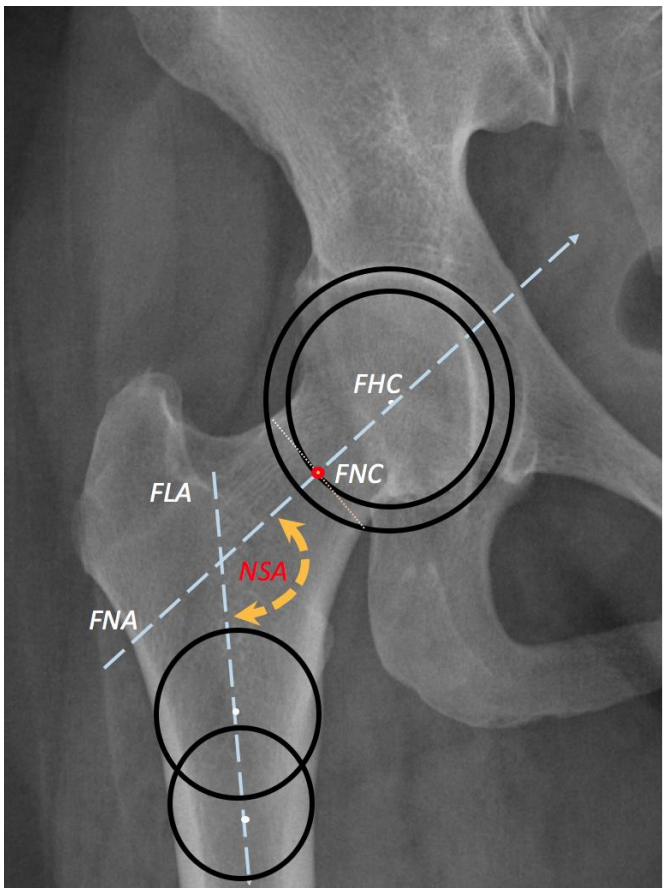
Supplemental TABLE 1. Imaging parameters to describe femoral morphology (see Figure 3 for corresponding illustration). AP: anteroposterior, CT: computed tomography, DDH: developmental dysplasia of the hip, IIL: ilioischial line, FH: femoral head, FHN: femoral head-neck, FN: femoral neck, MRI: magnetic resonance imaging, na: not applicable.

FEMUR AND JOINT	PARAMETER	UNIT	IMAGING TECHNIQUE	DEFINITION
FEMUR SPHERICITY	Alpha (beta) angle	(°)	Axial and AP pelvis CT and MRI	Angle formed by the FHN axis and line through the centre of the femoral head and the point where the anterior (posterior) FHN contour exceeds head radius
	Pistol-grip Deformity	Qualitative	Axial and AP pelvis	Seen as bump at the FHN junction other than osteophytes from seronegative arthritis and osteoarthritis
	Flattening of the lateral aspect of the femoral head	Qualitative	Axial and AP pelvis CT and MRI	Flattening of the normal concavity of the FHN junction;
	Asphericity	Qualitative	Axial and AP pelvis	The head is said to be aspherical if the femoral epiphysis extended more than 2 mm outside the reference circle corresponding to a spherical head
	Gamma (delta) angle	(°)	AP pelvis	Angle formed by the FHN axis (a) and line through the centre of the FH (C) and the point where the cranial (caudal) FHN contour exceeds the head radius
	Offset	[mm]	Axial and AP pelvis CT and MRI	Difference (o) between the FH radius (r) and the neck radius
	Offset ratio	na	Axial and AP pelvis CT and MRI	Ratio of offset (o) to the FH radius (r). If the ratio is <0.17, a cam deformity is likely present.
	Femoral distance	[mm]	Axial and AP pelvis CT and MRI	The perpendicular distance between a tangent along the cortex of the FN and the point of the largest osseous deformity at the FHN junction is measured.
	Triangular index	na	AP pelvis	A perpendicular line (p) is drawn at half the head radius (r). Distance (R) is measured from the FH centre (C) to the point where p intersects the anterior FHN contour. The triangular index is positive if R > r + 2 mm
	Omega angle	(°)	Radial imaging and 3D MRI/CT	This angle quantifies the extent of abnormally elevated α angles, providing information on cam magnitude (defined by the radial extension of the FHN deformity).
JOINT CONGRUENCY	Shenton's line	(intact/ interrupted)	AP pelvis	Interrupted if the caudal FHN contour and the superior border of the obturator foramen do not form a harmonic arc
	Lateralization of femoral head or position of the hip centre	(mm)	AP pelvis	Shortest distance between the medial aspect of the femoral head (FH) and the ilioischial line (IIL). Lateralized if greater than 10 mm.
ADDITIONAL FINDINGS	Cervicodiaphyseal angle or neck-shaft angle	(°)	AP pelvis CT/MRI	Angle formed by the FHN axis (C) and the femoral shaft axis (D)
	Femoral torsion	(°)	transverse images over proximal and distal femur (CT, MRI or Dunn 90°)	the angle between the longitudinal axis of the FN and the tangent at the condyles of the distal femur

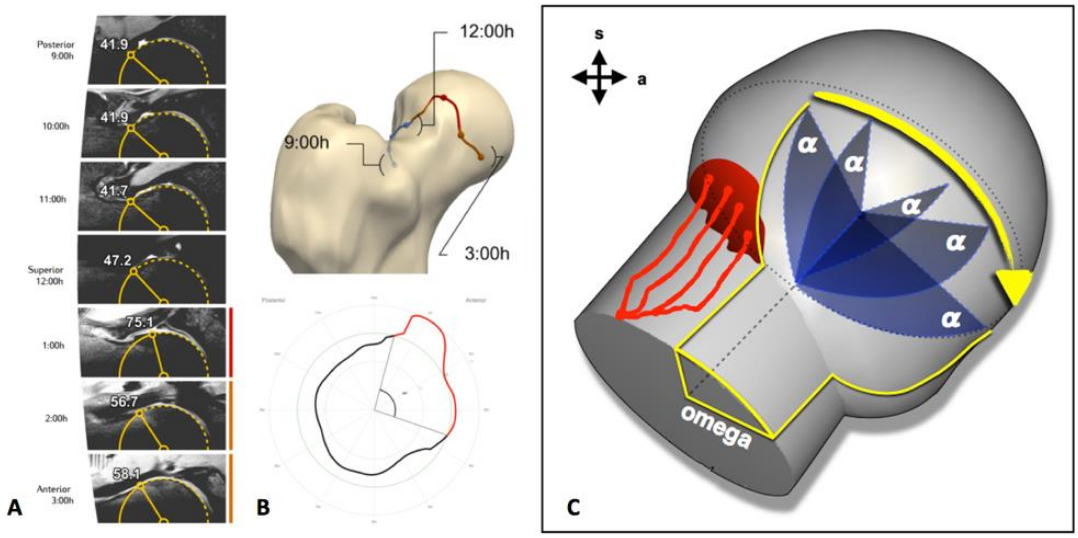
	Joint space width	(mm)	AP pelvis standing	JSW should be measured in the superior region of the hip joint. It is defined as the distance between the superior cortex of the femoral head and the acetabular sourcil.
	Minimum Joint space width	(mm)	AP pelvis standing	Measured as the inter-bone distance at the point of maximal narrowing in the superior part of the joint space
	Fovea angle delta	(°)	AP pelvis	Angle formed by a line through the medial edge of the acetabular roof (M) and the centre of the FH (C) and a line through the lateral border of the fovea capitis (F) and the centre of the FH (C). An angle ≤ 10° is associated with DDH.

Supplemental TABLE 2. Reference intervals for the neck-shaft angle in selected studies. CR: conventional radiography of the pelvis, including both hips, CT: computed tomography, No.: number of study subjects, Perc: percentile, SD: standard deviation, M: male, F: female

Authors	Population	No.	Modality	Age, years	2.5 perc.	Mean, Degree	97.5 perc.	SD
Boese et al 2015	Healthy adults	5089	CR	24-82		128.8		3.6-9
Boese et al 2015	Random	400	CT	18-100		129.6		5.9
	M	200		53.2		129.6		5.9
	F	200		55.4		131.9		6.8
Mascarenhas et al 2018	Asymptomatic	590	CT 3D	14-45	120	130	141	5.4
	M				118	129	139	5
	F				122	132	142	6
Mascarenhas et al 2018	Asymptomatic	1111	CT 3D	14-45	120	130.5	141	5.4
	M				118	129	139	5
	F				122	132	142	6



Supplemental FIGURE 1. Neck-shaft (NSA) angle measurement example (note that at least four different radiographic methods have been reported). Right hip AP radiograph. Femoral neck axis (FNA) and femoral long axis (FLA). FNA is usually defined by a line connecting the femoral head centre (FHC) and the femoral neck centre (FNC; red circle). Usually, the FHC is the centre of a circle defined by three points around the circumference of the femoral head (which can be challenging in hips with head deformity). The FNC can be defined reproducibly by the proposed method of Müller, as the centre between the cutting points of a circle centred on the FHC and the lower and upper margin of the waist segment of the femoral neck. To define the FLA, the best reproducibility can be expected by using the method of Clark et al (1987), represented by a line crossing the centre of two circles placed in the femur at two positions. The centre of the first circle is positioned at the level of the lesser trochanter and the second circle 2 cm below the first. The circles should coincide with the outer margins of the femur.



Supplemental FIGURE 2. (A) Volumetric 3D MRI alpha-angle (α°) measurements made at different points around the femoral head/neck junction. α° measured at 9 o'clock (posterior); 10, 11, and 12 o'clock (superior); and 1, 2, and 3 o'clock (anterior). **(B)** upper image: 3D model representing the radial extension of the cam deformity (orange and red line representing increased alpha angles). Lower image: Polar plot (2D) of the 360° α° around the FHN, representing the Ω° angle (grey straight lines) and corresponding perimeter (red line) for a given α° threshold (55°). Red lines represent increased α°s for a given threshold. The Ω° is formed by two lines intersecting the centre of the femoral neck at the level of the head-neck junction. The most posterior line posteriorly intersects the point at which the α° angle begins to be abnormal beyond a best-fitting circle and the anterior line at the point where the α° angle returns to normal. (C) Schematic drawing of the proximal femoral head. Retinacular vessels at the postero-superior quadrant are represented (red lines and dots), with corresponding relationship with the radial angular measurement of the cam deformity (omega- Ω°; yellow lines) defined by increased α° at the antero-superior quadrant (blue lines).

Supplemental TABLE 3. Reference intervals of alpha angle measurements obtained in selected population-based studies* and asymptomatic populations**. CR: conventional radiography of the pelvis, including both hips, FL: frog-leg lateral, CT: computed tomography, MR: MRI of the pelvis, including both hips, No.: number of study subjects, Perc: percentile, SD: standard deviation

Authors	Population	No.	Modality	Age, years	Mean, Degree	97.5 perc.	SD
Gosvig et al 2007*	Healthy adults	3202	CR (AP pelvis)	64			
	M	1184		22-90	53.2		12.1
	F	2018		23-89	45.5		5.4
Laborie et al. 2014*	Random	2005	CR (AP, frog-lateral	18.6 (17.2 – 20.1)			
	M	837	AP/FL		62/47	93/68	
	F	1168	AP/FL		52/42	94/56	
Pollard et al 2010**	Asymptomatic	83	CR (cross-table)	46	47	62	8
	M	39		48	48	64	8
	F	44		44	47	62	8
Hack et al 2010**	Asymptomatic	400	MRI (3:00/ 1:30)	29 (21.4 – 50.6)	40.8/50.1		7/8.1
	M	178			44/54		7.8/8.5
	F	222			38.1/47		5/6.1
Fraitzl et al 2013.**	Random	339	CR (AP, frog-lateral	47			
	M	170	AP/FL	47	49.4/49.1	70	10.5
	F	169	AP/FL	55	45/46.1	61/66	8/9.9
Scheidt et al. 2014**	Asymptomatic	164	CR (Dunn 45°)	50.4	45.1		8.6
	M	56			47.5		
	F	108			43.8		
Lepage-Saucier et al. 2014**	Asymptomatic	188	CT (axial/ radial 1:30)	63.2	51/59		9/13
	M	98			50/59	68/83	9/12
	F	90			50/58	69/82	9/13
Mascarenhas et al 2017**	Asymptomatic	188	CT 3D (3:00/ 1:30)	18-48	46/59	56/72	4.9/6.8
	M	98		35	46/62	56/75	
	F	90		34.4	46/56	56/69	
Mascarenhas et al 2018**	Asymptomatic	590	CT 3D (3:00/ 1:30)	14-45	46/58	58/70	5.8/6.5
	M	271		14-45	46/60	63/71	5.9(6.5
	F	319		14-45	46/56	57/70	5.7/5.9
Mascarenhas et al 2018**	Asymptomatic	372	MR 3D (3:00/ 1:30)	33.9±8	46/56.6	57/70.5	5.8/7.1
	M	186		17-50	44.9/59.4	56/73.5	5.7/7.2
	F	186		17-50	45.3/54	57/66	5.8/6.1
Gollwitzer et al. 2018*	Random	1312	CT 3D (1:30)	61.2	59		9.4

*Population based-studies; **Asymptomatic cohort

Supplemental TABLE 4. The reference intervals for offset, offset ratio and femoral distance measurements obtained in selected studies. CR: conventional radiography of the pelvis, including both hips, CT: computed tomography, FL: frog-leg lateral, MR: magnetic resonance imaging, No: number of study subjects, Perc: percentile, SD: standard deviation.

Parameter	Authors	Population	No.	Modality	Age, years	2.5 perc.	Mean	97,5	SD
Offset	Eijer et al 2001	Asymptomatic	10	CR (crosstable)	19-45		11.6		0.7
		Symptomatic	12				7.2		0.7
	Ehrmann et al 2001	Asymptomatic	106	MRI (anterosuperior)	20-50		7.1-7.3		1.8-2.9
		Symptomatic					6.1-6.2		1.9-3.3
	Lepage et al 2014	Asymptomatic	188	CT (axial)		5	8-9	12	2
	Kang et al 2010	Asymptomatic	100	CT (axial)	15-40		9.49		
Femoral Distance	Ehrmann et al 2001	Asymptomatic	106	MRI (anterosuperior)	20-50		1.1-1.7		1.4-2.2
		Symptomatic					3-3.3		1.4-1.8
Offset Ratio	Eijer et al 2001	Asymptomatic	10	CR (crosstable)	19-45		0.21		0.03
		Symptomatic	12				0.13		0.05
	Pollard et al 2010	Asymptomatic	83	CR (crosstable)	22-72	0.14	0.19	0.24	0.03
	Fraitzl et al 2012	Asymptomatic	339	CR (FL and AP)	17-96		0.15-0.18		0.03-0.04
	Van Houcke et al 2015	Asymptomatic	201	CT	30-33		0.19-0.20		

Supplemental TABLE 5. Mean values of femoral antetorsion reported in the literature in adults (studies using a method of measurement similar to the one reported by Reikeras et al.).
N: number of limbs included, SD: standard deviation, CT: computed tomography, MR: magnetic resonance imaging

Author	Year	n	Study population	Mean ± SD	Modality
Boissonneault et al.	2017	105	symptomatic	14,1 ± 11°	CT
Fabricant et al	2015	243	asymptomatic symptomatic	16 ± 4 ° 10 ± 5°	CT
Klingenstein et al	2013	778	symptomatic	15 ± 10°	CT
Tibor et al.	2013	112	symptomatic	16 ± 10°	MR
Sutter et al.	2012	63 63	asymptomatic symptomatic	12,8 ± 10,1° 13,1 ± 9,8°	MR
Toogood et al.	2009	375	asymptomatic	9,7 ± 9,3°	Anatomic
Prasad et al.	1996	171	asymptomatic	12,3 ± 7,3°	Anatomic
Reikerås et al.	1983	47 39	asymptomatic symptomatic	13 ± 7° 19 ± 9°	CT

Supplemental TABLE 6. Imaging parameters to describe acetabular morphology (see Figure 6 for corresponding illustration).

FN: femoral neck, FH: femoral head, na: not applicable, MR: magnetic resonance imaging, CT: computed tomography, AP: anteroposterior, AASA: anterior sector angle, PASA: posterior sector angle.

ACETABULUM	PARAMETER	VALUES	IMAGING TECHNIQUE	DEFINITION
DEPTH	*Coxa profunda*	Positive/negative	AP pelvis	Acetabular fossa (AF) touches or crosses the ilioischial line (IIL)
	Protrusio acetabuli	Positive/negative	AP pelvis	Femoral head (FH) touches or crosses the ilioischial line (IIL)
	Acetabular depth	Positive/negative	CT/MRI-transverse oblique image of the FN long axis	Distance between the centre of the FH and the line connecting the anterior /posterior acetabular rim. Values are considered positive if the centre of the FH is lateral to this line and negative if medial. Values ≤3 mm are considered positive for pincer deformities (Leunig et al; 2013)
COVERAGE	Lateral centre-edge, L-CEA	(°)	AP pelvis CT/MRI	Angle formed by a vertical line (v), which is perpendicular to a line connecting the teardrops, and a line through the centre of the FH (C) and the lateral bony rim of the acetabulum
	Centre-edge angle of Wiberg, W-CEA	(°)	AP pelvis	Lateral end of the sourcil, i.e. the weightbearing area of the acetabulum, rather than the lateral rim of the acetabulum
	Acetabular inclination or Acetabular index or Sourcil angle	(°)	AP pelvis CT/MRI	Angle formed by a horizontal line and a line through the medial and lateral edge of the acetabular roof
	Extrusion index	(%)	AP pelvis	Percentage of the FH width which is not covered by the acetabulum
	Sharp angle	(°)	AP pelvis	Angle between a horizontal line (hL) and a line connecting the acetabular teardrop (TD) and lateral edge of the acetabulum (LEA)
	Acetabular depth-width ratio (ADR)	na	AP pelvis	The depth of the acetabulum divided by the width of the acetabulum, multiplied by 1000, presented as a ratio: (A/B)*1000
	Anterior centre-edge	(°)	False profile CT/MRI	Angle formed by a vertical line (V) and a line through the centre of the femoral head (C) and the anterior edge of the acetabulum (E)
	Coverage	(%)	CT/MRI	Technique to measure the % cover of the FH by the weight-bearing zone (pelvic position standardised relative to a specific anatomical plane).
	Acetabular version (1,2 and 3 o'clock)	(°)	CT/MRI	Intersection of a perpendicular to the line between the posterior pelvic margins and a line connecting the anterior/posterior acetabular rims.
	AASA	(°)	CT/MRI	Lines through the centre of the femoral head and contralateral femoral head and tangential to the anterior lip of the acetabulum.
	PASA	(°)	CT/MRI	Lines through the centre of the femoral head and contralateral femoral head and tangential to the posterior acetabular lip.
ORIENTATION	Posterior wall sign	Positive/negative	AP pelvis	Positive if the posterior wall (PW) runs medially to centre of FH (C).
	Anterior (AWI) and posterior acetabular wall index (PWI)	Positive/negative	AP pelvis	Ratio of the width of the anterior (AW)/posterior acetabular walls (PW) measured along the FN axis (a) divided by the FH radius (r)
	Crossover sign	Positive/negative	AP pelvis	Anterior wall (AW) crosses the posterior wall (PW)

	Retroversion index	(%)	AP pelvis	% of retroverted acetabular opening divided by entire opening
	Ischial spine sign	Positive/negative	AP pelvis	Positive if ischial spine (IS) is projected medially to pelvic brim (PB)
OTHERS	McKibbin index	-	CT/MRI	Sum of femoral version and the acetabular version (at 3 o'clock).

Supplemental TABLE 7. The Reference intervals of acetabular measurements obtained in selected population-based studies* and asymptomatic populations**.

W-CEA: centre edge angle of Wiberg, L-CEA: lateral centre edge angle, Ac-inclination: acetabular inclination or index, CR: conventional radiography of the pelvis, including both hips, MR: MRI of the pelvis, including both hips, CT: computed tomography, No: number of study subjects, Perc: percentile

Parameter	Authors	Sex	No.	Modality	Age, years	2.5 perc.	Mean, Degree	97.5 perc.
W-CEA	Laborie et al. 2013*	M	841	CR	19	18.4	35	42.8
		F	1,170	CR	19	17.1	35	42.0
L-CEA	Laborie et al. 2013*	M	841	CR	19	20.8	32.1	45.0
		F	1,170	CR	19	19.6	31.0	43.4
	Werner et al. 2012*	M	871	CR	14 - 97	18.0	34.5	47.0
		F	355	CR	14 - 97	18.0	33.2	48.4
	Fischer et al. 2018*	M	1,587	MR	21 - 90	17	30	44
		F	1,639	MR	21 - 88	18	32	45
	Mascarenhas et al 2018**	M	271	CT	14-45	20	35.8	47
		F	319	CT	14-45	22	34.4	45
	Mascarenhas et al 2018**	M	186	MR	17-50	20	36.4	48
		F	186	MR	16-50	20	35.2	49
Acetabular inclination	Laborie et al. 2013*	M	841	CR	19	-4.7	5.6	14.8
		F	1,170	CR	19	-4.1	5.8	15.6
	Werner et al. 2012*	M	871	CR	14 – 97	-6.1	4.7	15.3
		F	355	CR	14 – 97	-7.5	3.8	14.5
	Mascarenhas et al 2018**	M	271	CT	14-45	-9	2.4	14
		F	319	CT	14-45	-6	4	13
	Mascarenhas et al 2018**	M	186	MR	16-50	-8	2	12
		F	186	MR	16-50	-6	3.7	14
Ac-Version	Mascarenhas et al 2018**	M	271	CT	14-45	8	18.2	27
		F	319	CT	14-45	14	22.9	32
	Mascarenhas et al 2018**	M	186	MR	16-50	7	17.8	28
		F	186	MR	16-50	13	23.6	33

. *Population based-studies; **Asymptomatic cohort.