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MUSCULOSKELETAL RADIOLOGY

Femoro-acetabular impingement: what the general radiologist should know

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Abstract Femoro-acetabular impingement (FAI) is a common condition in young active subjects, which can lead to the development of early osteoarthritis if not correctly diagnosed. Imaging evaluation of FAI, mainly based on plain film and magnetic resonance evaluation, must be performed according to precise guidelines and is fundamental for reaching a final diagnosis. The purpose of this paper is to provide a clinical and radiological overview of FAI by describing the most common clinical tests, the imaging techniques used in the diagnosis, and the main radiological signs that may be encountered.

Keywords Hip · Femoro-acetabular impingement · Pelvis radiography · Magnetic resonance arthrography

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Introduction

First described by the Swiss orthopaedic surgeon Reinhold Ganz et al. [1], femoro-acetabular impingement (FAI) is a pathological condition that is frequently seen in young active subjects, often in conjunction with top-level sport activities, in which bony components of the hip joint do not match correctly. This pathological condition can be caused by an anomalous junction between the femoral head and neck, by an anomalous acetabular shape or orientation, or by a combination of both factors (the latter event being the most common, occurring in up to 86 % of cases) [2]. Femoro-acetabular impingement is currently considered one of the main causes of early hip osteoarthritis, especially in young active subjects [2].

Despite the extensive literature on this topic, the diagnosis of FAI is still challenging and is based on a combination of hip pain, reduced range of movement, positive conflict tests, and specific radiological findings. Although highly dedicated imaging tests exist (i.e. magnetic resonance arthrography, MRA) that can be aimed at detecting FAI, common imaging modalities and general radiologists play a crucial role [1].

The purpose of this paper is to summarise the clinical and radiological bases of FAI, with special emphasis on those findings that are commonly encountered in daily clinical practice.

Aetiology

Femoro-acetabular impingement is characterised by an abnormal contact of the bony components of the hip, particularly during flexion and intra-rotation, when the anterior aspect of the femoral head–neck junction hits the acetabulum, thus reducing hip range of movement [1]. In this setting, normal movements performed when an abnormal anatomical situation is present lead to abnormal contact between the articular surfaces, causing important degenerative abnormalities [3]. The cause of this pathological condition is mainly congenital [4]. Femoro-acetabular impingement can be considered one of the most frequent causes of early hip osteoarthritis, especially in young active subjects [4]. In these subjects, the repetition of movements, typical of sport activities, cause a repetition of conflict, thus making symptomatic a condition that would have never become manifest in sedentary subjects [5].

Classification

On the basis of different morphological alterations that can be found in the hip, two different kinds of FAI can be encountered (Fig. 1) [1]. In cam-type FAI, the main finding is a difference in the curvature of acetabulum and femoral head, not perfectly spherical in normal conditions, in which a large irregularity (bump) of the femoral head–neck junction can be seen, causing a typical pistol grip deformity (Fig. 1b) [6]. This finding is responsible for cartilage tears of the anterior superior aspect of the acetabulum, which may lead to labral avulsion at later stages [6]. In pincer-type FAI, the main cause is represented by an overcovering acetabulum—sometimes also associated with pelvis retroversion [7]—that covers almost completely the femoral head, thus limiting its movements (Fig. 1c). This overcoverage may also be secondary to FAI, as degenerative capsular thickening caused by repetitive microtraumas may be associated with osteophyte occurrence [8]. There is also a third type of FAI, in which morphostructural alterations of both types can be seen concurrently [1]. Furthermore, some authors have described a fourth type of FAI, typical of subjects performing sport activities in which the hip is heavily involved—e.g. dancing or martial arts. In these activities, the normal hip is heavily solicited by unfavourable transversal forces that may lead to develop the above-mentioned lesions [3, 8]. Finally, cam-type FAI may be also associated with an acetabular undercoverage, which represents residual dysplasia and may have different grades of severity. In this condition, the load is concentrated over a limited area of cartilage, thus favouring early damage and instability, in turn leading to the typical morphostructural alterations [9].

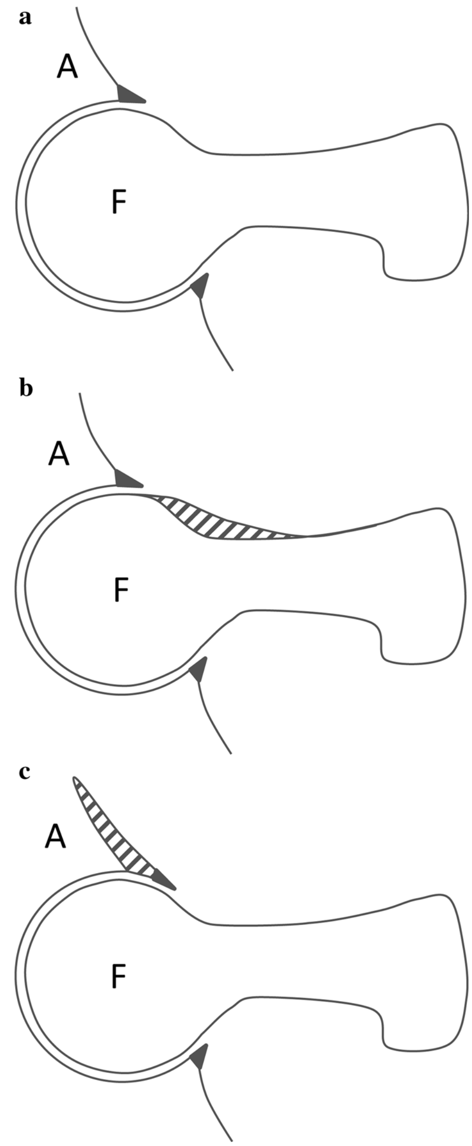

Fig. 1 Femoro-acetabular impingement: **a** normal hip; **b** cam type; **c** pincer type

Symptoms

Femoro-acetabular impingement generally has a subtle onset. Patients usually report groin pain, rarely posterior or lateral, and difficulty in performing movements in hyperflexion [10]. Symptoms are exacerbated when standing up after prolonged sitting. Sometimes, the hip may snap or partially block due to labral tears [10].

Clinical tests

Clinical examination of a patient with suspected FAI includes three tests [11].

(a) Anterior conflict test (flexion, adduction, intra-rotation = FADIR) is considered the most sensitive and specific test. With the patient lying supine on the table, the physician flexes 90° the patient's knee and rotates it internally, then adding an adduction movement. When positive, the test elicits groin pain.
(b) Drehmann test (flexion, abduction, extra-rotation = FABER). With the patient lying on the table, the physician moves the patient's foot of the affected side on the contralateral knee, then applying a medial-lateral pressure on the knee of the affected side. When positive, the test elicits hip pain.
(c) Posterior impingement test. With the patient lying supine and hip positioned on the edge of the bed, the physician forcedly extends and extra-rotates the affected limb. When positive, the test elicits posterior-lateral gluteal pain.

Imaging

X-ray evaluation

Patients with a clinical suspicion of FAI generally undergo X-ray evaluation first. This examination is very important in the diagnosis of FAI, as it allows for detecting the anatomical and skeletal abnormalities that are typical of this condition, both on the femur and on the acetabulum. At the beginning of the disease, subtle FAI findings can be seen, while characteristic signs of hip osteoarthritis are not already visible [2].

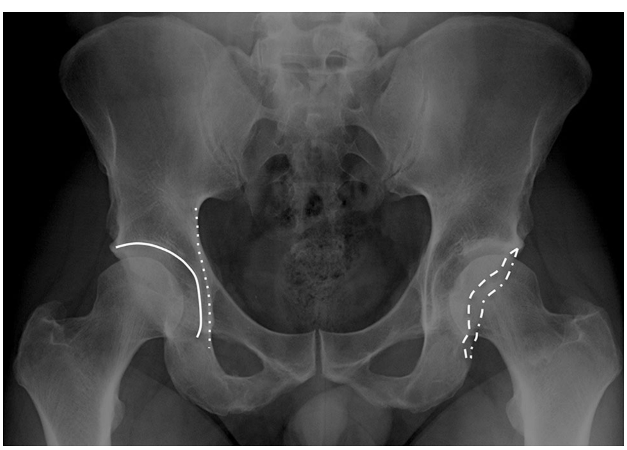

Fig. 2 Standing antero-posterior view of the pelvis. The sacrum–coccyx axis is oriented along the pubic symphysis and the ischiatic foramina are symmetrical. The bottom of the acetabulum is lateral to the ilio-ischiatic line. The anterior acetabular margin is lateral to the posterior margin. *Solid line* bottom of the acetabulum; *dotted line* ilio-ischiatic line; *dashed line* anterior acetabular margin; *dashed–dotted line* posterior acetabular margin

Anterior–posterior (preferably performed with patient standing) and axial 45° femoral flexion (also known as 45° Dunn view) projections should be always performed. Further projections can be performed, such as Lequesne's false profile and lateral pelvis projection to evaluate sagittal tilting. Radiographic evaluation must be always performed on both hips [2, 12].

(a) Anterior–posterior projection: the patient stands with the lower limbs in 15° of internal rotation. The symmetry of the ischiatic foramina and the alignment of the sacrum–coccyx axis with the pubic symphysis must be carefully checked (Fig. 2) [13].
(b) Axial 45° flexion femoral projection: patient is supine with the affected hip flexed 45° and abducted 20°. The greater trochanter should not be projected over the neck or the femoral head [12].
(c) Lequesne's false profile: the patient stands with the pelvis rotated 65° and the affected hip placed in contact with the radiographic plate. The foot of the affected side must be parallel to the plate and the X-ray beam must be centred on the femoral head [13].

Radiographic evaluation allows for detecting both direct signs of FAI (e.g. abnormal femoral head sphericity, acetabular over- or undercoverage, and acetabular retroversion) and the lesions caused on the articular structures [12].

Cam-type FAI can be detected as an abnormal femoral head sphericity, with the convex appearance of the head–neck junction due to the presence of a typical anterior or posterior bump (Fig. 3). This finding causes a conflict between the femur and the acetabulum during hip flexion and internal rotation. The anterior bump can be detected only in the anterior–posterior projection when located on the superior-lateral head–neck junction; only in the axial projection when located anterior to the head–neck junction; or in both projections when it has a larger extension. Such abnormality can be quantified by calculating the angle between the major axis of the femoral neck and the base of the femoral head–neck junction abnormality [1]. That angle, also known as α angle, is regarded as abnormal when greater than 55° (Fig. 3b).

Pincer-type FAI is caused by an overcoverage (coxa profunda and protrusio acetabuli) or a retroversion of the acetabulum. Acetabular depth is normal when the bottom of the acetabulum is projected laterally to the ilio-ischiatic line on the anterior–posterior projection (Fig. 4). When the acetabular bottom is in contact or crosses the ilio-ischiatic line on the medial side, a coxa profunda can be diagnosed.

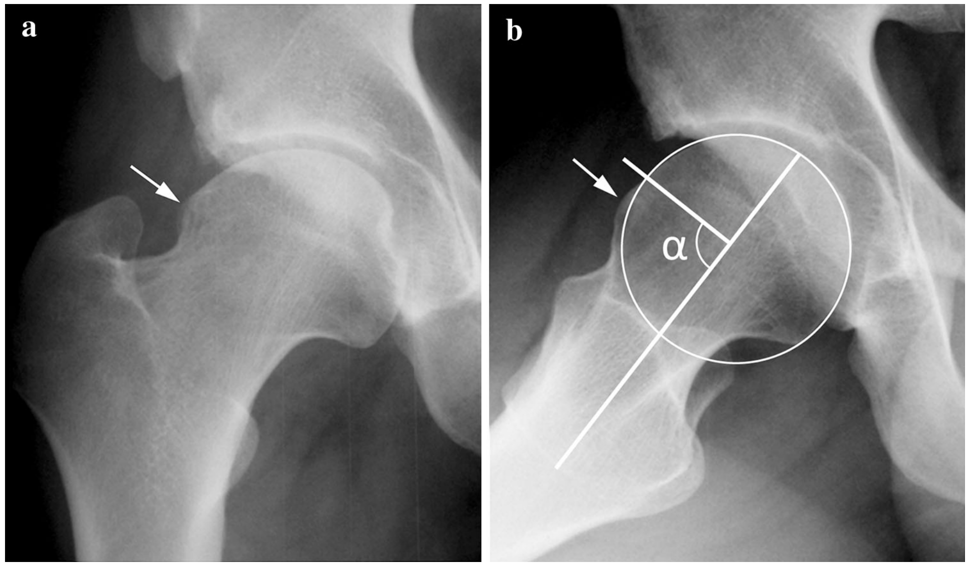

Fig. 3 Bony bump (*arrow*) in cam-type impingement that can be seen on both **a** the antero-posterior and **b** 45° Dunn view. In this latter view, the α angle can be calculated

Fig. 4 Antero-posterior view of the pelvis. Coxa profunda. The bottom of the acetabulum (*arrowheads*) is medial to the ilio-ischiatic line (*dotted line*)

When the femoral head is projected medially to the ilio-ischiatic line, a protrusion acetabuli can be diagnosed.

The relationship between the margin of the anterior and posterior acetabular profiles on the anterior–posterior projection allows for assessing the physiological acetabular anteversion or retroversion. When the acetabulum is anteverted, the anterior acetabular profile is located medially to the posterior profile, which remains lateral. When the acetabulum is retroverted, the anterior acetabular profile crosses the posterior profile, thus creating the typical "8-shaped" crossover sign (Fig. 5). If the radiographic projection is not correctly performed, the crossover sign cannot be correctly evaluated [7]. Moreover, a lateral pelvic projection is useful to assess the anterior–posterior tilt (normal value approximately 60°) [14].

Radiographic evaluation also has the role of establishing the conditions that can be potentially responsible for FAI due to coxo-femoral instability related to acetabular undercoverage (i.e. residual hip dysplasia). This condition can be quantified by measuring the Wiberg angle (Fig. 6) and acetabular index (Fig. 7) on the anterior–posterior projection. The Lequesne index, calculated on the Lequesne projection, can be also useful for quantifying an anterior acetabular undercoverage.

A number of studies have demonstrated that the above-mentioned findings can be found associated, thus generating mixed conditions of cam + pincer FAI (Fig. 5), and that both cam and pincer conditions may be associated with hip instability [1, 14].

Radiographic evaluation can also detect indirect signs of FAI. The detection of subcortical cysts at the site of conflict, particularly at the anterior femoral head–neck junction, is a typical sign of FAI in the most advanced cases (Fig. 8). What was once defined as a herniation pit is now considered as fibro-osteitis at the site of impact with the acetabulum in cam-type FAI [15]. The detection of an os acetabuli (Figs. 5, 9) is another finding frequently associated with FAI [16]. Thin calcifications around the acetabulum represent labral ossification, secondary to degeneration, which may be seen especially in pincer-type FAI (Figs. 8, 9) [24].

As previously reported, it is important to note that the radiographic findings must be closely correlated to clinical evaluation and the patient's age. For example, an anterior bony bump can be frequently seen in elderly patients affected by plain hip osteoarthritis.

The diagnostic performance of radiographic evaluation in FAI demonstrated variable results depending on the projection considered. For the anterior–posterior

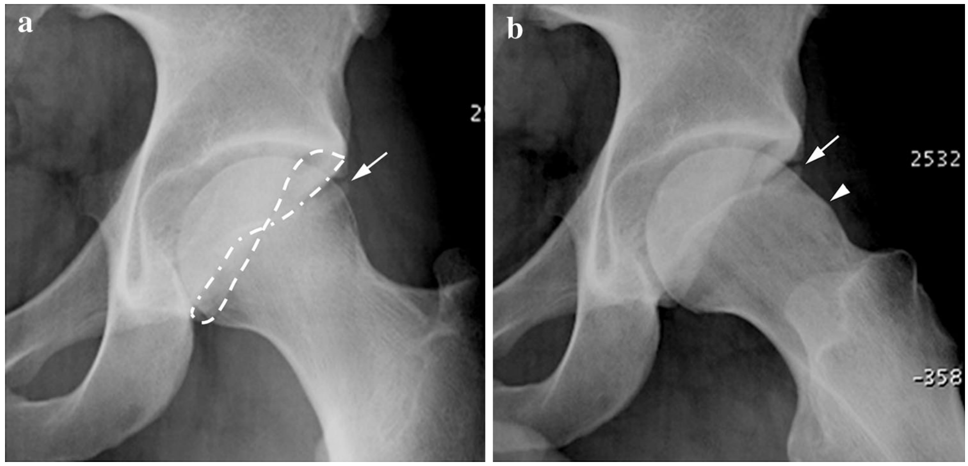

Fig. 5 Mixed-type femoro-acetabular impingement. **a** The antero-posterior view shows a cross of the anterior (*dashed line*) and the posterior (*dashed–dotted line*) acetabular margins. The typical 8-like pattern can be seen. This view does not clearly show the bony bump, which can be seen in the **b** 45° Dunn view (*arrowhead*). An os acetabuli can be seen (*arrow*)

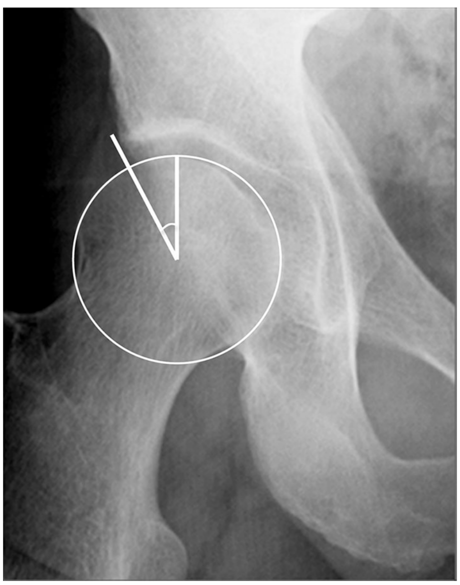

Fig. 6 Wiberg's angle can be calculated by tracing a line perpendicular to the transverse pelvic axis and passing over the centre of the femoral head and another line that joins the superior-lateral acetabular roof and the centre of the femoral head. Angle values less than 25° indicate an acetabular undercoverage

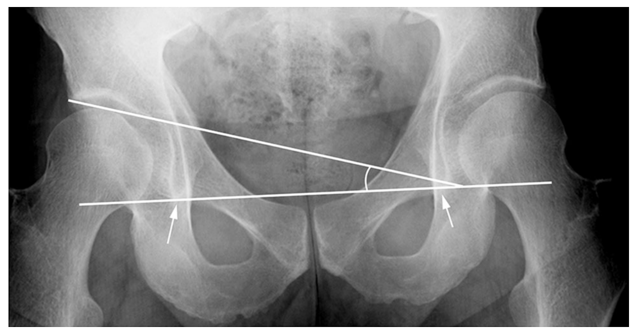

Fig. 7 Acetabular index or Tönnis angle can be obtained by intersecting a line that connects the acetabular drops (*arrows*) and another line that courses along the superior-lateral margin of the acetabulum and the femoral head. Normal values are between 0° and 10°. Values over 10° indicate potential instability

projection, the reported sensitivity was 60 % and specificity 81 %. For the axial hip projection, the same data were 70–74 % and 63 %, respectively, while the Dunn projection reached values of 91–69 % and 88 %, respectively [17, 18]. A recent paper on acetabular retroversion reported that the evaluation of such parameter is burdened by strong interobserver variability, which progressively decreases with increasing observer's experience [19].

Ultrasonography

The importance of ultrasonography in the diagnosis of FAI is limited. If this imaging modality is fundamental in the evaluation of the neonatal hip [20], in adults ultrasonography is limited to the detection of intra-articular effusion, evaluation of inflammatory, degenerative or post-traumatic conditions, or to the guidance of diagnostic or therapeutic intra-articular injections [21].

Because the hip is a deep joint, ultrasonography is commonly performed using a low-frequency convex probe.

Some authors reported that ultrasonography was able to detect most acetabular degenerative tears [22]. However, to date, the only study that proposed an ultrasonographic evaluation of FAI was performed by Buck et al. [23], who suggested three qualitative criteria to evaluate the anterior and anterior–superior profiles of the femoral head–neck junction, and to quantify the α angle in cam-type FAI.

The features of ultrasonography (low cost, wide availability and lack of ionising radiation) would make it the ideal imaging modality for preliminary cam-type FAI screening. However, the results [23] do not support such a hypothesis, particularly because the evaluation of the α angle alone may not be sufficient for the diagnosis of FAI [23]. Finally, as it is unable to evaluate intra-articular

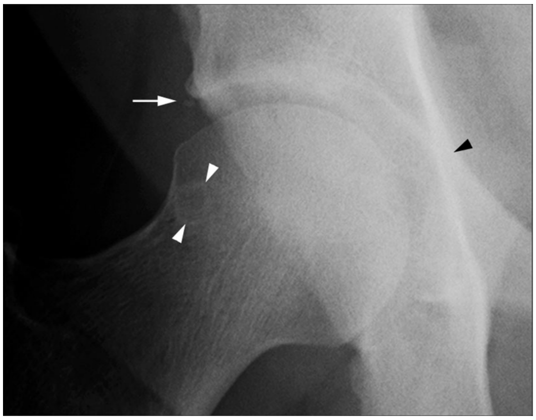

Fig. 8 Coxa profunda (*black arrowheads*) associated with a subchondral cyst (*white arrowheads*) at the head–neck junction. A small labral ossification can be seen (*arrow*)

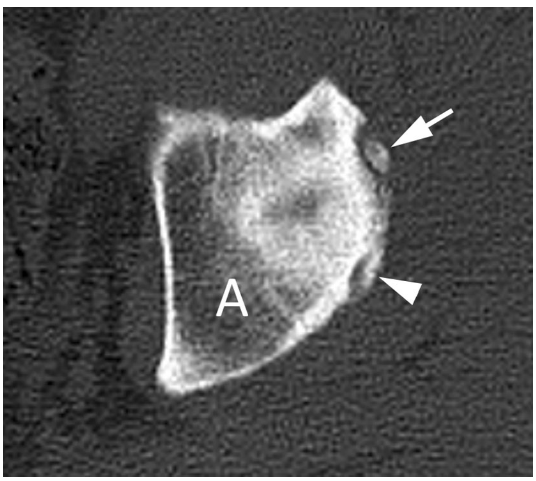

Fig. 9 Computed tomography axial scan (slice thickness = 3 mm). Presence of a typically round-shaped os acetabuli (*arrow*) and calcific metaplasia of the anterior labrum (*arrowhead*)

abnormalities, ultrasonography has a limited value in the assessment of patients with painful hip. However, in the hands of an expert operator, the detection of secondary signs of FAI may be useful by suggesting a correct diagnosis and then further workup with other modalities.

Computed tomography and magnetic resonance imaging

The radiographic evaluation of FAI is limited by the lack of visibility of nonosseous structural abnormalities of the hip joint: the labrum, sinovitis, and early chondral damage.

Computed tomography (CT) allows for a more accurate evaluation of the bone structures (Fig. 9), with limitations that are similar to radiographic evaluation [15]. The morphologic evaluation of the femoral head–neck junction with modern CT systems can be obtained by using multiplanar reconstructions oriented along the neck axis, with submillimetre slice thickness. Computed tomography allows for an accurate evaluation of calcific metaplasia of the labrum, scarcely detectable using magnetic resonance imaging (MRI).

Conversely, MRI allows for a more precise evaluation of subcortical bone damage, represented with low signal on T1-weighted sequences and high signal on T2-weighted sequences. However, the simple MRI evaluation allows for a limited analysis of the labrum and of the cartilage–labrum complex, which are of paramount importance when a surgical approach is anticipated [24, 25]. In this setting, MRA is considered the standard of reference [25, 26]. This technique implies the intra-articular injection of about 20 mL of a 1:250 solution of gadolinium-based contrast agent. The capsular distension caused by the injection allows for evaluating the anatomical structures and their damage with improved detail. It is advisable to perform intra-articular injection under imaging guidance, as it has been demonstrated that hip injection without guidance is burdened by a 40 % rate of failure [27]. The contrast agent must be injected very slowly, explaining to the patient that the procedure may be variably painful and may be associated with lameness lasting from few minutes to 7 days. Within the magnet, the patient is positioned in the supine position, and the feet should be bound together with adhesive tape in 15° intra-rotation, thus allowing for muscle relaxation. Magnetic resonance arthrography examination starts with axial and coronal T1- and T2-weighted fat-saturated and non-fat-saturated sequences, including the iliac wings and the lesser femoral trochanter. Then, T1-weighted or proton density sequences should be performed, with axial and coronal oblique orientation centred on the femoral neck and with double oblique sagittal orientation centred on the labrum. The examination can be completed with radial sequences oriented along the major axis of the femoral neck: these sequences can be included in the standard package provided with the MR system, or isotropic volumetric T1-weighted sequences can be reformatted in radial planes. These sequences have the greater advantage of sections that are always perpendicular to the labrum, with a low occurrence of artefacts, thus allowing a 360° evaluation of femoral head–neck junction [28]. Using fat saturation helps to obtain better images, but may limit the detection of important signs for FAI diagnosis, such as subcortical sclerosis, labrum calcifications, and labral myxoid degeneration [29].

In the diagnostic setting of FAI, several aspects should be considered.

(a) Evaluation of skeletal morphology: presence of pistol grip-like head–neck complex deformity and bump-like irregularity of the femoral head–neck junction

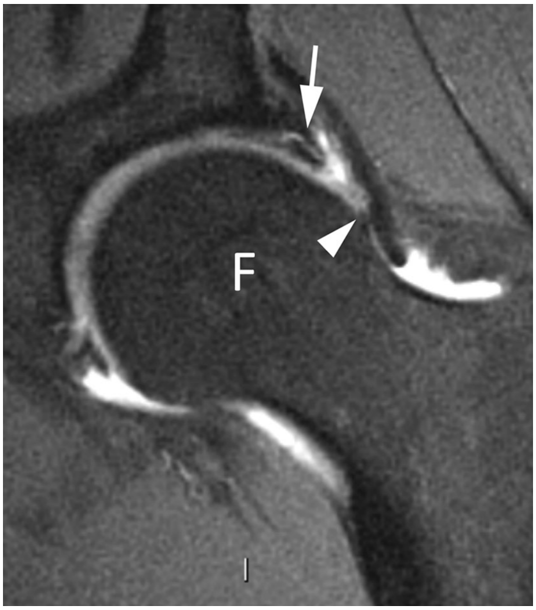

Fig. 10 Proton density-weighted fat-saturated coronal oblique scan (TE = 15 ms; TR = 3,310 ms; slice thickness = 3 mm). Bony bump at the anterior–superior femoral head–neck junction (*arrowhead*). An associated labral tear (*arrow*) can be seen, originating from the cartilage–labrum complex and extending up to the free border

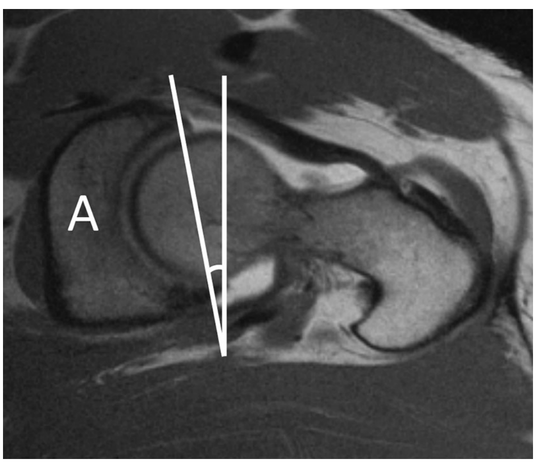

Fig. 11 T1-weighted axial scan (TE = 13 ms; TR = 954 ms; slice thickness = 3 mm). Acetabular anteversion angle, calculated between the crossing of the sagittal plane and a line connecting the anterior and the posterior labrum. *A* acetabulum

(Fig. 10). These conditions cause an increase over 55° of the α angle, typical of cam-type FAI. Standard nonoblique axial scans, also when performed for noncontrast examinations, can be used to measure the degree of acetabular anteversion or retroversion (Fig. 11) (to be evaluated together with the anterior–posterior pelvis projection) and the degree of femoral coverage (in association with Lequesne's projection), responsible for pincer-type FAI. The presence of femoral head structural failure should be

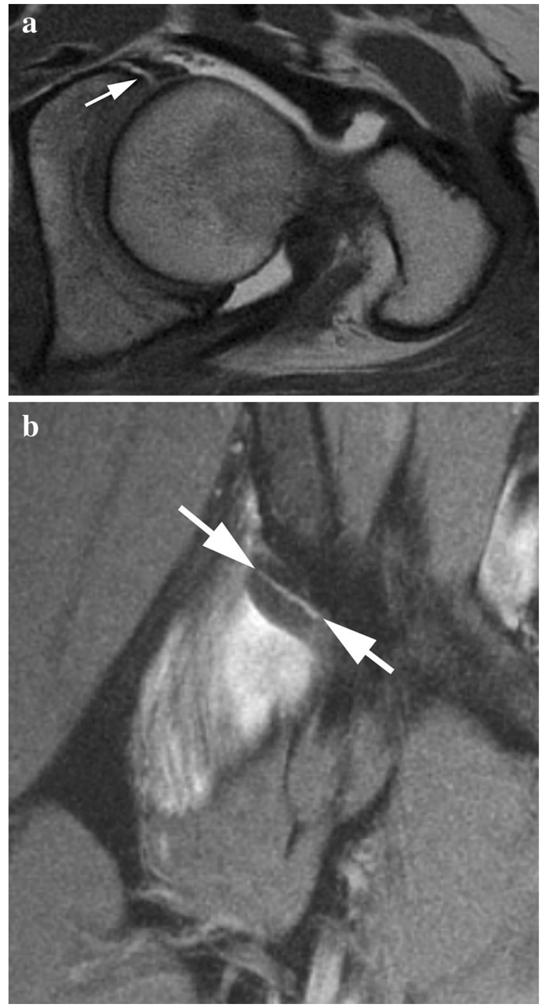

Fig. 12 **a** T1-weighted axial scan (TE = 13 ms; TR = 954 ms; slice thickness = 3 mm). Full-thickness tear of the anterior labrum with contrast leakage (*arrow*). **b** Proton density-weighted fat-saturated coronal oblique scan (TE = 15 ms; TR = 3,310 ms; slice thickness = 3 mm). Anterior–superior labral detachment with contrast leakage (*arrow*)

carefully evaluated and a precise quantification should be given. This parameter can be also evaluated on routine noncontrast sequences.

(b) Evaluation of chondral erosion and damage of the femoral head and acetabular surface: it is important to describe the articular rim (width and symmetry) [29] and calculate the extent of chondral damage (as a percentage or in centimetres). These parameters cannot be adequately evaluated using standard MRI, except for advanced chondropathy associated with subchondral oedema (hyperintense on T2-weighted sequences), which is extremely important for surgical planning. Regarding the site, chondral damage occurs more frequently on the anterior superior portion of the acetabulum in cam-type FAI, while an posterior inferior localisation is more frequent in pincer-type

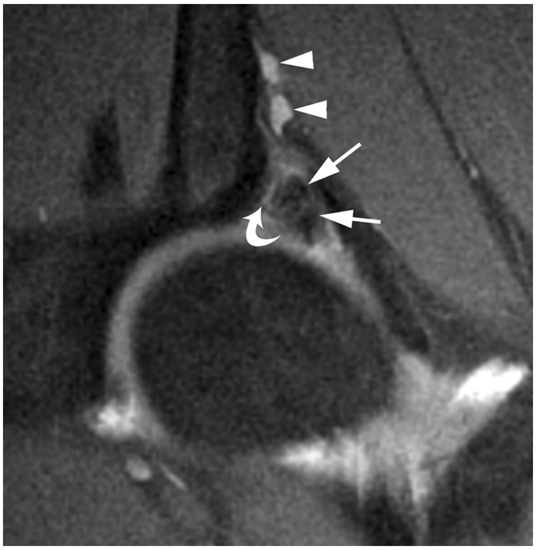

Fig. 13 Proton density-weighted fat-saturated coronal oblique scan (TE = 15 ms; TR = 3,310 ms; slice thickness = 3 mm). Cam-type impingement. Advanced labral degeneration. Note the inhomogeneous, rounded appearance (*arrows*), with labral detachment and contrast leakage (*curved arrow*). Two para-labral cysts can be seen (*arrowheads*)

FAI (countercoup lesion) [29]. Previous studies have demonstrated that MRA has variable sensitivity (50–77 %) and specificity (79–84 %) in the detection of cartilage tears [24, 26].

(c) Cartilage–labrum complex: it is important to differentiate advanced labral degeneration and a labrum that is morphologically normal, but detached from the acetabulum or affected by longitudinal tears (Figs. 10, 12, 13) [30]. Czerny et al. [24, 25] classified labral tears into traumatic and degenerative. Lage et al. [30] defined an arthroscopic classification subdividing abnormalities into four classes. However, these classifications are not completely accepted. Labral damage can occur with tears having horizontal (Fig. 10) or radial course (Fig. 12) or degenerative tears (Fig. 13), frequently associated with para-labral cysts (Fig. 13) or geodes [29–32]. The labrum may occasionally have a hypertrophic appearance, often due to calcific metaplasia (more easily detectable on CT), typical of cam-type FAI, associated with an unstable joint [9]. Similarly to what happens for the shoulder, conventional MRI is able to detect large abnormalities of the labrum, especially when associated with joint effusion that may mimic the arthrographic effect. Previous studies have shown that conventional MRI has 30 % sensitivity and 36 % accuracy in the detection of labral tears, in comparison to 90 and 91 %, respectively, of MRA.

Therapeutic options

In the literature, there is little agreement on the use of drugs and physiotherapy in patients with FAI. However, it is a widely held opinion that conservative treatment, being unable to modify the morphological aspects of this condition, cannot represent a real solution [33].

Patients with hip pain lasting over 6 months, unresponsive to conservative treatment, in whom radiographic signs of FAI are present, should undergo surgical treatment [34].

Three surgical techniques are available for treating the morphological abnormalities underlying FAI and the associated lesions:

(a) Open surgery: first described by Ganz et al. [35], implies surgical luxation of the hip and subsequent correction of femoral and acetabular bone abnormalities after labrum resection. Some orthopaedic surgeons also perform cartilage repair using mi™croperforations or chondroplasty [36].

(b) Arthroscopy: this is a less invasive technique, but more difficult to perform. Within the articular space, it is possible to treat cartilage tears and reduce the acetabular margin, detaching and re-inserting the labrum; outside the joint space, it is possible to reduce the femoral bump, checking the disappearance of conflict by using dynamic manoeuvres [37].

(c) Mini-open technique: this is a mixed technique, in which femoral neck osteoplasty is performed in open surgery without luxation through a small anterior incision, while intra-articular abnormalities are treated using arthroscopy [38].

At similar rates of post-surgical short- and long-term success, arthroscopy has a lower complication rate [39]. In open surgery, possible complications are trochanter pseudoarthrosis and trochanteric bursitis, heterotopic calcifications, and capsular fibrosis, while in mini-open surgery lateral femorocutaneous nerve lesion is the most frequent complication (17–45 %), followed by transitory neuroapraxis of the pudendal and femoral nerve [39].

In patients in whom FAI led to advanced osteoarthritis, conservative surgery is contraindicated and hip prosthesis represents the only solution.

The role of the general radiologist

In consideration of the above, it is clear that FAI diagnosis is extremely complex and involves a series of different parameters that cannot be summarised in a single radiological examination. Also, after the initial enthusiasm about FAI description and abundant literature published in a few years, the scientific community is now facing a possible problem of overdiagnosis. Indeed, abnormalities that are found in FAI are present in a number of asymptomatic subjects and can lead to an incorrect diagnosis if not closely correlated to clinical symptoms [2].

In this setting, the general radiologist has a crucial role. On the one hand, some subtle diagnostic signs are not clearly visible on routine radiological examinations. On the other, some radiological findings, correlated to young age and a specific clinical condition, may suggest the presence of FAI. The detection of such signs may provide clinicians with useful information to request further diagnostic workup with targeted examinations to reach an early diagnosis of FAI. This is particularly important, as it is thought that early conservative treatment is able to slow the progression of osteoarthritis, although long-term studies on this topic are still lacking [2, 7].

Conclusions

FAI is a pathological condition with multiple clinical and diagnostic aspects that affect the hip joint. Clinical evaluation—which remains fundamental—must be associated with imaging evaluation aimed at detecting the morpho-structural abnormalities typical of this condition. Since the clinical indication for radiological investigation of FAI patients is often nonspecific, the general radiologist should be able to detect the typical abnormalities of the condition which, if misdiagnosed, may lead to early juvenile osteoarthritis.

Conflict of interest Alberto Aliprandi, Francesco Di Pietto, Paolo Minafra, Marcello Zappia, Simona Pozza, and Luca Maria Sconfienza declare no conflict of interest.

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