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# Femoroacetabular impingement: normal values of the quantitative morphometric parameters in asymptomatic hips

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## Abstract

**Objective** To determine the means and the reference intervals of the quantitative morphometric parameters of femoroacetabular impingement (FAI) in normal hips with high-resolution computed tomography (CT).

**Methods** We prospectively included 94 adult individuals who underwent CT for thoracic, abdominal or urologic pathologies. Patients with a clinical history of hip pathology and/or with osteoarthritis on CT were excluded. We calculated means and 95 % reference intervals for imaging signs of cam-type (alpha angle at 90° and 45° and femoral head–neck offset) and pincer-type impingement (acetabular version angle, lateral centre-edge angle and acetabular index).

**Results** The 95 % reference interval limits were all far beyond the abnormal thresholds found in the literature for cam-type and to a lesser extent for pincer-type FAI. The upper limits of the reference intervals for the alpha angles (at 90°/45°) were 68°/83° (men) and 69°/84° (women), compared to thresholds from the literature (50°, 55° or 60°). Reference intervals were similar between genders for cam-type parameters, and slightly differed for pincer-type.

**Conclusion** The 95 % reference intervals of morphometric measurements of FAI in asymptomatic hips were beyond the

abnormal thresholds, which was especially true for cam-type FAI. Our results suggest the need for redefining the current morphometric parameters used in the diagnosis of FAI.

## Key Points

- 95 % reference intervals limits of FAI morphotype were beyond currently defined thresholds.
- Reference intervals of pincer-type morphotype measurements were close to current definitions.
- Reference intervals of cam-type morphotype measurements were far beyond the current definitions.
- Current morphometric definitions of cam-type morphotype should be used with care.

**Keywords** Hip · Femoroacetabular impingement · Multidetector computed tomography · Reference value · Normal value · Osteoarthritis · Anatomy · Variant

## Abbreviations

CT	computed tomography
FAI	femoroacetabular impingement
ICC	intraclass correlation coefficients
MPR	multiplanar reformatting
MRI	magnetic resonance imaging
OA	osteoarthritis
PACS	picture archiving and storage system

## Introduction

There has been increasing evidence that femoroacetabular impingement (FAI) causes chondrolabral abnormalities in the young adult population, especially young athletes, leading to pain and premature osteoarthritis (OA) [1–4]. FAI is defined as an impingement between the head–neck junction of

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the femur and the acetabular rim due to altered morphology of either or both of these structures. It can be classified as (1) cam-type impingement if the anterolateral or lateral femoral head–neck junction or the entire femoral head is prominent, (2) pincer-type impingement if the acetabulum presents general or focal overcoverage or (3) a combination of cam-type and pincer-type impingement [5]. It has been suggested that early diagnosis and treatment of FAI may prevent irreversible degenerative changes, with surgery being the preferred treatment [6–9].

The diagnosis of FAI is mainly based on the clinical examination, but many morphometric parameters at imaging have also been proposed and used as part of the diagnostic workup of FAI [1, 5]. These parameters have been validated on radiographs, magnetic resonance imaging (MRI) and on computed tomography (CT) [10–14]. However, to date, there is no consensus among authors as to the threshold values to define abnormal patients using these parameters, and only few studies have defined the normal range of the FAI morphometric values in normal hips [5, 13, 15–21]. Furthermore, several authors have recently pointed out the high prevalence of FAI signs in the asymptomatic population based on the currently used cut-off values and the need to redefine these abnormal thresholds [18, 19, 22–26]. As suggested by other authors, more work is needed to firmly establish the normal range of these morphometric parameters [17].

CT represents the imaging technique with the highest contrast and spatial resolution available for the 3D assessment of bone morphometry. To the best of our knowledge, the range of values of FAI morphometric parameters has never been established in a general population using CT.

The goal of this study was to determine the means and the 95 % reference intervals of the quantitative morphometric parameters of FAI in asymptomatic hips using high-resolution multidetector CT, in order to statistically define abnormal thresholds for these parameters.

## Materials and methods

### Patient population

Institutional ethical committee approval was obtained at our institution with written informed consent from all participating patients. No additional radiation than what was already needed for their current medical condition was given to any of the patients included in our study. We prospectively included all consecutive adult patients who obtained a (thoraco-)abdominopelvic CT for thoracic, abdominal or urogenital indications, from December 2011 to March 2012, in our institution. A questionnaire with “yes” or “no” answers was given to all participating patients about their clinical history: current or past hip/groin pain, any medical or surgical hip joint history, any history of hip trauma or any history of hip problems during childhood. All the patients who gave a positive answer to at least one of these questions were excluded.

We then excluded all patients with CT signs of OA on at least one hip. OA was defined at CT on the basis of strict criteria including the presence of at least one of the following: joint space narrowing, osteophytes, or subchondral bone changes including sclerosis or cysts. Finally, hips with any of the following diagnosis on CT were excluded: hip cartilage calcium deposition disease, post-traumatic deformity, Legg–Calve–Perthes disease, osteonecrosis, slipped capital femoral epiphysis, hip dysplasia or focal bone lesion.

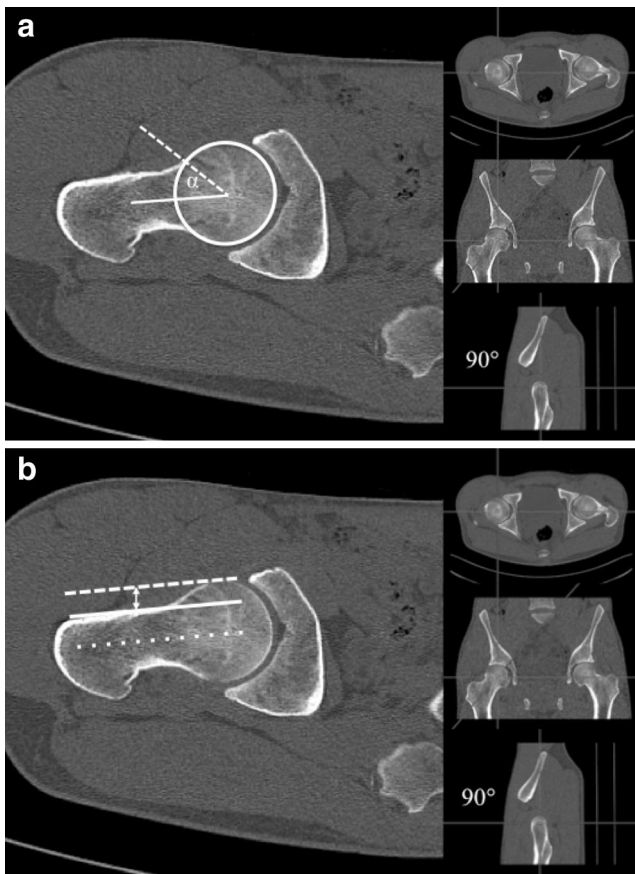
### CT examination

CT images were obtained on a 40-, 64- or 256-detector row scanner (Philips Brilliance 40, Brilliance 64 and ICT 256 respectively; Philips Medical Systems, Best, the Netherlands) with patients head first in supine position. The following parameters were used: tube voltage, 120 kVp; reference tube current–time product, 90–200 mAs with automated dose modulation. The CT covered the entire pelvis, including the ischial tuberosities. The raw data were reconstructed by using a bone algorithm.

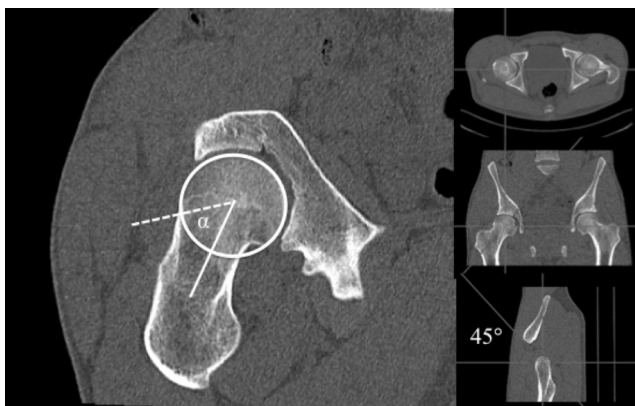
### Image analysis

Two fellowship-trained musculoskeletal radiologists (observer 1, 1.5 years of experience; observer 2, 4 years of experience) independently reviewed the CT images using our picture archiving and storage system (PACS) (Carestream PACS 11.3, Carestream Health Company, Raanana, Israel). The observers, both with previous practice of hip morphometry, together reviewed published morphometric parameters of FAI and trained on 10 hips that were not part of the study (Figs. 1, 2, 3 and 4). Prior to the study, all examinations were randomized (alphabetically ordered). Observer 1 executed the measurements on all hips according to the following procedure. Reformatted images in axial, axial oblique and double oblique planes were generated from the volumetric raw data. Then, a 100-mm-thick coronal multiplanar reformatted (MPR) image with an averaging of pixel intensities was also obtained, simulating a pelvic radiograph (Fig. 4) with the tip of the coccyx located approximately 2 cm above the pubic symphysis superior cortex on the midline [5]. In total, four reformatted images were created, cross-referencing with the sagittal and coronal planes:

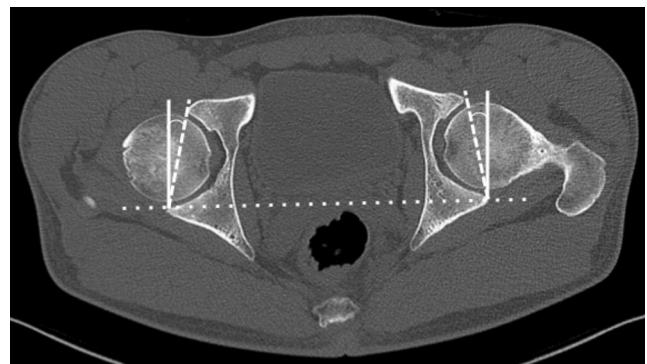
- Axial oblique plane (equivalent to radial plane) through the centre of the femoral head and the anterior aspect of the femoral head–neck junction, along the axis of the femoral neck (alpha angle 90° and femoral head–neck offset) (Fig. 1).
- Double oblique plane (equivalent to radial plane) through the centre of the femoral head and the anterosuperior aspect of the femoral head–neck junction at 45° to the axial plane, along the axis of the femoral neck (alpha angle 45°) (Fig. 2).
- Axial plane through the deepest part of the acetabula, parallel to the line through the posterior aspect of the acetabula (acetabular version angle) (Fig. 3).



**Fig. 1** **a** For the alpha angle 90° measurement, a circle was used to delineate the femoral head circumference. A first line was drawn between the centre of the circle and the centre of the narrowest part of the femoral neck (*solid line*). A second line was then traced from the centre of the circle to the point where the femoral neck extends beyond the femoral head circle (*dashed line*). The alpha angle was measured between those two lines. **b** The femoral head–neck offset is a measurement of the distance between two lines at the anterior aspect of the femoral neck (*solid line*) and at the anterior surface of the femoral head (*dashed line*). Those lines are parallel to the femoral neck (*dotted line*)



**Fig. 2** The measurement of the alpha angle 45° was performed according to the same definition as for the alpha angle 90°, on a double oblique reformatted image, which is equivalent to a radial reformatting at the anterosuperior position of the head–neck junction



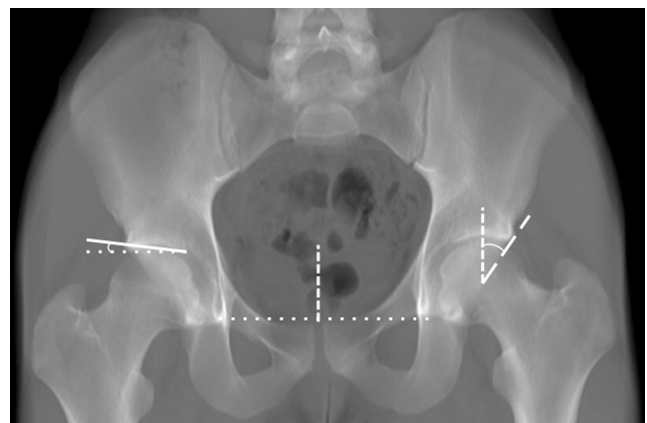
**Fig. 3** For the measurement of the acetabular version angle, a first line was traced between the posterior acetabular walls at the level where the acetabulum is the deepest (*dotted line*). The acetabular version angle was measured between a line perpendicular to that first line (*solid line*) and another one that joins the anterior and posterior walls of the acetabulum (*dashed line*)

- 100-mm-thick coronal MPR parallel to a line joining the lowest aspect of the radiographic teardrops (lateral centre-edge angle and acetabular index) (Fig. 4).

To ensure the consistency of the measurements made by observer 1, observer 2 performed the measurements on a subset of patients selected randomly (40 hips) according to the same procedure, and the interobserver agreement was calculated.

### Statistical analysis

For all the morphometric parameters, the mean values and standard deviations were determined. The one-sample Kolmogorov–Smirnov test was used to test whether data



**Fig. 4** Method of measurement of the acetabular index (right hip) and lateral centre-edge angle (left hip). The acetabular index (right hip) was measured between a line joining the inferior aspect of the teardrops (*dotted line*) and a line between the medial and lateral edge of the acetabulum roof (*solid line*). The lateral centre-edge angle (left hip) was measured between a line perpendicular to the inferior teardrop line (*dashed line*) and another line traced between the femoral head centre and lateral acetabular roof margin (*long dashed line*)

samples were normally distributed. Double-sided 95 % reference intervals were calculated following Clinical and Laboratory Standards Institute (CLSI) guidelines C28-A3 [27]. The normal distribution method was used for normally distributed variables. When the test for normal distribution failed, the non-parametric percentile method was used for sample sizes larger than 120, and the robust method (bootstrap method using 5,000 replications) for sample sizes below 120. The 90 % confidence intervals were given for the reference limits.

The proportion of men and women among the included and excluded patients was compared using a Chi-squared test.

Interobserver agreement was obtained with intraclass correlation coefficients (ICC). We used an absolute agreement model (systematic differences between readers considered relevant) for single measures (estimating the reliability of single ratings). The coefficients were analysed as follows:  $\leq 0$ =poor, 0.01–0.20=slight, 0.21–0.40=fair, 0.41–0.60=moderate, 0.61–0.80=substantial and  $\geq 0.81$ =almost perfect agreement. A *p* value of 0.05 was considered statistically significant for all analyses. Statistical analyses were performed using dedicated software (MedCalc version 11.6; MedCalc Software, Mariakerke, Belgium).

## Results

### Patient population

Of all the patients who underwent CT examination for thoracic, abdominal or urogenital indications in our institution during the 3-month period, 367 patients agreed to be part of the study. A total of 119 patients were excluded on the basis of at least one positive answer to the questionnaire and 154 on the basis of the presence of OA or other hip pathologies at CT. For the excluded patients, the mean age was 63.2 (SD 11.8) years old (Table 1). In total, 188 hips of 94 patients were included in

**Table 1** Included and excluded patients

	Number	Mean age	SD
Total included patients	94	49.0	16.6
Men	49	47.1	16.9
Women	45	51.2	16.2
Total excluded patients	273	63.2	11.8
Men	164	64.8	10.8
Women	109	60.6	12.7
Positive answer in questionnaire	119	62.4	11.7
Men	57	65.6	9.9
Women	62	59.2	12.4
Positive CT findings	154	63.8	11.8
Men	107	64.4	11.3
Women	47	62.4	13.0

the study (49 men and 45 women). The mean age of the included patients was 49.0 (SD 16.6) years old (Table 1). There was no statistically significant difference in the proportion of male and female individuals among the excluded and included patients (*p*=0.07).

### Image analysis

For the cam-type morphotype, the means were 51 (SD 9)° for the alpha angles at 90°, 59 (SD 13)° for the alpha angles at 45° and 9 (SD 2)mm for the femoral head–neck offset, when considering all patients together. For the pincer-type morphotype, the means were 19 (SD 6)° for the acetabular version angle, 32 (SD 6)° for the lateral centre–edge angle and 6 (SD 5)° for the acetabular index, when considering all patients together. Gender-specific and side-specific means and reference intervals are reported in Tables 2 and 3.

### Interobserver agreement

We found substantial to almost perfect agreement for all quantitative morphometric parameters measured in our study as seen in Table 4.

## Discussion

Imaging criteria are part of the diagnostic workup of FAI, along with the clinical examination [1, 5]. When morphological abnormalities are detected on the basis of these criteria, surgery has been advocated by some authors in order to alleviate the symptoms and possibly avoid the progression to early OA [7–9, 28]. Prior studies have used different cut-off values for the morphometric parameters of FAI [5, 13, 15–20]. Furthermore, recent studies have pointed out the high prevalence of FAI signs in the asymptomatic population based on the currently used thresholds, emphasizing the need for adjustment of these cut-offs [18, 22–24, 29].

Reference intervals can be used to define the variation range of a parameter in the normal population, which may be helpful in the differentiation of normal from abnormal [30]. By definition, reference intervals contain 95 % of values of a normally distributed variable in the normal population, if calculated from a representative sample. The lower and upper limits of the 95 % reference intervals can thus be used as the threshold between normal and abnormal subjects. In this study, means and 95 % reference intervals of the quantitative morphometric parameters of FAI were determined in asymptomatic patients using high-resolution multidetector CT.

For cam-type FAI, abnormal thresholds derived from the 95 % reference intervals were beyond the abnormal thresholds found in the literature. For example, the upper limits of the reference intervals calculated for the alpha angles at 90° and



**Table 2** Means, 95 % reference intervals and current abnormal cut-offs from the literature for the quantitative morphometric parameters of cam-type FAI

	Patients	Means	SD	Lower limits of 95 % reference interval*	Upper limits of 95 % reference interval*	Abnormal cut-offs from the literature
Alpha angle at 90° (°)	Men	50	9	33 [31; 36]	68 [65; 70]	>50° [22]; >55° [13]; >60° [19]
	Women	50	9	32 [30; 35]	69 [66; 72]	
	Right	50	9	33 [30; 35]	67 [65; 70]	
	Left	51	9	30 [27; 33]	68 [65; 72]	
Alpha angle at 45° (°)	Men	59	12	36 [32; 39]	83 [79; 86]	>50° [22]; >55° [13]; >60° [19]
	Women	58	13	32 [28; 36]	84 [80; 88]	
	Right	59	12	35 [32; 39]	82 [79; 86]	
	Left	59	13	33 [29; 37]	85 [81; 88]	
Femoral head–neck offset (mm)	Men	9	2	6 [6; 7]	12 [12; 13]	<8 mm [18]
	Women	8	2	5 [4; 5]	11 [11; 12]	
	Right	9	2	5 [5; 6]	12 [12; 13]	
	Left	9	2	5 [5; 6]	12 [11; 12]	

\*Data are limits of 95 % reference intervals, followed by 90 % confidence intervals in brackets

45° were 68° and 83° (men) and 69° and 84° (women), respectively, which are much higher than the 50°, 55° or 60° thresholds previously proposed [13, 17, 19] (Table 2). Of note, according to our data, the alpha angle was greater at the anterosuperior position (alpha angle 45°) than at the anterior position (alpha angle 90°) for both men and women, which is in agreement with other data in the literature [17, 19, 31]. Some of the variation between our results and previously reported values might be explained by the difference in the imaging modalities [17]. We used CT, which has high contrast and spatial resolution and allows easy delineation of the periphery of the femoral head and neck, and which could lead to potentially more accurate measurements than other techniques such as MR imaging.

Recently, several authors noted the high prevalence of FAI signs in the asymptomatic population on radiography and

cross-sectional imaging based on the previously described cut-off values [18, 23, 24, 29]. In a retrospective study on young asymptomatic subjects, Chakraverty et al. recently showed that at least one abnormal cam or pincer morphometric parameter was visualized in 66 % of joints, and two or more abnormal parameters were present in 29 % of joints [22]. The means that we calculated for the cam and pincer signs were very close to those obtained in that study. In a study by Sutter et al., the alpha angle did not allow adequate differentiation of healthy individuals from symptomatic patients, so the authors suggested an increase of the alpha angle threshold from 50–55° to 60°, in order to improve specificity [19]. They further concluded that the alpha angle is not an accurate method for distinguishing asymptomatic volunteers from patients with clinical FAI, because of the large overlap of alpha angles between these two populations [19]. The reported high

**Table 3** Means, 95 % reference intervals and current abnormal cut-offs from the literature for the quantitative morphometric parameters of pincer-type FAI

	Patients	Means	SD	Lower limits of 95 % reference interval*	Upper limits of 95 % reference interval*	Abnormal cut-offs from the literature
Acetabular version angle (°)	Men	17	5	7 [5; 8]	27 [26; 29]	<15° [20]
	Women	21	6	10 [8; 12]	32 [30; 33]	
	Right	19	5	8 [6; 10]	29 [28; 31]	
	Left	19	6	7 [6; 9]	30 [29; 32]	
Lateral centre-edge angle (°)	Men	35	6	22 [20; 24]	47 [45; 49]	≥45° [16]; ≥40° [5]
	Women	32	6	21 [20; 22]	44 [42; 46]	
	Right	33	6	21 [19; 23]	46 [44; 48]	
	Left	33	6	21 [19; 23]	46 [44; 48]	
Acetabular index (°)	Men	6	5	-3 [-4; -2]	14 [13; 16]	<0° [15]
	Women	6	4	-1 [-3; 0]	16 [15; 17]	
	Right	7	4	-3 [-4; -2]	15 [13; 17]	
	Left	7	5	-2 [-4; -1]	15 [14; 16]	

\*Data are limits of 95 % reference intervals, followed by 90 % confidence intervals in brackets

**Table 4** Interobserver agreement

	Interobserver agreement
<b>Cam impingement</b>	
Alpha angle at 90°	0.77 [0.59; 0.88]
Alpha angle at 45°	0.77 [0.59; 0.88]
Femoral head-neck offset	0.70 [0.47; 0.84]
<b>Pincer impingement</b>	
Acetabular version angle	0.90 [0.81; 0.95]
Lateral centre-edge angle	0.78 [0.61; 0.89]
Acetabular index	0.93 [0.84; 0.97]

Data are intraclass correlation coefficients and 95 % confidence intervals are given in brackets

prevalence of cam morphotype using these previously described imaging criteria and the width of the reference intervals found in our study suggest that the currently used morphometric criteria for cam-type FAI need to be redefined. More specifically, our results suggest that the alpha angle is not an appropriate parameter to define cam-type morphotype.

For pincer-type FAI, all the 95 % reference interval limits for the evaluation of the acetabular morphology were also beyond the abnormal thresholds reported in the literature, however, to a lesser extent than for cam-type FAI [5, 13, 15–20] (Table 3). Of note, the reference intervals for the lateral centre-edge angle for men (22, 47°) and women (21, 44°) were very close to what is found in the literature. A lateral centre-edge angle equal to or greater than 45° is suggestive of acetabular overcoverage and a lateral centre-edge angle equal to or less than 20–25–30°, depending on the authors, is classically thought to suggest hip dysplasia [16, 32]. Among the parameters that we evaluated, the lateral centre-edge angle has been most widely used in the literature to evaluate acetabular morphology and our results confirm previously reported cut-off values [33].

In our study, the upper limits of the reference intervals for the alpha angle and the femoroacetabular offset were similar between men and women, coherent with Pollard et al. [21], but divergent with Hack et al. [17]. For the pincer morphotype, there is also a controversy about the difference between men and women as far as these morphological variants are concerned [22, 23]. We found that differences between genders were less than 3° for the means of all morphometric parameters of pincer-type FAI. These small differences might be clinically irrelevant.

Our limits of confidence intervals were similar between right and left hips, comparable with previous reports [23]. Laborie et al. analysed the prevalence of the cam-type and pincer-type impingement signs and no significant differences were noted between the left and right sides [23].

This study has some limitations. First, our normal values were derived from a limited sample of 94 patients corresponding to 188 hips. However, according to Altman, a reference

interval can be reliably calculated if the sample size of a study is more than 50 observations [30].

Second, defining a normal sample population is a difficult task and may be subject to many biases. Although our sample was not selected from healthy volunteers, we prospectively included consecutive patients presenting for non-orthopaedic pathology to our department and excluded all patient with any history of current or past hip pathology or symptoms. Furthermore, we took great care to prospectively exclude any patients with signs of hip pathology (including OA) at CT, based on strict criteria. No physical evaluation of the hips was performed. However, we believe that the prospective exclusion of all patients with any symptoms, clinical history or CT signs of hip pathology allowed us to limit this potential bias because pain is a key symptom in FAI. Without pain as the main complaint, the diagnosis of FAI generally cannot be made. Furthermore, by excluding all patients with OA signs at CT, we ensured that potential abnormalities such as osteophytes would not bias our anatomic measures.

Third, part of our analysis was based on 100-mm-thick coronal MPR, simulating pelvic radiographs. Even though we did not obtain radiographs in these patients, this previously described technique allowed us to obtain reformatted images that precisely meet the requirements that are necessary for the radiographic evaluation of FAI morphotypes [5, 18].

Fourth, the interobserver agreement, which was substantial to almost perfect, was evaluated only on a small subset of randomly selected patients. However, the purpose of this analysis was mainly to verify the consistency of the application of the measurement method by observer 1, not the overall evaluation of the interobserver agreement for the assessment of FAI signs at CT.

Fifth, the imaging was performed on three different devices, which could have had an effect on the measurements. However, this potential bias was limited by the fact that all three devices were from the same manufacturer, and image quality was optimized by the same team of radiologists on all three of them, to ensure homogeneous quality.

In conclusion, we determined gender- and side-specific means and 95 % reference intervals of the cam and pincer morphometric parameters in the asymptomatic patient population based on high-resolution multidetector CT. The 95 % reference interval limits calculated for the FAI signs were all far beyond the abnormal thresholds found in the literature for cam-type and to a lesser extent for pincer-type FAI, except for the lateral centre-edge angle for which reference intervals are similar to previously reported normal values. Our results suggest that current definitions of FAI morphotype at imaging should be used with care. More specifically, this current work strengthens previous studies suggesting that the alpha angle is not an appropriate parameter to define cam-type FAI and needs to be redefined [19]. This parameter just seems to reflect normal anatomical variation. Having 95 % of an

asymptomatic population presenting alpha angles between 30° and 83° (depending on the quadrant where it is measured) is an indication that what has been considered as a pathological feature in the literature (an alpha angle >50°, 55° or 60°) just represents a normal variant. Under certain circumstances, such as in specific sports activities, the presence of a certain morphotype might predispose to the development of FAI. The pathogenesis of FAI is beyond the scope of this study, but in view of our results, it should be kept in mind that FAI remains a clinical diagnosis and that preventive surgery in asymptomatic subjects should not be planned on the basis of the presence of imaging signs alone [28, 34].

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