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ORIGINAL ARTICLE

Prevalence, topographic and morphometric features of femoral cam-type deformity: changes in relation to age and gender

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Abstract Femoroacetabular impingement (FAI) syndrome is a frequent cause of pain and in recent years considered to be a precursor of premature hip osteoarthritis. The structural abnormalities which characterize FAI syndrome, such as the cam-type deformity, are associated with morphological alterations that may lead to hip osteoarthritis. The aim of this study was to determine the prevalence and topographic and morphometric features of the cam deformity in a series of 326 femur specimens obtained from a Mexican population, as well as changes in prevalence in relation to age and gender. The specimens were subdivided into groups according to gender and age. A standardized photograph of the proximal femur of each specimen was taken, and the photograph was used to determine the alpha angle using a computer program; the location of the lesion was determined by quadrant and the morphometric characteristics were determined by direct observation. The overall prevalence of cam deformities in the femur specimens was 29.8 % (97/326), with a prevalence by gender of 35.2 % (64/182) in men and 22.9 % (33/144) in women. The mean alpha angle was 54.6° ± 8.5° in all of the osteological specimens and 65.6° ± 7.5° in those specimens exhibiting a cam deformity. Cam deformities were found topographically in the anterior–superior quadrant of the femoral head–neck junction in 86.6 % (84/97) of the femurs. Deformities were found in 28.2 % of the right femurs and 31.3 % of the left femurs. The prevalence of cam deformity was higher in the femur specimens of young men and in those of middle-aged and older women. There were no significant differences in this deformity in relation to the alpha angle according to age and gender.

Keywords Age · Alpha angle · Cam deformity · Femur · Gender · Prevalence

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Introduction

Femoroacetabular impingement (FAI) syndrome refers to a clinical condition which develops due to abnormal contact between the acetabulum and femoral head–neck junction during hip flexion. This abnormal contact leads to the development of deformities in the acetabular labrum and adjacent articular cartilage, which continue to progress and lead ultimately to degenerative joint disease (Ganz et al. 2003; Parvizi et al. 2007). FAI syndrome is a frequent cause of pain and is increasingly recognized as a potential precursor of hip osteoarthritis. The structural abnormalities associated with the development of this disease include abnormal morphology of the femoral head–neck junction and the acetabulum, causing a clinical presentation of chronic pain and functional limitation of the hip (Banerjee and Mclean 2011; Gosvig et al. 2007; Laborie et al. 2011; Nötzli et al. 2002).

There are three morphopathological mechanisms that can generate FAI: the cam deformity, the pincer deformity and a combination of these two deformities (Fraitzl et al. 2013). In the cam deformity, there is a morphological alteration in the proximal femur, specifically at the femoral head–neck junction (Cobb et al. 2010). In the pincer deformity, the acetabulum is altered due to acetabular overcoverage of the femoral head or by the presence of an anterior osteophyte. In both deformities, there is abnormal repeated contact between the femur and the acetabulum, which causes chondral lesions and labral tearing (Ganz et al. 2003).

Cam deformities have been reported as being more common in young male athletes, while pincer deformities are most often observed in middle-aged women (Banerjee and Mclean 2011). However, Beck et al. (2005) reported surgical findings of mixed deformities in up to 86 % of cases. Measurements of proximal femoral geometry, such the alpha angle, can be made from osteological specimens that have been stripped of their surrounding soft tissues (Streit et al. 2013). Although it is impossible to follow these osteological specimens over time, we suggest that insight into the natural history of a deformity left untreated may be gained by comparing specimens from patients of different ages with subsequent bony changes (Streit et al. 2013). Knowledge of these relationships is important to the practicing orthopaedic surgeon because the value of new treatments may be better appreciated when the natural history of uncorrected deformities is recognized (Streit et al. 2013).

To date, no studies analyzing the prevalence of cam deformities in the Mexican population have been conducted. Therefore, the aim of this study was to determine the prevalence of cam deformities in a Mexican population and its distribution by gender and age, as well as to conduct a topographic and morphometric study of the characteristics of this condition.

Materials and methods

This study was designed as an anatomic, observational, cross-sectional, descriptive and comparative study. The sampled material consisted of 326 dry femurs obtained from donated Mexican corpses of known gender (182 males, 144 females) and age (range 18–100 years). Specimens with structural damage were excluded from analysis.

To determine the prevalence of cam deformity and to perform the measurements and statistical analysis, we first divided the osteological specimens into groups based on gender, followed by further division into three subgroups based on age, resulting in six study groups (women aged 18–39 years, women aged 40–59 years, women ≥60 years, men aged 18–39 years, men aged 40–59 years, and men ≥60 years), as shown in Table 1.

Table 1 Classification of femurs analyzed in this study by age and gender

Age group (years)	Distribution of femurs		
	Male	Female	Total
18–39	64 (41.7 %)	36 (25 %)	100
40–59	66 (33.3 %)	52 (36.1 %)	118
≥60	52 (25 %)	56 (38.9 %)	108
Total (*n*)	182 (100 %)	144 (100 %)	326

Obtaining and measuring the alpha angle

To determine the presence of a cam deformity, we measured the alpha (α) angle following the method of Nötzli et al. (2002). The margin of the anterior concavity of the femoral neck was considered to be the "A" point, which represents the place where the distance from the bone to the center of the femoral head (CFH) first exceeds the radius of the cartilaginous cover of the femoral head. We measured the angle between the femoral neck axis and a line connecting the center of the head with the "A" point (Fig. 1). The femoral neck axis was defined as a line passing through the CFH and the center of the femoral neck at its narrowest point. Any angular measurement that was ≥55° was considered to indicate a positive cam deformity (Beall et al. 2005; Gosvig et al. 2007; Hong et al. 2010; Kassarjian et al. 2005).

We took photographs of the proximal femur following the method of Streit et al. (2013) to determine whether a cam deformity was present or not. The femur specimens were placed on a mechanical press in which the femoral condyles were held in position at both ends. Special care was taken to slightly raise the lateral femoral condyle to maintain the axis of the femoral neck in a position parallel to the floor (Fig. 2). This device keeps the osteological pieces in an upright and stable position, which optimizes the photographic process and standardizes the measurement technique. The photographs were taken perpendicular to the proximal femur with respect to the long axis of the femoral neck, from a top view, at a standardized distance of 30 cm using a 24-megapixel digital camera (model D 3200; Nikon Corp., Tokyo, Japan) positioned on a professional tripod (Canon Inc., Tokyo, Japan). MATLAB computing software (Mathworks, Inc., Natick, MA) was used to analyze the pictures and determine whether or not a cam deformity was present.

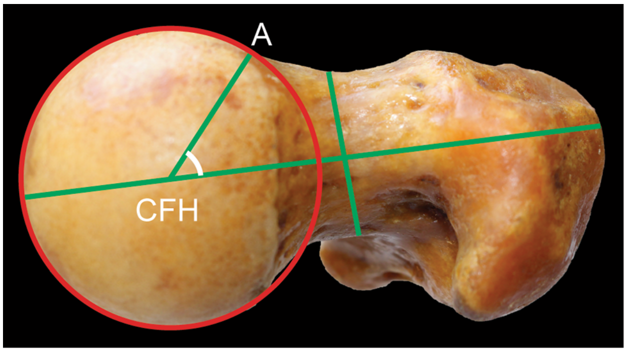

Fig. 1 Determination of the alpha (α) angle using the computer program. *Red line* Axis of the femoral neck. *CFH* Center of the femoral head, *A* point where the distance from the bone to the CFH first exceeds its radius

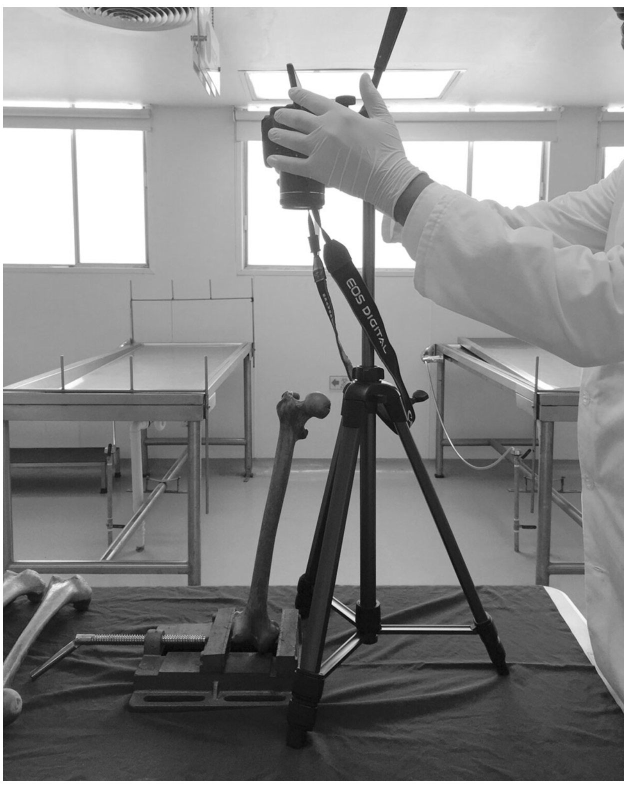

Fig. 2 Positioning of the femur and of the equipment used for photographing the specimens

Topography measurement of the cam lesion

In those specimens which we identified as having a positive cam deformity, based on our analysis of the photographs, we then determined the location of the specific area of the femur in which the deformity was located. The femoral neck was divided into quadrants (anterosuperior, anteroinferior, posterosuperior and posteroinferior). The anterior and posterior quadrants were defined by a line extending from the femoral neck axis towards the center of the femoral head in the coronal plane. The upper and lower quadrants were assigned based on a line that extended parallel to the femoral neck axis towards the femoral head center in an axial plane. In cases where a cam deformity was present in more than one quadrant, the deformity was ascribed to the quadrant containing >50 % of the spread of the deformity.

Using a digital Vernier caliper with an accuracy of 0.01 mm (Mitutoyo Digimatic Encoders w/series 500; Mitutoyo Corp., Kawasaki, Japan), we measured the superoinferior diameter (SID), transverse diameter (TD) and height of the cam deformity of each specimen (Fig. 3). The edges of a cam-type deformity were easily visible at the femoral neck, which explains why measuring it was easy at this level; with respect to the limit of the femoral head, the former could be identified by delimiting the point "A" surgical marker (previously explained).

The measurement parameters and results of each specimen were analyzed and the prevalence of cam deformity was determined in relation to gender, age, side (left and right), symmetry and topography of the deformities and morphometric characteristics.

Statistical analysis

The SPSS version 19.0 for Windows 7 computer program (IBM Corp., Armonk, NY) was used for the statistical analysis. For each of the groups, the mean and standard deviation (SD) of the α angle were measured, as was the morphometry of each cam deformity. The two-tailed Student's *t* test was used to determine the significance of the differences found in the results between men and women in the same age group, as well as to determine the significance of the differences between the results obtained by comparing different age groups within the same gender. The threshold of significance was taken as $p < 0.05$.

Results

A total of 326 femurs were studied. These were collected from corpses of known age and gender, all of Mexican origin. Prevalence of the cam deformity was determined according to gender, age and side. Likewise, the topographical and morphometric characteristics of the cam deformities identified were determined (Fig. 4).

Prevalence

The total prevalence of cam deformities in all of the femurs studied was 29.8 % (97/326). The prevalence of cam deformities according to gender was 35.2 % (64/182) in

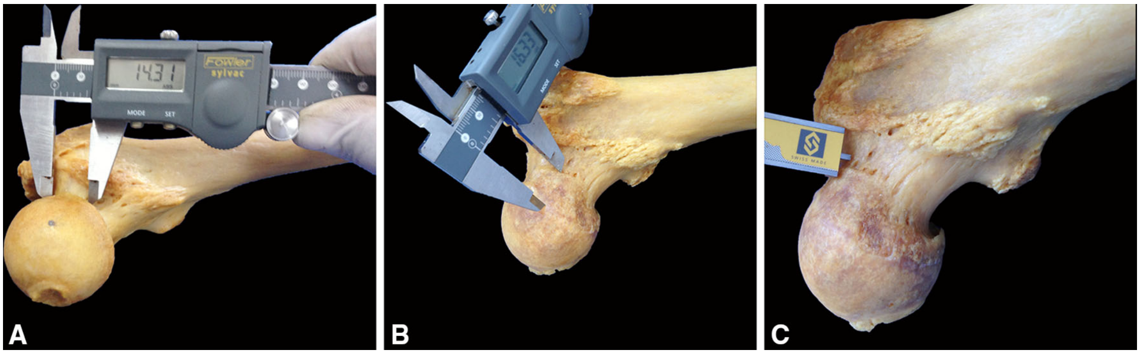

Fig. 3 Morphometrics taken from the femoral cam lesions. **a** Superoinferior diameter, **b** transverse diameter, **c** height

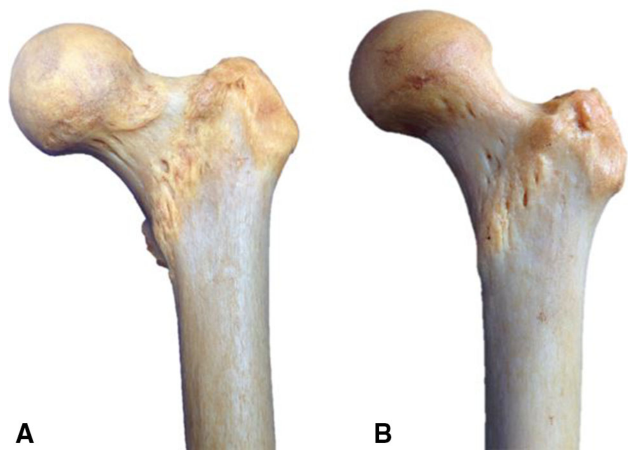

Fig. 4 Photograph of a femur with a cam-type deformity (**a**) and of a normal femur (**b**)

Table 2 Prevalence of femoral cam-type lesions in the studied femurs according to age and gender

Age group (years)	Distribution of cam lesions	
	Male (n = 182)	Female (n = 144)
18–39	32.8 % (21/64)	13.9 % (5/36)
40–59	43.9 % (29/66)	25 % (13/52)
≥60	26.9 % (14/52)	26.8 % (15/56)

males and 22.9 % (33/144) in females. The prevalence of cam deformities by age group is shown in Table 2. Cam deformities (regardless of gender) were found in 28.2 % (46/163) of the right femurs and 31.3 % (51/163) of the left femurs.

Cam deformities appeared at least on one side in 61 of the 163 donated corpses from which the samples were obtained. The deformity was bilateral in 59.0 % (36/61) and unilateral in 41.0 % (25/61) of these cases.

Table 3 Distribution of alpha angles for femurs with a positive cam lesion according to the different age and gender groups

Age group (years)	Alpha angle (n = 116)		p value
	Male (n = 64)	Female (n = 33)	
18–39	70.2° ± 9.5°	68.4° ± 14.1°	0.85
40–59	64.2° ± 6.1°	63.2° ± 6.0°	0.70
≥60	63.3° ± 4.6°	65.1° ± 6.2°	0.58

Results are presented as the mean ± standard deviation

Alpha angle by gender and age group

The mean α angle in all of the osteological specimens comprising the sample (326 femurs) was 54.6° ± 8.5°. The mean α angle in specimens with no evidence of cam deformities (204 femurs) was 49.9° ± 2.6°, and that angle in specimens exhibiting cam deformities (122 femurs) was 65.5° ± 7.5°.

The different mean α angles in the femurs of different ages with positive cam deformities are given in Table 3. There were no significant differences in the mean results for each age group between men and women ($p > 0.05$) (Table 3). There were also no significant differences in all age subgroups within the same gender group (Table 4).

Topography of cam lesions

Cam deformities (regardless of gender) were found topographically in the anterosuperior quadrant of the femoral neck in 86.6 % (84/97) of cases and in the anteroinferior quadrant in 13.4 % (13/97). There were no cam deformities in the posterosuperior or posteroinferior quadrants of the femoral neck. However, it should be noted that the lesion occupied two quadrants in 29.5 % (36/122) of the femurs with cam deformities.

Table 4 Comparison of the mean alpha angle of femurs with a positive femoral cam lesion among different age groups but withing the same gender group

Comparison groups	Alpha angle comparison	
	Male *p* value	Female *p* value
18–39 vs 40–59	0.13	0.39
18–39 vs ≥60	0.21	0.66
40–59 vs ≥60	0.60	0.48

Morphometry of cam deformities

The mean size of the cam deformity in all specimens where the lesion was present (97/326) (regardless of topography, gender, and age of the specimen) was an SID of 14.9 ± 3.9 mm, A TD of 20.2 ± 4.9 mm and a height of 3.2 ± 1.1 mm.

Discussion

There is very little published data on the prevalence of femoral cam-type deformities. Most current data are from studies involving patients undergoing hip surgery or from radiological prevalence studies conducted among patients with pain and/or functional limitation of the hip. Therefore, our study analyzing the prevalence of femoral cam-type deformities in a Mexican population provides valuable data. Measurement of the α angle has been shown to be a sufficiently reliable and valid method to detect cam-type FAI (Barton et al. 2011; Clohisy et al. 2007; Gosvig et al. 2007; Mast et al. 2011; Nötzli et al. 2002). Gosvig et al. (2007) established that the α angle measurement is also an effective and feasible method for use in epidemiological studies of prevalence.

Prevalence

It is important to determine the overall prevalence of cam deformities in order to be able to estimate its impact on the degenerative pathology of the hip. The overall prevalence of the cam deformity in our sample of femur specimens was 29.8 %. Hanzlik et al. (2012, unpublished data) studied osteological specimens and reported findings similar to our results, with an overall prevalence of cam deformities of 29.7 %. In a radiological study performed in a Danish study population, Gosvig et al. (2007) reported a prevalence of cam deformities of 6 % in men and 2 % in women in the overall population and of 44 % in men and 35 % in women in patients undergoing total hip replacement. In two studies involving asymptomatic volunteers, the prevalence of a pathological cam deformity, as defined by the α angle, was found to be 14.0 % in men and 5.6 % in women (Hack et al. 2010; Jung et al. 2011). These results show that there is a large variability in the reported prevalence of cam deformities.

The literature contains very few published studies showing variations in the prevalence of the cam deformity according to age and gender. In our study, 35.2 % of the specimens from men and 22.9 % of those from women had the cam deformity. Laborie et al. (2011) performed a radiological study in adults without previous hip pathology and obtained a prevalence of cam deformities of 35 % in men and 10.2 % in women. In their study of osteological specimens, Hanzlik et al. (2012, unpublished data) found cam deformities in 33 % of the specimens from men and in 20 % of those from women. FAI has been linked to childhood hip disorders, such as Legg–Calve–Perthes disease and slipped epiphysis of the femoral head, which are the most common abnormalities in men), hip dysplasia, septic arthritis, and previous fractures of the pelvis or femur (Leunig et al. 2009). This association may explain the higher prevalence in males. Despite these correlations, most FAI cases are of unknown origin (Leunig et al. 2009).

In terms of age, we found that the prevalence of cam deformities in our femur specimens from young men (18–39 years and 40–59 years) was higher than that in our femur specimens from older individuals (≥60 years). In contrast, we found that the prevalence of cam deformities in our femur specimens from the two older groups of women (40–59 and ≥60 years, respectively) was higher than that in the femur specimens of the younger group. The collection from which our osteological pieces were obtained corresponds to a Mexican contemporary collection (<20 years old). We hypothesize that there are anthropologically significant variations due to the amount of physical and occupational activities carried out by young people in the last two decades (mostly men) and that these variations could have led to an increase in the prevalence of the cam deformity. However, we do recognize that the natural history of this disease has not been completely elucidated.

LaFrance et al. (2014) conducted a radiological study to determine the prevalence of cam deformities in patients divided into two age groups (individuals aged >65 years and those aged 18–65 years, respectively). The patients of both groups underwent arthroplasty due to degenerative hip disease. These authors found that 70.47 % of the patients in the older group (>65 years) had cam deformities compared to 24.62 % of patients in the younger group. This result suggests a close relationship between the presence of femoral cam deformities and hip joint degeneration.

In our study, cam deformities were found on the right side in 28.2 % (46/163) of femur specimens and on the left side in 31.3 % (51/163) of femur specimens (regardless of gender and age). Hanzlik et al. (2012, unpublished data) reported very similar figures, with 31.7 % cam deformities on the right side and 27.7 % on the left side.

Alpha angle (differences between genders and age group)

Measurement of the α angle is very important because it is a commonly used tool to assess the presence of cam deformities in the overall population, and its use can be extrapolated to different hip imaging techniques. Mathew et al. (2014) measured a mean α angle of 67° in subjects with hip pathology. Notzli et al. (2002) reported a mean α angle of 42° in a control group of asymptomatic patients and of 74° in patients with pathology. In clinical studies on small patient populations as well as in an research study of a small sample of femurs from an osteologic collection, the mean α angle reported for asymptomatic subjects ranged from 42° to 51° (SD range 2.2–15.7) (Clohisy et al. 2007; Meyer et al. 2006; Nötzli et al. 2002). These results are similar to the findings obtained in our study.

Topography of the cam deformity

The topography of cam lesions is of interest for their arthroscopic treatment. Hanzlik et al. (2012, unpublished data) reported that the deformity was located in the anterosuperior quadrant in 91 % of cases and in the anteroinferior quadrant in 9 %. These values are consistent with our findings (86.6 % in the anterosuperior quadrant and 13.4 % in the anteroinferior quadrant). Taken together, it would appear that the cam deformity is most commonly found in the anterosuperior quadrant; consequently, contact with the acetabular rim will be more pronounced in these patients.

Morphometry of the cam deformity

A surgical resection of a femoral neck bump and/or part of the anterolateral aspect of the femoral neck is required when the abnormality is due to insufficient head–neck offset. Resection of a portion of the anterolateral aspect of the femoral head–neck junction improves the femoral head–neck ratio, increasing the range of motion before impingement occurs (Mardones et al. 2005). To the best of our knowledge, our study is the first to report on the morphometric characteristics of femoral cam-type deformities. As such, our data should facilitate surgeons in determining the mean size of the deformity to be resected during surgery.

Conclusions

Among our femur specimens, which originated from a Mexican population, the prevalence of cam deformities was greater in the femurs of young men and the femurs of middle-aged and older women. There were no significant differences in this deformity in relation to the alpha angle according to age and gender. These results are the only data currently available on this disease in the Mexican population, and its findings should be verified by other clinical or basic studies with larger samples.

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Compliance with ethical standards

Ethics statement This research protocol was approved by the local research ethics committee.

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Conflict of interest statement The authors declare that they have no conflict(s) of interest.

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