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ORIGINAL COMMUNICATION

The Femoral Calcar: A Computed Tomography Anatomical Study

THOMAS LE CORROLLER,[1,2,3]* **MELANIA DEDIU,**[2] **VANESSA PAULY,**[4] **NICOLAS PIRRO,**[1]
PATRICK CHABRAND,[3] AND **PIERRE CHAMPSAUR**[1,2,3]

[1]*Department of Anatomy, Faculté de Médecine de Marseille, Marseille, France*
[2]*Department of Radiology, Hôpital Sainte Marguerite, Marseille, France*
[3]*Institut des Sciences du Mouvement, UMR CNRS 6233, Université de la Méditerranée, Marseille, France*
[4]*DIM, Hôpital Sainte Marguerite, Marseille, France*

The femoral calcar is a dense internal septum reaching from the femoral neck to the distal part of the lesser trochanter. Our study aimed at providing an exhaustive radio-anatomical description of this structure. One hundred pelvic computed tomography examinations were retrospectively selected to bilaterally evaluate the shape, dimensions, and density of the femoral calcar. Then, its relation to the femoral cavity was assessed by recording the dimensions of the medullary canal at the level of the greatest length of the spur. The femoral calcar exhibited a variable shape classified as ridge-type 17% (34/200), spur-type 66.5% (133/200), and septum-type 16.5% (33/200). Its mean dimensions were: height = 33.03 mm (20–46), length = 9.94 mm (5–16), and thickness = 2.71 mm (1–4). These dimensions were positively correlated to the height and weight of the individuals ($P < 0.001$) and were higher in males ($P < 0.001$). Its mean density was 788.5 Hounsfield units (530–1,200). The longest oblique and anteroposterior diameters of the femoral cavity were respectively 38.74 mm (28–51) and 22.04 mm (17–27). The femoral cavity dimensions were positively correlated to the height and weight of the individuals ($P < 0.001$), to the femoral calcar dimensions ($P < 0.001$) and were higher in males ($P < 0.001$). The femoral calcar was constantly identified as a vertical plate of compact bone exhibiting a consistent anatomical pattern, which suggests a significant mechanical function within the upper femur. Our results may lead to a greater understanding of the hip fracture patterns and to alternative designs for hip arthroplasties. Clin. Anat. 24:886–892, 2011. © 2011 Wiley-Liss, Inc.

Key words: **femur; femoral calcar; cancellous bone; trabecular bone; computed tomography; anatomy**

INTRODUCTION

The first description of the femoral calcar (L. *calcar*, a spur) as a bony spur projecting into the cancellous tissue of the base of the femoral neck is classically attributed to the German anatomist Merkel (1874). He described a dense ridge extending from the thick mediodorsal part of the femoral cortex down to the

*Correspondence to: Thomas Le Corroller, Department of Anatomy, Faculté de Médecine de Marseille, 27 Boulevard Jean Moulin, Marseille, France. E-mail: Thomas.LeCorroller@ap-hm.fr

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lesser trochanter. Although Merkel was probably the first to use the term in this sense, the calcar had also been illustrated by Bigelow (1869) as a thin dense plate of bone continuous with the dorsal aspect of the femoral neck and plunging beneath the intertrochanteric ridge (Newell, 1997). Then, Merkel (1907) reported that the internal dense trabecular structure of the spur is important for stress distribution of the medial femoral cortex, and that it is part of the compressive trabecular system. The femoral calcar has later been described by Garden (1961), Griffin (1982), and Newell (1997) as a vertical plate of compact bone which develops in the postero-inferior portion of the femoral neck during adolescence. Superiorly it attaches to the mass of bone in the intertrochanteric region, as well as the posterior part of the horizontal trabeculae within the femoral neck (Hammer, 2010). Laterally it has an attachment with the protruding buttress that supports the proximal portion of the base of the horizontal trabeculae. Medially it attaches to the lower portion of the vertical trabecular mass. Even with progressing osteoporosis it tends to maintain its attachment to most of these structures, but gradually detaches from the internal buttress as this shrivels away (Hammer, 2010). Its development, junctional position, and retention throughout life suggest that it may have a significant mechanical function.

Although the femoral calcar can be visualized in lateral conventional radiographs when the spur is in line with the X-ray beam, it has not been assessed in further detail to our knowledge. Moreover, despite Garden's work (1961), many orthopedic surgeons still inappropriately apply the term ''calcar'' to the thickened cortical bone of the inferomedial femoral neck at its junction with the femoral shaft, as seen in an anteroposterior radiograph (Newell, 1997). On the other hand, a few previous computed tomography (CT) studies mentioned the femoral calcar as a remaining internal dense trabecular structure in cross-sectional slices after threshold image processing when selecting cortical bone (Dai et al., 1985; Walker and Robertson, 1988; Laine et al., 2000). As these studies were performed to evaluate the femoral cavity to design femoral stems for hip arthroplasty, the femoral calcar was not examined in more detail, and its biomechanical function neither studied further.

For all these reasons, our study was intented to exhaustively describe the femoral calcar, and to determine its relation to the femoral cavity in a nonselective group of patients undergoing CT for other purposes.

MATERIALS AND METHODS

A total of 100 consecutive patients (64 men, 36 women; mean age, 60.2 years; age range, 20–91

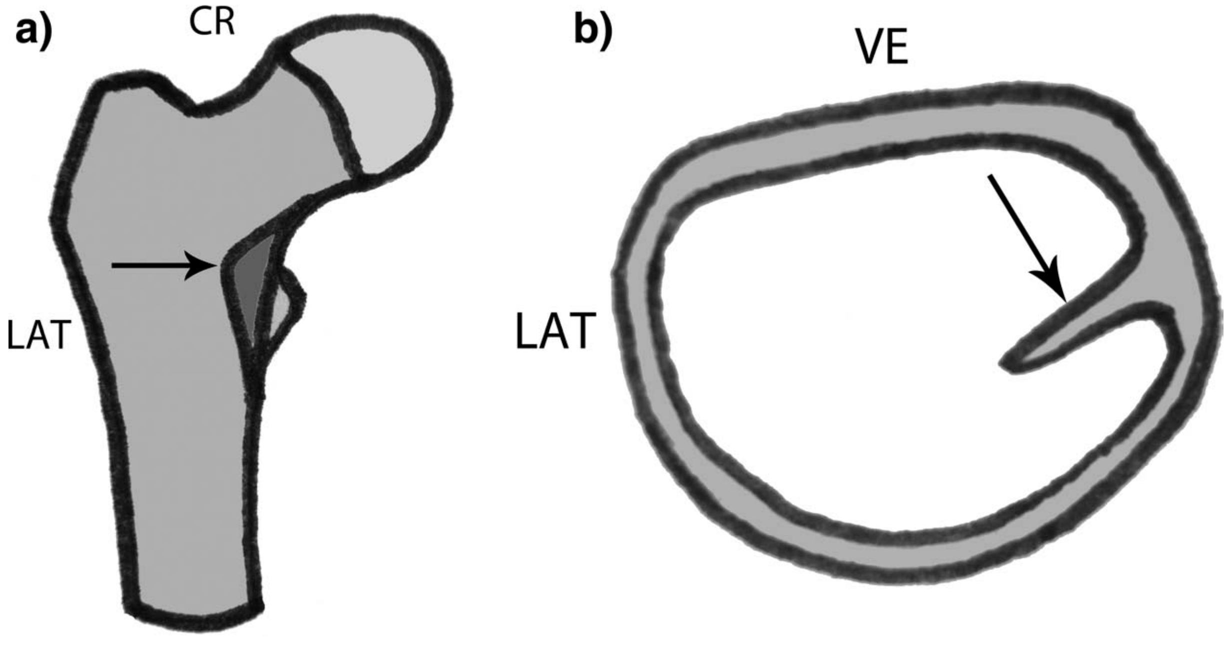

Fig. 1. **a:** Schematic anterior view of a right proximal femur. Measurements of the femoral calcar (dark gray) were performed in the horizontal plane at the level of the greatest length of the spur (arrow). **b:** Schematic horizontal slice at the level of the greatest length of the spur showing the midpoint (arrow) of the femoral calcar. The width and density (HU) of the femoral calcar were evaluated at its midpoint. The density (HU) of the adjacent posteromedial femoral cortex and the longest oblique diameter of the femoral cavity were determined on the same horizontal section. A line through the midpoint of the calcar and perpendicular to the femoral neck axis was drawn. Distances from the midpoint of the femoral calcar to the dorsal and to the ventral endosteal borders of the femoral cavity, and the width of the femoral cavity were measured along this line.

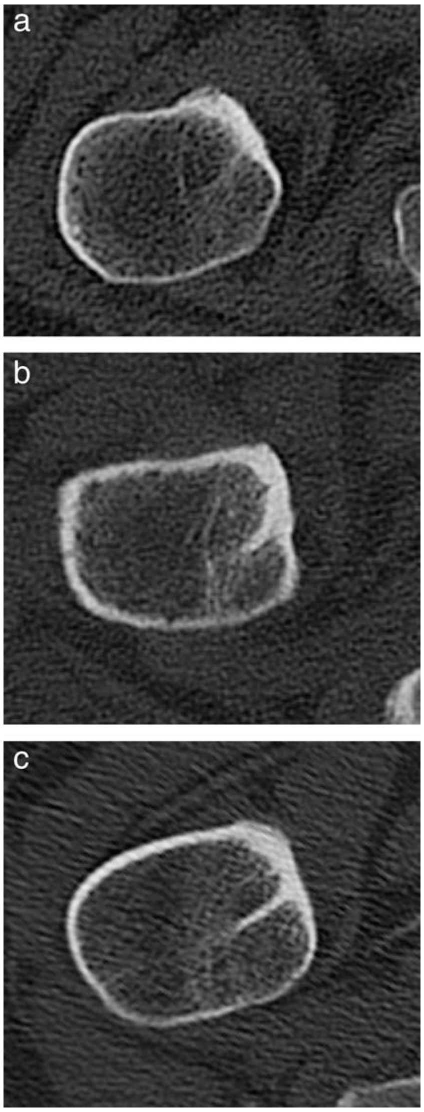

Fig. 2. Horizontal CT-slices of the proximal femur in three different individuals exhibiting the different shapes of the femoral calcar : ridge-type (**a**), spur-type (**b**), and septum-type (**c**).

years) who underwent a CT examination including the pelvic region in our Institution were retrospectively selected for the period between January 2010 and March 2010. Agreement to use the CT data for scientific purpose was obtained from each patient. Patients with traumatic or surgical past history were excluded. The mean height and weight in the evaluated population were 169.8 cm (150–191) and 70.0 kg (40–115), respectively. All CT scans were acquired in supine position by multislice CT (LightSpeed VCT 64, GE Medical Systems, Milwaukee, WI), with routine parameters (slice thickness 0.625 mm, 120–140 kV, 250–380 mA). These CT examinations consisted of either abdominal or combined thoracic and abdominal, examinations for the purpose of internal or urological diagnosis.

All CT examinations were analyzed by a staff radiologist with 5 years of experience. In addition, a fellow in musculoskeletal radiology independently assessed the 25 first CT studies to evaluate the interobserver variation. CT post-processing was performed on a dedicated workstation (AW Volume Share 2, GE Medical Systems, Milwaukee, WI). First, the cortical bone was extracted from the cancellous bone by density thresholding. A constant threshold for cortical bone could not be used because its density depends on patient properties and imaging parameters. The use of an individually evaluated threshold, usually between 600 and 800 Hounsfield units (HU), as previously described by Adam et al. (2001) resulted in a close match with cortical bone structure in the proximal femur. Then, the CT data were image-processed with thresholding to obtain a reconstruction of high-density bone formations and for three-dimensional imaging. In the lesser trochanteric area, a distinct vertical plate of high-density trabecular bone remained in the femoral cavity in all computed slices. Three-dimensional (3D) reconstructions were performed to provide a better morphological analysis of this structure.

The merging of the femoral calcar with the cortex of the dorsomedial neck proximally and the lower border of the lesser trochanter distally were defined respectively as cranial and caudal endpoints of the spur. Then, the height of the femoral calcar was measured between its endpoints in the craniocaudal axis. Next, its greatest length in a mediolateral direction was determined in horizontal CT sections (Fig. 1). The shape of the femoral calcar was here classified as ridge-type when it was short and thick, septum-type when it was thin and long, and spur-type between these two extremes (Adam et al.; 2001) (Fig. 2). Finally, all of the following parameters were recorded at the level of the greatest calcar length. The width and density (HU) of the femoral calcar were evaluated at its midpoint (Fig. 1). The density (HU) of the adjacent posteromedial femoral cortex was determined on the same horizontal section. The longest oblique diameter of the femoral cavity was then measured. A line through the calcar's midpoint and perpendicular to the femoral neck axis was drawn. Distances from the midpoint of the femoral calcar to the dorsal and to the ventral endosteal borders of the femoral cavity, and the width of the femoral cavity were measured along this line.

Statistical analysis was performed using SPSS 15.0 for Windows; and correlation coefficients were calculated with ANOVA-test and ACOVA-test. The interobserver variation was assessed using the intraclass correlation coefficient. The minimum probability level for accepting significance (*P*) was set at 0.05.

RESULTS

Femoral Calcar

A cortical-like spur protruding endosteally in the femoral cavity was identified bilaterally in all patients

Fig. 3. Coronal (**a**) and sagittal (**b**, **c**) CT-reformats of a right proximal femur showing the femoral calcar (arrowheads) forming an internal vertical plate of dense bone between the femoral canal and the lesser trochanter narrowing the proximal femoral cavity.

in the CT cross-sectional slices of the metaphyseal region. The uppermost part of the spur always started cranially from the mediodorsal femoral neck cortex, reaching down to the distal part of the lesser trochanter. In its proximal part, it was orientated parallel to the longitudinal axis of the femoral neck whereas the shorter distal part was parallel to the posterior femoral cortex. The femoral calcar constantly formed an internal vertical plate of dense bone between the femoral canal and the lesser trochanter narrowing the proximal femoral cavity (Fig. 3). It exhibited a variable shape with a predominant spur-type 66.5% (133/200) in our population, whereas the ridge-type and septum-type represented 17% (34/200) and 16.5% (33/200), respectively. No correlation was found between the shapes of the femoral calcar on the right side and on the left side in the same individual. The mean height of the femoral calcar was 33.03 mm (20–46) in the craniocaudal axis (Table 1). Its greatest length in a mediolateral direction was 9.94 mm (5–16). Its thickness at its midpoint was 2.71 mm (1–4) from anterior to posterior. The femoral calcar was thicker close to the cortex, and became thinner in the femoral cavity, ending in trabecular bone formations with connection to the opposite lateral cortex. The mean femoral calcar density at its midpoint was 788.5 HU (530–1,200), while the mean adjacent femoral cortex density was 1335.6 HU (1,060–1,530).

The femoral calcar height and length were positively correlated to the height ($P < 0.001$) and weight ($P = 0.007$) of the individuals, and were significantly higher in males than in females ($P < 0.001$) (Table 2). Interestingly, the length of the femoral calcar was positively correlated to its own height, thickness, and density ($P < 0.001$) (Table 3). The femoral calcar density was positively correlated to its thickness ($P < 0.001$) and was not correlated to the adjacent femoral cortex density. Besides, whereas the femoral cortex density was negatively correlated to the age ($P = 0.048$) of the individuals, the femoral calcar density was not correlated to the age, nor gender, height and weight of the individuals.

Femoral Cavity

The longest oblique diameter of the femoral cavity at the level of the greatest length of the spur was 38.74 mm (28–51) (Table 1). The distance between the midpoint of the spur and the ventral and dorsal endosteal borders of the femoral cavity were 12.40 mm (9–17) and 6.90 mm (4–11), respectively. The anteroposterior diameter of the femoral cavity measured on the same section was 22.04 mm (17–27).

The longest oblique and anteroposterior diameters of the femoral cavity were positively correlated to the height ($P < 0.001$) and weight ($P < 0.001$) of the individuals and were significantly higher in males ($P < 0.001$) (Table 2). In the same way, the distance between the midpoint of the spur and the ventral endosteal border of the femoral cavity was positively correlated to the height ($P = 0.003$), and weight ($P =$

TABLE 1. Descriptive Statistics Including Demographic Data of the Population, and CT-Measurements of the Femoral Calcar and Medullary Cavity at the Level of the Femoral Calcar Greatest Length

	Mean (min–max)	SD
Age	60.2 (20–91)	16.20
Height	169.8 (150–191)	8.02
Weight	70 (40–115)	11.74
Femoral calcar height (mm)	33.03 (20–46)	4.22
Femoral calcar length (mm)	9.94 (5–16)	1.92
Femoral calcar thickness (mm)	2.71 (1–4)	0.69
Femoral calcar density (HU)	788.52 (530–1,200)	119.87
Adjacent cortex density (HU)	1335.63 (1,060–1,530)	80.75
LODMC (mm)	38.74 (28–51)	3.64
APDMC (mm)	22.04 (17–27)	2.06
VDMC (mm)	12.40 (9–17)	1.75
DDMC (mm)	6.90 (4–11)	1.17

LODMC, longest oblique diameter of the medullary cavity; APDMC, anteroposterior diameter of the medullary cavity; VD, distance from the midpoint of the femoral calcar to the ventral endosteal border of the medullary cavity; DD, distance from the midpoint of the femoral calcar to the dorsal endosteal border of the medullary cavity.

TABLE 2. Correlation Between the CT-Measurements of the Femoral Calcar and Medullary Cavity and the Anthropometric Data: Gender, Age, Weight, and Height

	Gender	Age	Weight	Height
Femoral calcar height	$P < 0.001$	ns	0.007	$P < 0.001$
Femoral calcar length	$P < 0.001$	ns	$P < 0.001$	$P < 0.001$
Femoral calcar density	ns	ns	ns	ns
Adjacent cortex density	ns	0.048	ns	ns
LODMC	$P < 0.001$	0.011	$P < 0.001$	$P < 0.001$
APDMC	$P < 0.001$	ns	$P < 0.001$	$P < 0.001$
VDMC	0.007	ns	0.012	0.003
DDMC	ns	ns	0.047	ns

0.012) of the individuals and was higher in males ($P = 0.007$).

Moreover, the longest oblique diameter of the femoral cavity was positively correlated to the femoral calcar height and length ($P < 0.001$), and anteroposterior diameter of the femoral cavity ($P < 0.001$) (Table 3). In the same way, the anteroposterior diameter of the femoral cavity was positively correlated to the femoral calcar height and length ($P < 0.001$). The distance between the midpoint of the spur and the ventral endosteal border of the femoral cavity was positively correlated to the femoral calcar height ($P = 0.025$), length ($P < 0.001$), and thickness ($P < 0.001$), and to the longest oblique and anteroposterior diameters of the femoral cavity ($P < 0.001$).

Reproducibility

No significant interobserver variation was demonstrated. The intra-class correlation coefficients obtained after double-blinded assessment by two independent observers varied between 0.913 for the distance from the midpoint of the spur to the dorsal endosteal border of the femoral cavity, and one for the femoral calcar shape (Table 4).

TABLE 3. Correlation Between the CT-Measurements of the Femoral Calcar and of the Medullary Cavity

	Femoral calcar length	Femoral calcar thickness	Femoral calcar density	Adjacent cortex density	LODMC	APDMC	VDMC	DDMC
Femoral calcar height	$P < 0.001$	ns	Ns	ns	$P < 0.001$	$P < 0.001$	$P = 0.025$	$P < 0.001$
Femoral calcar length		$P < 0.001$	$P < 0.001$	ns	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$
Femoral calcar thickness			$P < 0.001$	ns	ns	ns	$P < 0.001$	$P = 0.003$
Femoral calcar density				ns	ns	ns	0.06	ns
Adjacent cortex density					ns	$P = 0.018$	$P = 0.006$	ns
LODMC						$P < 0.001$	$P < 0.001$	ns
APDMC							$P < 0.001$	$P < 0.001$
VDMC								ns

TABLE 4. Intraclass Correlation Coefficient Obtained in 25 Individuals After Double-blinded Assessment by Two Independent Observers

	ICC
Femoral calcar shape	1
Femoral calcar height	0.989
Femoral calcar length	0.989
Femoral calcar thickness	0.953
Femoral calcar density	0.964
Adjacent cortex density	0.983
LODMC	0.968
APDMC	0.998
VDMC	0.943
PDDMC	0.913

DISCUSSION

The femoral calcar was described in 1874 as a vertical plate of compact bone projecting into the cancellous tissue from the thick mediodorsal part of the femoral cortex down to the lesser trochanter (Merkel, 1874). This anatomical structure becomes visible in femur specimens at the age of 7 years (Braus, 1954). Merkel (1907) reported in his anatomical textbook that the internal cortical structure of the spur is important for the stress distribution of the medial cortex and that it is part of the compressive trabecular system. He even suggested that its resorption caused by osteoporosis may contribute to the high incidence of proximal femoral fractures in the elderly, which is consistent with recent quantitative CT studies demonstrating significant local deficits of cancellous bone in elderly women with femoral neck fractures (Cody et al., 2000). Yet, although the femoral calcar is related to the mechanical function of the femur, it has caught the attention of very few investigators only (Newell, 1997). For all these reasons, our study was intented to exhaustively describe the femoral calcar and to determine its relation to the femoral cavity in a nonselective group of patients undergoing CT for other purposes.

Some limitations may be considered inherent to the materials and methods used in this study. First of all, the measurements of the femoral calcar and femoral cavity were made using CT-scan imaging with thresholding to obtain a reconstruction of high-density bone formations. Thus, our data were not directly obtained from cadaver dissection, but from multiplanar CT-reformation. In addition, CT-based measurements of thin compact structures are known to be affected by the CT resolution and choice of HU thresholding (Sumner et al., 1989; Aamodt et al., 1999). The exactness of the multiplanar reconstructions used in our study relies on the resolution of the cross-sectional CT slices, which is influenced by the size of the image matrix and the reconstruction mode. The resolution along the cranio-caudal axis was considered crucial in our work, especially in the curved metaphyseal area of the proximal femur. So, we used a 0.625 mm slice thickness, 512 × 512 image matrix and a high-resolution image reconstruction mode to obtain sharp cancellous and cortical bone structures for exact thresholding. As an anatomically defined border does not exist between the femoral calcar and the surrounding cancellous bone, the dense spur protruding from the femoral inner cortical wall branches out into trabeculae and merges gradually with the surrounding cancellous bone (Decking et al., 2003). The dimensions of the septum recorded in our study may consequently be considered as rough measurements of an irregular structure, representing only the dense cortical stem of the femoral calcar. However, CT-scan imaging allowed a precise and reproducible assessment of the femoral calcar and medullary cavity in our population. Then, another limitation relates to the evaluated population. All patients included in this study underwent a CT examination including the pelvic region for the purpose of internal or urological diagnosis. They should not be consequently considered as a strictly ‘‘normal’’ population.

In our study, the femoral calcar was constantly identified in the CT cross-sectional slices of the metaphyseal region. Given its high density, the femoral calcar was not removed from the CT images by thresholding. As its mean density measured in our population was 788.5 HU, our use of an individually evaluated threshold, usually between 600 and 800 HU, as previously described by Adam et al. (2000), resulted in a close match with cortical bone structures in the proximal femur. Interestingly, the mean femoral calcar density was not correlated to the adjacent cortex density nor to the age of the individuals, which suggests that it may have an independent mechanical function throughout life. As bone is known to slowly adapts to the forces that are applied to it by changing its shape and structure, it is generally accepted that the structure and density of the bony trabeculae is determined by the forces to which they are subjected (Carter et al., 1989). In our population, the femoral calcar exhibited a characteristic but not uniform shape. It was formed like a tree, with the trunk rooting in the thick cortical bone of the dorsomedial femoral neck and the branches spreading out into the cancellous bone of the metaphysis (Adam et al., 2000). Here, our findings exhibited the great variations of the femoral calcar and showed that the shape of the proximal femoral medullary canal varies widely in accord with the study of Laine et al. (2000). The individual shape of the femoral calcar differed from short and thick in the ridge-type, to long and thin in the septum-type. The spur-type between these two extremes was nevertheless the most frequently encountered in our population. Our results also demonstrated the great variations of the femoral calcar dimensions. The femoral calcar height and length were significantly correlated to the gender, height and weight of the individuals, which may logically be related to its mechanical function in the proximal femur. In addition, the length of the femoral calcar was significantly correlated to its own height, own thickness, and own density. The femoral calcar narrowed the metaphyseal femoral cavity in its dorsal third and was aligned with the longitudinal axis of the femoral neck (Dai et al., 1985; Laine et al., 2000; Adam et al., 2001). The longest oblique and anteroposterior diameters of the femoral cavity were statistically correlated to the gender, height, and weight of the individuals. Moreover, the femoral cavity dimensions were strongly correlated to the femoral calcar dimensions in keeping with a consistent anatomical pattern of force transmission through the upper femur. Even with progressing osteopenia, the femoral calcar tends to maintain its attachment to the mass of trabecular bone in the intertrochanteric region, reflecting its significant mechanical function troughout life (Hammer, 2010). The alignment of the femoral calcar with the stress trajectories in the femoral neck and its higher density compared with the predominantly cancellous bone of the proximal femur also indicate a crucial role in the load transmission in the hip (Li et al., 1998). In particular, the stiffness and material properties of the compact bone from the femoral calcar were shown to be similar to the cortical bone, which suggests that the femoral calcar acts as a transitional structure to transfer stress from the trabecular bone of the femoral head and neck to the cortex of the femoral shaft (Li et al., 1997). Interestingly, the difference in density found between the cortical bone and the femoral calcar seems to be mainly related to a reduction in mineral mass, suggesting that the basic organic matrix is unchanged but is mineralized to a lesser extent within the calcar (Li et al., 1998). In the same way, the femoral calcar is located in an anatomical region essential for the support and primary stability of cementless total hip replacement femoral stems. Callaghan et al. (1992) and Dujardin et al. (1996) demonstrated that fit and fill of stems in the metaphyseal region correlated with the initial rotational and vertical stability of the implants. Nunn et al. (1989) showed that rotational stability of the stem is significantly increased by cortical contact between the stem and the femoral neck. Thus, the femoral calcar may not only affect the positioning of cementless femoral stems during manual broaching of the femoral canal, but also contribute to their primary stability. With CT-based preoperative planning, the implant can probably be placed against the dense part of the septum. So, the femoral calcar may become an important structure for the stabilization and mechanical load transfer of anatomically based femoral stems.

This study was intented to exhaustively describe the femoral calcar and to determine its relation to the femoral cavity in a nonselective group of patients undergoing CT for other purposes. Although CT anthropometric studies are necessarily static, some conclusions regarding the femoral calcar function may be inferred from our results. This study provides complementary data to some approaches to the biomechanical analysis of the upper femur, particularly when finite element analysis or other imaging techniques are used. The exhaustive description of the femoral calcar may also lead to a greater understanding of the hip fracture patterns and to alternative designs for hip arthroplasties that will take into account the specific patterns of force transmission through the upper femur.

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