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The Femoral Calcar Volume Ratio to Evaluate the Relationship Between Femoral Calcar and Age: A Preliminary Study

Relación del Volumen del Calcar Femoral para Evaluar la Relación Entre el Calcar Femoral y la Edad: Un Estudio Preliminar

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SUMMARY: Three-dimensional reconstruction and quantitative analysis of the femoral calcar were performed to assess the feasibility of utilizing the femoral calcar volume ratio as a method for evaluating the correlation between the femoral calcar and age. Computed tomography (CT) images of the hip were collected from 196 subjects who had undergone hip CT scans. Three-dimensional reconstruction of the femoral calcar was performed, and the following parameters were measured: the height, length, width, volume, and CT value of the femoral calcar, as well as the volume and CT value of the cortical bone at the same level. The femoral calcar volume ratio was then calculated as the ratio of the cortical bone volume at the same level to the femoral calcar volume. Subsequently, the correlation between measurements and age was analyzed. Three-dimensional reconstruction of the femoral calcar exhibited good reliability and reproducibility (ICC > 0.963, P < 0.001). Among the 196 femurs, the femoral calcar was not observed in 11 cases; neither age nor sex was identified as a factor contributing to the absence of the femoral calcar (P > 0.05). The femoral calcar displayed diverse shapes, with the spur-type being the most common (39.8 %), followed by the ridge-type (28.1 %) and septum-type (26.5 %). The femoral calcar volume ratio was positively correlated with age in all subtypes (r=0.580–0.694).The presence or absence of the femoral calcar is not associated with age or sex. Among study subjects with a femoral calcar, the femoral calcar volume ratio increased with age. Calculation of the femoral calcar volume ratio provides a new method for the clinical assessment of changes in the femoral calcar.

KEY WORDS: Femoral Calcar; Three-dimensional Reconstruction; Age; Correlation; Computed Tomography.

INTRODUCTION

The concept of the femoral calcar was first described by the German anatomist Merkel in 1874, originally referring to as the bony spur that extends into the cancellous bone at the base of the femoral neck (Merkel, 1874). Over many subsequent years of research, the concepts of the femoral calcar and Adams' arch have been confused (Bartoníc˘ek *et al*., 2023). The term femoral calcar refers to the vertical bony plate below the lesser trochanter of the femur, near the medial cortical. It is thickest at the junction with the medial cortical of the femoral neck and gradually thins from the inner to the outer part of the femur (Griffin, 1982).

The femoral calcar plays a central role in managing complex stresses at the junction of the femoral stem and neck (Hammer, 2019). It can bear and distribute loads from the femoral head, preventing overloading of the posterior and medial proximal femur and thus reducing the risk of fracture (Zhang *et al*., 2009). A biomechanical study by Kuzyk *et al*. (2012) revealed that placing screws above the femoral calcar during intertrochanteric fracture surgery significantly improved stability and reduced stress. If the femoral calcar is damaged or its volume is reduced, the risk of proximal femoral fracture increases significantly (Mei *et al*., 2021). Previous studies have shown that the risk of proximal femoral fracture increases with age (Viganò *et al*., 2023), but it remains unclear whether this is due to age-related changes in the morphology of the femoral calcar. Peacock *et al*. (1998) reported that, when measured via radiographs, the thickness of the femoral calcar at the lesser trochanter of the femur decreases with age, but their measurement site contained adjacent cortical bone and did not represent the true femoral calcar. Le Corroller *et al*. (2011) noted that femoral calcar length and height were positively correlated with individual height and weight but

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not with age. Without accounting for physical differences, rigorous comparisons of the correlation between femoral calcar morphology and age cannot be made.

Therefore, this study standardized the equipment and techniques used for quantitative analysis of three-dimensional reconstructions of the femoral calcar, conducting a quantitative analysis of the correlation between different measurements and age. To avoid the influence of physical differences, the ratio of the volume of cortical bone to the volume of the femoral calcar at the same level was used as an index to measure changes in the femoral calcar. Analyzing the trend of age-related changes in the femoral calcar provides new ideas for the clinical evaluation of changes.

MATERIAL AND METHOD

Research Subjects

This retrospective analysis included 196 cases (100 males and 96 females; mean age 53.82±20.49 years; age range 20–98 years) who underwent hip CT scans at our hospital from January 2021 to June 2024. The inclusion criteria included hip CT images covering the entire proximal femoral region, no history of proximal femoral trauma or surgery, no history of severe degenerative arthritis, and no history of tumors or connective tissue diseases. A total of 196 cases of proximal femoral images were measured and evaluated after three-dimensional reconstruction.

Acquisition of Hip CT Scans

Hip CT was performed via multislice CT (Discovery CT750 HD, GE Medical Systems) with a scanning speed of 120 kV and a slice thickness of 0.625 mm. The participants were placed supine in the middle of the scanning bed, with their arms raised and their thighs internally rotated bilaterally, and axial hip CT scans were performed. The resulting CT images were saved as 2-D digital imaging and communications in medicine (DICOM) files.

Three-dimensional Reconstruction of the Femoral Calcar

The hip CT image files were imported into Mimics21.0 software (Materialize NV Technologielaan, Leuven, Belgium) for post processing. Firstly, the method of Adam *et al*. (2001) was used to segment the cancellous bone from the proximal femur through threshold processing to obtain a mask that removes the cancellous bone. The femoral calcar and cortical bone in the cross section were subsequently divided into different masks layer by layer. Reconstruction and three-dimensional imaging of the femoral calcar and cortical bone at the same level were performed (Fig. 1).

Femoral calcar Measurement

In horizontal CT slices, the point where the femoral calcar merges with the cortical bone of the medial lower segment of the femoral neck was defined as the superior

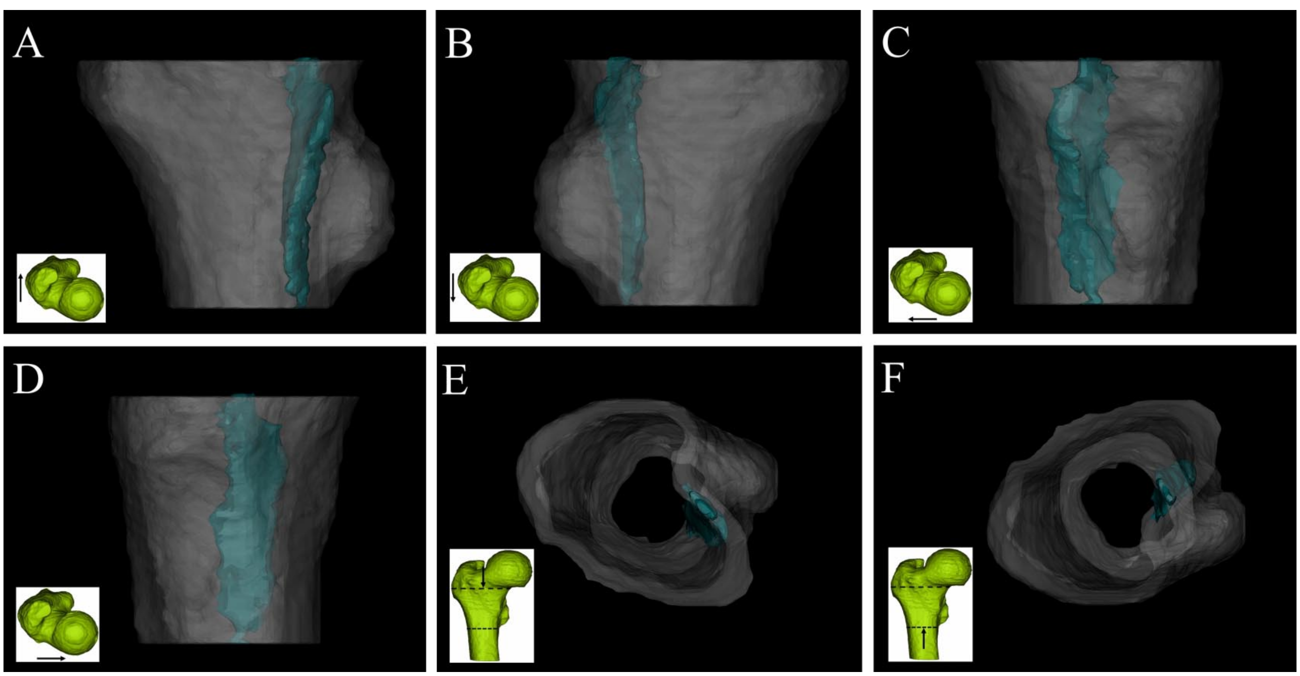

Fig. 1. Reconstruction of the femoral calcar and cortical bone at the same level. Main view (A); Posterior view (B); Left view (C); Right view (D); Top view (E); Elevation view (F). Femoral calcar (blue); Cortical bone (grey).

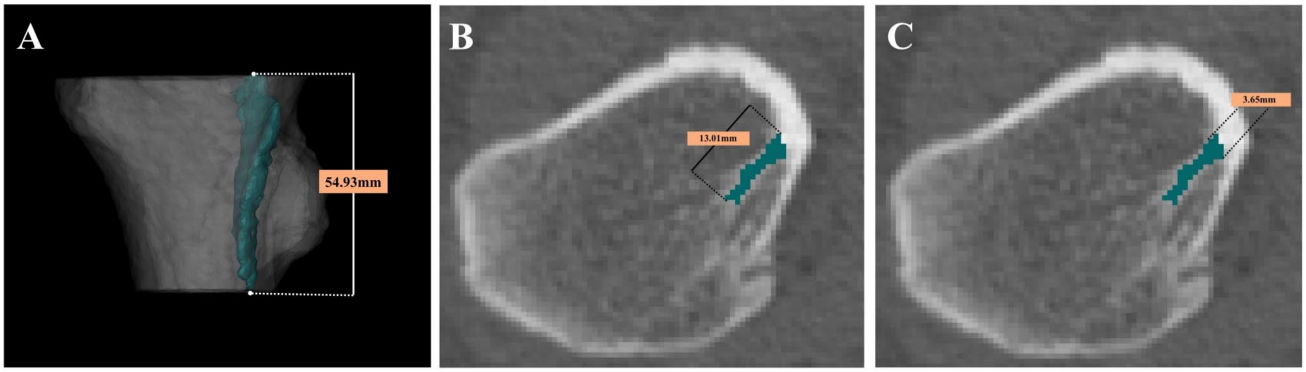

Fig. 2. Measurements of the femoral calcar height, length, and width. Femoral calcar height measurement (A); Femoral calcar length measurement (B); Femoral calcar width measurement (C). mm, millimeter; Femoral calcar (green)

endpoint. The merging point of the femoral calcar and the cortical bone at the lower edge of the lesser trochanter of the femur is the lower endpoint. The vertical distance between these two endpoints was designated as the height of the femoral calcar (Fig. 2A). The longest horizontal CT slice of the femoral calcar was selected, and the length and width of the femoral calcar were measured in this CT slice (Fig. 2). The volumes and CT values of the femoral calcar and its cortical bone at the same level were automatically calculated and generated via Mimics 21.0 software. The ratio of the volume of cortical bone at the same level of the femoral calcar to the volume of the femoral calcar was defined as the femoral calcar volume ratio (femoral calcar volume ratio = volume of cortical bone at the same level of the femoral calcar/volume of the femoral calcar). All the CT images were post processed and measured by two experienced radiologists who were blinded to each other to assess interobserver differences.

Statistical analysis

Statistical analysis was performed using SPSS (IBM SPSS 25.0, IBM Corporation). Descriptive statistics of the demographic characteristics and femoral calcar-related measurements were expressed as the means ± standard deviations (x±S). The chi-square test was employed for categorical variables, whereas the independent samples t-test was applied to compare the differences in measured values between various types of femoral calcar. The intraclass correlation coefficient (ICC) was used to evaluate the reliability of the measurements taken by two doctors. The Pearson correlation coefficient was used for correlation analysis. A p-value of less than 0.05 was considered statistically significant.

RESULTS

The method of three-dimensional reconstruction and measurement of the femoral calcar and its cortical at the same level in CT images of the hip via Mimics 21.0 software has high reliability and repeatability (ICC>0.963, P<0.001) (Table I).

Table I. ICC analysis of the measurement results from the two observers.

Measurement	**ICC**	***P***
Calcar femorale shape	1	<0.001
Calcar femorale height	0.988	<0.001
Calcar femorale length	0.987	<0.001
Calcar femorale width	0.963	<0.001
Calcar femorale volume	0.995	<0.001
Cortical bone volume	0.998	<0.001
Calcar femorale volume ratio	0.998	<0.001
Calcar femorale CT value	0.989	<0.001
Cortical bone CT value	0.998	<0.001

The femoral calcar volume ratio = volume of cortical bone at the same level of the femoral calcar/volume of the femoral calcar. Abbreviations: ICC, intraclass correlation coefficient.

In the horizontal CT slice, no femoral calcar was detected in 11 cases (5 males; 6 females), and in the remaining 185 cases, the cortical bone at the junction of the medial lower part of the femoral neck with the femoral stem was thickened and showed a spur-like protrusion towards the medial bone cancellous mass, which extended downwards to the distal part of the lesser trochanter (Fig. 1). No statistically significant differences in sex or age were observed between the groups with and without the femoral calcar (P>0.05). The shape of the femoral calcar was classified as septum-type (narrow and long), ridge-type (wide and short), and spur-type (between these two extremes) (Fig. 3). The spur-type was the most common, accounting for 39.8 % (78/196), followed by the septum-type and ridge-type accounted for 26.5 % (52/196) and 28.1 % (55/196), respectively. No statistically significant differences in femoral calcar shape distribution were found between different sex groups or age groups (P>0.05) (Table II).

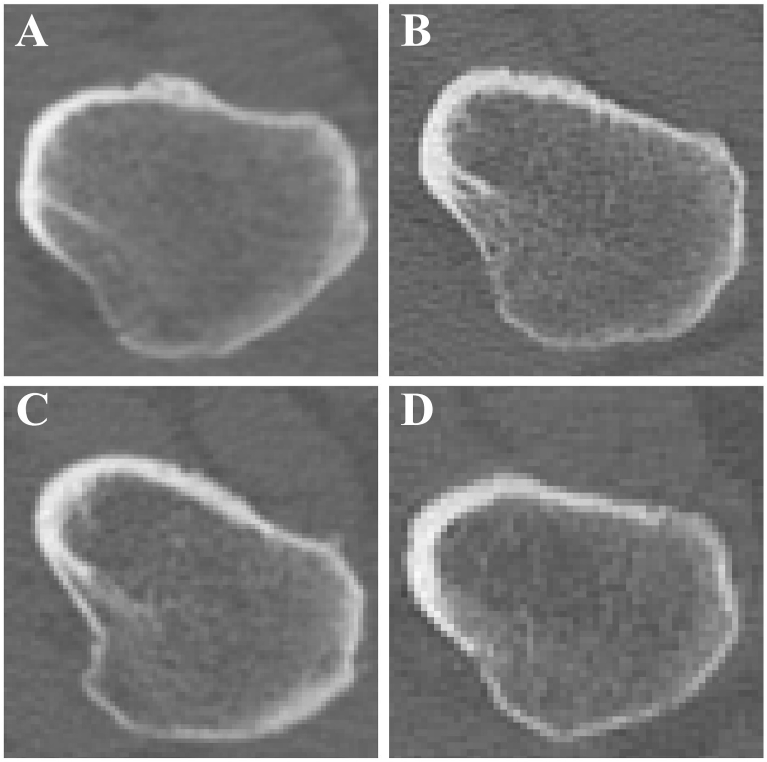

Fig. 3. Horizontal CT-slice observation of the femoral calcar. Septum-type (A); Spur-type (B); Ridge-type (C); Femoral calcar not found (D). CT, computed tomography.

There was no significant difference between the three types of femoral calcar height and cortical bone CT values at the same level (P>0.05). There were significant differences in the length of the femoral calcar among the three types (P<0.05). The septum-type timber was the longest (9.68±1.59 mm), followed by the spur-type timber (8.55±1.81 mm), and the ridge-type timber was the shortest (7.82±2.16 mm). The ridge-type was the widest (4.63±1.25 mm), with the largest volume (705.78±335.05 mm^3) and the highest CT value (935.09±70.66 HU), which were significantly different from those of the other two subtypes (P<0.05). There was a significant difference in the femoral calcar volume ratio between the subtypes (P<0.05), with the septum-type subtype being the largest (28.25±8.07), followed by the spur-type (24.83±7.62), and the ridge-type being the smallest (20.51±5.89) (Table III).

Grouped by sex, the correlation between femoral calcar volume and age was not statistically significant for males in the ridge-type (P = 0.386). The remaining groups showed a negative correlation between the femoral calcar volume and age (r = -0.486–0.724; P<0.05). The femoral calcar volume ratio showed a good positive correlation with age (r=0.580–0.694; P<0.05), irrespective of sex and subtype (Fig. 4, Table IV). Specifically, in females, the strongest correlation between the femoral calcar volume ratio and age was found for the septum type (r=0.694; P<0.001), and in males, the strongest correlation between the femoral calcar volume ratio and age was found for the spur-type (r=0.679; P<0.001) (Table IV).

Table II. Descriptive analysis of patient demographics.

Patient Information	**Total**	**Septum-type**	**Spur-type**	**Ridge-type**	**Not found**	***P***
Number	196	52	78	55	11	
Sex (Male/Female)	100/96	29/23	42/36	24/31	5/6	0.561
Age (Years)	53.82±20.49	58.62±19.3	51.9±18.71	52.4±23.32	51.91±22.28	0.274

Note: Data are expressed as the mean ± standard deviation.

Table III. Measurements of the femoral calcar and cortical bone at the same level as the femoral calcar.

	Septum-type	**Spur-type**	**Ridge-type**	***P*(Septum-type / Spur-type)**	***P*(Septum-type / Ridge-type)**	***P*(Ridge-type / Spur-type)**
Calcar femorale height (mm)	39.24±6.14	39.05±6.79	40.99±6.41	0.868	0.154	0.100
Calcar femorale length (mm)	9.68±1.59	8.55±1.81	7.82±2.16	<0.001	<0.001	0.036
Calcar femorale width (mm)	3.02±0.67	3.20±0.73	4.63±1.25	0.151	<0.001	<0.001
Calcar femorale volume (mm^3)	476.58±226.25	521.50±211.38	705.78±335.05	0.251	<0.001	0.001
Cortical bone volume (mm^3)	12514.44±3553.33	11846.06±3283.17	13154.69±4209.17	0.613	0.188	0.046
Calcar femorale volume ratio	28.25±8.07	24.83±7.62	20.51±5.89	0.016	<0.001	0.001
Calcar femorale CT value (HU)	856.38±133.02	897.12±135.87	935.09±70.66	0.094	<0.001	0.038
Cortical bone CT value (HU)	915.10±105.35	915.46±148.94	948.04±93.78	0.988	0.090	0.154

Note: Data are expressed as the mean ± standard deviation.

Table IV. Pearson correlation between the measurements of the femoral calcar and age.

	Septum-type				Spur-type				Ridge-type			
	Male		Female		Male		Female		Male		Female	
	r	***P***	r	***P***	r	***P***	r	***P***	r	***P***	r	***P***
Calcar femorale height	-0.041	0.832	-0.332	0.122	**-0.535**	<0.001	-0.222	0.193	0.206	0.335	0.089	0.634
Calcar femorale length	-0.198	0.303	**-0.550**	0.007	**-0.365**	0.018	-0.220	0.197	0.160	0.456	**-0.479**	0.006
Calcar femorale width	-0.365	0.051	-0.324	0.131	**-0.554**	<0.001	**-0.494**	0.002	**-0.425**	0.039	-0.195	0.294
Calcar femorale volume	**-0.486**	0.008	**-0.724**	<0.001	**-0.698**	<0.001	**-0.594**	<0.001	-0.185	0.386	**-0.633**	<0.001
Cortical bone volume	0.044	0.820	**-0.633**	0.001	**-0.406**	0.008	-0.256	0.132	0.274	0.195	-0.325	0.075
Calcar femorale volume ratio	**0.663**	<0.001	**0.694**	<0.001	**0.679**	<0.001	**0.615**	<0.001	**0.586**	0.003	**0.580**	0.001
Calcar femorale CT value	-0.355	0.058	**-0.727**	<0.001	-0.217	0.167	**-0.429**	0.009	0.086	0.691	**-0.409**	0.022
Cortical bone CT value	-0.333	0.078	**-0.691**	<0.001	**-0.331**	0.032	**-0.353**	0.035	**-0.481**	0.017	-0.340	0.062

Bold indicates statistically significant correlations (P< 0.05).

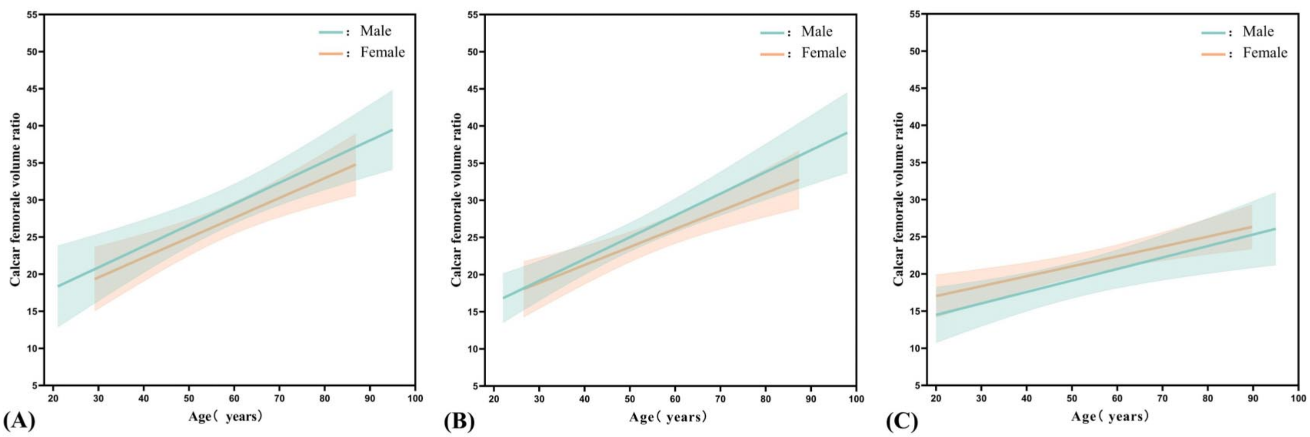

Fig. 4. Relationships between the femoral calcar volume ratio and age in males (green) and females (orange). Septum-type (A); Spur-type (B); Ridge-type (C). The light-colored area shows the 95 % confidence interval for the regression line.

DISCUSSION

With the global aging trend on the rise, the incidence of proximal femoral fractures continues to increase, making it one of the major orthopedic conditions in the elderly population (Viganò *et al*., 2023). This not only poses a significant threat to patients' health but also imposes a heavy burden on socioeconomic well-being (Prieto-Alhambra *et al*., 2018; Baghdadi *et al*., 2023). The femoral calcar is believed to be a human structure designed to accommodate bipedal locomotion (Kuperavage *et al*., 2018) and is capable of transmitting stresses from the cancellous bone of the femoral head to the cortical bone of the femoral stem (Li & Aspden, 1998), which reduces the risk of fracture by carrying and distributing the loads transmitted by the femoral head and allowing for stress redistribution (Zhang *et al*., 2009). Hammer *et al*. (2010) suggested that the femoral calcar is present throughout life but gradually decreases in size with age. An autopsy-based study revealed that the femoral calcar could not be clearly identified in three male specimens from individuals over 60 years of age (Kerr *et al*., 1986). Most previous studies of the femoral calcar have been based on autopsies (Kerr *et al*., 1986; Hammer, 2010), which do not provide a visual description of the relationship between femoral calcar morphological changes and age. Peacock *et al*. (1998) measured patients' femoral calcar via radiographs and reported that the femoral calcar thickness at the lesser trochanter of the femur decreased with age, but the measured values included adjacent cortical bone and were not true of the femoral calcar. Although the femoral calcar has also been described in the orthopedic literature (Griffin, 1982; Kerr *et al*., 1986), its size has rarely been quantified and analyzed. Le Corroller *et al*. (2011) post processed CT images of the proximal femur described a method for measuring the femoral calcar and reported that the size of the femoral calcar did not correlate with age. Physical differences affect femoral calcar size (Peacock *et al*., 1998; Le Corroller *et al*., 2011), and direct comparisons of femoral calcar morphology in correlation with age are not rigorous. In this study, we investigated the morphological characteristics of the femoral calcar and changes in the femoral calcar with age by performing three-dimensional reconstruction and quantitative analysis of CT images of the proximal femur in 196 cases, which provided new ideas for the clinical assessment of changes in the femoral calcar.

Different reconstruction algorithms affect the high contrast spatial resolution (HCSR) (Davis *et al*., 2018). The CT image resolution, as well as the setting of the HU threshold, affect the accuracy of geometric measurements of bone structures in CT scans (Lim Fat *et al*., 2012; Holcombe *et al*., 2018). The accuracy of multiplanar reconstruction of the femoral calcar in this study depended on the resolution of the cross-sectional CT slices. Therefore, we used a thinner slice thickness (0.625 mm), uniform CT equipment, and a scanning technique. Masks of the femoral calcar and its adjacent cortical bone were drawn separately on the proximal femoral CT images layer by layer via Mimics 21.0 software. The three-dimensional models of the femoral calcar and adjacent cortical bone were reconstructed and measured separately. This measurement method demonstrated good reliability and repeatability (ICC > 0.963, P< 0.001), providing a solid basis for subsequent analyses. The femoral calcar has a variety of shapes. Referring to the study by Adam *et al*. (2001), the femoral calcar was classified into three subtypes, with the spur-type being the most common (39.8 %), followed by the ridge-type (28.1 %) and the septum-type being the least prevalent (26.5 %), a result that is the same as that of previous studies (Adam *et al*., 2001; Le Corroller *et al*., 2011). However, contrary to the findings of Adam *et al*. (2001) and Le Corroller *et al*. (2011), Cazenave *et al*. (2022) did not identify a femoral calcar in a single modern cadaver dissection. Our study, for the first time, discovered *in vivo* that 5.6 % (11/196) of the subjects lacked a femoral calcar, and the presence of the femoral calcar showed no significant age-related difference (*P*=0.274). Hammer *et al*. (2010) suggest that the femoral calcar persists throughout life; thus, age cannot be considered a factor in its absence, which may be related to the subjects' congenital development.

The femoral calcar serves as a reference point for the proximal femoral nail antirotation (PFNA) system and is critical for implant placement (Öner, 2020). Moreover, the femoral calcar reduces the anteroposterior diameter of the medullary cavity and prevents the prosthesis from subsiding after hip arthroplasty (Politis *et al*., 2013). Unlike previous studies (Le Corroller *et al*., 2011), in order to describe the femoral calcar in more detail, we grouped the analyses according to the shape of the femoral calcar. The results of the study showed that the septum-type was the longest, the ridge-type was the widest, the volume was the largest, and the CT values were the highest. Analyzing the correlation between femoral calcar volume and age, our study found a negative correlation between femoral calcar volume and age in all groups ($P < 0.05$), except for the ridge-type in males, which was not statistically significant ($P = 0.386$). The size of the femoral calcar is positively correlated with the height and weight of the individual (Le Corroller *et al*., 2011), and directly analyzing the relationship between femoral calcar size and age without considering physical differences is not rigorous. This also explains why femoral calcar size did not correlate with age changes in the study by Le Corroller *et al*. (2011).

In our study, the ratio of the cortical bone volume to the femoral calcar volume at the same level was calculated to obtain the femoral calcar volume ratio. The size of the femoral cortical bone correlates with the height and weight of an individual (Zhang *et al*., 2016; Kira *et al*., 2023). When the correlation between femoral calcar morphology and age was analyzed, the application of the femoral calcar volume ratio was able to exclude the effects of height and weight differences in different individuals. Marshall *et al*. (2006) found that the size of the femoral stem cortical bone did not change with age. The femoral calcar volume ratio can more intuitively reflect the change in the femoral calcar volume relative to the volume of the surrounding cortical bone, which provides a new idea for assessing the trend of changes in the femoral calcar volume with age. Regardless of sex and femoral calcar subtype, the femoral calcar volume ratio was positively correlated with age (r=0.580–0.694; $P < 0.05$), with the femoral calcar volume decreasing with age.

Our study has several limitations. Firstly, this was a retrospective study, and although homogenous equipment and techniques were used and the study population was selected from patients who attended the clinic due to non-orthopedic conditions, it may still be affected by some uncontrollable factors. Future studies may consider designing prospective studies to assess the correlation between the femoral calcar and age more accurately. Secondly, the participants in our study were exclusively of Asian ethnicity, and the sample size was relatively limited. Both factors may compromise the generalizability of our findings to other ethnic groups and reduce the statistical reliability of the results. Subsequent investigations should address this limitation by enrolling larger, more ethnically diverse samples to enhance the external validity of the conclusions.

CONCLUSION

The method of measuring the femoral calcar after three-dimensional reconstruction is highly reliable. The presence or absence of the femoral calcar is not associated with age or sex. The shape of the femoral calcar varied, with the spur-type being the most common. The femoral calcar volume ratio was positively correlated with age in all subtypes, indicating that the volume of the femoral calcar decreases with age and that its volume decreases more rapidly than that of the adjacent cortical bone. This study provides new ideas for evaluating changes in the femoral calcar and lays a more solid scientific foundation for the prevention and treatment of proximal femoral fractures.

Ethics approval. This was an observational study. The General Hospital of Northern Theater Command Research Ethics Committee confirmed that no ethical approval is required.

Conflict of interest. The authors declare that they have no conflicts of interest.

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RESUMEN: Se realizó una reconstrucción tridimensional y un análisis cuantitativo del calcar femoral para analizar la viabilidad de utilizar la relación del volumen del calcar femoral como método para evaluar la correlación entre el calcar femoral y la edad. Se obtuvieron imágenes de tomografía computarizada (TC) de cadera de 196 sujetos sometidos a TC de cadera. Se realizó una reconstrucción tridimensional del calcar femoral y se midieron los siguientes parámetros: altura, longitud, anchura, volumen y valor de TC del calcar femoral, así como el volumen y valor de TC del hueso cortical al mismo nivel. La relación del volumen del calcar femoral se calculó como la relación entre el volumen del hueso cortical al mismo nivel y el volumen del calcar femoral. Posteriormente, se analizó la correlación entre las mediciones y la edad. La reconstrucción tridimensional del calcar femoral mostró buena confiabilidad y reproducibilidad (ICC > 0,963, P < 0,001). Entre los 196 fémures, el calcar femoral no se observó en 11 casos; ni la edad ni el sexo se identificaron como factores que contribuyeran a la ausencia del calcar femoral (P > 0,05). El calcar femoral mostró diversas formas, siendo el tipo espolón el más común (39,8 %), seguido del tipo cresta (28,1 %) y el tipo septum (26,5 %). La relación del volumen del calcar femoral se correlacionó positivamente con la edad en todos los subtipos (r = 0,580–0,694). La presencia o ausencia del calcar femoral no está asociada con la edad o el sexo. Entre los sujetos del estudio con un calcar femoral, la relación del volumen del calcar femoral aumentó con la edad. El cálculo del cociente del volumen del calcar femoral proporciona un nuevo método para la evaluación clínica de los cambios en el calcar femoral.

PALABRAS CLAVE: Cálcar femoral; Reconstrucción tridimensional; Edad; Correlación; Tomografía computarizada.

REFERENCES

Adam, F.; Hammer, D. S.; Pape, D. & Kohn, D. The internal calcar septum (femoral thigh spur) in computed tomography and conventional radiography. *Skeletal Radiol., 30(2)*:77-83, 2001.

Baghdadi, S.; Kiyani, M.; Kalantar, S. H.; Shiri, S.; Sohrabi, O.; Beheshti Fard, S.; Afzal, S. & Khabiri, S. S. Mortality following proximal femoral fractures in elderly patients: a large retrospective cohort study of incidence and risk factors. *BMC Musculoskelet. Disord., 24(1)*:693, 2023.

Cazenave, M.; Kivell, T. L.; Pina, M.; Begun, D. R. & Skinner, M. M. Calcar femorale variation in extant and fossil hominids: implications for identifying bipedal locomotion in fossil hominins. *J. Hum. Evol., 167*:103183, 2022.

Davis, A. T.; Palmer, A. L.; Pani, S. & Nisbet, A. Assessment of the variation in CT scanner performance (image quality and Hounsfield units) with scan parameters, for image optimisation in radiotherapy treatment planning. *Phys. Med., 45*:59-64, 2018.

Griffin, J. B. The calcar femorale redefined. *Clin. Orthop. Relat. Res., (164)*:211, 1982.

Hammer, A. The structure of the femoral neck: a physical dissection with emphasis on the internal trabecular system. *Ann. Anat., 192(3)*:168-77, 2010.

Hammer, A. The calcar femorale: a new perspective. *J. Orthop. Surg. (Hong Kong), 27(2)*:230949901984877, 2019.

Holcombe, S. A.; Hwang, E.; Derstine, B. A. & Wang, S. C. Measuring rib cortical bone thickness and cross section from CT. *Med. Image Anal., 49*:27-34, 2018.

Kerr, R.; Resnick, D.; Sartoris, D. J.; Kursunoglu, S.; Pineda, C.; Haghighi, P.; Greenway, G. & Guerra Jr., J. Computerized tomography of proximal femoral trabecular patterns. *J. Orthop. Res., 4(1)*:45-56, 1986.

Kira, K.; Chiba, F.; Makino, Y.; Torimitsu, S.; Yamaguchi, R.; Tsuneya, S.; Motomura, A.; Yoshida, M.; Saitoh, N.; Inokuchi, G.; *et al*. Stature estimation by semi-automatic measurements of 3D CT images of the femur. *Int. J. Legal Med., 137(2)*:359-77, 2023.

Kuperavage, A.; Pokrajac, D.; Chavanaves, S. & Eckhardt, R. B. Earliest known hominin calcar femorale in Orrorin tugenensis provides further internal anatomical evidence for origin of human bipedal locomotion. *Anat. Rec. (Hoboken), 301(11)*:1834-9, 2018.

Kuzyk, P. R. T.; Zdero, R.; Shah, S.; Olsen, M.; Waddell, J. P. & Schemitsch, E. H. Femoral head lag screw position for cephalomedullary nails: a biomechanical analysis. *J. Orthop. Trauma, 26(7)*:414-21, 2012.

Le Corroller, T.; Dediu, M.; Pauly, V.; Pirro, N.; Chabrand, P. & Champsaur, P. The femoral calcar: a computed tomography anatomical study. *Clin. Anat., 24(7)*:886-92, 2011.

Li, B. & Aspden, R. M. A comparison of the stiffness, density and composition of bone from the calcar femorale and the femoral cortex. *J. Mater. Sci. Mater. Med., 9(11)*:661-6, 1998.

Lim Fat, D.; Kennedy, J.; Galvin, R.; O'Brien, F.; McGrath, F. & Mullett, H. The Hounsfield value for cortical bone geometry in the proximal humerus--an in vitro study. *Skeletal Radiol., 41(5)*:557-68, 2012.

Marshall, L. M.; Lang, T. F.; Lambert, L. C.; Zmuda, J. M.; Ensrud, K. E. & Orwoll, E. S. Dimensions and volumetric BMD of the proximal femur and their relation to age among older U.S. men. *J. Bone Miner. Res., 21(8)*:1197-206, 2006.

Mei, J.; Pang, L. & Jiang, Z. Strategies for managing the destruction of calcar femorale. *BMC Musculoskelet. Disord., 22*:460, 2021.

Merkel, F. R. Betrachtungen über das Os femoris. *Arch. Pathol. Anat. Virchows Arch., 59*:237-56, 1874.

Öner, K.; Durusoy, S. & Özer, A. A new proximal femoral nail antirotation design: is it effective in preventing varus collapse and cut-out? *Jt. Dis. Relat. Surg., 31(3)*:426-31, 2020.

Peacock, M.; Liu, G.; Carey, M.; Ambrosius, W.; Turner, C. H.; Hui, S. & Johnston Jr., C. C. Bone mass and structure at the hip in men and women over the age of 60 years. *Osteoporos. Int., 8(3)*:231-9, 1998.

Politis, A. N.; Siogkas, G. K.; Gelalis, I. D. & Xenakis, T. A. Patterns of stress distribution at the proximal femur after implantation of a modular neck prosthesis. A biomechanical study. *Clin. Biomech. (Bristol), 28(4)*:415-22, 2013.

Prieto-Alhambra, D.; Reyes, C.; Sainz, M. S.; González-Macías, J.; Delgado, L. G.; Bouzón, C. A.; Gañan, S. M.; Miedes, D. M.; Vaquero-Cervino, E.; Bardaji, M. F. B.; *et al*. In-hospital care, complications, and 4-month mortality following a hip or proximal femur fracture: the Spanish registry of osteoporotic femur fractures prospective cohort study. *Arch. Osteoporos., 13(1)*:96, 2018.

Viganò, M.; Pennestrì, F.; Listorti, E. & Banfi, G. Proximal hip fractures in 71,920 elderly patients: incidence, epidemiology, mortality and costs from a retrospective observational study. *BMC Public Health, 23(1)*:1963, 2023.

Zhang, Q.; Chen, W.; Liu, H.; Li, Z. Y.; Song, Z. H.; Pan, J. S. & Zhang, Y. Z. The role of the calcar femorale in stress distribution in the proximal femur. *Orthop. Surg., 1(4)*:311-6, 2009.

Zhang, J.; Hislop-Jambrich, J. & Besier, T. F. Predictive statistical models of baseline variations in 3-D femoral cortex morphology. *Med. Eng. Phys., 38(5)*:450-7, 2016.

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