Research Article / Araştırma Makalesi

Evaluation of the Effects of Fovea Capitis Femoris Localization and Morphometry on the Femoral Head

Fovea Capitis Femoris Lokalizasyonun ve Morfometrisinin Femur Başı Üzerine Olan Etkilerinin Değerlendirilmesi

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Abstract

Background: The fovea capitis femoris (FCF) is a distinct depression on the femoral head, serving as the insertion point for the ligamentum capitis femoris and potentially allowing vascular entry. Avascular necrosis and degenerative illnesses, as well as hip biomechanics, may be impacted by anatomical differences of the FCF. This study aimed to analyze the morphometric features and quadrant-based localization of the FCF and assess their relationships with femoral head geometry.
Materials and Methods: Seventy-one adult dry femurs were examined. The mediolateral images were standardized. Morphometric parameters—including transverse and longitudinal diameters, depth, area, and perimeter—were measured using a digital caliper and ImageJ. Femoral head surface area and perimeter were also recorded. The location of the FCF was determined using a quadrant-based model. Statistical analysis involved ANOVA and Hochberg's GT2 for post-hoc test.
Results: Type II was the most common FCF configuration (64.8%), while Type I, III, and V were each found in 7.0% of cases. Type V showed the highest area and perimeter values, whereas Type I had the lowest. Significant differences were observed among types for longitudinal length (p = 0.005), area (p = 0.001), and perimeter (p = 0.001). Type I exhibited a significantly more compact profile, possibly indicating reduced ligament attachment and vascular ingress.
Conclusions: FCF morphology varies according to its structural type and may influence both ligamentous anchorage and vascular supply. Understanding these variations may aid in surgical planning and radiological assessment, particularly in procedures involving the femoral head.

Keywords: Femur, Femur head, Fovea capitis femoris, Hip joint, Ligamentum capitis femoris

Öz

Amaç: Fovea capitis femoris (FCF), femur başı üzerinde yer alan belirgin bir çöküntü olup, ligamentum capitis femoris'in distal tutunma noktasını oluşturmaktadır ve aynı zamanda vasküler yapıların girişine olanak tanıyan bir geçit işlevi görebilmektedir. FCF'nin anatomik varyasyonları, kalça ekleminin biyomekanik özelliklerini etkileyebileceği gibi avasküler nekroz ve dejeneratif hastalıklar gibi patolojik durumların gelişiminde de rol oynayabilir. Bu çalışmanın amacı, FCF'nin morfometrik özelliklerini ve kadran temelli lokalizasyonunu analiz etmek ve bu parametrelerin femur başı geometrisi ile olan ilişkisini değerlendirmektir.
Materyal ve Metod: Çalışmada yetmiş bir erişkin kuru femur incelenmiştir. Femur başlarının standardize mediolateral görüntüleri elde edilmiştir. Transvers ve longitudinal çaplar, derinlik, alan ve çevre gibi morfometrik parametreler dijital kumpas ve ImageJ yazılımı kullanılarak ölçülmüştür. Ayrıca femur başının yüzey alanı ve çevre uzunluğu da kaydedilmiştir. FCF'nin lokalizasyonu, kadran temelli bir model kullanılarak sınıflandırılmıştır. Elde edilen veriler, ANOVA ve Hochberg'in GT2 post-hoc testi ile istatistiksel olarak analiz edilmiştir.
Bulgular: FCF konfigürasyonları arasında en sık gözlenen tip Tip II olup, olguların %64,8'ini oluşturmaktadır. Tip I, III ve V konfigürasyonları ise her biri %7,0 oranında tespit edilmiştir. En yüksek ortalama alan ve çevre değerleri Tip V'de, en düşük değerler ise Tip I'de saptanmıştır. Longitudinal uzunluk (p = 0,005), alan (p = 0,001) ve çevre (p = 0,001) değişkenleri açısından gruplar arasında istatistiksel olarak anlamlı fark bulunmuştur. Tip I konfigürasyonunun daha kompakt morfolojik bir yapıya sahip olması, ligamentöz tutunma alanının ve vasküler girişin daha sınırlı olabileceğini düşündürmektedir.
Sonuç: FCF'nin morfolojik yapısı, tipolojik sınıflamasına bağlı olarak anlamlı varyasyonlar göstermektedir. Bu varyasyonlar, ligamentum capitis femoris'in tutunma potansiyelini ve femur başının vaskülarizasyonunu etkileyebilir. Söz konusu morfometrik farklılıkların cerrahi planlamada ve radyolojik değerlendirmelerde dikkate alınması, özellikle femur başını içeren girişimlerde komplikasyonların azaltılmasına katkı sağlayabilir.

Anahtar Kelimeler: Femur, Femur başı, Fovea capitis femoris, Kalça eklemi, Ligamentum capitis femoris

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Introduction

The fovea capitis femoris (FCF) is a distinct anatomical structure located on the posteroinferior aspect of the femoral head, forming a shallow depression that serves as the attachment site for the ligamentum capitis femoris (ligamentum teres)-a ligament thought to contribute to both mechanical stability and limited vascular support of the femoral head (1-3). Although the ligament's functional role has been debated, especially in adults, the anatomical region of its insertion, the FCF, has attracted increasing attention due to its potential involvement in pathological processes such as avascular necrosis, developmental dysplasia of the hip, and osteoarthritic changes (4-6).

The FCF may also contain small vascular foramina, which provide entry points for vessels that supply the femoral head with an additional blood supply, especially in the early stages of life, in addition to being a ligament attachment site. (7, 8). Disruption of these vascular channels, especially in the setting of femoral neck fractures or corticosteroid use, has been implicated in the pathogenesis of osteonecrosis. Therefore, the morphology and dimensions of the FCF may not only reflect normal anatomical variation but also provide clues to underlying vascular integrity and biomechanical stress distribution across the femoral head. Several anatomical and radiological studies have explored the shape, presence, or absence of the FCF in relation to ligament integrity, degenerative conditions, and congenital anomalies. Sampatchalit et al. (9) reported that degenerative hypertrophy of the ligamentum capitis femoris is often associated with wider and deeper FCFs, while Cerezal et al. (1) described hypoplastic or absent FCFs in cases of congenital ligament absence. However, despite the established anatomical significance of this region, detailed morphometric analyses of the FCF with femoral head morphology remain to be disclosed. Given that the FCF resides directly on the femoral head surface, it is reasonable to hypothesise that variations in the size and shape of the femoral head—including parameters such as the total surface area—might influence the morphological characteristics of the FCF, such as its transverse and vertical diameters, depth, area, and perimeter (10, 11). Understanding this anatomical relationship could provide deeper insight into the spatial organization of proximal femoral structures and the biomechanical and clinical significance of the FCF.

Current approach aimed to reveal the potential influence of femoral head geometry on the morphometric characteristics of the FCF. The findings of this study are likely to contribute to a better understanding of anatomical variations in this region and serve as a potential reference in radiological assessments, preoperative surgical planning, and anthropological identification.

Materials and Methods

This study was conducted on a total of 71 dry femora obtained from the Anatomy Department of Bilecik Seyh Edebali and Eskisehir Osmangazi Universities Faculty of Medicine. Specimens exhibiting any form of deformation likely to compromise measurement accuracy were excluded from the analysis. Information regarding the age and sex of the specimens was unavailable, and it was not possible to determine whether the right and left femurs originated from the same individual. Morphological and morphometric characteristics of the FCF and femoral head were assessed using methodologies established in previous studies (12).

Standardized mediolateral digital photographs of the femoral heads were obtained for morphometric evaluation. During image acquisition, a millimetric calibration ruler was placed adjacent to each specimen to ensure accurate scaling. All photographs were taken with the medial aspect of the femoral head facing the camera, and the femoral neck axis was carefully aligned parallel to the camera lens to maintain consistent mediolateral orientation across all samples. Morphometric evaluations were performed using a digital caliper (Koodmax digital carbon fiber caliper, China; sensitivity 0.01 mm) and Image J software (National Institutes of Health, USA) following proper calibration based on the ruler included in each image. The same researcher repeated the measurements three times, and mean values were used in the study.

Locational Typing of the FCF Based on Mediolateral Imaging

The anatomical localization of the FCF was evaluated based on mediolateral images of the femoral head. For this purpose, each femoral head image was digitally divided into four quadrants- anterosuperior, anteroinferior, posterosuperior, and posteroinferior by superimposing vertical and horizontal lines intersecting at the center of the femoral head using ImageJ software. According to the quadrant in which the FCF was predominantly located, five distinct localization types were defined (Figure 1).

Measurement of the Femoral Head and FCF Parameters

The area was calculated based on the circular contour surrounding the femoral head observed in mediolateral digital images. In addition to area measurement, the perimeter of the femoral head was also assessed using the same mediolateral images to provide a comprehensive evaluation of femoral head geometry (Figure 2).

The morphometric parameters of the FCF were defined and measured in accordance with previous anatomical studies (12). All linear measurements were performed using a digital caliper while area and perimeter calculations were obtained through ImageJ software on standardized mediolateral digital images. The anatomical landmarks and measured morphometric parameters of the FCF are illustrated in Figure 2.

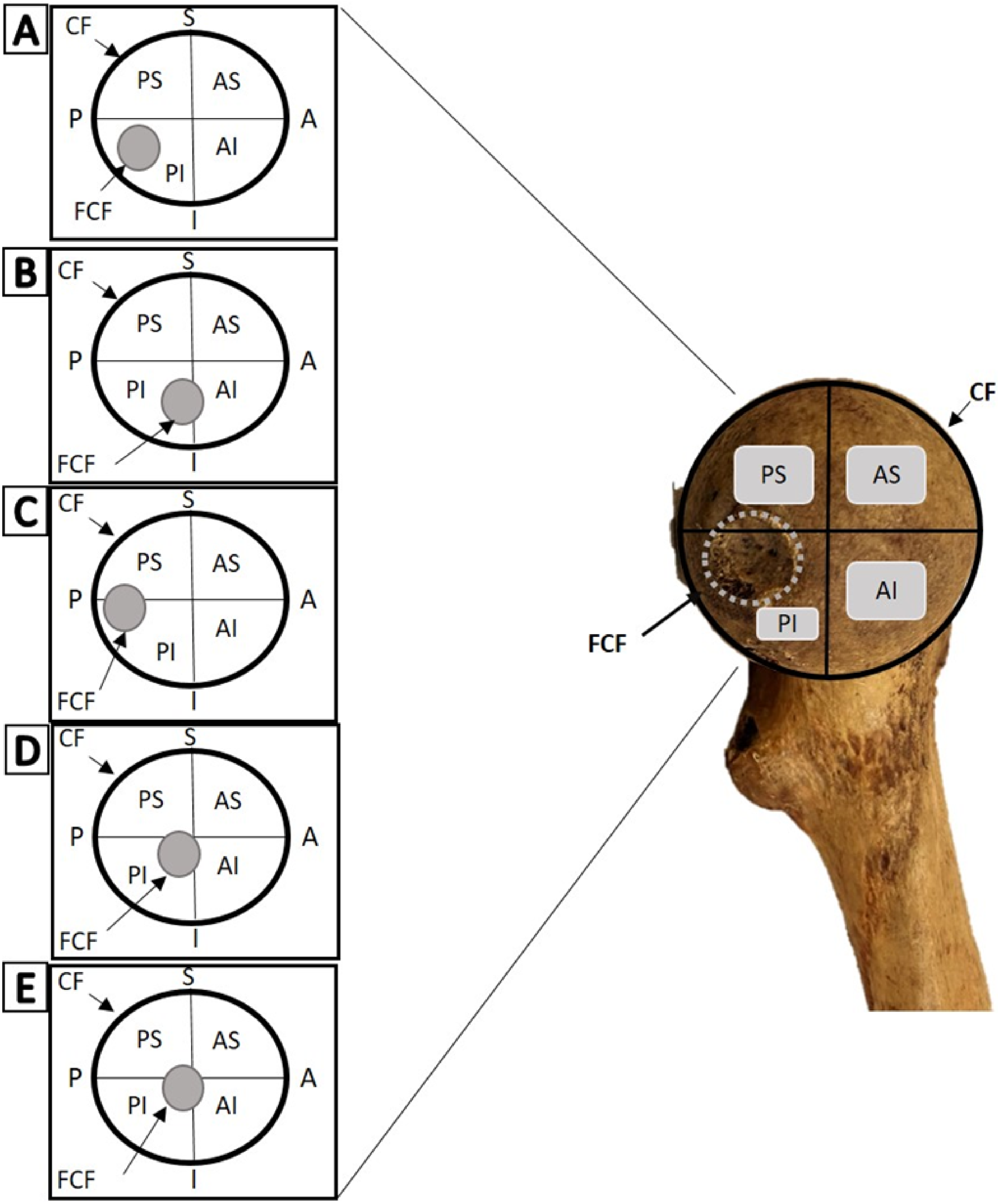

Figure 1. The localization types of the fovea capitis femoris (FCF) are illustrated based on its position on the femoral head (caput femoris, CF). The femoral head is divided into four anatomical quadrants: anterosuperior (AS), anteroinferior (AI), posterosuperior (PS), and posteroinferior (PI). The FCF, delineated by a dashed circle, is primarily located within the posteroinferior quadrant, but five distinct localization types (Type 1–Type 5) are defined according to the position of its center. Subfigures (A-E) demonstrate these types: (**A**) Type 1 localization, (**B**) Type 2 localization, (**C**) Type 3 localization, (**D**) Type 4 localization, and (**E**) Type 5 localization. The orientation of the femoral head is marked with directional labels: anterior (A), posterior (P), superior (S), and inferior (I).

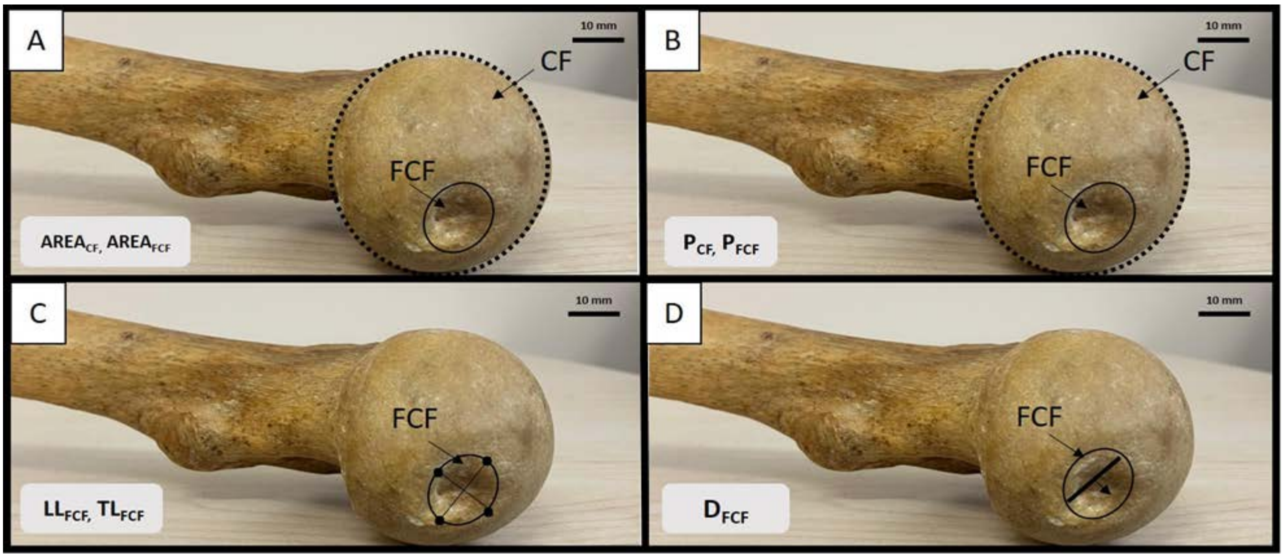

Figure 2. Representative views of the proximal femur showing the morphometric assessment of the fovea capitis femoris (FCF) in relation to the caput femoris (CF). (**A**) Measurement of the total surface area of the femoral head ($AREA_{CF}$) and the surface area of the fovea capitis ($AREA_{FCF}$). **(B)** Perimeter measurements of the femoral head (PCF) and the fovea capitis (P_{FCF}). **(C)** Evaluation of the longest longitudinal length (LL_{FCF}) and transverse length (TL_{FCF}) of the fovea. **(D)** Measurement of the depth of the fovea capitis femoris (D_{FCF}). All parameters were measured digitally using high-resolution calibrated images. Scale bars represent 10 mm.

- **Longitudinal Length of the FCF (LL_{FCF}):** The longest diameter of the FCF was measured directly using a caliper.
- **Transverse Length of the FCF (TL_{FCF}):** The shortest diameter of the FCF, oriented perpendicular to the longitudinal axis, was measured with a caliper.
- **Depth of the FCF (D_{FCF}):** The vertical distance from the deepest point of the FCF to the imaginary plane connecting the foveal margins was measured by a caliper.
- **Area of the FCF ($AREA_{FCF}$):** The area was calculated as the surface area enclosed by the geometric shape surrounding the foveal margins, based on mediolateral digital images analyzed via ImageJ.
- **Perimeter of the FCF (PER_{FCF}):** The perimeter was computed based on the traced outline of the FCF on digital images using ImageJ software.

Statistical Analysis

The statistical evaluation was carried out using SPSS software version 25.0 (IBM Corp., Armonk, NY, USA). The Shapiro-Wilk test was performed to assess the normality of the data distribution for each variable. Variables were analyzed using one-way analysis of variance (ANOVA) to determine statistically significant differences among the study groups. For post-hoc pairwise comparisons, Hochberg's GT2 test was applied, which is suitable for situations with unequal sample sizes between groups. A significance threshold of $p < 0.05$ was adopted for all statistical tests.

Results

The bone numbers and percentages of the typing made according to FCF shapes were given in Table 1. Among the 71 femoral heads analyzed, Type II was the most frequently observed configuration (64.8%, n=46) while Types I, III, and V were less common (7.0% each, n=5). Descriptive statistics for all morphometric parameters across shape types—including mean ± standard deviation and minimum-maximum values—were summarized in Table 2. Type V exhibited the highest mean values for both area (27.6 mm²) and perimeter (67.1 mm) of the FCF, whereas Type I had the lowest values in nearly all variables.

The one-way ANOVA revealed statistically significant differences between shape groups in three parameters: longitudinal length (LL) of the FCF ($p = 0.005$), area of the FCF ($p = 0.001$), and perimeter of the FCF ($p = 0.001$) (Table 3). No significant differences were observed in TL or depth values across groups.

According to the post-hoc analysis, femoral heads with Type I FCF demonstrated significantly lower LL values compared to all other groups. Furthermore, significant differences in area and perimeter were observed between Type I and Type II versus Types III, IV, and V, suggesting a measurable distinction in foveal morphology across these categories.

These findings indicated that more compact and less expansive FCF shapes (e.g., Type I) tend to present with smaller morphometric profiles, which may be relevant in understanding anatomical variation, ligament insertion area, or possible vascular implications.

Table 1. Bone numbers and percentages measured according to FCF typing

Type I	Type II	Type III	Type IV	Type V	Total Number
5 (7.0%)	46 (64.8%)	5 (7.0%)	10 (14.2%)	5 (7.0%)	**71**

Table 2. Descriptive statistics of the parameters evaluated according to groups (mm and mm^2)

Type		Perimeter of the CF	Area of the CF	LL of the FCF	TL of the FCF	Depth of the FCF	Area of the FCF	Perimeter of the FCF
Type I	**Mean±SD**	136.6±9.5	137.0±1.84	12.00±0.71	10.40±1.19	3.24±0.61	10.6±2.0	38.1±4.0
	Min. - Max.	128.4-152.2	121.0-164.0	10.90-12.80	9.70-12.50	2.40-4.10	8.7-13.5	32.9-42.1
Type II	**Mean±SD**	137.9±11.6	148.0±21.7	16.52±3.09	12.88±2.09	2.40±0.73	15.2±5.6	47.0±9.3
	Min. - Max.	115.3-159.0	100.8-188.8	12.30-24.80	9.20-18.40	1.00-3.80	3.3-29.3	26.8-68.3
Type III	**Mean±SD**	137.5±15.6	151.9±25.0	19.06±4.49	12.86±2.49	2.50±0.66	23.4±9.2	61.0±12.8
	Min. - Max.	120.4-159.2	115.9-185.1	14.60-25.70	10.10-15.10	1.60-3.30	12.9-34.3	46.8-72.3
Type IV	**Mean±SD**	146.7±16.7	166.8±26.9	17.61±3.58	11.99±3.23	2.67±0.59	24.7±8.3	59.7±9.7
	Min. - Max.	109.7-171.0	117.2-204.3	11.60-24.30	7.90-18.20	1.40-3.50	12.6-41.6	44.4-77.4
Type V	**Mean±SD**	140.5±10.1	148.0±17.5	19.40±5.33	14.24±3.20	2.50±0.82	27.6±7.5	67.1±4.0
	Min. - Max.	125.8-152.5	118.9-166.2	11.80-26.80	10.30-17.60	1.90-3.70	21.1-39.3	61.9-73.22

Table 3. ANOVA Table for the comparison of the variables

		Sum of Squares	df	Mean Square	F	p
LL of the FCF	Between Groups	184.388	4	46.097	4.101	**0.005***
	Within Groups	741.859	66	11.240		
	Total	926.247	70			
Area of the FCF	Between Groups	1678.137	4	419.534	10.693	**0.001***
	Within Groups	2589.535	66	39.235		
	Total	4267.672	70			
Perimeter of the FCF	Between Groups	4105.928	4	1026.482	12.308	**0.001***
	Within Groups	5504.259	66	83.398		
	Total	9610.187	70			

*df = degree of Freedom, F=Fisher Statistic, *p-values < 0.05*

Discussion

The present work aimed to provide a comprehensive morphometric and localization-based evaluation of the FCF using dry femoral specimens. The findings revealed notable differences in FCF measurements across localization types, particularly in longitudinal length, area, and perimeter values. The predominance of the posteroinferior quadrant localization is consistent with previous anatomical reports, supporting the notion that the FCF occupies a relatively fixed position on the femoral head. However, variations in its morphometric dimensions among subtypes suggest that not only its location but also its size and shape may differ substantially between individuals.

Numerous anatomical studies have consistently described the FCF as residing in the posteroinferior quadrant of the femoral head, a finding corroborated by the present study. In all specimens examined, the FCF was identified within this region, supporting the notion that its localization is relatively constant across individuals. Perumal et al. pointed out (8) this positional tendency in their assessment of dry femurs; however, they did not provide a detailed quadrant-based classification or morphometric correlation. Similarly, Ceynowa et al. (13) emphasized the surgical relevance of the posteroinferior FCF localization, particularly in hip arthroscopy, where it serves as a reliable intraoperative landmark. The consistent anatomical positioning observed in our study reinforces the clinical utility of the FCF, not only as a point of reference in imaging and surgical procedures, but also as a potential indicator of preserved vascular architecture, especially in the context of femoral head viability and reconstructive planning. The reproducibility of its location further supports the integration of the FCF in standardized anatomical mapping protocols, particularly in orthopedic and anthropological applications.

The present study revealed that Type I FCFs, characterized by a compact configuration, exhibited the smallest values across multiple morphometric parameters, including longitudinal length, area, and perimeter. This finding aligns with the results reported by Sampatchalit et al. (9), who demonstrated a correlation between the thickness of the ligamentum capitis femoris and the dimensions of the FCF. According to their MRI-based investigation, larger and deeper foveae were associated with hypertrophied ligaments while smaller foveae were typically linked to thinner or degenerative ligaments. These results support the notion that ligamentous loading and biomechanical stress may influence foveal morphology, potentially through adaptive responses or developmental shaping mechanisms.

Moreover, the reduced surface area in Type I configurations may imply a narrower insertion point for the ligament, which in turn could impact the mechanical stability of the hip joint in certain positions, particularly during flexion and external rotation. Additionally, since the fovea also accommodates minor vascular foramina, its smaller size may correspond to limited vascular ingress, a factor of clinical relevance in conditions such as avascular necrosis of the femoral head, where compromised blood flow plays a central role in pathogenesis (1, 9). These interpretations highlight the multifactorial significance of foveal morphometry-where size not only reflects anatomical variation but also serves as a potential marker for ligament integrity and vascular support. As such, the identification of smaller Type I FCFs in anatomical studies could inform both radiological evaluations and preoperative planning in orthopedic practice.

Based on the present analysis, Type II FCFs, characterized by a round morphology, were the most frequently observed configuration, accounting for 64.8% of the cases. This high prevalence suggests that Type II may represent the "average" or typical anatomical structure, offering a balanced form that provides both structural support and vascular function. Similar distributions have been reported in previous anatomical studies conducted on both cadaveric specimens and radiological imaging, indicating that circular or near-circular foveae are the most common variant (14). The moderate longitudinal length, area, and perimeter values observed in Type II FCFs suggest that this morphology offers adequate surface for ligament attachment and sufficient space for vascular foramina. Its symmetrical shape and frequent occurrence make it a dependable anatomical landmark in arthroscopic and radiological procedures, especially during femoral neck fracture repair or joint-preserving surgeries. The structural balance of Type II may reduce mechanical stress while ensuring vascular continuity, highlighting its relevance in both anatomical assessment and surgical planning.

As observed in this research, Type V FCFs demonstrated the highest mean values for both area and perimeter, suggesting a morphologically broader and more expansive structure. This anatomical configuration might have provided a wider surface area for the insertion of the ligamentum capitis femoris, potentially enhancing the ligament's functional capacity. Cerezal et al. highlighted the role of the ligamentum teres in contributing to hip joint stability, particularly during flexion, adduction, and external rotation, and emphasized its relevance in both surgical planning and pathological assessment (1).

Moreover, a larger foveal surface may accommodate a greater number or size of vascular foramina, which serve as entry points for small vessels supplying the femoral head. Zhao et al. reported that the absence or reduction of nutrient foramina in the FCF may compromise vascular inflow to the femoral head and is a potential risk factor for osteonecrosis, particularly following trauma or corticosteroid therapy (15). This suggests that a broader foveal morphology, as seen in Type V FCFs, could correlate with enhanced vascular supply and may confer a protective advantage in terms of femoral head viability.

Collectively, these findings imply that larger FCF morphologies may offer dual clinical advantages by providing a more robust site for ligamentous anchorage and enhancing vascular access to the femoral head. Recognition of such anatomical variations may prove valuable in arthroscopic navigation, preoperative surgical planning, and risk stratification for conditions such as avascular necrosis or femoral head dislocation.

Additionally, the femoral head surface area and perimeter measurements obtained in this study are generally consistent with previously reported morphometric investigations. Notably, the average femoral head perimeter values align closely with those reported by Perumal et al. and Yarar et al. supporting the comparability of measurement techniques (8, 12). These studies documented average perimeter lengths in the range of 135–145 mm, which closely match the mean values recorded in our sample.

These findings suggest that assessing femoral head surface area and perimeter is not only relevant for morphometric documentation but also carries clinical importance. Accurate evaluation of femoral head geometry plays a critical role in orthopedic procedures such as total hip arthroplasty, avascular necrosis assessment, and prosthesis planning (13, 16).

The morphometric characteristics of FCF are not only clinically relevant but also hold significance in anthropological research. Individual variations observed in FCF morphology may enhance the utility of the femoral head in forensic identification, including sex determination, age estimation, and population-based comparisons. Perumal et al. reported that FCF morphology can vary with age and sex, suggesting its potential value in forensic anthropology (8). These findings highlight that, beyond its surgical and radiological importance, the FCF may serve as a functional anatomical marker in the osteological assessment of human remains. Morphometric variability of the femoral head reflects individual variation and may serve as a useful parameter in studies on age estimation, sex determination, or population differences. As such, femoral head dimensions may be considered valuable reference data in larger-scale anthropological analyses (17).

In conclusion, this study presented a morphometric and localization-based evaluation of the FCF in relation to femoral head geometry. Significant differences in FCF measurements-particularly in longitudinal length, area, and perimeter-were observed across quadrantal localization types. Type I FCFs showed the smallest dimensions, suggesting limited ligament attachment surface and vascular access, which may have clinical implications in cases such as avascular necrosis, femoral neck fractures, and hip dysplasia.

Given that the FCF often serves as the only consistently visible arthroscopic landmark, a detailed understanding of its morphology is essential for accurate surgical navigation and graft placement in hip-preserving procedures. These findings might also inform radiological interpretation and preoperative planning. Future studies incorporating radiological and clinical data are needed to further explore the diagnostic and prognostic value of FCF morphology.

Strengths and Limitations of the Study

One of the primary strengths of this study is the use of dry femoral specimens, which allowed for precise morphometric evaluation without interference from soft tissue structures. This enabled the accurate delineation of anatomical landmarks and reliable measurement of surface-based parameters. However, a notable limitation is the lack of demographic data—specifically age and sex—associated with the specimens. As a result, it was not possible to assess potential morphometric variations based on demographic subgroups, which may influence the generalizability of the findings across different populations.

__Ethical Approval:__ This study does not include experiments on human participants or humans/animals. Since the skulls belong to the Department of Anatomy, there is no ethical committee decision. The authors affirm that the study was conducted in accordance with the ethical principles outlined in the 1964 Declaration of Helsinki and its subsequent revisions.

Author Contributions:
Concept: H.G.
Literature Review: H.G.
Design : H.G., N.T.C.
Data acquisition: H.G.
Analysis and interpretation: N.T.C.
Writing manuscript: H.G., N.T.C.
Critical revision of manuscript: H.G., N.T.C., Y.A.

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