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Original Article

Anatomy Section

Anatomical Variations of Nutrient Foramina in Dry Adult Femur Bones among North Indian Population: A Cross-sectional Study

VIKASH BHORIA[1], PRACHI SAFFAR ANEJA[2], SUSMITA SAHA[3], SAVITA BANSAL[4], RUCHIKA YADAV[5], SANYA KHURANA[6]

ABSTRACT

Introduction: The diaphysis of the femur is primarily supplied by the nutrient artery, which traverses the nutrient foramen. Typically, the femoral diaphysis presents with one or more nutrient foramina. Usually, two nutrient arteries originate from the first and third perforating branches of the profunda femoris artery. When only a single major nutrient artery is present, it originates from the second perforating branch. Generally, the nutrient foramen or foramina are located in the middle third of the femoral shaft, on or close to the linea aspera.

Aim: To comprehensively analyse the nutrient foramina in the femur by determining their number, location, and direction.

Materials and Methods: The present cross-sectional study was conducted on 50 dry adult femurs (25 right-sided and 25 left-sided) of unspecified sex, obtained from the bone bank of the Department of Anatomy, SGT University, Gurugram, Haryana, India. The number, location, and direction of the diaphyseal nutrient foramina were observed over a period of six months from May 2024 to October 2024 using visual inspection (subjective evaluation). All measurements were performed twice to minimise error, and the mean value was recorded. The data were analysed using Statistical Package for Social Sciences (SPSS) software (version 30). The mean, range, percentages, t-values, and p-values were calculated and presented in tabular form.

Results: All nutrient foramina were directed proximally. The number of foramina ranged from zero (one bone) to four (one bone). The majority of bones (32 femurs) had double foramina. Single foramina (14 femurs) were generally located in the upper third of the shaft, while double foramina (32 femurs) were more commonly located in the middle third. In the present study, a single nutrient foramen (2%) was observed on the popliteal surface of the left femur, a finding not reported in earlier studies.

Conclusion: Diaphyseal nutrient foramina show significant variation in number and location. The present study will be beneficial for orthopaedic surgeons in planning surgical procedures involving the femur, such as arthroplasty, bone grafting, and fracture reduction, where maintenance of adequate blood supply is essential for successful outcomes.

Keywords: Diaphysis, Femur, Linea aspera, Nutrient artery

INTRODUCTION

The femur is a typical long bone characterised by two epiphyses and a diaphysis, also known as the shaft. The shaft is cylindrical and composed of compact bone, with a large medullary cavity filled with bone marrow [1]. The femoral shaft is divided by three borders- medial, lateral, and posterior- into three surfaces: anterior, medial, and lateral. The diaphysis is narrowest at the centre and expands both proximally and distally. The medial and lateral surfaces converge posteriorly to form a rough ridge known as the linea aspera [2].

The linea aspera is a prominent crest on the posterior surface of the shaft. It further divides the posterior aspect into two surfaces: the posterior surface proximal to the linea aspera (upper third) and the popliteal surface distal to it (lower third) [3]. Superiorly, its medial lip continues as the spiral line, while the lateral lip continues as the gluteal tuberosity. The central region lies between the medial and lateral lips of the linea aspera. Inferiorly, the medial and lateral lips continue as the medial and lateral supracondylar lines, respectively [4].

Long bones of the appendicular skeleton are supplied by four interrelated vascular systems: the nutrient system, the metaphyseal complex, the epiphyseal complex, and the periosteal capillary system [3]. The primary supply is provided by the nutrient artery, which supplies the inner two-thirds of the cortex and the bone marrow [4].

Typically, the femoral diaphysis presents with one or two nutrient foramina that lead into a nutrient canal. Initially, the canal runs horizontally and later becomes oblique as the bone grows [5]. The direction of the nutrient canal is characteristic for long bones. In the femur, it is directed proximally, toward the upper end, because the lower end is the growing end. Thus, the direction of the nutrient foramen is opposite to the growing end of the bone due to differential growth [6].

The nutrient foramen transmits the nutrient artery into the medullary cavity. Usually, two nutrient arteries arise from the first and third perforating branches of the profunda femoris artery. When only a single artery is present, it commonly arises from the second perforating branch [7-9]. After entering the medullary cavity, the artery divides into ascending and descending branches to supply the bone.

Bone growth and vascularisation largely depend on the nutrient artery. The nutrient system is particularly crucial during childhood growth and early ossification, as nearly 80% of the interosseous blood supply is derived from it [10]. Because of its essential role in femoral vascularity, knowledge of nutrient foramina is clinically important. Variations in their number and location are frequently observed.

Understanding the location of nutrient foramina is especially important for orthopaedic surgeons, as preservation of blood supply is vital for successful surgical procedures involving the femur. Compromised vascularity may result in bone ischaemia and delayed healing [11].

Although several studies have examined the morphological features of nutrient foramina in different populations, limited data exist regarding their relationship to the linea aspera in the North

Indian population. Therefore, the present study was undertaken to comprehensively analyse the nutrient foramina of the femur in terms of number, location, and direction, and to compare findings between right and left femurs to identify any significant differences.

MATERIALS AND METHODS

The present cross-sectional study was conducted on 50 dry adult femurs (25 right-sided and 25 left-sided) of unspecified sex and age, stored in the bone bank of the Department of Anatomy, SGT University, Gurugram, Haryana, India, from May 2024 to October 2024. The bones present in the department were anonymised and randomly coded to delink them from any identifiable source. The study was carried out after obtaining approval for a waiver of consent in accordance with Consent Process Box 5.2 ("Conditions for granting waiver of consent") [12] from the Registered Screening Ethics Committee of the institution (SEC/FMHS/MSc/10/04/24-05), dated 10/04/2024.

Inclusion criteria: Intact dry adult femurs.

Exclusion criteria: Broken or damaged femurs and femurs with grossly visible pathology.

Study Procedure

Parameters: number and direction of nutrient foramina: A hypodermic needle was used to determine the direction of the nutrient foramina in relation to the long axis of the bone [Table/Fig-1].

Position of the primary nutrient foramen: The primary nutrient foramen (the largest foramen observed on each bone) was identified by visual inspection. Its position was documented along the femoral shaft (proximal, middle, or lower one-third). The distance from anatomical landmarks was also recorded:

From the upper end: Distance from the centre of the intertrochanteric crest to the nutrient foramen [Table/Fig-2a].

From the lower end: Distance from the centre of the posterior margin of the intercondylar fossa to the nutrient foramen [Table/Fig-2b].

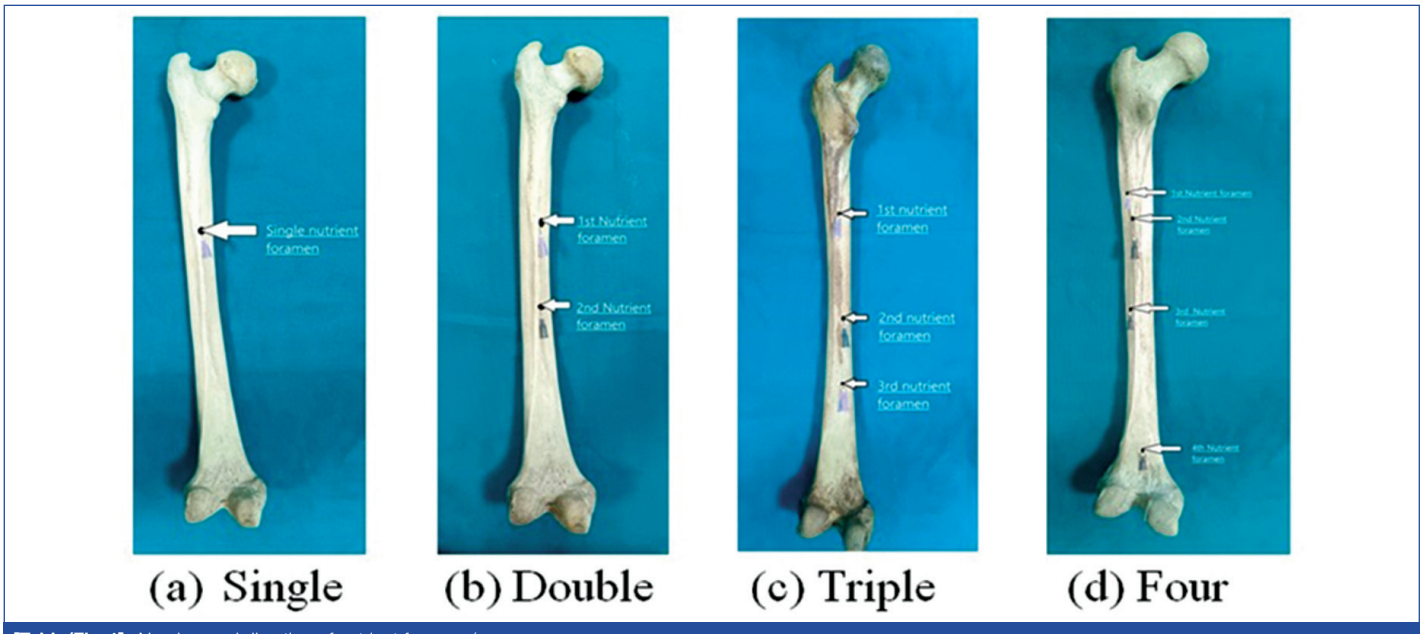
Location of the nutrient foramen: The foramen was noted on the medial surface, lateral surface, popliteal surface, linea aspera, and the medial and lateral lips of the linea aspera [Table/Fig-3].

STATISTICAL ANALYSIS

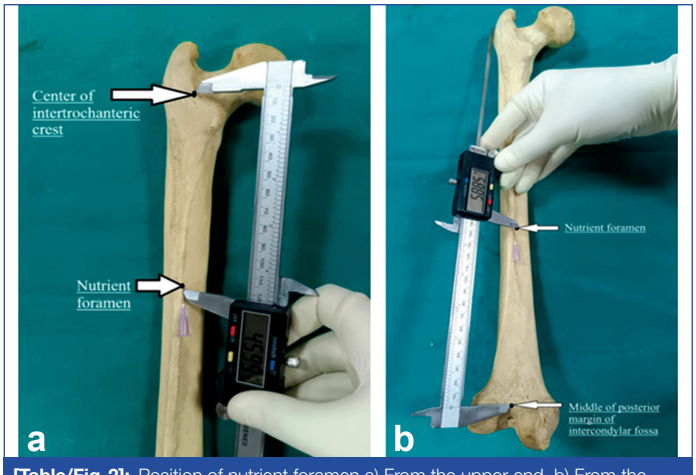
Descriptive analysis was performed using SPSS software (version 30) to calculate the mean, standard deviation, and percentage of the parameters studied. Comparisons between the right and left femurs were performed using the Student's t-test, and p-values were calculated to assess statistical significance.

RESULTS

Double nutrient foramina were observed in most bones, particularly in the left femurs, where 18 specimens exhibited this pattern. These foramina were predominantly located in the middle third of the femoral shaft, as shown in [Table/Fig-4]. The distances of the nutrient foramina from the intertrochanteric crest and intercondylar



[Table/Fig-1]: Number and direction of nutrient foramen/s.



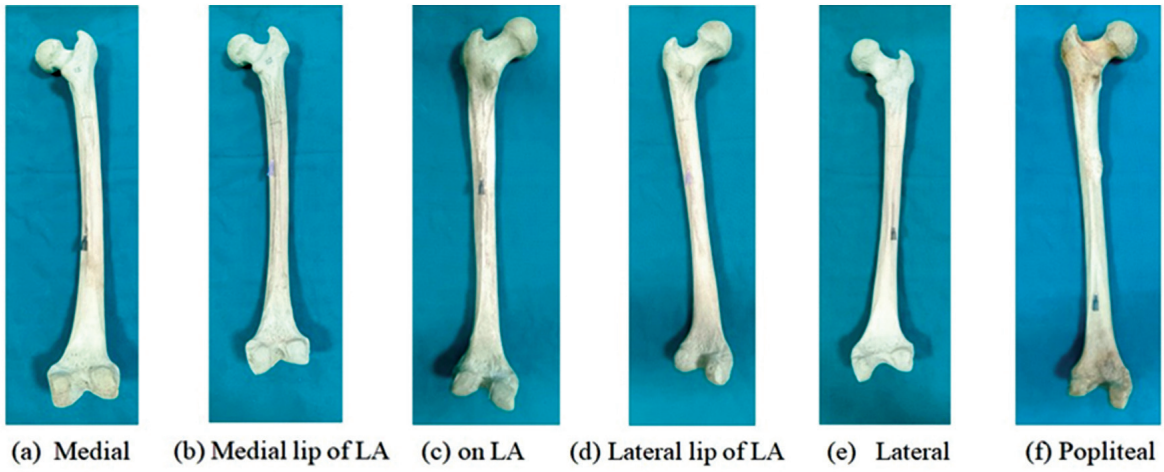
[Table/Fig-2]: Position of nutrient foramen a) From the upper end. b) From the lower end.

fossa were measured and are presented in [Table/Fig-5]. Most nutrient foramina were located on the medial lip of the linea aspera [Table/Fig-6].

DISCUSSION

In the present study, 50 adult dry human femurs were examined. The blood supply to the diaphysis is predominantly provided by the nutrient arteries, particularly in children, where the nutrient artery system contributes up to 80% of the total blood supply. Although anastomoses exist between periosteal and nutrient arteries, adequate blood flow through the nutrient arteries is especially critical during bone growth and fracture healing. Nutrient arteries enter the bone through nutrient foramina; therefore, studying these foramina is essential for understanding bone vascularity [13,14].

Several authors have reported that the number of nutrient foramina in the femur ranges from none to multiple, with most



[Table/Fig-3]: Location of nutrient foramen/s.

S. No.	Number of foramen/s	Femur side	Number of bone/s	Location of nutrient foramen on shaft		
				Upper 1/3rd	Middle 1/3rd	Lower 1/3rd
1.	Absent	Right	1	0	0	0
		Left	0	0	0	0
2.	Single	Right	9	7	2	0
		Left	5	3	1	1
3.	Double	Right	14	11	15	2
		Left	18	12	18	6
4.	Triple	Right	1	1	1	1
		Left	1	1	2	0
5.	Quadruple	Right	0	0	0	0
		Left	1	2	1	1

[Table/Fig-4]: Presents the number and location of nutrient foramen/s on the femoral shaft.

in the middle third. Bayat P et al., reported that 48.84% of foramina were located in the lower third of the femur [16]. Poornima B and Angadi AV observed that 56.1% were located at the junction of the upper and middle thirds [17].

Furthermore, most studies indicate that nutrient foramina are commonly found on or near the linea aspera, particularly on the medial surface, followed by the lateral surface. Patel DSM et al., however, reported a higher frequency on the medial lip of the linea aspera rather than the intermediate area of the ridge [18]. Observations regarding the number and location of nutrient foramina reported by various authors are summarised in [Table/Fig-7] [6-8,10,13,14,17-20] and [Table/Fig-8] [2,5-7,14-16,18, 21-24] respectively.

Knowledge of the number, location, and direction of nutrient foramina is crucial for orthopaedic surgeons during trauma management, resection procedures, and reconstructive surgeries.

S. No.	Parameters	Range (mm)		Mean±SD (mm)		t-value	p-value
		Right	Left	Right	Left		
1	Distance of NF from Intertrochanteric crest	64-244.9	71.2-238.8	140.3±47.9	160.5±49.6	1.9	0.05*
2	Distance of NF from middle of posterior margin of Intercondylar fossa	73.3-257.9	73.7-248.4	188.9±47.9	171.8±53.2	2	0.04*

[Table/Fig-5]: Distance of nutrient foramen from anatomical landmarks of upper and lower end.
NF-Nutrient Foramina

Side of femur	Number of foramen/s	No. of bone/s	MS	LS	LA	LL of LA	ML of LA	Popliteal surface
Right	Single	9	2	0	3	1	3	0
	Double	14	9	1	7	5	6	0
	Triple	1	1	1	1	0	0	0
Left	Single	5	1	2	2	0	0	0
	Double	18	9	5	8	5	9	0
	Triple	1	1	0	1	1	0	0
	Four	1	0	1	1	1	0	1

[Table/Fig-6]: Number of nutrient foramen/s present on various areas on the femoral shaft.
MS: Medial surface; LS: Lateral surface; LA: Linea aspera; ML of LA: Medial lip of LA; LL of LA: Lateral lip of LA; PS: Popliteal surface

bones showing one or two foramina. In the present study, the majority of femurs had two foramina. Sendemir E and Cimen A observed two bones with eight foramina and one bone with nine foramina [15].

The location of the nutrient foramen is equally important. Most authors have found that the foramina are located in the middle third of the femoral shaft [1,13]. In the present study, however, single foramina were primarily located in the upper third of the shaft, whereas bones with two foramina showed a higher concentration

S. No.	Author sample size			Number of Nutrient foramen/s				
				Zero	One	Two	Three	Four
1.	Murlimanju B et al., [14]	86		0	47.7%	44.2%	3.5%	0
2.	Oyedun OS [7]	95		0	74 (77.89%)	21 (22.1%)	0	0
3.	Poornima B, Angadi A V [17]	100		0	62 (62%)	37 (37%)	1 (1%)	0
4.	Patel DSM et al., [18]	40		0	16 (40%)	24 (60%)	0	0
5.	Gupta AK et al., [8]	100		3 (3%)	71 (71%)	25 (25%)	1 (1%)	0
6.	Vinay G, Mangala GSR [13]	90		0	60 (66.7%)	30 (33.3%)	0	0
7.	Rakate NS et al., [10]	40		0	21 (52.5%)	9 (22.5%)	10 (25%)	0
8.	Lanka R et al., [6]	81		0	47 (58%)	29 (36%)	5 (6%)	0
9.	Aggarwal N et al., [19]	100		0	78 (78%)	22 (22%)	0	0
10.	Padmashree BR et al., [20]	50		0	35 (70%)	15 (30%)	0	0
11.	Present study (2025)	50	Rt	1 (2%)	9 (18%)	14 (28%)	1 (2%)	0
			Lt	0	5 (10%)	18 (36%)	1 (2%)	1 (2%)

[Table/Fig-7]: Number of nutrient foramen/s on femur across multiple studies [6-8,10,13,14,17-20].

S. No.	Author	Sample size		On LA	On LL of LA	On ML of LL	MS	LS	PS
1.	Sendimer E and Cimen A [15]	102		41.2%	10.1%	35.3%	0	0	0
2.	Erika C et al., [21]	50		36.25%	8.75%	27.5%	21.25%	6.25%	0
3.	Murlimanju B et al., [14]	86		…….	66 (76.7%)	37 (43%)	16 (18.60%)	1 (1.16%)	0
4.	Kumar R et al., [22]	101		41 (27.33%)	17 (11.33%)	28 (18.66%)	37 (24.66%)	8 (5.33%)	0
5.	Oyedun OS [7]	95		(48.42%)	(12.63%)	(17.89%)	(18.9%)	(2.11%)	0
6.	Saha N et al., [5]	85		62.30%	5.7%	32%	0	0	0
7.	Patel DSM et al., [18]	40		9 (22.5%)	12 (30%)	16 (40%)	11 (27.5%)	3 (7.5%)	0
8.	Jayaprakash T [2]	50		28 (56%)	4 (8%)	24 (48%)	6 (12%)	1 (2%)	0
9.	Zahra SU et al., [23]	90		39 (43.3%)	13 (14.4%)	39 (43.3%)	18 (20%)	3 (3.3%)	0
10.	Bayat P et al., [16]	65		59 (90.76%)	2 (3.07%)	13 (20%)	13 (20%)	3 (4.6%)	0
11.	Joshi P, Mathur S [24]	50		35 (70%)	9 (18%)	6 (12%)	0	0	0
12.	Lanka R et al., [6]	81		31 (38%)	11 (14%)	26 (32%)	13 (16%)	0	0
13.	Present study (2025)	50	Rt	11 (22%)	6 (12%)	9 (18%)	12 (24%)	2 (4%)	0
			Lt	12 (24%)	7 (14%)	9 (18%)	11 (22%)	8 (16%)	1 (2%)

[Table/Fig-8]: Location of nutrient foramen on the femur observed across various studies [2,5-7,14-16, 18, 21-24].

Limitation(s)

Sexual dimorphism was not assessed in the present study and may be incorporated in future research within the same population. Additionally, radiographic techniques such as angiographic evaluation could be combined with anatomical observations to provide more precise data for improved surgical outcomes.

CONCLUSION(S)

An accurate anatomical description of nutrient foramina is essential for microvascular surgical procedures, particularly implant placement and vascular grafting. This knowledge assists surgeons in planning interventions with minimal postoperative complications.

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PARTICULARS OF CONTRIBUTORS:
1. Postgraduate Student, Department of Anatomy, SGT University, Gurugram, Haryana, India.
2. Professor and Head, Department of Anatomy, SGT University, Gurugram, Haryana, India.
3. Professor, Department of Anatomy, SGT University, Gurugram, Haryana, India.
4. Professor and Head, Department of Pathology, Manav Rachna Dental College, Faridabad, Haryana, India.
5. Tutor, Department of Anatomy, SGT University, Gurugram, Haryana, India.
6. Postgraduate Student, Department of Anatomy, SGT University, Gurugram, Haryana, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Prachi Saffar Aneja,
Professor and Head, Department of Anatomy, Faculty of Medicine and Health Sciences, SGT University, Gurugram, Haryana, India.
E-mail: dranejaprachi@gmail.com

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