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ORIGINAL RESEARCH ARTICLE

A Comparative Morphometric Analysis of Diaphyseal Nutrient Foramina in the Long Bones of the Forearm and Leg in the North Indian Population

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ABSTRACT

Introduction: The nutrient foramen (NF) is the opening in the shaft or diaphysis of a long bone that allows the nutrient artery to enter the medullary cavity, ensuring adequate blood supply to inner parts of the bone, which is critical for bone growth, remodeling, and healing. Knowledge of the location and number of nutrient foramina is essential during bone transplants, resections, or fixations, as in orthopedic surgeries. Ethnic and population variability is observed in the number and size of nutrient foramina among different populations. The study aims to find significant clinical-anatomical correlations of nutrient foramen between the bones of the forearm and leg in the North Indian population by comparative morphometric analysis.

Material and Methods: The present study was conducted on 240 adult long bones of the forearm and leg, 60 each of radius, ulna, tibia, and fibula of unknown sex and age, from the North Indian population, available in the Department of Anatomy, Shri Ram Murti Smarak Institute of Medical Sciences, Bareilly, Uttar Pradesh.

Results: The study showed the location of NF in the upper third in 75% of the radius, 70% in the ulna, while in the lower third in 76.6% of the tibia and 66.6% in the fibula. In all radius and ulna, nutrient foramina is directed towards the upper end, while in all tibia and fibula, it is towards the lower end. 91.6% of radius, 86.6% of ulna, 81.6% of tibia, and 91.6% of fibula accepted 26G of needle.

Conclusion: The present study confirms and expands upon existing knowledge of nutrient foramina anatomy by providing population-specific data from North India. This knowledge is crucial not only for academic anatomy but also for clinical applications such as fracture repair and reconstructive surgeries.

Keywords: Nutrient foramen, Diaphysis, Long bones, Nutrient artery.

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INTRODUCTION

The nutrient foramen (NF) is the opening in the shaft of a long bone that allows the nutrient artery to enter the medullary cavity, which are vital blood vessels that play a key role in maintaining the health and function of bones.[1,2] Once it enters the nutrient foramen, it travels through a canal into the interior of the bone, ultimately reaching the medullary cavity.[3,4] The rich blood supply is essential not only for providing oxygen and nutrients but also for removing waste products, which is critical for several biological processes such as bone growth, remodeling, and healing.[1,3,5] They are a fundamental part of the bone's vascular system and contribute greatly to the strength and regenerative ability of skeletal structures.[6,7]

The nutrient artery enters the shaft through a nutrient foramen and divides into branches, which again divide into multiple channels, forming hairpin loops and then anastomose with various other arteries.[1,6] The nutrient artery is responsible for supplying essential supplies to the medullary cavity, as well as to the inner two-thirds of the outer layer of compact bone, so it is a vital source of nourishment for the bone's growth.[5]

The oblique direction of a nutrient foramen in the shaft is opposite with the growing end of the long bone. This means the faster-growing end "pulls" the foramen in the opposite direction, i.e., the nutrient artery enters the side of the bone that grows more slowly, which ensures a stable blood supply to the developing bone.[1,2]

The end of the long bone that is growing more quickly—up to twice as quickly as the non-growing end—influences the direction of the nutrient foramen, demonstrating the difference between the upper and lower limbs' locations of the nutrient foramina structure.[6,3] In the upper limb (e.g., radius), the lower end grows more rapidly than the upper end. So, the nutrient foramen points upwards, while in the lower limb (e.g., tibia), the upper end grows faster than the lower end; therefore, the nutrient foramen points downwards.[1,3]

The location of the nutrient foramen is clinically significant as peripheral vascular disruption and nutrient artery rupture are the usual outcomes of longitudinal stress fractures, where the nutrient foramen is thought to be the point of commencement.

The direction of the nutrient foramen is specific for long bones. It is predominantly directed proximally in the radius and ulna as this orientation aligns with the slower-growing proximal end, ensuring the nutrient artery remains intact during bone elongation.[5] While in tibia and fibula, it is primarily directed distally as the distal direction aligns with the slower-growing end, maintaining vascular integrity during development. These findings underline the consistency of NF orientation in relation to bone growth patterns.[6,4]

There is a vital correlation between bone length and the number of NFs. Longer bones tend to have more foramina. For example, in tall humans, the femur and tibia may develop 2 or even 3 foramina to meet increased vascular demands during growth.[1,8]

Ethnic and population variability is also observed in the number and size of nutrient foramina among different populations. These differences are being used in population-based orthopedic implant designs to match bone vascular anatomy.[2,6,9]

The significance of the nutrient foramen might be understood by its pivotal role in the following extents:

Bone Healing and Grafting

The transfer of nutrients and oxygen, particularly in the marrow and cortical areas, depends on the nutrient foramen. As successful bone grafting relies on adequate blood supply, ensuring the integrity of the nutrient artery enhances graft viability and integration.[3,5]

Surgical Areas to be Told

Knowledge of nutrient foramina's location is essential in orthopedic surgeries. Post-operative avascular necrosis or impaired bone healing may arise from damaged nutrient arteries.[4,10]

Management Plan

Management of diaphyseal fracture of long bones is crucial if disruption to the nutrient foramen occurs since it may impede healing and result in delayed or non-union.[11,12]

Variation Across Different Bones

Individuals and bones may differ in the number, size, and placement of nutrient foramina, which may affect management plans and patient outcomes.[1,3]

Bone Vascularity in Disease

Conditions such as infections, osteoporosis, or bone cancers can change the blood flow to bones. Clinicians can diagnose and treat many bone disorders more effectively if they understand the vascular patterns.[10,13]

MATERIAL AND METHODS

The present study is conducted on adult human long bones of the forearm (i.e., radius and ulna) and leg (i.e., tibia and fibula) of unknown sex and age, present in the osteology bank of Department of Anatomy, Shri Ram Murti Smarak Institute of Medical Sciences, Bareilly, Uttar Pradesh, after obtaining prior approval from the Institutional Ethical Committee.

Inclusion Criteria

- All the bones were dry, macerated, thoroughly cleaned, and numbered.
- All bones selected for the study were complete in all respects.

Exclusion Criteria

All bones with apparent pathology or fractured ends were disqualified from the study.

Yamen's formula has calculated sample size:

$n = N / (1+N \times e^2)$, where 'n' is the sample size, 'N' is the population size, and 'e' is the margin of error.

Before starting the measurements, all bones were cleaned and dried, checked thoroughly for any pathology or broken ends, and then numbered as per the inclusion and exclusion criteria.

Different parameters related to nutrient foramen were measured as detailed below:

Length of individual bones

With the help of an osteometric board, the length (in mm) of individual bones is measured. The radial length was measured as the distance between the proximal end of the radius, i.e., radial head, and the distal end, i.e., styloid process of the radius, whereas the ulnar length was measured as the distance between the proximal end (tip of olecranon process) and the distal end, i.e., tip of the styloid process of the ulna. The distance between the most superior point on the medial condyle of the tibia and the tip of the medial malleolus was used to calculate the entire length of the tibia. In contrast, the distance between the apex of the fibula's head/ styloid process and the tip of the lateral malleolus was used to calculate the fibula's whole length.

Location of nutrient foramen

Visually inspect the bone and identify the small opening (NF) usually located in the shaft. This foramen appears as a tiny hole on the surface of the bone. They were identified by their raised borders and a distinctive groove near them. Foramina near the extremities of the bones were disregarded, and only well-defined foramina on the diaphysis were recognized.

Direction and size of nutrient foramen

Using a fine hypodermic needle (20, 24, 26 gauges) and a hand lens, the direction of NF was found in every bone. Gently a hypodermic needle is inserted into the foramen in the direction of the canal. The orientation of the needle is observed. Once the needle is fully inserted and stable, the angle and direction of the needle points represent the course of the nutrient canal. The size of needle which the foramen accepts, determines the size of foramen.

RESULTS

A total of 240 long bones comprising 60 each of radius, ulna, tibia, and fibula from the North Indian population were studied in detail to analyze the morphometric and topographic characteristics of the nutrient foramina (NF).

Each bone was evaluated for the number, direction, location, and size of the nutrient foramina, and the findings were compared across the upper and lower limb bones.

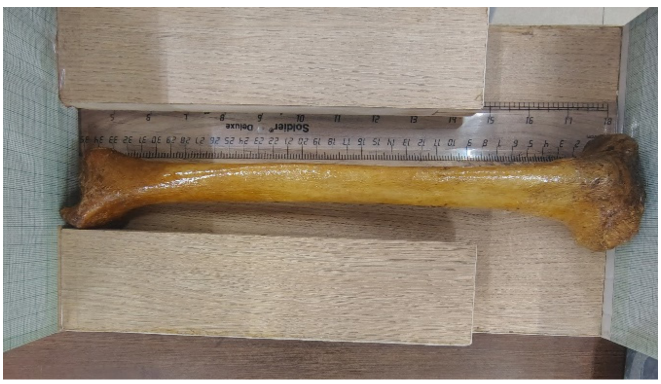

Figure 1: Tibial length measurement

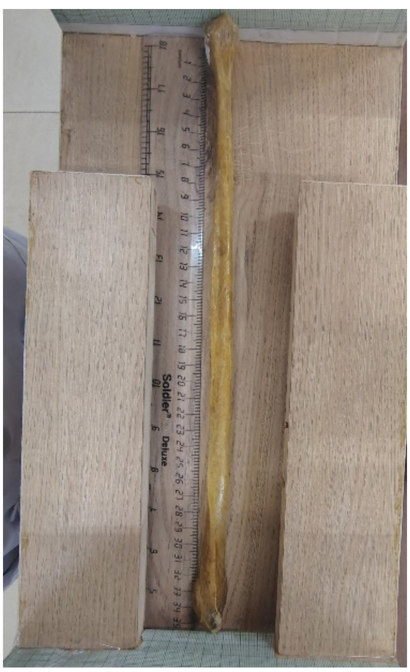

Figure 2: Fibular length measurement

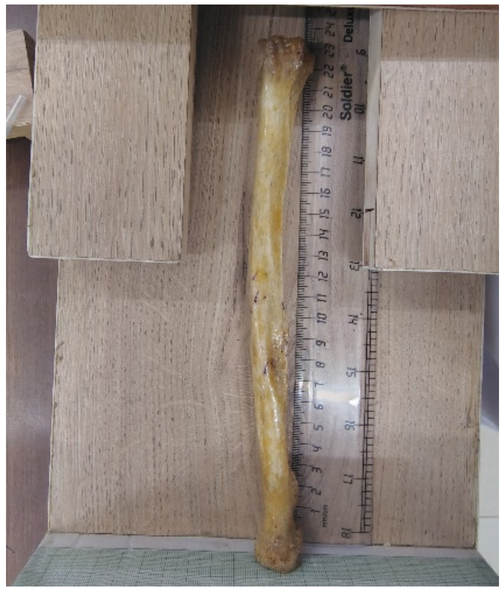

Figure 3: Radial length measurement

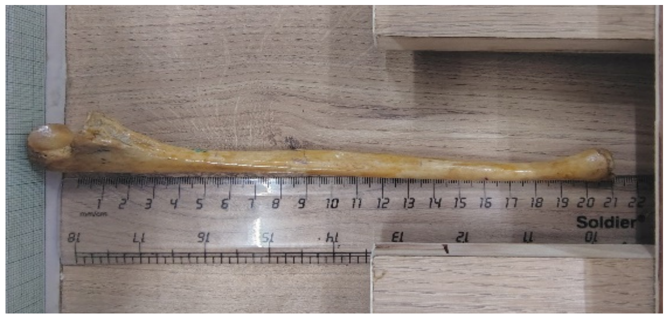

Figure 4: Ulnar length measurement

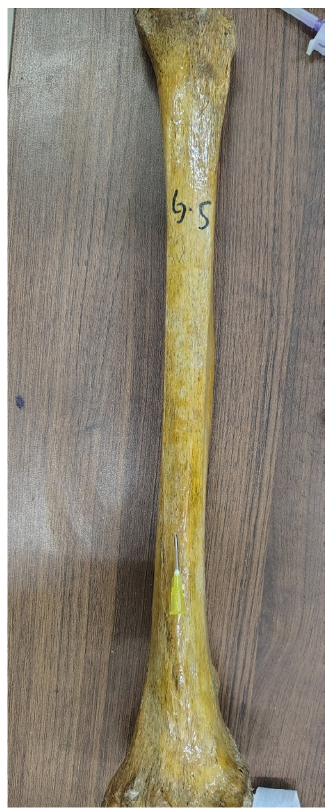

Figure 5: Showing direction and size of nutrient foramen in tibia

Location of Nutrient Foramina

The location of the nutrient foramina was categorized into the upper, middle, and lower thirds of the diaphysis. A distinct difference in the pattern was noted between the bones of the forearm (radius and ulna) and those of the leg (tibia and fibula) (Figures 1-4).

In the radius, 75% (45/60) of the foramina were located in the upper third, 8.3% (5/60) in the middle third, and 16.6% (10/60) in the lower third.

In the ulna, 70% (42/60) were in the upper third, 10% (6/60) in the middle third, and 20% (12/60) in the lower third.

In contrast, the tibia showed only 18.3% (11/60) in the upper third, 5% (3/60) in the middle third, and a high 76.6% (46/60) in the lower third.

The fibula also exhibited a distal concentration with 23.3% (14/60) in the upper third, 10% (6/60) in the middle third, and 66.6% (40/60) in the lower third.

Direction of Nutrient Foramina

In all samples, The radius and ulna unveiled nutrient foramina directed towards the upper end (100%). Conversely, tibia and fibula showed nutrient foramina directed towards the lower end (100%).

Number of Nutrient Foramina

Single nutrient foramen was observed in the majority of bones: Radius: 83.3% (50/60); Ulna: 76.6% (46/60); Tibia: 90% (54/60); and Fibula: 86.6% (52/60); Double nutrient foramina were seen in: Radius: 8.3% (5/60), Ulna: 11.6% (7/60), Tibia: 10% (6/60); Fibula: 13.3% (8/60).

Triple nutrient foramina were only found in radius (8.3%) (5/60) and ulna (11.6%) (7/60).

Size of Nutrient Foramina

The size of the foramina was assessed using hypodermic needles of gauges 20, 24, and 26. The majority of the nutrient foramina across all bones permitted insertion of a 26G needle, indicating very small diameter: Radius: 91.6% of foramina accepted a 26G needle, 8.3% a 24G; Ulna: 86.6% accepted 26G, 11.6% 24G, and 1.6% accepted a 20G needle, indicating a larger foramen, tibia: 81.6% accepted 26G, 16.6% 24G, and 1.6% 20G.; Fibula (Figure 5). 91.6% accepted 26G, 6.6% 24G, and 1.6% 20G.

DISCUSSION

The present morphometric study was undertaken to analyze and compare the anatomical characteristics of nutrient foramina in long bones of the forearm (radius and ulna) and leg (tibia and fibula) among individuals from the North Indian population (Table 1). The aim was not only to identify and document the number, direction, location, and size of the nutrient foramina but also to assess their potential clinical implications and compare our findings with existing literature. The results revealed distinctive and consistent patterns across the upper and lower limb bones, many of which align with established anatomical principles while also reflecting certain variations possibly unique to the population studied (Table 2).

One of the most consistent observations across the long bones was the directionality of the nutrient

Table 1: Showing different studied morphometric parameters of NF of forearm and leg bones like location, direction, number and size

	Radius	*Ulna*	*Tibia*	*Fibula*
Location of NF				
Upper 1/3rd of shaft	45 (75%)	42 (70%)	11 (18.3%)	14 (23.3%)
Middle 1/3rd of shaft	5 (8.3%)	6 (10%)	3 (5%)	6 (10%)
Lower 1/3rd of shaft	10 (16.6%)	12 (20%)	46 (76%)	40 (66%)
Direction of NF				
Towards the upper end	60 (100%)	60 (100%)	0	0
Towards the lower end	0	0	60 (100%)	60 (100%)
Number of NF				
Single	50 (83%)	46 (76%)	54 (90%)	52 (86%)
Double	5 (8.3%)	7 (11.6%)	6 (10%)	8 (13.3%)
Triple	5 (8.3%)	7 (11.6%)	0	0
Absent	0	0	0	0
Size of NF				
20G	0	1 (1.6%)	1 (1.6%)	1 (1.6%)
24G	5 (8.3%)	7 (11.6%)	10 (16.6%)	4 (6.6%)
26G	55 (91%)	52 (86%)	49 (81.6%)	55 (91%)

Table 2: Showing morphometric analysis of different studies done on various population

Study	*Population*	*Year*	*Radius*	*Ulna*	*Tibia*	*Fibula*
Gupta *et al*.	Indian	2013	Single NF; Middle 1/3; Directed distally; small to medium	Single NF; Upper 1/3; Directed distally; small	Middle 1/3; directed distally; small	Not studied
Pereira *et al*.	Brazilian	2011	Single NF; Anterior surface; distally; small	Single NF; Anterior surface; distally; small	Posteromedial surface; distal direction; medium	Posterior surface; distally; small
Prasad *et al*.	North Indian	2023	Single NF (97.4%); Middle 1/3; Directed distally	Single NF (100%); Upper 1/3; Directed distally	Single NF (93%); Posteromedial; Distal	Single NF (100%); Posterior surface; Middle Third
Choudhary *et al*.	Indian	2009	Single NF; Middle Third	Single NF; Upper third	Single NF; posteromedial	Single NF; Posterior third
Vadhel *et al*.	North Indian	2019	Single NF (97.7%); Middle 1/3; Distally; Small	Single NF (100%); Upper 1/3; Distally; Small	Not studied	Not studied
Sharma and Kullar *et al*.	Indian	2021	Not reported	Not reported	Single NF (93%); Posteromedial surface; distal direction	Single NF (100%); Posterior surface; Directed downward
Champa Pal *et al*.	Bengali women	2019	Single NF; Middle third; Small	Not studied	Not studied	Not studied
Present study	North Indian	2024	Single NF (83%); Upper ⅓; towards the upper end; small	Single NF (76%); Upper ⅓; towards the upper end; small	Single NF (90%); Lower ⅓; towards the lower end; small	Single NF (86%); Lower ⅓; towards the lower end; small

foramina, which reflects the "growing end" theory—suggesting that the nutrient canal is directed away from the more actively growing end of the bone. In our study, the nutrient foramina in the radius and ulna were directed toward the upper end (proximal) in 100% of cases. Similarly, in the tibia and fibula, all foramina were directed towards the lower end (distal). This pattern is in close agreement with findings reported by Gupta *et al*. (2013)[1] and Prasad *et al*. (2023),[3] and it reflects classical anatomical teaching, often summarized by the phrase "to the elbow I go, from the knee I flee." documented by Gupta *et al*. (2013)[1] and Prasad *et al*. (2023).[3] This directional difference is crucial in orthopedic surgeries involving intramedullary nailing or other fixation procedures, where preserving the vascular axis can significantly impact the healing process.

Another important aspect examined in this study was the location of the nutrient foramina along the length of the diaphysis, divided into upper, middle, and lower thirds. The bones of the forearm showed a predominance of foramina in the upper third—75% in the radius and 70% in the ulna—while the bones of the leg showed a major concentration in the lower third—76.6% in the tibia and 66.6% in the fibula. These findings corroborate the work of Sharma RK *et al*. (2021),[6] who also reported proximal diaphyseal foramina in upper limb bones and distal ones in lower limbs. However, a point of contrast emerges when comparing our findings with those of Patel SM *et al*.,[14] who documented the fibular nutrient foramina predominantly in the middle third (93.8%), a figure significantly different from our finding of just 10%. This difference may indicate population-specific anatomical variation, underscoring the need for regional anatomical studies to inform surgical approaches tailored to the patient demographic.

The number of nutrient foramina was also carefully analyzed. Most bones in our sample possessed a single nutrient foramen, including 83.3% of radii, 76.6% of ulnae, 90% of tibiae, and 86.6% of fibulae. The presence of double foramina was relatively rare and confined to a small proportion of specimens: 8.3% in radius, 11.6% in ulna, 10% in tibia, and 13.3% in fibula. Even fewer bones showed triple foramina, limited to some specimens of radius and ulna. Notably, no bones were found without a nutrient foramen, further reinforcing the critical role of this anatomical feature. These observations are in line with the reports by Vadhel *et al*. (2019)[2] who also observed a predominant pattern of single foramina, especially in lower limb bones. However, the detection of triple foramina in some upper limb bones may reflect either anatomical variation or possible duplications of the nutrient artery, which, although rare, are clinically relevant during surgeries involving periosteal stripping or diaphyseal exposure.

The size of nutrient foramina was evaluated using hypodermic needles of gauges 20, 24, and 26. The majority of the foramina were small enough to accommodate a 26G needle, indicating a very narrow diameter. This was true for 91.6% of radii, 86.6% of ulnae, 81.6% of tibiae, and 91.6% of fibulae. A few foramina allowed 24G needles, and only 1.6% of bones in each group had foramina large enough for a 20G needle.

These data demonstrate that most nutrient foramina are narrow, necessitating careful surgical techniques during orthopedic procedures to prevent vascular damage. This is consistent with findings by Prasad *et al*. (2023)[3] and Alwar *et al*. (2020),[4] who emphasized the need for precise anatomical knowledge due to the small caliber of nutrient canals. Even minor mechanical or thermal damage during bone sawing or drilling can compromise blood supply, leading to delayed union, non-union, or avascular necrosis, particularly in the metaphyseal and diaphyseal regions where the nutrient artery is the dominant supply. The clinical importance of this was also emphasized by Tuli and Kapoor (2004)[5] who described cases where improper handling of the nutrient artery led to prolonged postoperative healing times.

It is also essential to address the limitations of the present study. The bones analyzed were of unknown sex and age. While this approach was necessary due to the nature of osteological collections, it restricts our ability to examine variations that may be gender- or age-specific. Future studies incorporating radiological methods alongside morphometry in living individuals may further enrich our understanding of these variations.

CONCLUSION

The present study confirms and expands upon existing knowledge of nutrient foramina anatomy by providing population-specific data from North India. The results highlight a consistent and predictable pattern in both upper and lower limbs with regard to the number, direction, and position of the foramina. However, the presence of minor variations further underscores the need for surgeons, radiologists, and anatomists to consider individual anatomical differences, especially during orthopedic procedures involving long bones. This understanding is crucial not only for academic anatomy but also for clinical applications such as fracture repair, bone grafting, prosthesis placement, and reconstructive surgeries. Thus, the knowledge generated by this study has both educational and therapeutic value, strengthening the bridge between basic anatomical research and clinical practice.

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