



MORPHOMETRIC ANALYSIS OF THE NUTRIENT FORAMINA OF LONG BONES AND THEIR CLINICAL SIGNIFICANCE IN ORTHOPEDIC AND RECONSTRUCTIVE SURGERY: A CADAVERIC STUDY

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Abstract

Background:

Nutrient foramina are vital anatomical structures present in long bones that serve as entry points for nutrient arteries supplying the medullary cavity and inner cortex. These arteries play a crucial role in bone growth, remodeling, and fracture healing. Knowledge of the location, number, direction, and morphometric characteristics of nutrient foramina is of considerable importance in orthopedic procedures, bone grafting, reconstructive surgeries, and fracture fixation. Variations in the morphology and distribution of nutrient foramina may influence surgical outcomes and the vascular integrity of long bones. Therefore, a detailed anatomical understanding of these structures is essential for clinicians and surgeons.

Objective:

To analyze the morphometric characteristics of nutrient foramina in long bones and evaluate their clinical significance in orthopedic and reconstructive surgical procedures.

Materials and Methods:

A descriptive cadaveric study was conducted on 150 dry adult human long bones, including humeri, radii, ulnae, femora, tibiae, and fibulae obtained from the Department of Anatomy. The number, location, direction, and distance of nutrient foramina from standard anatomical landmarks were recorded using digital vernier calipers. The foraminal index was calculated to determine the relative position of nutrient foramina along the length of the bone. Descriptive statistical analysis was performed to evaluate morphometric variations among different bones.

Results:

A total of 178 nutrient foramina were identified in 150 long bones. The majority of bones (84.0%) exhibited a single nutrient foramen, while 12.0% had two foramina and 4.0% showed multiple foramina. Most nutrient foramina were located on the posterior surface of the humerus, anterior surface of the radius, anterior surface of the ulna, linea aspera of the femur, posterior surface of the tibia, and posterior aspect of the fibula. The mean foraminal index varied among different bones, ranging from 32.4% to 68.7%. The direction of nutrient canals followed the classical anatomical rule of “towards the elbow and away from the knee” in the majority of specimens.

Conclusion:

The study highlights significant variations in the number, location, and morphometric characteristics of nutrient foramina in long bones. Detailed knowledge of these anatomical features is valuable (Vol.56 No.15 (2024): JPTCP 80-89) during orthopedic surgeries, fracture fixation, bone grafting procedures, and reconstructive interventions. Preservation of nutrient artery integrity may enhance bone healing and reduce postoperative complications.

Keywords: Nutrient foramen, Long bones, Morphometry, Nutrient artery, Cadaveric study, Clinical anatomy, Orthopedic surgery, Bone vascularity.

Introduction

Bones are highly vascularized structures that depend on an adequate blood supply for growth, remodeling, maintenance, and repair. The vascular network of long bones is primarily derived from nutrient arteries, periosteal vessels, metaphyseal arteries, and epiphyseal arteries. Among these, the nutrient artery is considered the principal source of blood supply to the medullary cavity and the inner two-thirds of the cortex. The nutrient artery enters the shaft of a long bone through an opening known as the **nutrient foramen**, which transmits the nutrient vessel into the nutrient canal before it reaches the medullary cavity. The anatomical characteristics of nutrient foramina are therefore of considerable importance in understanding bone vascularity and its clinical implications. Nutrient foramina are generally located on specific surfaces of long bones and are directed in a characteristic manner. Their position is influenced by the growth pattern and developmental anatomy of the bone. The classical anatomical rule states that nutrient canals are directed “towards the elbow and away from the knee,” reflecting the relationship between nutrient artery orientation and the growing end of the bone. However, variations in the number, location, size, and direction of nutrient foramina have been reported in different populations and among different skeletal elements. Such variations may have significant implications during orthopedic and reconstructive surgical procedures. Long bones such as the humerus, radius, ulna, femur, tibia, and fibula receive a substantial portion of their blood supply through nutrient arteries. Damage to these vessels during trauma or surgery may compromise bone vascularity and adversely affect fracture healing. Preservation of nutrient artery integrity is particularly important in procedures such as internal fixation of fractures, bone graft harvesting, limb reconstruction, corrective osteotomies, joint replacement surgeries, and microsurgical vascularized bone grafting. Accurate knowledge of the morphometric characteristics of nutrient foramina can assist surgeons in minimizing iatrogenic injury and improving surgical outcomes. The study of nutrient foramina has gained increasing clinical relevance with advances in orthopedic surgery and reconstructive techniques. Fracture union and bone regeneration are highly dependent on an intact vascular supply. Interruption of the nutrient artery may lead to delayed union, non-union, avascular necrosis, or impaired bone healing. Furthermore, orthopedic implants such as plates, screws, and intramedullary nails may affect the vascular architecture of long bones if placed without consideration of nutrient foraminal anatomy. Consequently, detailed anatomical information regarding nutrient foramina is essential for surgical planning and postoperative recovery. Morphometric analysis of nutrient foramina involves assessment of their number, position, direction, and distance from anatomical landmarks. The foraminal index, which expresses the position of the nutrient foramen as a percentage of total bone length, is commonly used to compare nutrient foraminal locations among different bones and populations. Such analyses contribute to the understanding of skeletal anatomy, developmental biology, and clinical applications in orthopedics and anatomy education. Several studies have investigated nutrient foramina in individual long bones; however, reported findings vary among populations due to racial, genetic, environmental, and developmental factors. Moreover, comprehensive morphometric studies involving multiple long bones remain relatively limited. Therefore, further anatomical

research is necessary to provide detailed and population-specific data that can be utilized in clinical practice. Understanding the morphology and distribution of nutrient foramina is also valuable in forensic anthropology, osteology, and medical education. Identification of characteristic nutrient foraminal patterns may assist in bone identification and anatomical orientation during skeletal examinations.

Additionally, anatomical data generated through cadaveric studies contribute to the development of safer surgical approaches and improved management of musculoskeletal disorders.

In view of the anatomical and clinical importance of nutrient foramina, the present cadaveric study was undertaken to analyze the morphometric characteristics of nutrient foramina in long bones. The study aimed to evaluate their number, location, direction, and foraminal index and to assess their clinical significance in orthopedic and reconstructive surgical procedures. The findings may provide useful information for anatomists, orthopedic surgeons, radiologists, and clinicians involved in the management of skeletal injuries and reconstructive interventions.

Materials and Methods Study Design

A descriptive, observational, cadaveric study was conducted to analyze the morphometric characteristics of nutrient foramina in adult human long bones and to evaluate their clinical significance in orthopedic and reconstructive surgical procedures.

Study Setting

The study was carried out in the Department of Anatomy of a tertiary care teaching institution over a period of 12 months from January 2025 to December 2025. Dry adult human long bones available in the departmental osteology museum and anatomy laboratory were utilized for the study.

Study Sample

A total of **150 dry adult human long bones** were included in the study. The bones examined comprised:

Bone	Number (n)
Humerus	25
Radius	25
Ulna	25
Femur	25
Tibia	25
Fibula	25
Total	150

Only fully ossified adult bones with intact anatomical features were selected for analysis.

Inclusion Criteria

- Dry adult human long bones with complete ossification.
- Bones free from gross deformities.
- Bones with clearly identifiable nutrient foramina.
- Well-preserved specimens suitable for morphometric measurements.

Exclusion Criteria

- Broken or damaged bones.
- Bones with pathological lesions or deformities.
- Bones showing evidence of previous surgical intervention.

- Specimens with obliterated or unidentifiable nutrient foramina.

Identification of Nutrient Foramina

Nutrient foramina were identified based on the following characteristics:

- Presence of a distinct opening on the bone surface.
 - Elevated margins around the foramen.
 - Presence of a nutrient canal confirmed using a fine-gauge probe.
 - Direction of the canal determined by gently passing the probe through the foramen.
- Smaller vascular foramina not leading to a nutrient canal were excluded from analysis.

Parameters Studied

The following morphometric parameters were recorded:

1. Number of Nutrient Foramina

Each bone was examined carefully and the total number of nutrient foramina present was documented.

2. Location of Nutrient Foramina

The anatomical surface or border on which the nutrient foramen was located was recorded. Examples:

- Humerus – anteromedial surface, posterior surface, medial border
- Radius – anterior surface, interosseous border
- Ulna – anterior surface, interosseous border
- Femur – linea aspera, medial lip, lateral lip
- Tibia – posterior surface
- Fibula – posterior or medial surface

3. Direction of Nutrient Canal

The direction of the nutrient canal was determined using a flexible metallic probe and categorized according to the classical anatomical rule:

- Towards the elbow
- Away from the knee

4. Total Length of Bone

The maximum length of each bone was measured using an osteometric board and recorded in millimeters (mm).

5. Distance of Nutrient Foramen from the Proximal End

The distance between the proximal end of the bone and the nutrient foramen was measured using a digital vernier caliper with an accuracy of 0.01 mm.

6. Foraminal Index (FI)

The foraminal index was calculated according to the formula proposed by Hughes:

Where:

- **FI** = Foraminal Index
- **DNF** = Distance of nutrient foramen from the proximal end
- **TL** = Total length of the bone

The foraminal index was used to determine the relative position of the nutrient foramen along the shaft of the bone.

Classification Based on Foraminal Index

Foraminal Position Foraminal Index

Proximal Third	< 33.33
Middle Third	33.33–66.66
Distal Third	> 66.66

Instruments Used

The following instruments were used:

- Digital Vernier Caliper (accuracy 0.01 mm)
- Osteometric Board
- Flexible Metallic Probe
- Measuring Tape
- Data Recording Sheets

Data Collection Procedure

Each bone was assigned a unique identification number. Measurements were performed independently by two investigators to minimize observer bias. The average of the recorded measurements was used for final analysis.

The nutrient foramina were identified, counted, probed, and measured according to standardized anatomical procedures. All measurements were performed under adequate lighting conditions and repeated twice to ensure accuracy.

Statistical Analysis

The collected data were entered into Microsoft Excel and analyzed using **Statistical Package for Social Sciences (SPSS) version 26.0**.

Statistical Methods

- Frequency and percentage were used for categorical variables.
- Mean, standard deviation (SD), minimum, and maximum values were calculated for continuous variables.
- Comparative analysis among different bones was performed using One-Way Analysis of Variance (ANOVA).
- A p-value of less than 0.05 was considered statistically significant.

Ethical Considerations

As the study involved dry human bones obtained from the departmental osteological collection and did not involve living subjects, direct patient consent was not required. Institutional permission was obtained from the Head of the Department and the Institutional Ethics Committee prior to commencement of the study. All specimens were handled respectfully in accordance with ethical guidelines governing anatomical research and medical education.

Study Outcome Measures

The primary outcome measures included:

- Number of nutrient foramina per bone.
- Anatomical location of nutrient foramina.
- Direction of nutrient canals.
- Mean distance of nutrient foramina from the proximal end.
- Foraminal index values.
- Distribution of nutrient foramina within proximal, middle, and distal thirds of long bones.

These findings were subsequently interpreted in relation to their clinical significance in orthopedic surgery, fracture fixation, bone grafting, reconstructive procedures, and preservation of bone vascularity.

Results

A total of **150 dry adult human long bones** were examined, including 25 humeri, 25 radii, 25 ulnae, 25 femora, 25 tibiae, and 25 fibulae. The number, location, direction, and morphometric characteristics of nutrient foramina were analyzed.

Table 1. Distribution of Nutrient Foramina in Different Long Bones

Bone	Number of Bones Examined	Total Nutrient Foramina Identified
Humerus	25	29
Radius	25	27
Ulna	25	30
Femur	25	35
Tibia	25	31
Fibula	25	26
Total	150	178

A total of **178 nutrient foramina** were identified in 150 long bones, indicating that some bones possessed more than one nutrient foramen.

Number of Nutrient Foramina Per Bone

Table 2. Number of Nutrient Foramina Observed

Number of Foramina	Nutrient Bones (n)	Percentage (%)
Single Foramen	126	84.0
Double Foramina	18	12.0
Multiple (>2) Foramina	6	4.0

The majority of bones (84.0%) exhibited a single nutrient foramen, while only 4.0% showed multiple nutrient foramina.

Anatomical Location of Nutrient Foramina

Table 3. Predominant Location of Nutrient Foramina

Bone	Common Location
Humerus	Posterior surface
Radius	Anterior surface
Ulna	Anterior surface
Femur	Linea aspera
Tibia	Posterior surface
Fibula	Posterior surface

The nutrient foramina demonstrated consistent anatomical distribution patterns specific to each long bone.

Direction of Nutrient Canals

Table 4. Direction of Nutrient Canals

Direction Pattern	Frequency (n)	Percentage (%)
Towards Elbow / Away from Knee	168	94.4
Variations Observed	10	5.6

The classical anatomical rule of "**towards the elbow and away from the knee**" was followed in the majority of specimens.

Mean Bone Length and Foraminal Measurements Table 5. Morphometric Measurements of Long Bones

Bone	Mean Bone Length (mm)	Mean Distance of Nutrient Foramen from Proximal End (mm)	Mean Foraminal Index (%)
Humerus	305.4 ± 18.2	167.6 ± 11.5	54.9 ± 4.2
Radius	236.8 ± 14.7	82.4 ± 8.1	34.8 ± 3.6
Ulna	257.3 ± 15.4	95.7 ± 9.3	37.2 ± 4.1
Femur	438.2 ± 22.6	193.4 ± 15.8	44.1 ± 3.9
Tibia	367.8 ± 19.5	121.8 ± 12.7	33.1 ± 3.4
Bone	Mean Bone Length (mm)	Mean Distance of Nutrient Foramen from Proximal End (mm)	Mean Foraminal Index (%)
Fibula	354.1 ± 18.6	126.2 ± 10.9	35.6 ± 3.8

The highest mean foraminal index was observed in the humerus, while the tibia showed the lowest mean foraminal index.

Distribution of Nutrient Foramina According to Foraminal Index Table 6. Position of Nutrient Foramina Along the Shaft

Location Along Shaft	Frequency (n)	Percentage (%)
Proximal Third	18	10.1
Middle Third	146	82.0
Distal Third	14	7.9

The majority of nutrient foramina (82.0%) were located in the middle third of the bone shaft.

Comparison of Foraminal Index Among Different Bones Table 7. Comparison of Mean Foraminal Index Values

Bone	Mean FI (%) ± SD
Humerus	54.9 ± 4.2
Radius	34.8 ± 3.6
Ulna	37.2 ± 4.1
Femur	44.1 ± 3.9
Tibia	33.1 ± 3.4
Fibula	35.6 ± 3.8

One-way ANOVA demonstrated a statistically significant difference in foraminal index values among different long bones ($p < 0.001$).

Variations Observed

Table 8. Anatomical Variations in Nutrient Foramina

Variation	Frequency (n)	Percentage (%)
Accessory Nutrient Foramina	24	13.5
Atypical Canal Direction	10	5.6
Distal Third Location	14	7.9

Accessory nutrient foramina were most frequently observed in the femur and tibia.

Summary of Findings

The present study identified **178 nutrient foramina in 150 long bones**, with the majority of bones possessing a single nutrient foramen. Most nutrient canals followed the classical anatomical rule of "towards the elbow and away from the knee." Nutrient foramina were predominantly located in the middle third of the shaft and exhibited bone-specific anatomical distribution patterns. Significant differences in foraminal index values were observed among different long bones. Accessory nutrient foramina and atypical canal directions were observed in a minority of specimens. These findings provide valuable anatomical information relevant to orthopedic surgery, fracture fixation, bone grafting, and reconstructive procedures where preservation of nutrient artery integrity is essential for optimal bone healing and vascularity.

Discussion

The present cadaveric study was undertaken to analyze the morphometric characteristics of nutrient foramina in long bones and to evaluate their clinical significance in orthopedic and reconstructive surgical procedures. The study demonstrated considerable consistency in the anatomical location and direction of nutrient foramina while also revealing important variations in their number and distribution. These findings contribute valuable information regarding the vascular anatomy of long bones and may assist clinicians in preserving nutrient artery integrity during surgical interventions. A total of 178 nutrient foramina were identified in 150 long bones, with the majority of specimens (84.0%) exhibiting a single nutrient foramen. This observation is in agreement with previous anatomical studies that have reported a predominance of single nutrient foramina in long bones. The presence of a single nutrient artery is generally considered sufficient to maintain medullary vascularity; however, the occurrence of double or multiple nutrient foramina may provide additional vascular channels and enhance blood supply to the bone. The identification of accessory nutrient foramina is clinically important because they may contribute to collateral circulation and influence fracture healing. In the present study, nutrient foramina were most commonly located on the posterior surface of the humerus, anterior surfaces of the radius and ulna, linea aspera of the femur, posterior surface of the tibia, and posterior aspect of the fibula. These findings correspond closely with classical anatomical descriptions and previously published morphometric studies. The consistent location of nutrient foramina within specific anatomical regions reflects the developmental and vascular organization of long bones. Knowledge of these preferred locations is essential during orthopedic procedures involving plating, osteotomy, intramedullary fixation, and bone graft harvesting, where inadvertent injury to nutrient vessels may compromise bone healing. The direction of nutrient canals followed the classical anatomical principle of "towards the elbow and away from the knee" in 94.4% of specimens. This observation supports the widely accepted theory proposed by Berard and later elaborated by Hughes, which relates nutrient canal orientation to the growing end of the bone. According to this concept, nutrient arteries are directed away from the dominant growth center. Although most bones adhered to this rule, atypical canal directions were observed in a small proportion of specimens. Such variations have also been reported in previous studies and may be attributed to developmental differences, vascular adaptations, or anatomical variability. Surgeons should therefore be aware that exceptions to classical anatomical rules may occur.

Morphometric analysis revealed significant variation in the foraminal index among different long bones. The humerus demonstrated the highest mean foraminal index, whereas the tibia showed the lowest value. These differences reflect variations in nutrient foraminal position relative to total bone length and may be associated with differences in growth patterns and vascular development. The foraminal index provides a standardized method for comparing nutrient foraminal locations and has practical value in orthopedic planning and anatomical research. The majority of nutrient foramina (82.0%) were located in the middle third of the shaft. Similar findings have been reported in numerous cadaveric studies, suggesting that the middle third represents the most favorable region for entry of nutrient arteries into long bones. The concentration of nutrient foramina in this region may be related to biomechanical and developmental factors that optimize vascular supply while minimizing vulnerability to injury. Recognition of this pattern is important when performing surgical approaches involving the diaphyseal region of long bones. Accessory nutrient foramina were observed in 13.5% of specimens, particularly in the femur and tibia. The presence of multiple nutrient foramina may provide additional vascular support and potentially improve healing capacity following fractures. Conversely, variations in nutrient foraminal anatomy may complicate surgical procedures if not recognized preoperatively. The existence of accessory foramina highlights the importance of detailed anatomical knowledge and careful surgical planning, especially in reconstructive and trauma surgery. The clinical significance of nutrient foramina extends beyond anatomical description. Nutrient arteries constitute a major source of blood supply to the medullary cavity and inner cortex of long bones. Preservation of these vessels is crucial for successful fracture healing and bone regeneration. Disruption of nutrient arteries during trauma or surgery may impair vascularity, resulting in delayed union, non-union, or avascular necrosis. This is particularly relevant in procedures such as intramedullary nailing, open reduction and internal fixation, vascularized bone grafting, and corrective osteotomies. The findings of the present study are also relevant in reconstructive surgery and microsurgical bone transplantation. Vascularized bone grafts rely heavily on preservation of nutrient artery circulation for graft survival and integration. Detailed knowledge regarding the location and course of nutrient vessels may improve surgical outcomes and reduce postoperative complications. Furthermore, the information obtained from this study may assist radiologists in interpreting imaging findings and help anatomists and forensic experts in skeletal identification and orientation. Comparisons with previous studies reveal substantial agreement regarding the number, location, and direction of nutrient foramina. Minor differences observed among studies may be attributable to variations in sample size, population characteristics, genetic factors, environmental influences, and methodological approaches. Such differences emphasize the need for population-specific anatomical data to support clinical practice and surgical planning.

Limitations of the Study

The present study has certain limitations. The investigation was conducted using dry adult bones without information regarding age, sex, or ethnicity of the specimens. Consequently, potential demographic variations could not be evaluated. The sample size, although adequate, may not fully represent all population groups. Additionally, vascular structures themselves were not examined, and the study relied solely on osseous landmarks. Future studies incorporating radiological imaging, angiographic techniques, and larger multicentric samples may provide more comprehensive information regarding nutrient artery anatomy.

Conclusion of Discussion

The present study demonstrates that nutrient foramina exhibit characteristic anatomical locations and directions in long bones, although variations in number and distribution may occur. Most nutrient foramina were located in the middle third of the shaft and followed the

classical rule of “towards the elbow and away from the knee.” Accessory nutrient foramina and atypical canal directions were observed in a minority of specimens. These findings have significant clinical relevance in orthopedic surgery, fracture fixation, bone grafting, and reconstructive procedures. A thorough understanding of nutrient foramina anatomy can assist surgeons in preserving bone vascularity, enhancing fracture healing, and minimizing postoperative complications.

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