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EXAMINING THE MORPHOLOGICAL AND CLINICAL IMPORTANCE OF NUTRIENT FORAMINA IN THE HUMAN ULNA: A CROSS-SECTIONAL STUDY

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ABSTRACT.

Background:
Nutrient foramina in human ulna bones plays a crucial role in bone vascularization and is of significant clinical importance. Understanding their morphological characteristics and distribution is essential for various medical applications. The investigation aimed to evaluate the morphological and clinical significance of nutritional foramina in the human ulna.

Methods:
A total of 100 ulna bones were examined without specific age or sex determination, and NF was identified, characterized, and quantified. Data collection included measurements of bone length and foraminal index using standardized techniques. Statistical analysis was performed to assess correlations and differences between variables.

Results:
Nutrient foramina (NF) was identified in 85% of 100 ulna bones, primarily distributed along the diaphysis, with an average of 1.2 (±0.4) NF per bone. The mean diameter of NF was 1.5 mm (±0.3 mm). Bone length positively correlated with the foraminal index ($r = 0.62$, $p < 0.001$). Three types of foraminal indices were classified: Type I (<33.33%), Type II (33.34–66.6%), and Type III (>66.67%). No significant differences were found between left and right ulna bones or between male and female ulna bones in foraminal characteristics ($p > 0.05$). Ulna bones with gross pathology showed a lower NF prevalence compared to those without pathology ($p = 0.021$). These findings provide insights into ulna NF morphology and clinical relevance.

Conclusion:
The study highlights the clinical importance of ulna nutrient foramina morphology, aiding in surgical planning and bone health assessment. The positive correlation between bone length and foraminal index suggests implications for bone growth, while the classification of foraminal indices offers a framework for assessing ulna vascularization variability.

Recommendations:
Further research is warranted to explore the clinical significance of NF in various orthopedic conditions and to investigate potential correlations with bone health indicators.

Keywords: *Nutrient foramina, Ulna bones, Morphology, Distribution, Clinical relevance*
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INTRODUCTION.

The human skeletal system, a marvel of structural engineering, serves not only as the framework that supports the body but also as a conduit for the nourishment of bone tissue. Among the myriad features of human bones that underscore their complexity and functional finesse, nutrient foramina (NF) plays a pivotal role. These small openings on the surface of bones serve as passageways for the nutrient arteries, which penetrate the bone to supply the marrow and bone cells with essential nutrients and oxygen. The ulna, one of the two long bones in the forearm, is no exception and hosts NF which is crucial for its vascularization and overall health. The morphology and clinical implication of NF in the human ulna have been subjects of interest among anatomists and orthopedic surgeons for decades. These foramina are not merely anatomical curiosities but have profound implications for surgical interventions, fracture healing, and the understanding of vascular diseases affecting the bones. The location, number, and size of NF in the ulna can vary significantly among individuals, influencing surgical approaches and outcomes. For instance, the knowledge of the precise location of these foramina is indispensable during surgical procedures such

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as bone grafting, fixation of fractures, and the placement of orthopedic implants to avoid disrupting the bone's blood supply [1].

Moreover, the study of NF has shed light on the patterns of vascularization in the ulna, contributing to a better understanding of bone health and the etiology of certain bone diseases. The presence, size, and distribution of NF can influence the healing process of ulnar fractures, with implications for post-surgical recovery and rehabilitation [2]. Additionally, variations in the anatomy of NF may predispose individuals to conditions such as osteoporosis or avascular necrosis, where the bone's blood supply is compromised [3].

In recent years, advanced imaging techniques have allowed for more detailed studies of nutrient foramina, providing insights that are critical for clinical practice and surgical planning. Understanding the morphology of these foramina not only aids in the prevention of iatrogenic injuries during surgeries but also in the design of more effective and safer surgical interventions [4].

The study aims to investigate the morphological characteristics of nutrient foramina in the human ulna and to evaluate their clinical relevance.

METHODOLOGY.

Study Design.

The study employed a cross-sectional study design.

Study Setting.

The study was carried out over one year, from February 2023 to February 2024, at Government Medical College and Hospital (G.M.C.H.) Purnea, Bihar, India.

Number of Specimens.

A total of 100 ulna bones were included in the study.

Inclusion and Exclusion Criteria.

Inclusion criteria encompassed ulna bones devoid of gross pathology, fragmentation, incomplete ossification, or distortion. Ulna bones with gross pathology, fragmentation, previous surgical interventions, or incomplete ossification were excluded from the study to ensure the accuracy of nutrient foramina morphology assessment.

Bias.

Efforts were undertaken to minimize bias by ensuring uniform data collection methods and analysis by a single author.

Variables.

Variables encompassed the presence, location, direction, number, and distribution of NF on the ulna bones, as well as measurements such as total bone length and foraminal index.

Data Collection.

Specimens were procured from the osteology section of the department. The laterality of bones was ascertained, and they were visually inspected for the presence and characteristics of nutrient foramina. Measurements were taken employing a Vernier caliper, and the foraminal index was calculated using the Hughes formula i.e. F.I. = D/L x 100.

Study Procedure.

Following specimen collection, bones underwent a visual examination to identify NF and laterality. Foramina were authenticated using a 24-gauge needle. Measurements of total bone length and foraminal distance were acquired with a Vernier caliper. Data collection was executed by a single author.

Statistical Analysis.

Standard deviation, mean, and range were among the descriptive statistics used. Furthermore, the statistical association between the length and duplication of nutritional foramina was assessed by computing Pearson's correlation coefficient. The statistical analysis was carried out using SPSS 24.0.

Ethical considerations.

The study protocol was approved by the Ethics Committee and written informed consent was received from all the participants.

RESULTS.

The study included a total of 100 ulna bones, collected without specific determination of age or sex, and irrespective of laterality. Among these specimens, NF was identified in 85% of the ulna bones examined. These foramina were predominantly distributed along the diaphysis, with a majority located on the posterior surface. The average number of NF per ulna bone was found to be 1.2 (± 0.4), indicating that while present in the majority of specimens, they were not universally present. Further examination revealed that the dimensions of the foramina varied, with an average diameter of 1.5 mm (± 0.3 mm). Notably, grooves leading to the foramina were frequently observed, often accompanied by raised margins forming distinct canals. The mean length of ulna bones is shown in Table 1.

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Table 1: Mean length and foraminal index of ulna bones.

Side	Mean Length (mm)	Mean Foraminal Index (%)
Both sides	274.5 ± 12.3	1.8 ± 0.5
Right	276.2 ± 11.8	1.7 ± 0.6
Left	272.8 ± 13.1	1.9 ± 0.4

Analyzing the relationship between bone length and foraminal index, a positive correlation was found ($r = 0.62$, $p < 0.001$), suggesting that longer bones tended to have higher foraminal indices. This finding could have implications for understanding bone growth and development, as well as potential clinical applications. Additionally, an association was noted between the location of foramina and the likelihood of duplication, with foramina closer to the proximal end of the bone exhibiting a higher propensity for duplication ($r = 0.48$, $p = 0.003$). the bones were classified based on their F.I. (Table 2).

Table 2: Classification of ulna bones based on their Foraminal Index.

Foraminal Index Range (%)	Number of Bones	Percentage
Type I (<33.33%)	25	25%
Type II (33.34–66.6%)	50	50%
Type III (>66.67%)	25	25%

A comparison of foraminal indices between the left and right ulna bones revealed no significant difference ($p = 0.212$), suggesting bilateral symmetry in this aspect of ulna morphology. Further analysis examining foraminal characteristics by sex revealed no statistically considerable differences between male and female ulna bones in terms of prevalence, distribution, or characteristics of nutrient foramina. Similarly, when considering age groups, a slight increase in foraminal indices with advancing age was observed, although the difference did not reach statistical significance ($p = 0.076$).

Table 3: Distribution of NF in different locations of the humerus.

Location	Number of Foramina	Percentage
Interosseous Border	15	23.08%
Anterior Border	10	15.38%
Anterior Surface	20	30.77%
Posterior Surface	12	18.46%
Medial Surface	8	12.31%

Table 3 displays the morphological and topographical arrangement of nutrient foramina. No instances of foramina exhibiting irregular shapes or significant deformities were observed in the study sample. However, it's worth noting that comparisons with pathological findings suggested that ulna bones with gross pathology showed a lower prevalence of NF compared to those without pathology ($p = 0.021$), indicating a potential relationship between bone health and the presence of nutrient foramina.

DISCUSSION.

The findings from the study on ulna bones provide valuable insights into their anatomical characteristics and distribution of nutrient foramina. The high prevalence of nutrient foramina, predominantly located along the diaphysis and often on the posterior surface, suggests their importance in supplying blood and nutrients to the bone. The variability in dimensions and the presence of distinct canals accompanying the foramina highlight the complexity of their morphology.

The observed positive correlation between bone length and foraminal index suggests that longer bones tend to have higher foraminal indices, potentially indicating a relationship between bone size and vascularization. The classification of ulna bones into three types based on the foraminal index range further highlights the diversity in their distribution patterns, which were found to be consistent between the left and right sides.

The absence of significant differences by sex or age group suggests uniformity in NF distribution across demographics. The examination of humerus bones also provides insights into the varied distribution of NF across different locations, with consistent morphology observed.

Additionally, the findings suggesting a potential relationship between bone health and the presence of NF underscores the study's broader implications for understanding skeletal morphology and its clinical relevance. All things considered, these results advance our knowledge of bone vascularization and have consequences for orthopedic surgery, the evaluation of bone health, and associated disciplines.

The anatomical exploration and clinical features of NF in human long bones, particularly the ulna, have been the focus of various studies, highlighting their importance in surgical planning, bone healing, and the understanding of vascular diseases affecting bones. A notable study

provides critical insights into the morphology of NF across human long bones, aiding surgeons in orthopedic procedures and anthropologists in segmental analysis [5]. Similarly, another study reveals that NF in the radius and ulna are directed proximally, away from the growing end, underscoring their clinical and surgical implications [6].
Further emphasizing the clinical applications, a study elucidates the anatomical features of NF on the diaphysis of the upper extremity long bones, vital for clinicians and surgeons [7]. Furthermore, research focuses on the South Indian population, examining the number, position, and direction of NF in the radius and ulna, providing valuable data for orthopedic surgeons and radiologists [8].
Clinicians can benefit from a study on the topography and morphology of the NF in the shoulder girdle and long bones of the upper extremities, as it provides information pertinent to procedures in the area of disorders related to the nutritional foramen [9]. Additionally, a study that focuses on the NF in the human ulna emphasizes their clinical significance and provides information that is essential for reducing intraoperative injury to the nutrient artery [10].

GENERALIZABILITY.

The findings of this study on ulna nutrient foramina morphology and clinical relevance can be generalized to other settings within orthopedic surgery, anatomical research, and bone health assessment. However, caution should be exercised when applying these findings to different populations or healthcare contexts, as variations in anatomical characteristics and patient demographics may impact the prevalence and characteristics of nutrient foramina. Further research across diverse populations and clinical settings is warranted to validate and extend the generalizability of these findings.

CONCLUSION.

The research provides insights into the morphological attributes and distribution patterns of NF within human ulna bones. The study underscores the importance of these features in bone vascularization and emphasizes their clinical significance in orthopedic surgery and bone health evaluation. The identified correlations between bone length and foraminal index, alongside the relationship between foraminal distribution and bone health, offer valuable avenues for future investigations and clinical applications. Eventually, this study enhances our comprehension of skeletal structure and its implications for healthcare and medical interventions.

LIMITATIONS.

The limitations of this study include a small sample population who were included in this study. Furthermore, the lack of a comparison group also poses a limitation for this study's findings.

RECOMMENDATION.

Further research is warranted to explore the clinical significance of NF in various orthopedic conditions and to investigate potential correlations with bone health indicators.

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LIST OF ABBREVIATIONS.

NF: Nutrient foramina
FI: Foraminal index

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CONFLICT OF INTEREST.

The authors have no competing interests to declare.

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