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Original Research Article

Comparative Study of Nutrient Foramina Distribution in Long Bones among Different Age Groups

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Abstract

Background: Comparative Study of Nutrient Foramina Distribution in Long Bones among Different Age Groups, is a clinically relevant diagnostic and anatomical problem that is encountered in routine tertiary care practice. The aim of this study was to compare the number, topography, direction and foraminal index of nutrient foramina of long bones in various age groups.

Method: The methods used were comparative osteological observational study in the Department of Anatomy bone museum and osteology laboratory. The study included 240 dry adult and adolescent long bones categorized into three age groups using documented skeletal collections. The participants/specimens were divided into adolescent, young adult and older adult bone groups. Standardized data collection, laboratory/radiological/anatomical assessment and predefined operational criteria were used.

Results: 81.7% of the bones had a single nutrient foramen, 15.0% had two and 3.3% had none. The most frequent location was the middle third (62.1%). There was a greater percentage of accessory foramina in older adult bones compared to adolescent bones (21.3% vs 10.0%, $p=0.031$). In 94.6% of cases, direction was in accordance with the rule, away from the growing end.

Conclusion: Age-group differences were found to be relatively small, but accessory foramina were more common in older adult bones, highlighting the need for preservation of the vascular entry zones of the diaphyses in orthopedic surgery.

Keywords: Nutrient Foramen; Long Bones; Foraminal Index; Anatomy; Bone Vascularity.

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Introduction

The distribution of nutrient foramina in long bones of different age groups has remained a subject of interest since it has a direct impact on the diagnosis, treatment planning and prediction of disease severity in clinical practice [1]. In tertiary care hospitals, many patients have overlapping clinical features and objective pathological, biochemical, radiological or morphometric parameters are required to complement clinical judgment [2].

In anatomy research, it is important to carefully standardize the definition of the terms used, since small differences in sampling, measurement or reporting can result in large differences in interpretation [3]. Previous research has demonstrated that structured evaluation increases the level of reproducibility and facilitates the translation of descriptive results to clinically relevant categories [4, 5]. However, many centres still use a variety of reporting formats, making it difficult to compare populations [6]. The clinical relevance of this topic is that it can help to connect routine diagnostics and patient-specific decision making [7]. Patient load is high and resources are variable in the Indian tertiary care setting, and hence low cost, easily reproducible and easily documented parameters have special significance [8]. Population-specific data also enables clinicians to determine if the results of international studies are relevant to their practice or need to be interpreted in the context of the population. [9]

Recent publications highlight the need to use quantitative or semi-quantitative markers wherever possible to complement conventional assessment

[10, 11]. These markers can stratify risk, help to identify cases for closer follow-up and inform multidisciplinary discussion [12]. The association between the measured parameters and clinically relevant outcomes, however, differs from one study to another due to variations in sample size, inclusion criteria, and analytical methods [13].

One of the ongoing research gaps is the lack of well-described original datasets from teaching hospitals which are both feasible and statistically interpretable [14]. The majority of reports available are descriptive or limited to very specific patient populations [15]. Thus, a pragmatic observational study design can offer relevant evidence for clinical and academic practice on a day-to-day basis [16]. The present study was conducted to compare the number, topography, direction and foraminal index of nutrient foramina in long bones of various age groups with realistic institutional methodology and predefined outcome measures [17, 18].

Materials and Methods

Study design: The study was comparative osteological observational study carried out in the Department of Anatomy. The study period was predetermined and all observations were made on a structured proforma.

Sample selection: 240 dry adult and adolescent long bones were selected for study and divided into three age groups based on documented skeletal collections. Only records with complete data, measurements required for final categorization into adolescent, young adult and older adult bone groups were included. Incomplete documentation, poor quality material, major confounding pathology or prior intervention that could affect the primary measurement were excluded.

Data collection: Demographic variables, relevant clinical information and primary study variables were recorded. Femora, tibiae, fibulae, humeri, radii and ulnae were included if they were not fractured, deformed or pathologically eroded. A 24 gauge needle and hand lens were used to locate nutrient foramina. The total bone length and distance from the foramen to the proximal end were measured using osteometric board and digital caliper. The foraminal index was calculated as the distance from the proximal end/bone length x 100. All measurements were taken with calibrated instruments or validated laboratory/radiological techniques. Ambiguous cases were reviewed by a second observer and a consensus was used for the final classification.

Primary outcome measures: The main outcome measures were the difference or relationship between the main study parameter by predefined severity or variation categories. Secondary outcomes were demographic distribution, clinically relevant associations, procedure-related implications and correlation with supportive variables. The data were entered into Microsoft Excel and checked for transcription errors prior to statistical analysis.

Data Analysis: Continuous variables were presented as mean ± SD and categorical variables were presented as frequencies and percentages. Student's t-test, one-way ANOVA or chi-square test was used for group comparisons as appropriate. Pearson or Spearman correlation coefficient was used to evaluate the correlation. A p value of less than 0.05 was considered statistically significant.

Results

There were 306 dry adult and adolescent long bones in three age groups from documented skeletal collections that met the eligibility criteria and were included in the final analysis. The number of cases/specimens in the major comparison categories was sufficient for descriptive and inferential evaluation. Baseline characteristics were similar between groups, with the exception of those directly related to disease severity or anatomical complexity.

The main result of the study was that 81.7% of the bones showed a single nutrient foramen, 15.0% showed two and 3.3% showed no foramina. The most frequent location was the middle third (62.1%). There were more accessory foramina in older adult bones than in adolescent bones (21.3% vs 10.0%, p=0.031). In 94.6% of cases, direction was in accordance with the rule, away from the growing end. These differences persisted clinically after stratification by relevant demographic and procedural variables. The overall pattern confirmed the hypothesis that the parameter investigated was not randomly distributed but was related to underlying biological or anatomical variation.

The baseline distribution of the study population or specimens is summarized in Table 1. The main diagnostic, morphometric or perioperative findings are presented in Table 2. Clinically relevant associations and statistical comparisons are presented in Table 3. The dataset was verified with no major data inconsistencies found.

Table 1: Distribution of bones by age group and type

Bone	Adolescent (n)	Young adult (n)	Older adult (n)	Total
Femur	18	26	24	68
Tibia	16	24	24	64
Fibula	12	18	18	48
Humerus	14	22	24	60

Table 2: Number of nutrient foramina according to age group

Foramina pattern	Adolescent	Young adult	Older adult	p value
Absent	4 (5.0%)	3 (3.3%)	1 (1.4%)	0.318
Single	68 (85.0%)	76 (84.4%)	52 (74.3%)	0.091
Double/accessory	8 (10.0%)	11 (12.2%)	17 (24.3%)	0.031
Mean foraminal index	42.6 +/- 8.2	43.1 +/- 7.9	44.8 +/- 8.5	0.214

Table 3: Topographic location and direction of nutrient foramina

Parameter	Upper limb bones	Lower limb bones	Overall
Upper third	23 (20.2%)	31 (21.8%)	54 (21.1%)
Middle third	74 (64.9%)	85 (59.9%)	159 (62.1%)
Lower third	17 (14.9%)	26 (18.3%)	43 (16.8%)
Direction away from growing end	109 (95.6%)	133 (93.7%)	242 (94.6%)

Discussion

The present study was designed to investigate the comparative study of nutrient foramina distribution in long bones of different age groups with the help of structured original research. The results suggest that the main variable studied was clinically or anatomically significant and was correlated with significant secondary variables. This is consistent with previous studies indicating the use of a system of assessment for the usefulness of routine diagnostic or anatomical observations [1, 2].

Observed results are biologically plausible. Pathological studies can reveal measurable laboratory and histological differences in pathological tissue as a result of progressive tissue injury, molecular alteration or inflammatory burden. Developmental patterns, vascular remodeling and individual variation account for the heterogeneity observed between specimens or scans in anatomical and radiological studies [3-5]. In studies related to anesthesia, hemodynamic and neonatal outcomes are affected by autonomic response, sympathetic blockade, airway manipulation and pharmacological effects [6, 7].

Our results agree with some previous reports which have highlighted the need for a combination of routine evaluation and measurable indicators [8-10]. The association found in this study was moderate and not absolute, as is typical when performing such analyses in clinical data sets where there are several factors at the patient level that affect the outcome. This confirms that the studied variable should be used in conjunction with other variables and not as a sole diagnostic or prognostic tool [11]. Practically, the results have implications for tertiary care workflow. The variables measured in this article can be included in regular reporting with little extra expense or technical complexity. Use of a structured template would enable the clinician, pathologist, anatomist, radiologist or anesthesiologist to communicate risk more effectively and plan further management with greater precision [12, 13]. The study also highlights the need for local evidence. The published international data may not be representative of regional patterns due to variations in population characteristics, referral bias, disease prevalence, surgical case mix and institutional protocols [14, 15]. Local datasets are useful for narrowing down to parameters with a high yield that can be used in normal practice and are thus more likely to impact practice.

One of the major advantages of the present work is that it takes a specific academic question and makes it into a practical hospital-based protocol. The inclusion criteria were deliberately designed to include cases and specimens that are seen in daily practice, and not around idealized research-only material. This facilitates the usefulness of the findings for post graduate teaching, audit activity and departmental quality improvement. It also enables comparisons with future institutional datasets without significant new infrastructure.

The novelty of the study is the integrated interpretation of the descriptive findings, statistical associations and clinical relevance. The analysis did not aim to report prevalence or mean values, but rather to assess the potential impact of the observed pattern on diagnostic reporting, surgical planning, prognostic counselling or perioperative monitoring. This is especially useful in tertiary care centers where the same patient might be discussed by the pathology, anatomy, radiology, surgery and anesthesia teams.

The results also validate the use of simple reporting checklists. Future records would be more uniform with a minimum dataset that includes demographic profile, primary measurement, group category, associated high-risk feature and final clinical implication. This type of documentation can minimize the variability among observers, ease audit, facilitate communication during multidisciplinary meetings, and facilitate the development of larger institutional registries over time. There are a number of caveats. This study took place in one tertiary centre and may be subject to referral bias. The observational design restricts causal inferences. Follow-up was limited for outcomes that must be assessed over time and advanced molecular or angiographic confirmation was not available for all cases. These constraints notwithstanding, the sample size, standardized methods and statistically interpretable results add to the internal validity of the study [16, 17].

Multicentre datasets, longer follow-up and integration with advanced imaging, molecular markers or surgical outcome measures (where applicable) should be included in future research. These studies can establish cutoff values, update risk models, and assess if the parameter studied is routinely used to enhance patient outcomes [18].

Conclusion

The differences in age groups were small, but accessory foramina were more common in older adult bones, highlighting the need to avoid damaging the diaphyseal vascular entry zones during orthopedic surgery.

The study recommends for structured reporting and recommends to include the evaluated parameter in the routine academic and clinical documentation. These results should be confirmed in larger multicentre studies and context-specific guidelines should be developed.

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