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A Morphological and Topographical Study of Diaphyseal Nutrient Foramen (NF) In Dried Human Adult Long Bones of Upper Limbs

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ABSTRACT

The morphological and topographical characteristics of diaphyseal Nutrient Foramina (NF) in the long bones of the upper limbs is essential for optimizing surgical interventions, particularly in fracture management and bone grafting procedures. **Objective:** To assess the anatomical features (number, location and foramina index) of diaphyseal NF in cadaveric long bones of upper limb in adult Pakistani population. **Methods:** This cross-sectional study was undertaken on human cadaveric upper limb bones from the bone bank of the Anatomy department of FMH College of Medicine and Dentistry, Lahore. The age and gender of the bones were not known, and the duration of the study was four months. A total of 195 non-pathological, undistorted bones of upper limb (57 clavicles, 34 humeri, 50 radii and 54 ulnae) with were randomly selected. **Results:** In cases of clavicle 58% had a single NF (NF), 33% double & 5% triple, in humerus 100% had a single NF, 96% of radii had a single NF & 4% double whereas in ulna 98% had single NF and 2% double. In majority of the clavicle, humerii and radii the NF was in the $2/3^{rd}$ of the bone whereas in case of ulnae majority of NF occupied the proximal $1/3^{rd}$ of the shaft of the ulnae. **Conclusion:** A good knowledge about the anatomy of the NF is necessary for orthopaedic or trauma surgeons while doing critical bone reconstructive or graft implantation surgeries.

INTRODUCTION

During the active growth period of bone, diaphyseal Nutrient Artery (NA) serves the purpose of main artery supplying blood to the bone. Adequate blood supply, via periosteal as well as medullary arteries, ensures the recovery and success of the surgical procedures done for healing of the fractures of the long bones [1]. Vascular flow within the bone is mandatory for bone formation, its growth and repair after any kind of fracture or injury [2]. The importance of Nutrient Foramen (NF) is relevant to fracture treatment [3]. The point of entry of diaphyseal NA on external surface of bone is called NF that leads to the nutrient canal. The foramen could be one or more than one in number and its location and direction of the Nutrient Canal (NC) varies among various long bones [4]. NF are apertures in bones through which the blood vessels enter. The arteries entering through these foramina invade the cartilage that is ossifying during the formation of primary ossification center, hence these foramina are the telltale sign of the primary ossification centers [5]. Humphrey focused his research on the direction of the nutrient canals and their obliquity. He presented his periosteal slipping theory which stated that "nutrient canal is directed away

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from the growing end" to avoid injury or rupture of the NA due to the pull of growth of bone [5, 6]. Location and number of NF are independent of the length or age of the bone as well as the ossification centers. Rather than the development of the bone, it's the formation and development of the NA that is essential for the development of the Nutrient Canal (NC) [7]. In absence of the NA, periosteal vessels are held responsible for supplying blood to the bone [8]. During the surgical procedures such as fixation of fractures internally and bone grafting, the knowledge about site of location and number of NF are pivotal as it would avoid the damage to the NA and hence uninterrupted blood supply ensures healing by osteocytes and osteoblast [9]. Otherwise, the interruption in the blood supply could result in late union or un-united fractures of the bone, this highlights the importance of medullary blood system in callus formation and revascularizing the cortical bone undergoing necrosis at the site of the fracture [10]. Therefore, NF is crucial in maintaining the vascularization of long bones, significantly affecting the healing of fractures and the success of surgical procedures such as nailing and grafting. The NA, passing through these foramina, provides substantial blood supply to both the medulla and cortex internally, accounting for a considerable portion of the vascular support during the healing process. Understanding anatomical variations as well as site of locations of NF are therefore essential for enhancing surgical outcomes in treatment of fractures and reconstruction of bones. Surgeons can easily locate the NF of each bone and preserve the NA which ensures the presence of osteoblasts and osteocytes that are essential for healing and integration of vascular bone graft [11]. In addition, during bone grafting, avoiding the nutrient artery, due to the knowledge of site of the NF, can easily reduce the risk of ischemia to the bone and eventually prevents nonunion of the fractured bone or delayed osteogensis and thereby enhancing the efficacy of the surgical interventions and reducing the risk of complications due to adequate vascular supply [9, 11]. Detailed data regarding the NF is required for transplant and surgical resection techniques to avoid nonunion in orthopedics. Since physique, structure, and genetic make-up differ distinctly in the various ethnic groups, it is likely that the data regarding the NF of the long bones present in the upper limb considered standard for Western population might be relatively unlike than that of Pakistanis.

Therefore, this study was undertaken to eliminate gap of data for NF of long bones belonging to upper limb in Pakistani population as much as possible.

METHODS

This study was conducted from November 2023 to January 2024 and involved 195 human cadaveric bones and included 57 clavicles, 34 humerii, 50 radii and 54 ulnae. As the bones were taken from the bone bank of Anatomy department, FMH College of Medicine and Dentistry (FMHCMD), Lahore so their age and gender was not known (Figure 1). There was no participant or patient involved in the study, rather it was on cadaveric bones so consent was not applicable in this case. FMH College of Medicine and Dentistry Lahore ethical committee approved this study by providing the institutional review board approval certificate vide letter no. FMH-15/08/2023-IRB-1267. The bones with grossly visible pathologies were excluded from sample of this research project. All upper limb long bones were studied for locating the NF and the count of NF in each bone was also noted. For determining the location of the NF, each bone was divided into three equal parts lengthwise and named as proximal, middle and distal third of the bone. For a clear view, magnifying glass was also used. A Distinct Groove (NC) accompanied by a clearly defined, often slightly elevated edge marking the beginning of the canal is recognized as NF. Only NF of the shaft (diaphyseal) were observed, and their patency was confirmed by placing the 24-gauge needle in foramen.

Parameters

Number of NF

Location/site of the NF at various borders or the surfaces of diaphysis/shaft of bones

The foramina as close as 1 mm from any border were present on that particular border.

Hughes formula [1] was used to calculate foramen index (F.I.)

F.I. = D/L×100

Distance of foramen from proximal end (D)

Total length of bone (L)

The F.I. was determined for each of the bones included in the study. For locating NF, each bone was equally divided into three parts and topography noted, data tabulated in standardized sheet and analyzed.

Sample Size

A sample of size 195 is calculated using the expected mean of Khyber Pakhtunkhwa Population with 95.0% confidence level and 0.05 margin of error [12].

Formula

$$n = \frac{n_0}{1 + \frac{(n_0 - 1)}{N}}$$

Where,

n_0 = Cochran's sample size recommendation,

N= population size,

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n = sample size of our study

Simple Random sampling was done. Data were entered and analyzed by SPSS version 25.0. A descriptive analysis was conducted and mean+SD was calculated for quantitative variables and frequency and percentages for qualitative variables.

Figure 1: Long bones of upper limb (A: Clavicle, B: Humerus, C: Ulna, D: Radius); site of location of NF is marked on individual bones by colored head Pins

RESULTS

In the clavicles examined, 58% contained a single NF, 33% had two NF, and 5% had three. Additionally, 1.75% of clavicles presented with five NF, and another 1.75% had six. In contrast, all humeri (100%) exhibited a single NF. Among the radii, 96% had a single NF, while 4% displayed two. For the ulnae, 98% contained a single NF, with only 2% showed two foramina. (Table 1).

Table 1: Frequency of Nutrient Foramina (NF) in Different Bones

Bone	Single NF (%)	Two NF (%)	Three NF (%)	Five NF (%)	Six NF (%)
Clavicle	58%	33%	5%	1.75%	1.75%
Humerus	100%	0%	0%	0%	0%
Radius	96%	4%	0%	0%	0%
Ulna	98%	2%	0%	0%	0%

Table 2 presented the distribution of nutrient foramina (NF) in clavicles. The majority (50%) of NF were located on the inferior surface, making it the most common site. The posterior border contained 22% of the foramina, while 15% were found on the posterior surface. A smaller percentage (7%) were observed on the superior surface, whereas only 1.75% were located on both the anterior border and anterior surface.

Table 2: Distribution of Nutrient Foramina (NF) in Clavicles

Location on Clavicle	Percentage (%)
Inferior Surface	50%
Posterior Border	22%
Posterior Surface	15%
Superior Surface	7%
Anterior Border	1.75%
Anterior Surface	1.75%

Table 3 highlighted the distribution of NF in the humerus, radius, and ulna. In humeri, the anteromedial surface was the predominant site (73.5%), followed by the medial border (17%), with a minimal presence (0.08%) on the posterior surface. Among the radii, the anterior surface had the highest occurrence of NF (48%), while 28% were found on the posterior surface and 24% on the medial border. For ulnae, the anterior surface was the primary site (83%), whereas 17% of NF were positioned on the lateral border.

Table 3: Distribution of Nutrient Foramina (NF) in Humerus, Radius, and Ulna

Bone	Location of NF	Percentage (%)
Humerus	Anteromedial Surface	73.5%
	Medial Border	17%
	Posterior Surface	0.08%
Radius	Anterior Surface	48%
	Medial Border	24%
	Posterior Surface	28%
Ulna	Anterior Surface	83%
	Lateral Border	17%

The mean foramen index was calculated as 37.47 for clavicle, 55.5 for humerus, 33.41 for radius, and 33.4 for ulna (Table 4).

Table 4: Data of NF in Various Upper Limb Bones

Name of the Bone	Number of Bones	Number of NF (Each category shows the number of bones consisting of the respective number of foramen)						
		No foramen	One	Two	Three	Four	Five	Six
Clavicle	57	0	33	19	3	0	1	1
Humerus	34	0	34	0	0	0	0	0
Radius	50	0	48	2	0	0	0	0
Ulna	54	0	53	1	0	0	0	0

This study examined the distribution of nutrient foramina (NF) in various bones. In clavicles, 50% of NFs were found on the inferior surface, followed by the posterior border (22%) and posterior surface (15%). In humeri, most NFs (73.5%) were on the anteromedial surface. In radii, NFs were predominantly located on the anterior surface (48%) and posterior surface (28%). For ulnae, 83% of NFs were on the anterior surface, with 17% on the lateral border. These findings highlight the variation in NF distribution across different bones (Table 5).

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Table 5: Distribution of NF and Foramen Index

Name of the Bone	Location of NF on Diaphysis										Topography (longitudinal Division of Diaphysis)			Foramen Index (F.I)
	Border				Surface						1/3rd	2/3rd	3/3rd	Mean
	M	L	A	P	A	M	L	P	S	I				
Clavicle	-	-	1	13	1	-	-	9	4	29	5	45	7	37.47
Humerus	6	-	-	-	13	12	-	3	-	-	5	28	1	55.5
Radius	12	-	-	-	24	-	-	14	-	-	3	47	0	33.41
Ulna	-	9	-	-	45	-	-	-	-	-	39	15	0	33.44

(M: Medial, L: Lateral, A: Anterior, P: Posterior, S: Superior, I: Inferior)

Table 6: Comparison of Location of Foramina on Expected Site versus Variant Site

Name of the Bone	Location of NF Frequency (%)					
	Expected site	Variant Site				
		1	2	3	4	5
Clavicle	Inferior Surface 29 (50.87%)	Posterior Border 13 (22.80%)	Posterior Surface 9 (15.78%)	Superior Surface 4 (7.01%)	Anterior Surface 1 (1.75%)	Anterior Border 1 (1.75%)
Humerus	Anteromedial Surface 25 (73.5%)	Medial Border 6 (17%)	Posterior Surface 3 (0.08%)	-	-	-
Radius	Anterior Surface 24 (48%)	Medial Border 12 (24%)	Posterior Surface 14 (28%)	-	-	-
Ulna	Anterior Surface 45 (83%)	Lateral Border 9 (17%)	-	-	-	-

DISCUSSION

Bones in the human body are highly vascularized receiving approximately 10%-15% of cardiac output. NA along with metaphyseal and epiphyseal arteries, which arise from periosteal arteries and periarticular vascular plexus, supplies blood to the long bones [13]. In the current research, the inferior surface of the clavicle was observed to have the NF in most cases occupying the middle 2/3rd of the shaft which was also seen in a meta-analysis study done by Morten Ejlersen [14]. A recent study conducted on dry human clavicle bones also showed similar results [15]. In current research, anteromedial surface of humerus was found to have most of the NF, which is similar to the results of study conducted by Thakur and Sar along with their associates [2, 16]. Humerus was the only bone that showed single foramina in practically all the bones which is close to another study done by Kumar S *et al.*, in which 93% had only one foramen [17]. Only one NF was found in 96% radii in the current research. These findings agree with another study recently done exclusively on radii [18]. Regarding the site of NF, anterior surface had it in 48% radii while posterior surface had NF in 28%, which was also seen by Vaghela and associates in his study [19]. However, medial or interosseus border had NF in 24 % cases that is in accordance with a study done by Elif [18]. In the current study, NF were distributed most often in middle one third of radius with few in the proximal one third. Similar findings were observed in another study of Mishra *et al* [20]. In our study NF was single in 53(98%) of the ulna which was also seen by Dervisevic L *et al.*, in his study [6]. Regarding the location on radii, anterior surface had most NF, which is in accordance with observations made by Mahesh Dhoot *et al* [9]. While orthopedic and reconstructive surgeries on long bones, a detailed understanding of the location as well as characteristics of NF is essential for preventing intraoperative injuries [16]. The perforating vessels are the main contributing vessels in the blood supply of bones of the elbow that were arising from the neighboring arteries around the bone. These vessels can sustain trauma during reconstructive surgeries of the elbow. Hence a sound understanding of circulation within and around the bone is necessary to prevent iatrogenic injuries. Fractures of long bones are a common occurrence which can be complicated by delayed union. This complication can have multiple causes and one of them is poor nutrition caused by damage to the nutrient artery [11]. Non-union are more common in the proximal 1/3 of humerus and distal 1/3 of radius and ulna due to diminished blood supply of these areas caused by decreased branches of nutrient artery [10]. Therefore, understanding of anatomy of NF is crucial for preservation of circulation of bone during surgical procedures [21]. While allografting for elbow joint, the anatomical knowledge about the NF of the bones forming the elbow joint is crucial for the preservation of vasculature of the bone [3, 10]. The topography of NF should be kept in mind during surgeries and its clinical significance cannot be overemphasized in this regard. It is from the NF from where the entrance of the NA into the bone takes place to supply blood and nourish it. The nutrient artery is crucial for the healing of the fractures of weight-bearing bones by providing essential blood supply, which is vital for bone nutrition and growth [3]. Compromise of this blood flow, often due to the trauma involving the NA or the NF during

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stress fractures or surgical interventions, can lead to delayed union or nonunion of fractures, as adequate vascularization is necessary for effective healing [22]. Furthermore, the nutrient artery's role in providing essential nutrients and supporting the callus formation at the site of the fracture underscores its importance; without proper blood supply, the healing process is severely hindered, increasing the risk of complications such as avascular necrosis [10]. The surgical approach for bone grafting and fracture management is not only influenced by the number of the NF but also their site of location and it ensures the uncompromised blood supply and healing [23]. The site of location of the NF also influences choice of surgical technique to be used in particular circumstances [5]. Adequate knowledge about the distribution of NF in long bones topographically also augments in diagnosis and treatment of conditions relating to impaired bone healing and developmental abnormalities [22]. Moreover, knowledge of the foraminal index and the direction of NC leading to NF, improves the outcome and effectiveness of surgical interventions, ensuring preservation of osseous circulation, thereby ensuring optimal outcomes. This anatomical insight is vital for orthopaedic surgeons and clinicians involved in the management of bone-related injuries and conditions [17]. Most upper limb bones contain only one NF, generally directed toward the elbow joint and located on flexor surfaces [21-23]. The anatomical knowledge about the variations of NF reduces the risk to vascular supply and minimizes the chances of complications such as nonunion or delayed healing, which can be associated with the absence/damage to NF and artery.

CONCLUSIONS

Understanding the locations and number of the foramina, enables us to identify the safe zones for surgical procedures like pin insertions etc., in the long bones and optimizes the surgical planning for repair of the fractures, replacement of joints, and microvascular grafting of bone. Understanding anatomical variations is essential for microsurgical techniques, and CT imaging is recommended for assessing fractures. This study contributes to the limited literature on NF of upper limb bones in the population of Pakistan and offers valuable insights that are crucial for enhancing surgical efficacy.

Authors Contribution

Conceptualization: GPW
Methodology: SM, SS1, MS, NF
Formal analysis: GPW
Writing, review and editing: GPW, SM, SS1, MS, NF, AN, Ss[2]

All authors have read and agreed to the published version of the manuscript

Conflicts of Interest

All the authors declare no conflict of interest.

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