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A comprehensive study of nutrient foramina in human upper limb long bones of Indian population in Rajasthan state

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Abstract
Introduction: Nutrient foramen is a natural opening into the shaft of a bone, allowing for passage of blood vessels into the medullary cavity. This supply is essential during the growing period, during the early phases of ossification, and in procedures such as bone grafts, tumor resections, traumas, congenital pseudoarthrosis, and in transplant techniques in orthopedics.
This study aims to determine the number, location and direction of nutrient foramina in human upper limb long bones of Indian population in Rajasthan state.
Material and Method: The present study was conducted on 200 upper limb long bones (50clavicles, 50 humeri, 50 radii, 50 Ulnae).
Results: The majority of the bones studied had a single nutrient foramen, which may represent a single source of blood supply. In the results, 68% of the clavicles had a single foramen, 26% had double foramina and 6% had no nutrient foramen, 92% of the humeri had a single foramen, 2% had double foramina and 6% had no foramen. For the radii, 96% had single nutrient foramen and 4% had no nutrient foramen. 96% of the ulnae had a single nutrient foramen and 4% had double nutrient foramen. The mean foraminal index for the upper limb bones was 49.76% for the clavicle, 57.26% for the humerus, 35.48% for the radius, and 34.53% for the ulna.
Conclusion: This study recorded data related to the population of Rajasthan state, providing ethnic data to be used for comparison and that may help in surgical procedures and in the interpretation of radiological images. Information and details about these foramina is of clinical importance, especially in surgical procedures like bone grafting and microsurgical vascularized bone transplantation.

Keywords: Nutrient Foramen (NF), long bones, Foraminal Index (FI)

Introduction

Bones are structures that adapt to their mechanical environment, and from a fetal age adapt to the presence of naturally occurring holes. These holes or nutrient foramina, allow blood vessels to pass through the bone cortex [7].

The nutrient artery is the principal source of blood supply to a long bone, particularly import Anterior during its active growth period in the embryo and fetus, as well as during the early phase of ossification [14].

Nutrient foramen is the largest foramen on the long bones through which nutrient artery for that bones passes [2].

The role of nutrient foramen in nutrition and growth of the bones is evident from term “Nutrient” itself [5].

Nutrient foramen was derived from those that took part in the initial invasion of the ossifying cartilage, so that the nutrient foramen was at the site of original centre of ossification. The external opening of nutrient canal, usually referred to as the nutrient foramen, has a particular position and the canal has a certain direction, const Anterior for each bone [25].

Humphrey who worked on the direction and obliquity of nutrient canals Postulated periosteal slipping theory and stated that nutrient canal finally directed away from the growing end [11].

Position of nutrient foramina was on flexor aspect in their human long bone specimens [15].

Location does not have a significant relationship with bone age, but that the nutrient artery development is primarily responsible for the nutrient channels form, rather than the bone development [28].

A nutrient foramen is found in clavicle at the lateral end of the groove for subclavius running in lateral direction and transmits nutrient artery which is derived from suprascapular artery. The foramina of the clavicle do not always transmit the supraclavicular nerve, but occasionally the medial supraclavicular nerves pass through the foramina in the clavicle on their way to the Anterior of the chest. The nutrient foramen of the clavicle was found at the junction between the lateral and middle third regions [3].

The topographical knowledge of nutrient foramina of clavicle is useful to preserve arterial supply during radiation therapy, appropriate placement of internal fixation devices for treatment of fracture and in free vascularized bone grafts, so that the osteocytes and osteoblasts can survive [8].

However, there is still a need for a greater understanding of the location and number of nutrient foramina in long bones, Importance of nutrient foramina is relevant to fracture treatment, combined periosteal and medullary blood supply to bone cortex to explain the success of nailing of long bone fractures particularly in weight bearing like femur and tibia and deploying grafts of vascularised fibula bone in bony defects due to trauma.

Materials and Methods
The study was conducted on 200 adult human cleaned and dried bones of the upper limbs which include clavicle, humerus, radius, Ulna.
The specific age and sex characteristics of the bones studied were unknown.
The bones were obtained from the departments of Anatomy at Mahatma Gandhi Medical College and hospital Sitapura Jaipur, SMS medical collage Jaipur and National Institute of Medial Sciences Jaipur.
Bones which have gross pathological deformities were excluding from the study.
The number of individual bones which have been studied as follows -
Clavicle – 50 [right 28, left 22].
Humerus - 50 [right 25, left 25].
Radius – 50 [right 24, left 26].
Ulna – 50 [right 25, left 25].

All the bones were macroscopically observed for the number and location of nutrient foramina. A magnifying lens has been used to observe the foramina.
The nutrient foramina have been identified by presence of a well marked groove leading it to a canal, which has often slightly raised edges at commencement of canal.
The number and topography of the foramina in relation to specific borders or surfaces of the diaphysis were analyzed. The foramina within 1 mm from any border were taken as lying on that border.
A 24 gauge needle was passed through each foramen to confirm their patency.
The following data were studied on the diaphyseal nutrient foramina of each bone.

Direction
A fine stiff broomstick was used to confirm the direction and obliquity of the foramen.

Number
Bones were examined for the number of nutrient foramina.

Location
The position of all nutrient foramina have been determined by calculating a foraminal index [FI] by applying the Hughes formula i.e. dividing the distance of foramen from the proximal end [D] [Fig 2], by the total length of bone [L], which will be multiplied by hundred.

$$\text{Foraminal Index [FI]} = \frac{\text{D [Distance of foramina from the proximal end]}}{\text{TL [Total Length of Bone]}} \times 100$$

The positions of foramina have been divided into three types according to FI as follows:-

Type1: FI up to 33.33, the foramen in proximal third of the bone.
Type2: FI from 33.33 up to 66.66, the foramen in the middle third of the bone.
Type3: FI above 66.66, the foramen in the distal third of the bone.

All measurements have been taken to the nearest 0.1 mm using an INOX sliding vernier caliper [Fig 1]. Photographs have been taken by a Casio digital camera [12 mega pixels]. Each photograph should have a definition of 16x12 cm.
Total length of bones was measured with INOX sliding vernier caliper in point to point 2/3 additive stages. [Fig 3]

- Clavicle – length between sternal and acromial end of the clavicle measured in millimeters using sliding vernier caliper ignoring curves of clavicle.
- Humerus - Between the superior aspect of the head and most distal aspect of the trochlea.
- Radius - Between the most proximal aspect of the head of the radius and tip of the radial styloid process.
- Ulna - Between the most proximal aspect of the olecranon and the ulna styloid process.

Data Analysis
The observed Data were expressed as means and standard deviations for continuous variables and percentage for categorical variables by using SPSS [Statistical Package for the Social Sciences – Inc.]

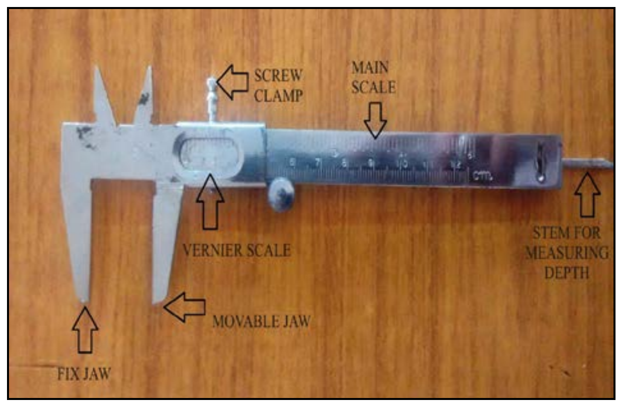

Fig 1: Sliding Vernier Caliper

Fig 2: Photographic Presentation of Measurment of DNF

Fig 3: Photographic Presentation of Measurement of Total Length of Bone

Results & Observations

In present study the following results were obtained:

Clavicle

Total numbers of foramina observed in clavicles were 47[94%], out of which single foramen in 34 [68%] and double foramina in 13 [26%]. Absence of nutrient foramen was found in 3 [6%] clavicles. [Table 1].

Numbers of Foramina were observed on Posterior surface 38 [76%], inferior surface of medial two third 8 [16%] and 1 [2%] on superior surface of lateral one third of clavicle. [Table 3]

Maximum NF was seen located on middle third of bone 46 [88.46%] and on proximal third part 1 [2%] [Table 2].

Mean Right + Left [R+L] DNF, Foraminal Index [F.I.] and Total Length [T.L.] for clavicle were 58.47mm, 47.76%, and 117.5mm. and their range were 8-80mm, 6.4 to 63.64% and 100-136 mm respectively [Table 4]

Humerus

The total numbers of foramina observed in humeri 47 [94%], single NF was found in 46 [94%], double foramina were in 1 [2%]. And Absence of nutrient foramen was found in 3 [6] humeri. [Table 1].

Maximum NF was seen on middle third of bone 46 [90%] and on distal third part of bone 2 [4%]. No foramen was seen on proximal third. [Table 2]

Numbers of foramina were seen on anteromedial surface 44 [88%], on Posterior surface 2 [4%] and 1 [2%] on medial border. [Table 3]

Mean [R+L] DNF, F.I. and T.L. for humerus were 153.62mm, 57.26% and 268.02mm. And their range were 115-220 mm, 46.15 to 74.58% and 115-220mm respectively. [Table 4]

Radius

The total numbers of foramina observed in radii 48 [96%], single NF was found in 48 [96%] and Absence of nutrient foramen was found in 2 [4%] radii. [Table 1]

Maximum NF was seen on middle third of bone 25 [50%], on proximal third part of bone 23 [46%] and to NF was found on distal third part of bone. [Table 2]

Numbers of foramina were observed on Anterior surface 44 [88%], on lateral surface 1 [2%] and 3 [6%] on Anterior border [Table 3].

Mean [R+L] DNF, T.L for humerus were 76.15mm, 35.48%, and 214.19mm and their range were 53-11mm, 25.20 to 50.90% and 181-250mm respectively. [Table 4]

Ulna

The total numbers of foramina observed in ulnaii 50 [100%], single NF was found in 48 [96%], double foramina were found in 2 [4%]. [Table 1]

Maximum NF was seen on proximal third 28 [56%], on middle third part of bone 22 [44%]. And Absence of nutrient foramen was observed in distal third.

Numbers of foramina were seen on Anterior surface 44 [88%], on lateral border of ulna 6 [12%].

Mean [R+L] DNF, F.I. and T.L. for ulna were 80.3mm, 34.53% and 232.94mm and their range were 50-107mm, 20.83 to 48.27% and 200-264mm respectively. [Table 4]

Table 1: Numbers of N.F. in Studied Various Long Bones

Name of Bone	Number of Foramina			
	0	1	2	3
Clavicle [N=50]	3[6%]	34[68%]	13[26%]	-
Humerus[N=50]	3[6%]	46[92%]	1[2%]	-
Radius [N=50]	2[4%]	48[96%]	-	-
Ulna [N=50]	-	48[96%]	2[4%]	-

Table 2: Morphological & Topographical Distribution of Nutrient Foramen in Studied Long Bones

Bone	Location		NO.OF N.F.
Clavicle		Anterior	
	Surface[medial 2/3]	Posterior	38[76%]
		Superior	
		Inferior	8[16%]
	Surface[lateral 1/3]	Superior	1[2%]
		Inferior	
Humerus		Anterior	
	Borders	Lateral	
		Medial	1[2%]
		Anteromedial	44[88%]
	Surfaces	Anterolateral	
		Posterior	2[4%]
Radius		Anterior	3[6%]
	Borders	Posterior	
		Medial	
		Anterior	44[88%]
	Surfaces	Posterior	
		Lateral	1[2%]
Ulna		Anterior	
	Borders	Posterior	
		Lateral	6[12%]
		Anterior	44[88%]
	Surfaces	Medial	
		Posterior	

Table 3: Location According to Foraminal Index [F.I.] in Different Long Bones

Location according to F.I			
Bones	**Type1 [upto 33.33%]**	**Type2 [33.33 to 66.66%]**	**Type3 [onward 66.66%]**
Clavicle [N=50]	1[2%]	46[88.46]	-
Humerus N=50]	-	45[90%]	2[4%]
Radius [N=50]	23[46%]	25[50%]	-
Ulna [N=50]	28[56%]	22[44%]	-

Table 4: Range, Mean, Standard Deviation [S.D.] of Measured D.N.F, T.L, & F.I. in Studied Human Long Bones

BONE		RANGE			MEAN			S.D.		
		RT	LT	R+L	RT	LT	R+L	RT	LT	R+L
	DNF[MM]	8-80	38-78	8-80	56.54	60.86	58.47	14.04	9.97	12.45
Clavicle	TL[MM]	103-136	100-134	100-136	118.5	116.68	117.5	9.29	8.88	9.06
[N=50]	F.I.[%]	6.4-58.82	34.13-63.64	6.4-63.64	47.57	52.6	49.76	10.17	7.7	9.42
	DNF[MM]	115-185	120-220	115-220	151.59	155.4	153.62	21.24	22.34	20.15
Humerus	TL[MM]	240-300	232-305	232-305	271.18	265.24	268.02	19.03	17.47	18.26
[N=50]	F.I.[%]	46.67-62.71	46.15-74.58	46.15-74.58	55.82	58.53	57.26	4.31	6.83	5.89
	DNF[MM]	56-113	53-103	53-113	79.52	73.04	76.15	15.63	13.14	14.6
Radius	TL[MM]	183-226	181-250	181-250	197.74	213.84	214.19	56.92	14.93	41.19
[N=50]	F.I.[%]	27.05-50.90	25.20-44.88	25.20-50.90	36.96	34.12	35.48	6.28	5.41	5.95
	DNF[MM]	50-107	60-105	50-107	81.04	79.56	80.3	15.2	12.48	13.78
Ulna	TL[MM]	203-264	200-255	200-264	234	231.88	232.94	11.55	18.49	12.13
[N=50]	F.I.[%]	20.83-48.27	23.92-45.85	20.83-48.27	34.63	34.42	34.53	6.2	5.79	5.94

Table 5: Comparison of Total Length (TL) & Foraminal Index (FI) of Present Study & Others

	Present Study (2015)		Bhatnagar (2014)		Kizilkanat (2007)		Pereira (2011)		Ukoha (2013)		Nagel (1993)	
	TL(R+L)	FI(R+L)	TL(R+L)	FI(R+L)	TL(R+L)	FI(R+L)	TL(R+L)	FI(R+L)	TL(R+L)	FI(R+L)	TL(R+L)	FI(R+L)
Clavicle	117.5	49.76		51.14								
Humerus	283	57.26		56.94	306	47.58	311.5	55.2	338	56.3	288	
Radius	234.2	35.48		37.36	229	35.53	233.6	35.7	263	33.7	237	
Ulna	262.8	34.53		36.38	252	40.04	254.3	37.9	283	36.7	255	

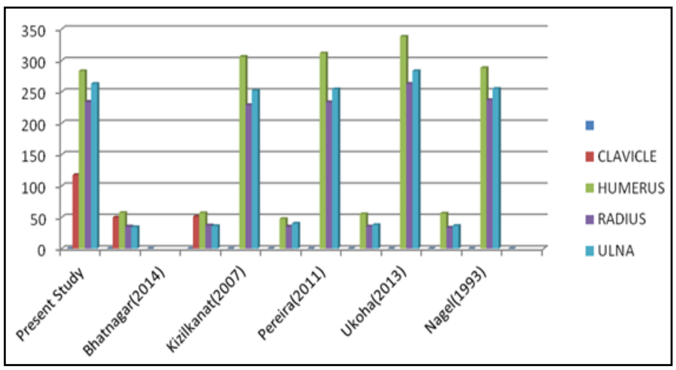

Fig 1: [Graphical presentation of comparative study between F.I. & T.L. of Present Study with Others.]

Discussion

Although measurements and observations were made on long bones from right and left sides, but no information was available regarding the age, sex and origin of other than that they were from Indian population of Rajasthan state.

Nutrient foramina in present study [2015] were seen to be absent in all studied bones except in ulna.

Single foramen was present in all bones but triple foramina were seen in none, double foramina were only present in clavicle [26%], humerus [2%], ulna [4%] but absent in other i.e. radius. [Table 1]

Single foramina frequency [68%] in clavicle is higher than Nita *et al.*, [23]. 21[42%] but lower than Bhatnagar *et al.*[1], 54[90%]. Double foramina are reported by all but absence of Nutrient Foramen [NF] is seen in current study 3[6%] and Patel *et al.*, [2] [2.66%], triple foramina are observed only by Nita *et al.* [23], 3[6%].

Agree with Longia *et al.* [15], Absence of nutrient foramina in humerus is observed in present study, [6%] and all others except Mysorekar [21] and Pereira *et al.* [26]. Frequency of single foramina is highest in all but less than present study [92%] except Murlimanju [18] [93.8%]. The existence of double foramen in less humerii reported by all workers, whose variability ranged from lowest 2% [current study] to highest 21.78% Kizilkanat *et al.* [13]. Three and four foramina were observed by Mysorekar [21] [2.79% and 1.12%], Bhatnagar *et al.* [1] [7.14% and 1.43%] and Kizilkanat *et al.* [13] [6.93% and 0.99%] respectively.

Murlimanju [18] observed 100% single foramina in ulna, as compared to current study 96% higher than Bhatnagar *et al.* [1] [95%] and Mysorekar [21] [93.33%] and Ukoha *et al.* [30] [78%] but less than Kizilkanat *et al.*[13] [99.01%] and Pereira *et al.*[26] [98.6%]. Double foramina were observed in current study [4%], Mysorekar [21] [5.56% higher], Bhatnagar *et al.* [1] [3.34%], Kizilkanat *et al.* [13] lower [0.99%] and Pereira *et al.* [26] [1.4%]. NF was absent in findings of Mysorekar [21] lowest [1.11%], Bhatnagar *et al.* [1][1.66%] and highest [22%] Ukoha *et al.* [30]. Longia [15] reported three foramina in two ulnae.

In majority of morphological and topographical position and distribution of nutrient foramina on Posterior surface [76%], anteromedial surface [88%], anterior surface [88%] in clavicle, humerus, radius and ulna respectively. The mean F.I. [57.26%] and range of humerus found between 46.15 to 74.58% are similar to observation by Bhatnagar *et al.* [1] [90.7%], Mysorekar [21], Longia *et al.* [15] and Ukoha *et al.* [2013] [56.28%], Nagel [22] and Pereira *et al.* [26] but Kizilkanat *et al.* [13] did not agree i.e. differed significantly [P<0.05].

NF in lower third of humerus distributed in present study [4%] and Bhatnagar *et al.* [1] [3.9%], who has also seen NF in proximal third [5.2%], in contrast not seen in present study, Murlimanju [18] and Ukoha *et al.* [30].

NF in radius was seen to locate in type 2 [50%] and type 1 [46%] F.I. i.e. middle third and proximal third, mean Foraminal index [F.I]. [35.48%] ranged between 25.20-50.90%, also observed similar findings by Ukoha *et al.* [30]

[mean F.I. 33.47%, type 2- 42.9%, type 1 -57.1%], Kizilkanat *et al.* [13] [35.53%] and Pereira *et al.* [26] [35.7%] but difference with Bhatnagar *et al.* [1] was statistically significant [P<0.05].

Ulna in Present study [2015] has revealed single foramina [96%] and double foramina [4%], on Anterior surface [88%] and lateral border [12%] and located in proximal third [56%] and middle third [44%] respectively. Mean F.I. is [34.53%], ranged between 20.83 – 48.27%. The observations found by Pereira *et al.* [26] [SF – 98.6%, DF – 1.4%, mean FI – 37.9%], Murlimanju [18] [SF – 100%, mean FI – 34.4%] Ukoha *et al.* [30] [SF – 78%, Absence of nutrient foramen – 22%, mean FI – 36.70%, Proximal third – 27%, middle third – 34.4%], Bhatnagar *et al.*[1] [SF – 95%, DF – 3.34%, Absence of nutrient foramen – 1.66%, proximal third – 36.06%, middle third – 63.93%] and Kizilkanat *et al.* [13] [SF – 99.01%, DF– 0.99%, mean FI – 40.64%]. Except Murlimanju [18], mean FI differed significantly [P<0.05] from current study [2015].

Schwalbe G explained that growth at the two ends of a long bone before the appearance of the epiphyses is equal. Hence, the nutrient foramen before the birth should be directed horizontally [27].

In humerus, the nutrient artery usually arises either from the brachial artery or from the profunda brachii artery as one or more branches or from the muscular branches of these arteries. The double foramina in humerus would suggest that one of them would be the main foramen and the other accessory one and hence the nutrient artery can arise either from the brachial or profunda brachii artery [21].

Longia GS *et al.* stated that the vascular theory offers the best explation of all reported anomalies as well as the normal fashioning of nutrient canal [15].

Delayed or nonunion in the middle or lower diaphysis following trauma may be directly related to the absence of nutrient arteries entering the bones in these areas

The posterior surface of radius & ulna often lack of nutrient foramina especially in middle and dorsal diaphysis. That is why the dorsal localization for the the plate is during operative procedure [6].

In summary, the present study supports previous findings and the contention that nutrient foramina in long bones are located on their flexor surfaces.

Conclusion

The study confirmed previous reports regarding the number and position of the nutrient foramina in the long bones of the limbs. It also provided important information to the clinical significance of the nutrient foramina.

A well understanding of the characteristic morphological features of the nutrient foramina by orthopedic surgeons is recommended. Exact position and distribution of the nutrient foramina in bone diaphysis is important to avoid damage to the nutrient vessels during surgical procedures

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