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A Comprehensive Study of Nutrient Foramina in Human Lower 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 lower limb long bones of Indian population in Rajasthan state.
Material and Method: The present study was conducted on 150 lower limb long bones (50femorii, 50 tibiae and 50 fibulae).
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 femurs had a single foramen, 16% had double foramina and 94% of the tibiae had a single foramen and 6% had no foramen. For the fibulae, 88% had single nutrient foramen and 12% had no nutrient foramen. The mean foraminal index for the lower limb bones was 45.58% for the femur, 31.74% for the tibia, 45.51% for the fibula.
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.

Key words: Nutrient foramen (NF), long bones, foraminal index (FI) Total length (TL).

INTRODUCTION

Nutrient foramen is an opening into the bone shaft which gives passage to the blood vessels of the medullary cavity of a bone, for its nourishment and growth. [11]
The role of nutrient foramen in nutrition and growth of the bones is evident from term "Nutrient" itself. [4]

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. [18]

Nutrient foramen is the largest foramen on the long bones through which nutrient artery for that bones passes. [3]

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. [7]

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. [22]

It has been suggested that the direction of the nutrient foramina is determined by the growing end of the bone, which is supposed to grow at least twice as fast as the non-growing end. As a result, the nutrient vessels move away from the growing end of the bone. As is popularly stated, they 'seek the elbow and flee from the knee' showing their varying directions in both limbs

Variations have been described in the direction of nutrient foramina in the lower limb bones. [10]

Variant foramina are common in the femur, rare in radius and very rare in other bones. Variations in the direction of nutrient foramina have been observed in many tetra pods and there is some similarity in the foraminal pattern in mammals and birds. [6]

Number of nutrient foramina does not seem to have a significant relationship with the bone length and the number of ossification centers. [17]

In case where the nutrient foramen is absent, it is therefore likely that the periosteal vessels are entirely responsible for the blood supply of the bone. [12]

Some pathological bone conditions such as developmental abnormalities, fracture and healing or acute hematogenic osteomyelitis are closely related to the vascular system of the bone. [23]

The topographical knowledge of nutrient foramina 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. [5]

It has been reported that when an ideal bone graft is taken for the free transfer should include blood supply [endosteal and periosteal] with good anastomosis. [26]

Detailed data on the blood supply to the long bones may contribute to be a major factor in the development of new transplantation and resection techniques in orthopaedics. [8]

Studies on the vascularization of long bones of various populations have been conducted to analyze the nutrient foramina morphometry, the vascular anatomy in reconstructive surgeries and the microsurgically vascularized bone transplant.

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 & METHODS

The study was conducted on 150 adult human cleaned and dried bones of the lower limbs which include femur, tibia and fibula.

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 were studied as follows -

Femur - 50 [right 26, left 24].
Tibia - 50 [right 21, left 29].
Fibula - 50 [right 24, left 26].

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] [Fig 3], 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 4]

- Femur – Between the superior aspect of head of femur and the most distal aspect of the medial condyle.
- Tibia - Between the superior margin of the medial condyle and the distal aspect of the medial malleolus.
- Fibula - Between the apex of the head of fibula and the distal aspect of the lateral malleolus.

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.].

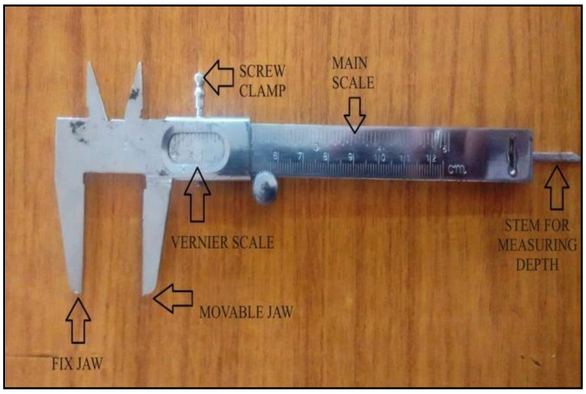


Fig-1: Sliding Verneir caliper

Figure-2: Area of bone B/W two arrow to measure DNF. Figure-3: Area of bone B/W two arrow to measure Total length

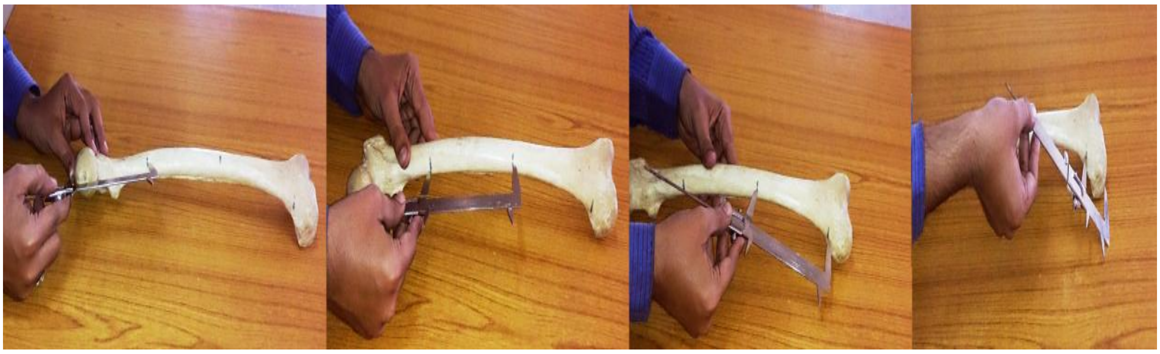


Figure -4: Photographic Presentation of Measurement of Total Length of Bone

RESULTS & OBSERVATIONS

In present study the following results were obtained.

Femur: The total numbers of foramina observed in femorii 50 (100%), single NF was found in 34 (68%) and double foramina were in 16 (32%). [Table 1]

Numbers of foramina were seen in between the two lips of linea aspera 35(70%), on the medial lip 6(12%), and 9(18%) on the lateral lip of linea aspera. [Table 3]

Maximum NF was seen on the middle third 41(82%), on proximal third part of bone 9(18%) and on no NF was found in the distal third part of bone. [Table 2]

Mean [R+L] DNF, F.I. and T.L. for femorii were 177.04mm, 45.58% and 399.89mm. And their ranges were respectively 120-265mm, 30.38 to 63.09% and 315-445mm respectively. [Table 4]

Tibia: The total numbers of foramina observed in tibiae 50 (100%), single NF was found in 47 (94%) and no NF was observed in 3(6%). [Table 1]

Numbers of foramina were seen on posterior surface 43(86%), on lateral border foramina were 3(6%), and 1(2%) on anterior border. [Table 3]

Maximum NF was seen on the proximal third 44(88%), on middle third part of bone 3(6%) and on no NF was found in the distal third part of tibia. [Table 2]

Mean [R+L] DNF, F.I. and T.L. for tibiae were 102.77mm, 31.74% and 326.26mm. And their ranges were respectively 82-122mm, 26.72 to 36.42% and 297-378mm respectively. [Table 4]

Fibula: The total numbers of foramina observed in fibulae 44 (88%), single NF was found in 44 (88%) and no NF was observed in 6(12%). [Table 1]

Numbers of foramina were seen on posterior surface 25(50%), on medial surface foramina were 10(20%), and 9(18%) on posterior border. [Table 3]

Maximum NF was seen on the middle third 44(88%), and no NF was found in proximal & distal third part of fibulae. [Table 2]

Mean [R+L] DNF, F.I. and T.L. for fibulae were 142.82mm, 45.51% and 335.68mm. And their ranges were respectively 103-210mm, 35.48 to 64.52% and 264-341mm respectively. [Table 4]

Table 1: Numbers of Nutrient Foramina (N.F.) in Studied Long Bones:

Name of Bone	Number of Foramina			
	0	1	2	3
Femur [N=50]	-	34[68%]	16[32%]	-
Tibia [N=50]	3[6%]	47[94%]	-	-
Fibula [N=50]	6[12%]	44[88%]	-	-

Table 2: Location of Nutrient Foramina according to Foraminal Index (F.I.) in studied long bones:

Location of nutrient foramina according to F.I			
Bones	Type1 [upto33.33%]	Type2 [33.33 to 66.66%]	Type3 [onward 66.66%]
Femur [N=50]	9[18%]	41[82%]	-
Tibia [N=50]	44[88%]	3[6%]	
Fibula [N=50]	-	44[84.61%]	-

Table 3: Morphological & Topographical Distribution of Nutrient Foramina in Studied Long Bones

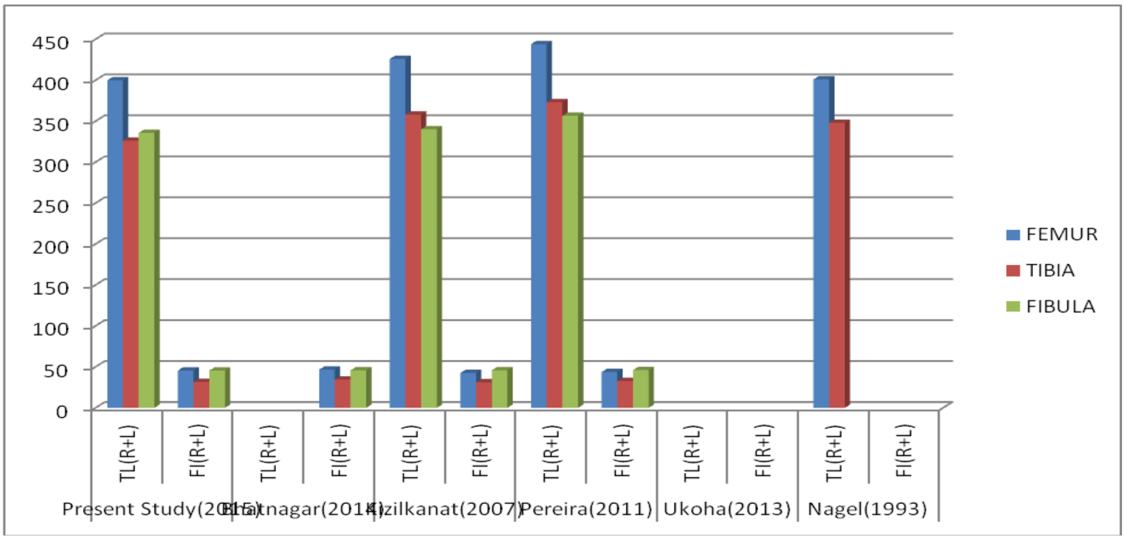
BONE	LOCATION		NO.OF N.F.
FEMUR		B/W LIPS	35(70%)
	LINEA ASPERA	MEDIAL LIP	6(12%)
		LATERAL LIP	9(18%)
TIBIA		ANTERIOR	1(2%)
	BORDERS	MEDIAL	
		LATERAL	3[6%]
		POSTERIOR	43[86%]
	SURFACES	MEDIAL	
		LATERAL	
FIBULA		ANTERIOR	
	BORDERS	POSTERIOR	9(18%)
		MEDIAL	
		POSTERIOR	25[50%]
	SURFACES	MEDIAL	10(20%)
		LATERAL	

Table 4: Range, Mean, and 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]	120-233	127-265	120-265	160.5	194.96	177.04	40.05	41.21	43.79
FEMUR	TL[MM]	315-430	320-445	315-445	395.09	369.91	399.89	30.22	28.34	29.43
[N=50]	F.I.[%]	30.38-59.73	33.16-63.09	30.38-63.09	41.54	49.96	45.96	9.65	10.03	10.62
	DNF[MM]	87-117	82-122	82-122	102.95	102.64	102.77	8.07	9.1	8.61
TIBIA	TL[MM]	305-348	297-378	297-378	328.45	344.64	326.26	84.26	81.38	83.32
[N=50]	F.I.[%]	27.97-34.82	26.72-36.42	26.72-36.42	31.85	31.67	31.74	1.8	2.83	2.45
	DNF[MM]	110-210	103-205	103-210	145.39	140	142.82	37.7	29.96	33.94
FIBULA	TL[MM]	295-341	264-338	264-341	339.9	331.45	335.68	17.2	20.3	19.28
[N=50]	F.I.[%]	35.48-64.52	37.73-60.65	35.48-64.52	45.94	45.03	45.51	11.17	7.39	9.46

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)
FIMUR	399.89	45.58		46.6	426	42.65	444.1	43.7			401	
TIBIA	326.26	31.74		34.49	358	31.2	373.1	32.7			348	
FIBULA	335.68	45.51		45.73	340.2	45.88	356.6	46.1				



Graph-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.

Single foramen was present in all bones but triple foramina were seen in none, double foramina were only present in femur [32%] but absent in others i.e. tibia and fibula [Table 1]

Report of Longia et al. [10] the major frequency of single foramen in femur was seen highest [68%] in present study than all others except Kizilkanat et al [9] [75%]. In contrast the existence of major double foramen frequency was seen by Nagel. [16] Bridge and Brooks [2] and Krirschner et al., [8] Mysorekar. [15] [50%] than all other's lesser frequency. Triple foramen was seen by Mysorekar. [15] [1.67%], Kirschner et al., [8] Nagel [16] and Pereira et al. [19] [1.3%] but Absence of nutrient foramen frequency was seen [3.33%] and [1.66%] by Mysorekar. [15] and Bhatnagar et al. [1] respectively.

There are reports of individual femora having as many as six [Mysorekar. [15]] or nine nutrient foramina [Sendemir and Cimen. [21]]

In majority of morphological and topographical position and distribution of nutrient foramina in lower limb bones i.e. femur, tibia and fibula foramina are situated between lips of linea aspera [70%], Posterior surface [86%] and Posterior surface [50%] respectively.

Femur in present study revealed occurrence of single [68%] and double foramina [32%], which was also seen by Bhatnagar et al [1] [Single foramen[SF] – 55% Double foramina [DF] – 43.34%], Kizilkanat et al. [9] [SF – 75% DF – 25%] Pereira et al. [19] [SF – 63.8% DF – 34.9%] and Mysorekar [15] [SF – 45% DF – 50%]. In addition last two researchers found triple foramina 1.3% and 1.6% respectively.

Main surface distribution in study was seen between lips of linea aspera [70%], but less on lateral lip [18%] and medial lip [12%], which is similar to Kizilkanat et al. [9] [44%] , Pereira et al. [19] [Right – 58% and Left – 55.2%] .

The femora mean Foraminal Index [FI] in study was found 45.58%, ranged between 30.38 – 63.09% and located predominantly middle third [82%] and 18% in proximal third. Femoral mean FI reported as by Bhatnagar et al. [1] [46.6%], Kizilkanat et al. [9] [42.65%] and Pereira et al [19] [43.7%] respectively, proved on comparison statistically insignificant [P>0.05].

Highly frequent single foramina in tibia were reported in all than current study [2015] [94%], which exclusively includes absence of nutrient foramen [6%] but double foramina were exclusively seen by Mysorekar, [15] [1.12%] Bhatnagar et al. [1] [5%] Kizilkanat et al [9] [2%] and Pereira et al. [19] [1.4%].

These nutrient foramina mainly distributed on Posterior surface [86%], like similar presence Kizilkanat et al. [9] [47.4%] and Pereira et al. [19] [42.4%].

Tibial mean FI was seen 31.74%, ranging between 26.72 to 36.42% and located mainly in proximal third [88%] than least [6%] in middle third.

Bhatnagar et al. [1] and Pereira et al [19] reported tibial mean FI as [34.49%] and [32.7%] respectively which statistically differed significantly [P<0.05] but mean FI [31.2%] by Kizilkanat et al. [9] was differed insignificantly from studied specimens.

Fibular single foramina were seen in all but lowest in present study [2015] [88%], double foramina were observed by Mysorekar. [15] [3.34%], Bhatnagar et al. [1] [5%], Kizilkanat et al. [9] [5.48%] and Pereira et al. [19] [0.99%]. But absence of NF was highest [12%] in present study than Mysorekar. [15] [3.88%] and Kizilkanat et al [9] [1.37%] respectively.

Highest frequency of foramina was present on Posterior surface [50%] than medial [20%] and located on middle third of fibula [84.61%]. Fibula mean FI [45.51%] had statistically insignificant [P<0.05] difference with others.

Bone formation is seen at mid part of diaphysis in long bones at 8 weeks. The formation of periosteal collar extends proximally and distally "GROWTH PLATE" i.e. future epiphyseal plate. [25]

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. [20]

Mysorekar observed that there was a good deal of bilateral symmetry in the foramina. Without any exception, the foramina were directed away from the growing end. [14]

Hughes H observed that variant foramina are common in the femur, rare in the radius and very rare in other bones. Variations in the direction of nutrient foramina have been observed in many tetrapods and there is some similarity in the foraminal pattern in mammals and birds. [6]

The observation of the present study that the majority [68%] of femora have a single nutrient foramen is similar to that reported by Longia et al., [10] with all remaining femora in the present study having two nutrient foramina. In contrast Mysorekar., [15] Nagel., [16] Bridgeman and Brookes [2] and Kirschner et al. [8] all reported the majority of femora have two nutrient foramina.

There is, however, agreement that the majority of foramina are associated with the linea aspera spreading into the medial lip, an observation confirmed in the present study with some foramina being located on the medial femoral surface adjacent to the medial lip.

The tibia is a good example of the rate of healing in relation to vascular supply, with those areas or regions with a good blood supply showing more rapid healing than those with a poor blood supply. [27] Fractures in the distal third of the tibial shaft tend to show delayed union or mal union: one suggestion being that there may be a tear of the nutrient artery at the fracture line, thus reducing the blood supply to distal site. [24]

In the majority of the specimens, the nutrient foramina were located in middle third of the fibula, which is the segment that must be used for the transplant, if one desires that the implant include endosteal vascularization and peripheral vascularization. [13]

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

FI of ulna in present study, frequency of distribution localized in proximal third [56%] and middle third [44%] differed significantly [P<0.05] from Bhatnagar et al., [1] Kizilkanat et al. [9] Pereira et al. [19] and Ukoha et al. [28] Nigerian but insignificant closely with Nagel [16] This may be correlated to geographical and ethnic racial difference from Turkish Caucasian, Europian and African race.

Variable difference and disagreement may be attributed to multifactorial based causative point's genetical, geographical, ethnic racial, different life style, culture, tradition, food habits, environmental and inadequate numbers of samples.

Inspite of meticulous follow up role of limitation of device, poor technique and instrumental calibration and subjective identification errors can't be denied and ignored.

The recorded data of present study related to Indian population of Rajasthan state may be providing ethnic data to be used for comparison, supports of previous findings and may help in bone graft surgical procedures to preserve circulation, in the interpretation of radiological images and enlightening to the clinical anatomist and morphologist.

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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