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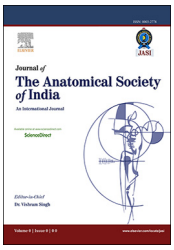

Original Article

A study of human diaphyseal nutrient foramina in fibula

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ARTICLE INFO

Article history:
Received 26 August 2014
Accepted 27 June 2015
Available online 30 July 2015

Keywords:
Nutrient artery
Foraminal index
Fibula

ABSTRACT

Introduction: Nutrient foramen is the external opening of the nutrient canal in a bone. The main blood supply to long bones is from nutrient arteries, especially during the active growing period in the embryo and during the early phases of ossification. An understanding of the location, number, direction, and caliber of diaphyseal nutrient foramina in fibula is very important clinically, especially in orthopedic surgical procedures.
Method: This study was conducted on 251 fibula (135 right and 116 left), macerated specimens of adult human fibula. Using osteometric board, Vernier calipers, hypodermic needles of size 20G and 24G, steel measuring scale, hand lens, and other basic instruments, all the parameters like average number, average distance of the nutrient foramen from the upper end of fibula, 'foraminal index', the most common location and the frequency of the location on the anatomical surfaces and borders of each of the fibula, the caliber, and the direction of each diaphyseal nutrient foramina were studied.
Results: The average number of diaphyseal nutrient foramina found in fibulas was 0.9.
Discussion: The foraminal index for the fibula, was 44.12%. All the nutrient foramina were on the posterior surface in fibulae, out of which 51.8% were found on the surface posterior to medial crest in the fibulae. In 21 out of the 251 fibula bones the nutrient foramina were found directed upwards. The fibula had only 3.18% dominant foramina.

1. Introduction

All arteries supplying the bone are 'nutrient' but the artery to the diaphysis has been known as 'nutrient artery' by most authorities. The original artery, which accompanies the initial invasion of the primitive cartilaginous rod by osteoclasts and osteoblasts, enlarges and persists as the nutrient artery. Bone is deposited round the vessel, thus forming a permanent track, which traverses the compact tissue thus forming a 'Nutrient canal'. Nutrient foramen is the external opening of the nutrient canal in a bone. The principal nutrient foramen is commonly displaced nearer to one extremity of a long bone than the other, and the canal is usually oblique with respect to

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http://dx.doi.org/10.1016/j.jasi.2015.06.002
0003-2778/

the long axis of the bone. Berard[1] was the first to point out that in the human long bones the nutrient canals were obliquely disposed, pointing towards the elbow in the upper limb and away from the knee in the lower limb. The dissection room jingle ''*To the elbow I go; from the knee I flee*'' is originally in French, ''Au coude je m'appuis, du genou je m'en fuis''. This is called the Berard's rule of canal direction.

Investigations on the vascular anatomy of long bones were in the past confined mostly to animals. A few authors have studied nutrient foramina in human long bones, including the fibula.[3,4] Some authors have studied the lower limb long bones, including the fibula.[5–10] Few have studied the nutrient foramina of fibula particularly.[11,12] In this study, we examine in detail the diaphyseal nutrient foramina in 251 fibula, which is the largest sample size studied, and also study a new parameter – the 'caliber' of the foramina.

2. Material and method

This study was conducted on 251 fibula (135 right and 116 left), macerated specimens of adult human fibula, available in bone store of Government Medical College, Surat. These were of Indian Gujarati race and of unknown sex. The instruments used for the study were an Osteometric board, Vernier Calipers, Hypodermic Needles of size 20G and 24G, Steel Measuring Scale, Hand lens, Divider, marking pen, etc.

Each fibula was numbered serially with a marking pen to help in identification. Their side (left or right) was determined. The diaphyseal nutrient foramina were observed in all the bones with a hand-lens and encircled with a black marker pen. Various parameters were recorded for each of the fibulas, and the nutrient foramen and all values are recorded in centimeters. Only the diaphyseal nutrient foramina were studied and other foramina like epiphyseal were excluded. The following methodology was used to study the parameters.

2.1. *The total length (TL)*

The total length (TL) of each fibula was measured with the help of osteometric board and recorded to the nearest millimeter. Determination of the total length of the individual bones was done by taking the measurement between the apex of the head of the fibula and the distal aspect of the lateral malleolus.

2.2. *Total number of nutrient foramina*

The diaphyseal nutrient foramina were observed in all the bones carefully with a hand-lens and the total number of foramina present on any surface or border was recorded. In bones where there was doubt as to the nature of a foramen, a fine wire was passed through it to confirm that it did enter the medullary cavity. Foramina at the ends of the bone were not taken into account.

2.3. *The distance of the foramen or foramina from the upper end of the bone (DNF) and calculation of foraminal index*

The distance of the foramen or foramina from the upper end of the bone was measured by means of Vernier sliding calipers and recorded as DNF. The range of distance of nutrient foramen from upper end and the mean of distance of nutrient foramen from upper end were obtained and recorded. The foraminal index (FI) for each nutrient foramen was obtained using the formula: FI = DNF/TL × 100, where DNF was the distance from the proximal end of the fibula to the nutrient foramina, and TL was the total bone length. Thereafter, the mean of foraminal index, least foraminal index, and the highest foraminal index for fibula were determined and recorded.

2.4. *The location of nutrient foramen*

All the surfaces of the bones were scrutinized in a regular order. Foramina within 1 mm from any border were taken to be lying on that border. The descriptive term used for the surface and borders of the diaphysis of each fibula was recorded according to the Gray's textbook of anatomy,[13] for uniformity and standardization. The location of the nutrient foramina was also recorded in terms of the fraction of the bone it occupied from the upper end. For this, the fibula were divided into three equal fractions from above downwards and denoted as I, II, and III.

2.5. *The directions of the nutrient foramina*

The directions of the obliquity of the nutrient foramina and their canals were noted. A long fine needle was passed through the nutrient foramen and canal, to ascertain the direction of the canal. It was recorded as 'up' or 'down' with respect to the proximal end of the fibula being up.

2.6. *Caliber of the foramen and canal*

Hypodermic needles of 20G and 24G were used to measure the caliber of the foramen and canal. If the size 20G passed through the nutrient foramen satisfactorily, it was classified as 'Large' sized. If the needle of size 24G passed through the foramen and the size 20G did not pass through, the nutrient foramen was classified as 'Middle' sized. Both large and middle-sized foramina were also categorized as being Dominant. If the needle of size 24G could not pass through the foramen it was classified as 'Small' sized or 'Secondary' nutrient foramen.

After measuring all the bones, the 'Range' and the 'Mean' of measurements were obtained.

3. Result

The total number of fibula bones examined was 251; of which, 135 were of right and 116 were of left side. The detailed observation is summarized in Tables 1–3, and illustrated in Photo 1.

4. Discussion

On detailed study of our findings and comparing with the existing literature, we present the following analysis. The mean total length of the fibula is found to be 35.83 cm, the right

Table 1 – General observations on study of fibula and nutrient foramina (NF).

Side	Total no. of fibula bones examined	Total no. of foramina in each fibula	Range of total length	Mean of total length	Range of distance of NF from upper end	Mean of distance of NF from upper end	Mean of foraminal index	Least foraminal index	Highest foraminal index
Right	135	107	32.8–42.4	36.37	12.5–20.9	15.50	42.46	31.65	56.43
Left	116	119	31.2–38.9	35.23	12–24	16.04	45.57	35.04	67.76
Combined	251	2247	31.2–42.4	35.83	12–24	15.78	44.12	31.65	67.76

Table 2 – Observations on the caliber (big, medium, and small), number and direction of nutrient foramina of fibula.

Side	NF of Big size	NF of Medium size	NF of Small size	No. of bones: NF not seen	No. of bones with 1 NF	No. of bones with 2 NF	No. of bones with 3 + NF s	Direction of NF upwards	Direction of NF downwards
Right	8	0	99	30	105	1	0	0	107
Left	0	0	119	2	109	5	0	21	98
Combined	8	0	218	32	214	6	0	21	207

Table 3 – Observations on the location of nutrient foramina of fibula (medial crest = MC; anterior to medial crest = A-MC; posterior to medial crest = P-MC).

Side	No. of NF located on MC	No. of NF located on A-MC	No. of NF located on P-MC	Location of NF on I part	Location of NF on II part	Location of NF on III part
Right	43	0	64	14	94	0
Left	47	19	53	0	115	4
Combined	90	19	117	14	209	4

Photo 1 – Fibula with nutrient foramina.

being 36.37 cm and the left side being 35.23 cm. Kizilkanat et al.[3] report a similar length of 34.02 cm. In the present study, the fibula bone was found to have variable number of nutrient foramina, ranging from '0′ (no nutrient foramina found) to '2′ number of nutrient foramina on a single bone. On comparing

Table 4 – Comparison of the foraminal indices of right and left sides fibula of present study.

Foraminal index	Right	Left
Mean foraminal index	42.46	45.57
Highest foraminal index	56.43	67.76
Lowest foraminal index	31.65	35.04

the result of the present study with other authors, who have done similar study before (Table 5), we find a higher incidence of bones, where the foramina are not found compared to Kizilkanat et al.[3] and Mysorekar,[4] but our finding is very less than of Murlimanju et al.,[5] who reports absent nutrient foramina in 9.8%. Other authors[8,12,13] also observed fibulae with no nutrient foramen. When the nutrient foramina is not found, it may be due to absent nutrient foramina, in which case the periosteal vessels form the main blood supply, or it may be due to the maceration process, which has obscured the small caliber nutrient foramina present, but in this study, it is considered as '0′ nutrient foramina. For the fibula, the most

Table 5 – Comparison of number of nutrient foramina on fibula reported in various studies.

Author	No. of bones	% OF bones with '0′ N.F.	% of bones with '1′ N.F.	% of bones with '2′ N.F.
Kizilkanat et al. (2007)[3]	73	1.36	93.15	5.48
Mysorekar (1967)[4]	180	3.8	98.33	3.33
Murlimanju et al. (2011)[5]	56	9.8	90.2	0
Present study	**251**	**12.75**	**85.26**	**1.9**

Table 6 – Comparison of % of fibula bone on right and left sides with reference to number of nutrient foramina per fibula bone.

Author	Total bones	'0' NF		'1' NF		'2' NF	
		R	L	R	L	R	L
Mysorekar (1967)[4]	180	2.2%	1.6%	45.5%	46.6%	1.6%	1.6%
Present	**251**	**11.9%**	**0.8%**	**41.8%**	**43.4%**	**0**	**1.99%**

Table 7 – Comparison of the foraminal indices reported in various studies.

Author	Lowest foraminal index	Highest foraminal index	Mean foraminal index
Kizilkanat et al. (2007)[3]	26	83	
Mysorekar (1967)[4]	27.08	70.66	
Forriol Campos et al. (1987)[9]	35	67	
Gümüsburun et al. (1994)[12]			47.82
Sendermir et al. (1991)[8]	29.8	67.8	
Murlimanju et al. (2011)[5]			49.2
Present Study	**31.65**	**67.76**	**44.12**

Table 8 – Comparison of location of NF reported in various studies (medial crest = MC; anterior to medial crest = A-MC; posterior to medial crest = P-MC).

Author	No. of bone studied	Total no. of NF	MC	AMC	PMC	MS	LS
Kizilkanat et al. (2007)[3]	73	76	84.5%	0.2%	15.7%		
Mysorekar (1967)[4]	180	179	55.8%	10.6%	32.9%	0	0
Murlimanju et al. (2011)[5]	51	46	36.9%	15.2%	43.5%	0	0
Present study	**251**	**226**	**39.8%**	**8.4%**	**51.8%**	**0**	**0**

common observation, including the present study, is a single nutrient foramen, which is also reported by most authors,[3,4,8–10,15] McKee et al.[14] also reported fibulae with three foramina while Murlimanju et al.[5] found none of the fibulae showing multiple foramina. The mean number of nutrient foramina per fibula bone was calculated as 0.9 for the present study. Similar value has been reported by Kizilkanat et al.[3] as 1.04 and Mysorekar[4] as 0.99. This signifies that the fibula is rarely supplied by more than one nutrient artery.

The incidence of fibula bones having variable number of nutrient foramina was analyzed with respect to the sides (right or left), and the result was compared with the other authors (Table 6). The only significant difference is that right side fibulae show little more incidence of absent nutrient foramina.

The mean foraminal index was obtained for the present study as 44.12%. The lowest is 31.65 and the highest is 67.76. These values are similar to most of the previous studies, and the range is little higher in the study of Kizilkanat et al.[3] (Table 7). The foraminal indices of both right and left side were compared in the present study, and it was found to be similar (Table 4).

The nutrient foramina were located on variable anatomical parts (surface and borders) of the fibula. This was studied, and on comparing the result of this study with the other authors (Table 8), we find that there is no nutrient foramina located on medial or lateral surface like the finding of Mysorekar,[4] while the posterior surface (medial crest, anterior, and posterior to it), contains similar frequency of nutrient foramina in all studies. There is more common location of nutrient foramina posterior to the medial crest than anterior to it in this study. Mysorekar[4] and Murlimanju et al.[5] also report the same.

The incidence of location of nutrient foramina on each surface and border of the fibula bones were analyzed with respect to the sides (right or left), and the result was compared with Mysorekar[4] (Table 9). The result is similar for both sides except that the left side antero-medial surface has more frequent location than the right side fibula in this study.

The location of the nutrient foramina on the fibula, with respect to the '1/3rd' fraction of the total length of the bone from the upper end, was documented in this study. On comparing the result with Mysorekar[4] (Table 10), slightly more frequency is reported on the 1st part, and yet the majority islocated on 2nd

Table 9 – Comparison of right and left sides with reference to % of nutrient foramina located on various surfaces and borders of fibula bone.

Author	Total NF	MC		AMC		PMC	
		R	L	R	L	R	L
Mysorekar (1967)[4]	179	29.6%	26.2%	6.1%	4.4%	13.4%	19.5%
Present Study	226	**19%**	**20.8%**	**0**	**8.4%**	**28.3%**	**23.5%**

Table 10 – Comparison of the location of the nutrient foramina on corresponding 'third' fractions from the upper end of the fibula.

Author	No. of bone	Total NFs	I	II	III
Mysorekar (1967)[4]	180	179	1.6%	96%	2.2%
Present Study	251	226	**6.2%**	**92.5%**	**1.8%**

Table 11 – Comparison of the right and left sides with reference to location of the nutrient foramina on corresponding 'third' fractions from the upper end of the fibula.

Author	Total NFs	I		II		III	
		R	L	R	L	R	L
Mysorekar (1967)[4]	179	1.1%	0.5%	47.5%	48.6%	1.1%	1.1%
Present Study	226	**6.2%**	**0**	**41.6%**	**50.9%**	**0**	**1.8%**

Table 12 – Comparison of the direction of the nutrient foramina.

Author	Total NF	Upwards	Downwards
Mysorekar (1967)[4]	179	9 (Rt.) 4 (Lt.) 5	170
Present Study	251	**21** **(Rt.) 0 (Lt.) 21**	**205**

part. With the exception of Guo,[15] who reported the majority of foramina to be located in the upper one-third of the diaphysis, in all other studies, they are in the middle one-third.

The incidence of location of nutrient foramina on the corresponding 3rd part from upper end of fibula bone was analyzed with respect to the sides (right or left), and the result was similar to that of Mysorekar[4] (Table 11). There is more frequency of location on the right side in the 1st fraction of the fibula. Other fractions have similar frequency for both sides.

As per Berard's law,[1] the nutrient foramina should have been always directed downwards, but 21 fibulae out of 251 showed abnormal upward direction (Table 12). This may be due to the peculiar ossification of the bone. It is possible that in the fibula, one end may act as the growing end for a time and then subsequently the other. The upwardly directed foramina were always found low down on the bone, similar to the finding of Mysorekar[4] If the nutrient artery to these fibulae arose from the lower part of the peroneal artery, the anomalous direction could be explained on this assumption. In four fibulae, one foramen was directed upwards and the other downwards (Photo 2); it is possible that each end acted alternately as the growing end. 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.[16] Many theories have been put forward to account for the direction of foramina and also the anomalously directed ones. Among them, the 'vascular theory' of Hughes[16] states that direction is determined by the unequal growth at the ends of the bones and 'periosteal slip' theory of Schwalbe[17] (as cited by Murlimanju et al.[5]) states that the canal finally becomes directed away from the growing end. In this study, the abnormal direction is found predominantly on left side.

'Big' or dominant foramina were little more common on the right side. There are only 3.18% dominant nutrient foramina, which may be due to the absent weight-bearing role of the fibula, and therefore, the need for great vascularity is perhaps reduced. Also, the surfaces are covered extensively by muscle attachments, so the periosteal blood supply is quite sufficient. The cortex of fibula is also thinner compared to other fibulas, thus making the demand for a dominant, large caliber nutrient artery unnecessary.

This study has a few limitations because it is done on macerated bones, and therefore, the clinical significance in vivo will not be directly determined. Another limitation of availability of literature for parameter of 'Caliber' was found because it has not been reported in existing literature, and we opine that it is a very important parameter, as the caliber directly represents the volume of blood that will be supplied through the nutrient artery, and therefore, dominant foramens will be of more clinical importance. Further studies using high-resolution digital radiography to determine the same parameters in vivo will validate the findings.

Photo 2 – Fibula with 2 nutrient foramina pointing in both upward and downward directions.

5. Summary and conclusion

The average number of diaphyseal nutrient foramina found in fibulas was 0.9. The foraminal index for the fibula was 44.12%. The frequency of the location of nutrient foramina, in fraction of total length; 'One Thirds' part of fibula, they were located most commonly on the 2nd (1/3rd) part (92.5%). In addition, the number and the distribution of the foramina in relation to specific regions/surfaces of the diaphysis were identified. 100% of nutrient foramina were on the posterior surface in fibulae; out of which, 51.8% were found on the surface posterior to medial crest in the fibulae. Variations have been observed in

the direction of nutrient foramina in fibulae. In 21 out of the 251 fibula bones, the nutrient foramina were found directed upwards. The caliber of the diaphyseal nutrient foramina and canal were determined in categories of big, medium (Dominant), and small sizes (Accessory or Secondary), and the frequency of each category in each of the fibula. The fibula had only 3.18% dominant foramina. It was observed that fibulas have equal distribution of dominant nutrient foramina on either side.

It is emphasized that an accurate knowledge of the location of the nutrient foramina in fibulas should help prevent intra-operative injuries in orthopedic, as well as in plastic and reconstructive surgery. Surgeons should avoid a limited area of the cortex of the fibula containing the nutrient foramen, particularly during open reduction, an improvement in the management of fractures and their healing problem might be attained. The findings of this study are significant because it has been done on a very large sample size (251) and a new parameter of 'Caliber' of the Diaphyseal Nutrient Foramina has been studied for the first time.

Conflicts of interest

The authors have none to declare.

Acknowledgements

The authors would specially like to thank Dr (Prof) C.D. Mehta and the Teaching and Non-Teaching staffs of Government Medical College, Surat, Gujarat, who have immensely helped in the successful completion of this study.

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