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Morphological and topographical anatomy of nutrient foramina in the lower limb long bonesand its clinical importance

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RESEARCH

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Abstract

Background
Knowledge regarding nutrient foramina of bones is useful in surgical procedures such as microvascular bone transfer in order to preserve the circulation. The objective of the present study was to study the morphology and topography of nutrient foramina and to determine the foraminal index of the lower limb long bones to provide detailed data on such features.

Method
The study comprised examination of 206 lower limb long bones which included femora, tibiae and fibulae. The nutrient foramina were identified analysed macroscopically and the foramen index calculated. Each bone was divided into five parts and topographical analysis was performed on each section.

Results
Femora had single nutrient foramen in 47.7% of the cases, double foramen in 44.2% of the cases, triple in 3.5% of the cases and an absence of foramen in 4.6%. In the case of tibiae, 98.6% showed single foramen and in 1.4% of the cases, the foramen was absent. With respect to fibulae, 90.2% had single foramen and foramen was absent in 9.8%. The mean foraminal index was 38.9 for the femora, 32.5 for tibiae and 49.2 for fibulae. The majority (51.3%) of the foramina in the femora were located at the $2/5^{th}$ part, 98.3% of the tibiae foramina at the $2/5^{th}$ part and 60% of the fibulae at the $3/5^{th}$ part.

Conclusion
The study provides information on the morphology and topography of nutrient foramina in lower limb long bones. The double foramina were more common in femur and rare in the tibia and fibula. The foramina of the femur and tibia were commonly observed at their upper part, whereas in the fibula they were present on the lower part. This knowledge of the nutrient foramina has to be kept in mind during surgical procedures.

Key Words
Foraminal index, long bones, morphology, nutrient foramen, topography

What this study adds:
1. The study provides data on the morphology and topography of the nutrient foramina in bony specimens.
2. The data is helpful for clinicians involved in vascular graft surgeries.
3. This research emphasises the anatomical description of nutrient foramina which is important as microvascular bone transfer is becoming more popular.

Background
Long bones are supplied by a nutrient artery that enters individual bones obliquely through a nutrient foramen. This foramen, in the majority of cases is located away from the growing end[1] hence the derivation of the axiom that foramina 'seek the elbow and flee from the knee'.[2] This is because one end of the limb bone grows faster than the other. Henderson[3] reported that their position in mammalian bones are variable and may alter during

growth. Though the foramina are directed away from the growing end, their topography might vary at the non-growing end. So the topographical anatomy of the nutrient foramina may be of worth. The topographical knowledge of these foramina is useful in certain operative procedures to preserve the circulation.[4-6] Therefore it is important that the arterial supply is preserved in free vascularised bone grafts so that the osteocytes and osteoblasts survive.[7]

When a bone graft is taken, the vascularisation of the remaining bones has to be considered with the vascularity of this area allowing various options in grafting.[8] It has previously been reported that the ideal bone graft for the free transfer should include endosteal and periosteal blood supply with good anastomosis.[5] The bony defect which is left behind following traumatic injuries, tumour resection procedures and pseudoarthrosis can all be reconstructed by bone grafting procedures and the preferred modality is free vascularised bone graft.[9] The importance of preoperative angiography remains important to exclude the possible vascular anomalies in both recipient and donor bones for the microvascular bone transfers.[10]

There are few reports available on the morphology of nutrient foramina of the lower limbs.[6, 10, 11] The aim of the present investigation was to study the topographic anatomy and morphology of the nutrient foramina in human adult lower limb long bones. The foraminal indexes for the lower limb long bones were also determined.

Method

The study included 206 lower limb long bones (Figure 1) which included 86 femora (36 right, 50 left), 69 tibiae (32 right, 37 left) and 51 fibulae (25 right, 26 left). Bones (Figure 1) were obtained from the osteology section of our Department of Anatomy. All the bones belonged to Asian Indian subjects, the age and gender of which were not determined. Bones which had gross pathological deformities were excluded from the study. All the bones were macroscopically observed for the number, location and direction of the nutrient foramina. A magnifying lens was used to observe the foramina. The nutrient foramina (Figure 2) were identified by the presence of a well marked groove leading to them and by a well marked, often slightly raised, edge at the commencement of the canal. Only diaphysial nutrient foramina were observed in all the bones (Figure 2) and a 24 gauge needle was passed through each foramen to confirm their patency. The number and topography of the foramina in relation to specific borders or surfaces of the diaphysis were analysed. The foramina within 1mm from any border were taken to be lying on that border. An elastic rubber band was applied around these foramina (Figure 1) and the photographs were taken with a digital camera, which was manufactured by Nikon (Coolpix S3000, made in China). The parameters were measured by using a scale bar which was kept over the photographs. The length of the bones in the photographs might vary while assessing the scale of the photos depending on the distance at which the photo was taken, but the ratio which was calculated remains constant. The foramen index (FI) was calculated by applying the Hughes[12] formula, dividing the distance of the foramen from the proximal end (D) by the total length of the bone (L) which was multiplied by hundred.

$$FI = D / L \times 100$$

Figure 1: The lower limb long bones (A- femora, B- tibiae, C- fibulae) with rubber bands tied at the level of the foramina

For those bones which had double nutrient foramina, the larger foramen was taken into consideration during the estimation of FI. The FI was determined for all the bones which give the location of the nutrient foramen, each bone was divided into five equal parts and was analysed topographically. The data was collected on a standardised sheet and tabulated. This analysis was done to interpret the topography in a better way and to represent the same in the form of a table.

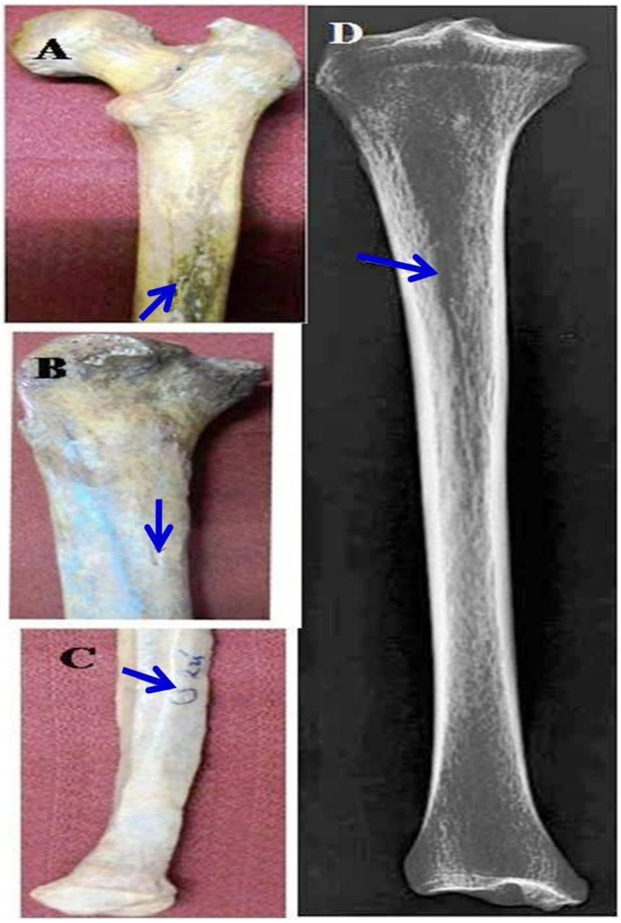

Figure 2: The femur (A), tibia (B) and fibula (C) bones showing the nutrient foramina (arrow mark), which are directed away from the knee joint (2D- radiographic film showing the lower limb long bone and its nutrient foramen, arrow mark)

Results

In the present study, 47.7% of the femora had a single nutrient foramen. The double foramen was observed in 44.2% of the cases, triple foramen in 3.5% and the foramen were found to be absent in 4.6% of the femora. Sixty-six femora showed the foramina on the linea aspera (LA), 37 at the medial lip of linea aspera (ML), 5 had foramen at the lateral lip of linea aspera (LL), 16 at medial surface (MS) and 1 each at lateral (LS) and popliteal surfaces (PS). The morphological and topographical distribution of the foramina of femur is represented in Table 1.

In the examined tibiae, 98.6% had single foramen and in 1.4% of the cases the foramen was absent. The multiple foramina were not observed in the case of tibiae. All the bones showed the foramina at the posterior surface. The foramen was present below the soleal line (BSL) in 66 cases and above the soleal line (ASL) in only 2 cases. In case of foramina below the soleal line, 47 were lateral to vertical line (LVL) which is present at the posterior surface and 19 tibiae had the foramen medial to vertical line (MVL). The detailed analysis of the distribution of the tibial nutrient foramen is shown in Table 2.

With respect to fibulae, 90.2% showed the single foramen. In the remaining 9.8% of the cases the nutrient foramen was absent. None of the fibulae showed the multiple foramina. The foramen was seen between the medial crest and interosseous border (MC/ IB) in 7 cases, between medial crest and posterior border (MC/ PB) in 20 cases, on the medial crest (ON MC) in 17 cases and on the interosseous border (IB) in 2 cases. The distribution is represented in Table 3.

The mean FI was 38.9 for the femora, 32.5 for the tibiae and 49.2 for the fibulae. The majority (51.3%) of the foramina in femur were located in the 2/5th region, 98.3% of the tibial foramina in the 2/5th region and 60% of the fibular foramina in the 3/5th region. Table 4 analyses the topography of the foramina along the length of the bones, i.e. in the 1/5th, 2/5th, 3/5th, 4/5th and 5/5th regions as seen from the FI. The radiographic appearance of the nutrient foramina in one of the lower limb long bones is shown in Figure 2D.

Discussion

It is well known that one of the causes of delayed union or non-union of fracture is lack of arterial supply.[13] The biologic process of repair of a traumatic or surgically induced fracture has been described as developing slowly or not at all.[14] The morphological knowledge of nutrient foramina is significantly important for orthopaedic surgeons undertaking an open reduction of a fracture to avoid injuring the nutrient artery and thus lessening the chances of delayed or non-union of the fracture.[13] The external opening of the nutrient canal, usually referred to as the nutrient foramen, has a particular position for each bone.[15] It is generally agreed that the vessels which occupy the nutrient foramen are derived from those that took part in the initial invasion of the ossifying cartilage, so that the nutrient foramen was at the site of the original centre of ossification.[15] Hughes[12] observed that the variant foramina were common in the femur, rare in the radius and very rare in other bones. However, Mysorekar[4] found anomalously directed foramina only in the fibula and opined that this was due to the peculiar ossification pattern in that bone. 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.[12] Schwalbe[16] 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. Many theories have been put forward to account for the direction of foramina and also the anomalously directed ones. Among them the 'periosteal slip' theory of Schwalbe[16] and vascular theory of Hughes[12] are widely accepted in the literature. Patake and Mysorekar[2] opined that the number of foramina does not seem to have any significant relation to the length of the bone. It was suggested that the direction of nutrient foramina is determined by the growing end of the bone. The growing end is supposed to grow at least twice as fast as the other end.[4] The nutrient artery runs away from the growing end as the growing bone might pull and rupture the artery. So the nutrient foramina are directed away from the growing end.

Two well-known factors may affect nutrient foramen position. These are growth rates at two ends of the shaft and bone remodelling.[3] Addressing the growth rates and bone remodelling, the bones of different age groups need to be studied. The fetal bones could also help in analysing this concept. The present study could not address these factors as the study involved cadaver dry bones. Lacroix[17] suggested that the pull of muscle attachments on the periosteum explained certain anomalous nutrient foramina directions. Nutrient arteries which are the main blood supply to long bones are particularly vital during the active growth period and at the early phases of ossification.[18] So the nutrient arteries should be kept patent until the growth is completed and even after the growth. Hence they are directed away from the growing end. These nutrient arteries pass through the nutrient foramina, the position of nutrient foramina in mammalian bones are variable and may alter during the growth.[3] The nutrient artery of femur may arise from the medial circumflex femoral artery or from any artery parallel to the diaphysis. In the tibia the artery originates directly from the popliteal or posterior tibial artery. The fibula is supplied from one or more branches of the peroneal artery.[4] Mysorekar[4] reported that both foramina of the femur should be treated as main ones and the presence of which is not surprising in view of the length of the femur. He reported that the femur usually has two nutrient foramina and they are restricted to the linea aspera or its surroundings in the middle third of the bone. In the present study, we observed the double nutrient foramen in 44.2% of the cases. According to other authors, the double nutrient foramen of the femur was observed in 42.8%,[10] 60%,[19] 46% by Sendemir and Cimen[20] and 55.6% by Laing.[21] The triple foramina were observed in 3.5% of the cases of the present study. This is slightly less compared to the previous studies. The triple foramina were noted in 10.7% of cases by Gumusburun et al.[10] The tibia and fibula usually have a single nutrient foramen.[4] In the present study, 98.6% of the tibiae had single foramen. This is similar to the reports of Gumusburun et al.,[10] who observed this in 84.9% of cases. We observed the single fibular foramen in 90.2% of the cases, which is similar to the reports of Restrepo et al.[22] (94%), Fen[23] (94.9%), McKee et al.[6] (86.4%) and Forriol Campos et al.[19] (100%). In tibiae the foramen occurs in its upper third lateral to the vertical line, which in turn arises from the soleal line and runs vertically downwards. The foramen of the fibula lies in its middle third.[4] In the present study, all tibiae had single foramen except one tibia in which the foramen was absent. The majority of the tibiae had foramina below the soleal line. A similar finding was observed by Forriol Campos et al.[19] who found that all the foramina of examined tibiae were below the soleal line and in examined fibulae, 90.2% showed the foramen; all were single and the double foramina were not observed. This is not in agreement with other authors as they reported the double foramen in their studies of fibulae, with Gumusburun et al.[10] reporting this finding in 11.7% of the cases and Mc Kee et al.[6] observing the triple foramen in one fibula.

Gumusburun et al.[10] report the mean of FI was 48.82 for femora, 33.17 for tibiae, and 47.82 for fibulae. In their study, the common location and number of foramina were two on the linea aspera in the middle third of the femur, one on the posterior surface of the upper third of the tibia and one on the posterior surface of the middle third of the fibula. Forriol Campos et al.[19] studied the nutrient foramina of both upper and lower limb long bones in Spanish specimens. They reported that the diaphysial nutrient foramina in the femur lie between 25 to 58%, in the tibia, at between 30 to 40% and in the fibula at between 35 and 67%. Collipal et al.[11] reported that nutrient foramen of the femur was located in the linea aspera in 36.25% cases, 8.75% in the lateral lip and 27.5% in the medial lip of linea aspera, 21.25% in the medial surface and 6.25% in the lateral surface of diaphysis of the bone. They also found the nutrient foramen of the tibia under the soleal line in a 94.33%, in the soleal line in 3.77% and in the lateral border in 1.88%. Additionally they reported that nutrient foramen of the fibula was found in 68% of the posterior surface, 14% in the medial surface, 12% on the medial border, 4% on the lateral surface and 2% at the lateral border. Sendermir and Cimen[20] observed that diaphysial nutrient foramina of femur were located between 26.7–84.4% of the total length, while of the tibia between 11–67.2% and on the fibula between 29.8–67.8% of the total length. According to the Turkish study from Kizilkanat et al.,[18] foramina were located on the diaphysis, 29–69% of the overall length of the femur, 27–63% for the tibia and 26–83% for the fibula. Kirschner et al.[24] found two foramina in 57%, one foramen in 35% and three foramina in 8% of the cases of the femur and tibia.

In the present study, it was observed that the foramina were located on the diaphysis 28–61% of the overall length of the femur, 28–54% for the tibia and 27–80% for the fibula. The majority (51.3%) of the foramina in the femora were located at the 2/5th part, 98.3% of the tibiae foramina at the 2/5th part and 60% of the fibulae foramina at the 3/5th part. These findings are almost similar to the previous reports from other studies, however there are a few differences observed which might have occurred due to racial variations. In a study of Caucasian bones, the nutrient foramen of the fibula was observed in the middle 1/3 region in 90% of the cases.[6]

The absence of nutrient foramina in long bones is well known.[4,25] It was reported that in instances where the nutrient foramen is absent, the bone is likely to be supplied by periosteal arteries.[2] In the present study, the nutrient foramen was absent in 4.6% of the femora, 1.4% of the tibiae and 9.8% of the fibulae.

The blood supply to the femoral diaphysis is provided by one or two nutrient arteries arising from the profunda femoris artery.[26] It was reported that, in femoral diaphysis transplant surgeries, the profunda femoris artery can be used. So the number and location of nutrient artery has to be considered in the case of graft surgeries. A graft with good vascular supply will have better results. Garcia,[27] in his study validated the circumference at the nutrient foramen of the tibia for sex determination on human osteological collections. The topographical knowledge of the nutrient foramina of fibula is important to proceed with the free implant of the vascularised bone.[11] The vascularised fibular grafts have been used for mandibular reconstruction, both alone as well as with the dental implants.[28] In light of these facts, we suggest that the anatomical details of the nutrient foramina are essential for the clinician who is involved in vascular graft procedures.

This study has some limitations. These include age and sex differences which were not considered as we were not able to estimate the age and gender of the bones studied. These differences might alter the results as the anatomy of foramina might differ in males and females. In old ages, some foramina might also get ossified. So it is better to consult a forensic expert to segregate the bones and analyse them based on a specific age group and gender. Since the nutrient foramina of the long bones may alter during growth, the sample long bones should be confined in a specific age group. Future implication of the present investigation includes the angiography or latex infusion study which may provide a more precise register of foramina morphology.

The present study provides information on the morphological and topographical anatomy on nutrient foramina of lower limb long bones. This is important for surgical procedures involving vascularised bone grafts to preserve the circulation within the bone. Further research defining a convention for the anatomical description of nutrient foramina is necessary to further define these structures.

Conclusion

The present investigation provides additional information on the lower limb long bone nutrient artery foramina. As techniques such as microvascular bone transfer are becoming more popular, information relating to the anatomical description of these foramina is vital to preserve the circulation of affected bony structures. It is also of relevance for those clinicians involved in surgical procedures where patency of the arterial supply to long bones is important.

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CONFLICTS OF INTEREST

The authors declare that they have no competing interests.

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Nil

TABLES

Table 1: Showing the morphological and topographical distribution of the nutrient foramina in the femur (n=86). (LA – linea aspera, ML – medial lip, LL – lateral lip, MS – medial surface, LS – lateral surface, PS - popliteal surface).

	No. of femur									
No. of foramina	Right side	Left side	Total	%	LA	ML	LL	MS	LS	PS
0	2	2	4	4.6	-	-	-	-	-	-
1	18	23	41	47.7	25	10	3	3	-	-
2	15	23	38	44.2	36	26	2	11	1	-
3	1	2	3	3.5	5	1	-	2	-	1
	36	50	86	100	66	37	5	16	1	1

Table 2: Showing the morphological and topographical distribution of the nutrient foramina in the tibia (n=69) (MVL – medial to vertical line, LVL – lateral to vertical line, ASL – above soleal line, BSL – below soleal line)

	No. of tibia							
No. of foramina	Right side	Left side	Total	%	MVL	LVL	ASL	BSL
0	-	1	1	1.4	-	-	-	-
1	32	36	68	98.6	19	47	2	66
	32	37	69	100	19	47	2	66

Table 3: Showing the morphological and topographical distribution of the nutrient foramina in the fibula (n=51) (MC/ IB – between medial crest and interosseous border, MC/ PB – between medial crest and posterior border, ON MC – on medial crest, IB – on interosseous border)

	No. of fibula							
No. of foramina	Right side	Left side	Total	%	MC / IB	MC / PB	ON MC	IB
0	3	2	5	9.8				
1	22	24	46	90.2	7	20	17	2
	25	26	51	100	7	20	17	2

Table 4: Showing the topographical distribution of the nutrient foramina based on the FI of the lower limb long bones (n=206)

Topography of foramina	Femur	Tibia	Fibula
1/5th part	nil	nil	nil
2/5th part	51.3%	98.3%	26.7%
3/5th part	42.6%	1.7%	60%
4/5th part	6.1%	nil	11.1%
5/5th part	nil	nil	2.2%
Mean FI	38.9	32.5	49.2