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Research Article

ANATOMICAL STUDY OF NUTRIENT FORAMINA IN LONG BONES OF HUMAN UPPER AND LOWER LIMBS

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ABSTRACT

Objectives: The objectives of the study are as follows: (1) To determine the number, location, position, and direction of nutrient foramina in the shaft of long bones. (2) To determine the foraminal index of the long bones.

Methods: This was a cross-sectional study, undertaken on dry cadaveric human long bones of unknown age and sex from the Department of Anatomy, M.S. Ramaiah Medical College, Bangalore. The duration of study was 2 years. In this study, 350 human long bones which include the clavicle, humerus, radius, and ulna from the upper extremity; femur, tibia, and fibula from the lower extremity were examined in detail for the number, position, location, and directions of the nutrient foramen. For statistical purposes, $p<0.05$ was taken as significant.

Results: All the bones had single nutrient foramina and a higher percentage of double nutrient foramina was seen in femur. The most common position was the middle one-third of the shaft and the surface distribution was different in different bones. All the bones had the nutrient foramina, which were directed away from the growing end. The mean foraminal index for clavicle, humerus, radius, and ulna was 52.85±9.24, 56.92±6.57, 34.80±6.07, and 36.0±5.85, respectively. Mean foraminal index for femur, tibia, and fibula was 43.54±10.32, 32.37±3.1, and 51.68±9.77.

Conclusion: Knowledge of nutrient foramina of long bones is crucial for orthopedic surgery, forensic identification, obtaining vascularized bone grafts, and treating trauma or malignant bone conditions.

Keywords: Nutrient foramina, Long bones, Foraminal index, Forensic identification.

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INTRODUCTION

Bone is a living, highly vascular, constantly changing, and mineralized connective tissue. It has both inorganic compounds and organic compounds. Inorganic compounds are hard and organic compounds are resilient. Bone resists both compressive and tensile forces. It resembles cast iron in tensile strength and steel in flexibility. The bone forms the skeletal basis of our body, giving shape and support to the body. It is also responsible for the motor activity of the body. It is richly supplied with blood vessels. The blood circulation within the bone supplies nutrition to the living bone tissue, the marrow, periosteum, epiphysis, cartilage in young bones, and part of the articular cartilages.[1]

Recent research indicates that the blood flow through the cortical bone is centrifugal and not centripetal as reported previously. The site of entry of nutrient artery into the shaft of bone and its angulations are almost constant and they are directed away from the dominant growing epiphysis. This forms the basis of the growing end hypothesis, which explains the positions and orientations of the nutrient foramina and the nutrient canals.[2]

In metacarpals and metatarsals, the nutrient foramina can be present or absent; can be single or double though more than 90% of them have a single nutrient foramina in the middle of shaft away from the epiphysis. In fibula, due to its unique pattern of ossification, nutrient canals are atypically directed.[3]

The blood supply to the shaft of long bones is by nutrient, juxta-epiphyseal, epiphyseal, and periosteal vessels. Nutrient arteries can be either one or two, which enter the shaft obliquely through the nutrient foramina which leads into nutrient canals. The tortuosity of the nutrient artery before it enters into the nutrient foramen will protect the artery from getting damaged during active muscular movements and it will also prevent the alteration in blood pressure. The direction of the nutrient canals follows the dictum "to the elbow I go, from the knee I flee".[4]

The blood supply to various long bones in the human body is essential for their growth, repair, and overall health. Each bone has specific nutrient foramina (small openings for blood vessels) that provide a direct blood supply. In the clavicle, the suprascapular artery supplies blood to the bone. The humerus receives a robust blood supply from various arteries, including the brachial artery, radial, and ulnar arteries. Damage to these nutrient vessels can lead to non-union at fracture sites.[5] The radius and ulna are supplied by radial, ulnar, anterior, and posterior interosseous arteries, with their nutrient foramina typically on the anterior surface. The femur's main nutrient artery is usually a branch of the profunda femoris artery, with one or two nutrient foramina near its linea aspera. The tibia's nutrient foramen is close to the soleal line, and its nutrient artery is typically a branch of the posterior tibial artery. The fibula's nutrient foramen is proximal to the midpoint of the posterior surface, directed distally, and supplied by the peroneal artery. The peroneal artery's origin can vary among individuals, classified into five types by Taylor. Understanding the location and sources of these nutrient foramina is crucial for surgical procedures and the management of bone fractures, ensuring adequate blood supply and promoting bone healing. It is also important for forensic experts to recognize the unidentified bodies.[6]

We undertook this study to determine the number, location, position, and direction of nutrient foramina in the shaft of long bones and to calculate the foraminal index.

Aims and objectives

The objectives of the study are as follows:
1. To determine the number, location, position, and direction of nutrient foramina in the shaft of long bones.
2. To determine the foraminal index of the long bones.

METHODS

This was a cross-sectional study, undertaken on dry cadaveric human long bones of unknown age and sex from the Department of Anatomy, M.S. Ramaiah Medical College, Bangalore. The duration of study was 2 years. The institutional ethical committee approved the study. In this study, 350 human long bones which include the clavicle, humerus, radius, and ulna from the upper extremity; femur, tibia, and fibula from the lower extremity were examined in detail for the number, position, location, and directions of the nutrient foramen. Based on the previous study conducted by Pereira *et al*, it was found that the number of one nutrient foramina observed in long bones was 90.8%. In the present study, sample size was calculated using a relative precision of 4% and with the desired confidence level of 95%, the sample size for the present study worked out to be 237 bones. However, an attempt was made to include more number of samples and hence the sample size in this study was 350 human long bones with 50 of each individual bones of right and left, respectively. Any long bone which was damaged was excluded from the study.

The bones for study were washed properly and dried. The nutrient foramina were identified by the presence of a well-marked groove and raised edges at the commencement of the canal. The exact position was identified whether it is in the upper, middle, or the lower 1/3rd of the bone. The total length of long bones and distance of the nutrient foramen from the proximal end has also been measured. The osteometric board, vernier digital slide calipers, measuring tape, and a magnifying glass have been used to observe the parameters.

Each long bone was examined for following parameters (Table 1 and Fig. 1).

Statistical analysis was done using SPSS version 21.0 software. Quantitative data were presented as mean and standard deviation. Qualitative data were presented with incidence and percentage tables. For quantitative data, unpaired t-test was applied and for qualitative data, Chi-square test was used. $p<0.05$ was taken as statistically significant.

RESULTS

In the present study, forty clavicles (80%) had single nutrient foramen. Nine clavicles (18%) had double nutrient foramina and one clavicle (2%) had triple nutrient foramina. The total number of nutrient foramina was 61. Nutrient foramina were found in the middle one-third of the shaft in all specimens, with two additional foramina in the proximal one-third. Three right-sided clavicles had two nutrient foramina, and in all cases, both were in the middle one-third, while six left-sided clavicles had two nutrient foramina, mostly in the middle one-third, except for one clavicle with one in the proximal one-third and the other in the middle one-third. One left-sided clavicle had three nutrient foramina, two in the middle one-third and one in the proximal one-third. The mean position of nutrient foramina was 7.56±1.33 for all clavicles, 7.60±1.46 on the right side, and 7.56±1.34 on the left side, with a p=0.82. Most nutrient foramina (88%) were located on the posterior surface, while 10% were on the inferior surface, and 2% were on the superior surface. In instances of two nutrient foramina, they were typically both on the posterior surface, except for one case where one was on the posterior surface and the other on the inferior surface. In cases with three nutrient foramina, two were on the posterior surface, and one was on the superior surface. The mean foraminal index for all clavicles was 52.85±9.24, with a mean foraminal index of 52.23±7.58 for the right side and 51.73±10.39 for the left side, and p=0.59, indicating that nutrient foramina were predominantly located in the middle one-third of the clavicle shaft, with a consistent direction toward the acromial end (Table 2).

Table 1: Parameters for analysis of long bones

Parameters	Description
Number of the nutrient foramina	Number of the nutrient foramina in shaft of each bone was determined.
Position of the nutrient foramina	The total length of the long bone was measured with osteometric board and will be divided into upper, middle and lower 1/3rd. The exact position of the foramina was identified.
Location of the nutrient foramina	The location of the nutrient foramina was identified in each bone with respect to the borders and surfaces of the bones.
Direction of the nutrient foramina	Direction of the nutrient foramina determined with respect to the growing end of the long bone was determined.
Foraminal index (FI) of the long bones	Calculated using the formula Hughes' formula based on the foraminal index the position of the nutrient foramina in a long bone can be predicted. FI=(DNF/TL) 100

In the present study, 48 humerus (96%) had single nutrient foramen and 2humerus (4%) had double nutrient foramina. The total number of nutrient foramina were 52. In this study of 50 humeri, all nutrient foramina were consistently located in the middle one-third of the shaft. Two left-sided humeri had two nutrient foramina, both within the middle one-third. The mean position of nutrient foramina was 17.50±1.83 for all humeri, 17.49±1.92 on the right side, and 17.50±1.83 on the left side (p=0.88). Nutrient foramina were predominantly on the anteromedial surface (50%) and the medial border (46%). A few were found on the posterior surface (2%) and the lateral border (2%). In cases of double nutrient foramina, both were consistently located either in the anteromedial surface or on the medial border. The direction of all nutrient foramina was consistently toward the elbow. The mean foraminal index for all humeri was 56.92±6.57. 57.49±5.06 on the right side, and 56.39±7.78 on the left side (p=0.34), indicating that nutrient foramina were consistently situated in the middle one-third of the shaft (Table 3).

In the present study, all the 50 radius (100%) had a single nutrient foramen. The total number of nutrient foramina was 50. In this study of 50 radius bones, 70% had nutrient foramina in the middle one-third of the shaft, 26% in the upper one-third, and 4% at the junction of these two-thirds. The mean position of nutrient foramina was 8.34±1.61, with a slightly higher mean on the right side (8.28±1.55) than on the left side (7.31±0.72), with p=0.68. Nutrient foramina were predominantly located on the anterior surface (62%), followed by the interosseous border (18%), anterior border (12%), and posterior surface (8%). The direction of all nutrient foramina was consistently toward the elbow.

The mean foraminal index for all radius bones was 34.80±6.07, 34.44±3.29 on the right side, and 30.80±0.12 on the left side, with p=0.46, indicating that nutrient foramina were primarily situated in the middle one-third of the shaft (Table 4).

In the present study, 48 ulna (96%) had single nutrient foramen and 2 ulna (4%) had double nutrient foramina. The total number of nutrient foramina was 52. In this study involving 50 ulna bones, the majority (72%) had nutrient foramina located in the middle one-third of the shaft, while 22% had them in the upper one-third, and 6% had them at the junction of the upper and middle one-third. Among these ulnas, one right-sided ulna had two nutrient foramina, one in the middle one-third and the other in the upper one-third, while one left-sided ulna had two nutrient foramina both in the upper one-third.

The mean position of the nutrient foramina was 9.50±1.68, with a slightly higher mean on the left side (10.08±1.72) than on the right side (9.61±1.64), with p=0.325. Regarding their location, 76% of ulnas had nutrient foramina on the anterior surface, 16% on the anterior border, and 8% on the interosseous border. In cases with two nutrient foramina, both were consistently located on the anterior surface. The direction of all nutrient foramina was consistently toward the elbow. The mean foraminal index for all ulna bones was 36.0±5.85, 36.92±5.47 on the right side, and 38.26±6.26 on the left side, with p=0.414, indicating a consistent presence of nutrient foramina in the middle one-third of the shaft (Table 5).

In this study of 50 femurs, 70% had a single nutrient foramen, while 30% had double nutrient foramina, totaling 65 foramina. The majority (94%) of femurs had nutrient foramina in the middle one-third of the shaft, with 4% in the upper one-third and 2% at the junction of these two-thirds. Among the right-sided femurs, eight had two nutrient foramina, primarily in the middle one-third, and one with one in the proximal one-third and the other in the middle one-third. Among

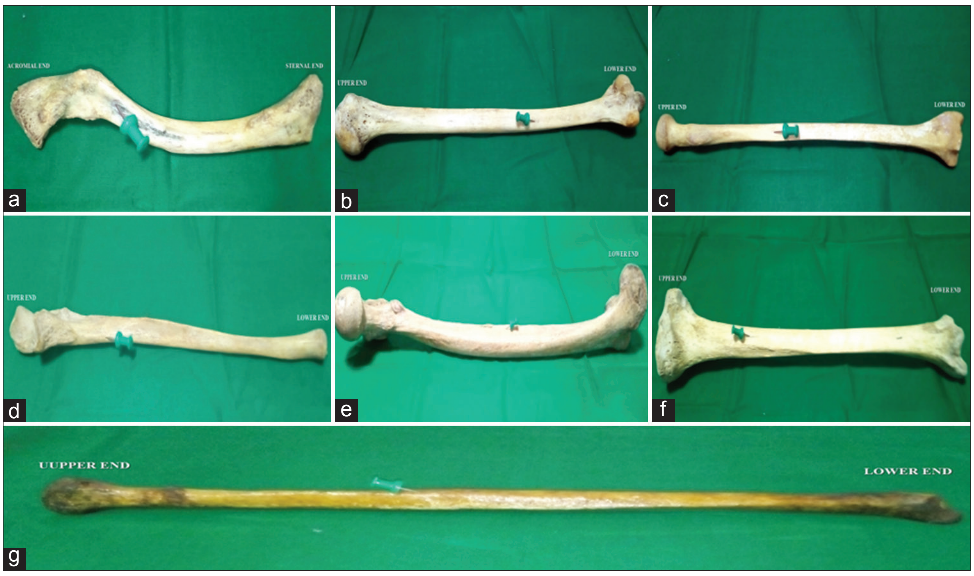

Fig. 1: Nutrient formaina of clavicle (a), humerus (b), radius (c), ulna (d), femur (e), tibia (f), and fibula (g)

Table 2: Number of nutrient foramina and foraminal index of clavicle

Clavicle	Number of nutrient foramina					Foraminal index		
	n=50	Absent	Single (%)	Double (%)	Triple	n=50	Range	Mean
Right	25	-	22 (88)	3 (12)	-	25	37.03–68.18	52.23±7.58
Left	25	-	18 (72)	6 (24)	1 (4%)	25	29.57–62.41	51.73±10.39
Total	50	-	40 (80)	9 (18)	1 (2%)	50	29.57–68.18	52.85±9.24

Table 3: Number of nutrient foramina and foraminal index of humerus

Humerus	Number of nutrient foramina				Foraminal index		
	n=50	Absent	Single (%)	Double (%)	n=50	Range	Mean
Right	25	-	25 (100)	-	25	51.16–69.02	57.49±5.06
Left	25	-	23 (92)	2 (8)	25	51.89–65.11	56.39±7.78
Total	50	-	48 (96)	2 (4)	50	51.89–69.02	56.92±6.57

Table 4: Number of nutrient foramina and foraminal index of radius

Radius	Number Of Nutrient Foramina				Foraminal Index		
	n=50	Absent	Single (%)	Double	n=50	Range	Mean
Right	25	-	25 (100)	-	25	27.88–39.52	34.44±3.29
Left	25	-	25 (100)	-	25	30.93–43.44	30.98±0.12
Total	25	-	50 (100)	-	50	27.88–43.44	34.80±6.07

Table 5: Number of nutrient foramina and foraminal index of ulna

Ulna	Number of nutrient foramina				Foraminal index		
	n=50	Absent	Single (%)	Double (%)	n=50	Range	Mean
Right	25	-	24 (96)	1 (4)	25	29.84–51.85	36.92±5.47
Left	25	-	24 (96)	1 (4)	25	26.45–48.35	38.26±6.26
Total	50	-	48 (96)	2 (4)	50	26.45–51.85	36.0±5.85

the left-sided femurs, seven had two nutrient foramina, with various combinations.

The mean position of the nutrient foramen was 18.61±4.15 for all femurs, with minimal variation between right (18.76±4.90) and left (18.46±4.68) sides (p=0.77). Most femurs (70%) had nutrient foramina on the linea aspera, while others had them on the medial surface (28%), and a few on the lateral surface (2%). Even in cases with two nutrient foramina, they were often located on the linea aspera, with some exceptions. These findings suggest a consistent pattern of nutrient foramina primarily located in the middle one-third of the femur shaft, mostly on the linea aspera, and consistently directed away from the knee. The mean foraminal index was 43.54±10.32 for all femurs, 43.45±9.11 on the right side, and 43.63±11.58 on the left side, with no significant side-based variation (p=0.94) (Table 6).

In the present study, 49 tibia (98%) had single nutrient foramen. One tibia (2%) had double nutrient foramina. The total number of nutrient foramina was 51. In this study involving 50 tibia bones, nutrient foramina were mostly located in the upper one-third (66%), with a portion in the middle one-third (30%), and a few at the junction of the upper and middle one-third (4%). One left-sided tibia had two nutrient foramina, both in the upper one-third. The mean position of nutrient foramina was 11.55±1.14, with a slightly higher mean on the left side (11.71±1.26) than on the right side (11.38±1.01), with a p=0.303.

The majority of tibia (86%) had nutrient foramina on the posterior surface, while a few had them on the soleal line (6%) and the interosseous border (8%). In cases with two nutrient foramina, both were consistently located on the posterior surface. The direction of all nutrient foramina was consistently away from the knee. In the present study, the mean foraminal index was 32.37±3.1 which indicates that the majority of the nutrient foramina were present in the upper one-third of the shaft of the tibia. The mean foraminal index on the right side was 31.59±2.86 and on the left side, it was 33.12±3.21 p=0.078 (Table 7).

In the present study, 43 fibula (86%) had single nutrient foramen. In seven fibula (14%), the nutrient foramina was absent. The total number of nutrient foramina was 43. In the study of 50 fibula bones, nutrient foramina were predominantly located in the middle one-third of the shaft (82%), with a few in the upper one-third (2%) and lower one-third (2%). The mean position of nutrient foramina was 18.14±3.65, with a slightly higher mean on the left side (18.71±3.44) than on the right side (17.76±3.83), with a p=0.43.

Regarding their location, nutrient foramina were found on the posterior border (34%), in the posterior surface (22%), the lateral surface (14%), the medial surface (8%), and the interosseous border (8%). The direction of all nutrient foramina was consistently away from the knee. In the present study, mean foraminal index was 51.68±9.77, which indicates that the nutrient foramina were present in the middle one-third of the shaft. The mean foraminal index on the right side was 50.86±10.68 and on the left side, it was 52.70±8.65 with p=0.94 (Table 8).

DISCUSSION

In the present study of 50 clavicles, 40 clavicles (80%), with right 22 clavicles (88%) and left 18 clavicles (72%) had single nutrient foramen which have been reported in the previous studies with a range of 38.5–72%. Nine clavicles (18%) with 3 right-sided clavicles (12%) and 6 left-sided clavicles (24%) had double nutrient foramina. Murlimanju *et al*. conducted a study to the topographic anatomy and morphology of neurovascular foramina of the human adult clavicles.[7] For this 52 clavicles were macroscopically observed for the number, location, and direction of the nutrient foramina. The foramen index was calculated for each clavicle by applying the Hughes formula. The neurovascular foramen was observed in 50 (96.1%) clavicles. The foramen was single in 20 (38.5%) clavicles, double in 23 cases (44.2%), and there were more than 2 foramina in 7 clavicles (13.4%). The foramen was present at the middle 1/3 region in 92.3% clavicles, at the medial 1/3 region in 9.6%, and at the lateral 1/3 part in 1.9% clavicles. It was on the inferior surface in 55.8% clavicles, on the posterior surface in 69.2%, and at the superior surface in only 1.9% of clavicles. Similar findings were also reported by the authors such as Malukar and Joshi[8] and Rai *et al*.[9]

In the present study of 50 humerus, 48 humerus (96%), with 25 right-sided humerus (100%) and 23 left-sided humerus (92%) had single nutrient foramen. Mysorekar conducted a study to analyze nutrient foramina of long bones.[10] In this study, 1080 bones consisting of 180 each of femur, tibia, fibula, humerus, radius, and ulna were studied. The authors found that out of 179 humeri, 75 (42%) had more than one foramen. Of the 263 foramina, 185 (70%) were in the fourth-sixth and 67 (25.5%) in the third-sixth. Of the 263 foramina, 106 (40%) were on the anteromedial surface, 101 (40%) on the medial border, and 50 (19%) in the spiral groove. In specimens (75) having multiple foramina, 38 (51%) had one each in the spiral groove and on the anteromedial surface or medial border. In one specimen, there were as many as three foramina in the spiral groove. Similar findings were also reported by the authors such as Patel *et al*.[11] and Mansur *et al*.[12]

In the present study of 50 radius with 25 right radius (100%) and 25 left radius (100%), all the radius (100%) had a single nutrient foramina. In the present study of 50 ulna, 48 ulna (96%), with 24 right ulna (96%) and 24 left ulna (96%) had single nutrient foramina. In the present study of 50 ulna, 36 ulna (72%), with 16 right-sided ulna (64%) and 20 left side ulna (80%) had the nutrient foramina in the middle one-third of the shaft which was also reported by the authors such as Roul and Goyal[13] and Ukoha *et al*.[14]

In the present study of 50 femur, 35 femur (70%) with 17 right femur (16%) and 18 left femur (72%), had single nutrient foramen. Gupta

Table 6: Number of nutrient foramina and foraminal index of femur

Femur	Number of nutrient foramina				Foraminal index		
	n=50	Absent	Single (%)	Double (%)	n=50	Range	Mean
Right	25	-	17 (76)	8 (32)	25	32.42–65.39	43.45±9.11
Left	25	-	18 (72)	7 (28)	25	28.21–61.00	43.63±11.58
Total	50	-	35 (70)	15 (30)	50	28.21–65.39	43.54±10.32

Table 7: Number of nutrient foramina and foraminal index of tibia

Tibia	Number of nutrient foramina				Foraminal index		
	n=50	Absent	Single (%)	Double (%)	n=50	Range	Mean
Right	25	-	25 (100)	-	25	28.88–38.33	31.59±2.86
Left	25	-	24 (96)	1 (4)	25	28.65–38.58	33.12±3.21
Total	50	-	49 (98)	1 (2)	50	28.88–38.33	32.37±3.1

Table 8: Number of nutrient foramina and foraminal index of fibula

Fibula	Number of nutrient foramina				Foraminal index		
	n=50	Absent (%)	Single (%)	Double	n=50	Range	Mean
Right	25	1 (4)	24 (96)	-	25	31.91–66.03	50.86±10.68
Left	25	6 (24)	19 (76)	-	25	42.09–64.93	52.70±8.65
Total	50	7 (14)	43 (86)	-	50	31.91–66.03	51.68±9.77

and Ambekar conducted a study to analyze nutrient foramina in adult human femur bones.[15] For this purpose, the authors conducted a study on 100 adult dry femur bones (50 right and 50 left). All the important parameters were studied using osteometric board, vernier calipers, and needles of different gauges. The study found that mean distance of nutrient foramen from upper end was 18.09 cm. The most common location of NF was on lateral surface 58.8%. In 71% femur, only one NF was seen, while 25% had two NF, 1% femur had three NF, and 3% femur had no NFs. In 64.5% femur, big size or dominant NFs were seen in the study. Similar findings were also reported by the authors such Gupta and Gupta[16] and Poornima and Angadi[17]

Finally, the analysis of nutrient foramina of tibia and fibula showed that out of 50 tibia, 49 tibia (98%), with right side 25 tibia (100%) and left side 24 tibia (96%) had single nutrient foramina and out of 50 fibula, 43 fibula (86%) with 24 right (96%) and 19 left (76 %) had a single nutrient foramen. Venkatesh *et al*. conducted a study to analyze the position of primary nutrient foramina of tibia and fibula.[18] For this purpose, 137 adult dry bones including 71 tibias and 66 fibulas were studied. The number and position of primary nutrient foramina were noted and the foraminal index was calculated. The study found that a single primary nutrient foramen was observed in all the tibia and fibula. About 97.18% of tibia had foramen on the posterior surface and 2.82% on medial surface. In the fibula, all the foramina were on the posterior surface. The mean foraminal index was 32.08 in tibia and 44.60 in fibula. In the tibias, 74.65% of the foramina were in the upper third and in the fibula, 95.45% of the foramina were in the middle third. Similar findings were also reported by the authors such as Nidhi *et al*.[19] and Sinha *et al*.[20]

CONCLUSION

This study examines nutrient foramina, their number, position, and location in various bones. Most bones have a single foramen, except the clavicle with three and the femur with double foramina. They are typically located in the middle one-third of the shaft, except in the tibia (upper one-third). The specific location varies by bone. Understanding these foramina is crucial for orthopedic surgery, forensic identification, obtaining vascularized bone grafts, and treating trauma or malignant bone conditions.

CONFLICTS OF INTEREST

None

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