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Topographic and morphometric features of the nutrient foramina of the fibula in the South African mixed-ancestry population group and their surgical relevance

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SUMMARY

Nutrient foramina are canals that convey nutrient arteries and nerves into the diaphysis of long bones to supply the medullary cavity. The aim of the present study was to investigate the direction, number, location and position of nutrient foramina on the shafts of the fibulae. 201 dry fibulae of adult 20th-century mixed-ancestry South Africans were macroscopically examined for direction, number, location and position of the nutrient foramina. For each bone, a Foraminal Index was calculated giving the position of the nutrient foramina in relation to the bone length. Most of the fibulae (87.1%) had their nutrient foramina directed towards the ankle joint, while **few** (5.5%) had their nutrient foramina directed towards the knee joint. A single nutrient foramen (90.0%) was most frequent, and also the posterior surfaces of the shafts of the fibulae harbored the majority (50.6%) of the nutrient foramina. A rare location of the nutrient foramina was identified on the interosseous borders (22.2%) of the fibulae in this population. Nutrient foramina were positioned mainly on the middle third (1/3) of the shafts of the fibulae with the Foraminal Index ranging between 33.02-75.57% and a mean of 42.46±14.42%. In conclusion, the middle segment of the shafts of the fibulae of the mixed-ancestry South African population was the most common site for nutrient foramina, and thus makes it ideal for harvesting long portions of free vascularised cortical bone grafts for treatment of massive bone loss and fractures.

Key words: Nutrient foramen – Fibula – Mixed-ancestry – Foraminal Index – Endosteal vessels – Free vascularised fibula graft – South Africa

INTRODUCTION

The fibula is considered a clinically expendable long bone which contributes insignificantly to weight bearing (Funk et al., 2004). Approximately 6-19% of the body weight is borne by the fibula depending upon the position of the ankle (Funk et al., 2004). The fibula contributes to the formation of the tibiofibular syndesmosis and the stability of the ankle joint during the strike phase of gait (Weinert et al., 1973). Clinically the fibula is the commonest vital source of autologous cortical bone grafts (Finkemeier, 2002) to replace large bone defects, especially in mandibular reconstructions (Taylor et al., 1975; Fernandes, 2006). Imperatively, this is possible as the fibula provides with long pedicles for bone grafting (Imran et al.,

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2003). In addition, vascularised fibula grafts facilitate early bone union, complete incorporation and graft hypertrophy with loading (Imran et al., 2003). Rapid healing and union of the graft at the host-graft interface requires that the graft be adequately vascularised (Finkemeier, 2002; Imran et al., 2003), and the success of any transplant is largely dependent on the ability to preserve its blood supply (Pho, 1988).

The blood supply to the fibula shaft includes branches from the peroneal artery which gives off the periosteal vessels (Schulman, 1959; Patake and Mysorekar, 1977; Forriol Campos et al., 1987) and most importantly the endosteal vessels which enter the medullary cavity of the shaft of the bone through the nutrient foramen (Patake and Mysorekar, 1977; Sendemir and Çimen, 1991; Gümüsburun et al., 1994). The nutrient foramen enters the shaft of the long bone obliquely and its direction has been described as generally towards the elbow in the upper limb long bones and away from the knee in lower limb long bones (Mysorekar, 1967).

The number, location, position and direction of the nutrient foramina are known to vary in human long bones (Matsuura et al., 1999). Therefore, preoperative angiography is important to avoid injuries to arteries supplying the bone surfaces during surgery (Pereira et al., 2011). The anatomy of the nutrient foramina in human long bones has been widely studied in varied populations globally: Mysorekar (1967) and Murlimanju et al. (2011) in Indians; Guo (1981) in Chinese; McKee et al. (1984) in Canadian Caucasians**;** Forriol Campos et al. (1987) in Spaniards; Sendemir and Çimen (1991), Gümüsburun et al. (1994) and Kizilkanat et al. (2007) in Turkish; Nagel (1993) in Americans; Lee et al. (2000) in Japanese; Pereira et al. (2011) in Southern Brazilians and Mazengenya and Fasemore (2015) in Black and White South Africans. However, there is no information on the anatomy of the nutrient foramina on the fibula in the mixed-ancestry population group of South Africa. The South African mixed-ancestry population group also known as the "Coloured" population could be defined as a distinct cultural and social population that has its origin in various groupings from East and Central Africa, indigenous Khoisan and Europe: hence the term "mixed-ancestry population group" (L'Abbé et al., 2011).

The current study focused on the direction, number, location and position of the nutrient foramina on the fibulae in the mixed-ancestry South African population group in order to provide information on suitable free vascularised fibula grafts to be harvested for a successful bone grafting. This information on the nutrient foramina is also important during generation of stress fractures on long bones and/or fracture repair.

MATERIALS AND METHODS

A total of 201 dry fibulae from 104 skeletons of adult 20th-century mixed-ancestry South Africans were analysed and measured. The sample consisted of both right and left fibulae from 68 males and 36 females ranging in age from 20 to 104 years. The specimens were obtained from the Raymond A. Dart Collection of Human Skeletons housed in the School of Anatomical Sciences, Faculty of Health Sciences at the University of the Witwatersrand. Fibulae with notable physical deformity and pathological signs were excluded from the study. The location, number, position and direction of nutrient foramina were observed macroscopically and analysed. The following measurements were done on the fibulae using an osteometric board (*Paleo-Tech Concepts*): the total length of the fibula (measured between the apex of the head of the fibula and the most distal aspect of the lateral malleolus) and the distance between the apex of the head of the fibula and the distal edge of dominant nutrient foramen (Fig. 1A). Nutrient foramina were calibrated using hypodermic needles. All foramina which could admit a 25 gauge hypodermic needle were considered as a viable nutrient foramen and a dominant nutrient foramen was defined as that which admits the largest hypodermic needle (18-20 gauge) (Carroll, 1963). The direction of the nutrient foramen was confirmed by inserting a hypodermic needle though the foramen, and its orientation was noted as being directed towards the knee or the ankle (Fig. 1B and C). Plain X-rays were also undertaken to further confirm that the hypodermic needles were actually being inserted into the nutrient foramina (Fig. 2A and B). The position of the nutrient foramen was expressed as the percentage of the total bone length and was calculated by the formula according to Hughes (1952): **FI=DNF/TL×100**, where FI is the Foraminal Index; DNF is the distance from the apex of the head of the fibula to the distal edge of the dominant nutrient foramen, and TL is the total length of the bone.

Statistical analysis was done using SPSS version 11 and $P \leq 0.05$ was used to infer on the level of statistical significance. The following statistical analyses were undertaken: Frequency tables were used to calculate measures of central tendency (mean, range and standard deviation); Chi-squared test was used to evaluate the association between the nutrient foramina parameters with sex and sidedness; Students *t*-test was used for the comparison of two means between males and females and right and left sides. This research was undertaken in accordance with the University of the Witwatersrand Ethics Committee on the use of human cadavers and skele-

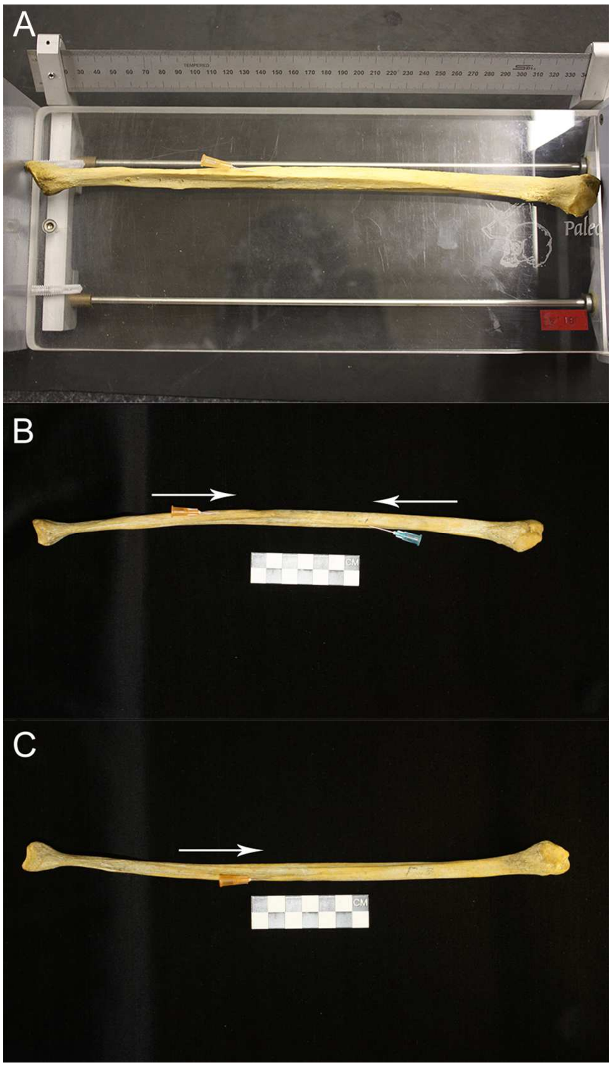

Fig. 1. Photographic images of the fibula. **(A)** Laboratory osteometric board used to measure the maximum length of the fibula. **(B)** Fibula with double nutrient foramina directed both distally and proximally. **(C)** Fibula with a single nutrient foramen directed distally.

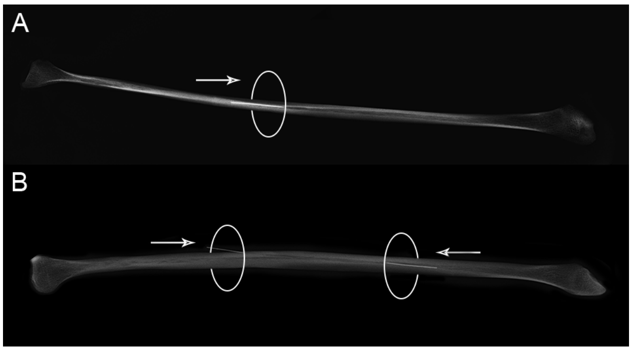

Fig. 2. Radiographic images of the fibula with a hypodermic needle inserted into the nutrient foramen. (**A**) Fibula with single nutrient foramina directed distally. (**B**) Fibula with double nutrient foramina directed both distally and proximally.

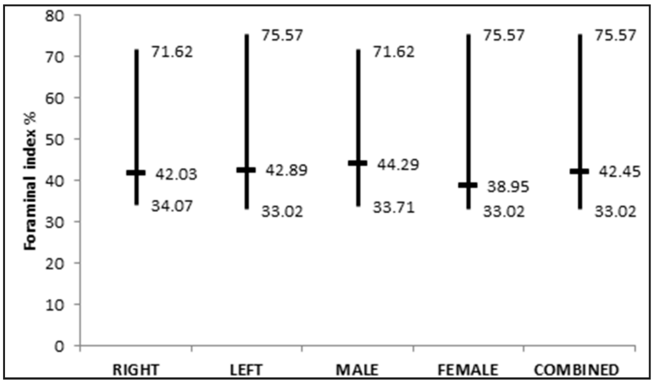

Fig. 3. Range of positions of the nutrient foramina based on the foraminal index (FI) of the fibula. The horizontal lines of the graph represent the means and the vertical lines represent the full range of the FI values.

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RESULTS

Length: The mean total length of the fibula was 349.32±25.14 mm; males (358.84±20.99 mm) and females (331.10±22.29 mm). The mean fibula length was significantly larger ($p \leq 0.05$) in males than in females but no side differences were found (Table 1).

Direction: The majority (87.1%) of the fibulae had nutrient foramina directed distally towards the ankle joint and 5.5% of the fibulae had nutrient foramina directed proximally towards the knee joint while 7.5% of the fibulae had missing nutrient foramina (Table 2). There was no significant association between the direction of the nutrient foramina with sex and/or sidedness ($p \geq 0.05$).

Number: The majority of the fibulae (90.0%) had a single nutrient foramen but cases of zero (7.5%) and two (2.5%) nutrient foramina were also present (Table 3). No statistically significant association was found between the number of the nutrient foramina with sex and/or sidedness ($p \geq 0.05$).

Location: The location of the nutrient foramina on the surfaces and borders of the shafts of the fibulae was as follows: 50.6% on the posterior surface, 20.6% on the medial surface, 6.7% on the medial crest, and 22.2% on the interosseous border (Table 3). No statistically significant associations were identified between the location of the nutrient foramina with sex and sidedness ($p \geq 0.05$).

Position: The nutrient foramina were distributed mainly in the middle third of the fibula diaphysis (Fig. 3). The Foraminal Index **(FI)** of the total sample ranged between 33.02- 75.57% and the mean was 42.46±14.42%. Males had a

Table 1. The mean length of the fibulae (mm)

Sex	Side	No. of fibulae	Mean	Std. deviation
M	R	68	358.21	21.03
	L	64	359.52	21.09
	Combined	132	358.84*	20.99
F	R	33	328.30	21.85
	L	36	333.67	22.68
	Combined	69	331.10*	22.29
Total		**201**	**349.32**	**25.14**

Abb: M, male; F, female; *statistically significant

Table 2. The direction of the nutrient foramina

Sex	Side	No. of fibulae		Direction of the nutrient foramina		
		Missing	Valid	Distal %	Proximal %	Missing %
	R	3	65	89.7	5.9	4.4
M						
	L	3	61	90.6	4.7	4.7
	Combined	6	126	90.2	5.3	4.5
	R	6	27	72.7	9.1	18.2
F	L	3	33	88.9	2.8	8.3
	Combined	9	60	81.2	5.8	13.0
Total		**15**	**186**	**87.1**	**5.5**	**7.5**

Abb: M, male; F, female.

Table 3. The number and location of the nutrient foramina on the shaft of the fibula

Population	Sex	Side	No. of nutrient foramina			Location of the nutrientforamina			
Mixed			**0**	**1**	**2**	**IB%**	**PS%**	**MC%**	**MS%**
	M	R	3	62	3	25.4	49.2	6.3	19.0
		L	3	61	0	18.3	53.3	8.3	20.0
		Combined%	4.5	93.2	2.3	22.0	51.2	7.3	19.5
	F	R	6	26	1	19.2	42.3	11.5	26.9
		L	3	32	1	25.8	54.8	0.0	19.4
		Combined%	13.0	84.1	2.9	22.8	49.1	2.3	22.8
Overall %			**7.5**	**90.0**	**2.5**	**22.2**	**50.6**	**6.7**	**20.6**

Abb: M, male; F, female; IB, interosseous border; PS, posterior surface; MC, medial crest; MS, medial surface

Table 4. Number of the nutrient foramina on the fibula in different populations around the world

Author and year	Population	No. of nutrient foramen			
		0	**1**	**2**	**3**
McKee et al. (1984)	Canadian Caucasians	5.6%	86.4%	7.7%	0.3%
Mysorekar (1967)	Indians	3.9%	92.8%	3.1%	-
Pereira et al. (2011)	Southern Brazilians	-	99.1%	0.9%	-
Gümüsburun et al. (1994)	Turkish	3.3%	85%	11.7%	-
Gümüsburun et al. (1996)	Turkish	3.9	92.2	3.9	-
Forriol Campos et al. (1987)	Spanish	-	100%	-	-
Sendemir and Çimen (1991)	Turkish	18.9%	73.9%	7.2%	-
Kizilkanat et al. (2007)	Turkish	1.4%	93.2%	5.5%	-
Mazengenya and Fasemore (2015)	White South Africans	5.0%	86.1%	8.9%	-
	Black South Africans	7.2%	87.2%	5.0	1.3%
Current study	Mixed South Africans	7.5%	90.0%	2.5%	-

FI range of 33.71-71.62% and the mean was 44.29±12.64%, while females had a range of 33.02-75.57% and the mean was 38.95±16.86% as shown in Fig. 3. The mean **FI** of males was larger than that of females (p≤0.05) but no statistical significant side differences were found (p≥0.05).

DISCUSSION

The current study reports on the topography and morphometry of the nutrient foramina on the fibulae in the mixed-ancestry population of South African. The average length of the fibulae was 349.32±25.14 mm. This average length of the fibulae was approximately 5% less than the values reported in Turkish populations (Gümüsburun et al., 1994; Kizilkanat et al., 2007), in Chileans (Collipal, 2007), in Southern Brazilians (Pereira et al., 2011), and Black and White South Africans (Mazengenya and Fasemore, 2015). Limb size determination was considered to be influenced by genetic (Eveleth and Tanner, 1990), environmental (Silventoinen, 2003) and climatic factors (Ruff, 2002). Many researchers concurred that climatic adaptation has a strong effect on the determination of distal limb segment length specifically for increasing the surface area for heat dissipation (Allen, 1877; Ruff, 2002; Steegmann, 2005; Stock, 2003, 2006).

In the present study, the majority of the fibulae (87.1%) had their nutrient foramina directed towards the ankle joint while 5.5% of the fibulae had their nutrient foramina directed towards the knee joint and on the remaining 7.5% the fibulae had missing nutrient foramina. Similar findings were also reported in the Chinese population (Lee et al., 2000). According to Mysorekar (1967) the direction of the nutrient foramina in the fibula is usually towards the ankle joint and only in fewer cases the nutrient foramina may be directed upwards towards the knee joint as a result of an unusual pattern of ossification. The direction of the nutrient foramen is thought to be a result of differences in the rate of growth at the two epiphyses of long bones, causing the nutrient artery to diverge away from the faster growing end (Mysorekar, 1967).

Regarding the number of the nutrient foramina in this study, a single nutrient foramen was the most common (90.0%). This has been reported similarly in other studies (Mysorekar, 1967; Guo, 1981; McKee et al., 1984; Forriol Campos et al., 1987; Sendemir and Çimen, 1991; Gümüsburun et al., 1994, 1996; Kizilkanat et al., 2007; Pereira et al., 2011; Mazengenya and Fasemore, 2015) (Table 4). Fibulae with two (2.5%) and missing nutrient foramina (7.5%) were also observed in the current study, and they ranged from 0 to 18.9% and 0 to 11.7% in other studies respectively (Guo, 1981; McKee et al., 1984; Forriol Campos et al., 1987; Sendemir and Çimen, 1991; Gümüsburun et al., 1994, 1996; Kizilkanat et al., 2007; Pereira et al., 2011; Mazengenya and Fasemore, 2015). Fibulae with up to three nutrient foramina were reported by McKee (1984) in Canadian Caucasians and by Mazengenya and Fasemore (2015) in Black South Africans. This was not observed in the current study. In situations where the nutrient foramina are absent, it is assumed that the periosteal vessels are entirely responsible for the blood supply of the diaphysis (Patake and Mysorekar, 1977).

Variations on the location of the nutrient foramina on the shafts of the fibulae were identified.

In the current study, nutrient foramina were found most frequently on the posterior surface, followed by the interosseous border, medial surface, and least on the medial crest of the fibulae. The posterior surface was reported to be the most frequent site of the nutrient foramina on the fibulae (McKee et al., 1984; Gümüsburun et al., 1994, 1996; Lee et al., 2000; Collipal et al., 2007; Kizilkanat et al., 2007; Mazengenya and Fasemore, 2015). Alternatively, other surfaces of the fibulae were also found to harbour the majority of the nutrient foramina such as the medial surface (Sendemir and Çimen, 1991), both medial and posterior surface equally (Forriol Campos et al., 1987), lateral surface (Pereira et al., 2011) and the medial crest (Mysorekar, 1967). The frequent location of nutrient foramina on the posterior surfaces of the fibulae could be explained by observing the orientation of the nutrient vessels to the diaphysis, which are branches of the peroneal arteries that enter the fibulae from their postero-medial surface (Carr et al., 1988; Kocabiyik et al., 2007). The majority of the nutrient foramina were reported to be located in the middle third of the shafts of the fibulae (Forriol Campos et al., 1987; Gümüsburun et al., 1994, 1996; Kizilkanat et al., 2007; Pereira et al., 2011; Mazengenya and Fasemore, 2015), in the middle two fourths by Taylor (1975), in the third sixth by Sendemir and Çimen (1991) and in the upper third by Guo (1981). In the present study, most of the nutrient foramina occupied the middle third of the shafts of the fibulae and the Foraminal Index **(FI)** ranged between 33.02-75.57% with a mean of 42.46±14.42%. The middle third of the shaft of the fibula is more robust, offers attachments to the muscles of the leg and therefore is often subjected to habitual torsional forces during various mobility patterns (Marchi and Shaw, 2011). This notion may explain the location of the nutrient foramina in this bone segment. However, there are no studies which have assessed the association between muscle attachments and topography of the nutrient foramen.

In conclusion, the mixed-ancestry population group of South Africa showed a general trend in relation to the parameters around the nutrient foramina when compared to other studied populations. The specific parameters included the number, direction, position and location. However, the location of the nutrient foramina had the unique exception in terms of their site on the interosseous border which was not identified in any other studied populations. Considering the variations around the nutrient foramina in different populations, preoperative angiography remains an important tool to facilitate harvesting of vascularised bone segments.

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