Nutrient Foramina in the Upper and Lower Limb Long Bones: Morphometric Study in Bones of Southern Brazilian Adults

Forámenes Nutricios en los Huesos Largos de los Miembros Superiores e Inferiores:
Estudio Morfométrico en Huesos de Adultos del Sur de Brasil

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SUMMARY: The major blood supply to long bones occurs through the nutrient arteries, which enter through the nutrient foramina. 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. The present study analyzed the location and the number of nutrient foramina in the diaphysis of 885 long bones of the upper and lower limbs of adults: 174 humeri, 157 radii, 146 ulnae, 152 femora, 142 tibiae and 114 fibulae. The location of the nutrient foramina is predominant on the anterior aspect of the upper limb long bones, and on the posterior aspect of the lower limb long bones. The majority of the bones studied had a single nutrient foramen, which may represent a single source of blood supply. The mean foraminal index for the upper limb bones was 55.2% for the humerus, 35.7% for the radius, and 37.9% for the ulna, and for the lower limb bones, 43.7% for the femur, 32.7% for the tibia and 46.1% for the fibula. This study recorded data related to the population of Southern Brazil, providing ethnic data to be used for comparison and that may help in surgical procedures and in the interpretation of radiological images.

KEY WORDS: Nutrient foramina; Long bones; Vascularization; Brazilian population.

INTRODUCTION

The nutrient foramina are cavities that conduct the nutrient arteries and the peripheral nerves. The major blood supply for long bones originates from the nutrient arteries, mainly during the growing period and during the early phases of ossification (Lewis, 1956; Brookes 1963; Sendemir & Çimen, 1991; Gümüşburun *et al.*, 1994; Kizilkanat *et al.*, 2007). During childhood, long bones receive about 80% of the interosseous blood supply from the nutrient arteries, and in the case of their absence, the vascularization occurs through the periosteal vessels (Trueta, 1953). In bone grafts, the nutrient blood supply is crucial and it should be preserved in order to promote the fracture healing (Longia *et al.*, 1980; Gümüşburun *et al.*). Moreover, the presence of preserved nutrient blood flow is essential for the survival of the osteocytes in cases of tumor resection, traumas, and congenital pseudoarthrosis (Sendemir & Çimen; Gümüşburun *et al.*). Currently, the detailed study of blood supply to long bones is a determining factor for the success of new techniques for bone transplant and resection in orthopedics (Guo, 1981; Kirschner *et al.*, 1998).

In transplant techniques, the use of statistical data on the nutrient foramina distribution in long bones makes it possible for the professional to select the osseous section levels of the receptor in order to place the graft without damaging the nutrient arteries, preserving, thus, the diaphyseal vascularization and the transplant consolidation (Wavreille *et al.*, 2006). Studies on the vascularization of long bones of various populations were conducted analyzing the nutrient foramina morphometry (Sendemir & Çimen; Nagel, 1993; Ciszek & Glinkowski 2000; Lee *et al.*, 2000; Dyankova, 2004; Chen *et al.*, 2007; Kizilkanat *et al.*), the nutrient blood supply (Guo; Teot *et al.*, 1984; Sheetz *et al.*, 1995; Ebraheim *et al.*, 1998; Kocabiyik *et al.*, 2007; Thammaroj *et al.*, 2007), the vascular anatomy in reconstructive surgeries (Hallock *et al.*, 1993; Choi *et al.*, 2001; Dyankova; Schiessel & Zweymüller, 2004) and the micro surgically vascularized bone transplant (Guo; Bonnel, 1981). Particularly on nutrient foramina, Shulmann (1959) considered that their 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. In addition, Patake & Mysorekar (1977) reported that the number of nutrient foramina does not seem to have a significant relationship with the bone length and the number of ossification centers.

The aim of this study was to record the location and number of nutrient foramina in long bones of the upper and lower limbs of adults in Southern Brazil.

MATERIAL AND METHOD

We analyzed 885 long bones from the Anatomy Laboratory of Universidade Luterana do Brasil, Canoas, Rio Grande do Sul state: 174 humeri, 157 radii, 146 ulnae, 152 femora, 142 tibiae and 114 fibulae. The laterality of the bones was the only known data, and right side and left side bones were identified; data about their age and gender were not available.

The localization, size and number of nutrient foramina were analyzed in each bone. Foramina smaller than a size 24 hipodermic needle were considered secondary

Table I. Location and number of nutrient foramina in the osseous surface in each of the upper limb bones. Humerus: AS- anterior surface, PS- posterior surface, PLS- posterolateral surface, AMS- anteromedial surface; ulna: AS- anterior surface, ALS- anterolateral surface, AMS- anteromedial surface; radius: AS- anterior surface, ALS- anterolateral surface, PMS- posteromedial surface, AMS- anteromedial surface.

Bone	Number of foramina	
	1	2
	Number of bones(%)	Number of bones (%)
Humerus	n= 174	n= 20
AS	8 (4.6)	
OS	6 (6)	2 (10)
PLS	4 (2.3)	1 (5)
MAS	156 (89.7)	17 (85)
Ulna	n= 146	n= 2
AS	120 (82.2)	1 (50)
ALS	17 (11.6)	1 (50)
MAS	9 (6.2)	
Radius	n= 157	n= 1
AS	115 (73.2)	
ALS	5 (3.2)	
PMS	5 (3.2)	
MAS	32 (20.4)	1 (100)

foramina (Carroll, 1963; Lee *et al.*; Sendemir & Çimen; Kizilkanat *et al.*), and these were not analyzed or reported in this study. Therefore, only the data on dominant foramina were considered and are referred to as nutrient foramina (NF). The NF distribution in the bone length was determined by calculating a foraminal index (FI), according to Hughes (1952), Shulman and Kizilkanat *et al.*, using the formula: $FI = (DNF/TL) \times 100$, where DNF is the distance from the proximal end of the bone to the NF, and TL is the total bone length. Determination of the total length of individual bones was taken according to Forriol Campos *et al.* (1987) and Kizilkanat *et al.* A Vernier 500 mm paquimeter was used for all measurements.

The statistical data analysis was carried out using SPSS (Statistical Package for Social Sciences), version 15.0 for Windows. The descriptive statistical analysis was performed through frequency tables (single and crossed) and the calculation of the central tendency and variability measures (range, mean and standard deviation).

RESULTS

Most of the NF in the upper limb bones is located in the anterior aspect of the bones: 89.7% in the humerus, 82.2% in the ulna, and 73.2% in the radius (Table I). In the lower limb bones, most of the NF is found in the posterior aspect: 93.4% in the femur and 93.7% in the tibia, while in the fibula, 98.2% is located in the lateral aspect (Table II).

Table II. Location and number of nutrient foramina in the osseous surface in each of the lower limb bones. Femur: LA- linea aspera, LS- lateral surface, MS- medial surface; tibia: PS- posterior surface, MS- medial surface; fibula: LS- lateral surface, PS- posterior surface.

Bone	Number of foramina		
	1	2	3
	Number of bones (%)	Number of bones (%)	Number of bones (%)
Femur	n= 152	n= 61	n= 2
LA	142 (93.4)	30 (19.7)	2 (100)
LS	10 (6.6)	30 (19.7)	
MS		1 (0.7)	
Tibia	n= 142	n= 2	
PS	133 (93.7)		
MS	9 (6.3)	2 (100)	
Fibula	n= 114	n= 1	
LS	112 (98.2)	1 (100)	
PS	2 (1.8)		

The number of NF observed in each bone is shown in Table III. Of all analyzed bones, 90.8% had a single nutrient foramen, and 8.9% had two NF. Only the femur had three NF. None of the bones had no NF in this study. The mean length for each bone was: 311.5 mm (humerus), 254.3 mm (ulna), 233.6 mm (radius), 444.1 mm (femur), 373.1 mm (tibia) and 356.6 mm (fibula). The humerus, the radius and the ulna showed the FI range, regardless of the surface, of: 32.1-68.8%, 22.8-57.5% and 27.4-52.5% respectively; the femur, the tibia and the fibula showed the following values, respectively: 26.1-68.9%, 26.2-73.7% and 33.5-67.1% (Table IV). Also, results on the mean, standard deviation and range of FI were obtained – an analysis of each bone, location and laterality (Table V).

Table III. Number of nutrient foramina observed in long bones.

Bone	Number of foramina	Number of bones	%
Humerus (n= 154)	1	154	88.5
	2	20	11.5
Ulna (n= 146)	1	144	98.6
	2	2	1.4
Radius (n= 157)	1	156	99.4
	2	1	0.6
Femur (n=152)	1	97	63.8
	2	53	34.9
	3	2	1.3
Tibia (n= 142)	1	140	98.6
	2	2	1.4
Fibula (n= 114)	1	113	99.1
	2	1	0.9
Total	1	804	90.8
	2	79	8.9
	3	2	0.2

Table IV. Descriptive statistics for foraminal index – analysis by bone.

FI	n	Range (min - max)	Mean	DP
Bone		%		
Humerus	174	32.1 – 68.8	55.2	7.0
Ulna	146	27.4 – 52.5	37.9	5.5
Radius	157	22.8 – 57.5	35.7	5.6
Femur	152	26.1 – 68.9	43.7	8.4
Tibia	142	26.2 – 73.7	32.7	4.6
Fibula	114	33.5 – 67.1	46.1	8.4

DISCUSSION

The results, like those found by Forriol Campos *et al.*, show that the NF of the upper limb bones are located nearer the elbow than the shoulder or wrist; in the lower limb bones, the NF is located closer to the hip on the femur, and at the junction of the proximal and medial bone on the tibia, with little variation (Fig. 1).

Humerus. The average length found in the humerus is similar to those obtained in previous studies (Carroll; Gualdi-Russo & Galletti, 2004; Kizilkanat *et al.*), as well as the predominant location on the anteromedial surface (Forriol Campos *et al.*; Kizilkanat *et al.*). 100% of humeri have a single NF, different from the approximately 60% found by Carroll, Forriol Campos *et al.* and Kizilkanat *et al.* As for the percentage of bones with two NF, the results resemble those of Forriol Campos *et al.* and Kizilkanat *et al.* Carroll did not report the presence of two NF in these bones. The FI values are close to those reported by Carroll and Forriol Campos *et al.*

Radius. The radius average length is consistent with the data reported by Russo & Gualdi-Russo & Galletti and Kizilkanat *et al.* The predominance of NF was on the anterior surface (73.2%), different from the 100% and the 29.8% reported by Forriol Campos *et al.* and Kizilkanat *et al.*, respectively. Our results concerning the percentage of bones with a single NF (100%) and two NF (0.63%) are similar to previous studies (Forriol Campos *et al.*; Kizilkanat *et al.*). The FI found corroborates previous studies (Forriol Campos *et al.*; Kizilkanat *et al.*).

Ulna. The ulna average length is similar to the results reported by Guladi-Russo & Galletti and Kizilkanat *et al.* 82.2% of the NF of the ulna is located on the anterior surface (Forriol Campos *et al.*), different from Kizilkanat *et al.* who reported the predominance in the anteromedial surface. All ulnae examined have at least one NF and 0.63% of the bones have two NF (Kizilkanat *et al.*). Forriol Campos *et al.* found values similar to the ones in this study for the presence of a single NF, but they reported 9% of the bones with two NF, a more expressive value than the 1.4% found in this analysis. The values of FI of 27.4 to 52.5% are close to those reported by Forriol Campos *et al.* and Kizilkanat *et al.*

Femur. The average length of the femur fits the results reported by Sendemir & Çimen, Gümüşburun *et al.*, Kizilkanat *et al.* and Collipal *et al.* (2007). The location in the linea aspera in 93.4% of the bones is similar to that reported by Forriol Campos *et al.*, however, for Sendemir & Çimen and Kizilkanat *et al.*, in approximately 40% of the

Table V. The mean, standard deviation (SD) and range of foraminal indices - for each bone, localization e side (right and left).

			I1		I2		I3	
Bone	Location	Side	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)
a) Humerus – right (R) and left (L) side								
Humerus (n=174)	Anterior surface	R	26.1 - 50.2	41.3 (10.6)	26.1 - 44.5	35.3 (13.0)	.	.
		L	39.8 - 55.0	46.9 (7.6)	38.4 - 45.0	41.7 (3.3)	.	.
	Posterior surface	R	35.7 - 54.4	44.8 (7.9)	28.0 - 45.1	36.5 (12.1)	.	.
		L	46.7 - 58.1	52.4 (8.1)	40.1 - 40.1	40.1 (0.0)	.	.
	Postero-lateral surface	R	40.9 - 56.6	48.3 (7.9)	33.9 - 33.9	33.9 (0.0)	.	.
		L	60.4 - 60.4	60.4 (0.0)	60.0 - 60.0	60.0 (0.0)	.	.
	Antero-medial surface	R	40.4 - 68.8	56.1 (6.1)	37.2 - 49.8	40.9 (4.6)	.	.
		L	42.4 - 67.6	56.9 (5.3)	37.5 - 44.6	40.9 (2.9)	.	.
b) Radium - right (R) and Left (L) side								
Radium (n = 157)	Anterior surface	R	25.6 - 48.1	34.5 (4.6)	31.1 - 31.1	31.1 (0.0)	.	.
		L	22.8 - 46.3	35.6 (5.5)	.	.	.	.
	Antero-lateral surface	R	30.8 - 30.9	30.8 (0.1)	.	.	.	.
		L	28.2 - 42.5	34.2 (7.4)	.	.	.	.
	Postero-medial surface	R	35.4 - 36.4	35.9 (0.7)	.	.	.	.
		L	38.3 - 40.8	39.7 (1.3)	.	.	.	.
	Antero-medial surface	R	29.1 - 44.1	37.2 (4.8)	.	.	.	.
		L	25.0 - 51.2	37.1 (7.4)	.	.	.	.
c) Ulna - right (R) and left (L) side								
Ulna (n = 146)	Anterior surface	R	27.9 - 47.5	36.9 (5.0)	.	.	.	.
		L	27.4 - 51.7	37.6 (5.1)	36.5 - 42.2	39.4 (4.0)	.	.
	Antero-lateral surface	R	38.1 - 48.5	42.7 (3.9)	.	.	.	.
		L	29.1 - 52.5	43.4 (8.4)	.	.	.	.
	Antero-medial surface	R	32.0 - 45.9	37.7 (5.0)	.	.	.	.
		L	32.1 - 39.2	35.6 (5.1)	.	.	.	.
d) Femur - right (R) and left (L) side								
Femur (n = 152)	Linea aspera	R	27.1 - 68.9	40.6 (8.7)	44.9 - 66.8	58.0 (5.9)	.	.
		L	26.1 - 64.0	38.1 (7.3)	31.1 - 64.7	55.2 (7.1)	40.8 - 63.0	51.9 (15.7)
	Medial surface	R	28.2 - 28.2	28.2 (0.0)	.	.	.	.
		L	.	.	.	.	.	.
	Lateral surface	R	29.5 - 56.4	47.4 (15,,)	53.1 - 53.1	53.1 (0.0)	.	.
		L	33.7 - 59.0	52.6 (8.8)	.	.	.	.
e) Tibia - right (R) and left (L) side								
Tibia (n = 142)	Posterior surface	R	26.2 - 73.7	32.9 (6.0)	42.0 - 42.8	42.4 (0.5)	.	.
		L	26.4 - 42.7	32.3 (2.8)	.	.	.	.
	Medial surface	R	29.5 - 40.1	32.3 (4.1)	.	.	.	.
		L	30.7 - 35.6	33.0 (2.5)	.	.	.	.
f) Fibula – right and left (L) side								
Fibula (n = 114)	Lateral surface	R	33.5 - 67.1	45.6 (8.9)	.	.	.	.
		L	33.7 - 63.4	46.5 (7.8)	63.7 - 63.7	63.7 (0.0)	.	.
	Posterior surface	R	.	.	.	.	.	.
		L	34.2 - 54.6	44.4 (14.4)	.	.	.	.

bones the NF are located in this region. Although 97.4% of the bones examined have only one NF, Forriol Campos *et al.*, Gümüşburun *et al.* and Kizilkanat *et al.* reported

approximately 30% with this feature. The observation that about 40% of the bones have two NF is similar to that reported by Mysorekar (1967), Sendemir & Çimen and

Gümüşburun *et al.* and differs from the values reported by Forriol Campos *et al.* (75%) and Kizilkanat *et al.* (60%). Three NF were found only in 1.28% of the femora studied, in disagreement with Forriol Campos *et al.* and Gümüşburun *et al.*, who reported approximately 10%. Although no femur showed more than three NF, previous studies have reported femora with eight to nine NF (Sendemir & Çimen) and with four to six NF (Gümüşburun *et al.*). In agreement with Sendemir & Çimen and Kizilkanat *et al.*, none of the bones studied showed an absence of NF, although Gümüşburun *et al.* reported 1.9%. The result of the FI is similar to those reported by Forriol Campos *et al.*, Gümüşburun *et al.* and Kizilkanat *et al.*

Tibia. The average length of the tibia is similar to previous results (Sendemir & Çimen; Gümüşburun *et al.*; Kizilkanat *et al.*; Collipal *et al.*, 93.7%) of NF is on the posterior surface (Forriol Campos *et al.*; Gümüşburun *et al.*; Kizilkanat *et al.*, 100%) of the tibiae have one NF (Forriol Campos *et al.*; Gümüşburun *et al.*; Kizilkanat *et al.*). Only 1.4% of the bones studied have two NF (Kizilkanat *et al.*), different from the 7% and 11.3% found by Forriol Campos *et al.* and Gümüşburun *et al.*, respectively. The latter showed the presence of 2.8% of the bones with three NF. None of the tibia showed no NF. The values of FI are close to those reported by Gümüşburun *et al.* and Kizilkanat *et al.* and far from those by Forriol Campos *et al.* (30 - 40.6%).

Fibula. Gümüşburun *et al.*, Kizilkanat *et al.* and Collipal *et al.* found values similar to the ones in this study regarding the average length of the fibula. Predominance of NF occurred on the lateral surface, in disagreement with the results of Forriol Campos *et al.*, Gümüşburun *et al.*, Lee *et al.* and Kizilkanat *et al.*, who reported that the posterior surface was predominant. All fibulae analyzed have at least one NF (Guo; Forriol Campos *et al.*; Gümüşburun *et al.*; Lee *et al.*; Kizilkanat *et al.*), while 0.87% has two NF. Guo, Kizilkanat *et al.* and Gümüşburun *et al.* found two NF in the fibulae, 3.3%, 5.4% and 11.6%, respectively. No bones showed an absence of NF, which differs from Gümüşburun *et al.* and Kizilkanat *et al.*, who recorded 3.3% and 1.3%, respectively. Data for the FI are similar to previous studies (Forriol Campos *et al.*; Gümüşburun *et al.*; Lee *et al.*), although Kizilkanat *et al.* found a FI between 25.8 and 82.6%. Forriol Campos *et al.* and Gümüşburun *et al.* reported the middle third as the location of NF, and Guo, the upper third of the bones.

CONCLUSIONS

The results on the nutrient foramina incidence and distribution in long bones are consistent with most studies. The analysis on the nutrient foramina distribution indicates

Fig. 1. Graphic localization of the nutrient foramina (NF), independent of the surface in each bone, based on the range of the index foramen (IF) of the humerus, ulna, radius, femur, tibia and fibula.

that they are located predominantly on the anterior surface in long bones of the lower limbs, which corroborates with previous results on the localization of NF in the flexor surface of those bones. Of all parameters examined in this study on subjects from Southern Brazil, the FI was the one which came closest in comparison with previous studies on the Turkish and Spanish populations. The results on the localization of NF in the fibula disagreed with the results of

studies on the Turkish, Japanese and Spanish populations. Most long bones analyzed in this study have only one NF and may represent the only source of blood supply. Thus, the areas of NF distribution must be, whenever possible, avoided during surgery. This study recorded data related to the population of Southern Brazil, providing ethnic data to be used for comparison and that may help in surgical procedures and in the interpretation of radiological images.

PEREIRA, G. A. M.; LOPES, P. T. C.; SANTOS, A. M. P. V. & SILVEIRA, F. H. S. Forámenes nutricios de los miembros superiores e inferiores en huesos largos: Estudio morfométrico en huesos de adultos del sur de Brasil. *Int. J. Morphol.*, 29(2):514-520, 2011.

RESUMEN: El importante aporte de sangre para los huesos largos se produce a través de las arterias nutricias, que penetran por los forámenes nutricios. Este suministro es esencial durante el período de crecimiento, las primeras fases de osificación y en los procedimientos como injertos óseos, resecciones tumorales, traumas, pseudoartrosis congénita y en las técnicas de trasplante en ortopedia. El estudio determina la ubicación y el número de forámenes nutricios en las diáfisis de 885 huesos largos de los miembros superiores e inferiores pertenecientes a individuos adultos. Fueron estudiados 174 húmeros, 157 radios, 146 ulnas, 152 fémures, 142 tibias y 114 fíbulas. La ubicación de los forámenes nutricios era predominante en la parte anterior de la diáfisis de los huesos largos del miembro superior y en la parte posterior de los huesos largos del miembro inferior. La mayoría de los huesos estudiados tenía un solo foramen nutricional, representando una sola fuente de suministro de sangre. El índice medio foraminal en los huesos del miembro superior fue de 55,2% para el húmero, 35,7% para el radio, y 37,9% para el ulna; en los huesos del miembro inferior fue 43,7% para el fémur, 32,7% para la tibia y 46,1% para la fibula. Este estudio registró datos relativos a la población del Sur de Brasil, proporcionando antecedentes étnicos que además puedan servir de ayuda en los procedimientos quirúrgicos y en la interpretación de imágenes radiológicas.

PALABRAS CLAVE: Foramen nutricional; Hueso largo; Vascularización; Población brasileña.

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