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RESEARCH ARTICLE

Anatomical variations of nutrient foramina on the long bones of the upper extremities - Importance and application in everyday clinical practice

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Objectiv: Anatomic characterization of the nutrient artery of upper extremity long bones differs among the several textbooks on human anatomy. To elucidate the anatomical features of the nutrient foramen (NF) through which the nutrient arteries pass, we examined the morphology and topography of the NF on the diaphysis of the long bones of the upper extremities. **Methods**: A total of 150 (50 humeri, 50 radii, 50 ulnae) macerated and degreased adults, long bones of the upper extremities, unknown age, and gender were used as material in this study. The following parameters were determined for each bone: total number of NF, foramina index (FI), total bone length, position of the NF based on the FI value and the surface of the shaft/body of the bones, and obliquity of the nutritional canal (NC). **Results**: The largest number of NF was found on the middle third of the anteromedial side of the humerus diaphysis, with NC directed distally, that is, towards the elbow. Radius and ulna had predominantly one NF, on middle third of anterior surface, with NC directed proximally. **Conclusion**: This study provides additional and important information on the location and number of NF in the long bones of the upper and lower extremities in the Bosnian and Herzegovinian population.

Keywords: humerus, radius, ulna, nutrient arteries, nutrient foramina

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Introduction

Long bones have three distinct vascular systems that are interconnected. Nutrient arteries are the main source of blood for long bones, providing blood to the bone marrow and internal two-thirds of the bone cortex [1,2]. Nutrient arteries enter the long bone diaphysis obliquely through one or more nutrient foramina (NF), leading into the nutrient canal (NC) [2].

The importance of NF research is not only morphological, but also primarily clinical. Some pathological processes in bone, such as developmental abnormalities, impaired healing of fractures, or acute osteomyelitis, are viewed to be associated to changes in the degree of bone vascularization [3]. In view of the above, there is still a need for a better understanding of the number, topography and the direction of NC in the bones. The aim of our study was to determine variation regarding NF and NC in body of human long bones of the upper extremity.

Methods

The research was design as an observational, descriptive study, conducted on the total of 150 (50 humeri, 50 radii, 50 ulnae) macerated and degreased long bones of the upper extremities of adults whose age and gender were not identified. All selected bones were anatomically preserved, with no visible pathological changes. Specimens were selected based on the following criteria: no evident osteoarthritis or morphological changes within the body of each bone, and both epiphyses were complete and undamaged. Bones with evident damage were excluded from the study. Only NF on the body/shaft of bones was taken into account. The NF has been observed macroscopically, using a slightly raised edge of the NF and a shallow groove that exists proximally to the NF, using a 6× hand magnifier. On each bone, within each group, the total number of macroscopically observed NF on the bony body was recorded. A probe was passed through each hole to confirm its existence of the hole. A thin rubber was wrapped around each NF and photographed with a digital camera.

The precise location of each NF is determined by calculating the Foramina Index (FI), applying the Hughes formula [4].

$$FI = (DNF / TL) \times 100$$

DNF = distance between the proximal end of the bone and the nutrient foramina
TL = total length of the bone

In those bones that had two NF and more, the largest of them is taken to calculate the FI. The total bone length was noted individually for each bone by using the osteometric board, within each group and expressed in centimetres (cm), according to the following [5]: humerus: the distance between the top of the humerus head and the superior point of the trochlea; radius: the distance between the proximal point of the radius head and the top of the

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styloid process; ulna: the distance between the proximal point of the olecranon and the apex of the styloid process.

The whole length of each bone was divided into three equal segments: zone I (proximal 1/3), zone II (middle 1/3) ,and zone III (distal 1/3). Nutritive foramina were categorized into three groups according to the value of FI, as follows:

– Type 1: FI lower than 33.33 - the NF is in the zone I
– Type 2: FI from 33.33 to 66.66 - the NF is in the zone II
– Type 3: FI larger than 66.66 - the NF is in the zone III [6].

The location of each NF was determined by taking into account the sides of the bone shaft on which it is located and the distance from the edges of the bone. The surfaces considered for each bone were: humerus - anteriorlateral, anteriormedial and posterior; radius: anterior, lateral, and posterior; ulna: anterior, medial and posterior [7].

The size of the NF was determined by pulling a 25 G diameter (*MedCare*, Italy) needle through NF. NF with diameter smaller than 0.56 mm were considered secondary NF, while those 0.56 mm in diameter or larger were considered dominant NF.

A thin, subcutaneous needle, which was passed through the NC was used to determine the direction of the canal (whether it is directed towards the proximal or distal end of the bone) and its obliqueness.

Statistical analysis

The Social Sciences (SPSS) software version 13, (IBM, Chicago, Illinois, United States of America) was used for the data analysis. Frequencies and percentages were used to present values of categorical variables. The Chi-square test or Fisher's exact test was used to determine the significance of differences in frequency within relevant subgroups. The association between categorical variables was tested with the Chi-square test. Depending on the sample size, normality of distribution for continuous variables was identified using the Kolmogorov-Smirnov or Shapiro-Wilk test.

Independent continuous variables with a normal distribution are presented as mean and standard deviation (SD). The Student's *t* test was used to test the significance of the difference for the continuous independent variables that accompany the normal distribution. The sample size was calculated using a sample size calculator [8]. The results were considered statistically significant ifthe p value was less than 0.05.

Results

The study included 50 humerus [20 (40.0%) right and 30 (60.0%) left], 50 radius [24 (48.0%) right and 26 (52.0%) left] and 50 ulna [27 (54.0%) right and 23 (46.0%) left]. The average length for right humerus, radius and ulna were 31.21 ± 2.27 cm, 23.41 ± 1.51 cm and 25.27 ± 2.02 cm, respectively, and 31.30 ± 2.51 cm, 22.86 ± 1.53 cm, 24.85 ± 1.82 cm for left humerus, radius and ulna. There were not statistically significant differences in length between right and left extremity for humerus, radius and ulna ($p = 0.902$, $p > 0.05$; $p = 0.204$, $p > 0.05$; $p = 0.44$; $p > 0.05$, respectively) (Table I).

On the bones of the right side, one NF was observed in 13 (72.2%) humerus, 22 (91.7%) radius and 19 (70.4%), and on the bones of the left side on 18 (60.0%) humerus, 21 (91.3%) radius and 19 (82.6%) ulna. Double NF were present on 5 (27.8%) humerus, 2 (8.3%) radius and 7 (25.9%) ulna from right side, and on 9 (30.0%) humerus, 2 (8.7%) radius and 4 (17.4%) ulna from left side. Triple NF were observed on 3 (10.0%) left humerus and 1 (3.7%) right ulna (Table II).

On 39 (81.2%) humerus NF was located on the anteromedial surface [12 (66.7%) right and 27 (90.0%) left]. On 8 (16.7%) humerus NF was located on the posterior surface [6 (33.3%) right and 2 (6.7%) left]. Only in one humerus on the left side, 1 (2.1%), NF was observed on the anterolateral side. On a total of 36 (76.6%) radii NF were found on the anterior surface [21 (87.5%) right and 15 (65.2%) left]. On the posterior surface NF were observed at 11 (23.4%) radii [3 (12.5%) right and 8 (34.8%) left]. NFs were not found on the lateral surface. All 50 (100%) ulnas had NF located on anterior surface (Table III).

The frequency of NF on the anteromedial surface on right humerus was 30.8% and 69.2% for left. The frequency of NF on the posterior surface 75.0% for right

Table I. Length of humerus, radius and ulna on right and left extremity

	Humerus		Radius		Ulna	
	Right (n=20)	Left (n=30)	Right (n=24)	Left (n=26)	Right (n=27)	Left (n=23)
Length (cm)	31.21±2.27	31.30±2.51	23.41±1.51	22.86±1.53	25.27±2.02	24.85±1.82
Min.	26.3	25.7	20.5	20.2	22.2	21.5
Max.	35.1	35.8	26.0	25.9	30.4	27.8

Table II. Total number NF on the humerus, radius and ulna

Number of NF	Humerus				Radius				Ulna			
	Right (n=20)		Left (n=30)		Right (n=24)		Left (n=26)		Right (n=27)		Left (n=23)	
	n	%	n	%	n	%	n	%	n	%	n	%
1	13	72.2	18	60.0	22	91.7	21	91.3	19	70.4	19	82.6
2	5	27.8	9	30.0	2	8.3	2	8.7	7	25.9	4	17.4
3	0	0.0	3	10.0	0	0.0	0	0.0	1	3.7	0	0.0
Total	18	100	30	100	24	100	23	100	27	100	23	100

and 25.0% for left. Due to sample size, we did not analyze the frequency of NF on the anterolateral surface on any humerus. Analyzing the correlation between the extremity side to which the humerus belongs and the position of the NF in relation to the body surfaces, we found a statistically significant dependence ($\chi2$ = 5.496; p = 0.02, p <0.05). The frequency of NF on the anterior surface was 58.3% for right and 41.7% for left radius, and 27.3% for right and 72.7% for left radius on posterior surface. Analyzing the correlation between the extremity to which the radius belongs and the position of the NF in relation to the defined body surfaces, we did not determine the existence of a statistically significant dependence (p = 0.09, p> 0.05). All ulnae on both the right and left sides had NF on the anterior body surface (results not present).

All humeri from the right and left extremities had NC directed toward the distal end of the bone, and all radii and ulnae on both sides had NC directed toward the proximal end of the bone (Table IV).

By analyzing the position of NF based on the value of FI on the humerus, we found that in 46 (95.8%) humerus NF were located in the middle third of bone body [17 (94.4%) right and 29 (96.7%) left], in 1 (2.1%) humerus from right extremity had NF in the proximal third and in 1 (2.1%) humerus fomr left extremity in the distal third of the bone body. At 18 (38.3%) radii NF were located in the proximal third [13 (54.2%) right and 5 (21.7%) left] and at 29 (61.7%) in the middle third bone body [11 (45.8%) right and 18 (78.3%) left]. On the ulna, in 12 (24.0%) bones the NF were located in the proximal third of the body [7 (25.9%) right and 5 (21.7%) left], while in 38 76.0%) of the bones NF were located in the middle third of the body [20 (74.1%) of the right and 18 (78.3%) of the left] (Table V).

Table III. The location of the NF on the surfaces of the bone body

Bone	Surface of body	Right side		Left side	
		n	%	n	%
Humerus	Anteromedial	12	66.7	27	90.0
	Anterolateral	0	0.0	1	3.3
	Posterior	6	33.3	1	6.7
Radius	Anterior	21	87.5	15	65.2
	Posterior	3	12.5	8	34.8
	Lateral	0	0.0	0	0.0
Ulna	Anterior	27	100.0	23	100.0
	Posterior	0	0.0	0	0.0
	Medial	0	0.0	0	0.0

Table IV. Obliquity of nutritional canal

Bone	Bone epiphysis							
	Proximal				Distal			
	Right		Left		Right		Left	
	n	%	n	%	n	%	n	%
Humerus	0	0.0	0	0.0	18	100.0	30	100.0
Radius	24	100.0	23	100.0	0	0.0	0	0.0
Ulna	27	100.0	23	100.0	0	0.0	0	0.0

Table V. Position of NF based on Foramina Index

Bone	Bone epiphysis											
	Proximal 1/3				Middle 1/3				Distal 1/3			
	Right		Left		Right		Left		Right		Left	
	n	%	n	%	n	%	n	%	n	%	n	%
Humerus	1	5.6	0	0.0	17	94.4	29	96.7	0	0.0	1	3.3
Radius	13	54.2	5	21.7	11	45.8	18	78.3	0	0.0	0	0.0
Ulna	7	25.9	5	21.7	20	74.1	18	78.3	0	0.0	0	0.0

Table VI. Correlation between the position of the NF based on the FI and the number of NF

Bone	Bone epiphysis												p
	Proximal 1/3				Middle 1/3				Distal 1/3				
	Right		Left		Right		Left		Right		Left		
	n	%	n	%	n	%	n	%	n	%	n	%	
Humerus	1	5.6	0	0.0	17	94.4	29	96.6	0	0.0	1	3.4	χ^2 = 2.27 p=0.32
TOTAL	1 (2.1%)				46 (95.8%)				1 (2.1%)				
Radius	13	72.2	5	27.8	11	37.9	18	62.1	0	0.0	0	0.0	χ^2 = 5.226 **p=0.02**
TOTAL	18 (38.3%)				29 (61.7%)				0 (0.0%)				
Ulna	7	77.3	5	22.7	20	52.6	18	47.4	0	0.0	0	0.0	χ^2 = 3.579 p=0.059
TOTAL	22 (44.0%)				38 (56.0%)				0 (0.0%)				

We did not find a statistically significant correlation between the position of NF based on the FI value and the number of NF on the right and left humerus ($\chi2 = 2.27$; $p = 0.32$, $p> 0.05$). Based on the FI value, the frequency of NF on the proximal third of the bone body in the right radius was 72.2% and on the left 27.8%. On the middle third of the body the frequency was 37.9% in the right and 62.1% in the left radius. Statistically significant correlation was observed between the position of NF based on the FI value and the number of NF on the radii of the right and left extremities ($\chi2 = 5.226$; $p = 0.02$, $p <0.05$). The incidence of NF in the proximal third of the bone body was 77.3% on the right ulna and 22.7% on the left. In the middle third, the incidence of NF was 52.6% for the right ulna and 47.4% for the left. Correlation between the position of NF based on FI and the number of NF on the ulna of the right and left extremities was not statistically significant ($\chi2 = 3.579$; $p = 0.059$, $p> 0.05$) (Table VI).

Discussion

Bone tissue is very rich in blood supply, with a developed network that is different, not only in different bones, but also in certain parts of the same bone. The anabolic and catabolic processes of the cells of the skeletal system depend on the vascularization of the bone [9]. The data about anatomical variations of the NF on the diaphysis of the long bones of the upper extremity, in the broadest sense of the word, as well as knowledge of its relationships with surrounding structures is of great importance in everyday clinical practice, whether open or closed fracture reduction or about the preoperative procedure as part of a bone transplant [10]. More variation can lead to an increased risk in terms of injury to important neurovascular structures. The biological process of repairing traumatic or surgically induced discontinuity in bone continuity may be slow or not develop at all [11]. By knowing the area where the nutritional artery enters the NC, surgeons can prevent further damage to it and minimize or reduce the possibility of nonunion or delayed fracture healing [12].

The humerus received a nutritional artery from a brachial artery or deep brachial artery, or as a muscular branch of the mentioned arteries [13]. In our study we found that in 96% of humerii had NF, while 4.0% of humerii had no NF. The largest number had present one NF (72.2% right and 60.0% left humerii), while two NF were recorded in 27.8% right and 30.0% left humerii, and three NF were observed in 10.0% left humerii. Analysing the available literature, we found similar results. Results from Hemang et al. [12], Sharma et al. [14], Chandrasekaran et al. [15] are in accordance with our results. The results of our and previous studies indicate that in most cases the humerus has one NF, and that it receives vascularization in one place. This is considered a vital, clinically significant point on the diaphysis. In 81.2% cases these NF were located in anteromedial surface. We also recorded a statistically significant correlation between the side of the limb to which the humerus belongs and the position of the opening in relation to the sides of the bone diaphysis. Results from Pereire et al, [16] and Gopalakrishna et al. [17]. showed that in 89.7% and 83.09% cases, respectively, NF on humerii are located on anteromedial surface. A lower incidence of NF on the anteromedial surface was found in the study of Solanke et al. [18] and Kizilkanat et al. [19], which can be due to race and national differences. According to FI value in 95.8% of the humerii NF was found in the middle third of the body, which is in agreement with Ukoha et al. [6] and Murlimanju et al [13]. Based on our results, we conclude that the essential area of the bone body that should be avoided during operative manipulations is middle third of anteromedial side, because in most cases the humerus receives vascularization through NF located in that particular zone. By avoiding the anteromedial aspect of the humerus during procedures, not only will the nutrient artery be preserved, but other neurovascular structures also, while it is commonly know that the brachial plexus with all branches also pass on the medial aspect of a upper arm.

Nutrient arteries for radius and ulna are often branches of radial and ulnar artery [20]. Knowledge of variations of NF in the forearm is also important when interpreting radiographs, because NC can appear on the image as a dark hairline, which can be very similar to fractures. Fractures of the body of the radius and ulna are quite common when a strong force acts on it, for example injuries in traffic accidents, falls from great heights or gunshot wounds. We found that 94.0% of radii and in all 100% ulna, NF were present. Most of radii and ulnae had one NF (91.7% right and 91.3% left radii; 91.7% right and 91.3% left ulna), while two NF were observed in 8.3% right and 8.7% left radii, and on 25.9% right and 17.4% left ulna. All observed NF on ulna, independent of a number were located on anterior surface, while in radii they were located mostly on also on anterior surface. The rest of NF on radii were located on posterior surface. We did not determine the existence of a statistically significant correlation between the extremity to which the radius belongs and the position of the NF on the radius in relation to the defined sides. While the location of NF on the anterior surface on the ulna varies from 82.2% [16], 76.62% [18] and 98.9% [21], number and location of NF on radii in our study is in agreement with results from others [19]. With reported incidences ranging from 2% to 10%, aseptic nonunion remains a important late complication of diaphyseal forearm fractures [22]. According to FI value, most of the radii (61.7%) and ulnae (76.0%) had their NF in middle third of body, which is in agreement with other reports published in the literature [17]. The most common forearm fractures in adults are the distal radius and ulna fractures, which are primarily caused by a fall onto an extended hand [23]. On the forearm, the muscles cover and connect mainly to the proximal half of the radius, but also the ulna. However, there are no significant muscle insertions on the distal half of the radius and ulna diaphysis, which corresponds to a lack of NF in that part of the bone. Therefore, nonunion or delayed healing of fractures in the distal half of the diaphysis may be directly related to the lack of nutrient arteries in these areas [24]. Although the periosteum of this area receives part of the blood from the branches of the adjacent anterior and posterior interosseous artery, these branches can often be damaged during sudden stretching of the interosseal membrane, especially during sudden pronation. A complete radiologic evaluation of a distal radius and ulna fracture requires at least two views (posteroanterior and lateral) of the wrist [25]. Oblique radiography is often required to fully assess the extent of the fracture, while NC that pass throughout the cortex can often mislead and be pronounced as a fracture. In our study, all NC on radii and ulna were directed toward the proximal part, while NC in humerii distally penetrated the cortical bone layer, which is in agreement with other results found in the literature [17,26]. Because of such anatomical position of NF, safe zones for procedures such as insertions of pin on ulna, during pronation, would be along the whole axis between the extensor carpi ulnaris and the flexor carpi ulnaris, while for radius, during supination, any pins need to be inserted under direct vision using retractors down to the bone to avoid injury of nutrient artery. For more precise results, further research is needed where the age and gender parameters of the person from whom the bones come are known. In this way, one would get insight into the number of nutritional openings and their location with regard to age and gender.

Unfortunately, the study of anatomical variations has been neglected by recent trends in undergraduate medical studies, due to reduced dissection, reduced dissected specimens, increased use of plastic preparations, computer images, loss of experienced teachers and diminishing morphological approach. The study of anatomical variations, therefore, will always have a significant place in medical education, both in terms of explaining their occurrence and frequency of occurrence, and in terms of practical application of acquired knowledge in clinical terms.

Conclusion

Knowing the most common positions of nutrient foramina on the diaphysis of the long bones of the upper extremities, allows surgeons to avoid these areas in daily clinical practice, and minimize manipulation in these parts, thus the least chance of vascular supply to long bones is compromised and allows surgical procedures be successful.

Author Contributions

LD: Conceptualization, Data curation, Investigation, Methodology, Drafting the manuscript;
AD: Software, Supervision, Assisting in drafting the manuscript
ZA: Analyzing and interpreting study data, Investigation, Formal Analysis, Writ-ing - original draft
EK: Data curation, Investigation, Writing - original draft
AL: Data curation, Investigation, Writing - original draft
AV: Data curation, Supervision, Validation, Visualization, Writing - re-view & editing
ET: Project administration, Validation, Visualization, Writing - re-view & editing
All authors have accepted responsibility for the entire content of this manuscript and approved its submission

Conflict of interest

None to declare.

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