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Research Article

An Investigation of the Nutrient Foramen in the Long Bones of the Upper and Lower Limbs in Turkish Population

Türk Populasyonunda Üst Ve Alt Ekstremite Uzun Kemiklerinde Foramen Nutricium'larin İncelenmesi

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Abstract

Aim: We aimed to examine the presence, number, anatomic location of the nutrient foramen in the long bones of the upper and lower limbs and calculate the foramen index.

Materials and Methods: Our study was conducted on a total of 295 bones, including 25 clavicle, 59 humerus, 49 radius, 32 ulna, 59 femur, 49 tibia, and 22 fibula. The number of the nutrient foramen in each bone, the anatomic location of the nutrient foramen on the bone, and the direction of its opening were determined and recorded. All bones were photographed with a millimeter ruler. The bone length and the distance of the nutrient foramen to the proximal of the bone were measured using the ImageJ program. The foramen index was calculated for each foramen.

Results: At least one nutrient foramen was observed in all bones, except for one humerus and three fibula. The highest mean foramen index belonged to the humerus and clavicle, while the lowest mean foramen index belonged to the tibia. The direction of the nutrient foramen is mostly toward the acromial end (87.5%) in the clavicle, toward the distal in the humerus (97.6%), tibia (96.15%) and fibula (75%), and toward the proximal in the radius (96.36%), ulna (100%), and femur (98.97%).

Conclusion: There are few studies on the nutrient foramen in which bones of the upper and lower limbs are examined together and comparisons between populations are made. Therefore, we think that our study will enrich the limited literature on this subject and contribute to clinicians.

Keywords: Foramen index, fracture, localization, nutrient artery

Öz

Amaç: Üst ve alt ekstremite uzun kemiklerinde foramen nutricium'ların varlığını, sayısını, anatomik konumunu incelemeyi ve foramen indeksini hesaplamayı amaçladık.

Materyal ve Metot: Çalışmamız 25 clavicula, 59 humerus, 49 radius, 32 ulna, 59 femur, 49 tibia ve 22 fibula olmak üzere toplam 295 kemik üzerinde gerçekleştirildi. Bütün kemiklerdeki foramen nutricium'ların sayısı, foramen nutricium'ların kemik üzerindeki anatomik konumu ve açıklığının yönü belirlenerek kaydedildi. Tüm kemikler bir milimetrik cetvel ile fotoğraflandı. Kemik uzunluğu ve foramen nutricium'ların kemiğin proksimaline olan mesafesi ImageJ programı kullanılarak ölçüldü. Bütün foramenler için foramen indeksi hesaplandı.

Bulgular: Bir humerus ve üç fibula dışında tüm kemiklerde en az bir foramen nutricium gözlendi. En yüksek foramen indeksi ortalaması humerus ve clavicula'ya aitken, en düşük foramen indeksi ortalaması tibiaya aitti. Foramen nutricium'ların açıklığının yönü clavicula'da çoğunlukla extremitas acromialis'e (%87,5), humerus'ta (%97,6), tibia (%96,15) ve fibula'da (%75) distale ve radius (%96,36), ulna (%100) ve femur'da (%98,97) proksimale doğruydu.

Sonuç: Üst ve alt ekstremite kemiklerinin birlikte incelendiği ve popülasyonlar arası karşılaştırmaların yapıldığı foramen nutricium'larla ilgili az sayıda çalışma bulunmaktadır. Bu nedenle çalışmamızın bu konudaki sınırlı literatürü zenginleştireceğini ve klinisyenlere katkı sağlayacağını düşünüyoruz.

Anahtar Kelimeler: Foramen indeksi, kırık, lokalizasyon, arteria nutricia

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INTRODUCTION

The nutrient foramen (NF) is an opening in the shaft of the bone that provides nutrition and growth of the bone thanks to the artery passing through it. The nutrient artery enters the bone obliquely from the NF (1). The nutrient artery is the main source of nutrition for the long bones. The restriction of the blood flow from this nutritional source can cause ischemia in the bones (2). This artery is especially important in the active growth period of the embryo and fetus and the early stage of ossification (1).

The fracture of the long bones is a common situation. Delayed union is one of the most common complications after a fracture. This complication may have many causes. Poor bone nutrition is one of the conditions that cause this complication to occur. Therefore, the nutrient artery plays an important role in fracture healing (3). It has been reported that places where union problems are common in the forearm are correlated with the localization of the NF (4). Longitudinal stress fractures may cause the rupture of the nutrient artery. Moreover, conditions such as developmental abnormalities and hematogenic osteomyelitis, apart from fracture healing, are also related to the nutrition of the bone (2). It has been emphasized that union problems may occur due to the injury of the nutrient artery during open reduction (4). Therefore, the topography of the NF is important in surgery for the protection and maintenance of circulation (1). Furthermore, the details about the nourishment of the long bones are very important in the development of new transplantation and resection techniques in orthopedics. Therefore, the variety of studies on the NF gains importance (5).

Thus, in the present study, we aimed to examine the presence, number, and anatomic location of the NF in bones of the upper and lower limbs and determine in which of the proximal, middle, and distal 1/3 parts of the bone it is localized through the foramen index.

MATERIAL AND METHOD

Our study was conducted on a total of 295 bones, including 25 clavicle, 59 humerus, 49 radius, 32 ulna, 59 femur, 49 tibia, and 22 fibula of unknown age and sex in the Anatomy Department Laboratory of the Faculty of Medicine. Broken or deformed bones were not included in the present study since they could be misleading with regard to the findings. This study was approved by the Clinical Research Ethics Committee of the Faculty of Medicine (Date: 11.17.2020, Decision No: 362).

The number of the NF in each bone was determined. The anatomic location and direction of the NF on the bone were determined and recorded. All bones were photographed with a millimeter ruler. Anatomically, two parallel lines passing through the most distal and proximal parts of the bone were drawn on the photographs. These lines were taken as a reference, and the bone length and the distance of the NF to the proximal of the bone (Figure 1) were measured using the ImageJ program. Data analysis was done using SPSS 20.0 for Windows. Means and standard deviations of the bone length, the distance of the NF to the proximal of the bone and foramen index were determined. In addition results regarding the number, location and direction of the nutrient foramen obtained by frequency analysis. Since the gender of the bones was not known, the differences between male and female could not be compared.

Figure 1. The distance of the nutrient foramen in the upper and lower limb bones to the proximal. a. Clavicle b. Humerus c. Radius d. Ulna e. Femur f. Tibia g. Fibula (Arrows show the nutrient foramen)

Hughes (6) described the foramen index (FI) formula to determine the localization of the NF. The present study, the following formula described by Hughes (6) was used when calculating the FI.

$$\text{Foramen Index (FI)} = \frac{\text{Distance of the foramen to the proximal end of the bone}}{\text{Total length of the bone}} \times 100$$

Upon examining the FI value, as in the literature, the foramen with an FI value of 0-33.33% was accepted to be localized in the proximal 1/3 of the bone (in the medial 1/3 in the clavicle), the foramen with an FI value of 33.33-66.66% was accepted to be localized in the middle 1/3 of the bone, the foramen with an FI value of 66.66-100% was accepted to be localized in the distal 1/3 of the bone (in the lateral 1/3 in the clavicle) (1,7,8).

RESULTS

1. The number of the nutrient foramen

Of the 295 bones examined in our study, 217 (73.56%) had a single NF, 59 (20%) had two, 9 (3.06%) had three, 2 (0.68%) had four, 4 (1.35%) had five NF, while 4 (1.35%) had no NF. One of the bones without the nutrient foramen was the humerus, and three were the fibula (Table 1).

2. The foramen index

In all bones, except for the tibia, the NF was mostly localized in the middle 1/3 of the bone (Table 1). In the tibia, the NF was mostly found in the proximal 1/3 of the bone. The highest mean FI belonged to the humerus and clavicle, while the lowest mean FI belonged to the tibia (Table 2).

Table 1. The number of bones, the number and the localization of nutrient foramen

		Clavicle*	Humerus	Radius	Ulna	Femur	Tibia	Fibula
Number of Bones	Right (N)	12	24	25	16	31	30	9
	Left (N)	13	35	24	16	28	19	13
	Total	**25**	**59**	**49**	**32**	**59**	**49**	**22**
Number of NF	0	-	1	-	-	-	-	3
	1	15	39	43	29	27	46	18
	2	3	16	6	3	27	3	1
	3	4	1	-	-	4	-	-
	4	-	1	-	-	1	-	-
	5	3	1	-	-	-	-	-
	Total	**48**	**83**	**55**	**35**	**97**	**52**	**20**
Localization of NF	Proximal 1/3	12	9	25	9	15	37	-
	Middle 1/3	30	64	30	26	80	15	19
	Distal 1/3	6	10	-	-	2	-	1

NF: Nutrient foramen, * Instead of the medial 1/3 in the clavicle, the expression "proximal 1/3" was used, and the expression "distal 1/3" was used instead of the lateral 1/3

Table 2. Foramen indices of the upper and lower limbs

Bone	Total length of the bone (mm)	Distance of the NF to the proximal end of the bone (mm)	Foramen Index
Clavicle	137.93±13.6	66.96±27.78	52.27±19.12
Humerus	311.33±30.9	160.92±45.67	52.39±14.84
Radius	228.39±15.87	77.88±16.95	34.11±7.08
Ulna	254.71±21	96.34±18.9	37.75±6.46
Femur	432.28±36.89	196.61±52.32	45.64±11.34
Tibia	373.55±26.74	123.92±24.45	33.23±6.31
Fibula	339.11±23.02	166.86±36.19	47.14±14.37

NF: Nutrient foramen

3. The anatomic location of the nutrient foramen

Of the NF present in the clavicle, 52.08% were in the inferior surface, 35.42% were in the posterior of the bone, 10.42% were in the superior surface, and 2.08% were present in the anterior of the bone. Of the NF present in the humerus, 45.79% were determined in the anteromedial surface, 25.30% in the posterior surface, 19.28% in the medial border, 8.43% in the intertubercular sulcus, and 1.20% were determined in the anterior border. Of the NF present in the radius, 85.45% were in the anterior surface, 9.1% in the interosseous border, and 5.45% in the posterior surface. Of the NF present in the ulna, 80% were in the anterior surface, 17.14% were in the interosseous border, and 2.86% were in the posterior surface. While 98.97% of the NF detected in the femur were located in the posterior surface, 1.03% were in the anterior surface. Of the NF determined in the femur, 49.48% were found in the medial of the linea aspera, 42.27% were above the linea aspera, and 7.22% were in the lateral of the linea aspera. The location of 1.03% of the NF with respect to the linea aspera could not be evaluated since the NF was not on the surface where the linea aspera was present. Of the NF present in the tibia, 96,16% were found in the posterior surface, 1.92% were in the anterior of the bone, and 1.92% were in the medial border. Of the NF present in the tibia, 86.54% were in the lateral of the soleal line, and 7.7% were above the soleal line. The location of 3.84% of the NF in the tibia with respect to the soleal line could not be evaluated since the NF was not on the surface where the soleal line was present, and the location of 1.92% with respect to the soleal line could not be evaluated since the NF was in the body. Of the NF present in the fibula, 40% were in the medial surface, 20% were in the interosseous border, 15% were in the lateral surface, 15% were in the posterior surface, and 10% were in the anterior border.

4. Direction of the nutrient foramen

Of the NF in the clavicle, 87.5% were directed to the acromial end, 12.5% were directed to the sternal end; of the NF in the humerus, 97.6% were directed distally, and 2.4% were directed proximally; of the NF in the radius, 96.36% were directed proximally, and 3.64% were directed distally. All the NF present in the ulna were directed proximally. This suggests that the NF is generally directed to the elbow joint.

Of the NF in the femur, 98.97% were directed proximally, 1.03% were directed distally; of the NF in the tibia, 96.15% were directed distally, and 3.85% were directed proximally; of the NF in the fibula, 75% were directed distally, and 25% were directed proximally. It is note worthy that the NF is directed in the opposite direction to what is frequently observed in some clavicle, humerus, radius, and femur, and this NF is the other NF from the main NF feeding the bone.

DISCUSSION

The presence, number, anatomic location, and localization of the NF are important in the nutrition of the bone, fracture healing, in the surgical interventions to be performed after the fracture, and in the nutrition and recovery of the bone after surgical interventions. Due to this clinical significance, there are many studies in the literature (2,4,9,10).

Injury of the nutrient artery associated with femoral shaft fractures is considered a cause of delayed union (11). However, even in the long bones of the upper and lower extremities, a few is known about the origin and bone course of the nutrient arteries, but this information is crucial for preserving the feeding arteries during operative procedures (10).

We examined the previous studies in the literature investigating the NF and compared the results of these studies with our study. When the studies examining the NF in upper limb bones were compared, it was observed that there was mostly one NF in the humerus, radius, and ulna in our study in line with the literature (Table 3).

While there are studies reporting a single NF in most of the clavicles examined, as in our study (12,13), there are also studies reporting double NF (Table 3) (14-16). Furthermore, 5 NF were detected in 3 clavicles and one humerus in our study (Figure 2).

Figure 2. Views of the humerus and clavicle with five nutrient foramina, a. Humerus (posterior) b. Humerus (anterior) c. Clavicle (anterior) d. Clavicle (superior) e. Clavicle (posterior) f. Clavicle (inferior) (Acupuncture needles are inserted into the nutrient foramina for a clearer understanding)

In the literature review we performed, we did not encounter any other study in which five NF were observed in the clavicle and humerus (Table 3). Similar to the results of previous studies examining the NF in lower limb bones, mostly single NF was observed in the tibia and fibula in our study (Table 4).

Table 3. Comparison of studies examining nutrient foramen in upper limb bones

Study	Bone	Year	Population	Number of Bones	Foramen Index	Number of NF						Total number of NF	Proximal 1/3	Middle 1/3	Distal 1/3
						0	1	2	3	4	5				
Rai et al. (14)	Clavicle	2014	India	40	48.01	-	17	21	2	-	-	65	10	48	7
Tanna et al. (15)		2015	India	50	49.01	-	21	26	3	-	-	82	15	59	8
Saha et al. (13)		2017	India	54	47.65	-	29	22	3	-	-	82	14	61	7
Hussain at al. (16)		2018	Pakistan	60	51.41	-	22	30	6	2	-	108	-	54	6
Leschinger et al. (33)		2019	Germany	317	53.2	17		300				317	1	287	12
Kumar et al. (12)		2019	India	102	-	10	75	15	2	-	-	92	-	92	-
Our Study		2021	Turkey	25	52.27±19.12	-	15	3	4	-	3	48	12	30	6
Xue et al. (24)	Humerus	2016	China	38	43.76	1	32	5	1	-	-	42	-	-	-
Pankaj et al. (23)		2017	India	350	-	19	283	47	4	-	-	380	2	371	7
Ghule et al. (25)		2018	India	100	R:56.31 L: 56.88	-	100	-	-	-	-	100	1	92	7
Khandve et al. (26)		2018	India	80	-	3	70	29	-	-	-	128	-	94	2
Rathwa et al. (7)		2019	India	68	55.20	-	64	4	-	-	-	72	6	62	4
Kumari et al. (22)		2019	India	64	-	-	58	5	-	-	-	63	-	52	1
Our Study		2021	Turkey	59	52.39±14.84	1	39	16	1	1	1	83	9	64	10
Rangasubhe et al. (19)	Radius	2014	India	100	-	-	97	3	-	-	-	103	68	35	-
Solanke et al. (27)		2014	India	80	34.36	4	74	2	-	-	-	78	18	58	-
Kumar et al. (34)		2017	India	110	R: 35.64 L: 34.96	-	108	2	-	-	-	112	-	-	-
Our Study		2021	Turkey	49	34.11±7.08	-	43	6	-	-	-	55	25	30	-
Solanke et al. (27)	Ulna	2014	India	80	36.52	3	77	-	-	-	-	77	18	59	-
Chavda et al. (28)		2018	India	150	35.34	3	145	2	-	-	-	149	33	95	21
Rangasubhe et al. (20)		2019	India	100	-	-	86	13	1	-	-	115	98	14	3
Priya et al. (29)		2019	India	200	35.83±6.12	-	188	12	-	-	-	212	80	120	-
Our Study		2021	Turkey	32	37.75±6.46	-	29	3	-	-	-	35	9	26	-

NF: Nutrient foramen

Table 4. Comparison of studies examining nutrient foramen in upper limb bones

Study	Bone	Year	Population	Number of Bones	Foramen Index	Number of NF						Total number of NF	Proximal 1/3	Middle1/3	Distal 1/3
						0	1	2	3	4	5				
Gupta et al. (17)	Femur	2016	Nepal	100	-	3	71	25	1	-	-	124	26	97	1
Zahra et al. (2)		2018	Turkey	107	R:44.58±10.25 L:45.29±11.46	17	69	20	1	-	-	112	15	97	-
Uzuner et al. (18)		2018	Turkey	131	-	-	58	120	-	-	-	298	95	83	10
Our Study		2021	Turkey	59	45.64±11.34	-	27	27	4	1	-	97	15	80	2
Singh et al. (30)	Tibia	2015	India	70	-	-	70	-	-	-	-	70	70	-	-
Sinha et al. (35)		2017	India	50	-	-	-	-	-	-	-	70	59	11	-
Udaya Kumar et al. (36)		2017	India	151	R: 32.09±3.76 L: 32.12±3.13	-	131	18	2	-	-	173	-	-	-
Zahra et al. (2)		2018	Turkey	91	L: 32.5±4.6 R:32.39±2.21	1	88	2	-	-	-	92	66	26	-
Chavda et al. (8)		2019	India	70	R: 33.8±5.43 L: 33.5±5.56	-	70	-	-	-	-	70	45	25	-
Ghosh et al. (37)		2020	India	172	-	-	172	-	-	-	-	172	161	2	-
Our Study		2021	Turkey	49	33.23±6.31	-	46	3	-	-	-	52	37	15	-
Zahid et al. (38)	Fibula	2015	Pakistan	168	49.03±9.88	-	164	4	-	-	-	172	1	156	10
Jayaprakash et al. (32)		2016	India	50	43.73±9.69	4	45	1	-	-	-	47	5	39	3
Zahra et al. (2)		2018	Turkey	67	L: 49.51±8.36 R: 46.02±7.46	14	52	1	-	-	-	54	1	53	-
Gaharwar ve Sinha (21)		2020	India	100	-	-	78	22	-	-	-	122	122	-	-
Our Study		2021	Turkey	22	47.14±14.37	3	18	1	-	-	-	20	-	19	1

NF: Nutrient foramen

While there are studies stating that mostly single NF is observed in the femur, it has also been reported that double NF can be found (Table 4) (2,17,18). Result of study, the number of femur with single and double NF was equal (Table 4).

When the localization of the NF in the clavicle and humerus was examined, our results were similar to the results of previous studies (Table 3). Result of this study, most of the NF in the radius and ulna are localized in the middle 1/3 of the bone, while there are studies in the literature in which the NF is mostly localized in the proximal 1/3 of the bone (Table 3) (19,20). This strengthens the likelihood of differences between populations.

The present study, it was observed that the NF in the tibia was mostly localized in the proximal 1/3 of the bone, and the NF in the femur and fibula were localized in the middle 1/3 of the bone, similar to the results of other studies, except for two studies we encountered (Table 4) (18,21).

There are studies reporting that NF in the clavicle is mostly located on the posterior and lower surface of the bone (12-16). Result of this study, the NF in the clavicle was most frequently observed in the inferior surface, and the NF was also found in the superior surface and anterior of the bone. As in our study, there is a study reporting the NF located in the superior surface and anterior of the bone (13).

In previous studies, the most common anatomical location of NF in the humerus was the anteromedial surface, as in our study, while a study we encountered reported the most common anatomical location of NF as the medial border (22-26).

In the radius we examined, the most common anatomical location of NF was on the anterior surface, similar to the results of other studies. We encountered the NF also in the interosseous border in the current study, differently from the literature (7,27). In the ulna we examined, the most common anatomic location of the NF was the anterior surface, as in previous studies (20,24-26). While there are studies indicating the NF in the anterior border and medial surface of the ulna, we did not encounter the NF in the anterior border and medial surface in our study (27-29).

Studies in the literature have indicated that NF in the femur is mostly located on the posterior surface, although there are differences in localization compared to the linea aspera (2). The current study, we also found 1 NF in the anterior surface, although the NF in the femur was mostly found in the posterior surface. The present study, similar to the results in the literature, while the NF in the tibia was mostly found in the posterior surface, differently, the NF was found in the anterior of the bone (2,8,30,31). It has been reported that the NF in the fibula is most frequently observed in the posterior surface (2,21,32). Result of this study, the most common anatomic location of the NF in the fibula was the medial surface. We think that this is due to differences between and within populations.

Similar to the results in the literature, in the present study, the NF in the clavicle was mostly directed toward the acromial end (12). It has been reported that NF in the humerus is mostly directed distally (7,22-25). The current study, it was observed that the NF in the humerus was mostly directed distally, while there was also NF directed proximally. Previous studies have reported that all of the NF in the radii examined are directed proximally. On the other hand, in our study, although most of the NF were proximally directed, there were also NF directed distally (19,27). Similar to the results in the literature, all of the NF in the ulna we examined in the present study were proximally directed. Furthermore, another study reported that it was directed distally and horizontally (20,27-29).

The present study, as in other studies, the NF in the femur was mostly directed proximally. Although it has been reported that there is horizontally directed NF in the femur, we did not find any NF directed horizontally in our study (2). However, we encountered one distally directed NF. The distally directed NF was the third NF in the same bone. As in previous studies, although the NF in the tibia and fibula were mostly directed distally, there were also NF directed proximally (2,8).

Our study had some limitations. These are the low number of bones we examined and not knowing the age and sex of bones and the existence of metabolic pathologies (such as osteoporosis) that would affect the bone structure.

CONCLUSION

In addition to the fact that most of the data in the literature are similar to our study, it also draws attention that there are differences. Due to the results we obtained in the present study, we think that the data on the NF may differ between populations. This reveals that the NF should be examined in more studies, and the literature should be expanded in this field. There are few studies on the NF that examine the bones of the upper and lower limbs together and make comparisons between populations. Therefore, we think that our study will enrich the limited literature on this subject and contribute to clinicians.

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