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ORIGINAL RESEARCH

Ulnar Nutrient Foramen Morphology and Minimizing Screw Damage in Ulnar Fractures

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ABSTRACT

The aim of this study is providing an in-depth investigation of the morphological and morphometric characteristics of the nutrient foramen (NF) to minimize the damaging of the NF during fixation of ulnar fractures. This study was performed by using a sample of 110 dry ulnae (47 right, 63 left). The ulnar length (UL), distance between the NF and the most proximal point of olecranon (NFO), as well the distance between the NF and interosseous border (NFIB) were taken under measurement. The number, location, direction, position, and size of NF was evaluated. Also, the foraminal index (FI) was calculated. In addition, forearm fracture was created experimentally on a cadaver belonging to a 73-year-old Turkish female in our department, and ulnar open reduction internal fixation was performed. After the removal of the plate and screws, the effect of plate fixation on the NF was evaluated and examined for further treatment decisions. The mean UL, NFO, NFIB and FI were measured to be 244.16 ± 17.65 mm, 93.76 ± 18.11 mm, 8.23 ± 3.67 mm, and 38.29 ± 6.45%, respectively. In general, 1 NF was detected on the ulnae, which was located anterior surface, directed upwards, on 2/5 zone and smaller than 22-gauge size. The distances between the most proximal first, second and third screws and interosseous border were measured to be 4.39 mm, 6.20 mm, and 6.56 mm, respectively. The screws were found not to have damaged the NF on fractured ulna of cadaver. According to our dry bone and cadaveric results, being knowledgeable about the morphologic and morphometric characteristics of NF is important in screwing the plate, which should be done to the distal parts of shaft if possible and near the anterior border of ulna for minimizing the damage to the nutrient foramen in order to preserve the blood supply of the bone.

Keywords: Ulna. Nutrient foramen. Fracture. Screw. Cadaver. Anatomy.

Ulna'nın Foramen Nutricium Morfolojisi ve Ulnar Kırıklarda Vida Hasarını En Aza İndirme

ÖZET

Bu çalışmanın amacı, ulnar kırıkların tespiti sırasında foramen nutricium'un (NF) zarar görmesini en aza indirmek için NF'nin morfolojik ve morfometrik özelliklerinin derinlemesine incelenmesidir. Bu çalışma, 110 kuru ulna örneği (47 sağ, 63 sol) kullanılarak gerçekleştirilmiştir. Ulna uzunluğu (UL), NF ile olekranonun en proksimal noktası arasındaki mesafe (NFO) ve NF ile interosseöz kenar arasındaki mesafe (NFIB) ölçüldü. NF'nin sayısı, konumu, yönü, durumu ve boyutu değerlendirildi. Ayrıca, foraminal indeks (FI) hesaplandı. Ayrıca, bölümümüzde 73 yaşındaki bir Türk kadavrası üzerinde deneysel olarak ön kol kırığı oluşturuldu ve ulnar açık redüksiyon internal fiksasyon uygulandı. Plaka ve vidaların çıkarılmasından sonra, plaka fikstürünün NF üzerindeki etkisi değerlendirildi ve ileri tedavi kararları için incelendi. Ortalama UL, NFO, NFIB ve FI sırasıyla 244,16 ± 17,65 mm, 93,76 ± 18,11 mm, 8,23 ± 3,67 mm ve 38,29 ± 6,45% olarak ölçüldü. Genel olarak, ulna kemiklerinde anterior yüzeyde, yukarıya doğru, 2/5 bölgesinde ve 22-gauge boyutundan daha küçük olan 1 NF tespit edildi. En proksimal ilk, ikinci ve üçüncü vidalar ile interosseöz kenar arasındaki mesafeler sırasıyla 4,39 mm, 6,20 mm ve 6,56 mm olarak ölçüldü. Vidaların kadavradaki kırık ulna üzerindeki NF'ye zarar vermediği bulundu. Kuru kemik ve kadaverik sonuçlarımıza göre, NF'nin morfolojik ve morfometrik özellikleri hakkında bilgi sahibi olmak, plakanın vidalanmasında önemlidir; bu vidalama mümkünse şaftın distal kısımlarına ve ulnanın anterior kenarına yakın bir yerde yapılmalı, böylece besleyici foramenin zarar görmesi en aza indirilerek kemiğin kan akışının korunması sağlanmalıdır.

Anahtar Kelimeler: Ulna. Foramen Nutricium. Kırık. Vidalama. Kadavra. Anatomy.

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Ulnar shaft fractures constitute one of the most common injuries observed in the forearm. Unstable fractures of ulna usually occur on the proximal 1/3 of the ulna. For these fractures, plate fixation with open reduction and internal fixation techniques are used[1]. In the human body, the skeleton is formed by bones, making up the passive component of movement[2]. The arterial supply of long bones are provided by metaphyseal, epiphyseal, periosteal and nutrient arteries[3]. The main blood supply to a long bone derives from the nutrient arteries, which is crucial during the prenatal phase of long bones as well as during the early ossification phase[4,5]. Furthermore, 70–80% of the nutrition of the bones is supplied by nutrient arteries, particularly during puberty. Inadequate vascularization of the epiphyseal plate causes medullary bone ischemia as bone nutrition is diminished[6]. The regional arteries frequently serve as the source for nutrient arteries. The nutrient artery enters the long bones' shafts through a foramen known as the nutrient foramen (NF). The NF is an aperture on the long bone's shaft that allows the passage of peripheral nerves and nutrient arteries into the medullary cavity[2]. The nutrient artery divides into ascending and descending branches in the medullary cavity and supplies the inner two-thirds of the cortex and the bone marrow[7]. The preservation of the nutrient arterial supply is crucial in various surgical procedures and pathologic conditions: microsurgical vascularized bone transplantation, tumor resections, bone grafts, acute osteomyelitis and fracture healing[8,9].

To avoid damage to the NF during fixation of the ulnar fracture, it is important to protect the normal vascular supply of ulna. For this purpose, this study investigated the morphological and morphometric characteristics of the NF in detail in order to minimize damaging of the NF when applying fixation for the ulnar fractures.

Material and Method

This study was performed by using a sample of 110 dry ulnae (47 right, 63 left), which were obtained from the anatomy laboratory of authors. The age and sex of the ulnae were unknown. The bones with cortical deformity, osteoporotic appearance, and fractures were excluded from the study. The ethical approval was obtained from the Ethics Committee of authors' University (date: 09/01/2024, number: 2024/01-56). Initially, the NF was detected macroscopically on the surfaces (anterior, posterior, medial) and borders (anterior, posterior, interosseous) of ulna by using magnifying glass. The presence of the well-defined groove and canal was accepted as NF. 20 (1.1 mm)-22 gauge (0.8 mm) sized hypodermic needles were used to determine the size of foramen, respectively.

The following parameters were evaluated:

1) The ulnar length (UL): distance between the most proximal point of olecranon and the most distal point of styloid process (Fig. 1)
2) Number of NF
3) Location of NF according to surfaces and borders
4) Direction of NF (upward, downward)
5) Position of NF
6) Size of NF
7) Distance between the NF and the most proximal point of olecranon (NFO) (Fig. 1)
8) Distance between the NF and interosseous border (NFIB) (Fig. 1)
9) Foraminal index: (NFO/UL)*100

The ulnar length was measured by use of tape measure and the other measurements were conducted by using 0.001 mm accuracy digital Vernier caliper. The position of NF on ulna was divided under 5 types according to foraminal index:

Zone 1: the foraminal index was lower than 20%
Zone 2: the foraminal index was between the 20% and 40%
Zone 3: the foraminal index was between the 40% and 60%
Zone 4: the foraminal index was between the 60% and 80%
Zone 5: the foraminal index was between the 80% and 100%

Also, localization of NF was divided into 5 types according to interosseous border:

Type 1: NF was located on the interosseous border
Type 2: NF was 0-5 mm away from interosseous border
Type 3: NF was 5-10 mm away from interosseous border
Type 4: NF was 10-15 mm away from interosseous border
Type 5: NF was 15-20 mm away from interosseous border

In addition, a cadaver that belonged to a 73-year-old Turkish female in our department with no forearm fractures and intact subcutaneous muscle integrity, access to the ulnar shaft was achieved via a Subcutaneous Approach between the extensor carpi ulnaris and flexor carpi ulnaris muscles in order to demonstrate the relationship of the NF to the ulnar shaft with anatomical plating on the left sided ulna. An experimental segmental ulnar shaft fracture model was successfully created using a saw and chisel[10,11]. Subsequently, anatomical bridge plate fixation was applied to the ulnar shaft fracture. Following dissection of the muscles and ligaments adhering to the ulna and excision of the ulna for examination of the experimental model, the plate and screws were removed (Fig. 2).

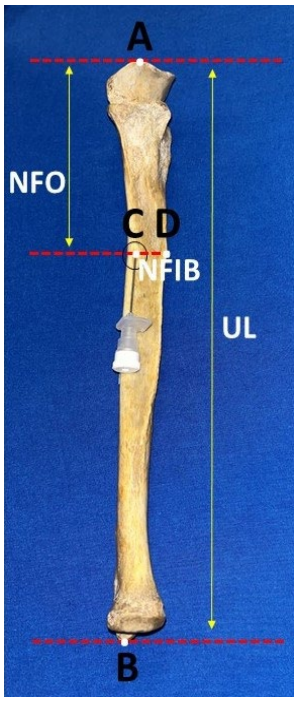

Fig. 1:
Demonstration of morphometric measurements of nutrient foramen. A: the level of the most proximal point of olecranon, B: the level of the most distal point of styloid process, C: the level of entrance of nutrient foramen, D: the interosseous level of nutrient foramen. UL (A-B): the ulnar length, NFO (A-C): distance between the nutrient foramen and the most proximal point of olecranon, NFIB (C-D): distance between the nutrient foramen and interosseous border. Black circle indicates the entrance point of the hypodermic needle into the nutrient foramen.

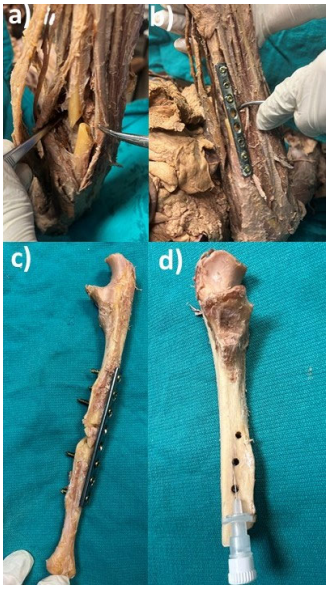

Fig. 2:
Demonstration of fixation of ulnar fracture. a) fractured ulna, b) fixation of ulnar fracture, c) excision of the ulna d) relationship between the screw points and nutrient foramen.

Statistical analysis

Descriptive analyzes (percentage, mean, standard deviation, minimum and maximum values) were performed using the SPSS version 23 (Statistical Package for the Social Sciences–SPSS Inc.) software. The normal distribution of the parameters was examined by histogram graphs and Kolmogorov-Smirnov/Shapiro-Wilk tests. The differences between the right and left side were compared using the Student's t test or the Mann-Whitney U test, depending on whether the parameters were normally distributed. Whether there was a statistical difference between the right and left side in categorical parameters was investigated by using the Chi-square test, and Fisher's exact test was used in cases where the Chi-square test assumptions could not be met. p value lower than 0.05 was considered statistically significant.

Results

Number of NF

One hundred and ten ulnae were evaluated in this study. No NF was detected on 3 of 110 (2.73%) ulnae. One NF was detected on 107 of 110 (97.27%) ulnae. On the right side, no NF was detected in 1 of 47 (2.13%) ulnae and 1 NF was detected in 46 of 47 (97.87%) ulnae. On the left side, no NF was detected in 2 of 63 (3.17%) ulnae and 1 NF was detected in 61 of 63 (96.83%) ulnae (Table I).

Table I. Number of NF

Number of NF	Right n (%)	Left n (%)	Total n(%)
0	1 (2.13)	2 (3.17)	3 (2.73)
1	46 (97.87)	61 (96.83)	107 (97.27)

NF: nutrient foramen, n: number

Direction of NF

All of the NF were observed to be directed upward.

Localization of NF

96 of 107 (89.72%) NF were located on anterior surface, 7 of 107 (6.54%) on anterior border, 3 of 107 (2.81%) on interosseus border and 1 of 107 (0.93%) on posterior surface. No NF was observed on medial surface and posterior border. On the right side, 40 of 46 (86.96%) NF were located on the anterior surface, 5 of 46 (10.87%) on the anterior border, 1 of 46 (2.17%) on the interosseous border. On the left side, 56 of 61 (91.80%) NF were located anterior surface, 2 of 61 (3.28%) on the anterior border, 2 of 61 (3.28%) on the interosseous border, and 1 of 61 (1.64%) on the posterior surface. There was no statistically significant difference between right and left sides regarding the location of NF (p=0.401) (Table II).

Table II. Localization of NF

Surface and border	Right n(%)	Left n(%)	Total n(%)	p value
Anterior Surface	40 (86.96)	56 (91.80)	96 (89.72)	0.401
Posterior Surface	-	1 (1.64)	1 (0.93)	
Medial surface	-	-	-	
Anterior Border	5 (10.87)	2 (3.28)	7 (6.54)	
Posterior border	-	-	-	
Interosseous Border	1 (2.17)	2 (3.28)	3 (2.81)	

NF: nutrient foramen, n: number

Size of NF

The sizes of 46 of 107 (42.99%) NF were lower than 22-gauge size, 33 of 107 (30.84%) NF were equal or higher than 20 gauge and 28 of 107 (26.17%) NF were within the 20–22-gauge interval. On the right side, 21 of 46 (45.65%) NF were lower than 22 gauge, 14 of 46 (30.44%) were equal or more than 20 gauge, 11 of 46 (23.91%) NF were between the 20-22 gauge. On the left side, 25 of 61 (40.98%) NF were lower than 22-gauge size, 19 of 61 (31.15%) were equal or higher than 20 gauge, 17 of 61 (27.87%) NF were within the 20–22-gauge interval. There was no statistically significant difference between the right and left sides regarding the size of NF (p=0.863) (Table III).

Table III. Size of NF

Size	Right n(%)	Left n(%)	Total n(%)	p value
≥20 gauge	14 (30.44)	19 (31.15)	33 (30.84)	0.863
Between 20-22 gauge	11 (23.91)	17 (27.87)	28 (26.17)	
<22 gauge	21 (45.65)	25 (40.98)	46 (42.99)	

NF: nutrient foramen, n: number

The ulnar length (UL)

The mean value of UL was found to be 244.77±17.42 mm on the right side, 243.71±17.94 mm on the left side, and 244.16±17.65 mm overall. No statistically significant difference was found between the right and left sides regarding UL (p=0.759) (Table IV).

Table IV. Morphometric properties of NF

Parameter	Right	Left	Total	p value
UL (mm)	244.77±17.42	243.71±17.94	244.16±17.65	0.759
NFO (mm)	91.51±13.91	95.45±20.68	93.76±18.11	0.268
NFIB (mm)	8.75±3.50	7.84±3.77	8.23±3.67	0.278
FI (%)	37.43±5.15	38.95±7.25	38.29±6.45	0.339

NF: nutrient foramen, UL: the ulnar length, NFO: distance between the NF and most proximal point of olecranon, NFIB: distance between the NF and interosseous border, FI: foraminal index

Distance between NF and most proximal point of olecranon (NFO)

The mean value of NFO was found to be 91.51±13.91 mm on the right side, 95.45±20.68 mm on the left side, 93.76±18.11 mm overall. No statistically significant

Distance between the NF and interosseous border (NFIB)

The mean value of NFIB was found 8.75±3.50 mm on the right side, 7.84±3.77 mm on the left side, 8.23±3.67 mm overall. No statistically significant difference was found between the right and left sides for NFIB (p=0.278) (Table IV).

Foraminal index (FI)

The mean value of FI was found to be 37.43±5.15% on the right side, 38.95±7.25% on the left side, 38.29±6.45% overall. No statistically significant difference was found between the right and left sides regarding FI (p=0.339) (Table IV).

Position of NF

72 of 107 (67.29%) NF were detected on Zone 2, 34 of 107 (31.78%) NF on Zone 3 and 1 of 107 (0.93%) NF on Zone 4. No NF was detected on Zone 1 and Zone 5. On the right side, 32 of 46 (69.57%) NF were detected on Zone 2 and 14 of 46 (30.43%) NF on Zone 3. No NF was detected on Zone 1, Zone 4 and Zone 5. On the left side, 40 of 61 (65.57%) NF were detected on Zone 2, 20 of 61 (32.79%) NF on Zone 3 and 1 of 61 (1.64%) NF on Zone 4. No NF was detected on Zone 1 and Zone 5. No statistically significant difference was found between the right and left sides regarding the position of NF (p=0.906) (Table V).

Table V. Position of NF

Position	Right n(%)	Left n(%)	Total n(%)	p value
Zone 1	0 (0)	0 (0)	0 (0)	0.906
Zone 2	32 (69.57)	40 (65.57)	72 (67.29)	
Zone 3	14 (30.43)	20 (32.79)	34 (31.78)	
Zone 4	0 (0)	1 (1.64)	1 (0.93)	
Zone 5	0 (0)	0 (0)	0 (0)	

NF: nutrient foramen, n: number

Distribution of nutrient foramen according to interosseous border

The distance between NF and interosseous border was divided into 5 types, and 52 of 107 (48.60%) NF were observed to be 5-10 mm away (Type 3) from interosseous border, 31 of 107 (28.97%) NF were 10-15 mm away (Type 4), 19 of 107 (17.76%) NF were 0-5 mm away (Type 2), 3 of 107 (2.80%) NF were on the interosseous border (Type 1) and 2 of 107 (1.87%) NF were 15-20 mm away (Type 5). On the right side, 23 of 46 (50.00%) NF were 5-10 mm away (Type 3) from interosseous border, 15 of 46 (32.62%) NF were 10-15 mm away (Type 4), 6 of 46 (13.04%) NF were 0-5 mm away (Type 2), 1 of 46 (2.17%) NF was on

the interosseous border (Type 1) and 1 of 46 (2.17%) NF was 15-20 mm away (Type 5). On the left side, 29 of 61 (47.54%) NF were 5-10 mm away (Type 3) from interosseous border, 16 of 61 (26.23%) NF were 10-15 mm away (Type 4), 13 of 61 (21.31%) NF were 0-5 mm away (Type 2), 2 of 61 (3.28%) NF were on the interosseous border (Type 1) and 1 of 61 (1.64%) NF was 15-20 mm away (Type 5). No statistically significant difference was found between the right and left sides regarding the distribution of NF according to interosseous border (p=0.824) (Table VI).

Table VI. Distribution of NF according to interosseous border

Distance from IB (mm)	Right n(%)	Left n(%)	Total n(%)	p value
On the IB (Type 1)	1 (2.17)	2 (3.28)	3 (2.80)	0.824
0-5 (Type 2)	6 (13.04)	13 (21.31)	19 (17.76)	
5-10 (Type 3)	23 (50.00)	29 (47.54)	52 (48.60)	
10-15 (Type 4)	15 (32.62)	16 (26.23)	31 (28.97)	
15-20 (Type 5)	1 (2.17)	1 (1.64)	2 (1.87)	

NF: nutrient foramen, IB: interosseous border, n: number

Cadaveric results

The length of fractured ulna was observed to be 225 mm. The distance between the fracture line and the most proximal point of olecranon was found to be 126.39 mm. One NF was detected on fractured ulna. The size of NF was between the 20-22 gauge and 96.59 mm away from the most proximal point of ulna. Foraminal index of this NF was 42.93% and located on the anterior surface. The distance between the NF and interosseous border was 8.89 mm. The distance between the most proximal first, second and third screws and the most proximal point of olecranon were 80.07 mm, 92.81 mm, 103.76 mm, respectively. The distances between the most proximal first, second and third screws and interosseous border were 4.39 mm, 6.20 mm, and 6.56 mm, respectively.

Discussion and Conclusion

While ulnar shaft fractures are relatively rare compared to other bones of the upper limb, these fractures result in joint instability, malunion and nonunion. Ulnar shaft fractures may be treated with non-operative and operative approaches. One of the operative approaches is the open reduction and internal fixation[12]. Nutrient arteries provide the main blood supply of long bones which enter the bone through the NF on the shaft of the long bones[13,14]. In a study of Kinose et al., they dissected a total of 67 forearms on cadavers belonging to deceased Japanese persons. As a result, it is found out that the majority of ulnar nutrient arteries originated directly from proximal part of ulnar artery (27 of 68 ulnar nutrient arteries) and anterior interosseous artery (21 of 68 ulnar nutrient arteries)[15]. During fixation of the ulnar shaft fracture, screwing should be done carefully in order to not damage the nutrient foramen. In the event the nutrient foramen is damaged, the nutrition of the bone may be interrupted and delayed fracture healing or non-union may occur. In our experimental ulnar shaft fracture, we did no damage to the nutrient foramen but according to our dry bone results of ulnar NF, screws on the ulna were inside the danger zone according to measurement of distance between NF and interosseous border. Majority of the NF were found near the interosseous border (0-10 mm away from interosseous border) in our study. We should perform screw fixation close to the anterior border in order to minimize damaging of the NF.

The ulnar length was measured as 258.8 ± 37.9 mm by Yılar et al, 249.64 ± 18.96 mm on the right side and 246.80 ± 19.60 mm on the left side by Cihan and Toma, 252.7 ± 20.2 mm on the right side and 248.5 ± 18.2 mm on the left side by Dervisevic et al., 254.5 ± 18.3 mm by Priya et al., 254.3 mm by Pereira et al., 252.5 ± 18.5 mm on the right side and 252.2 ± 18.5 mm on the left side by Desai and Damor, 254.71 ± 21 mm by Özturk et al., 282.8 ± 12.4 mm by Ukoha et al., 259.8 ± 12.3 mm by Veeramuthu et al.[8,13,16-22]. In our study, the ulnar length was measured to be 244.16 ± 17.65 mm, lower than the findings of the aforementioned studies and in compliance with that of Chavda et al. (244.8 mm)[23]. The distance between the NF and most proximal point of olecranon and foraminal index were measured in our study as 93.76 ± 18.11 mm and 38.29 ± 6.45%, which were in accordance to other studies[8,16-23]. Morphometric characteristics of NF were summarized comparatively under Table VII.

Size of NF: Knowing the size of the NF is important as it gives us information about the diameter of the nutrient artery. There are a limited number of studies measuring the size of the NF. In a study by Veeramuthu et al., they evaluated the size of NF by use of 22, 24 and 26 gauge sized hypodermic needles and in the majority of size of NF (42 (71.18%)) were found to be between 0.5 mm and 0.7 mm[21]. Unlike Veeramuthu et al., Rangasubhe and Havaldar, who predominantly revealed size of NF (68 (59.13%)) between 0.71 mm and 1.1 mm[24]. In accordance to the study by Veeramuthu et al., the size of NF was mostly (46 (42.99%)) detected as smaller than 22 gauge (0.8 mm) in this study[21].

Distance between NF and interosseous border: It is described that the NF was localized close to the interosseous border[2]. Unlike this description, Ukoha et al. found the majority of NF (24 (64.9%)) was close to the anterior border[20]. Differing from previous studies the mean value of NFIB was measured in our study as

Table VII. Comparison of morphometric properties of NF

Study (Year)	Population	N	UL (mm)	NFO (mm)	FI (%)
Yılar et al. (2023) [22]	Turkey	155 (70 R, 85 L)	258.8±37.9	94.8±15.7	37.45
Cihan and Toma (2023) [16]	Turkey	89 (38 R, 51 L)	R: 249.64±18.96 L: 246.80±19.60		R: 37.36±5.98 L: 37.17±4.40
Chavda et al. (2018) [23]	India	150 (75 R, 75 L)	244.8	91.0	35.34
Dervisevic et al. (2023) [13]	Bosnia and Herzegovina	50 (27 R, 23 L)	R: 252.7±20.2 L: 248.5±18.2		
Priya et al. (2019) [19]	India	200 (88 R, 112 L)	254.5±18.3		35.83±6.12
Pereira et al. (2011) [8]	Brasil	146	254.3		37.9
Desai and Damor (2022) [17]	India	81 (35 R, 46 L)	R: 252.5±18.5 L: 252.2±18.5	R: 86.2±23.0 L: 88.9±26.5	R: 34.10 L: 30.83
Ozturk et al. (2022) [18]	Turkey	32 (16 R, 16 L)	254.71±21	96.34±18.9	37.75±6.46
Ukoha et al. (2013) [20]	Nigeria	50	282.8±12.4	103.3±13.1	36.70±4.56
Veeramuthu et al. (2017) [21]	India	59	259.8±12.3	97.1±13.7	36.39±5.61
Present study (2024)	Turkey	110 (47 R, 63 L)	244.16±17.65	93.76±18.11	38.29±6.45

N: sample size, R: right, L: left, NF: nutrient foramen, UL: the ulnar length, NFO: distance between the NF and most proximal point of olecranon, FI: foraminal index

Table VIII. Comparison of number of NF

Study (Year)	Population	N	0 NF n(%)	1 NF n(%)	2 NF n(%)	3 NF n(%)
Yılar et al. (2023) [22]	Turkey	155 (70 R, 85 L)	13 (8.39)	139 (89.67)	3 (1.94)	-
Cihan and Toma (2023) [16]	Turkey	89 (38 R, 51 L)	14 (15.91)	65 (73.86)	6 (6.82)	3 (3.41)
Chavda et al. (2018) [23]	India	150 (75 R, 75 L)	3 (2)	145 (96.67)	2 (1.33)	-
Dervisevic et al. (2023) [13]	Bosnia and Herzegovina	50 (27 R, 23 L)	-	R: 19 (70.4), L: 19 (82.6)	R: 7 (25.9), L: 4 (17.4)	R: 1 (3.7), L: -
Pereira et al. (2011) [8]	Brasil	146	-	144 (98.6)	2 (1.4)	-
Challa and Nanna (2019) [7]	India	50	-	49 (98)	1 (2)	-
Desai and Damor (2022) [17]	India	81 (35 R, 46 L)	2 (2.47)	75 (92.59)	4 (4.94)	-
Ozturk et al. (2022) [18]	Turkey	32 (16 R, 16 L)	-	29 (90.63)	3 (9.37)	-
Ukoha et al. (2013) [20]	Nigeria	50	11 (22)	39 (78)		
Rangasubhe and Havaldar (2019) [24]	India	100 (50 R, 50 L)	-	86 (86)	13 (13)	1 (1)
Veeramuthu et al. (2017) [21]	India	59	1 (2)	57 (96)	1 (2)	-
Present study	Turkey	110 (47 R, 63 L)	3 (2.73)	107 (97.27)	-	-

NF: nutrient foramen, R: right, L: left, N: sample size, n: number

8.23 ± 3.67 mm. Furthermore, NFIB was divided into 5 types. In accordance to the general description, NF was found closer to the interosseous border in general and the majority of NF (52 (48.60%)) were detected as Type 3 (5-10 mm away from interosseous border) in our study. No comparable studies were found for NFIB. Knowing the mean value of NFIB gives us information regarding the distance of the nutrient foramen from the interosseous border. This knowledge is important as it gives us reliable information about where we shou ld place the screws relative to the interosseous border in order to avoid damaging the nutrient foramen. We consider that this data is of importance for screw fixation procedures. When screwing, in order to minimize damage to NF, it should be better to apply screw fixation closer to the anterior border.

Number of NF: In the previous studies, 1 NF was detected on ulna in general. In accordance to the previous studies, 1 NF was detected on 107 (97.27%) ulnae in our study[7,8,13,16-18,20-24]. In certain studies, either no NF or more than 1 NF could be detected on the ulnae. No NF was detected on 13 (8.39%) ulnae by Yılar et al., on 14 (15.91%) ulnae by Cihan and Toma, on 3 (2%) ulnae by Chavda et al., on 2 (2.47%) ulnae by Desai and Damor, on 11 (22%) ulnae by Ukoha et al., and on 1 (2%) ulna by Veeramuthu et al.[16,17,20-23]. In our study, no NF was detected on 3 (2.73%) ulnae. Two NF were detected on 3 (1.94%) ulnae by Yılar et al., on 6 (6.82%) ulnae by Cihan and Toma, on 2 (1.33%) ulnae by Chavda et al., on 7 (25.9%) right sided ulnae, on 4 (17.4%) left sided ulnae by Dervisevic et al., on 2 (1.4%) ulnae by Pereira et al., on 1 (2%) ulna by Challa and Nanna, on 4 (4.94%) ulnae by Desai and Damor, on 3 (9.37%) ulnae by Özturk et al., on 13 (13%) ulnae by Rangasubhe and Havaldar, and on 1 (2%) ulna by Veeramuthu et al.[7,8,13,16-18,21-24]. Three NF were detected on 3 (3.41%) ulnae by Cihan and Toma, on 1 (3.7%) right sided ulna by Dervisevic et al., and on 1 (1%) ulna by Rangasubhe and Havaldar[13,16,24]. In our present study, no ulna was detected to possess more than 1 NF (Table VIII).

Direction of NF: During growing period, proximal or distal end of long bones grows up faster than the other zones, and the nutrient canal usually becomes slanted.

On the long bones, direction of nutrient foramen is described as away from knee, towards the elbow[25]. The direction of the NF was found on all of ulnae to be upward (towards the elbow) in the majority of previous studies and, likewise, in our study[7,13,17,18,21-23]. In certain cases, NF could be directed downward or horizontally. Cihan and Toma detected downward directed 1 (1.1%) NF within a sample comprising of Turkish population[16]. Rangasubhe and Havaldar detected downward directed 2 (1.74%) NF and horizontally directed 1 (0.87%) NF among India population[24] (Table IX).

Table IX. Comparison of position and direction of NF

Study (Year)	Population	N	Position of NF n(%)		Direction n(%)
Yılar et al. (2023) [22]	Turkey	155 (70 R, 85 L)	Zone 1	33 (22.76)	U: 145 (100)
			Zone 2	112 (77.24)	
			Zone 3	-	D: -
Cihan and Toma (2023) [16]	Turkey	89 (38 R, 51 L)	Zone 1	20 (32.2)	U: 86 (98.8)
			Zone 2	42 (67.7)	
			Zone 3	-	D: 1 (1.1)
Chavda et al. (2018) [23]	India	150 (75 R, 75 L)	Zone 1	33 (22.15)	U: 149 (100)
			Zone 2	95 (63.76)	
			Zone 3	21 (14.09)	D: -
Dervisevic et al. (2023) [13]	Bosnia and Herzegovina	50 (27 R, 23 L)	Zone1	R: 7 (25.9), L: 5 (21.7)	U: 50 (100)
			Zone 2	R: 20 (74.1), L: 18 (78.3)	
			Zone 3	-	D: -
Priya et al. (2019) [19]	India	200 (88 R, 112 L)	Zone 1	80 (40)	
			Zone 2	120 (60)	
			Zone 3	-	
Challa and Nanna (2019) [7]	India	50	Zone 1	6 (11.8)	U: 51 (100)
			Zone 2	45 (88.2)	
			Zone 3	-	D: -
Desai and Damor (2022) [17]	India	81 (35 R, 46 L)	Zone 1	34 (40.96)	U: 83 (100)
			Zone 2	49 (59.04)	
			Zone 3	-	D: -
Ozturk et al. (2022) [18]	Turkey	32 (16 R, 16 L)	Zone 1	9 (25.71)	U: 35 (100)
			Zone 2	26 (74.29)	
			Zone 3	-	D: -
Ukoha et al. (2013) [20]	Nigeria	50	Zone 1	10 (27)	
			Zone 2	27 (73)	
			Zone 3	-	
Rangasubhe and Havaldar (2019) [24]	India	100 (50 R, 50 L)	Zone 1	98 (85.22)	U: 112 (97.39)
			Zone 2	14 (12.17)	D: 2 (1.74)
			Zone 3	3 (2.61)	H: 1 (0.87)
Veeramuthu et al. (2017) [21]	India	59	Zone 1	19 (32)	U: 59 (100)
			Zone 2	40 (68)	
			Zone 3	-	D: -
Present study	Turkey	110 (47 R, 63 L)	Zone 1	-	U: 107 (100)
			Zone 2	72 (67.29)	
			Zone 3	34 (31.78)	
			Zone 4	1 (0.93)	D: -
			Zone 5	-	

N: sample size, n: number, R: right, L: left, NF: nutrient foramen, U: upward, D: downward, H: horizontal

Table X. Comparison of localization of NF on ulna

Study (year)	Population	N	AS n(%)	PS n(%)	MS n(%)	AB n(%)	PB n(%)	IB n(%)
Yılar et al. (2023) [22]	Turkey	155 (70 R, 85 L)	135 (93.12)	-	-	5 (3.44)	-	5 (3.44)
Cihan and Toma (2023) [16]	Turkey	89 (38 R, 51 L)	64 (73.5)	-	-	-	-	-
Chavda et al. (2018) [23]	India	150 (75 R, 75 L)	134 (89.93)	-	-	8 (5.37)	-	7 (4.7)
Dervisevic et al. (2023) [13]	Bosnia and Herzegovina	50 (27 R, 23 L)	50 (100)	-	-	-	-	-
Priya et al. (2019) [19]	India	200 (88 R, 112 L)	158 (79)	-	2 (1)	33 (16.5)	-	19 (9.5)
Pereira et al. (2011) [8]	Brasil	146	121 (81.76)	18 (12.16)	9 (6.08)	-	-	-
Challa and Nanna (2019) [7]	India	50	40 (78.4)	6 (11.8)	-	2 (3.9)	-	3 (5.9)
Ozturk et al. (2022) [18]	Turkey	32 (16 R, 16 L)	28 (80)	1 (2.86)	-	-	-	6 (17.14)
Rangasubhe and Havaldar (2019) [24]	India	100 (50 R, 50 L)	112 (97.39)	1 (0.87)	2 (1.74)	-	3 (5)	-
Veeramuthu et al. (2017) [21]	India	59	45 (76)	1 (2)	-	9 (15)	-	-
Present study	Turkey	110 (47 R, 63 L)	96 (89.72)	1 (0.93)	-	7 (6.54)	-	3 (2.81)

N: sample size, n: number, R: right, L: left, AS: anterior surface, PS: posterior surface, MS: medial surface, AB: anterior border, PB: posterior border, IB: interosseous border

Position of NF: Position of NF was divided into three parts (at proximal 1/3, at middle 1/3 and at distal 1/3) according the foraminal index in previous studies and NF was located usually on the middle 1/3 of ulna[7,13,16-23]. Several studies revealed that no NF was located at distal 1/3 of ulna[7,13,16-22]. Positioning of NF on distal 1/3 of ulna is observed to be a rare condition. Position of NF on the distal 1/3 of ulna was found on 21 (14.09%) ulnae by Chavda et al., and on 3 (2.61%) ulnae by Rangasubhe and Havaldar[23,24]. In our study, position of NF was examined in detail and divided into five zones. Majority of NF were detected at the 2/5 zone (20%-40%) of ulnae. No NF was detected at the 1/5 zone (0%-20%) and the 5/5 zone (80%-100%) (Table IX).

Localization of NF: In accordance to the former studies, the majority of NF (96 (89.72%)) were observed to be located on the anterior surface of ulna in our study. Former studies and our study reveal that NF may be localized on various surfaces and borders of the ulna, besides the anterior surface[7,8,18,19,21-24] (Table X).

In conclusion, it has been found out that usually there was 1 NF on the ulna, located on the anterior surface and at the 2/5 zone of shaft, directed upwards, smaller than 22-gauge size, 5-10 mm away from interosseous border. According to our dry bone and cadaveric results, screwing the plate should be performed on the distal parts of shaft if possible and close the anterior border in order to minimize damage to the nutrient foramen.

Study Limitation

This study had certain limitations. The age and genders of the ulnae were unknown. Therefore, age and gender differences for morphology of nutrient foramen could not be evaluated. Secondly, although the cadaveric simulation of fracture fixation provided valuable anatomical insights, it was performed on only one specimen. Therefore, the findings from this part of the study particularly regarding the placement of screws to avoid damaging the nutrient foramen of the ulna should be interpreted with caution and cannot be generalized without further support from larger cadaveric series.

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