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Anatomical and Morphometric Characteristics of the Nutrient Foramen of the Radius: Safe Approaches for Fracture Fixation

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ABSTRACT

The aim of this study is to evaluate the morphological and morphometric properties of the nutrient foramen (NF) in detail in order to minimize damaging to NF when applying fixation of radial fractures for fracture healing. This study was performed on 109 (right: 54, left: 55) dry radii. The radius length (RL), distances between NF and the most proximal point of head of radius (NFP) and interosseous border (NFIB) were measured and foraminal index (FI) was calculated. The number, position, location, size and direction of NF was assessed. Additionally, a radius fracture was experimentally induced on a cadaver obtained from a 73-year-old Turkish female, followed by radius open reduction and internal fixation. The mean values of RL, NFP, FI, NFIB were measured as 225.56±17.02 mm, 79.26±12.80 mm, 35.09±4.62% and 6.82±3.78 mm, respectively. All of radii had 1 NF and that all foramina were directed upward. Seventy-seven (70.64%) of 109 NF were located on the anterior surface. Forty-five (41.28%) of 109 NF were found to be between 20-22 gauge sized. Ninety one of 109 (83.49%) NF were observed on the zone 2. Forty-five of (41.28%) 109 NF were type 3 (5.01-10mm away from IB). The screws were determined to have not damaged to NF upon examination of the fractured radius in cadaver. Based on our findings, it is advisable to place screws for the plate on the distal parts of the shaft whenever possible and in near to the anterior border to minimize the risk of damaging NF for fracture healing.

Keywords: Radius, nutrient foramen, fracture, open reduction and internal fixation

Introduction

Diaphyseal fractures of radius and ulna (double bone) are common orthopedic condition but isolated diaphyseal radial fractures are relatively uncommon due to ulna and muscles protects radius from direct traumas and open reduction and internal fixation technique is used as gold standard for preserving rotational, axial stabilities and bone length in this fracture (1, 2). Blood supply of long bones are provided by periosteal, metaphyseal, epiphyseal and nutrient arteries (3). Nutrient arteries are the main blood source of the long bones during the early ossification phases, active growing period and which supplies the 70%-80% of the nutrition of long bones especially during the puberty (4, 5). In case, when nutrient arteries are absent or damaged, periosteal arteries promote nutrition of long bones (5). Nutrient arteries and corresponding peripheral nerves enter the long bones obliquely through the nutrient foramen (NF) which is located on the diaphysis and provides nutrition of inner 2/3 of cortex and bone marrow (6, 7). In 1691, Havers first described the NF (8). The most common complications of the fractures are delayed union and non-union, diminished nutrition to the bone causes this complication, for this reason, nutrient arterial system is important for nutrition of the bone in fracture healing (9). In free vascularized bone graft, removing and transferring the nutrient artery along with the NF is crucial for the survival of osteoblasts and osteocytes, which has important role in the bone healing process (10, 11). Also, nutrient arterial system is essential in some surgical procedures and clinical conditions: tumor resections, vascularized bone transplantation, acute hematogenic osteomyelitis, joint replacement surgery (8, 12).

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To minimize damaging to the NF during fixation of the radial fracture, it is important to protect the blood supply of radius for fracture healing. For this purpose, we evaluated the morphological and morphometric properties of the NF in detail in order to avoid damage to the NF when applying fixation of radial fractures.

Materials and Methods

This study was performed on 109 (right: 54, left: 55) dry radii of a sample from Turkey. The sex and age of the radii were unknown. Radii with cortical deformation were excluded from the study. The study protocol was found ethically appropriate by the local Ethics Committee of the Hacettepe University (date: 09.01.2024, registration no: 2024/01-57).

The radius length (RL) was measured as distance between the most proximal point of head of radius and the most distal point of styloid process. Furthermore, distances between the NF and the most proximal point of head of radius (NFP) and interosseous border (NFIB) were measured (Figure 1). The foraminal index (FI) was calculated to assess the position of the NF on the radius. It is calculated as (NFP/RL)*100. Position of NF was divided 5 regions according to foraminal index: zone 1 (00.00%-20.00%), zone 2 (20.01%-40.00%), zone 3 (40.01%-60.00%), zone 4 (60.01%-80.00%), zone 5 (80.01%-100.00%). NFIB was divided 4 types according to distance from interosseous border (IB): type 1 (on the IB), type 2 (00.01 mm-5.00 mm away from IB), type 3 (5.01 mm-10.00 mm away from IB), type 4 (10.01 mm-15.00 mm away from IB). The presence of the NF was evaluated by the magnifying glass. 20-22 gauge sized hypodermic needles were used to ensure patency of the foramen. The number, location, size and direction of the NF was recorded. The RL was measured by tape measure and the other parameters were measured by digital Vernier caliper (150 mm) of 0.01 mm accuracy. The measurements were repeated three times by MÜ and averaged for avoiding intraobserver error.

The cadaver part of the study simulated open reduction internal fixation on 73-year-old female cadaver's left forearm. Firstly, an experimental segmental radial shaft fracture model was successfully created using a saw and chisel. Bridging plating was then applied to the radial shaft fracture. The radius was excised and the muscles and ligaments linked to it were dissected before the plate and screws were removed (Figure 2). The distances between the screws and the most proximal point of head of radius and interosseous border were measured. The screw index was calculated by dividing the distance between the screw and the most proximal point of head of radius and radius length and multiply by 100.

Statistical analysis: Descriptive statistical analyses were performed on the data using SPSS version 23 (Statistical Package for the Social Sciences – IBM Inc.). The normal distribution of the parameters was examined using histogram graphs and Kolmogorov-Smirnov/Shapiro-Wilk tests. According to the normality analysis of the data, independent samples t test or Mann-Whitney U test was applied for side comparisons. Categorical parameters were compared using the chi-square test. If the test assumptions were not met, Fisher's exact test was used instead. A p value below 0.05 was considered statistically significant.

Results

It was observed that all radii have 1 NF and that all foramina were directed upward. Seventy-seven (70.64%) of 109 NF were located on the anterior surface, 20 (18.35%) of 109 on the anterior border, 7 (6.42%) of 109 on the posterior surface and 5 (4.59%) of 109 on the interosseous border. No NF was observed on the lateral surface and posterior border. There was no statistically significant difference between the right and left side for location of NF (p=0.929) (Table 1).

Forty-five (41.28%) of 109 NF were found to be between 20-22G, 42 (38.54%) of them were smaller than 22G, 22 of (20.18%) them were larger than 20G. There was no statistically significant difference between the right and left side for size of the foramen (p=0.496) (Table 2).

The mean value of RL was measured as 227.46±16.81 mm on the right side, 223.69±17.18 mm on the left side and 225.56±17.02 mm in total. The mean value of NFP was measured as 81.59±12.42 mm on the right side, 76.97±12.87 mm on the left side, 79.26±12.80 mm in total. The mean value of FI was calculated as 35.85±4.62% on the right side, 34.34±4.54% on the left side and 35.09±4.62% in total. The mean value of NFIB was measured as 6.85±4.05 mm on the right side, 6.79±3.54 mm on the left side and 6.82±3.78 mm in total. There were no statistically significant differences between the right and left side for RL, NFP, FI, NFIB measurements (p>0.05) (Table 3).

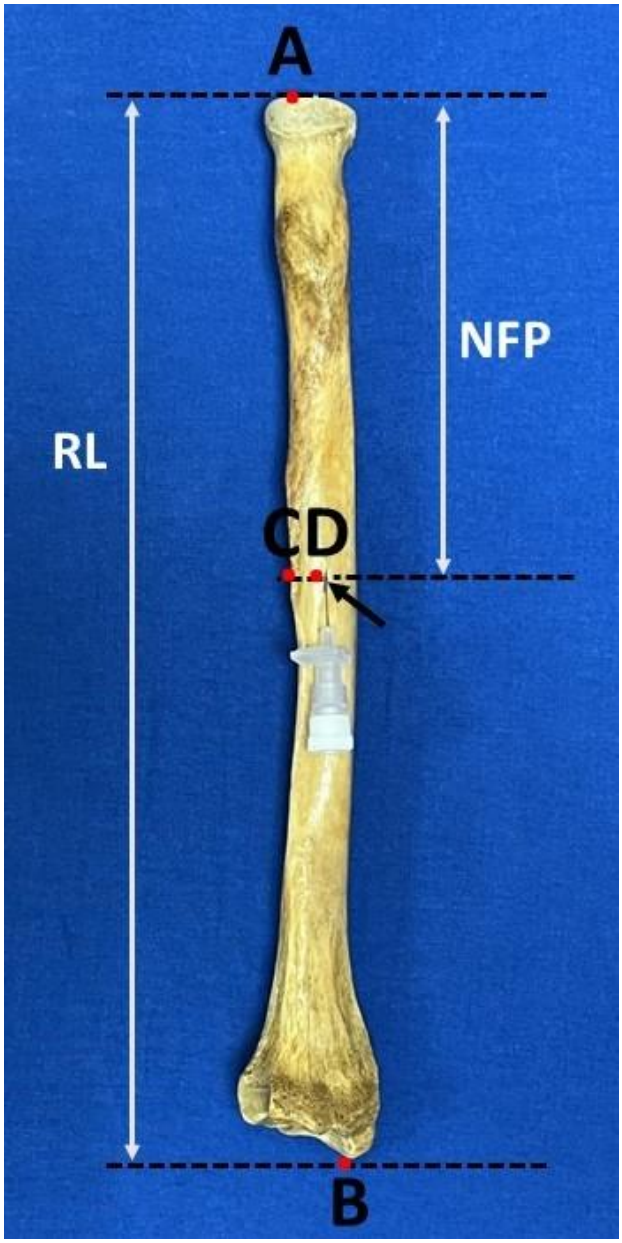

Fig. 1. Demonstration of morphometric measurements. A: the level of the most proximal point of head of radius, B: the level of the most distal point of styloid process, C: interosseous point closest to the nutrient foramen, D: entrance point of nutrient foramen. RL (A-B): the radius length, NFP (A-D): distance between the nutrient foramen and the most proximal point of head of radius, NFIB (C-D): distance between the nutrient foramen and interosseous border. Black arrow indicates the entrance point of the nutrient foramen by hypodermic needle.

Fig. 2. Demonstration of radius fracture fixation. a) fractured radius, b) radius fracture fixation, c) fixated radius removed from cadaver d) demonstration of relationship between the nutrient foramen and screw points

Ninety one of 109 (83.49%) NF were observed on the zone 2, 18 of 109 (16.51%) NF on the zone 3. No NF was observed on the proximal and distal parts of radius (zone1, zone 4, zone 5). No statistically significant difference was found between the right and left side for position of NF ($p = 0.283$) (Table 4). In addition, it was determined that the lowest foraminal index was 24.31%, highest foraminal index was 45.21%.

Forty-five of (41.28%) 109 NF were type 3 (5.01-10mm away from IB), 32 of (29.36%) 109 NF were type 2 (0.01-5.00mm away from IB), 27 of (24.77%) 109 NF were type 4 (10.01-15.00mm away from IB), and 5 (4.59%) of them were type 1 (on the IB). There was no statistically significant difference between the right and left side for distribution of NF according to interosseous border ($p = 0.775$) (Table 5).

Table 1: Localization of Nutrient Foramen

Localization	Right n(%)	Left n(%)	Total n(%)	p
Anterior surface	38 (70.37)	39 (70.91)	77 (70.64)	
Posterior surface	4 (7.41)	3 (5.45)	7 (6.42)	0.929
Lateral surface	-	-	-	
Anterior border	9 (16.67)	11 (20)	20 (18.35)	
Posterior border	-	-	-	
Interosseous border	3 (5.55)	2 (3.64)	5 (4.59)	

n: number

Table 2: Size of Nutrient Foramen

Foramen size	Right n(%)	Left n(%)	Total n(%)	p
Smaller than 22G	18 (33.33)	24 (43.64)	42 (38.54)	
Between 20-22G	25 (46.30)	20 (36.36)	45 (41.28)	0.496
Larger than 20G	11 (20.37)	11 (20.00)	22 (20.18)	

n: number, G: gauge

Table 3: Morphometric properties of Nutrient Foramen

Parameters	Right	Left	Total	p
RL (mm)	227.46±16.81	223.69±17.18	225.56±17.02	0.198
NFP (mm)	81.59±12.42	76.97±12.87	79.26±12.80	0.59
FI (%)	35.85±4.62	34.34±4.54	35.09±4.62	0.087
NFIB (mm)	6.85±4.05	6.79±3.54	6.82±3.78	0.990

RL: radius length, NFP: distance between the nutrient foramen and the most proximal point of head of radius FI: foraminal index, NFIB: distance between the nutrient foramen and interosseous border

Table 4: Position of Nutrient Foramen on Radius

Foraminal index (%)	Right n(%)	Left n(%)	Total n(%)	p
Zone 1	0 (0)	0 (0)	0 (0)	
Zone 2	43 (79.63)	48 (87.27)	91 (83.49)	
Zone 3	11 (20.37)	7 (12.73)	18 (16.51)	0.283
Zone 4	0 (0)	0 (0)	0 (0)	
Zone 5	0 (0)	0 (0)	0 (0)	

n: number

Table 5: Distribution of nutrient foramen according to interosseous border

NFIB (mm)	Right n(%)	Left n(%)	Total n(%)	p
Type 1	3 (5.55)	2 (3.64)	5 (4.59)	
Type 2	16 (29.63)	16 (29.09)	32 (29.36)	0.775
Type 3	20 (37.04)	25 (45.45)	45 (41.28)	
Type 4	15 (27.78)	12 (21.82)	27 (24.77)	

n: number, NFIB: distance between the nutrient foramen and interosseous border

The fractured radius length of cadaver was measured as 202 mm. The NF on the fractured radius was observed on the anterior surface, 66.52 mm away from the most proximal point of head of radius (foraminal index = 32.93%) and 1.67 mm away from the interosseous border. The distances between the most proximal three screws and the most proximal point of head of radius were measured 51.13 mm (screw index: 25.31%), 61.06 mm (screw index: 30.23%), 74.03 mm (screw index: 36.65%), respectively. The distances between the most proximal three screws and

Table 6: Comparison of Morphometric Properties of Nutrient Foramen

Study (Year)	Population	N	RL (mm)	NFP (mm)	FI (%)
Ozturk et al. (2022) (19)	Turkey	49 (25 R, 24 L)	228.39±15.87	77.88±16.95	34.11±7.08
Ashwini et al. (2017) (23)	India	69		87.1	
Cihan and Toma (2023) (8)	Turkey	102 (49 R, 53 L)	R: 241.28±16.47 L: 229.41±18.14	R: 85.09±12.84 L: 78.43±9.34	R: 34.93±4.01 L: 35.18±4.60
Bozer et al. (2023) (20)	Turkey	37	229.9±12.3	79.5±10.9	34.60±4.59
Kumar et al. (2017) (21)	India	110 (57 R, 53 L)	R: 236.8 L: 235.4	R: 84.4 L: 82.3	R: 35.64 L: 34.96
Pereira et al. (2011) (12)	Brasil	157	233.6		35.7
Dervisevic et al. (2023) (6)	Bosnia and Herzegovina	50 (24 R, 26 L)	R: 234.1±15.1 L: 228.6±15.3		
Campos et al. (1987) (24)	Spain	33 (17 R, 16 L)			36.34
Singh et al (2023) (7)	India	100 (50 R, 50 L)	R: 237.2±19.3 L: 233.5±17.5	R: 82.6±11.8 L: 81.2±11.8	R: 34.92±4.97 L: 34.79±4.43
Akbari et al. (2019) (22)	India	63 (31 R, 32 L)	240±21.2	86.5±17.6	36.14±7.11
This study	Turkey	109 (54 R, 55 L)	225.56 ± 17.02	79.26±12.80	35.09 ± 4.62

N: sample size, R: right, L: left, RL: radius length, NFP: distance between the nutrient foramen and the most proximal point of head of radius, FI: foraminal index

interosseous border were 11.33 mm, 12.01 mm, and 11.19 mm, respectively.

Discussion

While high-energy trauma causes radial fracture in young people, falls from height, athletic injuries and motor vehicle accidents cause it in adults (13). Trauma in radial fracture is the most frequent cause and usually resulting from a direct blow to the forearm or an axial load on an outstretched hand. Radial fractures in the elderly are frequently caused by poor bone quality as a result of osteoporosis (14). Open reduction and internal fixation with plate and screws and intramedullary nailing approaches are used in the surgical treatment of radial fractures. Advantages of the intramedullary nailing are decreased scarring and short operation time but open reduction and internal fixation is more successful in providing rotational stability and is therefore the gold standard approach in radius fractures (15, 16). Following surgical approach to the radius fracture, there may be complications such as neurovascular damage, malunion, non-union, cross union (17). Nutrient arteries are main blood source of long bones and damage to the nutrient arterial system and NF in screwing the radius fracture causes union troubles (1, 9). In a study of Kinose et al., they dissected 27 adult Japanese cadavers for evaluation of radial and ulnar nutrient arteries and they observed that majority of radial nutrient arteries were originated from anterior interosseous artery (38 of 68 radial nutrient arteries) (18). During open reduction and internal fixation of the radius shaft fracture, screwing should be done carefully for avoid damaging the nutrient foramen. If the NF is damaged, the blood supply of the bone may be diminished and union trouble of fractured bone may occur. In our cadaveric experimental radius shaft fracture, NF was not damaged by screws and according to our dry bone results of NF of radius, screws were safe zone according to measurement of NFIB. Majority of NF were observed near the interosseous border (0-10 mm away from interosseous border) and the mean value of NFIB was 6.82±3.78 mm in our study. To minimize damaging the NF, we should perform screw fixation away from interosseous border and close to the anterior border. According

Table 7: Comparison of Number of Nutrient Foramen

Study (Year)	Population	N	0 NF n(%)	1 NF n(%)	2 NF n(%)
Ozturk et al. (2022) (19)	Turkey	49 (25 R, 24 L)	-	43 (87.76)	6 (12.24)
Ashwini et al. (2017) (23)	India	69	-	62 (89.8)	7 (10.2)
Cihan and Toma (2023) (8)	Turkey	102 (49 R, 53 L)	13 (12.75)	83 (81.37)	6 (5.88)
Bozer et al. (2023) (20)	Turkey	37	-	37 (100)	-
Kumar et al. (2017) (21)	India	110 (57 R, 53 L)	-	108 (98.18)	2 (1.82)
Pereira et al. (2011) (12)	Brasil	157	-	156 (99.4)	1 (0.6)
Sharma et al. (2013) (26)	India	40 (20 R, 20 L)	2 (5)	32 (80)	6 (15)
Dervisevic et al. (2023) (6)	Bosnia and Herzegovina	50 (24 R, 26 L)	3 (6)	43 (86)	4 (8)
Campos et al. (1987) (24)	Spain	33 (17 R, 16 L)	-	33 (100)	-
Singh et al (2023) (7)	India	100 (50 R, 50 L)	3 (3)	93 (93)	4 (4)
Akbari et al. (2019) (22)	India	63 (31 R, 32 L)	-	63 (100)	-
This study	Turkey	109 (54 R, 55 L)	-	109 (100)	-

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

to our literature examination, NFIB parameter was not measured previously. We think that this parameter is important for decide to the screw placement on the bone according to interosseous border for minimize damaging the NF.

The radius morphometry shows variability in various geographical regions or different parts of same geographical regions. The radius length was measured 225.56 ± 17.02 mm in our study which was lower than Öztürk et al. (19) in Turkey (228.39±15.87 mm), Cihan and Toma (8) in Turkey (right: 241.28±16.47 mm, left: 229.41±18.14 mm), Bozer et al. (20) in Turkey (229.9±12.3 mm), Kumar et al. (21) in India (right: 236.8 mm, left: 235.4 mm), Pereira et al. (12) in Brasil (233.6 mm), Dervisevic et al. (6) in Bosnia and Herzegovina (right: 234.1±15.1 mm, left: 228.6±15.3 mm), Singh et al. (7) in India (right: 237.2±19.3 mm, left: 233.5±17.5 mm), Akbari et al. (22) in India (240±21.2 mm). The distance between the nutrient foramen and the most proximal point of head of radius and foraminal index were measured 79.26±12.80 mm and 35.09 ± 4.62%, respectively, which were accordance with measurements of previous studies (7, 8, 12, 19-24) (Table 6).

Size of NF: Knowing the diameter of the NF gives us information about the diameter of the nutrient artery. There are very rare studies evaluating the size of the NF. In a study of Bozer et al. (20) with 37 dry radii in Turkey, the mean size of NF was measured 0.98±0.24 mm. Singh et al. (7) performed a study on morphometry of NF of radius with 100 radii in India and they observed majority of NFs were between the 0.55-0.71 mm (38.14%). We observed majority of size of NF was between the 20 (1.1 mm) - 22 (0.8 mm) G sized 45 (41.28%), which was accordance with Bozer et al. (20) and more than Singh et al. (7).

Distance between NF and interosseous border: In a study of Mysorekar, majority of NFs were observed on the anterior surface, near to the anterior border, but he did not measured distance between the NF and anterior or interosseous border (25). There is no study which measured distance between NF and interosseous border. We measured distance between NF and interosseous border and majority of NFs were located 5.01-10.00 mm away from interosseous border 45

Table 8: Comparison of Position and Direction of Nutrient Foramen

Study (Year)	Population	N	Position of NF n(%)		Direction n(%)
Ozturk et al. (2022) (19)	Turkey	49 (25 R, 24 L)	Proximal 1/3	25 (45.45)	U: 53 (96.36)
			Middle 1/3	30 (54.55)	
			Distal 1/3	-	D: 2 (3.64)
Cihan and Toma (2023) (8)	Turkey	102 (49 R, 53 L)	Proximal 1/3	18 (48.6)	U: 95 (100)
			Middle 1/3	19 (51.3)	
			Distal 1/3	-	D: -
Dervisevic et al. (2023) (6)	Bosnia and Herzegovina	50 (24 R, 26 L)	Proximal 1/3	18 (38.3)	U: 47 (100)
			Middle 1/3	29 (61.7)	
			Distal 1/3	-	D: -
Singh et al (2023) (7)	India	100 (50 R, 50 L)	Proximal 1/3	34 (35.05)	U: 97 (100)
			Middle 1/3	63 (64.95)	
			Distal 1/3	-	D: -
Akbari et al. (2019) (22)	India	63 (31 R, 32 L)	Proximal 1/3	19 (30.16)	U: 61 (96.83)
			Middle 1/3	42 (66.67)	
			Distal 1/3	2 (3.17)	D: 2 (3.17)
This study	Turkey	109 (54 R, 55 L)	Zone 1	-	U: 109 (100)
			Zone 2	91 (83.49)	
			Zone 3	18 (16.51)	
			Zone 4	-	D: -
			Zone 5	-	

N: sample size, R: right, L: left, n: number, U: upward, D: downward

(41.28%). We think that, knowing the distance of the NF to the interosseous borders indicates where the screw should be applied relative to the interosseous border when plating for minimize the damage to the NF.

Number of NF: Previous studies and our study show that there is mostly 1 NF on the radius. In our study, all radii had 1 NF which was accordance with Bozer et al. (20), Campos et al. (24), Akbari et al. (22). In some cases, no foramen or more than 1 NF may be detected on the radius. No NF was detected on 13 (12.75%) radii by Cihan and Toma (8), on 2 (5%) radii by Sharma et al. (26), on 3 (6%) radii by Dervisevic et al., on 3 (3%) radii by Singh et al. Two NFs were detected on 6 (12.24%) radii by Öztürk et al. (19), on 7 (10.2%) radii by Ashwini et al. (23), on 6 (5.88%) radii by Cihan and Toma (8), on 2 (1.82%) radii by Kumar et al. (21), on 1 (0.6%) radius by Pereira et al. (12), on 6 (15%) radii by Sharma et al. (26), on

Table 9: Comparison of Localization of Nutrient Foramen

Study (Year)	Population	N	AS n(%)	PS n(%)	LS n(%)	AB n(%)	PB n(%)	IB n(%)
Ozturk et al. (2022) (19)	Turkey	49 (25 R, 24 L)	47 (85.45)	3 (5.45)				5 (9.1)
Ashwini et al. (2017) (23)	India	69	53 (69.60)					
Cihan and Toma (2023) (8)	Turkey	102 (49 R, 53 L)	62 (65.26)					
Bozer et al. (2023) (20)	Turkey	37	37 (100)					
Kumar et al. (2017) (21)	India	110 (57 R, 53 L)	110 (98.22)	1 (0.89)	1 (0.89)			
Pereira et al. (2011) (12)	Brasil	157	115 (72.78)					
Sharma et al. (2013) (26)	India	40 (20 R, 20 L)	14 (31.82)			15 (34.09)		15 (34.09)
Dervisevic et al. (2023) (6)	Bosnia and Herzegovina	50 (24 R, 26 L)	36 (70.59)	11 (21.57)				
Campos et al. (1987) (24)	Spain	33 (17 R, 16 L)	33 (100)					
Singh et al (2023) (7)	India	100 (50 R, 50 L)	73 (75.26)	2 (2.06)	1 (1.03)	4 (4.12)		17 (17.53)
Akbari et al. (2019) (22)	India	63 (31 R, 32 L)	52 (82.54)	9 (14.29)	1 (1.59)			1 (1.59)
This study	Turkey	109 (54 R, 55 L)	77 (70.64)	7 (6.42)		20 (18.35)		5 (4.59)

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

4 (8%) radii by Dervisevic et al. (6), on 4 (4%) radii by Singh et al. (7). In previous studies and our study, no radius with more than two NFs were detected (6-8, 12, 19-24, 26) (Table 7).

Direction of NF: In human long bones, the NFs are observed to away from knee and face the elbow. This phenomenon is attributed to the unequal growth rates between the ends of long bones (23). Accordance with this phenomenon, majority of previous studies and our study show that all of the NFs were directed upward (face the elbow) (6-8). In some studies, it has been found that a small number of NFs were directed downward. Ozturk et al. (19) detected downward directed 2 (3.64%) NFs in Turkey. Akbari et al. (22) detected downward directed 2 (3.17%) NFs in India (Table 8).

Position of NF: According the foraminal index, position of NF was divided three parts (proximal 1/3, middle 1/3 and distal 1/3 of radius), majority of NF was detected middle 1/3 of radius and no NF was detected distal 1/3 of radius in previous studies (6-8, 19, 22). In our study, position of NF was divided 5 zones from proximal to the distal end of radius and majority of NF was detected zone 2 (20.01-40.00% part of radius) 91 (83.49%) and no NF was detected zone 1, zone 4 and zone 5. It indicates that no NF was detected on the most proximal and most distal parts of the radius (Table 8).

Localization of NF: We detected majority of NFs on the anterior surface 77 (70.64%) consistent with most previous studies (6-8, 12, 19-24). Unlike these studies, Sharma et al. (26) detected majority of NF on anterior border 15 (34.09%) and interosseous border 15 (34.09%). Our study and previous studies reveal that NF may be localized on other surfaces and borders of radius, besides the anterior surface (6-8, 12, 19, 21-23) (Table 9).

This study is subject to certain limitations. Firstly, the age and sex of the radii were not known, thus

preventing the evaluation of age and sex differences in NF. Additionally, the sample size was limited, consisting of only 109 radii. Future studies will aim to address these limitations by employing larger sample sizes and including bones with known age and sex. All parameters were measured by one observer for this reason inter observer reliability could not be evaluated.

In conclusion, one NF was detected on the radius, directed upwards and usually located on the anterior surface and zone 2 (20.01%-40.00%) of the radius, ranging between 20 (1.1 mm) - 22 (0.8 mm) G in size, and 5.01-10.00 mm away from the interosseous border. Based on our findings, it is advisable to place screws for the plate on the distal parts of the shaft whenever possible and in near to the anterior border to minimize the risk of damaging the NF for fracture healing.

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