

Number and localisation of nutrient foramen on clavicle and its relationship with other clavicle parameters

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Background: Nutrient foramen (NF) is a hole in the long bones that allows the passage of the nutrient artery. The vasculature of the bone is very important for fracture healing and vascularised bone grafting. Therefore, information about the location and number of NFs is important for surgical and clinical practice. The clavicle is the most commonly fractured bone. The aim of this study was to analyse the relationship between the location and number of NFs on the clavicle and other clavicle parameters.

Materials and methods: This study was performed on 86 dry clavicles of contemporary adult individuals without age and gender records. Some clavicle parameters and NF parameters were measured and the relationship between them was analysed. Measurements were performed using a digital caliper.

Results: Most of the clavicles had a single NF. There was a positive correlation between DF_{ant}/DF_{post} (distance between NF and anterior border/distance between NF and posterior border) and vertical thickness of sternal end (VTs), vertical thickness of thinnest point (VTt) and clavicular thinnest point index (CIt) in all cases ($p < 0.05$). Sagittal thickness of acromial end (STa), vertical thickness of clavicle (VTc), sagittal thickness of clavicle (STc), and sagittal thickness of thinnest point (STt) were associated with NF counts. The most common localisation of NFs was type 2. The NFs were mostly located in the inferior position.

Conclusions: Relationships between the number and morphometric characteristics of NFs and some clavicle parameters were determined. We suggest that knowledge of the number and morphometric characteristics of NFs is important for the protection of the nutrient artery in orthopaedic surgery applications. (Folia Morphol 2025; 84, 1: 231–242)

Keywords: nutrient foramen, clavicle, localisation, morphometry

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INTRODUCTION

The clavicle is one of the bones of the pectoral girdle (the only long bone that is horizontal) located horizontally at the root of the neck and resembles the letter S [26]. It provides a direct connection between the upper extremity and the axial skeleton, and transfers the weight of the upper extremity to the axial skeleton [26, 27]. It also plays an integral role in the mechanics of the shoulder girdle, upper extremity, and thorax [9]. There is a subclavian groove on the inferior surface of the clavicle, and there is usually a nutrient foramen (NF) lateral to this groove [26]. The NF is a hole in the body of long bones that allows the nutrient artery, which is essential for bone development, especially during intrauterine life, to reach the bone tissue [5, 15, 24, 26]. A fascicle of the supraclavicular nerve also passes through the NF at the clavicle along with the nutrient artery [12, 14].

The clavicle is the most commonly fractured bone (c.10% of all fractures) [1, 9, 27]. 70–80% of these fractures occur in the middle third of the clavicle, which is the weakest part of the clavicle [9]. Most clavicle fractures can be treated without surgery, but symptomatic nonunions require surgery [9]. The vasculature of the bone is very important for fracture healing, and delayed healing has been observed especially in stress fractures accompanied by nutrient artery rupture [5]. Preservation of the nutrient artery during surgical reduction and application of internal fixation devices is important for postoperative recovery. In addition, preservation of the nutrient artery in NF is necessary for surgical success in the development of new graft and resection techniques and free vascularised bone grafts [6]. Therefore, information regarding the location and number of NFs is surgically and clinically important.

There are some differences in the literature regarding the relationship between vascularisation and NF of the clavicle. A previous study stated that the major arterial support of the clavicle is provided by the periosteal arteries, and emphasised that the NF may be the passage of a vein that provides venous drainage [13]. However, an NF indicating a branch of the suprascapular artery was found on the inferior surface of the clavicle in a study by Havet et al. [9]. On the other hand, many studies have been conducted on the morphometric characteristics, localisation, position and variations of NF on the clavicle [6, 14, 15, 21, 24, 27]. There have also been many studies on the

morphological and morphometric characteristics of the clavicle [2, 4, 7, 19, 28]. However, these studies did not include information on how the NF affects other morphometric characteristics of the clavicle such as length and thickness. For this reason, we thought that a study should be conducted to determine whether the presence or absence, number and localisation of NFs affects other parameters of the clavicle.

MATERIALS AND METHODS

This study was performed on 86 dry clavicles (46 left, 40 right) with complete epiphyseal fusion of contemporary adult individuals in the anatomy laboratories of Atatürk University Faculty of Medicine, Kafkas University Faculty of Medicine, and Erzincan Binali Yıldırım University Faculty of Medicine, Türkiye. There was no record of the age, race or sex of the people to whom the bones belonged. A match between the right and left clavicles could not be made, as it was not known whether they belonged to the same person. Bones with deformities such as fractures or cracks that would affect the measurements were excluded from the study. All measurements were made with a digital caliper (BTS-12045 DIGITAL CALIPER 0–200 mm, 0.008 mm) (Fig. 1).

Measurement of clavicular parameters

Measurement of clavicular parameters is presented in Figures 2 and 3. Definitions of measurements are shown in Table 1.

Determination of NF number and dominant foramen

The feature that distinguishes NFs from other holes in the bone is the presence of a distinct vascular groove at the entry site [5]. NFs were detected using a magnifying lens (80 mm 10 × Lens Round Magnifier) and their number was noted. In the presence of two or more NFs, the more or most prominent one was defined as the dominant foramen.

Measurement of NF parameters

Measurements were taken for the dominant foramen (Fig. 4). Definitions of measurements are shown in Table 2.

Determination of localisation of NF

Three types of localisation were defined according to FI values [5]:

— Type 1: $FI < 33.33$ (NF located in medial third);



Figure 1. Parameter measurement with digital caliper.

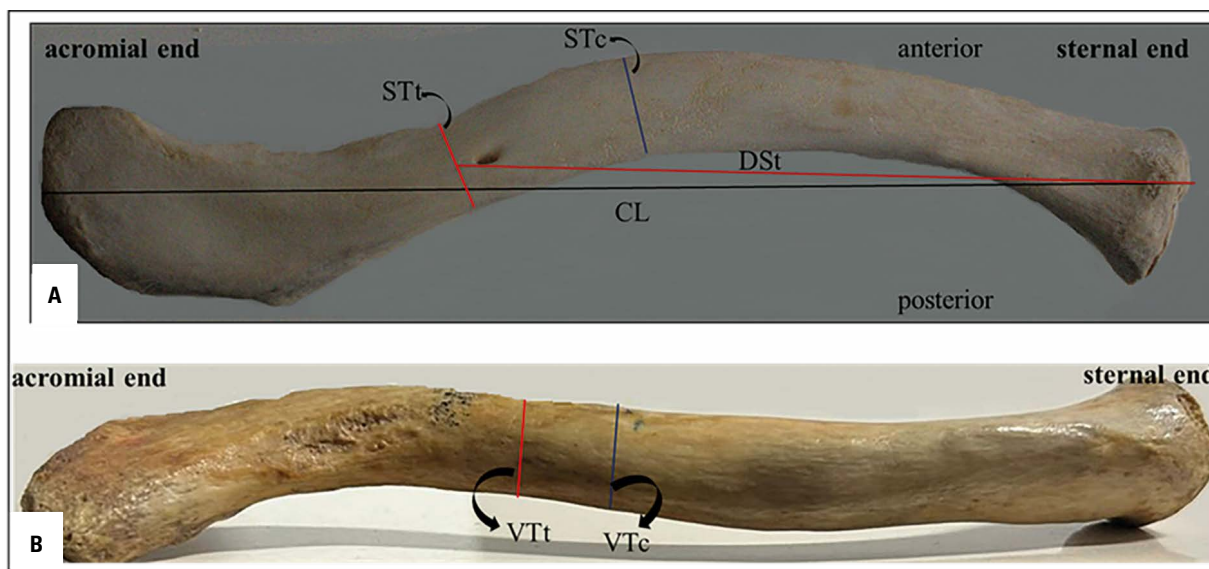


Figure 2A. Superior view of left clavicle; **B.** Anterior view of right clavicle. CL — clavicular length; DSt — distance between thinnest point and sternal end; STc — sagittal thickness of clavicle; STt — sagittal thickness of thinnest point; VtC — vertical thickness of clavicle; VTt — vertical thickness of thinnest point.

- Type 2: FI = 33.33 – 66.66 (NF located in middle third);
- Type 3: FI > 66.66 (NF located in lateral third).

In addition, the location of the NF was determined according to the anterior and posterior borders of the clavicle:

- $DF_{ant} / DF_{post} > 1$ (NF is closer to posterior border);
- $DF_{ant} / DF_{post} < 1$ (NF is closer to anterior border).

Determination of position of NF

This was performed for all NFs. The nutrient foramina were observed with a magnifying lens (80 mm

10 × Lens Round Magnifier), and the surface of the clavicle where the foramina were located was noted.

Statistical analysis

Data was evaluated using the statistical package program IBM SPSS Statistics 25.0 (IBM Corp., Armonk, NY, USA). Normal distribution of data of numerical variables was evaluated with the Shapiro-Wilk normality test and Q-Q graphs. Categorical variables were given as frequency and percentage. Descriptive statistics are given as Mean ± Standard Deviation and Median (IQR) values. Homogeneity of group variances

was evaluated with the Levene test. Independent samples *t*-test was used to compare two groups of independent continuous variables where the normal distribution assumption was met, and Mann-Whitney U-test was used when this assumption was not met. Comparisons of more than two independent groups were performed by one-way analysis of variance or the Kruskal-Wallis test. In cases of a difference as a result of one-way analysis of variance, Tukey's multiple

comparison test was used. The relationship between categorical variables was evaluated with the Pearson Chi-Square test in *r* × *c* Tables. A value of *p* < 0.05 was considered statistically significant.

RESULTS

The mean values and standard deviations (SD) of the clavicular and the NF parameters are shown in Table 3. VTs and DFant/DFpost values were found to be greater on the left side, STs, DFS, FI and DFpost values were found to be greater on the right side (*p* < 0.05). There was no significant difference between the right and left side for other parameters (*p* > 0.05) (Tab. 3).

The correlation values between the NF parameters and the clavicular parameters are shown in Table 4. There was a positive correlation between FI and CL on the left side ($\rho = 0.353$, *p* = 0.019), but a negative correlation on the right side ($\rho = -0.367$, *p* = 0.021). There was no correlation between FI and all clavicular parameters in all cases (*p* > 0.05). There was a positive correlation between DFant/DFpost value and Clt on the left side ($\rho = 0.318$, *p* = 0.036). There was a positive correlation between DFant/DFpost value and STs and VTt on the right side ($\rho = 0.414$, *p* = 0.009 and $\rho = 0.404$, *p* = 0.011, respectively). There was a positive correlation between DFant/DFpost value and VTs, VTt and Clt in all cases ($\rho = 0.220$, *p* = 0.045, $\rho = 0.240$, *p* = 0.029 and $\rho = 0.248$, *p* = 0.024, respectively) (Tab. 4).

There was a single NF in 57 cases (66.3%), two NFs in 16 cases (18.6%), three NFs in eight cases (9.3%), and four NFs in two cases (2.3%), while there was no NF in three cases (3.5%). There was no significant

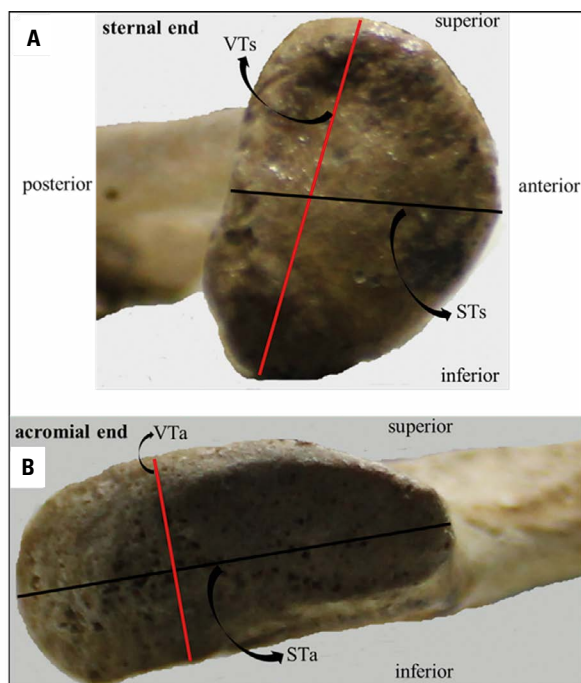


Figure 3A. Sternal end of clavicle; **B.** Acromial end of clavicle; STa — sagittal thickness of acromial end; STs — sagittal thickness of sternal end; VTa — vertical thickness of acromial end; VTs — vertical thickness of sternal end.

Table 1. Definitions of measured clavicular parameters.

CL (clavicular length)	Distance between extreme points of sternal and acromial ends of clavicle
VTs (vertical thickness of sternal end)	Distance between upper and lower points of sternal end
STs (sagittal thickness of sternal end)	Distance between most anterior and posterior points of sternal end
VTa (vertical thickness of acromial end)	Distance between upper and lower points of acromial end
STa (sagittal thickness of acromial end)	Distance between most anterior and posterior points of acromial end
VTc (vertical thickness of clavicle)	Vertical thickness of midpoint of clavicle body
STc (sagittal thickness of clavicle)	Sagittal thickness of midpoint of clavicle body
VTt (vertical thickness of thinnest point)	Vertical thickness of thinnest point of clavicle
STt (sagittal thickness of thinnest point)	Sagittal thickness of thinnest point of clavicle
DSt (distance between thinnest point and sternal end)	Distance between thinnest point and sternal end of clavicle
Clt (clavicular thinnest point index)	$DSt/CL \times 100$ (In literature review, no index calculation regarding thinnest point of clavicle was found. This formula was determined by us). Thinnest point of clavicle was determined using a calibrated narrow strip of graph paper

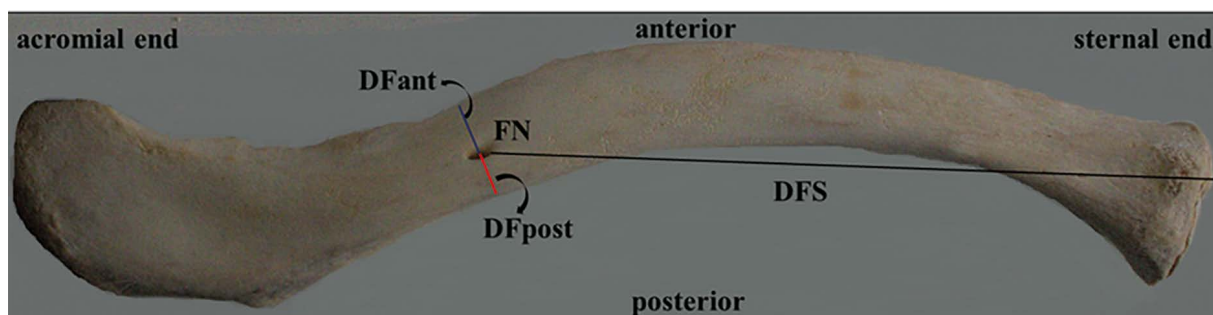


Figure 4. Superior view of clavicle; DFant — distance between NF and anterior border; DFpost — distance between NF and posterior border; DFS — distance between NF and sternal end; NF — foramen nutricium.

Table 2. Definitions of measured NF parameters.

DFS (distance between NF and sternal end)	Distance from NF to sternal end of clavicle
FI (foraminal index)	Calculated according to Hughes formula $[FI = (DFS/CL) \times 100]$ [10]
DFant. (distance between NF and anterior border)	Distance from NF to anterior border of clavicle
DFpost. (distance between NF and posterior border)	Distance from NF to posterior border of clavicle
DFant / DFpost	Ratio of DFant to DFpost was calculated and noted

difference in NF counts between the right and left sides (Tab. 5).

The relationship between NF counts and clavicle parameters is shown in Table 6. STa was statistically greater in clavicles with no NF than in clavicles with one, two and three NFs. VTc was statistically greater in clavicles with three NFs than in clavicles with one NF. STc was statistically greater in two-NF clavicles than in one-NF clavicles. STt was statistically greater in clavicles with two and four NFs than in clavicles with one NF (Tab. 6).

The foraminal index (FI) was 52.54 ± 6.82 on the left side and 58.17 ± 9.05 on the right side (Tab. 3). According to these results, the most common localisation of NF was type 2 (middle third of the clavicle). There was no NF with type 1 localisation (Tab. 7). Most of the NFs were closer to the distal (acromial) end (due to FI value greater than 50 on both sides) and the posterior edge (due to $DFant/DFpost > 1$ on both sides) (Tab. 3).

The NFs were most frequently located in the inferior position, followed by the posterior position. There were eight NFs in the superior position and only one in the anterior position. There was no statistically significant difference in the position of the NFs between the right and left side (Tab. 8).

DISCUSSION

The long bones are supplied by nutrient, metaphyseal, epiphyseal, and periosteal arteries [26]. The

NF is a hole in the body of long bones that allows the nutrient artery to reach the bone tissue [15, 26]. Studies of the arterial blood supply to the clavicle have shown that the bone is supplied by the suprascapular, thoracoacromial, and internal thoracic arteries [9, 13]. Knudsen et al. [13] demonstrated that the clavicle is supplied by the periosteal branches of these arteries, that it does not have a distinct nutrient artery, and that the NF probably mediates venous drainage. The same study emphasised that a nutrient branch of the suprascapular artery could not be observed or distinguished from the periosteal arteries [13]. Havet et al. [9] examined the branches of the thoracoacromial and suprascapular arteries extending to the clavicle. They found that, in addition to the periosteal branches of these arteries, a nutrient branch of the suprascapular artery was inserted into the bone through the NF in all cases. Similarly, another study found that the clavicle is supplied by a dominant nutrient artery branching off the suprascapular artery [8].

Therefore, knowing the location of the NF on the clavicle is very important so as to avoid damaging the nutrient artery during surgical applications such as fracture reduction, internal fixation, or free vascularised graft.

The localisation of NF on the clavicle was determined by calculating the foraminal index (FI) according to a previous study [10]. In our study, NF was most frequently (76%) located in the middle third

Table 3. Comparing clavicular parameters and nutrient foramen parameters according to left and right clavicular results.

Clavicular parameters	Groups		p value
	Left clavicle (n = 46)	Right clavicle (n = 40)	
	Mean ± SD Median (IQR)	Mean ± SD Median (IQR)	
CL	143.45 ± 13.01 144.45 (15.75)	140.64 ± 12.34 139.76 (16.69)	0.309 [*]
VTs	23.34 ± 4.11 22.64 (5.70)	20.75 ± 3.12 20.27 (3.31)	0.002[*]
STs	20.34 ± 4.14 19.82 (7.15)	22.78 ± 4.55 22.97 (5.31)	0.011[*]
VTa	10.79 ± 1.71 10.78 (2.50)	11.41 ± 2.02 11.00 (2.45)	0.123 [*]
STa	26.05 ± 4.69 26.41 (5.62)	26.14 ± 4.36 26.31 (6.27)	0.925 [*]
VTc	9.88 ± 1.25 9.67 (1.43)	10.00 ± 1.36 9.97 (1.67)	0.662 [*]
STc	12.14 ± 1.52 12.30 (2.47)	12.50 ± 1.38 12.59 (2.06)	0.254 [*]
VTt	9.30 ± 1.40 9.34 (1.58)	9.42 ± 1.19 9.32 (1.89)	0.680 [*]
STt	11.59 ± 1.63 11.56 (2.38)	11.81 ± 1.46 11.76 (2.72)	0.510 [*]
Clt	48.94 ± 11.17 51.83 (10.63)	50.16 ± 7.73 50.55 (7.15)	0.700 ⁺
Nutrient foramen parameters	Left clavicle (n = 44)	Right clavicle (n = 39)	
DFS	75.12 ± 13.03 74.63 (20.00)	81.44 ± 12.84 82.97 (17.00)	0.029[*]
DSt	70.50 ± 18.07 75.15 (15.32)	70.65 ± 13.28 73.29 (16.75)	0.640 ⁺
FI	52.54 ± 6.82 54.72 (10.60)	58.17 ± 9.05 56.94 (9.26)	0.009⁺
DFant.	9.92 ± 1.84 9.94 (3.00)	9.66 ± 2.33 10.03 (3.00)	0.577 [*]
DFpost.	4.98 ± 2.43 4.38 (3.00)	6.58 ± 2.58 6.89 (4.00)	0.005 [*]
DFant. / DFpost.	2.82 ± 2.38 2.21 (1.45)	1.96 ± 1.63 1.37 (1.03)	0.010⁺

^{*}Independent samples *t*-test; ⁺Mann-Whitney *U*-test. Clt — clavicular thinnest point index; CL — clavicular length; DFant — distance between nutrient foramen and anterior border; DFpost — distance between nutrient foramen and posterior border; DFS — distance between nutrient foramen and sternal end; DSt — distance between thinnest point and sternal end; FI — foraminal index; IQR — interquartile range; SD — standard deviation; STa — sagittal thickness of acromial end; STc — sagittal thickness of clavicle; STs — sagittal thickness of sternal end; STt — sagittal thickness of thinnest point; VTa — vertical thickness of acromial end; VTc — vertical thickness of clavicle; VTs — vertical thickness of sternal end; VTt — vertical thickness of thinnest point. *P* < 0.05 is significant.

of the clavicle (type 2 localisation) (Tab. 7). However, NF with type 1 localisation was not observed, as in the study by Cihan et al. [5]. Many previous studies have shown similar results to our findings, and have shown that the most common type of localisation is type 2 localisation [5, 15, 16, 22, 24]. An FI value above 50 indicates that the NF is further away from the proximal (sternal) end and closer to the distal

(acromial) end. In this study, the average FI was found to be greater than 50 on both the right and left sides (Tab. 3). Therefore, most of the foramina in our study were closer to the acromial end. Although there are many studies in the literature supporting our findings [4, 5, 11, 15, 18, 22], there are also studies that have reported that the NF is closer to the sternal end [1, 12, 16, 21, 27].

Table 4. Correlation between nutrient foramen parameters and clavicular parameters in left, right and total.

		Nutrient foramen parameters	
		DFant./DFpost	FI
Left clavicular parameters (n = 46)			
CL	<i>rho</i>	0.052	0.353*
	p value	0.736	0.019
VTs	<i>rho</i>	0.215	0.096
	p value	0.162	0.535
STs	<i>rho</i>	0.139	-0.020
	p value	0.367	0.896
VTa	<i>rho</i>	-0.215	0.070
	p value	0.160	0.649
STa	<i>rho</i>	0.078	0.079
	p value	0.613	0.612
VTc	<i>rho</i>	0.175	0.059
	p value	0.255	0.702
STc	<i>rho</i>	0.092	0.107
	p value	0.553	0.489
VTt	<i>rho</i>	0.168	0.088
	p value	0.276	0.568
STt	<i>rho</i>	0.109	0.079
	p value	0.483	0.608
Clt	<i>rho</i>	0.318*	-0.203
	p value	0.036	0.185
Right clavicular parameters (n = 40)			
CL	<i>rho</i>	0.296	-0.367*
	p value	0.067	0.021
VTs	<i>rho</i>	0.127	0.146
	p value	0.442	0.374
STs	<i>rho</i>	0.414**	-0.135
	p value	0.009	0.413
VTa	<i>rho</i>	0.200	-0.316
	p value	0.223	0.050
STa	<i>rho</i>	0.069	-0.180
	p value	0.677	0.273
VTc	<i>rho</i>	0.221	-0.268
	p value	0.176	0.099
STc	<i>rho</i>	0.115	-0.092
	p value	0.487	0.577
VTt	<i>rho</i>	0.404*	-0.248
	p value	0.011	0.128
STt	<i>rho</i>	0.170	-0.130
	p value	0.301	0.431
Clt	<i>rho</i>	0.207	-0.013
	p value	0.207	0.936

→

Table 4 (cont). Correlation between nutrient foramen parameters and clavicular parameters in left, right and total.

		Nutrient foramen parameters	
		DFant./DFpost	FI
Total clavicular parameters (n = 86)			
CL	<i>rho</i>	0.161	-0.017
	p value	0.146	0.876
VTs	<i>rho</i>	0.220*	0.001
	p value	0.045	0.998
STs	<i>rho</i>	0.142	0.010
	p value	0.201	0.931
VTa	<i>rho</i>	-0.062	-0.070
	p value	0.579	0.532
STa	<i>rho</i>	0.060	-0.037
	p value	0.593	0.737
VTc	<i>rho</i>	0.164	-0.081
	p value	0.138	0.469
STc	<i>rho</i>	0.065	0.048
	p value	0.559	0.665
VTt	<i>rho</i>	0.240*	-0.031
	p value	0.029	0.779
STt	<i>rho</i>	0.120	0.015
	p value	0.280	0.896
Clt	<i>rho</i>	0.248*	-0.126
	p value	0.024	0.255

*Correlation is significant at 0.05 level (2-tailed). **Correlation is significant at 0.01 level (2-tailed). Clt — clavicular thinnest point index; CL — clavicular length; DFant — distance between nutrient foramen and anterior border; DFpost — distance between nutrient foramen and posterior border; FI — foraminal index; Rho — Spearman rho coefficient; Sta — sagittal thickness of acromial end; STc — sagittal thickness of clavicle; STs — sagittal thickness of sternal end; STt — sagittal thickness of thinnest point; VTa — vertical thickness of acromial end; VTc — vertical thickness of clavicle; VTs — vertical thickness of sternal end; VTt — vertical thickness of thinnest point.

Table 5. Nutrient foramen counts in left, right and total.

	Left clavicle (n = 46)	Right clavicle (n = 40)	Total clavicle (n = 86)	p value
Nutrient foramen counts	n [%]	n [%]	n [%]	0.524 ^{**}
0	2 (4.3)	1 (2.5)	3 (3.5)	
1	32 (69.6)	25 (62.5)	57 (66.3)	
2	9 (19.6)	7 (17.5)	16 (18.6)	
3	3 (6.5)	5 (12.5)	8 (9.3)	
4	0 (0.0)	2 (5.0)	2 (2.3)	

^{**}Pearson Chi-Square test, p < 0.05 is significant.

The traditional view has been that the NF is located on the inferior surface of the clavicle and lateral to the subclavian groove [26]. However, previous studies have shown that NF can be found not only on the inferior surface of the clavicle, but also on other surfaces [2–5, 7]. In our study, NFs were most commonly located on the inferior surface (48%) and secondarily on the posterior surface (44%). In addition, eight

NFs (7%) were detected on the superior surface and only one (1%) was detected on the anterior surface (Tab. 8). Many previous studies have found that NF is mostly located on the posterior surface [5, 11, 14, 16, 21, 22]. However, there are also studies showing that the NF is most often located in the inferior position, as in our study [20, 24]. Similarly to our study, some studies have shown that the numbers of NFs on the

Table 6. Comparing clavicular parameters according to nutrient foramen counts.

Clavicular parameters	Nutrient foramen counts					p value
	0	1	2	3	4	
	(n = 3)	(n = 57)	(n = 16)	(n = 8)	(n = 2)	
	Mean ± SD Median (IQR)	Mean ± SD Median (IQR)	Mean ± SD Median (IQR)	Mean ± SD Median (IQR)	Mean ± SD Median (IQR)	
CL	158.05 ± 8.21 161.66 (7.59)	140.14 ± 12.03 139.39 (15.87)	145.69 ± 13.08 143.38 (21.60)	141.22 ± 14.99 145.48 (22.58)	150.70 ± 0.13 150.70 (0.19)	0.056 ⁺
VTs	26.95 ± 6.66 26.83 (6.67)	21.60 ± 3.56 22.07 (4.44)	22.19 ± 3.57 21.29 (4.15)	23.20 ± 4.35 22.94 (7.51)	25.52 ± 6.65 25.52 (9.4)	0.097 ⁺
STs	24.57 ± 1.26 23.88 (1.11)	20.96 ± 4.57 21.28 (6.51)	22.55 ± 4.26 21.58 (4.38)	21.92 ± 4.94 23.00 (5.86)	21.31 ± 5.22 21.31 (7.39)	0.534 ⁺
VTa	13.79 ± 2.64 12.32 (2.32)	10.86 ± 1.77 10.55 (2.14)	10.95 ± 1.76 10.91 (1.94)	11.54 ± 2.10 11.96 (3.97)	12.40 ± 0.59 12.40 (0.83)	0.134 ⁺
STa	36.16 ± 4.10 ^a 35.76 (4.09)	24.96 ± 3.96 ^b 25.26 (5.69)	27.58 ± 3.57 ^b 27.77 (5.37)	27.11 ± 5.38 ^b 26.61 (10.59)	27.23 ± 1.78 ^{a,b} 27.23 (2.52)	< 0.001 [*]
VTc	11.60 ± 1.53 ^{a,b} 11.10 (1.46)	9.65 ± 1.09 ^a 9.50 (1.39)	9.90 ± 1.30 ^{a,b} 10.24 (1.89)	10.94 ± 1.66 ^b 10.94 (2.09)	11.32 ± 1.34 ^{a,b} 11.32 (1.90)	0.003 [*]
STc	13.41 ± 0.91 ^{a,b} 13.86 (0.83)	11.93 ± 1.39 ^a 12.07 (2.29)	13.07 ± 1.38 ^b 12.81 (2.33)	12.65 ± 1.38 ^{a,b} 12.74 (2.48)	14.20 ± 0.83 ^{a,b} 14.20 (1.17)	0.006 [*]
VTt	10.05 ± 0.58 10.38 (0.50)	9.19 ± 1.27 9.18 (1.77)	9.22 ± 1.18 9.23 (1.47)	10.21 ± 1.55 10.46 (2.95)	10.97 ± 1.05 10.97 (1.48)	0.106 ⁺
STt	12.91 ± 1.13 ^{a,b} 13.26 (1.09)	11.23 ± 1.45 ^a 11.30 (2.12)	12.72 ± 1.40 ^b 12.91 (2.23)	11.83 ± 1.12 ^{a,b} 11.66 (1.62)	14.14 ± 0.55 ^b 14.14 (0.78)	< 0.001 [*]
Clt	53.83 ± 4.98 55.73 (4.70)	49.73 ± 9.77 50.85 (9.69)	47.73 ± 8.55 50.03 (5.88)	48.76 ± 13.54 53.62 (7.00)	53.93 ± 6.96 53.93 (9.85)	0.576 ⁺

⁺Kruskal-Wallis test; ^{*}one-way analysis of variance; SD: Standard Deviation, IQR: Interquartile Range. P < 0.05 is significant. ^{a,b}Difference between group means in nutrient foramen counts. Meanings of same letter are similar

Clt — clavicular thinnest point index; CL — clavicular length; Sta — sagittal thickness of acromial end; STc — sagittal thickness of clavicle; STs — sagittal thickness of sternal end; STt — sagittal thickness of thinnest point; VTa — vertical thickness of acromial end; VTc — vertical thickness of clavicle; VTs — vertical thickness of sternal end; VTt — vertical thickness of thinnest point
STa multiple comparisons: 0–1 p: < 0.001; 0–2 p: 0.011; 0–3 p: 0.013; other pairwise comparisons not significant (p > 0.05).

VTc multiple comparisons: 1–3 p: 0.043; other pairwise comparisons not significant (p > 0.05).

STc multiple comparisons: 1–2 p: 0.034; other pairwise comparisons not significant (p > 0.05).

STt multiple comparisons: 1–2 p: 0.003; 1–4 p: 0.039; other pairwise comparisons not significant (p > 0.05).

Table 7. Localisation of NF on clavicle.

	Left clavicle (n = 44)	Right clavicle (n = 39)	Total clavicle (n = 83)	p value
NF localisation	n [%]	n [%]	n [%]	0.003 [*]
Type 1 (FI < 33.33) — medial third	0 (0.0)	0 (0.0)	0 (0.0)	
Type 2 (FI: 33.33–66.66) — middle third	44 (100.0) ^a	32 (82.1) ^b	76 (92%)	
Type 3 (FI > 66.66) — lateral third	0 (0.0) ^a	7 (17.9) ^b	7 (8%)	

^{*}Pearson Chi-Square test, ^{a,b}difference between group distributions in NF localisation. Meanings of same letter are similar. n — number of clavicles; NF — nutrient foramen; FI — foramen index.

Table 8. Position of nutrient foramen (NF) on clavicle.

	Left (n = 44) NF (n = 56)	Right (n = 39) NF (n = 62)	Total (n = 83) NF (n = 118)	p value
NF position	n [%]	n [%]	n [%]	0.488 [*]
Superior	4 (7.1)	4 (6.5)	8 (7)	
Inferior	24 (42.9)	33 (53.2)	57 (48)	
Anterior	0 (0.0)	1 (1.6)	1 (1)	
Posterior	28 (50.0)	24 (38.7)	52 (44)	

^{*}Pearson Chi-Square test. n — number of clavicles.

posterior and inferior sides are similar [12, 24]. When looking at the literature, NF has rarely been found in superior and anterior positions, and these findings are compatible with our study [16, 20, 21].

Having considered all the studies on the localisation and position of the NF, it is clear that this structure is mostly located in the middle third of the clavicle and on the posterior or inferior surface. In addition, one study reported that the suprascapular artery runs posteroinferiorly to the clavicle [13], and another study reported that the same artery gives off a nutrient artery on the inferior surface of the clavicle [9]. It is thought that the nutrient artery coming to the clavicle may originate from the suprascapular artery, but further studies are needed.

There were statistical differences between some clavicular and NF parameters between the right and left sides. While the VTs was found to be greater on the left side, STs, DFS, FI and DFpost were found to be greater on the right side (Tab. 3). Similarly to this study, Vatansever et al. [27] found that the distance of the NF to the posterior edge and the distance to the sternal end (in men) were greater on the right side. Cihan et al. [5] reported that the side difference was not significant for clavicle length, distance of NF to the sternal end, and FI values. There are also studies in the literature reporting that the clavicular length is greater on the left side than on the right [2, 23]. Factors such as asymmetric vascularisation, lateralised behaviour, activity-related changes, or greater mechanical loading of the clavicle on the dominant hand side may be possible explanations for clavicle asymmetry [6]. Studies by gender have reported that clavicle characteristics such as length, thickness, and weight are greater in men [2, 7, 17, 19, 29]. Because the sex of the bones used in our study was unknown, a comparison with the literature could not be made.

When examining the relationship between NF parameters and clavicular parameters, there was a positive correlation between FI and CL on the left side, but a negative correlation on the right side (Tab. 4). FI was calculated as the ratio of NF distance from sternal end (DFS) to clavicular length (CL). Therefore, increasing the FI value means that the NF moves away from the sternal end and approaches the acromial end. A positive correlation between FI and CL on the left side was found in this study. Accordingly, it can be interpreted that the clavicle length increases in cases where the NF and the nutrient artery are close to the acromial end. However, the opposite

situation was observed on the right side, and there was a negative correlation between FI and CL in our study. Since these results contradict each other, it cannot be said with certainty that the distance of the NF from the sternal or acromial end may affect the length of the clavicle. In any case, no significant correlation between FI and CL was found in all cases in this study. In our review of the literature, no study was found that examined the relationship between FI and other clavicular parameters.

We observed that the NF was closer to the posterior border of the clavicle ($DF_{\text{ant}}/DF_{\text{post}} > 1$) in this study (Tab. 3). Our results are consistent with the study by Vatansever et al. [27]. There was a positive correlation between $DF_{\text{ant}}/DF_{\text{post}}$ value and STs and VTt on the right side, and VTs and VTt in all cases in this study (Tab. 4).

Accordingly, it can be said that when the NF is closer to the posterior border, the sagittal and vertical thickness of the sternal end and the vertical thickness of the thinnest point of the sternum increase.

In the literature, the weakest part of the clavicle is defined as the junction of the middle and lateral thirds, and this is the junction of the medial and lateral curvatures [26]. Clavicle fractures are most common in this region [5, 9, 24, 26]. In this study, the clavicular thinnest point index (ClIt) was calculated as the ratio of the distance from the thinnest point of the clavicle to the sternal end (DS_{t}) to the length of the clavicle (CL). An increase in this index indicates that the thinnest point is approaching the acromial end. In this study, there was a positive correlation between $DF_{\text{ant}}/DF_{\text{post}}$ and ClIt on the left side and in all cases (Tab. 4).

According to our results, when the NF is closer to the posterior border, the thinnest point of the clavicle approaches the acromial end. In the literature review, no study was found that examined the relationship between $DF_{\text{ant}}/DF_{\text{post}}$ and ClIt and other clavicular parameters.

When the number of NFs was examined, a single NF was found in most of the clavicles (57 cases — 66.3%) (Tab. 5). Many previous studies have reported that the number of clavicles containing a single NF is higher, which is consistent with our study [1, 4, 14, 18, 20]. But contrary to our findings, there are also studies reporting that the number of clavicles with two NFs is higher [11, 16, 22, 24]. There was no NF in three clavicles (3.5%) in our study. Sharmada et al. [24] found no NF in 3/104 clavicles (2.88%) and

Dakshayani et al. [6] found no NF in 3/100 clavicles (3%), and these results are compatible with our study. However, Cihan et al. [5] reported no NF in 6/61 clavicles (9.8%) and Kumar et al [14] reported no NF in 10/102 clavicles (9.8%). In our study, four NFs (2.3%) were found in two clavicles. Hussain et al. [11] found four NFs in 3.3% and Cihan et al [5] found four NFs in 1.6%. In most of the literature, including our study, no description was found regarding the presence of more than four NFs on one clavicle. Only one study has reported five NFs in 3/48 clavicles (6.3%) [18].

When the relationship between the number of NFs and clavicular parameters was analysed, STa was statistically greater in clavicles with no NFs than in clavicles with one, two and three NFs. This shows that the clavicle, and especially the acromial end, can be supplied only by the periosteal arteries without being dependent on the nutrient artery. There have been studies reporting that since there is no medullary space in the clavicle, it can be assumed that it does not have NF and does not need a nutrient artery for its nutrition [13, 24]. On the other hand, VTc was statistically greater in clavicles with three NFs than in clavicles with one NF, STc was statistically greater in clavicles with two NFs than in clavicles with one NF, and STt was statistically greater in clavicles with two and four NFs than in clavicles with one NF (Tab. 6).

Based on these findings, it can be said that the vertical and sagittal thickness of the clavicle and the sagittal thickness of its thinnest point are greater in clavicles with a higher number of NFs. Therefore, clinically, it can be said that a high number of nutrient arteries affects the thickness of the clavicle, plays an important role in the strength of the clavicle, and may reduce the risk of fracture. However, since the nutrient arteries generally originate from vessels that invade the cartilage during ossification, it is also believed that the bone may be weaker in the area where the NF and nutrient channels are located, and so the tendency to fracture may be increased [1, 25]. When we reviewed the literature, we could not find any study that investigated the relationship between the number of NFs and clavicle parameters. This situation limits our findings, and more studies are needed in order to reach more accurate conclusions.

CONCLUSIONS

It is important to know the anatomical characteristics of the clavicle because it is the most common bone to fracture, and some of these fractures require

surgical intervention. In this study, we observed that the number of NFs affected the thickness of the clavicle. It has been reported that bone blood supply is very important for fracture healing, and fracture healing is delayed especially in cases of rupture of the nutrient artery [5]. Therefore, preservation of the nutrient artery in surgical procedures for this bone will affect the postoperative healing process.

For this reason, information about the location and number of NFs through which the nutrient artery passes on the clavicle is very important in orthopaedic surgical practice.

Limitation of study

This study is a dry bone study with no age or gender records. This limits analysis and discussion. The results of this study should be supported by future studies on dry bones with age and sex records, as well as radiological studies.

ARTICLE INFORMATION AND DECLARATIONS

Data availability statement

The data from this study is available to the journal.

Ethics statement

This study was approved by the Atatürk University Non-Interventional Clinical Research Ethics Committee (Date: 01.06.2023, Decision No: 41).

Author contributions

BY— project development, data collection and analysis, manuscript writing and editing; YA, ABK, MS — project development and editing; BE — project development and data analysis.

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Conflict of interest

The authors declare that they have no conflict of interest.

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