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ORIGINAL ARTICLE

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The study of the number and localization of the nutrient foramen on the clavicle and its relationship with other clavicle parameters

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ABSTRACT

Background: Nutrient foramen (NF) is a hole on the long bones that allows the passage of the nutrient artery. The vasculature of the bone is very important for fracture healing and vascularized 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 analyze 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 analyzed. Measurements were performed using a digital caliper.

Results: Most of the clavicles had a single NF. There was a positive correlation between DFant/DFpost (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 localization 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. It was suggested that the knowledge of the number and morphometric characteristics of NFs is important for the protection of the nutrient artery in orthopedic surgery applications.

Keywords: nutrient foramen, clavicle, localization, morphometry

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 [6, 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 (approximately 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 [6]. 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 vascularized bone grafts [7]. Therefore, information about the location and number of NF is surgically and clinically important.

There are some differences in the literature regarding the relationship between vascularization and NF of the clavicle. In a previous study, it was stated that the major arterial support of the clavicle is provided by the periosteal arteries, and it was emphasized 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 conducted by Havet et al [9]. On the other hand, many studies have been conducted on the morphometric characteristics, localization, position and variations of NF on the clavicle [7, 14, 15, 21, 24, 27]. There are also many studies on the morphological and morphometric characteristics of the clavicle [2–4, 19, 28]. However, these studies did not include information on how NF affects other morphometric characteristics of the clavicle (such as length and thickness). For this reason, it was thought that a study should be conducted to determine whether the presence or absence, number and localization of NFs affects other parameters of the clavicle, and this study was conducted.

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. There was no record of the age, race and sex of the people to whom the bones belonged. A match between the right and left clavicles could not be made as it is not known whether they belong 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 (Fig. 2, 3)

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 [6]. NFs were detected using a magnifying lens (80 mm 10 × Lens Round Magnifier) and their number was noted. In the presence of 2 or more NFs, the 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 the localization of the NF

Three types of localization were defined according to FI values [6]:

- Type 1: FI < 33.33 (NF is located in the medial 1/3);
- Type 2: FI = 33.33 – 66.66 (NF is located in the middle 1/3);
- Type 3: FI > 66.66 (NF is located in the lateral 1/3).

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

- DFant / DFpost > 1 (NF is closer to the posterior border);
- DFant / DFpost < 1 (NF is closer to the anterior border).

Determination of the position of the NF

It 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

The data were evaluated in the statistical package program IBM SPSS Statistics 25.0 (IBM Corp., Armonk, NY, USA). The normal distribution of the 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 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 case 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 $r \times c$ 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 CIt 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 CIt 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%), 2 NFs in 16 cases (18.6%), 3 NFs in 8 cases (9.3%), and 4 NFs in 2 cases (2.3%), while there was no NF in 3 cases (3.5%). There was no significant 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 1, 2, and 3 NF. VTc was statistically greater in clavicles with 3 NFs than in clavicles with 1 NF. STc was statistically greater in 2 NF clavicles than in 1 NF clavicles. STt was statistically greater in clavicles with 2 and 4 NF than in clavicles with 1 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 localization of NF was type 2 (middle 1/3 of the clavicle). There was no NF with type 1 localization (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 / DFant > 1 on both sides) (Tab. 3).

The NFs were most frequently located in the inferior position, followed by the posterior position. There were 8 NFs in the superior position and only 1 NF 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] stated 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. In the same study, it was emphasized 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 and 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 important to avoid damaging the nutrient artery during surgical applications (such as fracture reduction, internal fixation, free vascularized graft).

The localization 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 1/3 of the clavicle (type 2 localization) (Table 7). However, NF with type 1 localization was not observed as in the study by Cihan et al. [6]. Many previous studies have shown similar results to our findings and have shown that the most common type of localization is type 2 localization [6, 15, 16, 22, 24]. The FI value above 50 indicates that the NF is farther 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, it was found that most of the foramina in our study were closer to the acromial end. Although there are many studies in the literature supporting our findings [5, 6, 11, 15, 18, 22], there are also studies reporting that the NF is closer to the sternal end [1, 12, 16, 21, 27].

Classical texts state 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 (2–6). In our study, NFs were most commonly located on the inferior surface (48%) and secondarily on the posterior surface (44%). In addition, 8 NFs (7%) were detected on the superior surface and only 1 NF (1%) was detected on the anterior surface (Tab. 8). Many previous studies have found that NF is mostly located on the posterior surface [6, 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]. Similar to our study, some studies show that the number of NFs on the posterior and inferior sides are close to each other [12, 24]. When looking at the literature, it has been observed that NF is rarely found in superior and anterior positions, and these findings are compatible with our study [16, 20, 21].

Considering all the studies on the localization and position of the NF, it is clear that this structure is mostly located in the middle 1/3 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]. Considering these studies, it is believed 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). Similar to our 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. [6] 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 side [2, 23]. Factors such as asymmetric vascularization, lateralized behavior, activity-related changes, or greater mechanical loading of the clavicle on the dominant hand side may be possible explanations for clavicle asymmetry (7). Studies by gender have reported that clavicle characteristics such as length, thickness, and weight are greater in men [2, 3, 17, 19, 29]. Because the sex of the bones used in our study was not recorded, 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 the review of the literature, no study was found that examined the relationship between FI and other clavicular parameters.

It was observed that the NF was closer to the posterior border of the clavicle (DFant/DFpost > 1) in our study (Tab. 3). Our results were consistent with the study by Vatansever et al. [27]. There was a positive correlation between DFant/DFpost 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 1/3 parts, and this is the junction of the medial and lateral curvatures [26]. Clavicle fractures are most common in this region [6, 9, 24, 26]. In this study, the clavicular thinnest point index (CIt) was calculated as the ratio of the distance from the thinnest point of the clavicle to the sternal end (DSt) 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 DFant/DFpost and CIt 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 DFant/DFpost and CIt 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, 5, 14, 18, 20]. Contrary to our findings, there are also studies reporting that the number of clavicles with 2 NFs is higher [11, 16, 22, 24]. There was no NF in 3 clavicles (3.5%) in our study. Sharmada et al. [24] found no NF in 3 out of 104 clavicles (2.88%) and Dakshayani et al. [7] found no NF in 3 out of 100 clavicles (3%), and these results are compatible with our study. However, Cihan et al. [6] reported no NF in 6 of 61 clavicles (9.8%) and Kumar et al [14] reported no NF in 10 of 102 clavicles (9.8%). In our study, 4 NFs (2.3%) were found in 2 clavicles. Hussain et al. [11] found 4 NFs in 3.3% and Cihan et al [6] found 4 NFs in 1.6%. In most of the literature, including our study, no information was found regarding the presence of more than 4 NFs on one clavicle. Only one study reported 5 NFs in 3 of 48 clavicles (6.3%) [18].

When the relationship between the number of NFs and clavicular parameters was analyzed, STa was statistically greater in clavicles with no NFs than in clavicles with 1, 2, and 3 NF. 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 in the literature 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 3 NFs than in clavicles with 1 NF, STc was statistically greater in clavicles with 2 NFs than in clavicles with 1 NF, and STt was statistically greater in clavicles with 2 and 4 NFs than in clavicles with 1 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 the 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 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 the discussion of our findings, and more studies similar to our study are needed to reach more accurate conclusions.

CONCLUSIONS

In conclusion, 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, it was 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 [6]. 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 important in orthopedic surgical practice.

Limitation of this study

This study is a dry bone study with no age or gender records. This situation limits analysis and discussion. The results of this study can 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 are 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 — project development and editing. ABK — project development and editing. 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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Table 1. Definitions of measured clavicular parameters.

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

Table 2. Definitions of measured NF parameters.

DFS (distance between NF and sternal end)	Distance from the NF to the sternal end of the clavicle.
FI (foraminal index)	It was calculated according to the Hughes formula [FI = (DFS / CL) × 100] [10].
DFant. (distance between NF and anterior border)	Distance from NF to anterior border of the clavicle.
DFpost. (distance between NF and posterior border)	Distance from the NF to the posterior border of the clavicle.
DFant / DFpost	The ratio of DFant to DFpost was calculated and noted.

Table 3. Comparing clavicular parameters and Nutrient foramen parameters according to the left end right clavicular results.

	Groups		
	Left Clavicle (n = 46)	Right Clavicle (n = 40)	
Clavicular parameters	Mean ± SD Median (IQR)	Mean ± SD Median (IQR)	p value
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. CIt — 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.

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	*rho*	0.052	**0.353***
	p value	0.736	**0.019**
VTs	*rho*	0.215	0.096
	p value	0.162	0.535
STs	*rho*	0.139	–0.020
	p value	0.367	0.896
VTa	*rho*	–0.215	0.070
	p value	0.160	0.649
STa	*rho*	0.078	0.079
	p value	0.613	0.612
VTc	*rho*	0.175	0.059
	p value	0.255	0.702
STc	*rho*	0.092	0.107
	p value	0.553	0.489
VTt	*rho*	0.168	0.088
	p value	0.276	0.568
STt	*rho*	0.109	0.079
	p value	0.483	0.608
Clt	*rho*	**0.318***	–0.203
	p value	**0.036**	0.185
Right clavicular parameters (n = 40)			
CL	*rho*	0.296	**–0.367***
	p value	0.067	**0.021**
VTs	*rho*	0.127	0.146
	p value	0.442	0.374
STs	*rho*	**0.414****	–0.135
	p value	**0.009**	0.413
	rho	0.200	–

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed). CIt — 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.

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

	Nutrient foramen counts					
	0 (n = 3)	1 (n = 57)	2 (n = 16)	3 (n = 8)	4 (n = 2)	
Clavicular Parameters	Mean ± SD Median (IQR)	Mean ± SD Median (IQR)	Mean ± SD Median (IQR)	Mean ± SD Median (IQR)	Mean ± SD Median (IQR)	p value
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}	27.11 ± 5.38^{b}	27.23 ±1.78$^{a, b}$	**< 0.001***

			27.77 (5.37)	26.61 (10.59)	27.23 (2.52)	
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**[*]
CIt	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]The difference between group means in the nutrient foramen counts. The meanings of the same letter are similar.

CIt — 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. Localization of NF on the clavicle.

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

*Pearson Chi-Square test, [a, b]the difference between group distributions in the NF localization. The meanings of the same letter are similar. n — number of clavicles; NF — nutrient foramen; FI — foraminal index.

Table 8. Position of NF on the 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; NF — nutrient foramen.

Figure 1. Parameter measurement with digital caliper.

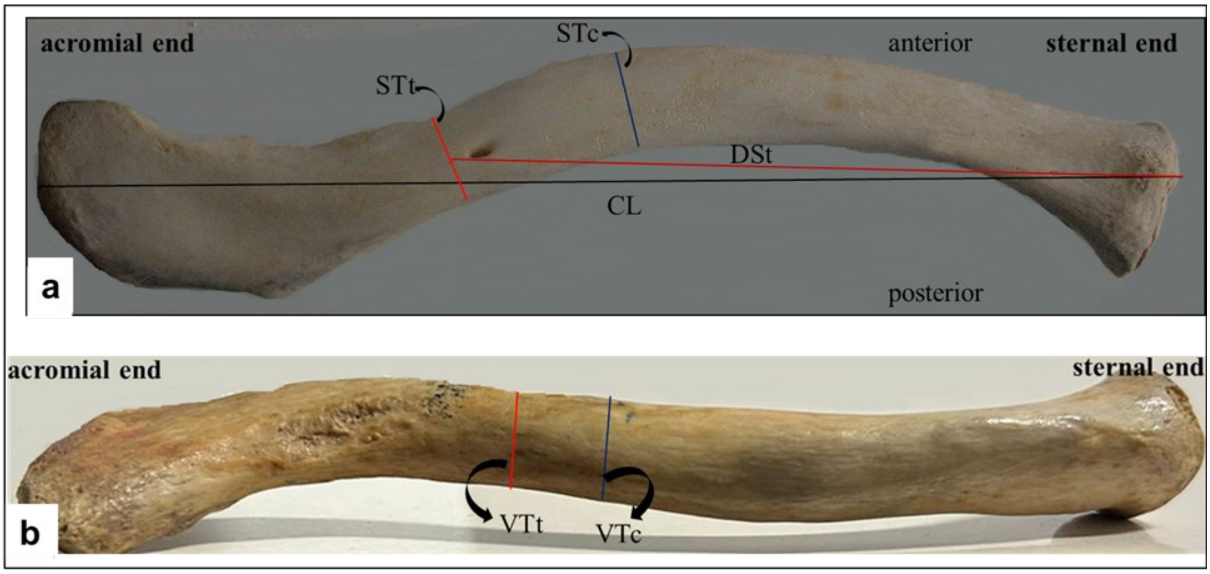

Figure 2A. Superior view of left clavicle; **B.** Anterior view of right clavicle, CL — clavicular length; DSt — distance between thinnest point and sternal end; STc — sagittal thickness of clavicle; STt — sagittal thickness of thinnest point; VTc — vertical thickness of clavicle; VTt — vertical thickness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

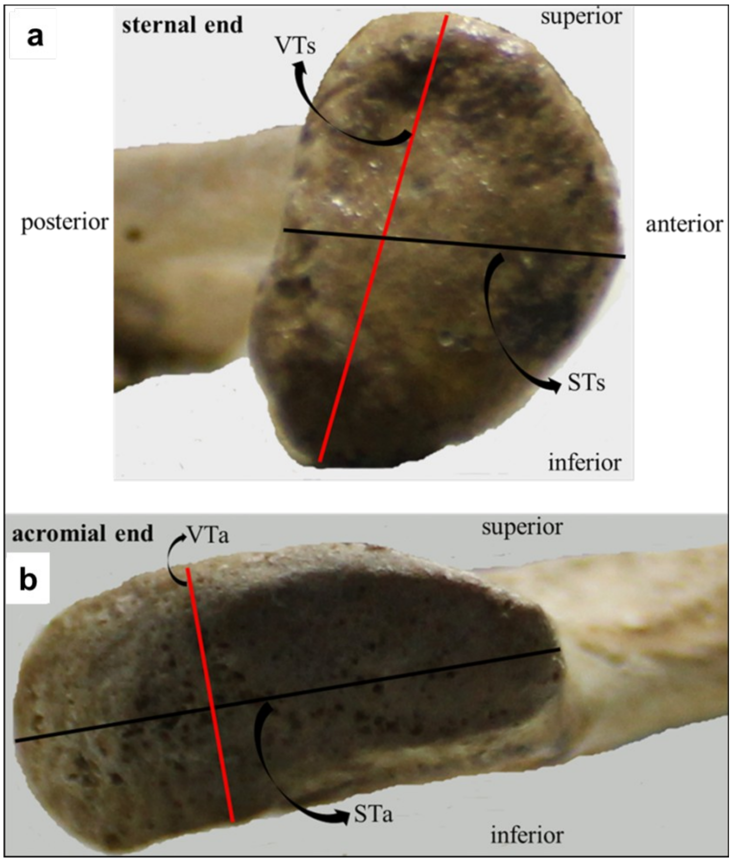

Figure 3A. Sternal end of clavicle; **B.** Acromial end of clavicle; STa — sagittal thickness of acromial end; STs — sagittal thickness of sternal end; VTa — vertical thickness of acromial end; VTs — vertical thickness of sternal end.

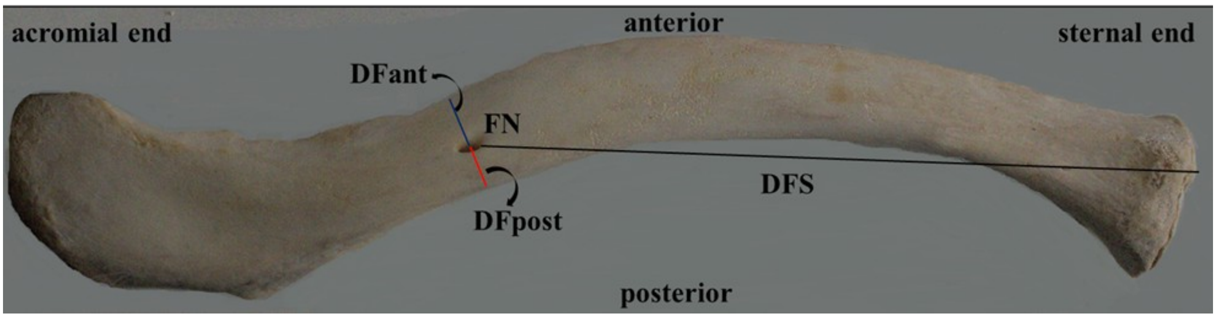

Figure 4. Superior view of clavicle; Dfant — distance between NF and anterior border; Dfpost — distance between NF and posterior posterior; DFS — distance between NF — and sternal end; NF — foramen nutricium.