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Original Article

Anatomy Section

Morphological and Topographical Anatomy of the Nutrient Foramen in the Clavicle: A Cross-sectional Study

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ABSTRACT

Introduction: The clavicle is the first bone to ossify during the fifth to sixth week of gestation and the last to complete the process. It develops from intramembranous ossification. Opinions vary regarding the significance of the nutrient foramen in the clavicle.

Aim: To comprehensively understand the topographic anatomy of the nutrient foramen in adult human clavicles and its clinical importance.

Materials and Methods: This cross-sectional study was conducted on 50 clavicles at the Department of Anatomy, Government Medical College Srinagar, from September 2023 to December 2023. The nutrient foramina were macroscopically observed using a magnifying lens to determine their number, location, direction, and patency. Vernier calipers were used to measure various foraminal dimensions, and the Foramen Index (FI) was calculated using the Hughes formula. The data was entered into Microsoft Excel 2016 and analysed using Statistical Package for Social Sciences (SPSS) version 22.0.

Results: The study included 20 right-sided clavicles and 30 left-sided clavicles (total 50). Approximately 47 (94%) clavicles had a single nutrient foramen, while 3 (6%) clavicles had double nutrient foramina. All right-sided clavicles (100%) had a single nutrient foramen. Among the left-sided clavicles, 27 (90%) had a single foramen, and three clavicles (10%) had double foramina. Nutrient foramina were patent in 20 (100%) right-sided clavicles and 9 (30%) left-sided clavicles, meaning they were non-patent in 21 (70%) left-sided clavicles. Most clavicles had the nutrient foramen located on the posterior surface (42, 84%), while 8 (4%) had the nutrient foramen on the inferior surface. The nutrient foramen was noted in the middle third of the clavicle in about 35 (70%) clavicles, on the medial third in 10 (20%) clavicles, and on the lateral third in 5 (10%) clavicles.

Conclusion: Nutrient foramina are predominantly located in the middle one-third region and on the posterior surface of the clavicle. As microvascular bone graft transfer is gaining popularity, surgeons must be familiar with the topography of the nutrient foramina of the clavicle to ensure successful bone grafting.

Keywords: Bone grafting, Collar bone, Foramen index, Intramembranous ossification

INTRODUCTION

The clavicle is a subcutaneous and sinuously curved modified long bone of the pectoral girdle placed horizontally at the root of the neck. It acts as a prop to place the scapula laterally so that the upper limb can swing freely from the side of the trunk. It also transmits forces from the upper limb to the axial skeleton through the coraco-clavicular ligament and the medial two-thirds of the bone. It has a shaft and two ends: sternal and acromial. The lateral one-third of the shaft is flattened from above downwards, giving it two borders (anterior and posterior) and two surfaces (superior and inferior) [1]. The anterior border is concave, and the posterior one is convex. The superior surface is subcutaneous, and the inferior surface bears an elevation called the conoid tubercle and a ridge known as the trapezoid ridge. The medial two-thirds of the shaft are rounded and have four surfaces. The anterior surface is convex, and the posterior surface is concave. The superior surface is smooth in its medial part, and the inferior surface bears a rough oval impression on its medial part. The clavicle has two ends: the lateral and medial ends, and a cylindrical shaft [2].

An unusually long clavicle has some unique embryological features. The clavicle is the first bone to begin and the last to complete its ossification. It develops from intramembranous ossification [1]. The clavicle is an s-shaped structure that connects the upper limb to the trunk [3]. The shaft of the bone has an opening called the nutrient foramen, which allows the passage of blood vessels into the bone for its growth and nourishment [4]. A small foramen may be present along the superior border in the middle one-third of the clavicle. The nutrient artery is transmitted through this foramen. Sometimes, the supraclavicular nerve also transmits through this foramen [2]. Some authors have suggested that the clavicle has its primary blood supply by periosteal arteries, and no nutrient artery supplies it [5].

The clavicle forms a direct joint between the upper extremity and the axial skeleton. Clavicle fractures compose 10% of all fracture cases. Therefore, most studies have focused on avoiding unexpected neurovascular injuries during clavicle osteosynthesis [6-8]. Various anatomical studies have demonstrated its clinical importance in other bones and provided detailed information concerning surgical and trauma-related aspects [9-11]. Several opinions have been put forth about the significance of the clavicle's nutrient foramen. Supraclavicular nerve entrapment syndrome can occur if this nerve gets entrapped. Hence, thorough knowledge of foramina is required [11]. Knowledge of the neurovascular foramina of the clavicle is clinically important as these are involved in supraclavicular nerve entrapment syndrome. The topography and morphology of these foramina are enlightening for the operating surgeon in free vascularised bone grafts and microsurgical vascularised bone transplantation. Delineating the clavicle blood supply could provide greater insight into understanding non-unions [5,8]. The present study aimed to understand the detailed topographic anatomy of the nutrient foramen of human adult clavicles to provide operating surgeons with detailed information about the variations that could be encountered and prevent further complications.

MATERIALS AND METHODS

This cross-sectional study was conducted in the Department of Anatomy at Government Medical College Srinagar from September 2023 to December 2023. Institutional Ethical Committee clearance

(146/ETH/GMC, dated: 15-10-2022) was obtained. Fifty clavicles were collected from the osteology section of the Department of Anatomy at Government Medical College Srinagar for the study, regardless of age and sex.

Inclusion criteria: The study included only adult clavicles without any gross pathology or deformity.

Exclusion criteria: Clavicles that displayed significant damage or possessed attributes rendering the foramina unidentifiable were explicitly excluded to ensure the study's integrity.

Procedure

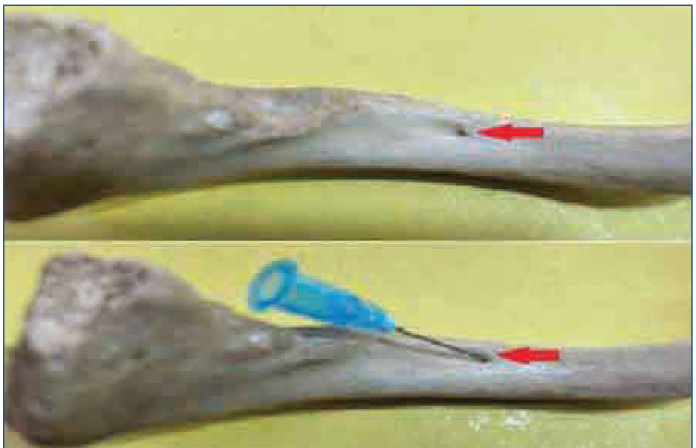
The clavicles were macroscopically observed using a magnifying lens to determine the number, location, direction, and patency of the nutrient foramina. To confirm patency, a 24-gauge needle was passed through the foramen. Specific surfaces were analysed to check the number and topography of foramina. The clavicle's length was measured using a Vernier caliper, and the bone was divided into three equal parts: medial 1/3, middle 1/3, and lateral 1/3. The Foramen Index (FI) was calculated using the Hughes formula, which involved dividing the distance of the foramen from the sternal end (D) by the total length of the bone (L) and multiplying it by 100 [9].

STATISTICAL ANALYSIS

For all the clavicles, the FI was calculated, and the foramina were topographically classified into the medial 1/3, middle 1/3, and lateral 1/3 regions. The recorded data was compiled and entered into a spreadsheet using Microsoft excel 2016. Subsequently, the data was exported to the data editor of SPSS Version 22.0 (SPSS Inc., Chicago, Illinois, USA) for statistical analysis. Continuous variables were expressed as mean and standard deviation, while categorical variables were summarised as percentages.

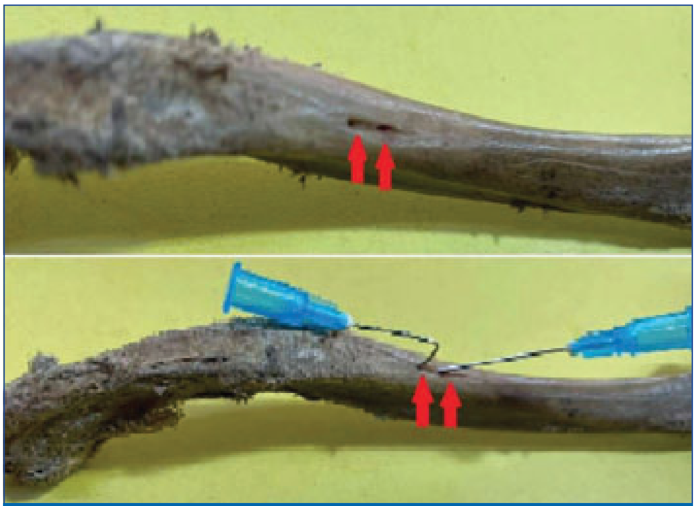
RESULTS

The study included 20 clavicles on the right side and 30 clavicles on the left side, making a total of 50 clavicles. Among them, 47 clavicles (94%) had a single nutrient foramen, while 3 clavicles (6%) had double nutrient foramina. All right-sided clavicles (100%) had a single nutrient foramen, whereas on the left side, 27 clavicles (90%) had a single foramen [Table/Fig-1], and 3 clavicles (10%) had double foramina [Table/Fig-2,3]. Among the right-sided clavicles, all 20 (100%) had patent nutrient foramina, while on the left side, only 9 clavicles (30%) had patent foramina, and the remaining 21 clavicles (70%) had nonpatent foramina.



[Table/Fig-1]: Left-sided clavicle with single nutrient foramen (red arrow) on the posterior surface in the middle one-third of the clavicle.

A total of 42 clavicles (84%) had nutrient foramina on the posterior surface [Table/Fig-2], and 8 clavicles (81%) had nutrient foramina on the inferior surface. Among the clavicles, nutrient foramina were noted on the middle third in 35 cases (70%), on the medial third in 10 cases (20%), and on the lateral third in 5 cases (10%). The direction of the nutrient foramina was away from the growing end (i.e., sternal end), and



[Table/Fig-2]: Left-sided clavicle with two nutrient foramina (red arrows) on the posterior surface in the middle one-third of the clavicle.

Number of nutrient foramen	Right		Left		Total	
	No.	%	No.	%	No.	%
Single	20	100	27	90	47	94
Double	0	0.0	3	10	3	6
Total	20	100	30	100	50	100

[Table/Fig-3]: Number of nutrient foramina in the clavicle.

they were directed towards the acromial end in all clavicles. The average distance of the foramen from the sternal end was 6.76 cm (67.6 mm). The mean Foraminal index was 50.1 [Table/Fig-4].

Parameter	Mean	SD	Min	Max
Mean	7.1	2.024	4.6	13.0
Foraminal index	50.1	14.36	34.7	93.5

[Table/Fig-4]: Distance of nutrient foramen from the sternal end of the clavicle and Foraminal indices.

DISCUSSION

The principal source of nutrition in long bones is the nutrient arteries, which are crucial for bone development at every stage. These arteries enter the bone through the nutrient foramen, the largest foramen on the shaft of the long bone, allowing the passage of the nutrient artery. The healing process of fractures heavily relies on adequate blood supply [12,13]. Injuries to the nutrient arteries during fractures can predispose individuals to malunion or non-union [14]. Stress fractures, characterised by a disruption of the nutrient artery, often result in delayed healing [10]. During puberty, the nutrient artery provides 70-80% of the bone's nutrition, particularly during active growth and early ossification stages. Insufficient bone nutrition can lead to reduced vascularisation of the epiphyseal plate, resulting in medullary bone ischemia [15]. The nutrient artery is responsible for supplying nutrients to approximately two-thirds of the bone and the entire medulla, highlighting its vital role in bone nutrition and growth. Due to this crucial role, the term "nutrient" has been suggested to describe these arteries and the corresponding foramen, emphasising their nutritive function. Additionally, the nutrient artery supports the formation of callus at the fracture site, as the healing process relies on adequate blood circulation, similar to other types of wounds [16]. Fractures can often involve the rupture of the nutrient artery, and in long bones, they may be associated with stress fractures, periosteal detachment, disruption of peripheral arteries, nutrient artery rupture, and soft-tissue damage [10].

Recent studies have confirmed the hypothesis that vascularised bone and joint allografts heavily rely on the blood supply of the bone. Surgical methods such as plated osteosynthesis and intramedullary nailing can potentially cause soft tissue damage and increase the

Factor	Present study	Aggarwal P and Ghorai S 2023 [22]	Suma MP et al., 2018 [23]	Sahu Santosh K and Dali M 2017 [24]	Sowmiya G et al., 2016 [25]	Sinha P et al., 2015 [26]	Murlimanju BV et al., 2011 [9]
Mean TL	14.14 cm	14.14 cm	13.91 cm	12.64 cm	14.27 cm	-	
Mean DNF	6.46 cm	6.15 cm	9.11 cm	6.58 cm	6.76 cm	-	6.44 cm
Mean FI	50.1	43.82	65.5	52.06	47.31	-	44.72
Maximum number of foramina (in %)	Single (94)	Single (55.69)	Single (78)	Double (50.93)	Single (72.7)	Single (70)	Double (44.2)
Position of foramen	Posterior surface (84%)	Posterior surface (52.50%)	Inferior surface (62.9%)	Posterior surface (63.1%)	Posterior Surface of middle 1/3rd (63.6%)	Inferior surface (69.7%)	Posterior surface (69.2%)
Location	Middle 1/3rd (67.9%)	Middle 1/3rd (67.5%)	Middle 1/3rd (85.5%)	Middle 1/3rd (71.42%)	Middle 1/3rd (90.1%)	Middle 1/3rd (61.1%)	Middle 1/3rd (92.3%)
Direction of nutrient canal	All towards acromial	All towards acromial	All towards acromial end	All towards acromial end	Mostly towards acromial end	All towards acromial end	All towards acromial end

[Table/Fig-5]: Comparison of data between present and previous studies [9,22-26].
TL: Total length of the clavicle; FI: Foramen index; DNF: Distance of foramina from sternal end

risk of infection in fracture repair surgeries. Therefore, achieving stabilisation through open reduction and internal fixation methods is recommended. In particular, during open reduction, surgeons need to be mindful of the area surrounding the nutrient foramen to ensure optimal postoperative outcomes [17]. Preserving the circulation of bone fragments is crucial in this surgical technique to minimise complications. Thus, orthopedic surgeons should have a thorough understanding of the nutrient artery and its entry point in the bone to effectively treat fractures. With advancements in bone fixation techniques and increasing patient expectations, surgical intervention has become more common for treating bone fractures rather than conservative approaches. Therefore, it is essential to preserve good circulation for successful free vascular bone grafting.

In the present study, the authors observed that 47 clavicles (94%) had a single nutrient foramen, while three cases (6%) had double nutrient foramina. Additionally, the nutrient foramen was non-patent in 70% of left-sided clavicles. Previous studies conducted by Murlimanju BV et al., reported a single nutrient foramen in 38.5% and double nutrient foramina in 44.2% of clavicles [9]. Another study by Rai R et al., found a single foramen in 42% and double foramina in 52.5% of the clavicles [18]. Similar to the present study findings, these studies also observed that the nutrient foramen was predominantly located on the posterior surface of the clavicle [9,18,19]. Furthermore, this study observed that the maximum number of nutrient foramina was predominantly found in the middle one-third of the clavicle. In contrast, Prasad KRS and Janaki V observed that the maximum number of nutrient foramina were located in the medial two-thirds of the clavicle [20].

In the present study, the average distance of the nutrient foramen from the sternal end was 6.76 cm (67.6 mm), and the FI was 48.01. These findings are similar to those of Murlimanju BV et al., who reported an average distance of the nutrient foramen from the sternal end as 64.4 mm and a mean foraminal index of 44.72 [9]. It has been observed that the nutrient foramen has a specific location for each bone and may exhibit variations. These variations can be attributed to the different growth rates at both ends of the bone and the bone remodeling process [18,21].

In the present study, the authors also found that the majority of clavicles had a single nutrient foramen (94%), which is consistent with the findings of Aggarwal P and Ghorai S, Suma MP et al., Sahu Santosh K and Dali M, and Sowmiya G et al., [22-25]. However, studies conducted by Murlimanju BV et al., and Sahu Santosh K and Dali M showed that most clavicles had double nutrient foramina [9,24]. In the present study, the authors observed three clavicles (6%) with double foramina, but none of the clavicles studied showed the absence of a foramen or more than two foramina. [Table/Fig-5] illustrates the differences in data between the present study and previous studies [9,22-26].

Limitation(s)

The study sample size was small, as only 50 bones were available for analysis in the department. Conducting the study with a larger sample size and involving multiple centers could potentially provide more accurate results. Additionally, obtaining age and gender-specific information about the individual bones studied would have allowed for more specific and detailed findings.

CONCLUSION(S)

The findings of the present study suggest that the nutrient foramen on the clavicle is more commonly located on its posterior surface. Furthermore, the foramen is often multiple and directed towards the acromial end. Understanding the location and characteristics of these nutrient foramina is valuable for surgeons when performing procedures involving the clavicle, as it allows for the preservation of proper circulation. Knowledge about the nutrient foramen is particularly important for clinicians involved in bone grafting and other surgical procedures, especially as microvascular bone transfer techniques become increasingly popular.

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