

Research Article

Morphological Study of Nutrient Foramen of Left Human Clavicle in Male and Female

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Abstract

Background: The clavicle demonstrates significant morphological variations between males and females, making it valuable for sex determination in forensic investigations. The nutrient foramen's location and characteristics are crucial for surgical procedures, yet comprehensive morphometric data specific to certain populations remains limited.

Objectives: This study aimed to analyze the morphological variations in left clavicles, focusing on sexual dimorphism and nutrient foramen characteristics, to establish population-specific morphometric standards and enhance surgical and forensic applications.

Methods: A cross-sectional analytical study was conducted on 120 dry ossified left human clavicles (70 male, 50 female) using standardized measurement techniques. Measurements included basic morphometric parameters, angular measurements, curvature characteristics and nutrient foramen features. Data were analyzed using Student's t-test, with statistical significance set at $p \leq 0.05$.

Results: Significant sexual dimorphism was observed in most parameters. Male clavicles showed greater mean length (136.83 ± 6.79 mm vs 128.36 ± 4.43 mm), midclavicular circumference (36.80 ± 1.60 mm vs 34.35 ± 1.89 mm) and weight (16.45 ± 2.76 g vs 12.86 ± 1.94 g) compared to females ($p < 0.001$). Single nutrient foramina predominated in both sexes (92.86% males, 86% females), typically located on the posterior surface (90% males, 88% females) in the middle third of the clavicle (93% males, 92% females). While most parameters showed significant sexual differences, the robustness index and some articular surface measurements demonstrated no significant variation between sexes.

Conclusion: This study establishes comprehensive morphometric standards for the studied population, demonstrating significant sexual dimorphism in most parameters and consistent patterns in nutrient foramen characteristics. These findings provide valuable reference data for

surgical procedures, forensic investigations and anthropological studies, while highlighting the importance of population-specific morphometric standards.

Keywords: Clavicle, Morphometry, Sexual Dimorphism, Nutrient Foramen, Forensic Anthropology

Introduction

The clavicle or collarbone, is a unique long bone that lies horizontally at the root of the neck, serving as the only bony connection between the upper limb and axial skeleton [1]. It exhibits considerable variability in shape and size compared to other long bones of the human skeleton, making it a subject of significant interest for clinicians and forensic anthropologists [2]. The clavicle begins ossification before any other bone in the body and is the last to complete its ossification [3]. The nutrient foramen of the clavicle,

typically located lateral to the subclavian groove, is a critical anatomical feature that transmits the nutrient artery derived from the suprascapular artery [4]. This vascular supply is essential during active growth, early phases of ossification and various pathological conditions such as fracture healing and acute hematogenic osteomyelitis [5]. Understanding the morphology and position of nutrient foramina is particularly crucial in surgical procedures, including bone grafting and microsurgical vascularized bone transplantation [6]. Recent trends in the treatment of clavicular fractures have shifted from conservative management to interventional techniques, emphasizing the importance of detailed morphometric knowledge for orthopedic surgeons [7]. Additionally, the clavicle demonstrates sexual dimorphism, making it valuable for forensic identification and anthropological studies [8]. The determination of sex from skeletal remains is essential in forensic investigations, with the clavicle showing reliable levels of accuracy in sex discrimination through various parameters including length, weight, midclavicular circumference and rhomboid fossa characteristics [9]. While extensive research has been conducted on clavicular morphometry in various populations worldwide, there is limited data available for certain geographical regions [10-15]. This study aims to analyze the morphological variations of the nutrient foramen in left clavicles, examining their number, position and size, while also investigating sexual dimorphism in these parameters. The findings will contribute to the existing knowledge base for surgical applications and forensic investigations.

Ethical Statement

The study was conducted after obtaining approval from the Research Review Committee (RRC) and Ethical Review Committee (ERC) of Dhaka Medical College, Dhaka.

Material and Methods

Study Design and Sample

This cross-sectional, analytical study was conducted on 120 dry ossified left human clavicles from January 2022 to December 2022 at the Department of Anatomy, Dhaka Medical College. The samples were collected through purposive, convenient sampling [11].

Sample Size Calculation

The sample size was calculated using the following equation:

$$n = [(Z\alpha + Z\beta)^2 \times (\sigma_1^2 + \sigma_2^2)] / (\mu_1 - \mu_2)^2$$

Where:

- n = sample size in each group
- μ_1, μ_2 = means of male and female groups
- σ_1, σ_2 = standard deviations of male and female groups
- $Z\alpha$ = z-value at 99.99% confidence level
- $Z\beta$ = z-value at power 0.99

Based on previous morphometric data from Yang, et al., the calculated sample size was 57 for each group [16]. For convenience, 60 clavicles were taken for each sex, totaling 120 specimens.

Inclusion and Exclusion Criteria

Inclusion criteria comprised morphologically normal dry ossified left human clavicles. Specimens were excluded if they showed:

- Missing or broken parts
- Fractures
- Deformities
- Degenerative changes

Sex Determination

Sex determination was performed using linear discriminant function analysis technique. The technique utilized measurements including maximum length of clavicle and distance of nutrient foramen from the sternal end [17]. Parameters Measured The following measurements were recorded:

1. Length of clavicle using digital vernier caliper
2. Midclavicular circumference using flexible metallic wire

3. Medial and lateral angles using protractor
4. Weight using electronic weighing machine
5. Anterior and posterior curve lengths
6. Depth of medial and lateral curvatures
7. Maximum length and width of medial articular surface
8. Maximum length and width of acromial surface
9. Length and breadth of rhomboid fossa
10. Distance of nutrient foramen from sternal end

Observation Parameters

The following features were observed and documented:

1. Number of nutrient foramina
2. Position of nutrient foramina
3. Location of nutrient foramina
4. Subclavian groove characteristics
5. Types of clavicles

Calculated Indices

The following indices were calculated:

1. Robustness index = (Mid-point circumference $\times$ 100) / Length of clavicle
2. Index of rhomboid fossa = (Breadth of rhomboid fossa $\times$ 100) / Length of rhomboid fossa
3. Foramen index = (Distance of nutrient foramen from sternal end $\times$ 100) / Length of clavicle
4. Index of curvature = Medial angle + Lateral angle

Statistical Analysis

Data were analyzed using Statistical Package for Social Science (SPSS) version 25.0. Statistical significance was accepted at $p \leq 0.05$. Unpaired Student's t-test was used for comparison between variables.

Results

The study analyzed 120 dry ossified left human clavicles with 70 male and 50 female specimens. The findings revealed significant morphological variations between males and females across multiple parameters.

1. Primary Morphometric Measurements

The length, midclavicular circumference and weight measurements demonstrated clear sexual dimorphism (Fig. 1, Table 1). Male clavicles were consistently longer, with a mean length of 136.83 ± 6.79 mm compared to 128.36 ± 4.43 mm in females ($p < 0.001$). This pattern extended to the midclavicular circumference, where males averaged 36.80 ± 1.60 mm versus 34.35 ± 1.89 mm in females ($p < 0.001$). Weight measurements followed the same trend, with male clavicles (16.45 ± 2.76 g) being significantly heavier than female ones (12.86 ± 1.94 g, $p < 0.001$).

Parameter	Male (n=70)	Female (n=50)	p-value
Length (mm)	136.83 ± 6.79 (121.42-154)	128.36 ± 4.43 (118.48-138.34)	<0.001*
Midclavicular circumference (mm)	36.80 ± 1.60 (34-40.12)	34.35 ± 1.89 (31.11-37.40)	<0.001*
Weight (g)	16.45 ± 2.76 (12.25-25.05)	12.86 ± 1.94 (9.10-16.50)	<0.001*
*Statistically significant ($p < 0.001$)			

Table 1: Primary morphometric parameters of left clavicle by sex.

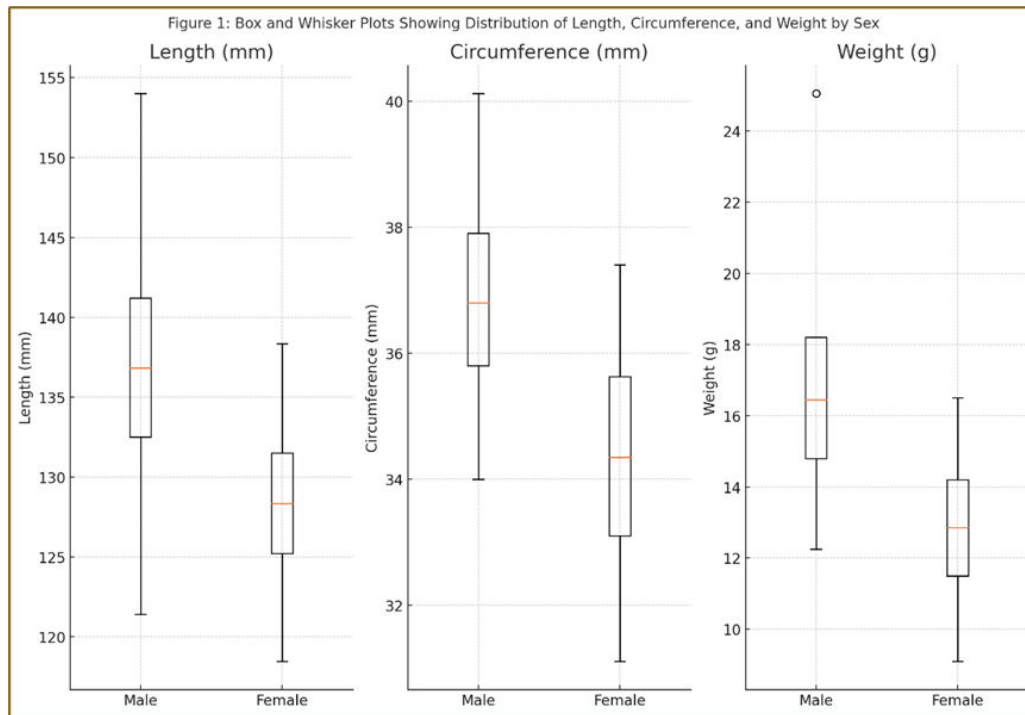


Figure 1: Box and whisker plots showing distribution of length, circumference and weight by sex.

2. Angular and Curvature Characteristics

The angular measurements revealed significant differences in both medial and lateral angles between sexes (Fig. 2, Table 2). Male clavicles exhibited greater medial ($151.60^\circ \pm 6.20^\circ$) and lateral angles ($144.66^\circ \pm 5.21^\circ$) compared to females ($148.28^\circ \pm 2.56^\circ$ and $137.26^\circ \pm 5.84^\circ$ respectively, $p < 0.001$).

Parameter	Male (n=70)	Female (n=50)	p-value
Medial angle ($^\circ$)	151.60 ± 6.20 (135-168)	148.28 ± 2.56 (145-153)	$<0.001^*$
Lateral angle ($^\circ$)	144.66 ± 5.21 (136-154)	137.26 ± 5.84 (129-148)	$<0.001^*$
Anterior curve length (mm)	137.41 ± 4.97 (124.32-145.24)	122.58 ± 3.83 (116.39-128.81)	$<0.001^*$
Posterior curve length (mm)	147.07 ± 3.42 (142.70-159.73)	133.76 ± 3.84 (127.51-140.87)	$<0.001^*$

*Statistically significant ($p < 0.001$)

Table 2: Angular and curvature measurements.

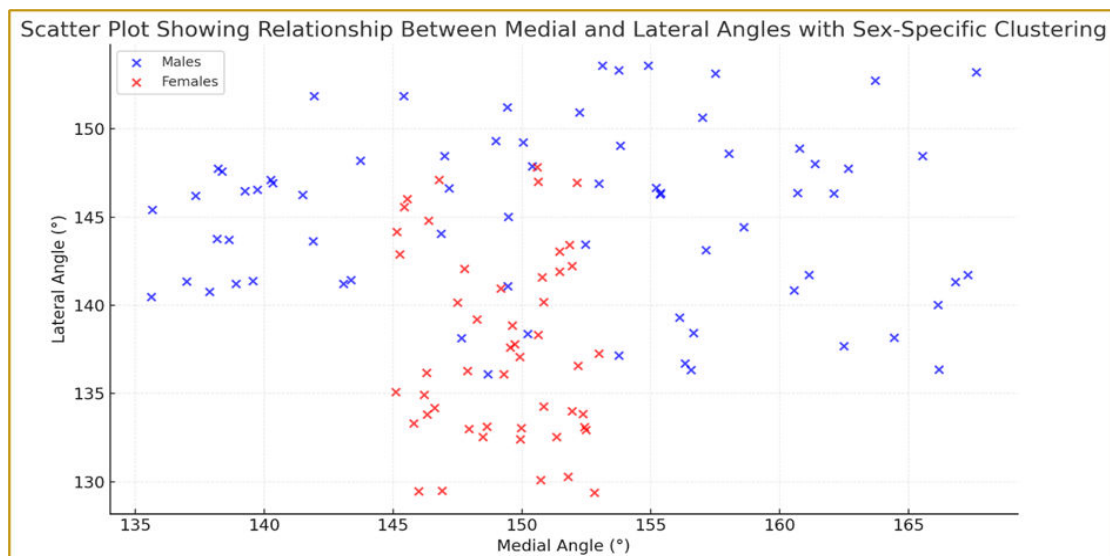


Figure 2: Scatter plot showing relationship between medial and lateral angles with sex-specific clustering.

3. Nutrient Foramen Analysis

The analysis of nutrient foramina revealed interesting patterns in their number, position and location (Fig. 3, Table 3). Single nutrient foramina were predominant in both sexes, with 92.86% occurrence in males and 86% in females. The posterior surface was the most common position (90% in males, 88% in females) and the middle third of the clavicle was the preferred location (93% in males, 92% in females).

Characteristic	Male (n=70) No. (%)	Female (n=50) No. (%)	p-value
Number			
Single	65 (92.86)	43 (86.00)	0.221
Double	5 (7.14)	7 (14.00)	
Position			
Posterior surface	63 (90.00)	44 (88.00)	0.715
Inferior surface	7 (10.00)	6 (12.00)	
Location			
Middle third	65 (93.00)	46 (92.00)	0.856
Medial third	3 (4.00)	3 (6.00)	
Lateral third	2 (3.00)	1 (2.00)	

*Statistically significant (p<0.001)

Table 3: Distribution of nutrient foramina characteristics.

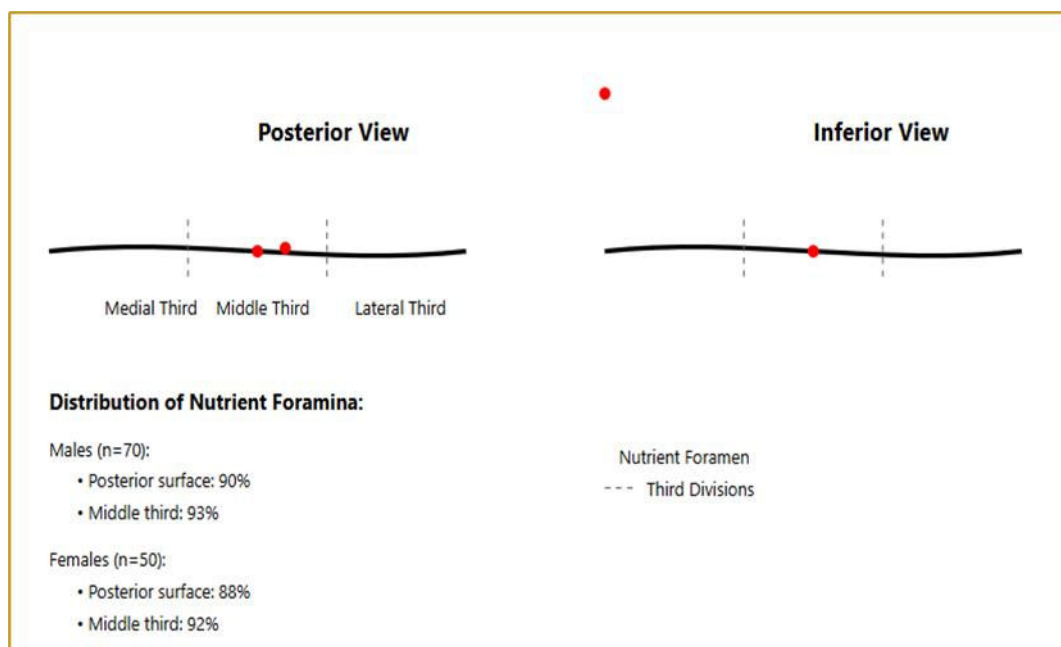


Figure 3: Composite diagram showing typical nutrient foramen positions and locations.

4. Indices and Derived Measurements

The calculated indices provided additional insights into morphological variations (Table 4). While the robustness index showed no significant sexual dimorphism (p=0.618), the index of curvature demonstrated significant differences between males (296.26 ± 11.07) and females (285.54 ± 6.60 , p<0.001).

Index	Male (n=70)	Female (n=50)	p-value
Robustness index	26.96 ± 1.83 (22.87-31.97)	26.80 ± 1.76 (23.17-31.13)	0.618
Index of curvature	296.26 ± 11.07 (277-319)	285.54 ± 6.60 (274-298)	<0.001*

*Statistically significant (p<0.001)

Table 4: Comparative analysis of calculated indices.

These comprehensive results demonstrate significant sexual dimorphism in most morphometric parameters of the left clavicle, with male specimens generally showing larger dimensions. The findings regarding nutrient foramina distribution and positioning provide valuable information for surgical applications and morphological studies.

Discussion

The present study analyzed various morphometric parameters and nutrient foramen characteristics of 120 dry ossified left human clavicles, revealing significant sexual dimorphism and consistent patterns in nutrient foramen distribution. This discussion examines our findings in relation to previous research across different populations.

Length and Basic Morphometry

The mean length of male clavicles (136.83 ± 6.79 mm) was significantly greater than females (128.36 ± 4.43 mm), consistent with findings from multiple populations. Balwar, et al., reported similar sexual dimorphism in Indian populations (males: 141.64 ± 8.54 mm, females: 128 ± 8.32 mm) [1]. Our results also aligned with Kaewma, et al., Thai population study (males: 150.2 ± 0.97 mm, females: 133.5 ± 0.63 mm), though their absolute values were higher, suggesting population-specific variations [2].

The midclavicular circumference demonstrated significant sexual dimorphism (males: 36.80 ± 1.60 mm, females: 34.35 ± 1.89 mm), comparable to Sherawat and Pathak's findings (males: 38.52 ± 3.28 mm, females: 32.66 ± 2.57 mm) [3]. This consistency across studies reinforces the reliability of midclavicular circumference as a sex determination parameter.

Angular Measurements and Curvature

Our findings regarding medial and lateral angles showed significant sexual differences, with males exhibiting greater angles. This aligns with Dehiya, et al., work, though their absolute values differed slightly (medial angle - males: $152.80 \pm 5.7^\circ$, females: $150.36 \pm 8.5^\circ$) [4]. The variation might be attributed to different measurement techniques or population-specific characteristics.

Nutrient Foramen Characteristics

The predominance of single nutrient foramina (92.86% in males, 86% in females) corresponds with Ratnesh, et al., findings (63.33% single foramina) [5]. The preference for posterior surface location (90% in males, 88% in females) mirrors Sinha, et al., observations (55.88% posterior surface) though our percentages were higher [6].

The middle third location prevalence (93% in males, 92% in females) strongly correlates with multiple studies: Sahu and Meher, (66.10%), Rai, et al., (73.8%) and Malukar, et al., (59.10%) [7-9]. This consistency across populations suggests a relatively stable anatomical pattern, likely related to optimal vascular distribution.

Articular Surface Measurements

The sexual dimorphism observed in articular surface measurements partially agrees with Kaewma, et al., findings [10]. However, our study found no significant differences in maximum widths, contrary to some previous studies. This discrepancy might reflect population-specific variations or measurement methodology differences.

Clinical and Forensic Implications

The significant sexual dimorphism observed in multiple parameters supports the clavicle's utility in forensic sex determination, confirming previous findings by Bagal and Takale [11]. The consistent patterns in nutrient foramen location provide valuable guidance for surgical procedures, particularly relevant given the recent shift toward interventional techniques in clavicular fracture management noted by Sen, et al. [12].

Indices and Derived Measurements

The robustness index showed no significant sexual dimorphism, contrasting with Sherawat and Pathak's findings [13]. However, the index of curvature demonstrated significant sexual differences, aligning with Dehiya, et al., observations [14]. These variations highlight the importance of population-specific standards in anthropometric studies [18-20]. Comparing our results with international studies reveals both similarities and differences, emphasizing the importance of population-specific data. The consistent patterns in nutrient foramen characteristics across populations suggest fundamental anatomical principles, while

variations in morphometric measurements highlight the influence of genetic, environmental and lifestyle factors.

Conclusion

Based on our comprehensive morphometric analysis of 120 dry ossified left human clavicles, several significant conclusions can be drawn that have important implications for both clinical practice and forensic applications. The study decisively demonstrates significant sexual dimorphism in most morphometric parameters of the clavicle. Male clavicles consistently exhibited larger dimensions in length, midclavicular circumference and weight measurements, with statistically significant differences ($p < 0.001$). These findings provide reliable criteria for sex determination in forensic investigations and anthropological studies. The analysis of nutrient foramina revealed consistent patterns, with single foramina predominantly occurring on the posterior surface in the middle third of the clavicle. This anatomical consistency across both sexes provides valuable guidance for surgical procedures, particularly in bone grafting and microsurgical vascularized bone transplantation.

The angular measurements and curvature characteristics showed clear sexual differentiation, with male clavicles displaying greater medial and lateral angles. This information enhances our understanding of biomechanical differences between male and female shoulder girdles and may inform orthopedic surgical planning. Interestingly, while most parameters showed sexual dimorphism, some measurements, such as the robustness index and maximum widths of articular surfaces, demonstrated no significant differences between sexes. This suggests that these parameters may be more influenced by functional demands common to both sexes rather than gender-specific characteristics. These findings contribute to the existing knowledge base of clavicular morphometry and establish population-specific standards that can be valuable for clinical, forensic and anthropological applications. However, further research with larger sample sizes and diverse population groups would be beneficial to validate these findings and explore potential geographical and ethnic variations. The comprehensive data generated from this study provides a reliable reference for orthopedic surgeons, forensic experts and anthropologists, particularly in the context of the studied population. This information can enhance surgical precision, improve forensic identification accuracy and advance our understanding of human skeletal variation.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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Consent to Participate

Informed consent was obtained from each participant prior to specimen collection.

Financial Disclosure

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Data Availability

Data is available for the journal. Informed consents were not necessary for this paper.

Author's Contribution

The authors contributed equally.

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