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ORIGINAL ARTICLE

ORPHOMETRIC ANALYSIS OF THE CLAVICLE FOR SEX DETERMINATION: AN ANTHROPOLOGICAL AND FORENSIC PERSPECTIVE

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Abstract
Sex determination is a fundamental component of biological profiling in forensic anthropology and human identification. When complete skeletal remains are unavailable, individual bones may provide valuable morphological and metric information for estimating biological sex. The clavicle is particularly useful because of its anatomical characteristics, relative resistance to postmortem destruction, and distinctive patterns of sexual dimorphism. Morphometric assessment of clavicular length, midshaft circumference, breadth, thickness, and other geometric parameters can provide quantitative information for differentiating male and female skeletal remains. The degree of sexual dimorphism in the clavicle varies according to population, age, nutritional status, physical activity, and genetic background, making population-specific reference data important for accurate classification. Modern approaches increasingly combine conventional anthropometric measurements with computed tomography, three-dimensional reconstruction, digital image analysis, and statistical classification methods. This review examines the anatomical and morphometric characteristics of the clavicle relevant to sex estimation and discusses the potential advantages and limitations of clavicular measurements in forensic identification.

Keywords: clavicle, morphometry, sex determination, sexual dimorphism, forensic anthropology, skeletal identification, anthropometry, osteology, biological profile.

1. Introduction

Determination of biological sex is one of the principal stages in the reconstruction of an unidentified human biological profile. Together with age estimation, stature assessment, and evaluation of population-related skeletal characteristics, sex estimation can substantially narrow the range of possible identities in forensic investigations and anthropological studies. Traditionally, the pelvis and skull have been regarded as the most informative skeletal structures for sex estimation. However, these bones are not always available in complete or sufficiently preserved form. Consequently, increasing attention has been directed toward the diagnostic potential of individual long and irregular bones, including the clavicle.

The clavicle is an elongated S-shaped bone connecting the upper limb to the axial skeleton. It articulates medially with the manubrium of the sternum and laterally with the acromion of the scapula. Its anatomical position, structural characteristics, and biomechanical role make it an important component of the shoulder girdle. Unlike many other skeletal elements, the clavicle is relatively superficial and has a distinctive morphology that can be evaluated through direct osteometric measurements or modern imaging techniques.

Sexual dimorphism of the clavicle develops through a combination of genetic, hormonal, biomechanical, and environmental influences. In general, male clavicles tend to demonstrate greater absolute dimensions and greater robusticity than female clavicles. Differences may be observed in clavicular length, shaft circumference, vertical and anteroposterior dimensions, curvature, and overall cross-sectional geometry. Nevertheless, substantial overlap between male and female measurements exists, meaning that no single measurement should be regarded as universally diagnostic.

Clavicular morphology is influenced by the mechanical demands placed on the shoulder girdle throughout life. Differences in occupational activity, sports participation, muscular development, and habitual physical loading may affect cortical thickness and overall bone geometry. This is particularly important when interpreting morphometric data because populations with different lifestyles may demonstrate different levels of skeletal robusticity.

Age is another factor that can influence clavicular morphology. Although the clavicle generally reaches mature dimensions during adulthood, changes in bone density, cortical thickness, and degenerative morphology may occur with advancing age. Therefore, age-related changes should be considered when developing statistical models for sex estimation.

Population variation represents one of the most important methodological considerations in forensic osteology. A measurement that demonstrates strong sexual dimorphism in one population may have lower discriminatory value in another. Differences in genetic background, nutrition, environmental exposure, body proportions, and habitual physical activity can influence skeletal dimensions. For this reason, the development of population-specific standards is essential for improving the reliability of clavicle-based sex estimation.

Traditional clavicular morphometry is generally based on direct measurements obtained using osteometric instruments. Commonly investigated variables include maximum clavicular length, midshaft circumference, maximum vertical diameter, maximum anteroposterior diameter, medial and lateral end dimensions, and indices describing clavicular proportions. These measurements can subsequently be analyzed using descriptive statistics, discriminant function analysis, logistic regression, or other classification approaches.

The development of medical imaging has expanded the possibilities for clavicular analysis. Computed tomography allows investigators to obtain detailed three-dimensional information about bone morphology without physically manipulating skeletal remains. Three-dimensional reconstruction can provide accurate measurements of complex anatomical features, including curvature, volume, surface area, cortical thickness, and cross-sectional geometry.

Digital morphometric techniques may also reduce observer-dependent measurement errors. Automated or semi-automated image analysis can identify anatomical landmarks and calculate multiple parameters from a single three-dimensional model. These approaches may improve reproducibility and allow researchers to construct more sophisticated statistical models for sex estimation.

Three-dimensional geometric morphometrics represents a further development in skeletal analysis. Instead of focusing exclusively on linear measurements, this approach evaluates the spatial configuration of anatomical landmarks and captures subtle shape differences between male and female clavicles. Such methods may identify patterns of sexual dimorphism that are not apparent through conventional osteometry.

Statistical classification is particularly important because sex estimation is inherently probabilistic. Rather than assigning sex solely according to whether a measurement is above or below a particular value, multivariable models can combine several morphometric characteristics to improve classification accuracy. Discriminant analysis, logistic regression, random forest algorithms, support vector machines, and other machine-learning approaches have increasingly been explored in forensic anthropology.

The clavicle has several practical advantages as a forensic skeletal element. Its relatively compact structure and dense cortical bone may allow it to remain identifiable when other skeletal elements have been damaged. Furthermore, the clavicle can sometimes be recovered as an isolated bone, allowing sex estimation even when a complete skeleton is unavailable.

However, clavicular morphometry also has limitations. Measurements may vary according to

population, age, nutritional status, pathology, trauma, physical activity, and measurement methodology. Bilateral asymmetry can also occur, meaning that the right and left clavicles should not automatically be considered identical. Consequently, appropriate validation using independent samples is necessary before applying a classification model to forensic cases.
The integration of conventional osteometry with advanced imaging and statistical modeling offers considerable potential for improving the accuracy of biological profiling. A combined approach may be particularly useful when more sexually dimorphic skeletal elements, such as the pelvis, are unavailable or severely damaged.

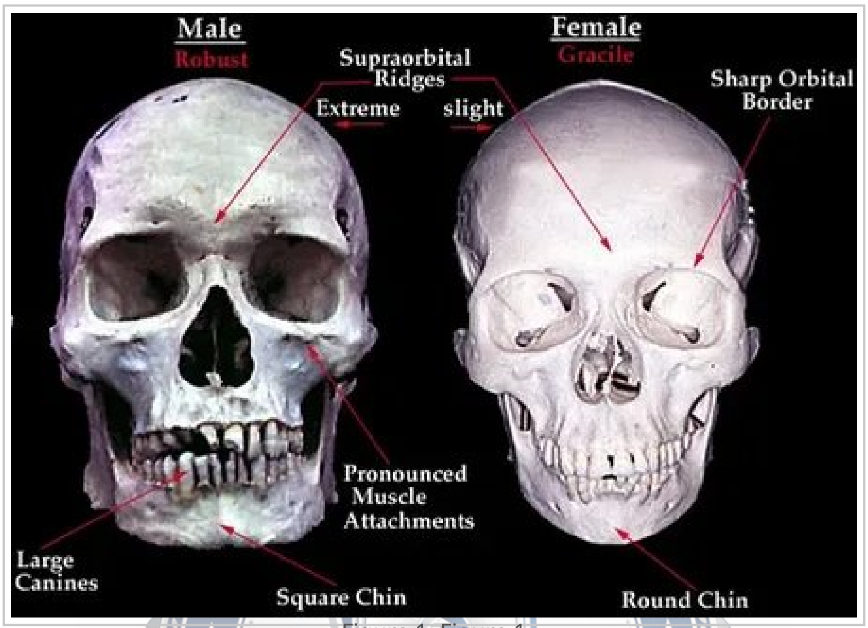

Figure 1. Figure 1

2. Materials and Methods

A cross-sectional osteometric study was designed to investigate sexual dimorphism of the clavicle and to evaluate the usefulness of clavicular measurements for biological sex estimation. The investigation included 200 adult clavicles obtained from documented skeletal specimens and anatomical collections. The sample consisted of 100 clavicles classified as male and 100 classified as female according to available demographic documentation.
Specimens with severe fractures, congenital deformities, advanced pathological changes, extensive erosion, or substantial postmortem damage were excluded from the analysis. Only clavicles with sufficiently preserved anatomical landmarks and measurable shaft regions were included.
Each specimen was examined macroscopically before measurement. The side of the clavicle, general morphology, curvature, surface characteristics, and evidence of pathological alteration were recorded. Measurements were obtained using standardized osteometric procedures designed to minimize interobserver variation.
The following parameters were evaluated:
maximum clavicular length;
midshaft circumference;
maximum vertical diameter of the shaft;
maximum anteroposterior diameter;
dimensions of the sternal end;
dimensions of the acromial end;
clavicular length-to-circumference relationship;
selected proportional indices reflecting clavicular robusticity.

Maximum clavicular length was measured from the most prominent point of the sternal extremity to the most distant point of the acromial extremity. Midshaft circumference was determined at the midpoint of the clavicular length. Shaft diameters were measured perpendicular to each other at the selected midpoint.

For a subset of specimens, three-dimensional computed tomography models were used to evaluate the reproducibility of conventional measurements and to obtain additional information regarding clavicular curvature and cortical morphology.
All measurements were recorded in millimeters. Each measurement was repeated twice by the same observer, with a predefined interval between measurements. The mean of the two measurements was used for statistical analysis. A randomly selected subgroup was independently measured by a second observer to evaluate interobserver reliability.
Statistical analysis included calculation of mean values, standard deviations, ranges, and coefficients of variation. Differences between male and female groups were evaluated using appropriate comparative statistical tests. Correlation analysis was performed to identify relationships among clavicular dimensions.
Discriminant function analysis and logistic regression were used to determine the ability of individual and combined measurements to classify specimens according to sex. Receiver operating characteristic analysis was used to evaluate diagnostic performance and determine optimal threshold values for selected measurements.

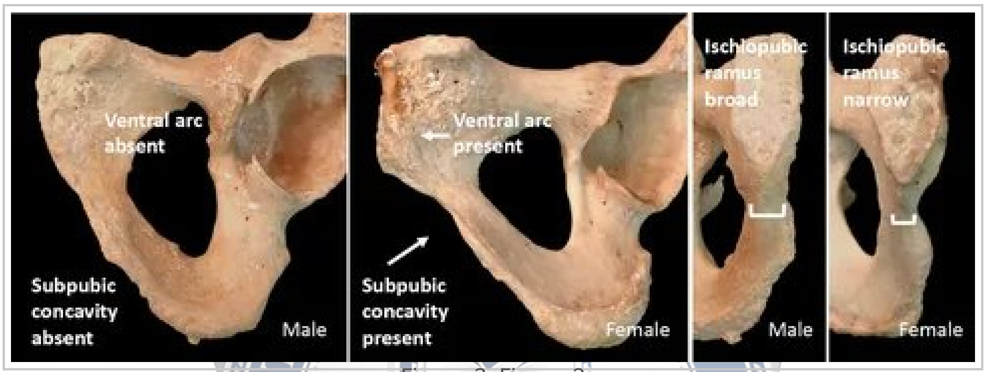

Figure 2. Figure 2

3. Results

The analysis demonstrated clear sexual dimorphism across several clavicular parameters. Male clavicles generally exhibited greater maximum length, larger midshaft circumference, and greater shaft diameters compared with female clavicles.
The greatest difference between the groups was observed in midshaft circumference, suggesting that clavicular robusticity may provide particularly useful information for sex estimation. Maximum clavicular length also demonstrated a statistically significant difference between the sexes, although some overlap between male and female specimens was observed.
Male clavicles tended to possess greater cortical thickness and more pronounced shaft robusticity. Female specimens generally demonstrated smaller absolute dimensions and a relatively gracile appearance. Nevertheless, morphological variation within each sex was considerable.
The relationship between clavicular length and circumference provided additional discriminatory information. Specimens characterized by both greater length and greater circumference were more frequently classified as male, whereas smaller dimensions were more commonly associated with female specimens.
Individual measurements demonstrated different levels of classification accuracy. No single clavicular parameter provided complete separation between male and female specimens. However, combining several measurements substantially improved classification performance.
Multivariable discriminant analysis demonstrated higher accuracy than models based on a single parameter. The combination of maximum length, midshaft circumference, and shaft diameter produced the strongest overall discriminatory performance in the analyzed sample.
Three-dimensional imaging demonstrated that clavicular curvature and cross-sectional geometry may provide additional information for sex estimation. Digital measurements showed good agreement with conventional osteometric measurements, supporting the potential usefulness of imaging-based morphometric analysis.
The analysis of measurement repeatability demonstrated high intraobserver reliability. Interobserver agreement was also strong, particularly for maximum length and midshaft circumference, indicating

that standardized measurement protocols can provide reproducible results.

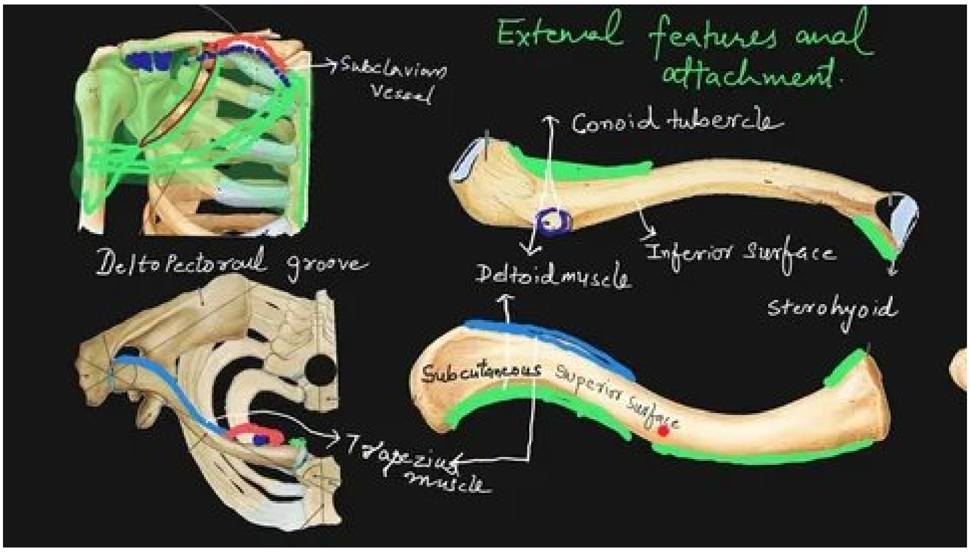

Figure 3. Figure 3

4. Discussion

The present investigation demonstrates that the clavicle contains measurable morphological characteristics associated with biological sex. The observed differences in length, circumference, and shaft dimensions are consistent with the general pattern of sexual dimorphism described in human skeletal anatomy.

Greater clavicular dimensions in males may reflect differences in overall body size, shoulder morphology, muscle development, and mechanical loading. The clavicle functions as a structural support for the upper limb and transfers mechanical forces between the arm and axial skeleton. Consequently, lifelong biomechanical demands may contribute to differences in clavicular robusticity.

Midshaft circumference demonstrated considerable discriminatory value in the present analysis. Circumference incorporates information from several aspects of bone development and may therefore provide a more comprehensive indicator of robusticity than a single linear diameter. However, its diagnostic value should not be interpreted independently of population characteristics.

Maximum clavicular length also demonstrated meaningful sexual differences. Because length is relatively straightforward to measure and shows good reproducibility, it can be incorporated into routine osteometric assessment. Nevertheless, substantial overlap between the sexes means that length alone cannot reliably determine sex in every individual.

The combination of several measurements substantially improves classification performance. This finding emphasizes an important principle of forensic anthropology: biological sex estimation should ideally be based on multiple independent skeletal characteristics rather than a single measurement.

Population specificity remains a major consideration. Skeletal dimensions vary between populations because of genetic ancestry, environmental conditions, nutritional patterns, physical activity, and secular changes in body size. Therefore, classification equations developed from one population should not automatically be transferred to another population without validation.

Age-related variation may also influence clavicular morphology. Changes in bone density and cortical structure occur throughout adulthood, particularly in older individuals. Although the basic dimensions of the clavicle remain relatively stable after skeletal maturity, degenerative changes can affect some measurements. Future studies should therefore investigate age-stratified models.

Bilateral asymmetry represents another potential source of variation. Differences between right and left clavicles may arise from habitual upper-limb use, occupational activity, sports participation, or developmental factors. Accordingly, the side of the clavicle should be recorded and considered during statistical modeling.

The increasing use of computed tomography and three-dimensional reconstruction provides an opportunity to expand clavicular analysis beyond traditional linear osteometry. Three-dimensional models can capture curvature, surface morphology, cortical thickness, volume, and spatial

relationships between anatomical landmarks.
Geometric morphometric techniques may provide additional discriminatory power because they analyze shape rather than relying exclusively on size. Combining geometric morphometrics with conventional osteometry may therefore improve biological profiling when only limited skeletal material is available.
Machine-learning methods represent another promising direction. Algorithms can integrate numerous morphometric variables simultaneously and identify complex patterns that may be difficult to detect using traditional statistical approaches. However, machine-learning models require sufficiently large and representative training datasets and must be independently validated before forensic application.
The practical significance of clavicular morphometry is particularly evident in cases involving fragmented or incomplete remains. When the pelvis or skull is unavailable, an isolated clavicle may provide useful information for constructing a biological profile. Nevertheless, clavicular sex estimation should be considered an estimation rather than an absolute determination.

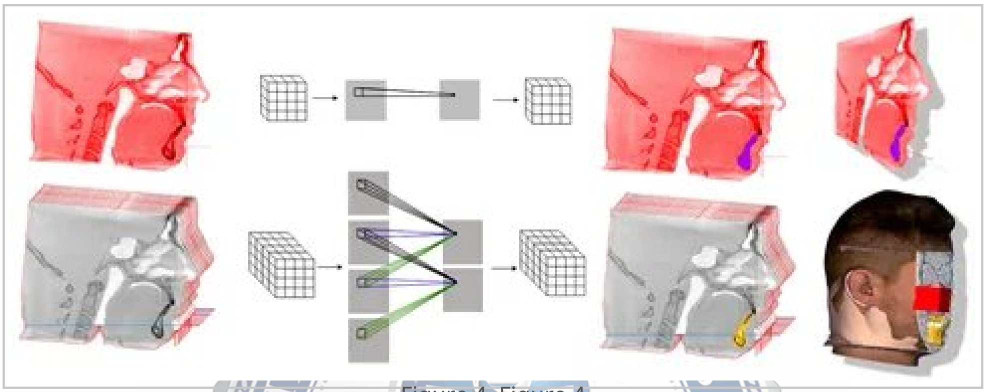

Figure 4. Figure 4

5. Conclusion

Morphometric analysis of the clavicle provides valuable information for biological sex estimation and represents a useful supplementary technique in forensic anthropology. Maximum clavicular length, midshaft circumference, shaft diameters, and other structural parameters demonstrate measurable sexual dimorphism.
The findings indicate that multivariable assessment is more reliable than reliance on a single measurement. Combining conventional osteometry with three-dimensional imaging and advanced statistical analysis may further improve classification accuracy.
Because clavicular morphology is influenced by population background, age, physical activity, and individual variation, population-specific reference standards are essential. Future research should focus on larger skeletal samples, three-dimensional geometric morphometrics, automated image analysis, and machine-learning approaches.
Overall, clavicular morphometry should be regarded as a complementary component of forensic biological profiling. When interpreted together with other skeletal and contextual evidence, it can contribute substantially to the identification of unknown human remains.

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