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Variability in anatomical features of human clavicle: Its forensic anthropological and clinical significance

Jagmahender Singh Sehrawat [a, *], R.K. Pathak [b]

[a] Anthropology Department, Institute of Forensic Science and Criminology, Panjab University, Chandigarh 160014, India
[b] Department of Anthropology, Panjab University, Chandigarh 160014, India

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ABSTRACT

Bones can reflect the basic framework of human body and may provide valuable information about the biological identity of the deceased. They, often, survive the morphological alterations, taphonomic destructions, decay/mutilation and decomposition insults. In-depth knowledge of variations in clavicular shape, size and its dimensions is very important from both clinical (fixation of clavicular fractures using external or inter-medullary devices, designing orthopedic fixation devices) as well as forensic anthropological perspectives. Human clavicle is the most frequently fractured bone of human skeleton, possessing high degree of variability in its anatomical, biomechanical and morphological features. Extended period of skeletal growth (up to third decade) in clavicle imparts it an additional advantage for forensic identification purposes. In present study, five categories of clavicular features like lengths, diameters, angles, indices and robustness were examined to explore the suitability of collarbone for forensic and clinical purposes. For this purpose, 263 pairs of adult clavicles (195 Males and 68 Females) were collected from autopsied cadavers and were studied for 13 anatomical features. Gender and occupational affiliations of cadavers were found to have significant influences on anatomical dimensions of their clavicles. Product index, weight and circumference of collarbone were found the best univariate variables, discriminating sex of more than 80% individuals. The best multivariate Function-I ($DF: -17.315 + 0.054$ CL-L$+0.196$ CC-R$+0.184$ DM-L) could identify sex and occupation of 89.4% (89.2% Male and 89.7% Female) and 65.4% individuals, respectively. All clavicular variables were found bilaterally asymmetric; left clavicles being significantly longer in length, lighter in weight, smooth in texture and less curved than the right side bones. Among non-metric traits, sub-clavian groove, nutrient foramina and 'type' of clavicle exhibited significant sexual dimorphism. Thus, both metric and non-metric features of clavicle can have decisive role in forensic identifications and clinical interventions. Present results would be of great significance for anatomists, orthopedicians, surgeons and the forensic anthropologists in their professional endeavors.

1. Introduction

The clavicle is the only horizontally placed long bone of the human skeleton which shows high variability in its shape and size; more frequently than other long bones of human skeleton [1]. The anatomical variability of this important bone of the anterior human thoracic skeleton has been widely explored by clinicians and forensic anthropologists. Its mean dimensions may be similar in unrelated races which are geographically separate, or it may be of different dimensions in related racial groups [2]. Much of the adult morphology of human clavicle (a double-curved S-shaped outline) is attained early in fetal life well before birth [3]. Males and females attain 80% of their total clavicle length by 12 and 9 years of age, respectively [4]. Clavicle has a longer period of skeletal growth during which it may respond to a variety of mechanical loadings and shear stresses. Variations in mechanical forces, asymmetric vascularization, lateralized behavior, activity-induced changes or more stress loadings of the dominant hand side of the clavicle may be factors responsible for asymmetrization of various clavicular features [5], among others.

Murphy [6] and Králik et al. [7] reported that later-maturing skeletal elements (like clavicle) display a greater degree of sexual

* Corresponding author. Teachers' Flat # 14, Panjab University Campus, Sector 14, Chandigarh 160014, India.
E-mail addresses: jagminder@pu.ac.in, jagmindera@yahoo.com (J.S. Sehrawat).

dimorphism and bilateral asymmetry than the early-maturing skeletal districts due to the fact that physical activity and work distribution an individual may influence clavicular morphology [8]. Auerbach and Raxter [9] have reported that activity patterns of an individual, mechanical behavior and unique developmental pathway of clavicle may significantly contribute to its atypical asymmetric pattern and varied diaphyseal breadths; the latter being more sensitive to the effects of loadings than the lengths. Clavicle has been found thicker and more curved in manual workers [10–12]. Clavicle possesses sex-, side-, activity-, laterality- and occupation-dependent osteological variations in its features and; these factors need to be considered while carrying out forensic anthropological or clinical (orthopedic or anatomical) examinations using this bone. Clavicle has an additional forensic advantage of being having extended growth period sufficient to indent additional identifying features in it. Its physical dimensions (metric) and characteristic appearance (non-metric) are useful for forensic identifications, particularly in age and sex estimations of unknown skeletal remains [12,13]. Though some previous studies have reported significant sex and age-dependent variations in its features [7,12,14–20], it still remains underrepresented in literature as a potential estimator of identity of an unknown skeleton [12,19].

In-depth knowledge of variations in clavicular anatomical features has been found essential for inter-medullary fixation of clavicular fractures and designing orthopedic fixation devices [21,22]. Significant shortening or asymmetry of clavicle in skeletally mature adults can affect clinical/surgical treatment strategies [20]. In traumatic settings, clavicle is found as the most commonly fractured bone of human skeleton (being about 4% of total skeleton and 35–45% of shoulder girdle fractures). It gets commonly fractured at its middle third portion (80%) followed by lateral third (10–18%) and medial third (2–10%) portion, particularly in adults and children [21]. Most often such fractures are managed non-operatively [23] by orthopedicians or bone-settlers. Pre- and post-operative complications of clavicle fixations can be better understood and prevented by having detailed information of complex anatomical and biomechanical features (like dimensions, diameters, curvatures, angles, robusticity etc.) of this bone. Increased rates of non-unions and more demands for use of nail and plate fixative devices for treating clavicular fractures have necessitated some extensive studies based on examination of its anatomical and morphological features. Present forensic anthropological study was conducted on the clavicles collected from medico-legal autopsies of Northwest Indian subjects with the following objectives:

- To estimate mean value of various anatomical dimensions of clavicle.
- To assess degree of sexual dimorphism, bilateral asymmetry and activity-pattern specific variations in the clavicle
- To highlight inter-disciplinary significance, if any, of various morphometric and non-metric features of clavicle.

2. Materials and methods

Present study is based on osteometric and morphological analysis of 263 pairs of clavicles collected from 195 male and 68 female adult cadavers (17–94 years) whose post-mortem examinations were carried out at the Department of Forensic Medicine, Postgraduate Institute of Medical Education and Research (PGIMER), Chandigarh, India. The research proposal for present study was ethically approved by the Institutional Ethics Committee, and a well-informed written consent was obtained from relatives of each deceased before starting bone collection and examination.

Indian population has been classified into various distinctive heterogeneous groups, clustered together on the basis of their similarity in morphological, environmental (nutrition, climate, food habit) and genetic features [24–28]. The studied population group is heterogeneous one having individuals from five North-western Indian states of Punjab, Haryana, Himachal Pradesh, Uttar Pradesh and Chandigarh. Cadavers from other states were ignored for bone collection to avoid any distortion in the clavicular dimensions as people from different Indian zones have different body sizes and dimensions, skeletal proportions and measurements (10, 15–16). Clavicles were also arbitrarily classified into two groups of strenuous and non-strenuous workers depending upon occupational activity patterns of the deceased. Clavicles were collected only from right-handed cadavers and their handedness was inquired about from the relatives.

Both clavicles and the sternum were removed as a single piece during routine post-mortem procedures by giving incisions at the acromio-clavicular, sterno-olecranon and costo-sternal junctions along a standard linear midline incision [29]. Clavicle was removed from the sternum and then boiled, cleaned, washed, dried and prepared for taking measurements using standard detergent maceration protocol [30]. The left-over attached soft tissue, if any, were removed manually with the help of blunt scalpels. The bone/s showing any malformation, fracture, surgical treatment or abnormal anatomy etc., were removed from final analyses. Both clavicles were replaced into the dead body before handing over it to the claimant relatives. Each measurement was taken three times; their average was recorded as the mean value of the parameter. All the measurements were taken by the first author and intra-observer errors were calculated for different variables. Great care was taken while recording measurements on the clavicle as a small change in its orientation can introduce large differences in its dimensions, thus affecting the accuracy, precision and reproducibility of analyses. The outline/contour of each clavicle was drawn on a paper sheet (with its anterior and posterior borders in the same horizontal plane) after taking measurements. The medial and lateral angles were measured with protractor; and two curvature depths were estimated with a foot ruler on the outlined figure of the bone. A brief description of various clavicular measurements has been diagrammatically represented in Fig. 1 and explained as below:

2.1. Metric measurements

2.1.1. Dimensions

(i) Clavicular length (CL): It is measured as the maximum distance between the outermost tips of the sternal and acromial ends of clavicle placed on an osteometric board (ignoring curves of the bone) accurate to within 0.5 mm [12,19,31,32].

(ii) Articular Length of Clavicle (AL): It is the straight distance between the mid-points of the sternal and acromial articular ends of clavicle measured with the help of a spreading caliper with pointed ends, accurate to within 0.5 mm as per the technique used by Parsons [14].

(iii) Mid-point Circumference (CC): The midpoint of clavicular shaft is marked between acromial and sternal ends of clavicle placed in anatomical position on the osteometric board and circumference is measured at this point with a strip of graph paper marked in millimeters, accurate to be within 0.5 mm [12,19,31,32].

(iv) Weight of Clavicle (WC): The completely cleaned, dried but still wet clavicles were weighed with the help of an electronic weighing machine ("ΔIcoscl" EK-6000G, Bombay