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Research Paper

Stature Estimation from Clavicular Length Using Multidetector Computed Tomography in an Adult North Indian Population

Sonia Beniwal[1*], Prachi Saffar Aneja[1], Susmita Saha[1], Neeru Kapur[2], Arjun Narula[3]

1. *Department of Anatomy, SGT University, Gurugram, India.*
2. *Department of Radiology, SGT University, Gurugram, India.*
3. *Narula Diagnostic Center, Rohtak, India .*

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ABSTRACT

Background: Stature estimation is an essential component of the biological profile in forensic anthropology. When primary long bones are fragmented or unavailable, alternative skeletal elements must be evaluated. This study aimed to examine the relationship between adult Haryanvi clavicular measurements and stature using multidetector computed tomography (MDCT) and to evaluate the performance of population-specific regression equations.

Methods: MDCT scans of 68 adult individuals (33 males, 35 females; aged 20–80 years) were evaluated, yielding 136 clavicular observations. Clavicle length was measured on 3D reconstructed images. Sex-specific differences, bilateral symmetry, and correlations with stature were statistically analyzed.

Results: The left clavicle was significantly longer than the right side in both males ($p = 0.0176$) and females ($p = 0.0247$), though the absolute differences were small (~2 mm). The clavicular height index demonstrated significant sexual dimorphism when both sides were combined ($p = 0.0083$). Stature correlated moderately with clavicle length in the pooled sample ($r = 0.5356$, $p < 0.0001$) and weakly to moderately in females ($r = 0.3625$, $p = 0.0020$). Correlations in males were negligible and statistically non-significant ($r = 0.1079$, $p = 0.3884$).

Conclusion: Clavicular length demonstrates modest predictive value for stature estimation in the pooled Haryanvi sample and female subgroup, but lacks predictive utility in males. Due to its limited accuracy, it should be utilized as an exploratory or secondary method when primary long bones are missing.

*** Corresponding Author:**
Sonia Beniwal, MD
Department of Anatomy, SGT University, Gurugram, India.
E-mail: *soniabeniwal99@gmail.com*

Introduction

Stature estimation is a key part of the biological profile in forensic anthropology and helps identify unknown human remains. Stature estimate using regression-based approaches based on skeletal dimensions is still common in medicolegal investigations due to its convenience and reliability. Genetic, environmental, dietary, and socioeconomic factors affect the relationship between skeletal dimensions and height, hence experts recommend group specific norms [1-3]. The clavicle connects the upper limb to the axial skeleton. It is frequently found in degraded, fractured remains. When lengthy bones are unavailable, clavicle measurements can estimate stature [4, 5]. Several studies have established relationships between clavicular measures and stature and created regression equations for different populations [6, 7]. Multidetector computed tomography (MDCT) offers reliable osteometric testing without skeletal touch. Anthropometric studies employing CT on living humans allow the construction of new forensic datasets that represent current populations [7, 8]. Torimitsu et al. used 3D CT images to create regression equations for the two sexes to study the link between clavicular measures and stature in Japanese people [7]. More research from India has demonstrated that clavicular length can accurately predict stature, but the equations are population-specific and not generalizable. [6, 9] Region-specific CT-based regression models are needed to explore the predictive utility and limitations of the clavicle for forensic stature estimation. Thus, this study examined the relationship between adult Haryanvi clavicular measures and stature and developed population-specific regression equations for stature prediction. Individual identification in medicolegal instances with fragmentary skeletal remains and regional anthropometric data base construction may be possible with the results.

Materials and Methods

Study Design and Population

The present cross-sectional study was conducted in SGT University, Gurugram, India on multidetector computed tomography (MDCT) scans obtained from 68 adult individuals belonging to the Haryanvi population, including 33 males and 35 females aged between 20 and 80 years, had full demographic information, including sex and height, and high-quality CT scans showing complete visualization of both clavicles were included in the study. CT Scans with previous clavicular surgery or fixation, skeletal deformities or congenital abnormalities were excluded from the study. Measurements were obtained from both right and left clavicles, yielding a total of 136 clavicular observations (66 male clavicles and 70 female clavicles). CT images were retrieved from the institutional Picture Archiving and Communication System (PACS) after obtaining approval from the Institutional Ethics Committee.

CT Image Acquisition and Measurements

The CT examinations were performed utilising a 384-slice MDCT scanner in the Department of Radiology. The images were obtained with a slice thickness of 1 mm and rebuilt into three-dimensional (3D) images by software on a dedicated workstation. Clavicular measures were derived from the reconstructed images with the help of RadiAnt DICOM Viewer. The maximal clavicular length was determined as the linear distance between the most medial point of the sternal end and the most lateral point of the acromial end. Measurements were taken to the closest 0.1 mm. The standing height of each participant was measured at the time of evaluation. All measurements were made by a single observer following a standardised technique (Figure 1).

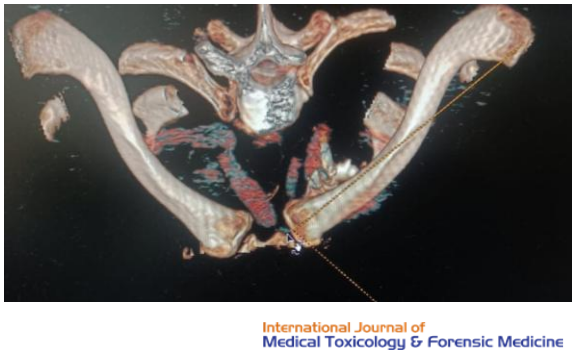

Figure 1. Showing the measurement of clavicle length in mm from midpoint of sternal to midpoint of acromial end.

Measurement Reliability

To assess measurement reliability, 20 randomly selected CT scans were re-measured by the same observer after a two-week interval. Intra-observer reliability was evaluated using the Intraclass Correlation Coefficient (ICC). The ICC values ranged from 0.92 to 0.97, indicating excellent agreement and high reproducibility of the clavicular measurements.

Statistical Analysis

Data were analysed using SPSS version 26.0. Descriptive statistics (mean, standard deviation, minimum and maximum values) were calculated. The Shapiro–Wilk test was employed to assess the

normality of data distribution. Sex differences in clavicular measures were assessed using independent samples t-test. Pearson's correlation coefficient was used to establish the association of clavicular measures with stature. Linear regression assumptions including normality of residuals, homoscedasticity and linearity were verified before regression modelling. Regression coefficients with 95% confidence intervals, coefficient of determination (R^2) and standard error of estimate (SEE) were calculated. Statistical significance was considered at $p<0.05$.

Results

Clavicular Morphometry and Clavicular Length Index

The study evaluated MDCT scans of 136 clavicles from 68 adult Haryanvi individuals. The mean length of the clavicle in males was 145.08 ± 10.49 mm on the right side and 147.58 ± 10.36 mm on the left side. In females, it was 130.95 ± 8.43 mm on the right side and 132.91 ± 8.78 mm on the left side.

Paired t-test analysis demonstrated a statistically significant directional asymmetry between the sides, where the left clavicle was significantly longer than the right clavicle in both males ($p = 0.0176$) and females ($p = 0.0247$). Similarly, the calculated clavicular height index was significantly greater on the left side for both sexes ($p < 0.05$). No difference was observed in the height of individuals between the two sides ($p = 1.000$), confirming procedural symmetry in stature values. Although statistically significant, the absolute side-to-side differences were small (~2 mm), indicating a modest left-sided predominance in clavicular measurements (Tables 1 and 2).

Table 1. Distribution of Clavicular Height Index of Males (right and left) Measured Using CT Scans N=66. Clavicular Height Index = Clavicle Length (mm) / Height of Individual (cm) x 100. Males — Right (n = 33) vs Left (n = 33).

Parameter	Right Mean ± SD	Left Mean ± SD	p-value
Clavicle Length (mm)	145.08 ± 10.49	147.58 ± 10.36	0.0176*
Height of Individual (cm)	167.33 ± 6.24	167.33 ± 6.24	1.0000
Clavicular Index	86.80 ± 6.83	88.29 ± 6.78	0.0171*

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Paired 't' test applied. P value <0.05 was considered as statistically significant

When evaluating sexual dimorphism, the overall mean clavicular height index across combined sides was 87.55 ± 6.79 in males and 84.69 ± 5.63 in females,

Table 2. Distribution of Clavicular Height Index of Females (right and left) Measured Using CT Scans N=70. Females — Right (n = 35) vs Left (n = 35).

Parameter	Right Mean ± SD	Left Mean ± SD	p-value
Clavicle Length (mm)	130.95 ± 8.43	132.91 ± 8.78	0.0247*
Height of Individual (cm)	155.94 ± 7.07	155.94 ± 7.07	1.0000
Clavicular Index	84.06 ± 5.49	85.32 ± 5.78	0.0279*

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Paired t' test applied. P valus <0.05 was considered as statistically significant

showing a statistically significant sex-stratified

Table 3. Distribution of Clavicular Height Index of Females (right and left) Measured Using CT Scans N=70. Females — Right (n = 35) vs Left (n = 35).

Side	Gender	N	Mean ± SD	p-value
Both Sides	Male	66	87.55 ± 6.79	0.008*
	Female	70	84.69 ± 5.63	
Right	Male	33	86.80 ± 6.83	0.072
	Female	35	84.06 ± 5.49	
Left	Male	33	88.29 ± 6.78	0.055
	Female	35	85.32 ± 5.78	

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Unpaired 't' test applied. P value <0.05 was considered as statistically significant

difference (Table 3; $p = 0.0083$). However, when evaluated on a side-specific basis using an unpaired t-test, the differences between males and females did not achieve statistical significance on either the right side ($p = 0.0721$) or the left side ($p = 0.0551$).

Relationship of Clavicle Length to Height

Pearson correlation analysis showed a statistically significant positive correlation between clavicle length and stature when evaluating the aggregated study sample. The clavicular length was positively correlated with stature on the combined sides ($r = 0.5356$, $p < 0.0001$). The coefficient of determination ($R^2 = 0.2869$) indicated that pooled clavicle length alone explains approximately 28.7% of the variation in stature in this sample. Side-specific analyses yielded

Table 4. Pearson correlation (Height vs Clavicle Length) Analysis overall. Interpretation: Moderate positive.

Side	N	r	r^2	p-value
Right	68	0.5361	0.2874	<0.0001
Left	68	0.5398	0.2914	<0.0001
Both Sides	136	0.5356	0.2869	<0.0001

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similar results: the right clavicle showed a correlation coefficient of r = 0.5361 (R^2 = 0.2874; p < 0.0001), and the left clavicle presented a slightly higher correlation (r = 0.5398; R^2 = 0.2914; p < 0.0001), as detailed in Table 4.

Sex-stratified analyses revealed stark differences between the genders. Clavicle length in males demonstrated negligible and statistically non-significant correlations with stature on the right side (r = 0.1069, p = 0.5539), the left side (r = 0.1106, p = 0.5401), and both sides combined (r = 0.1079, p = 0.3884), as shown in Table 5.

Table 5. Pearson correlation Analysis in Males. Interpretation: Negligible.

Side	N	r	r²	p-value
Right	33	0.1069	0.0114	0.55
Left	33	0.1106	0.0122	0.54
Both Sides	66	0.1079	0.0116	0.38

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Conversely, females exhibited weak-to-moderate statistically significant positive correlations between clavicle length and stature. The strongest association was found on the right side (r = 0.3745, p = 0.0267), followed by the combined female sample (r = 0.3625, p = 0.0020) and the left side (r = 0.3558, p = 0.0359), as documented in Table 6.

The scatter plot analysis revealed a positive linear correlation between clavicle length and stature, especially among females and the combined sample.

Table 6. Pearson correlation Analysis in Females. Interpretation: Weak positive.

Side	N	r	r²	p-value
Right	35	0.3745	0.1402	0.0267
Left	35	0.3558	0.1266	0.0359
Both Sides	70	0.3625	0.1314	0.0020

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Table 7. Estimation of stature from clavicle length.

Group	Side	N	r	R²	SEE (cm)	p-value
Overall	Both Sides	136	0.535	0.28	7.41	<0.0001
	Right	68	0.536	0.28	7.46	<0.0001
	Left	68	0.539	0.29	7.44	<0.0001
Male	Both Sides	66	0.107	0.01	6.21	0.3884
	Right	33	0.106	0.01	6.31	0.5539
	Left	33	0.110	0.01	6.30	0.5401
Female	Both Sides	70	0.362	0.13	6.59	0.0020
	Right	35	0.374	0.14	6.66	0.0267
	Left	35	0.355	0.12	6.71	0.0359

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The regression lines and confidence intervals also support the positive association of these variables. Predictive equations for stature estimation were obtained by simple linear regression analysis (Table 7).

The strongest model was pooled population height (cm) = 106.9670 + 0.3923 × Clavicle Length (mm).

Table 8. Equations for the side-specific analyses overall.

Side	Formula	95% CI (Slope)
Both Sides	Height = 106.9670 + 0.3923 × CL	0.2867 – 0.4980
Right	Height = 106.5533 + 0.3985 × CL	0.2443 – 0.5527
Left	Height = 106.4156 + 0.3932 × CL	0.2425 – 0.5438

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Both models were significant at p < 0.0001.

This equation accounted for 28.69% of the variation in stature ($R^2 = 0.2869$), and the standard error of estimate (SEE) was 7.41 cm. The equations for the side-specific analyses were in Table 8. Both models were significant at p < 0.0001. The regression equation for the combined sides for females was in Tables 9 and 10 (Height = 116.8984 + 0.2959 CL). Overall, the study population model showed a modest predictive performance (Figure 2) (R 2 = 0.1314, SEE = 6.59 cm) and accounted for 13.14% of the variation in stature.

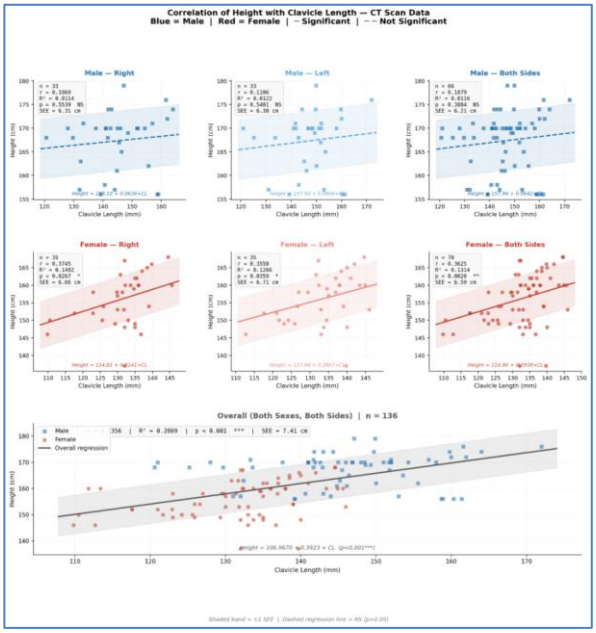

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Figure 2. Graph Showing correlation of Height with Clavicle

Predicting Height using Regression Model

The scatter plot analysis supported these numerical conclusions. Female plots displayed a discernible

Table 9. Equations for the side-specific analyses in Females.

Side	Formula	95% CI (Slope)
Both Sides	Height = 116.8984 + 0.2959 × CL	0.1118 – 0.4801
Right	Height = 114.8105 + 0.3141 × CL	0.0386 – 0.5895
Left	Height = 117.8356 + 0.2867 × CL	0.0200 – 0.5534

(R 2 = 0.1314, SEE = 6.59 cm) and accounted for 13.14% of the variation in stature.

Table 10. Equations for the side-specific analyses in Male.

Side	Formula	95% CI (Slope)
Both Sides	Height = 157.9437 + 0.0642 × CL *(NS)*	−0.0834 – 0.2118
Right	Height = 158.1006 + 0.0636 × CL *(NS)*	−0.1532 – 0.2805
Left	Height = 157.4999 + 0.0666 × CL *(NS)*	−0.1527 – 0.2860

Overall, the study population model showed a modest predictive performance.

upward linear trend and narrower confidence intervals, validating their modest positive relationship. Conversely, male plots exhibited high scatter around the regression line, verifying the poor predictive capacity of the male models within this sample.

Discussion

In the adult Haryanvi population, the current study established population-specific CT-based regression equations for estimating stature from clavicular length. This is one of the first multidetector CT-based studies from North India to investigate the utility of clavicular morphometry for stature estimation, to the best of our knowledge. The study revealed a moderate positive correlation between clavicular length and stature in the aggregated population, as well as significant sexual dimorphism in clavicular measurements.

Sexual Dimorphism and Index of Clavicle Length

In the present study, the clavicular length index was higher in males than in females on either side. The overall mean clavicular length index was 87.55 ± 6.79 for males and 84.69 ± 5.63 for females, and the difference was moderate statistically significant (p = 0.0083). These findings are consistent with prior anthropological and radiological research demonstrating a greater size of the clavicle in males. 3D CT reconstruction by Torimitsu et al, [7] found significantly larger clavicular measurements in Japanese males than in females. Singh and Pathak [10] found greater clavicular length among North Indian males, while Frutos [11] found marked sexual dimorphism of the clavicle in a contemporary skeletal population. The increased value of the clavicular length index in males can be explained by longer skeletal growth, greater periosteal bone deposition under the action of androgens, and more musculoskeletal development [12].

Clavicle Measurements: Bilateral Symmetry

In the current study, a statistically significant directional asymmetry was observed, with the left clavicle being significantly longer and presenting a higher clavicular height index than the right side in both sexes (males: p = 0.0176, females: p = 0.0247). While statistically significant, the absolute mean differences between the sides were minor (~2 mm). This minor but significant left-sided dominance contrasts with studies reporting absolute symmetry, such as those by Murphy [14] and Haque et al [13]. However, it aligns with broader anthropological observations noting left-sided asymmetry in upper limb long bones, which is often inversely related to right-handed mechanical dominance. Given the small absolute difference, both sides remain contextually valuable for stature estimation, though the side-specific equations derived here should be utilized to account for this variation.

Correlation of clavicle length with stature

The study revealed a moderate positive association between clavicle length and stature in the study population (r = 0.5356, p < 0.0001). The coefficient of determination (R^2 = 0.2869) indicates that clavicle length explains 29% of the variability in stature. This study revealed similar correlation coefficients to

Bidmos [1], who observed a strong correlation between clavicular dimensions and stature among South Africans. CT-based assessments by Torimitsu et al [7] also identified substantial associations between clavicle length and stature in Japanese people. Jit and Singh found that clavicular measurements can help establish North Indian stature [15].

Sex-Specific Correlation Analysis

The considerable gender disparity in correlation coefficients was remarkable in this study. In women, clavicular length correlated positively with stature ($r = 0.3625$, $p = 0.0020$). Right clavicle had the strongest correlation ($r = 0.3745$), followed by combined and left-sided analysis. In contrast, male associations were insignificant ($r \approx 0.11$, $p > 0.05$). Only 1% of stature variance was due to male models. This differs from prior studies. Both genders had strong stature-clavicle associations, according to Torimitsu et al, [7]. Bidmos found useful sex-independent predictive connections [1].

Stature Estimation Regression Model

The overall pooled regression equation in this investigation was: Height (cm) = 106.9670 + 0.3923 × Clavicle Length (mm), which demonstrated the highest R^2 within this sample (R^2 = 0.2869, SEE = 7.41 cm). The female-specific equations presented lower SEE values of 6.59–6.71 cm, though their explanatory power was low (R^2 approx 0.13). No male-specific regression models were significant. The overall predictive performance of these models must be characterized as modest. The clavicle is not a weight-bearing bone, and its development is heavily influenced by biomechanical usage of the upper extremity rather than purely linear skeletal growth. However, the SEE values obtained here are comparable to earlier clavicle studies. In Bidmos [1], SEE values ranged from ~5 to 8 cm depending on the population studied, and Torimitsu et al [7] similarly noted moderate predictive accuracy in CT-derived clavicular measurements.

The present study has certain limitations. It was conducted at a single center with a relatively small sample, limiting the generalizability of the findings. Both clavicles from the same individuals were included in the pooled analysis, resulting in paired observations that were not completely independent. The regression models showed only moderate predictive performance, were not externally validated, and the male-specific models were not statistically significant. Therefore, the findings should be interpreted cautiously until validated in larger multicentric studies.

Conclusion

MDCT-derived clavicular length showed a moderate association with stature in the contemporary Haryanvi population and enabled the development of population-specific regression equations for stature estimation. Although the predictive performance was modest and male-specific models were not statistically significant, clavicular morphometry may serve as a valuable adjunct when long bones are unavailable or fragmented. The CT-based measurements provide a reliable, non-invasive approach that may assist forensic anthropologists, radiologists, anatomists, and medicolegal experts in the identification of unknown individuals using contemporary population-specific data. Further multicentric studies with larger samples and external validation are required before routine forensic application.

Ethical Approval

The study was conducted in accordance with ethical standards and was approved by the Institutional Ethics Committee of SGT University, Gurugram (IEC Approval No. IEC/PhD/2025-20).

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Conflicts of Interest

The authors report there are no competing interests to declare.

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