The Model for Stature and Gender Prediction in Indians Using Upper Limb Measurements

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Abstract: Introduction: Estimating stature and gender in the process of forming an individual's identity, various parts of the body are important for forming a biological profile, especially when damaged and amputated bodies are discovered. An important aspect of any forensic study is its human stature and gender estimate. Aim: The study's main purpose was to estimate the individual's stature and gender by using upper limb measurements like arm and forearm lengths, elbow breadth, and wrist breadths and circumferences. Materials and Methods: To create the equations, five anthropometric measurements were taken of 568 healthy adult Indian volunteers, 294 males and 274 females, ranging in age from 18 to 25 years. A digital vernier caliper was used to measure the arm and ulnar lengths, elbow breadth, and circumference in millimeters. The data was analyzed using SPSS 20. Results: A significant correlation was revealed between stature and arm, forearm, elbow, and wrist dimensions on both sides using linear regression models. Approximately 71% to 86% accurate gender estimation of the research population. Conclusion: A study has found that arm and forearm length, elbow and wrist breadth, and wrist circumference can all be used to predict stature and gender in Indians. Key Words: Stature, Gender, Upper limb measurements

Introduction:
Establishing an individual's identity is referred to as personal identification. Personal identification is required in natural disasters such as earthquakes, tsunamis, landslides, and floods, as well as in man-made disasters such as terrorist attacks, bomb explosions, and mass murders, as well as in cases where the body is highly decomposed or dismembered to hide the identity of the deceased. (1) The first step in obtaining personal identification is to determine whether or not the skeletal remains are human. If the remains are those of an individual, anthropological methods may be used to classify the deceased. Age, sex, height, and ethnicity are the "big four" in personal identity. (2) There is very little information on studies done in the Indian population to determine gender and stature using the dimensions of various upper-limb parts. As a result, the focus of this research is to reduce those gaps. The goal of this study is to see if arm and ulnar length, elbow breadth, wrist breadth, and circumference can be used to determine gender and stature in an Indian population.

Material and Methods:
Study design and area:
This cross-sectional study was conducted at the Krishna Institute of Medical Sciences, Deemed To Be University, Karad, from the years 2018-2020. Ethical approval:
The work protocol was approved by the ethics committee, and the relevant permissions were obtained from the Krishna Institute of Medical Sciences Deemed To Be University in Karad. (Dated 02/02/2018, KIMSDU/IEC/01/2018).

Selection criteria:
Inclusion criteria:
According to the ethical committee for human experimentation's standard ethics, 568 adults (294 males and 274 females) aged 18-25 years participated in the study of Indian origin irrespective of their caste, religion, dietary habits, and socio-economic status.

Exclusion criteria:
Individuals with obvious deformities, injuries, fractures, amputations or history of any surgical procedure on the hand or previous history of trauma to the hands, feet, spine, and limbs were excluded from the study.
Data acquisition:
The proposed studies' aims and objectives were explained to the students, and their informed consent was recorded on the pro-forma sheet. To assess the students' health status and rule out any deformities or injuries, a general physical examination was undertaken. The following information was collected: age, sex, height, and weight. To avoid inaccuracies, the data was collected and the measurements were repeated. To reduce diurnal variation, the measurements were taken at a fixed time between 3:00 and 5:00 p.m.

The upper limb measurements like arm length, elbow breadth, ulnar length, wrist breadth, and wrist circumference of each of these participants were measured by a digital vernier caliper in millimeters.

Arm length was measured as the distance between the acromion (the most lateral point at the end of the acromial process of the shoulder blade) and the most distal point on the capitulum of the humerus. This is done by holding the forearm at right angles to the upper arm, when the capitulum of the humerus can be palpated very easily.(3)

Elbow breadth was measured from the humeral bicipital epicondylar distance.

Ulnar length was measured as the direct distance between the most proximal point of the olecranon process and the styloid process while the elbow is flexed to 90 degrees and the fingers are extended in the direction of the long axis of the forearm.(3)

Wrist breadth was measured as the distance between the ulnar and radial styloid processes.(4)

Wrist circumference was measured from the superficial distance around the edge of the wrist.(5)

Stature was measured using a stadiometer. It was measured as the vertical distance from the vertex to the floor. The measurement was taken by making the subjects stand erect on a horizontal resisting plane bare footed with shoulder blocks and buttocks touching the rod. The palms of the hands are turned inwards and the fingers are horizontally pointing downwards. Anthropometer placed in a straight vertical position in front of the subject with the head oriented in the Frankfurt plane. The movable rod of the anthropometer is brought into contact with the vertex in the mid-sagittal plane.(3)

Statistical analysis:
The mean and standard deviation (SD) of all measurements were estimated. Pearson’s Correlation Coefficient (r) was used to determine the correlation between stature and each of the arm, forearm, elbow, and wrist measurements. The stature of the individual was statistically significant with arm, forearm, elbow, and wrist measurements were estimated using Backward Linear Regression analysis. The cut-off value for the arm, forearm, elbow, and wrist measurements were determined using Receiver Operating Characteristic (ROC) Curve analysis, which had good sensitivity and specificity in differentiating between male and female populations. These cut-off values were used to categorize the measurements. The gender of the participants was determined using these categorized variables. The model for estimating gender was further developed using Backward Wald Binary Logistic Regression analysis. The SPSS-20 version was used to analyze the data.

Results
The average stature of the 294 male participants was 172.4 cm, with a standard deviation of 7.0 cm, whereas the average stature of the 274 female participants was 159.8 cm, with a standard deviation of 7.1 cm. According to the comparison, males were significantly taller than females (unpaired t test = 21.419, p<0.001).

As shown in Table 1, there was a significant correlation between stature and arm length, elbow breadth, ulnar length, wrist breadth and circumference in both the male and female populations.

Table 1: Male and female correlation coefficients (r) between stature and upper limb measurements

<table>
<thead>
<tr>
<th>Upper limb measurements</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALRT</td>
<td>0.567**</td>
<td>0.165**</td>
</tr>
<tr>
<td>ALLT</td>
<td>0.571**</td>
<td>0.162**</td>
</tr>
<tr>
<td>EBRT</td>
<td>0.599**</td>
<td>0.258**</td>
</tr>
<tr>
<td>EBLT</td>
<td>0.585**</td>
<td>0.289**</td>
</tr>
<tr>
<td>ULRT</td>
<td>0.608**</td>
<td>0.346**</td>
</tr>
<tr>
<td>ULLT</td>
<td>0.610**</td>
<td>0.377**</td>
</tr>
<tr>
<td>WBRT</td>
<td>0.615**</td>
<td>0.377**</td>
</tr>
<tr>
<td>WBLT</td>
<td>0.354**</td>
<td>0.249**</td>
</tr>
<tr>
<td>WCRT</td>
<td>0.356**</td>
<td>0.306**</td>
</tr>
</tbody>
</table>

**Correlation is significant at the 0.01 level (2-tailed).

As shown in Table 2, males showed significantly higher values than females in all dimensions. Males' right and left arm lengths, elbow breadth, ulnar length, wrist breadth and circumference are all significantly larger than females'. Using these upper limb measurements, backward linear regression analysis was used to estimate male and female stature. Estimating the dependent variable "stature" using right and left arm lengths, elbow breadths, ulnar length, wrist breadth, and circumference is statistically significant (p<0.05) for both genders, indicating that it is significantly more accurate. For given values of arm, forearm, elbow, and wrist measures, the regression model equations can be used to estimate stature.

Regression model equations to determine the stature of a male by using right, left and both side arm and elbow measurements:
Stature = 104.183 + 1.489×ALLT + 1.779×EBRT, ANOVA F =96.668, P<0.001; Adjusted R²=0.399
Regression model equations to determine the stature of a male by using right, left and both side ulna and wrist measurements:
Stature = 104.091 + 1.489×ALLT + 1.779×ULRT, ANOVA F =96.668, P<0.001; Adjusted R²=0.399

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Stature = 104.091 + 1.489×ALLT + 1.779×ULRT, ANOVA F =96.668, P<0.001; Adjusted R²=0.399

Table 2: Gender-specific mean & standard deviation (SD) of the upper limb measurements

<table>
<thead>
<tr>
<th>Upper limb measurements</th>
<th>Mean</th>
<th>SD</th>
<th>Mean</th>
<th>SD</th>
<th>Unpaired 't' test value</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALRT</td>
<td>33.56</td>
<td>2.03</td>
<td>36.10</td>
<td>2.71</td>
<td>12.535</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ALLT</td>
<td>33.58</td>
<td>2.04</td>
<td>36.08</td>
<td>2.72</td>
<td>12.315</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>EBRT</td>
<td>7.19</td>
<td>0.79</td>
<td>8.15</td>
<td>1.10</td>
<td>11.941</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>EBLT</td>
<td>7.19</td>
<td>0.79</td>
<td>8.15</td>
<td>1.10</td>
<td>11.919</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ULRT</td>
<td>25.84</td>
<td>1.88</td>
<td>28.50</td>
<td>1.48</td>
<td>18.756</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ULLT</td>
<td>25.86</td>
<td>1.88</td>
<td>28.47</td>
<td>1.48</td>
<td>18.456</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>WBRT</td>
<td>4.61</td>
<td>0.35</td>
<td>5.44</td>
<td>0.63</td>
<td>18.988</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>WBLT</td>
<td>4.61</td>
<td>0.35</td>
<td>5.43</td>
<td>0.64</td>
<td>18.927</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>WCRT</td>
<td>14.42</td>
<td>0.97</td>
<td>16.41</td>
<td>1.06</td>
<td>23.184</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>WCLT</td>
<td>14.42</td>
<td>0.97</td>
<td>16.37</td>
<td>1.06</td>
<td>22.830</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

As shown in Table 2, males showed significantly higher values than females in all dimensions. Males' right and left arm lengths, elbow breadth, ulnar length, wrist breadth, and circumference are all significantly larger than females'. Using these upper limb measurements, backward linear regression analysis was used to estimate male and female stature. Estimating the dependent variable "stature" using right and left arm lengths, elbow breadths, ulnar length, wrist breadth, and circumference is statistically significant (p<0.05) for both genders, indicating that it is significantly more accurate. For given values of arm, forearm, elbow, and wrist measures, the regression model equations can be used to estimate stature.
Regression model equations to determine the stature of a female by using right, left and both side arm and elbow measurements:

Stature =101.419 + 1.290×ALRT + 2.096×EBRT, ANOVA F =37.565 P<0.001; Adjusted R2=0.517
Stature =102.303 + 1.264×ALLT + 2.093×EBLT, ANOVA F =36.982 P<0.001; Adjusted R2=0.514
Stature =101.406 + 1.290×ALRT + 2.100×EBLT, ANOVA F =37.635 P<0.001; Adjusted R2=0.515

Regression model equations to determine the stature of a female by using right, left and both side ulna and wrist measurements:

Stature =107.506 + 1.065×ULRT + 5.373×WRISTBRT, ANOVA F =31.613 P<0.001; Adjusted R2=0.518
Stature =107.540 + 1.059×ULLT + 5.397×WRISTBRT, ANOVA F =31.351 P<0.001; Adjusted R2=0.512
Stature =103.731 + 1.037×ULRT + 4.161×WRISTCRT + 7.563×WRISTCLT, ANOVA F =17.554 P<0.001; Adjusted R2=0.515

Regression model equations to determine the stature of an Irrespective of gender by using right, left and both side ulna and elbow measurements:

Stature =75.101 + 1.938×ALRT + 3.077×EBRT, ANOVA F =308.166 P<0.001; Adjusted R2=0.522
Stature =75.684 + 1.924×ALLT + 3.066×EBLT, ANOVA F =302.997 P<0.001; Adjusted R2=0.518
Stature =75.097 + 1.938×ALRT + 3.075×EBLT, ANOVA F =308.012 P<0.001; Adjusted R2=0.522

Regression model equations to determine the stature of an Irrespective of gender by using right, left and both side ulna and wrist measurements:

Stature =76.310 + 2.003×ULRT + 1.082×WRISTBRT + 1.946×WRISTCRT, ANOVA F =220.196; Adjusted R2=0.537
Stature =75.750 + 1.988×ULLT + 1.056×WRISTBRT + 2.020×WRISTCLT, ANOVA F =219.245; Adjusted R2=0.536
Stature =75.891 + 1.998×ULRT + 1.059×WRISTBRT + 1.992×WRISTCLT, ANOVA F =221.673; Adjusted R2=0.539

As shown in Table 3, Receiver Operating Characteristic (ROC) Curve analysis was used to determine the gender-discriminating demarking points, i.e. cut-off values for each right and left arm length, elbow breadth, ulnar length, wrist breadth, and circumference. These values show that the sensitivity and specificity of the data are both high. To determine gender, a logistic regression model was created using categorical arm, elbow, forearm and wrist measurements as independent variables. These models were created using the backward Wald method.

GENDER PROBABILITY = \frac{e^{g(x)}}{1 + e^{g(x)}}

<table>
<thead>
<tr>
<th>Upper limb measurements</th>
<th>Cut-off as per ROC Curve</th>
<th>Observed Gender</th>
<th>Value to be entered into the calculation of g(x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALRT</td>
<td>≥34.45</td>
<td>Female n=274</td>
<td>Male n=294</td>
</tr>
<tr>
<td></td>
<td>&lt;34.45</td>
<td>189</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>≥34.45</td>
<td>85</td>
<td>208</td>
</tr>
<tr>
<td></td>
<td>≥7.54</td>
<td>194</td>
<td>83</td>
</tr>
<tr>
<td>EBRT</td>
<td>&lt;4.95</td>
<td>228</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>≥4.95</td>
<td>44</td>
<td>246</td>
</tr>
<tr>
<td>ALLT</td>
<td>&lt;34.45</td>
<td>221</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>≥34.45</td>
<td>53</td>
<td>251</td>
</tr>
<tr>
<td>EBLT</td>
<td>&lt;7.54</td>
<td>228</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>≥7.54</td>
<td>46</td>
<td>246</td>
</tr>
<tr>
<td>ULRT</td>
<td>&lt;26.95</td>
<td>231</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>≥26.95</td>
<td>53</td>
<td>251</td>
</tr>
<tr>
<td>WristBRT</td>
<td>&lt;4.95</td>
<td>231</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>≥4.95</td>
<td>46</td>
<td>246</td>
</tr>
<tr>
<td>WristCRT</td>
<td>&lt;15.35</td>
<td>222</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>≥15.35</td>
<td>52</td>
<td>246</td>
</tr>
</tbody>
</table>

Model 1: Estimation of gender from right arm length and elbow breadth

\( g(x) = 1.571x_{ALRT} + 1.716x_{EBRT} - 1.598 \)

In model 1, on the right side of the upper limb, gender was found to be significantly correlated with right arm length and elbow breadth. The gender prediction derived from the right arm and elbow measurements was quite close to the actual gender values. Model 1 had an overall accuracy rate of 71.3 percent, with 70.8 percent of females and 71.8 percent of males correctly classified.

Model 2: Estimation of gender from left arm length and elbow breadth

\( g(x) = 1.583x_{ALLT} + 1.774x_{EBLT} - 1.674 \)

In model 2, on the left side of the upper limb, gender was found to be significantly correlated with left arm length and elbow breadth. Gender predictions based on left arm and elbow measurements were quite close to actual gender values. Model 2 had an overall accuracy rate of 71.3 percent, with 70.8 percent of females and 71.8 percent of males correctly classified.

Model 3: Estimation of gender from right arm length and elbow breadth

\( g(x) = 1.572x_{ALRT} + 1.742x_{EBRT} + .882x_{ALLT} - 1.680 \)

In model 3, gender was found to be significantly correlated with arm length on the right and left side and elbow breadth only on the right side of the upper limb. The gender prediction based on right and left arm and elbow measurements was quite close to the actual gender values. Model 3 had an overall accuracy rate of 71.3 percent, with 70.8 percent of females and 71.8 percent of males correctly classified.

Model 1: Estimation of gender from right ulnar length, wrist breadth and circumference
\[ g(x) = 2.305 \times \text{ULRT} + 3.034 \times \text{WristBRT} - 2.609 \]
In model 1, the ulnar length and wrist breadth on the right side of the upper limb were found to be significantly correlated with gender. The gender prediction based on the right forearm and wrist measurements was quite close to the real gender values. Model 1 had an overall accuracy of 87.1%, with 86.9% of females and 87.4% of males correctly identified.

Model 2: Estimation of gender from left ulnar length, wrist breadth, and circumference
\[ g(x) = 2.108 \times \text{ULLT} + 2.691 \times \text{WRISTBLT} + .566 \times \text{WRISTCLT} - 2.659 \]
In model 2, the ulnar length, wrist breadth, and circumference of the left side of the upper limb were found to be significantly correlated with gender. The gender prediction based on left forearm and wrist measurements was quite similar to the actual gender values. The total accuracy of this model 2 was 86.3%, with 82.1% of females and 90.1% of males correctly identified.

Model 3: Estimation of gender from right and left ulnar length, wrist breadth and circumference
\[ g(x) = 2.305 \times \text{ULRT} + 3.034 \times \text{WristBRT} - 2.609 \]
In model 3, the ulnar length and wrist breadth of the right side of the upper limb were found to be significantly correlated with gender. This model considers only the right side measurements. The gender prediction produced by the right and left forearm and wrist measurements was quite similar to the true gender values. The overall accuracy classification percentage for this model 3 was 87.1%, with 86.9% of females and 87.4% of males correctly classified.

The independent variables’ values, such as arm length, elbow breadth, ulnar length, wrist breadth, and circumference, should be entered into the model according to the instructions in table 3. The arm, elbow, forearm, and wrist measures are female if the GENDER PROBABILITY value is less than 0.5; otherwise, they are male. Using the three logistic regression models constructed, gender estimation was achieved with greater than 71%-86% accuracy.

### Discussion
The current study was compared to other studies. Table 4 illustrates that different age groups and sample sizes were used to calculate stature and gender in different regions of India and other nations. The table shows that arm and forearm measurements are used to determine stature, with only a few studies estimating gender. In this investigation, different parts of the upper limb were used to determine gender and stature. Models that estimate gender yield reliable and accurate gender predictions with low prediction errors and excellent accuracy rates. (7)

Findings from other studies developed regression formulas for their respective populations, and they are effective in predicting stature and gender.(10,14) Arm and forearm measurements are a good indicator of stature and gender.(10,13,14)

In this study, arm ulnar lengths, elbow breadths, wrist circumference and breadth were used to assess male and female stature. The cut-off values were determined using a Receiver Operating Characteristic (ROC) Curve analysis. These figures demonstrate that the data has a high level of sensitivity and specificity. A logistic regression model with categorical independent variables was used to determine gender. The backward Wald Binary Logistic Regression analysis was used to make these models. The logistic regression models created used arm, forearm, elbow, and wrist dimensions to estimate gender with greater than 71% to 86% accuracy.

<table>
<thead>
<tr>
<th>Researcher &amp; Year</th>
<th>Study region / Country</th>
<th>Sample size</th>
<th>Age group (yrs.)</th>
<th>Upper limb measurements</th>
<th>Estimate Stature/ Gender</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sukumar CD(6) 2017</td>
<td>Andhra Pradesh, India.</td>
<td>50</td>
<td>21-24 yrs.</td>
<td>UL,UL Both side</td>
<td>Stature</td>
</tr>
<tr>
<td>Uzun O(7) 2017</td>
<td>Ortahisar, Turkey</td>
<td>112</td>
<td>18-25yrs.</td>
<td>AL, FAL, WB, WC Both side</td>
<td>Gender</td>
</tr>
<tr>
<td>Rasouli MA(8) 2018</td>
<td>United States</td>
<td>1,177</td>
<td>1 mth to 23 yrs.</td>
<td>UL</td>
<td>Stature</td>
</tr>
<tr>
<td>Bridge AL(9) 2018</td>
<td>Australia</td>
<td>-</td>
<td>18–59yrs.</td>
<td>RL,UL, Left side</td>
<td>Stature</td>
</tr>
<tr>
<td>Uzun Ö(10) 2019</td>
<td>Trabzon, Turkey</td>
<td>200</td>
<td>18-25yrs.</td>
<td>AL,UL, WB, WC Both side</td>
<td>Stature</td>
</tr>
<tr>
<td>Gul H(11) 2020</td>
<td>Multan, Pakistan</td>
<td>50</td>
<td>20 to 27 yrs.</td>
<td>UL Both side</td>
<td>Stature</td>
</tr>
<tr>
<td>Paul M(12) 2020</td>
<td>Kolkata, India.</td>
<td>250</td>
<td>20-50yrs.</td>
<td>UL Both side</td>
<td>Stature</td>
</tr>
<tr>
<td>Balachandran M(13) 2021</td>
<td>Kerala, India.</td>
<td>100</td>
<td>18-60yrs.</td>
<td>FAL Both side</td>
<td>Stature</td>
</tr>
<tr>
<td>Shakya T(14) 2021</td>
<td>Lalitpur, Nepal.</td>
<td>75</td>
<td>18-55yrs.</td>
<td>AL Both side</td>
<td>Stature</td>
</tr>
<tr>
<td>Present study 2021</td>
<td>Maharashtra, India</td>
<td>294</td>
<td>18-25yrs.</td>
<td>AL,UL,EB, WB, WC Both side</td>
<td>Stature/ Gender</td>
</tr>
</tbody>
</table>

Strength and limitations
The research was limited to a certain age range (18-25 years). Only healthy people were measured. As a result, the data may not apply to people who have injuries or deformities, as well as those who have congenital abnormalities. The models for determining sex and stature in dry bone measurements were not tested in this study. A major strength of this study was that the regression equations were derived from arm, forearm, elbow, and wrist dimensions, and this study detailed new forensic norms for Indian people in terms of stature and gender estimation.

Conclusion
Estimating stature and gender from limbs or mutilated body parts is essential for personal identification, especially when the use of DNA analysis is limited due to cost restrictions or other challenges, such as conflicts or natural disasters. In both genders, there is a significant relationship between stature and arm, forearm, elbow, and wrist measurements on both sides. The gender prediction methods were all able to estimate the study population accurately. The gender was estimated with greater than 71% to 86% accuracy using the arm, forearm, elbow, and wrist dimensions obtained by the logistic regression models. The regression equations were derived from arm, forearm, elbow, and wrist measurements, and new forensic standards for Indian people for stature and gender estimation were outlined in this study.

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References