Assessment of body weight from percutaneous widths of the bones and joints—Implications in forensic and clinical examinations

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Abstract. Background: Estimation of age, stature, sex, and ancestry contributes to the establishment of the biological profile of the deceased in forensic examinations. Assessment of the body weight aids in the approximation of the overall body size of the individual which may help in the forensic identification process. In clinical examinations, body weight assessment assumes importance in cases where body weight measurement is a challenging task due to illness and body deformity. Objective: The present research was conducted to estimate the body weight from the percutaneous width of the bones and joints with the help of prediction equations. Methods: The study was carried out on 344 adults (172 Females and 172 Males) aged between 18 and 25 years from the Himachal Pradesh State of North India. Eleven anthropometric measurements including height vertex, mid-arm circumference, humerus bicondylar width, transverse chest breadth, sagittal chest breadth, bi-iliac breadth, hand breadth, femur bicondylar breadth, ankle breadth, foot breadth, and body weight were taken on each individual. The sex differences were evaluated by using independent student t-test and Mann-Whitney U test and the correlation between the body weight and the anthropometric variables was investigated by using both Karl Pearson's correlation coefficient and Spearman's rank correlation coefficient depending upon the normality of the data. Regression models for the estimation of body weight were calculated. Further, a validation study was carried out to check the accuracy and utility of the derived regression models by calculating the mean absolute percent prediction error (MAPPE). Results: Significant sex differences were observed among all the anthropometric variables. The transverse chest breadth and mid-arm circumference were strongly correlated with the body weight, whereas, a good correlation was also observed in other measurements except for the ankle breadth. The SEE (Standard error of estimate) of the derived linear regression models was compared, and it was found that multiple linear regression models show better accuracy than simple linear regression models. The MAPPE was found to be less in the case of multiple linear regression models than the linear ones. Conclusion: The present investigation concludes that regression models can be used in the estimation of body weight from the percutaneous measurements and joint widths with reasonable accuracy in an Indian population. (www.actabiomedica.it)

Key words: Forensic Anthropology, Anthropometry, Body weight assessment, Clinical and forensic considerations, Mean absolute percent prediction error, percutaneous bone widths.

Introduction

Body weight of an individual is defined as the weight of the body involving skeletal mass, muscle mass, and fat mass. Estimation of the body weight of the deceased from skeletal remains is an important step in the identification process and has been a major concern of forensic anthropologists as well as archeologists (1, 2). Body weight assessment is also a crucial part of drug dose calculation in emergency departments,
tidal volumes in ventilated patients, estimation of renal function, and nutritional status. In these kinds of medical setups, body weight measurement is a challenging task due to mobility compromising illnesses, or body deformities (3-7). Earlier, the studies have derived certain prediction equations for the estimation of body weight from skeletal remains and suggested two different approaches i.e. mechanical and morphometric methods for this purpose. “The mechanical method is based on the functional association between a weight-bearing element and a body weight whereas the morphometric method includes the direct reconstruction of body shape and/or size (i.e., body breadth relative to body length) from the preserved elements” (8). The mechanical method is further sub-divided into the articular surface dimension and the diaphyseal breadths (cross-sectional dimensions) (8). In the mechanical method, the breadths were used to predict the body mass which includes mostly the articular surfaces i.e., joints such as femoral head breadth (9-12), knee breadth (10), and pelvic breadth (13) while the bi-iliac breadth and the stature were mostly used in the morphometric method (9, 11, 13, 14). The size of the joint does not change, once the ossification of bone is complete, regardless of the changes in loading due to body mass or activity; this may be one of the reasons that the focus of the researchers shifted to the weight-bearing element which includes joints (15). Femoral head breadth is the most studied element (10) in this regard. Groote and Humphrey (16) also estimated the femoral head diameter, femoral length, and body mass from the first metatarsal bone from a mixed population skeletal sample (16).

The estimation of body mass or body weight is not only applicable in archeological and forensic context but are also widely used in the medical scenario. In a medical scenario, there are various therapeutic mediations which are based on body weight (3, 4, 17). In the case of critically ill patients and obese patients, where direct measurement of body weight is practically impossible (18, 19) due to immobility, illness, or body deformity (3, 17), the assessment of body weight through indirect method is a major concern. In such situations, body weight is measured to track the nutritional status, clinical conditions, drug dosages, renal functioning, tidal volumes in ventilated patients, thrombosis in stroke patients, degenerative joint diseases, and cardiovascular diseases (3-7, 17, 20, 21). In the pediatric emergency department, body weight is mostly estimated with the help of various methods such as Broselow tape, Cattermole formula, etc. (22-26). Out of these methods, Broselow tape is the best estimator of body weight (25). However, in children older than 6 years, the Cattermole formula is a better option than Broselow tape (26). The Cattermole formula is calculated based on mid-arm circumference (26). Efforts have been made to estimate the body mass from anthropometric measurements by using computed tomography (27) and dual-energy x-ray absorptiometry (DXA) scans (15). The femoral head, neck, proximal shaft diameters (15), mid-arm circumference (17), knee breadth (28), stature, and bi-iliac breadth (29) were used for the body mass assessment. The femur, bi-iliac breadth, and knee breadth are the weight-bearing elements of the body, whereas, mid-upper arm circumference is a marker of undernutrition (30).

The objective of the present research is to estimate body weight from the percutaneous width of the bones and joints with the help of prediction equations so that the relationship between body weight and the percutaneous width of the bones and joints can be drawn. The study may be useful in the circumstances where the bone and joint widths are available for forensic casework as well as in the archaeological and palaeoanthropological context.

**Material and Methods**

A cross-sectional sample of 344 adults (172 Females and 172 Males) with an age range from 18 to 25 years (with mean age 19.06±1.19 years) was collected from the Shimla Town of the Himachal Pradesh State in North India. The investigation was part of a large study conducted for the Master’s degree dissertation in the Department of Anthropology, Panjab University, Chandigarh, India (31, 32). Informed consent was obtained from the participants before initiating the data collection for the study. The purpose and the details of the study were explained to every participant. The physically handicapped participants or those with
any physical disability related to the extremities were excluded from the study.

Eleven anthropometric measurements along with the general demographic data were collected from the study participants. The measurements comprised of height vertex, mid-arm circumference, humerus bicondylar width, transverse chest breadth, sagittal chest breadth, bi-iliac breadth, hand breadth, femur bicondylar breadth, ankle breadth, foot breadth, and body weight. The anatomical landmarks involved and the techniques for obtaining the anthropometric measurements were followed by Singh and Bhasin (33) and Weiner and Lourie (34) (Table 1). All the measurements were taken by two trained physical anthropologists under the supervision of an experienced physical and forensic anthropologist.

Table 1. Table showing the details of the anthropometric measurements used in the present study

| Measurements                        | Landmarks involved | Definition                                                                 | Instrument used                | Technique followed |
|------------------------------------|--------------------|---------------------------------------------------------------------------|-------------------------------|--------------------|
| Height vertex                      | Vertex             | It measures the straight distance from the vertex to the floor.           | Anthropometric rod            | Singh and Bhasin (33) |
| Mid Arm Circumference              | Acromion, Radiale  | It measures the maximum circumference of the upper arm taken at the midpoint of upper arm length. | Steel tape                    | Weiner and Lourie (34) |
| Humerus Bicondylar breadth         | Lateral epicondyle and Medial epicondyle | It measures the straight distance taken across the two epicondyles of the humerus when the elbow is bent to a right angle. | Sliding Caliper              | Weiner and Lourie (34) |
| Transverse Chest Breadth           | Mesosternale       | It measures the most laterally places points of the ribs at the height of the mesosternale. | The first segment of Anthropometer or Rod compass | Singh and Bhasin (33) |
| Sagittal Chest Breadth             | Mesosternale       | It measures the straight distance of mesosternale to the horizontally placed point in the vertebral column. The arms should hang normally on the sides. | The first segment of Anthropometer or Rod compass | Singh and Bhasin (33) |
| Bi-iliac Breadth                   | Iliocristale       | It measures the straight distance between the two iliocostale points.     | The first segment of Anthropometer or Rod compass | Singh and Bhasin (33) |
| Femur Bicondylar Breadth           | Lateral epicondyle and Medial epicondyle | It measures the straight distance taken across the two epicondyles of the femur when the knee is bent to a right angle. | Sliding Caliper              | Weiner and Lourie (34) |
| Ankle Breadth                      | Lateral malleolus and Medial malleolus | It measures the straight distance across the lateral and medial malleolus of fibula and tibia respectively. | Sliding Caliper              | Weiner and Lourie (34) |
| Hand breadth                       | Metacarpal radiale and Metacarpal ulnare | It measures the straight distance between metacarpal radiale and metacarpal ulnare | Sliding Caliper              | Singh and Bhasin (33) |
| Foot breadth                       | Metatarsal tibiale and Metatarsal fibulare | It measures the straight distance directly between metatarsal tibiale and metatarsal fibulare | First Segment of Anthropometric Rod or Campass | Singh and Bhasin (33) |
| Body weight                        | -----              | Weight should be taken using a standard weighing machine with fine accuracy. | Weighing machine             | Singh and Bhasin (33) |
Statistical analysis

The statistical analysis for the present study was carried out with the help of IBM-SPSS (Statistical Product's and service solution, version 16.0) computer software. From the total data, 5% of the data was segregated for the validation study by using the random data selection method in IBM-SPSS software. The normality of the data was assessed by using different methods which include a visual examination of their histograms, normal Q-Q plots, and box plots, then by investigating the descriptive statistics, and finally by using a confirmatory test i.e., Shapiro Wilk’s test (p>0.05). While, four parameters (height vertex, sagittal chest breadth, bi-iliac breadth, and foot breadth) showed normal distribution, the others (mid-arm circumference, humerus bicondylar breadth, femur bicondylar breadth, hand breadth, transverse chest breadth, ankle breadth, and body weight) were not normally distributed. As a result, both parametric, as well as non-parametric tests were applied. For the evaluation of sex differences, the independent student t-test was applied for normally distributed parameters while the Mann-Whitney U test was used for all other measurements. Further, the correlation between the body weight and the anthropometric variables was conducted by using Karl Pearson’s correlation coefficient in the case of normally distributed parameters, whereas, Spearman’s rank correlation coefficient for the other parameters to verify the association between them. Simple linear and multiple linear regression models were formulated for the estimation of body weight. Step-wise regression models were developed with stepping criteria of f-probability (f-to-enter or f-to-remove threshold). The measurements with f-probability between 0.05 and 0.5 were included in the study and the rest were excluded. Further, the accuracy and utility of the regression models were tested by substituting the segregated data in the regression models. For this purpose, the predicted values were then compared by descriptive statistics, and the calculated mean absolute percent prediction error (MAPPE).

Results

Test of normality by descriptive statistics and Shapiro-Wilk’s test is shown in table 2, and the descriptive statistics and sex differences among males and females participants are documented in table 3. Parametric tests deal with the mean of the sample population whereas non-parametric tests use the median for further calculation. Therefore, both mean and median were recorded in the descriptive statistics. Significant sex differences were observed among all the recorded anthropometric measurements (Table 3). For the evaluation of the

Table 2. Test of normality by descriptive statistics and Shapiro-Wilk’s test.

| Measurements                  | Minimum (cm) | Maximum (cm) | Mean (cm) | Median (cm) | Mode (cm) | Standard Deviation (cm) | Shapiro-Wilk’s test | p-value |
|-------------------------------|--------------|--------------|-----------|-------------|-----------|-------------------------|---------------------|---------|
| Height vertex                 | 142.40       | 187.30       | 163.14    | 162.80      | 163.50    | 8.47                    | 0.992               | 0.069   |
| Mid arm circumference          | 16.30        | 30.50        | 22.76     | 22.50       | 22.00     | 2.53                    | 0.983               | <0.01   |
| Humerus bicondylar breadth    | 4.90         | 7.40         | 6.24      | 6.20        | 6.00      | 0.51                    | 0.984               | <0.01   |
| Hand breadth                  | 6.10         | 9.60         | 7.87      | 7.80        | 7.20      | 0.64                    | 0.983               | <0.01   |
| Transverse Chest width        | 21.80        | 32.80        | 25.92     | 25.50       | 25.50     | 2.21                    | 0.977               | <0.01   |
| Sagittal Chest depth          | 15.90        | 24.10        | 19.71     | 19.70       | 20.50     | 1.70                    | 0.992               | 0.076   |
| Billiac breadth               | 21.40        | 29.60        | 25.58     | 25.50       | 25.50     | 1.62                    | 0.993               | 0.137   |
| Femur bicondylar breadth      | 7.40         | 10.70        | 9.02      | 8.95        | 8.90      | 0.62                    | 0.989               | 0.013   |
| Ankle width                   | 4.50         | 8.00         | 6.27      | 6.20        | 6.50      | 0.64                    | 0.989               | 0.010   |
| Foot breadth                  | 7.10         | 11.20        | 9.07      | 9.05        | 8.60      | 0.77                    | 0.995               | 0.287   |
| Body weight                   | 32.00        | 84.00        | 53.02     | 52.00       | 47.00     | 9.06                    | 0.982               | <0.01   |
Table 3. Descriptive statistics and sexual dimorphism in the studied population.

| Measurements          | Females (N=172) |                  | Males (N=172) |                  | Student's t-test/ Mann Witney test | p-value |
|-----------------------|-----------------|------------------|---------------|------------------|-----------------------------------|---------|
|                       | Minimum (cm)    | Maximum (cm)     | Mean (cm)     | Median (cm)      | Minimum (cm)                      | Maximum (cm) | Mean (cm) | Median (cm) | Standard Deviation (cm) |
| HV                    | 142.40          | 169.40           | 156.88        | 157.20           | 5.30                              | 152.00      | 187.30     | 169.32       | 169.00           | 6.11                | 19.994 | <0.001 |
| SCB                   | 16.00           | 24.00            | 20.14         | 20.20            | 1.59                              | 15.90       | 24.10      | 19.27        | 19.15            | 1.70                | 4.681  | <0.001 |
| BB                    | 21.40           | 29.60            | 25.37         | 25.40            | 1.69                              | 22.70       | 29.60      | 25.78        | 25.70            | 1.53                | 2.388  | 0.018  |
| FB                    | 7.30            | 10.40            | 8.61          | 8.60             | 0.60                              | 7.10        | 11.20      | 9.52         | 9.50             | 0.65                | 13.374 | <0.001 |
| MAC                   | 16.30           | 27.00            | 21.69         | 21.40            | 2.19                              | 19.20       | 30.50      | 23.82        | 23.50            | 2.39                | 6926.00 | <0.01  |
| HBB                   | 4.90            | 6.70             | 5.87          | 5.90             | 0.33                              | 5.40        | 7.40       | 6.61         | 6.60             | 0.36                | 1903.00 | <0.01  |
| HB                    | 6.10            | 8.40             | 7.39          | 7.40             | 0.37                              | 7.10        | 9.60       | 8.34         | 8.35             | 0.47                | 1494.00 | <0.01  |
| TCB                   | 21.80           | 29.20            | 24.54         | 24.45            | 1.43                              | 23.30       | 32.80      | 27.26        | 27.20            | 1.95                | 3374.00 | <0.01  |
| FBB                   | 7.40            | 10.40            | 8.67          | 8.65             | 0.44                              | 7.50        | 10.70      | 9.39         | 9.40             | 0.55                | 3871.00 | <0.01  |
| AB                    | 4.90            | 7.10             | 5.99          | 6.00             | 0.43                              | 4.50        | 8.00       | 6.56         | 6.60             | 0.68                | 6329.00 | <0.01  |
| BW                    | 32.00           | 74.00            | 47.91         | 47.00            | 6.88                              | 44.00       | 84.00      | 58.05        | 57.00            | 8.14                | 4383.00 | <0.01  |

Height vertex= HV, Mid Arm Circumference= MAC, Humerus Bicondylar breadth= HBB, Hand Breadth= HB, Transverse Chest Breadth= TCB, Sagittal Chest Breadth= SCB, Bi-iliac Breadth= BB, Femur Bicondylar Breadth= FB, Ankle Breadth= AB, Foot Breadth= FB, Body Weight= BW.
relationship between the body weight and other anthropometric measurements, both the Spearman's correlation coefficient and Karl Pearson's correlation coefficient were assessed (Table 4). The correlation was measured for the known sex as well as for combined sex. All the anthropometric measurements show a statistically significant correlation with body weight. The transverse chest breadth and mid-arm circumference were found to be strongly correlated with the body weight, whereas a good correlation was observed in the case of height vertex, hand breadth, humerus bicondylar breadth, bi-iliac breadth, femur bicondylar breadth, sagittal chest breadth, and foot breadth except for the ankle breadth (Table 4).

Based on this relationship, simple linear and multiple linear prediction models were devised. The derived simple and multiple linear regression models are shown in Table 5. Along with the models, the correlation coefficient (r), the adjusted coefficient of multiple determination (R²), the standard estimated error for the model and the significance level of each measurement used as well as the significance level of the model (p-value) were recorded for all regression models. In multiple linear regression models, the correlation coefficient “r” indicates the combined effect of all the independent variables whereas, in the simple linear regression model, it simply represents the correlation coefficient. The coefficient of multiple determinations i.e. “R²”, and its value adjusted for sample size i.e., adjusted R², help to assess the amount of variations in the body weight accounted for by the independent variables can be explained by the model (13). The adjusted R² is used to judge the goodness-of-fit for the regression model. While observing the simple linear regression models the highest goodness-of-fit i.e. 50% to 60%, for the models were found to be recorded only in case of the mid-arm circumference and transverse chest breadth equation for females and combined sex. Whereas 40% to 50% goodness-of-fit were documented in the case of the mid-arm circumference and bi-iliac breadth prediction equations for males, transverse chest breadth, and sagittal chest breadth equations for females and height vertex, femur bicondylar breadth and foot breadth prediction equations for combined sex. Moreover, 30% to 40% goodness-of-fit for the model was reported in the case of humerus bicondylar breadth, hand breadth and bi-iliac breadth equations for combined sex, transverse chest breadth and sagittal chest breadth equations for males, and bi-iliac breadth and femur bicondylar breadth for females while the rest prediction models were found to have below 30% goodness-of-fit. The simple regression SEE's for female models fall in the range of 3.8-6.8. This range was slightly less in the case of males and combined sex i.e., 5.3-8.0 and 5.8-8.5 respectively.

The accuracy of the multiple regression models was found to be more than the linear ones. The regression model for combined sex with almost all measurements shows 81% goodness-of-fit. Since the f-probability

| Measurements                          | Females     | Males      | Unknown    |
|---------------------------------------|-------------|------------|------------|
| Height vertex                         | 0.386**     | 0.499**    | 0.671**    |
| Sagittal Chest breadth                 | 0.648**     | 0.579**    | 0.342**    |
| Billiac breadth                       | 0.617**     | 0.649**    | 0.583**    |
| Foot breadth                          | 0.466**     | 0.453**    | 0.643**    |
| Spearman's correlation (for variables that were not normally distributed) |
| Mid arm circumference                  | 0.705**     | 0.657**    | 0.761**    |
| Humerus bicondylar breadth            | 0.443**     | 0.365**    | 0.648**    |
| Hand breadth                          | 0.470**     | 0.301**    | 0.651**    |
| Transverse Chest breadth              | 0.658**     | 0.598**    | 0.782**    |
| Femur bicondylar breadth              | 0.580**     | 0.450**    | 0.691**    |
| Ankle width                           | 0.154*      | 0.204**    | 0.397**    |
Table 5. Body weight estimation regression models (both linear and multiple regression models).

| Measurements | Sex       | Regression model                                      | R   | Adjusted R² | p-value | SEE   |
|--------------|-----------|------------------------------------------------------|-----|-------------|---------|-------|
| HV           | Male      | BW = -54.477 + 0.665x HV**                           | 0.499 | 0.249       | <0.01   | 7.071 |
|              | Female    | BW = -30.563 + 0.500x HV**                           | 0.386 | 0.143       | <0.01   | 6.364 |
|              | Combined sex | BW = -64.088 + 0.718 x HV**                        | 0.671 | 0.448       | <0.01   | 6.733 |
| MAC          | Male      | BW = 4.327 + 2.257x MAC**                            | 0.662 | 0.438       | <0.01   | 6.117 |
|              | Female    | BW = -0.864 + 2.248x MAC**                           | 0.717 | 0.512       | <0.01   | 4.806 |
|              | Combined sex | BW = -8.642 + 2.709x MAC**                       | 0.755 | 0.569       | <0.01   | 5.953 |
| HBB          | Male      | BW = 6.725 + 7.767x HBB**                            | 0.343 | 0.113       | <0.01   | 7.665 |
|              | Female    | BW = -1.384 + 8.391x HBB**                           | 0.403 | 0.158       | <0.01   | 6.312 |
|              | Combined sex | BW = -16.753 + 11.174x HBB**                    | 0.624 | 0.387       | <0.01   | 7.094 |
| HB           | Male      | BW = 11.646 + 5.569x HB**                            | 0.324 | 0.100       | <0.01   | 7.721 |
|              | Female    | BW = -13.115 + 8.254x HB**                           | 0.444 | 0.193       | <0.01   | 6.179 |
|              | Combined sex | BW = -17.283 + 8.937x HB **                     | 0.627 | 0.391       | <0.01   | 7.071 |
| TCB          | Male      | BW = -9.742 + 2.489x TCB**                           | 0.597 | 0.353       | <0.01   | 6.546 |
|              | Female    | BW = -35.686 + 3.407x TCB**                          | 0.707 | 0.499       | <0.01   | 4.881 |
|              | Combined sex | BW = -27.985 + 3.126x TCB**                    | 0.761 | 0.578       | <0.01   | 5.888 |
| SCB          | Male      | BW = 4.758 + 2.768x SCB**                            | 0.579 | 0.331       | <0.01   | 6.655 |
|              | Female    | BW = -9.559 + 2.804x SCB**                           | 0.648 | 0.417       | <0.01   | 5.251 |
|              | Combined sex | BW = 17.114 + 1.821x SCB **                     | 0.342 | 0.114       | <0.01   | 8.530 |
| BB           | Male      | BW = -30.744 + 3.446x BB**                           | 0.649 | 0.417       | <0.01   | 6.210 |
|              | Female    | BW = -15.780 + 2.511x BB**                           | 0.617 | 0.380       | <0.01   | 5.429 |
|              | Combined sex | BW = -30.329 + 3.258x BB **                       | 0.583 | 0.338       | <0.01   | 7.375 |
| FBB          | Male      | BW = 0.313 + 6.154x FBB**                            | 0.418 | 0.170       | <0.01   | 7.413 |
|              | Female    | BW = -34.497 + 9.530x FBB**                          | 0.616 | 0.379       | <0.01   | 5.436 |
|              | Combined sex | BW = -34.660 + 9.722x FBB **                    | 0.669 | 0.446       | <0.01   | 6.746 |
| AB           | Male      | BW = 42.662 + 2.355x AB*                             | 0.194 | 0.032       | <0.01   | 8.006 |
|              | Female    | BW = 30.201 + 2.958x AB*                             | 0.187 | 0.035       | <0.01   | 6.776 |
|              | Combined sex | BW = 17.604 + 5.647x AB **                        | 0.397 | 0.155       | <0.01   | 8.333 |
| FB           | Male      | BW = 3.879 + 5.695x FB**                             | 0.453 | 0.201       | <0.01   | 7.275 |
|              | Female    | BW = 1.724 + 5.365x FB**                             | 0.466 | 0.213       | <0.01   | 6.102 |
|              | Combined sex | BW = -15.362 + 7.543x FB **                      | 0.631 | 0.412       | <0.01   | 6.950 |
| TCB, MAC     | Male      | BW = -18.289 + 1.380x TCB** + 1.627x MAC**           | 0.717 | 0.508       | <0.01   | 5.708 |
|              | Female    | BW = -32.499 + 2.029x TCB** + 1.411x MAC**           | 0.788 | 0.616       | <0.01   | 4.263 |
|              | Combined sex | BW = -31.523 + 1.872x TCB** + 1.585x MAC**         | 0.830 | 0.687       | <0.01   | 5.091 |
| TCB, MAC, HV | Male      | BW = -79.080 + 1.145x TCB** + 1.457x MAC** + 0.421x HV** | 0.778 | 0.597       | <0.01   | 5.162 |
|              | Female    | BW = -89.060 + 1.753x TCB** + 1.471x MAC** + 0.396 x HV** | 0.843 | 0.706       | <0.01   | 3.731 |
|              | Combined sex | BW = -68.619 + 1.139x TCB** + 1.533x MAC** + 0.351 x HV** | 0.872 | 0.758       | <0.01   | 4.479 |

(continued)
Measurements | Sex | Regression model | R | Adjusted R^2 | p-value | SEE |
|---------------|-----|------------------|---|--------------|---------|-----|
| TCB, MAC, HV, BB | Male | BW = -81.902 + 0.869x TCB** + 1.222x MAC** + 0.295 x HV** + 1.447 x BB** | 0.806 | 0.640 | <0.01 | 4.879 |
| | Female | BW = -89.518 + 1.499x TCB** + 1.306x MAC** + 0.340 x HV** + 0.751 x BB** | 0.856 | 0.727 | <0.01 | 3.596 |
| | Combined sex | BW = -83.299 + 1.025x TCB** + 1.306x MAC** + 0.327 x HV** + 1.042 x BB** | 0.886 | 0.783 | <0.01 | 4.241 |
| TCB, MAC, HV, BB, FBB | Male | BW = -91.827 + 0.856x TCB** + 1.187x MAC** + 0.211 x HV** + 1.378x BB** + 2.677 x FBB** | 0.823 | 0.666 | <0.01 | 4.699 |
| | Female | BW = -93.855 + 1.425x TCB** + 1.171x MAC** + 0.298x HV** + 0.625 x BB** + 2.225 x FBB** | 0.863 | 0.738 | <0.01 | 3.522 |
| | Combined sex | BW = -85.030 + 0.939x TCB** + 1.209x MAC** + 0.249 x HV** + 0.972 x BB** + 2.299 x FBB** | 0.893 | 0.795 | <0.01 | 4.118 |
| TCB, MAC, HV, BB, FBB, SCB | Male | BW = -92.205 + 0.624x TCB** + 0.991x MAC** + 0.206 x HV** + 1.329 x BB** + 2.241x FBB** + 1.009 x SCB** | 0.841 | 0.696 | <0.01 | 4.483 |
| | Female | BW = -94.889 + 1.253x TCB** + 0.969x MAC** + 0.285 x HV** + 0.481 x BB** + 2.380 x FBB** + 0.672 x SCB** | 0.871 | 0.749 | <0.01 | 3.444 |
| | Combined sex | BW = -96.517 + 0.895x TCB** + 1.053x MAC** + 0.297 x HV** + 0.739 x BB** + 2.326 x FBB** + 0.713 x SCB** | 0.901 | 0.808 | <0.01 | 3.990 |
| TCB, MAC, HV, BB, FBB, SCB, FB | Male | BW = -90.099 + 0.598x TCB** + 0.953 x MAC** + 0.141 x HV** + 1.394x BB** + 1.500 x FBB** + 1.000 x SCB** + 1.680 x FB** | 0.848 | 0.706 | <0.01 | 4.413 |
| | Female | BW = -94.608 + 1.219x TCB** + 0.953 x MAC** + 0.262x HV** + 0.440x BB** + 2.224 x FBB** + 0.684 x SCB** + 0.710 x FB** | 0.872 | 0.750 | <0.01 | 3.346 |
| | Combined sex | BW = -94.645 + 0.858x TCB** + 1.039x MAC** + 0.254 x HV** + 0.733 x BB** + 1.877 x FBB** + 0.722 x SCB** + 1.146 x FB** | 0.903 | 0.811 | <0.01 | 3.951 |

Height vertex= HV, Mid Arm Circumference= MAC, Humerus Bicondylar breadth= HBB, Hand Breadth= HB, Transverse Chest Breadth= TCB, Sagittal Chest Breadth= SCB, Bi-iliac Breadth= BB, Femur Bicondylar Breadth= FBB, Ankle Breadth= AB, Foot Breadth= FB, Body Weight= BW.

The regression models were validated and statistics related to this are represented in table 6. The sample that was randomly selected during the first stage of the study was used for this validation study. For this purpose, the difference between the estimated body weight and the actual body weight was computed. This difference was further used to calculate the mean absolute percent prediction error (MAPPE) followed by Ruff et al. (35). After that, the descriptive statistics of the actual body weight and the estimated body weight were calculated (Table 6). In the simple linear regression models, the mean of the estimated body

of 0.05 to 0.5 was used for building multiple linear regression models so the combinations with less than 0.5 f-probabilities were excluded from the models. The rest of the models also show 60% to 80% goodness-of-fit. The standard error estimates in the case of multiple linear regression models for combined sex fall in the range of 3.9-5.1. These values in the case of males and females vary from 4.4-5.7 and 3.4-4.3 respectively. When the SEE of both the regression models was compared, it was found that the multiple linear regression models show less error as compared to the simple linear regression models.
weight ranges from 50.91cm-59.16cm (Std. ±2.85-7.75) and 46.19cm-52.28cm (Std. ±1.81-12.21) in the case of males and females respectively, whereas the actual body weight for males and females was found to be 57.08cm (Std. ±7.42) and 47.67cm (Std. ±11.91) respectively. On the other hand, for the combined sex, the estimated body weight was varied from 50.8cm-53.89cm (Std. ±3.83-10.2) and the actual body weight was 52.68cm (Std. ±10.66). The calculated mean absolute percent prediction error for the female equations (range: 5.97-20.73) was more than males (range: 5.44-10.53) and combined sex (range: 7.82-15.64) equations (Table 6). When the body weight was estimated using multiple linear regression models, it was found that mean of estimated body weight among males and females ranges from 54.26cm-56.10cm (Std. ±3.39-7.67) and 42.44cm-43.03cm (Std. ±8.53-9.76) respectively. While the actual body weight recorded was 57.08cm (Std. ±7.42) and 47.67cm (Std. ±11.91) in the case of males and females respectively. In the case of combined sex, the estimated body weight was found to be 48.95cm-49.90cm (Std. ±8.69-9.68) which is almost close to the mean of the actual body weight i.e., 52.68cm (Std. ±10.66). Even the mean absolute percent prediction error was less in the case of multiple linear regression models than the linear ones. In multiple linear regression models, 7.59-8.41 was recorded in the case of combined sex, whereas 4.39-8.11 and 9.68-11.06 were documented in the case of males and females, respectively.

Table 6. Descriptive statistics with mean absolute percent prediction error of the validation study.

| Sex       | Regression model                                                                 | Minimum (cm) | Maximum (cm) | Mean (cm) | Standard Deviation (cm) | MAPPE (cm) |
|-----------|----------------------------------------------------------------------------------|--------------|--------------|-----------|-------------------------|------------|
| Male      | Actual body weight                                                              | 46.50        | 65.00        | 57.08     | 7.42                    | -----------|
|           | BW = -55.271 + 0.669 x HV**                                                      | 54.60        | 65.01        | 59.16     | 4.14                    | 6.33       |
|           | BW = 3.737 + 2.282 x MAC**                                                       | 48.52        | 60.44        | 54.39     | 4.52                    | 5.44       |
|           | BW = 5.189 + 7.991 x HBB**                                                       | 50.29        | 62.58        | 58.11     | 4.30                    | 8.13       |
|           | BW = 10.722 + 5.684 x HB**                                                       | 46.17        | 62.26        | 54.21     | 5.30                    | 7.13       |
|           | BW = -8.581 + 2.443 x TCB**                                                      | 52.67        | 71.42        | 58.61     | 6.77                    | 10.53      |
|           | BW = 4.477 + 2.782 x SCB**                                                       | 48.25        | 56.45        | 51.75     | 2.89                    | 7.37       |
|           | BW = -29.062 + 3.383 x BB**                                                      | 41.35        | 62.20        | 50.91     | 7.75                    | 5.48       |
|           | BW = -1.283 + 6.322 x FBB**                                                      | 47.00        | 61.59        | 55.92     | 6.10                    | 6.09       |
|           | BW = 43.290 + 2.250 x AB*                                                        | 49.23        | 61.65        | 56.57     | 4.40                    | 10.43      |
|           | BW = 2.830 + 5.799 x FB**                                                        | 52.53        | 60.07        | 57.43     | 2.85                    | 8.34       |
|           | BW = -18.289 + 1.380 x TCB** + 1.627 x MAC**                                    | 51.64        | 61.98        | 56.10     | 3.39                    | 8.11       |
|           | BW = -79.080 + 1.145 x TCB** + 1.457 x MAC** + 0.421 x HV**                      | 51.34        | 64.34        | 56.43     | 5.31                    | 4.91       |
|           | BW = -81.902 + 0.869 x TCB** + 1.222 x MAC** + 0.295 x HV** + 1.447 x BB**       | 49.96        | 66.69        | 55.05     | 6.91                    | 5.24       |
|           | BW = -89.827 + 0.856 x TCB** + 1.187 x MAC** + 0.211 x HV** + 1.378 x BB** + 2.677 x FBB** | 48.01       | 67.27        | 54.80     | 7.67                    | 5.28       |
|           | BW = -92.205 + 0.624 x TCB** + 0.991 x MAC** + 0.206 x HV** + 1.329 x BB** + 2.241 x FBB** + 1.009 x SCB** | 47.10       | 65.86        | 54.26     | 7.60                    | 4.80       |
|           | BW = -90.099 + 0.598 x TCB** + 0.953 x MAC** + 0.141 x HV** + 1.394 x BB** + 1.500 x FBB** + 1.000 x SCB** + 1.680 x FB** | 47.30       | 65.79        | 54.35     | 7.37                    | 4.39       |

(continued)
| Sex            | Regression model                                                                 | Minimum (cm) | Maximum (cm) | Mean (cm) | Standard Deviation (cm) | MAPPE (cm) |
|----------------|----------------------------------------------------------------------------------|--------------|--------------|-----------|-------------------------|------------|
| **Female**     | Actual body weight                                                              | 33.00        | 64.00        | 47.67     | 11.91                   | -----------|
|                | BW = -33.146 + 0.157 x HV**                                                     | 44.04        | 55.17        | 48.02     | 3.77                    | 17.12      |
|                | BW = -0.933 + 2.255 x MAC**                                                     | 37.41        | 67.21        | 47.21     | 12.16                   | 9.37       |
|                | BW = -1.495 + 8.241 x HBB**                                                     | 36.88        | 52.53        | 46.19     | 5.32                    | 18.91      |
|                | BW = -13.446 + 8.302 x HB**                                                     | 43.49        | 52.43        | 47.96     | 3.30                    | 19.03      |
|                | BW = -35.277 + 3.393 x TCB**                                                    | 37.35        | 62.98        | 46.26     | 9.57                    | 10.61      |
|                | BW = -10.423 + 2.899 x SCB**                                                    | 48.07        | 60.64        | 52.28     | 4.83                    | 11.58      |
|                | BW = -18.108 + 2.603 x BB**                                                     | 45.58        | 60.90        | 51.61     | 5.89                    | 14.84      |
|                | BW = -34.326 + 9.514 x FBB**                                                    | 43.12        | 58.67        | 48.14     | 5.55                    | 17.94      |
|                | BW = 4.713 + 5.018 x FB**                                                       | 44.98        | 58.56        | 49.26     | 5.52                    | 20.73      |
|                | BW = -32.499 + 2.029 x TCB** + 1.411 x MAC**                                   | 34.60        | 53.31        | 42.44     | 8.10                    | 10.17      |
|                | BW = -89.060 + 1.753 x TCB** + 1.471 x MAC** + 0.396 x HV**                    | 34.30        | 56.90        | 42.84     | 9.76                    | 9.68       |
|                | BW = -89.518 + 1.499 x TCB** + 1.306 x MAC** + 0.340 x HV** + 0.751 x BB**     | 35.05        | 56.65        | 43.03     | 9.27                    | 9.73       |
|                | BW = -93.855 + 1.425 x TCB** + 1.171 x MAC** + 0.298 x HV** + 0.625 x BB** + 2.225 x FBB** | 35.41     | 54.34      | 42.80     | 8.53                     | 10.93      |
|                | BW = -94.889 + 1.253 x TCB** + 0.969 x MAC** + 0.285 x HV** + 0.481 x BB** + 2.380 x FBB** + 0.672 x SCB** | 35.11 | 54.44 | 42.76 | 8.53 | 10.98 |
|                | BW = -94.068 + 1.219 x TCB** + 0.953 x MAC** + 0.262 x HV** + 0.440 x BB** + 2.224 x FBB** + 0.684 x SCB** + 0.710 x FB** | 34.98 | 54.48 | 43.02 | 8.53 | 11.06 |
| **Combined sex** | Actual body weight                                                             | 33.00        | 65.00        | 52.38     | 10.66                   | -----------|
|                | BW = -64.195 + 0.718 x HV**                                                    | 44.04        | 65.01        | 53.59     | 6.94                    | 11.36      |
|                | BW = -8.430 + 2.701 x MAC**                                                    | 37.41        | 67.21        | 50.80     | 9.52                    | 7.82       |
|                | BW = -16.276 + 11.094 x HBB**                                                   | 36.88        | 62.58        | 52.15     | 7.75                    | 12.94      |
|                | BW = -17.462 + 8.961 x HB**                                                     | 43.49        | 62.26        | 51.19     | 5.33                    | 13.67      |
|                | BW = -28.013 + 3.127 x TCB**                                                   | 37.35        | 71.42        | 52.43     | 10.20                   | 10.47      |
|                | BW = 15.604 + 1.897 x SCB**                                                     | 48.07        | 60.64        | 52.26     | 3.83                    | 12.95      |
|                | BW = -30.450 + 3.264 x BB**                                                     | 41.35        | 62.20        | 51.26     | 6.57                    | 12.24      |
|                | BW = -34.833 + 9.739 x FBB**                                                    | 43.12        | 61.58        | 52.03     | 6.88                    | 11.64      |
|                | BW = 18.332 + 5.519 x AB**                                                      | 48.66        | 61.65        | 53.89     | 4.26                    | 15.64      |
|                | BW = -14.569 + 7.449 x FB**                                                     | 44.98        | 60.07        | 53.34     | 5.98                    | 14.32      |
|                | BW = -31.523 + 1.872 x TCB** + 1.585 x MAC**                                   | 35.34        | 61.50        | 49.10     | 8.69                    | 8.41       |
|                | BW = -68.619 + 1.139 x TCB** + 1.533 x MAC** + 0.351 x HV**                    | 36.07        | 64.25        | 49.90     | 9.68                    | 7.59       |
|                | BW = -83.299 + 1.025 x TCB** + 1.306 x MAC** + 0.327 x HV** + 1.042 x BB**     | 36.34        | 65.95        | 49.31     | 9.51                    | 7.68       |
|                | BW = -85.030 + 0.939 x TCB** + 1.209 x MAC** + 0.249 x HV** + 0.972 x BB** + 2.299 x FBB** | 36.02     | 66.37 | 49.19 | 9.49 | 8.27 |
|                | BW = -96.517 + 0.895 x TCB** + 1.053 x MAC** + 0.297 x HV** + 0.739 x BB** + 2.326 x FBB** + 0.713 x SCB** | 35.75 | 65.25 | 48.95 | 9.63 | 7.75 |
|                | BW = -94.645 + 0.858 x TCB** + 1.039 x MAC** + 0.254 x HV** + 0.733 x BB** + 1.877 x FBB** + 0.722 x SCB** + 1.146 x FB** | 35.39 | 65.05 | 49.14 | 9.49 | 7.67 |
**Discussion**

The relationship between the body weight and percutaneous bone and joint widths may be useful in the assessment of the body size of an individual which may help in forensic identification. In cases, where skeletal remains and body parts are recovered for forensic examinations, identification of the deceased is a prior concern. One can easily estimate the age, sex, and ancestry but estimation of body weight from skeletal remains is a challenge for forensic anthropologists. Authors have devised prediction equations for the estimation of body weight based on skeletal remains (9-14, 36) however; the literature is scanty regarding the estimation of body weight from the percutaneous measurements of the bone and joint widths. In this regard, Ruff et al. (9) tried to devise an equation of conversion of skeletal bi-iliac breadth (SBIB) to the living/percutaneous bi-iliac breadth (LBIB) \( (LBIB = 1.17 \times SBIB - 3 \text{ cm}) \). They have derived these equations for the Pleistocene Homo by comparing them with the modern human species. Further, Ruff (29) has an estimated body mass of elite athletes from stature and bi-iliac breadth. The SEE was found to be 3.6 Kg and 4.1 kg in males and females respectively. But the present study has recorded the SEE from 5.4 – 7.4 kg in the case of bi-iliac breadth whereas 6.3-7.1 kg in the case of stature.

Studies have been conducted on the estimation of body weight of the hospitalized patients with abnormalities (3, 4, 17-19, 37-40). In such studies, doses of the drug are based on the body weight so accuracy during estimation of body weight is a major concern. For that purpose, the regression equation is the best method to accomplish the desired results. Mostly, these prediction equations were based on the data from hospitalized patients whereas very few studies were carried out on the normal adult population (40). The equations derived in the present study are specific for the normal adult population.

Most of the studies have derived body weight estimation equations based on the percutaneous anthropometric measurements (3, 4, 17-19, 37-41). Despite this, studies have used either the computed tomography (27) or dual-energy x-ray absorptiometry (DXA) scans (15). The most common method used in the hospital emergency departments is the visual examination of body weight but the error rate in this method was quite high (35-37). In a study conducted by Martin et al. (37) on 133 cardiac arrest patients, estimated body weight by visual examination and the error rate was found to be more than 10% in 26% cases. Almost similar results were documented by Coe et al. (38) and Leary et al. (39) in their studies. The error rate in the present study was recorded in the form of SEE. The value for SEE in simple linear regression models was found to be 5.8-8.5 in the case of combined sex whereas 5.3-8.0 and 3.8-6.8 were recorded in the case of males and females respectively. This error was found to be quite small in the case of multiple linear regression models. It was 3.9-5.1 for combined sex whereas these values in the case of males and females vary from 4.4-5.7 and 3.4-4.3 respectively (Table 5).

However, in the validation study, this error was measured in the form of a mean absolute percent prediction error (MAPPE). The MAPPE for the female equations (range: 5.97-20.73) was found to larger than males (range: 5.44-10.53) and combined sex (range: 7.82-15.64) equations. The MAPPE was found to be less in the case of multiple linear regression models i.e. 7.59-8.41 was recorded in case of combined sex whereas, 4.39-8.11 and 9.68-11.06 were documented in the case of males and females respectively (Table 6).

In the pediatric emergency department, the stature is mostly used to predict body weight (22-26). They used a tape measure (i.e., Broselaw tape) with the approximated body weight printed over it. The present study also used stature and derived simple linear regression models. But the value of adjusted \( R^2 \) was very low (0.143-0.448) whereas SEE was very high (6.4-7.1) which indicates that it is not a good predictor of body weight which suggests that its simple linear regression model has less practical utility (Table 5).

The earlier studies have also used skinfolds thickness and body circumferences as a predictor of body weight (42, 43). In the present study, in addition to the bone and joint widths, the mid-arm circumference was also used for the estimation of body weight which was found to have a good correlation with body weight. Darnis et al. (3) derived two prediction equations of body weight estimations separately for males and females in hospitalized patients; one equation was based on height, waist circumference, and hip
circumference whereas the other was on height and arm circumference. Crandall et al. (19) derived body weight estimation equations by using arm circumference and height. The R² value for the equation with arm circumference and height was found to be 59.2% in males and 54.7% in females. In the present study also, the arm circumference and height show a good correlation with body weight i.e. 0.7 and 0.6 respectively (Table 4). The simple linear regression model based on mid-arm circumference show 43.8% -56.9% goodness-of-fit for the model with SEE ranges from 4.8-6.1 (Table 5). Moreover, Lorenz et al. (39) conducted a study on 7000 participants and constructed regression equations based on anthropometric measurements which include body height, and waist and hip circumference. They have validated their formulae on a sample of 178 patients and calculated error in the form of mean absolute difference. According to them, these simple anthropometric measurements gave the most accurate estimation with the mean absolute difference of 3.1 (2.6) kg.

Body weight is a highly variable parameter of the human body. It may show significant diurnal variations which may alter the results of such prediction investigations. However, in the present study, this aspect was not taken into consideration; further investigations are suggested in such more controlled conditions for reliable and accurate results.

In the present study, it was found that the multiple linear regression models show better results than linear models in the estimation of body weight from the bone and joint breadths, stature, and mid-arm circumference as they indicate lower values of SEE and MAPPE. Finally, it was observed that as more parameters with good correlation coefficients are added, the accuracy of the model increases, and the value of the SEE decreases. The present study indicates that multiple linear regression models have more practical utility than the linear ones in the estimation of body weight.

**Conclusion**

The present study investigates the relationship of percutaneous body widths, joint widths, stature, and mid-arm circumference with body weight which may help in the assessment of body size of an individual in forensic and other examinations.

The study indicated that the transverse chest breadth and mid-arm circumference were strongly correlated with the body weight, whereas a good correlation was observed in other anthropometric measurements except for the ankle breadth. The multiple linear regression models show better results than linear models. When the SEE of both the regression models was compared, it was found that the multiple linear regression models show less error as compared to simple linear regression models. The value of adjusted R² was more in multiple linear regression models which indicates that these models can be more practically applicable. The practical applicability of the models is further verified by evaluating the mean absolute percent prediction error (MAPPE). The MAPPE was found to be smaller in the case of multiple linear regression models than the linear ones. Hence, it can be concluded that multiple linear regression models are more practically valid for the estimation of body weight from the percutaneous bone and joint widths. The present study was conducted on a specific population; there may a lot of variations in estimating body weight from anthropometric measurements among people of different regions and ancestries. Therefore, further studies are suggested among diverse populations residing in different environmental conditions for further validation of body weight estimation.

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Authors' contributions: DR, KK and TK conceived and conceptualized the idea of writing this paper. DR and AK collected the data under the supervision of KK. DR conducted the analysis and presented the idea of writing this paper. DR and AK collected the data and compiled the results. DR, KK, AK and TK wrote the initial draft of the manuscript. DR, KK, and TK edited and approved the final version of the manuscript. KK and TK supervised the work.

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