**Exploring Anthropometric Measurements for Prediction of Body Build Weight and Gender**

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**ABSTRACT**

Objective: to evaluate the relationships between body measurements and to develop and evaluate prediction models for body build weight and gender.

Methods: Anthropometric measurements were taken for 247 male and 260 female participants. Linear regression was used with the best model selection method to predict body build weight. Body mass index (BMI) was evaluated with respect to body build weight, muscle mass, and fat status. Forward and backward stepwise selection was used with logistic regression to predict gender. Internal validation was carried out for each prediction model using cross-validation.

Results: The model that predicted body build weight the best included skeletal biacromial, skeletal biiliac, skeletal bitrochanteric, skeletal chest depth, skeletal chest, skeletal elbow, knee girth, ankle girth, wrist girth, age, height, and gender. The model had an AIC of -1481.04. BMI was not a good predictor of body build weight with an adjusted R2 of 0.540. Variables selected for the prediction of gender from skeletal measurements included chest depth, bitrochanteric, biacromial, wrist, knee, elbow, and height measurements. This model had a sensitivity and specificity of 96.5% and 95%, respectively.

Conclusions: Skeletal measurements are able to predict body build weight accurately, but this predicted weight is not well correlated with BMI. Additionally, we found that a number of skeletal measurements are able to be used to predict gender.

**BACKGROUND**

Anthropometric measurements are taken to evaluate the size, shape, and composition of the human body. These measurements include body mass index (BMI), waist to hip ratio, and girth measurements at different sites of the body. Constant measures such as skeletal measurements and wrist, knee, and ankle girths may also provide an estimation of body composition. Previous studies have examined the reliability and predictive ability of anthropometric measurements, but many present conflicting results 1,2. A mixture of skinfold measurements, circumferences, weight, and height are proposed; however, these may differ between gender and race/ethnicity 3-7.

A number of studies have also focused on how well anthropometric measurements other than height and weight correlate with BMI 8,9. Since BMI is only based on weight and height, often self-reported, this measurement is subject to bias. BMI does not take into account fat composition or muscle mass and therefore, people may be inadequately grouped into categories of obesity10,11.

Additionally, skeletal measurements have been reviewed for their relationship with body composition and other factors, such as gender. Men’s and women’s skeletal remains have defining features in which gender can be discriminated from, particularly the pelvis. The relationship between other skeletal measurements and gender is not well known though.

In this study, we aim to predict weight using constant anthropometric measurements in an adult population of men and women and to determine the relationship between predicted weight and BMI. Additionally, we aim to predict gender from skeletal measurements. To explore the relationships between body measurements, we use a combination of statistical methods such as linear regression, logistic regression, model selection, and internal validation.

**METHODS**

*Study Population*

The dataset contains 247 male and 260 female participants. For each individual, nine skeletal and twelve girth measurements were taken. Initial measurements were collected at San Jose State University and at the U.S. Naval Postgraduate School in Monterey, California and additional measurements were taken at health and fitness clubs1. Participants were in their twenties to early thirties and were physically active.

Constant measurements included the nine skeletal measurements and ankle, wrist, and knee girths. Changeable girths included shoulder, chest, waist, navel, hip, thigh, bicep, forearm, and calf. Additional measurements included height and weight. Age and gender were also obtained for each participant. We described baseline characteristics of participants by gender. All analyses were completed using Stata Version 14.2/15.

*Aim 1a.*

The outcome, weight, was log transformed for normality. First, linear regression was used for model selection where the input variables included all skeletal measurements, height, gender, and age. The selection criterion used was the Akaike information criterion (AIC). Skeletal ankle, knee, and wrist were replaced with corresponding girth measures to compare the model performance with the first model. Additional analyses were done to explore the efficiency of quadratic models using all girth measures, as well as using three constant girth measures – ankle, knee, and wrist.

Model diagnosis was conducted on the two best models, one linear model and the other quadratic model. Ten-fold cross-validation was done to assess the internal validity.

*Aim 1b.*

We used the predicted weight from our model as body build weight. Since the majority of subjects were in normal weight range, and the body build weight was predicted using body measures which were constant over time, the body build weight can be considered as the normal weight given the body build frame. We regressed the body build weight (log transformed) on BMI with and without gender to evaluate the utility of BMI in relation to body build weight.

We also checked the utility of BMI among subjects with high/low fat mass or muscle mass. Fat status was assessed using the difference between measured waist girth and body build waist girth predicted by chest, biiliac, and bitrochanteric diameters as well as chest depth. A difference of > 5 cm or < -5 cm was defined as high or low fat mass, respectively. Similarly, muscle mass was assessed using difference between measure forearm girth the the body build one predicted by wrist girth, chest diameter and chest depth. A difference of > 1 cm or < -1 cm was defined as high or low muscle mass, respectively.

*Aim 2.*

Logistic regression was used for the prediction of gender from skeletal measurements. For model building, forward and backward stepwise selection were used. A p-value for addition of 0.1 was used and a p-value of 0.25 was used for removal of variables from the model. Model selection was completed with and without height added in the beginning model.

Model diagnostics such as AIC, Bayesian information criterion (BIC), and log-likelihood for each model were calculated and reported. Sensitivity and specificity were also computed for each predictive model. ROC curves were created for the best predictive model including height and the best predictive model without height. Internal validation was completed using cross-validation with ten partitions. The pseudo-R2 was calculated from the ten partitions.

**RESULTS**

The study population contains 247 male and 260 female participants. Baseline characteristics are shown in Table 1. The median age was 27 (25th, 75th percentile: 23, 36) years. The majority of females (78%) and slightly more than half of males (57%) have a BMI of 18.5 to 25. Male participants had higher values for skeletal and girth measurements.

*Aim 1a.*

First, the linear regression model selection was done using all skeletal measurements, height, gender, and age. Backward and forward selection yielded the same result. The best model, Model 1.1, contained skeletal chest depth, skeletal chest, skeletal knee, skeletal bitrochanteric, skeletal wrist, skeletal biiliac, skeletal biacromial, height, and age. We then replaced skeletal ankle, knee, and wrist with corresponding girth measures, and ran the same selection procedure. The best model, Model 1.2, contained skeletal biacromial, skeletal biiliac, skeletal bitrochanteric, skeletal chest depth, skeletal chest, skeletal elbow, knee girth, ankle girth, wrist girth, age, height, and gender. Between the above two models, the second model is preferred due to smaller AIC (-1481.04), which is our best linear model. Ten-fold cross validation was used for internal validation, which yielded a pseudo R2 of 0.9140.

Secondly, quadratic models were fitted on all girth measures plus gender and age, as well as only three constant girth measures (knee, ankle, and wrist) plus gender and age. The quadratic relationship between girth measures and weight was modeled in two ways. One method (method 1) summed all girth measures, squared the sum, and then the sum was multiplied by height. The other method (method 2) multiplied each measure by the height, then was summed, and then squared. The quadratic term was then fitted in a linear model with gender and age as covariates. The first quadratic model, named Model 2.1, had all girth measures, age, and gender using method 1. However, gender was not significant, and the corresponding confidence interval was quite close to null, so we decided to run another model using the same method but without gender, Model 2.2. The third quadratic model, Model 2.3, had all girth measures, age, and gender using method 2. The fourth model, Model 2.4, had only three constant girth measures, age, and gender using method 1. The fifth model, Model 2.5, had only three constant girth measures, age, and gender using method 2. AIC was used to assess the model performance, and the best quadratic model was Model 2.2 (AIC=-1853.18). Ten-fold cross validation was used for internal validation, which yielded a pseudo R2 of 0.9594.

Both linear and quadratic best models gave extremely high adjusted R2, and the linear model was chosen for Aim 1b due to simpler form.

*Aim 1b*

When regressing body build weight on BMI, the adjusted R2 is 0.540, and the pseudo-R2 is 0.536 by ten-fold cross-validation. When regressing body build weight on BMI and gender, the adjusted R2 is 0.748, and the pseudo-R2 is 0.750 by ten-fold cross-validation. Body build waist girth was predicted by chest, biiliac, and bitrochanteric diameters as well as chest depth, with an adjusted R2 of 0.776. Body build forearm girth was predicted by wrist girth, chest diameter and chest depth, with an adjusted R2 of 0.787.

The BMI among subjects with high/low fat mass or muscle mass was shown in Table 3. A total of 49.4% of subjects with high fat mass had a BMI in 25-30, while 16.3% of subjects with low fat mass had a BMI ≤ 20. Of note, females with low fat mass were more likely to have a BMI ≤20 than males with low fat mass. A total of 40.6% of subjects with high muscle mass had a BMI from 25-30, while 19.5% of subjects with low muscle mass had a BMI ≤20. Compared with males with low muscle, females with low muscle mass were more likely to have a BMI ≤20 than males with low muscle mass.

*Aim 2*

We aimed to predict gender using skeletal measurements. In a model including all skeletal measurements and height, the AIC was 129.8. After forward stepwise regression, chest depth, bitrochanteric, biacromial, wrist, knee, elbow, and height measurements were selected into the model (Model 3.2). After backwards stepwise regression, biiliac and ankle measurements were additionally added to the predictive model (Model 3.3). Model diagnostics are shown in Table 4. Model 3.2 from forward stepwise regression had the best log-likelihood, AIC, and BIC. The sensitivity and specificity of this model was 96.5% and 95%. Figure 1 represents the ROC curve for the best model predicting gender with chest depth, bitrochanteric, biacromial, wrist, knee, elbow, and height measurements.

Predictive models were also built without the inclusion of height in the list of skeletal measurements. The model including all skeletal measurements had an AIC of 131.5 (Model 3.4). Forward stepwise regression and backwards stepwise regression selected the same variables of chest depth, bitrochanteric, biacromial, wrist, knee, elbow, and ankle skeletal measurements (Model 3.5 and 3.6). This model had a sensitivity and specificity of 96% and 95%. Figure 2 shows the ROC curve for the best predictive model without height and chest depth, bitrochanteric, biacromial, wrist, knee, elbow, and ankle skeletal measurements. The AIC and BIC were higher for the models with height included, and these models also had increased specificity and sensitivity.

Internal validation was completed for the two best predictive models (Model 3.2 and 3.5) using cross-validation. The pseudo-R2 for Model 3.2 was 0.8420. After internal validation, the pseudo-R2 was 0.8523. For Model 3.5, the pseudo-R2 was 0.8402. Cross-validation returned a pseudo-R2 of 0.8456.

**DISCUSSION**

In this study, we evaluated the relationships between body measurements and developed prediction models for body build weight and gender. The model with the best prediction of body build weight included skeletal biacromial, skeletal biiliac, bitrochanteric, chest depth, chest, elbow, knee girth, ankle girth, wrist girth measurements, age, height, and gender. When evaluating the relationship between body build weight and BMI, we found that BMI is not a good predictor of body build weight. The model with the best prediction of gender included chest depth, bitrochanteric, biacromial, wrist, knee, and elbow skeletal measurements and height.

Both linear and quadratic best models showed great explainability. In the linear model, six skeletal measures, three girth measures, together with age, height and gender, explains 91.70% of all variability in actual weight. Male participants have 0.02 times increased weight as compared to female participants, though the effect was not statistically significant with 95% confidence interval of (-0.01,0.04) and p value of 0.15. We found that when knee, ankle, and wrist skeletal measures were replaced with girth measures, the girth model was not inferior to the skeletal model. This implies that when the skeletal measures are unavailable, those three measures could be replaced with corresponding girth measures.12 The linear model passed the diagnostic tests on homogeneity and normality besides a reasonable amount of influence and leverage points. Internal validation was also conducted which yielded a high pseudo R^2 of 0.9140.

On the other hand, the quadratic model showed an even higher adjusted R2. The model contained a transformation of all girth measures and height, in addition to age. The transformation first summed all girth measures, squared the sum, and then multiplied the sum by height. It’s worth noting that gender wasn’t included in this model. We compared the full model with gender and the parsimonious model without gender based on likelihood ratio test, and we failed to reject the null with test statistic of 0.08, one degree of freedom, and p value of 0.78; therefore, the parsimonious model didn’t differ much from the full model, so the model without gender was preferred. Our finding is consistent with previous literature.12 We also explored using a subset of constant girth measures for the transformation, and the models didn’t outperform our best model using all girth measures. Internal validation of the quadratic model yielded a pseudo R^2 of 0.9594.

Previous studies have shown some limitations of BMI as a measure of adiposity. BMI cannot reflect the central obesity accurately, and people with central obesity are susceptible to obesity-related diseases at a relatively lower BMI13. Our findings indicate that BMI is a poor predictor for the body build weight, and BMI is not a good measure for adiposity especially for subjects with high/low fat or muscle mass. For subjects with high fat or muscle mass, they had a larger body frame for their height, and the BMI tends to classify those subjects as overweight or obese (BMI >25). For one subject with a larger body weight than usual, BMI does not tell whether the extra weight is due to fat or muscle. Similarly, BMI tends to classify subjects who are in low muscle or fat mass as underweight (BMI <20). The findings of our study support the limitation reported by previous studies.

We found that height, chest depth, bitrochanteric, biacromial, wrist, knee, and elbow skeletal measurements best predicted gender in this dataset. Additionally, we evaluated predictive models without height and found that the addition of height adds predictive ability of the model. Overall, the models predicted gender well with high sensitivity and specificity.

Measurements on skeletal remains can be used to predict gender. One of the major skeletal remains used in predicting gender is the pelvic bone, as there are significant differences in male and female pelvic bones14,15. It is estimated that there is more than a 90% accuracy rate of determining gender if skeletal remains are complete16,17. This is similar our findings, as we had over 95% of the participants correctly classified. Although the pelvis is thought of as one of the most predictive of gender, we found that the biiliac measurement was not included after model selection.

When skeletal remains are not complete, the classification becomes less accurate. If not all skeletal remains are found, height might not be observable. In our analysis, we additionally developed predictive models without height to evaluate how well the skeletal measurements predicted gender. Without height, the best predictive model included the ankle skeletal measurement. The model without height was not as good at predicting gender and had less sensitivity. However, the two best predictive models (with and without height) still correctly classified 95.7% and 95.5% of participants.

There are a number of limitations for this study. First, different methods of variable selection were used for each aim. In Aim 1, the best model selection method was used, and in Aim 2, only forward and backward selection were able to be completed. Although different methods were used, the same diagnostic criteria to pick the best models were used for each aim. Additionally, external validation was not able to be carried out. This could result in less generalizability for the study; however, internal validation was completed and showed valid models for this population.

In conclusion, our study found that skeletal measurements are able to predict body build weight accurately, but this predicted weight is not well correlated with BMI. Additionally we found that a number of skeletal measurements are able to be used to predict gender. Based on these findings, we recommend that more than BMI be used to examine body composition, and that skeletal measurements could be integrated more often into clinical care and body composition evaluation.

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**TABLES**

|  |  |  |  |
| --- | --- | --- | --- |
| **Table 1. Baseline characteristics (Median (25th, 75th percentile) or N(%))** | | | |
|  | **Overall (N=507)** | **Female (N=260)** | **Male (N=247)** |
| Age (years) | 27 (23, 36) | 26 (22, 34) | 29 (24, 37) |
| Height (cm) | 170.3 (163.8, 177.8) | 164.5 (160, 169.5) | 177.8 (172.8, 182.9) |
| Weight (kg) | 68.2 (58.4, 78.9) | 59 (54.4, 65.7) | 77.3 (70.9, 85.5) |
| BMI Category |  |  |  |
| Less than 18.5 | 13 (2.6) | 12 (4.6) | 1 (0.4) |
| 18.5-25 | 344 (67.9) | 203 (78.1) | 141 (57.1) |
| 25-30 | 132 (26.0) | 36 (13.9) | 96 (38.9) |
| Over 30 | 18 (3.5) | 9 (3.4) | 9 (3.6) |
| *Skeletal Measurements* |  |  |  |
| Biacromial (cm) | 38.7 (36.2, 41.2) | 36.4 (35.2, 37.8) | 41.2 (39.9, 42.7) |
| Biiliac (cm) | 28 (26.5, 29.3) | 27.8 (26.2, 29.2) | 28 (26.8, 29.5) |
| Bitrochanteric (cm) | 32 (30.6, 33.4) | 31.5 (30, 32.9) | 32.4 (31.4, 33.8) |
| Chest depth (cm) | 19 (17.3, 20.9) | 17.5 (16.5, 18.7) | 20.6 (19.3, 22.1) |
| Chest (cm) | 27.8 (25.6, 30) | 25.9 (24.9, 27.1) | 29.9 (28.6, 31.4) |
| Elbow (cm) | 13.3 (12.4, 14.4) | 12.4 (11.8, 12.9) | 14.4 (13.8, 15.1) |
| Wrist (cm) | 10.5 (9.8, 11.2) | 9.8 (9.4, 10.4) | 11.2 (10.8, 11.7) |
| Knee (cm) | 18.7 (17.9, 19.6) | 18 (17.3, 18.7) | 19.5 (18.8, 20.4) |
| Ankle (cm) | 13.8 (13, 14.8) | 13 (12.4, 13.8) | 14.8 (14.2, 15.3) |
| *Girth Measurements* |  |  |  |
| Shoulder (cm) | 108.2 (99.4, 116.6) | 99.5 (96.1, 104.0) | 116.5 (112.2, 121) |
| Chest (cm) | 91.6 (85.3, 101.2) | 85.5 (82.0, 89.5) | 101 (95.9, 106.1) |
| Waist (cm) | 75.8 (68, 84.5) | 68.3 (64.7, 72.8) | 83.4 (77.9, 90) |
| Navel (cm) | 84.6 (78.8, 91.7) | 82.4 (76.6, 90.1) | 87.3 (81.5, 92.7) |
| Hip (cm) | 96 (92, 101) | 95.0 (90.7, 99.5) | 97.4 (93.2, 101.6) |
| Thigh (cm) | 56.3 (53.7, 59.5) | 56.4 (53.8, 59.8) | 56 (53.7, 59.2) |
| Bicep (cm) | 31 (27.6, 34.5) | 27.8 (26.4, 29.8) | 34.4 (32.5, 36.4) |
| Forearm (cm) | 25.8 (23.6, 28.4) | 23.6 (22.7, 24.7) | 28.4 (27.1, 29.4) |
| Knee (cm) | 36 (34.4, 38) | 35 (33.5, 36.8) | 37 (35.7, 38.5) |
| Calf (cm) | 36 (34.1, 38) | 34.9 (33.1, 36.6) | 37.3 (35.5, 39) |
| Ankle (cm) | 22 (21, 23.3) | 21.1 (20.3, 22) | 23 (22, 24.3) |
| Wrist (cm) | 16.1 (15, 17.1) | 15 (14.5, 15.6) | 17.1 (16.5, 17.9) |

**Table 2. Model selection for body build weight.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Model | Method | Variables | Adjusted R2 | AIC | BIC | Coefficient (CI) of gender | P value for gender |
| **a.)** Predict body build weight with all measurements | | | | | |  |  |
| Model 1.1 | `vselect` | Skeletal Biacromial | 0.8908 | -1345.17 | -1302.89 | na | na |
| Skeletal Biiliac |  |  |  |  |  |
| Skeletal Bitrochanteric |  |  |  |  |  |
| Skeletal chest depth |  |  |  |  |  |
| Skeletal chest |  |  |  |  |  |
| Skeletal wrist |  |  |  |  |  |
| Skeletal knee |  |  |  |  |  |
| Age |  |  |  |  |  |
| Height |  |  |  |  |  |
| Model 1.2 | Replace skeletal measures with girth measures for knee, ankle, and wrist | Skeletal Biacromial | 0.9170 | -1481.04 | -1426.07 | 1.02 | 0.15 |
| Skeletal Biiliac |  |  |  | (0.99, 1.04) |  |
| Skeletal Bitrochanteric |  |  |  |  |  |
| Skeletal chest depth |  |  |  |  |  |
| Skeletal chest |  |  |  |  |  |
| Skeletal elbow |  |  |  |  |  |
| Knee girth |  |  |  |  |  |
| Ankle girth |  |  |  |  |  |
| Wrist girth |  |  |  |  |  |
| Age |  |  |  |  |  |
| Height |  |  |  |  |  |
| Gender |  |  |  |  |  |
| **b.)** Predict the body build weight with “sum, square and multiple” | | | | | | |  |
| Model 2.1 | All girth measures (girth)2\*height, age, and gender | Shoulder girth | 0.9591 | -1851.26 | -1838.58 | 1.00 | 0.78 |
| Chest girth |  |  |  | (0.99, 1.01) |  |
| Waist girth |  |  |  |  |  |
| Navel girth |  |  |  |  |  |
| Hip girth |  |  |  |  |  |
| Thigh girth |  |  |  |  |  |
| Bicep girth |  |  |  |  |  |
| Forearm girth |  |  |  |  |  |
| Knee girth |  |  |  |  |  |
| Calf girth |  |  |  |  |  |
|  |  | Ankle girth |  |  |  |  |  |
|  |  | Wrist girth |  |  |  |  |  |
|  |  | Age |  |  |  |  |  |
|  |  | Gender |  |  |  |  |  |
| Model 2.2 | All girth measures (girth)2\*height, and age | Shoulder girth | 0.9592 | -1853.18 | -1844.73 | na | na |
| Chest girth |  |  |  |  |  |
| Waist girth |  |  |  |  |  |
| Navel girth |  |  |  |  |  |
| Hip girth |  |  |  |  |  |
|  | Thigh girth |  |  |  |  |  |
|  | Bicep girth |  |  |  |  |  |
|  | Forearm girth |  |  |  |  |  |
|  | Knee girth |  |  |  |  |  |
|  |  | Calf girth |  |  |  |  |  |
|  |  | Ankle girth |  |  |  |  |  |
|  |  | Wrist girth |  |  |  |  |  |
|  |  | Age |  |  |  |  |  |
| Model 2.3 | All girth measures, (girth\*height)2, gender, and age | Shoulder girth | 0.9253 | -1545.84 | -1533.15 | 1.02 | <0.0001 |
| Chest girth |  |  |  | (1.01, 1.04) |  |
| Waist girth |  |  |  |  |  |
| Navel girth |  |  |  |  |  |
| Hip girth |  |  |  |  |  |
| Thigh girth |  |  |  |  |  |
| Bicep girth |  |  |  |  |  |
| Forearm girth |  |  |  |  |  |
| Knee girth |  |  |  |  |  |
| Calf girth |  |  |  |  |  |
| Ankle girth |  |  |  |  |  |
| Wrist girth |  |  |  |  |  |
| Age |  |  |  |  |  |
| Gender |  |  |  |  |  |
| Model 2.4 | Three constant girth measures (girth)2\*height, gender, and age | Knee girth | 0.8228 | -1105.64 | -1088.72 | 1.06 | <0.0001 |
| Ankle girth |  |  |  | (1.04, 1.08) |  |
| Wrist girth |  |  |  |  |  |
| Age |  |  |  |  |  |
| Gender |  |  |  |  |  |
| Model 2.5 | Use only three constant girth measures (girth\*height)2, gender, and age | Knee girth | 0.7981 | -1041.32 | -1028.63 | 1.05 | <0.0001 |
| Ankle girth |  |  |  | (1.03, 1.07) |  |
| Wrist girth |  |  |  |  |  |
| Age |  |  |  |  |  |
| Gender |  |  |  |  |  |

**Table 3. BMI for subjects with high/low fat mass or muscle mass.**

**(a)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **High fat mass, n (%)** | | | **Low fat mass, n (%)** | | |
| **BMI** | **Total** | **Male** | **Female** | **Total** | **Male** | **Female** |
| <20 | 2 (2.5) | 0 (0) | 2 (5.6) | 13 (16.3) | 3 (6.5) | 10 (29.4) |
| 20-25 | 26 (32.9) | 13 (30.2) | 13 (36.1) | 56 (70.0) | 33 (71.7) | 23 (67.7) |
| 25-30 | 39 (49.4) | 24 (55.8) | 15 (41.7) | 11 (13.8) | 10 (21.7) | 1 (2.9) |
| >30 | 12 (15.2) | 6 (14.0) | 6 (16.7) | 0 (0) | 0 (0) | 0 (0) |

**(b)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **High muscle mass, n (%)** | | | **Low muscle mass, n (%)** | | |
| **BMI** | **Total** | **Male** | **Female** | **Total** | **Male** | **Female** |
| <20 | 3 (2.8) | 1 (1.3) | 2 (7.4) | 22 (19.5) | 3 (6.5) | 19 (28.4) |
| 20-25 | 56 (52.8) | 40 (50.6) | 16 (59.3) | 70 (62.0) | 26 (56.5) | 44 (65.7) |
| 25-30 | 43 (40.6) | 35 (44.3) | 8 (29.6) | 18 (15.9) | 16 (34.8) | 2 (3.0) |
| >30 | 4 (3.8) | 3 (3.8) | 1 (3.7) | 3 (2.7) | 1 (2.2) | 2 (3.0) |

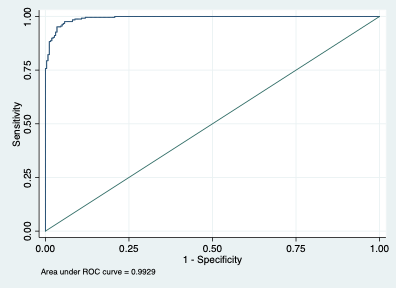
|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Table 4. Model selection for gender based on skeletal measurements** | | | | | |  |  |
| Model | Method | Variables | Log-  Likelihood | AIC | BIC | Sensitivity | Specificity |
| Height and all skeletal measurements | | | | | |  |  |
| Model 3.1 | All skeletal variables and height | Skeletal chest depth  Skeletal chest  Skeletal bitrochanteric  Skeletal biiliac  Skeletal biacromial  Skeletal wrist  Skeletal knee  Skeletal ankle  Skeletal elbow  Height | -53.9 | 129.8 | 176.3 | 95.95% | 95.77% |
| Model 3.2 | Forward selection  P for addition: 0.10  P for removal: 0.25 | Skeletal chest depth  Skeletal bitrochanteric  Skeletal biacromial  Skeletal wrist  Skeletal knee  Skeletal elbow  Height | -55.5 | 127.0 | 160.8 | 96.36% | 95.00% |
| Model 3.3 | Backward selection  P for addition: 0.10  P for removal: 0.25 | Skeletal chest depth  Skeletal bitrochanteric  Skeletal biiliac  Skeletal biacromial  Skeletal wrist  Skeletal knee  Skeletal ankle  Skeletal elbow  Height | -53.9 | 127.8 | 170.1 | 95.95% | 95.77% |
| Without Height in Prediction Model | | | | | |  |  |
| Model 3.4 | All skeletal variables | Skeletal chest depth  Skeletal chest  Skeletal bitrochanteric  Skeletal biiliac  Skeletal biacromial  Skeletal wrist  Skeletal knee  Skeletal ankle  Skeletal elbow | -55.7 | 131.5 | 173.8 | 95.95% | 95.77% |
| Model 3.5 | Forward selection  P for addition: 0.10  P for removal: 0.25 | Skeletal chest depth  Skeletal bitrochanteric  Skeletal biacromial  Skeletal wrist  Skeletal knee  Skeletal ankle  Skeletal elbow | -56.1 | 128.3 | 162.1 | 95.95% | 95.00% |
| Model 3.6 | Backward selection  P for addition: 0.10  P for removal: 0.25 | Skeletal chest depth  Skeletal bitrochanteric  Skeletal biacromial  Skeletal wrist  Skeletal knee  Skeletal ankle  Skeletal elbow | -56.1 | 128.3 | 162.1 | 95.95% | 95.00% |

**FIGURE LEGEND**

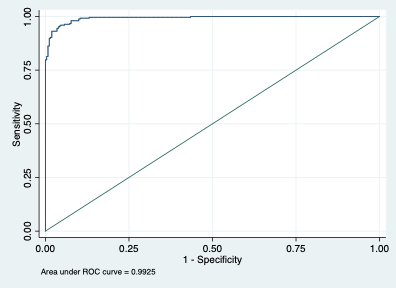
**Figure 1.** Receiver operating characteristic (ROC) curve for the prediction model of gender with skeletal chest depth, skeletal bitrochanteric, skeletal biacromial, skeletal wrist, skeletal knee, skeletal elbow, and height measurements.

**Figure 2.** Receiver operating characteristic (ROC) curve for the prediction model of gender with skeletal chest depth, skeletal bitrochanteric, skeletal biacromial, skeletal wrist, skeletal knee, skeletal elbow, and skeletal ankle measurements.

**FIGURES**



*Figure 1.*



*Figure 2.*