Total body muscle mass estimation from bioelectrical impedance analysis & simple anthropometric measurements in Indian men

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Background & objectives: Skeletal muscle mass represents about 30-40 per cent of the total body weight, and has important roles in function and metabolism. Although newer methods of measuring muscle mass are accurate and sophisticated, there is a need for methods that can be used in low resource settings. Existing methods of predicting muscle mass are based on mid upper arm circumference (MUAC) measurements, sometimes corrected for triceps skinfold fat. The present study was undertaken to develop predictive equations for estimating muscle mass from simple and non-invasive methods such as bioelectrical impedance (BIA) and anthropometric measurements (circumferences and skinfold thickness) in Indian men.

Methods: BIA measurements and anthropometric measurements were carried out on 67 normal, healthy men between the ages of 18 and 45 yr. True muscle mass was measured from 24 h creatinine excretion. Multiple linear regression with step-wise forward selection was used to predict total muscle mass using measurements like height^2/impedance, height and weight and using arm muscle area (AMA), thigh muscle area (TMA) and calf muscle area (CMA).

Results: The prediction equation for muscle mass (kg) using height^2/impedance and height was -12.347+ (0.363xheight^2/impedance) + (0.122xheight) [R^2 = 0.55; Standard error of estimate (SEE) = 2.58 kg], while the equation using appendicular muscle area was 10.122 + (0.23xAMA) + (0.049xTMA) [R^2 0.36; SEE 3.07 kg].

Interpretation & conclusions: This study provides prediction equations for estimating muscle mass in healthy Indian males from simple non invasive methods such as BIA and anthropometric measurements such as circumferences and skinfold thickness. Further studies need to be done on a larger sample size and using an external group to validate the equations.

Key words Bio-electrical impedance - creatinine - Indian men - mid upper arm circumference - muscle mass

The accurate assessment of skeletal muscle mass has a significant role in physiology, nutrition and clinical medicine. Muscle wasting is common in all forms of protein energy malnutrition and starvation, where muscle protein undergoes catabolism and reduces in size. Regardless of its cause, muscle wasting...
affects disease outcome leading to weakness, disability, impaired quality of life and increased hospitalization. Thus, halting the progression of muscle wasting associated with a disease could improve survival and enrich the quality of life of a patient\(^2\).

Asians have higher insulin resistance compared to white Caucasians and this is thought to be due to physiological and structural alterations in the muscle due to poor nutritional status\(^3\). A lower total body muscle mass, which has an independent effect on insulin sensitivity and glucose disposal\(^4,5\) could also determine the risk for developing insulin resistance. Since muscle is so plastic, and amenable to easily instated lifestyle modifications such as exercise, the early detection of low muscle mass, and its response to intervention will be useful in identifying risk for developing chronic diseases as well as the appropriateness of different lifestyle interventions.

Methods such as computerized axial tomography (CT)\(^6\), magnetic resonance imaging (MRI)\(^7\), dual energy X-ray absorptiometry (DEXA)\(^8\) have been used recently to measure skeletal muscle mass accurately. However, these methods are expensive, labour intensive and the CT exposes the individual to radiation. There is therefore a need to develop simple methods to estimate muscle mass. The bioelectrical impedance (BIA) is a relatively simple, quick and non invasive method of measuring body water and fat free mass. The BIA is based on the relation between the volume of a conductor and its electrical impedance, although measures of impedance have been used empirically in determining associations with different body compartments such as fat and the fat free mass. BIA has also provided valid estimates of skeletal muscle mass in western studies of healthy adults varying in age and adiposity\(^9\). However, no studies have been conducted on the Indian population to predict muscle mass from BIA. Another simple method of estimating muscle mass is by the conjoint use of anthropometric measurements such as triceps skinfold thickness and mid arm circumference (MAC), or of circumferences of mid-arm, mid-thigh and calf with the allied skinfold thickness (triceps, mid-thigh and calf) to generate prediction equations\(^10-13\), although studies on the Indian population are limited and based only on the MAC and triceps skinfold\(^14\).

The present study was therefore conducted to derive predictive equations for estimating muscle mass (determined by creatinine method) based on the simple, non invasive methods such as BIA and anthropometric parameters such as circumferences and skinfold measurements in an Indian male population.

**Material & Methods**

**Subjects:** Sixty seven normal, healthy male subjects participated in the study. The subjects were staff, students and volunteers from the neighbouring areas of St. John’s Medical College Hospital, Bangalore. They were informed about the aim of the study and their main reason for participation was interest in finding out their muscle mass and body composition. The inclusion criteria for the study included normal healthy males in the age range of 18 to 45 yr, and subjects who could refrain from meat and excessive physical activity for 3 days. Subjects with any organ failure were excluded from the study. The subjects were made to undergo a complete medical history and physical examination. The study was approved by the Institutional Ethics Review Board and written informed consent was obtained from each subject.

**Anthropometric measurements:** The anthropometric measurements included body weight, height, and circumferences such mid-arm, waist, hip, mid-thigh and medial calf. Subjects were weighed in minimal clothing using a digital scale (AfcoSet, India) to the nearest 0.1 kg. Height was measured using a vertically mounted stadiometer (Parameter, UK) to the nearest 0.1 cm and the circumferences were measured to the nearest 0.1 cm using a non-elastic measuring tape. Body mass index (BMI) was calculated from the height and weight as follows; BMI = weight (kg)/height\(^2\) (m).

Skinfold measurements were carried out on the subjects in triplicate in the standing position and the mean of each taken for further calculation: biceps, triceps, subscapular and suprailiac. The skinfold measurements were carried out to the nearest 0.2 mm using skinfold calipers (Holtain, Crymych, UK). The logarithm of the sum of the four skinfolds was used in age and gender specific equations\(^15\) to obtain the body density, from which estimates of percentage of body fat were made\(^16\). Additional skinfold measurements included those of the mid-thigh and calf. The measurements were all standardized\(^17\) according to accepted protocols, and were taken by one observer.

The mid-arm circumference (cm) and triceps skinfold measurement (cm) were used to calculate arm muscle area (AMA)\(^18\) as follows

\[
AMA (cm^2) = \frac{(MAC - (\pi \times TSF))^2}{4\pi}
\]
where TSF was the triceps skinfold (cm), and MAC was the mid-arm circumference (cm). The AMA was corrected for bone area by assuming that this was 10 cm² in males, to yield the corrected AMA (CAMA). Similarly the calf circumference (cm), calf skinfold (cm) and thigh circumference, thigh skinfold (cm), were used to calculate the calf muscle area- (CMA) (cm²) and the thigh muscle area (TMA) (cm²) as follows\textsuperscript{18}

\[
\text{CMA (cm}^2\text{)} = \frac{(\text{MCC} - (\pi \times \text{CSF}))^2}{4\pi}
\]

\[
\text{TMA (cm}^2\text{)} = \frac{(\text{MTC} - (\pi \times \text{THSF}))^2}{4\pi}
\]

where MCC was the medial calf circumference, CSF was the calf skinfold, MTC was the mid-thigh circumference and THSF was the thigh skinfold.

**Bioelectrical impedance**: Bioelectrical impedance (BIA) was measured in a fasted state, using the Quadscan 4000 (Bodystat, UK) BIA analyzer. A single frequency bioimpedance (Body stat 1500, Bodystat, UK) which costs less (about INR 78,000) can also be used for such a study. The subject was made to lie in a supine position on a non conducting surface, with the arms slightly abducted from the trunk and the legs slightly separated. Surface electrodes were placed on the right side of the body on the dorsal surface of the hands and feet proximal to the metacarpal-phalangeal and metatarsal-phalangeal joints, respectively, and also medially between the distal prominences of the radius and ulna and between the medial and lateral malleoli at the ankle\textsuperscript{19}. The impedance used in the present study was obtained at frequency of 50 kHz at 800 µA.

**Diet and experimental protocol**: The subjects were asked to follow a meat-free diet for a period of 3 days and were encouraged to maintain their customary levels of physical activity\textsuperscript{20}. On the day of the experiment, the subjects reported to the metabolic laboratory of Division of Nutrition, St. John’s Research Institute, Bangalore at 0800 h. A 3-day recall of the patient’s food intake was recorded. The subjects were then asked to empty their bladder and thereafter the urine was completely collected for a period of 24 h. Urinary creatinine (g/day) excretion was estimated using Jaffe’s method\textsuperscript{21} and the creatinine excretion was used to compute values of muscle mass from the equation\textsuperscript{22}

\[
\text{Muscle mass} = 18.9 \text{Cr} \text{ (g/day)} + 4.1
\]

where Cr is the 24 h urinary creatinine excretion.

**Statistical analysis**: Pearson’s correlation coefficient was used to assess the correlation of muscle mass from creatinine with height²/impedence, arm muscle area, thigh muscle area and calf muscle area. As these correlations were found to be significant, multiple linear regression with step-wise forward selection was used to build prediction model for total muscle area using measurements like height²/impedence, height and weight and another prediction model using arm muscle area, thigh muscle area and calf muscle area. The assumptions of multiple linear regression such as multicollinearity were examined. The prediction models obtained were validated using the Jackknife method\textsuperscript{23}. In order to assess whether the CAMA was a good predictor of muscle mass, linear regression was carried out between muscle mass by creatinine estimation and the CAMA. A prediction model with randomly selected sub-set (data set 1) of the whole data was used in order to compute the muscle mass of the unselected sub-set (data set 2). In order to assess the agreement of muscle mass estimation using creatinine and BIA, a Bland Altman plot for data set 2 was generated using the mean of the observed (muscle mass from creatinine) and predicted values (muscle mass from regression equation with height, height²/impedence) in the X axis and in their corresponding differences in the Y axis. The statistical analysis was done using SPSS (Version 13.0, SPSS Inc, Chicago, Illinois) and SYSTAT (Version 11.0, Systat Software Inc, California, USA).

**Results**

The age and characteristics of the subjects are summarized in Table I. The age of the subjects ranged from 18 to 45 yr. The BMI and per cent fat range of the subjects was 14.0 to 24.7 kg/m² and 4.8 to 32.8 per cent

<table>
<thead>
<tr>
<th>Table I. Characteristics of the subjects included in the study</th>
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<tbody>
<tr>
<td><strong>Age (yr)</strong></td>
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<tr>
<td><strong>Body weight (kg)</strong></td>
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<tr>
<td><strong>Height (cm)</strong></td>
</tr>
<tr>
<td><strong>Body mass index (kg/m²)</strong></td>
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<tr>
<td><strong>Mid-arm circumference (cm)</strong></td>
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<tr>
<td><strong>Mid-thigh circumference (cm)</strong></td>
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<tr>
<td><strong>Mid-calf circumference (cm)</strong></td>
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<tr>
<td><strong>Waist circumference (cm)</strong></td>
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<tr>
<td><strong>Hip circumference (cm)</strong></td>
</tr>
<tr>
<td><strong>Bicep skinfold (mm)</strong></td>
</tr>
<tr>
<td><strong>Tricep skinfold (mm)</strong></td>
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<tr>
<td><strong>Subscapular skinfold (mm)</strong></td>
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<tr>
<td><strong>Suprailiac skinfold (mm)</strong></td>
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<tr>
<td><strong>Thigh skinfold (mm)</strong></td>
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<tr>
<td><strong>Calf skinfold (mm)</strong></td>
</tr>
<tr>
<td><strong>% Fat</strong></td>
</tr>
<tr>
<td><strong>Fat free mass (kg)</strong></td>
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<td><strong>Muscle mass from creatinine (kg)</strong></td>
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</tbody>
</table>

All values are in means ± SD (n=67)
respectively. The wide range of BMI was chosen as we wanted to derive an equation that worked across a wide range of muscle mass. The urinary creatinine excretion of the subjects ranged from 0.75 g to 1.5 g/24 h and the estimated muscle mass from urinary creatinine ranged from 19.2 to 32.2 kg.

The ratio of height (Ht) square and of impedance was used to predict muscle mass. The latter, obtained by 24 h creatinine estimation, showed a significant positive correlation with Ht²/impedance values (r = 0.72; P < 0.01). The Bland-Altman plot generated for data set 2 using the validation equation from data set 1 showed a mean error in prediction of 0.14 ± 2.9 kg (Fig.).

Similar significant positive correlations were observed between the measured muscle mass and arm muscle area (r = 0.56; P < 0.01), thigh muscle area (r = 0.54; P < 0.01) and calf muscle area (r = 0.41; P < 0.01). The prediction of muscle mass improved with multiple regressions, and the results of these multiple linear regressions with step-wise forward selection for prediction of muscle mass are summarized in Table II. The Ht²/impedance explained 52 per cent of variance in muscle mass, and on adding height (cm) to the regression model 55 per cent of the variance in skeletal muscle was explained. The prediction equations obtained were as follows:

\[
\text{Muscle mass (kg)} = 4.419 + (0.441 \times \text{Ht}^2/\text{impedance}) \hspace{1cm} (\text{Eq 1})
\]

\[R^2 = 0.52; \text{SEE} = 2.65 \text{ kg (10.3%); SEE expressed as a percentage of muscle mass} \]

\[
\text{Muscle mass (kg)} = -12.347 + (0.363 \times \text{Ht}^2/\text{impedance}) + (0.122 \times \text{height}) \hspace{1cm} (\text{Eq 2})
\]

\[R^2 = 0.55; \text{SEE} = 2.58 \text{ kg (10.0%)} \]

Table II. Multiple linear regression model with step-wise forward selection for predicting muscle mass (by creatinine estimation) from BIA and anthropometric measurements

<table>
<thead>
<tr>
<th>Variable</th>
<th>( R^2 )</th>
<th>( \text{SEE (kg)} )</th>
<th>Significance ( P \text{ value} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ht²/impedance</td>
<td>0.52</td>
<td>2.65</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Ht²/impedance, ht (cm)</td>
<td>0.55</td>
<td>2.58</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>AMA (cm²)</td>
<td>0.31</td>
<td>3.17</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>AMA, TMA</td>
<td>0.36</td>
<td>3.07</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Ht²/impedance – height (cm)/impedance</td>
<td>( \text{Ht, height in cm; AMA, arm muscle area; TMA, thigh muscle area; SEE, standard error of estimate} )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Prediction equations for muscle mass derived from anthropometric parameters were as follows:

From AMA, the equation was

\[
\text{Muscle mass (kg)} = 11.054 + (0.366 \times \text{AMA}) \hspace{1cm} (\text{Eq 3})
\]

\[R^2 = 0.31; \text{SEE} = 3.17 \text{ kg (12.4%)}. \]

From multiple linear regressions with step-wise forward selection for prediction of muscle mass from AMA and TMA, the equation was

\[
\text{Muscle mass (kg)} = 10.122 + (0.23 \times \text{AMA}) + (0.049 \times \text{TMA}) \hspace{1cm} (\text{Eq 4})
\]

\[R^2 = 0.36; \text{SEE} = 3.07 \text{ kg (11.9%)}. \]

The relationship of measured muscle mass with CAMA was also explored, since this is an anthropometric measure that was corrected for bone area. The prediction equation for muscle mass from CAMA was

\[
\text{Muscle mass (kg)} = 14.718 + (0.366 \times \text{CAMA}) \hspace{1cm} (\text{Eq 4})
\]

\[R^2 = 0.31; \text{SEE} = 3.17 \text{ kg (12.4%)}. \]

Discussion

Skeletal muscle is involved in many biological processes and hence its quantification would provide new and important insights. Muscle weakness and chronic fatigue are the symptoms that are seen in diseases such as chronic obstructive pulmonary disorder, chronic heart failure and chronic renal disease. Since muscle wasting is related to symptom intensity, functional capacity and quality of life, treating the wasting process has been associated with beneficial effects for the patient. The estimation of total body skeletal muscle mass is also important for relating muscle mass to exercise performance and evaluating the influence of physical training on muscle mass.

Recent methods in body composition methods such as CT, MRI and DEXA can accurately assess the skeletal muscle mass in adults. Muscle mass can also be
estimated from urinary creatinine excretion, because creatine, the precursor of creatinine is mainly present in the skeletal muscle, although a small amount is produced in smooth muscle, brain and other organs24. However, the creatinine excretion varies on a day to day basis depending on the diet. Thus, although muscle mass can be estimated by highly specific technical methods in a hospital or laboratory, field methods are lacking. The BIA is a simple, rapid, portable and non invasive method that could be used in epidemiological, clinical and field settings. Studies conducted in the western volunteers have developed equations for estimating lean body mass from BIA measurements25, and have demonstrated the BIA to be a valid method of estimating lean body mass. Strong correlations have been also observed between BIA and skeletal muscle measurements in the arms and legs26. However, it should be remembered that several factors such as positioning of the electrodes, hydration status, food intake and exercise must be controlled to ensure reliable BIA measurements19.

Anthropometry is another method which can be used in practical and field settings and the instruments used for measuring anthropometric dimensions are simple, inexpensive, and portable; procedures are non-invasive and require minimal training. Earlier studies performed on cadavers11,12 using anthropometric measurements, provided predictive equations for muscle mass with good accuracy (SEE - 1.5 kg and R² – 0.97). These studies used corrected girth circumferences, which were circumferences (fore arm, mid-thigh and calf) adjusted for skinfold thickness. Later anthropometric prediction models for determining muscle mass using limb circumferences and skinfold thicknesses were developed in non obese and obese subjects31.

Our study provided predictive equations for estimating muscle mass from BIA (R² - 0.55; SEE - 2.58 kg) and arm and thigh muscle area (R² = 0.36; SEE 3.07 kg) for healthy Indian males. The SEE in these methods is between 5-10 per cent of the total muscle mass, but is still low enough to detect differences between groups of otherwise normal subjects with differing nutritional status. For example, the ratio of muscle to visceral weight within the fat free mass (FFM) is lower in undernourished (0.55) subjects than in well nourished subjects (0.62)27. These ratios, when applied to undernourished subjects (assuming a body weight of 50 kg with 10% fat) and well nourished subjects (assuming a body weight of 65 kg with 20% fat) yields a difference in muscle mass of about 7.5 kg between the two groups. This difference is well above the error of the prediction. These measurements may also be important in the measurements of appendicular muscle atrophy in clinical situations of forced bed rest or splinting of limbs. Although limb girth measurements are commonly used to assess muscle atrophy in clinical situations, in reality it is a measure of both bone and fat in that cross-sectional part. The impedance method is useful because it renders a whole body measurement of muscle mass. The present study also assessed muscle mass by linear regression using the CAMA. These results were similar to our previous study14 (r = 0.62; SEE = 3.29 kg), suggesting an internal consistency to the data. The anthropometric prediction equations obtained from the present study can be used to provide a fast and reliable estimate of muscle mass in Indian male populations. These simple measurements are more practical, less expensive and faster than the more sophisticated techniques. The limitations of the present study were that it was conducted only on male subjects and that the prediction equation was validated in the same group of subjects. The unexplained variation observed in this study could be due to small sample size and due to assumptions inherent in the technique such as the oversimplification of the shape of the human body to cylinder and the behaviour of electrical currents in the body. Thus, there is a need for studies with more number of subjects. The Fig. showed a systematic error in the prediction of muscle mass using BIA. However, the mean error was small (0.14 kg). The plot suggested that the prediction equation (n=67) obtained was preferred for groups and should be used with caution in individuals.

In conclusion, the present study documented predictive equations for muscle mass derived from simple methods such as BIA and anthropometric measurements (circumferences and skinfold thickness) in Indian males. Increasing the sample size and using an external group to validate the equation are needed in future studies. Additionally studies for deriving predictive equations in women and individuals of different age groups need to be planned.

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References


