Comparison on two algorithms of skeletal muscle mass index: an observational study in 141,451 Chinese adults

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Research

Keywords: physical examination, body weight, total muscle mass, skeletal muscle mass index, body mass index

Posted Date: August 9th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-779117/v1

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Abstract

Background/Aims

There were two methods used for measuring skeletal muscle mass index (SMI); one is SMM (%) = skeletal muscle mass (kg) / body weight mass (kg) × 100%, and the other is SMH (kg/m^2) = skeletal muscle mass (kg) / height (m)^2. The aim of this study was to compare on the distribution of the two algorithms of SMI.

Methods

This study included 141,451 participants who accepted physical examination. Body mass index (BMI), and body fat percentage (BFP) were estimated using a bioelectrical impedance analyzer. SMI was calculated by the two algorithms.

Results

Levels of BMI, BFP, SMM and SMH differed significantly among the sexes. BMI and BFP were significantly positively correlated with age, while SMM was significantly negatively correlated with age (β = -0.23, P < .001). There was no significant correlation between SMH and age. Furthermore, there was a negative correlation between SMM and BMI (β = -0.53, P < .001), and a positive correlation between SMH and BMI (β = 0.79, P < .001). Both SMM (β = -0.98, P < .001) and SMH (β = -0.0642, P < .001) were negatively correlated with BFP. Nevertheless, the correlation coefficient of the former was significantly greater than that of the latter. In gender stratification, SMM maintained the analogous correlation, while the correlation between SMH and other indicators changed. SMM showed a gradual downward trend, but SMH and BFP showed a gradual upward trend from low body weight to grade III obesity.

Conclusions

SMM may be a more ideal algorithm for reflecting SMI, compared to SMH.

Introduction

The mass and strength of human muscles are closely related to the various functions of the human body. With the progressive aging of the general population, sarcopenia has emerged as a medical and socio-economic problem. In terms of human health, sarcopenia not only increases the risk of diabetes [1], arthritis [2], osteoporosis [3], respiratory diseases [4], heart disease [5], but also causes Parkinson's disease and cancer [6,7]; leading to lowered quality of life and contributing to death [8,9]. Sarcopenia severely compromises the ability of daily living, hampers the quality of life, and thus, is an increasingly prominent issue, particularly in aging societies [10]. The diagnosis of sarcopenia consists of both reduced skeletal muscle mass and decreased skeletal muscle function in patients [11,12,13]. There are two methods commonly used for measuring skeletal muscle mass; one is to use skeletal muscle mass as
a percentage of body weight (SMM) [14,15], and the other is to divide skeletal muscle mass by the square of height (SMH). Both procedures are called skeletal muscle mass index (SMI) [11–15].

SMI is a well-established index for assessment of skeletal muscle mass and diagnosis of sarcopenia [16,17]. Furthermore, body mass index (BMI) is widely used as an alternative measurement of body composition in clinical and research settings. However, the discordant discovery of obesity paradox has aroused people's attention to the shortcomings of BMI in measuring body characteristics and predicting disease risk [18]. The divergence of research findings may be attributed to the most fundamental problem of inaccurate measurement. Clinical complications and mortality are also different in patients with similar BMIs, often because race, age, gender and body composition vary greatly. Recent studies show that we need to use body composition, such as SMI, to measure the human body more accurately, rather than BMI, height or weight for more accurate health assessment and disease risk assessment [19,20].

Accurate analysis of body composition measurements is the basis of individualized treatment and intervention strategies. The present study aims to investigate the distribution of two algorithms of SMI in a large-scale people who had health examination, so as to explore the different features among SMM, SMH, BMI, and BFP; especially the different changes with aging and gender.

**Methods**

**Study Design and Setting**

This retrospective observational study was conducted. Participants were recruited in our hospital from September 2014 to March 2019. All subjects were informed that their health examination data could be used anonymously for scientific research and signed informed consent. This study was approved (S2017-003-02) by the Chinese People's Liberation Army General Hospital Ethics Committee and complied with the principles of the Declaration of Helsinki and its contemporary amendments.

**Study Population**

Subjects who finished the health examination were enrolled. Exclusion criteria were applied: not approval of this study; with severe debilitating diseases such as definite stroke with paralysis, severe cardiac insufficiency, renal insufficiency, the inability to move by themselves; with a medical history of major operations, including amputation; malignant tumor ; under 18 years or over 100 years.

**Data Collection**

All participants were subjected to a clinical survey and physical examination. Each subject completed an investigator administered questionnaire that covered details of demographic characteristics.

**Body Composition Parameters**

Body mass and composition were estimated using a bioelectrical impedance analyzer (InBody 720 analyzer, InBody Co. Ltd, Seoul, Korea), which uses a tetrapolar, 8-point tactile electrode system that
separately measures impedance of the arms, trunk, and legs at six different frequencies (1, 5, 50, 250, 500, and 1000 kHz). The InBody 720 automatically estimates weight, height, BMI and body fat percent (BFP, body fat/weight x 100%). SMM (total muscular mass / weight x 100%) and SMH (total muscular mass/height $^2$, kg/m$^2$) were also calculated.

**Subject Classifications**

A body mass index (BMI) categorical variable was defined as follows: underweight (BMI < 18.5 kg/m$^2$), normal (BMI 18.5–23.9 kg/m$^2$), overweight (BMI 24.0-27.9 kg/m$^2$). The obese subjects were divided into subgroups: grade I obesity (28.0-31.9 kg/m$^2$), grade II obesity (32.0-35.9 kg/m$^2$), grade III obesity ($\geq$ 36.0 kg/m$^2$). For this study, subjects were divided into young group (age < 45 years), middle-age group (45 $\leq$ age < 60 years), the elderly group (60 $\leq$ age < 80 years), and the advanced age group (age $\geq$ 80 years).

**Statistical Analysis**

The data of the questionnaire were encoded and quantified and inputted into the computer. Statistical analysis was performed using STATA, version 11.0, for Windows (STATA, College Station, TX).

The measurement data were presented as mean ± standard deviation (SD), and the classification data were expressed as rate. The Kolmogorov-Smirnov method or graphic method was used to test the normality. Firstly, the descriptive statistics were performed to characterize the study participants. The two-sample Wilcoxon rank-sum test, single factor analysis, or $t$-test was used to compare baseline characteristics of the subjects. Secondly, differences in levels of BMI, BFP, SMM and SMH among different age groups or BMI groups were compared by using single factor analysis of variance or analysis of covariance, and Bonferroni method for pairwise comparison. Thirdly, the univariate correlations of age, BMI, BFP, SMM and SMH were calculated. Statistical significance was determined based on a $P$ value < .05.

**Results**

**Participant Characteristics**

Of the 150035 subjects who finished the health examination from September 2014 to March 2019, 8584 subjects were excluded because they met the exclusion criteria. Therefore, 141,451 subjects were included, in which 90,526 (64.0%) cases were male and 50,925 (36.0%) cases were female. Mean age was 46.9 ± 9.8 years. Baseline characteristics are shown in Table 1. BMI ($Z = 129.5, P < .001$), BFP ($Z = 154.9, P < .001$), SMM ($Z = 158.4, P < .001$) and SMH ($Z = 269.9, P < .001$) were significantly different between males and females using the two-sample Wilcoxon rank-sum test.
Table 1
Results of body composition parameters in different groups

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>weight (kg)</th>
<th>muscle mass (kg)</th>
<th>BFP (%)</th>
<th>SMM (%)</th>
<th>SMH (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
<td>141451</td>
<td>71.0 ± 12.9</td>
<td>49.3 ± 8.9</td>
<td>25.4 ± 6.1</td>
<td>69.6 ± 5.9</td>
<td>17.2 ± 2.0</td>
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<td><strong>gender</strong></td>
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<td></td>
</tr>
<tr>
<td>female</td>
<td>50925</td>
<td>60.4 ± 9.0</td>
<td>39.7 ± 4.0</td>
<td>28.7 ± 5.9</td>
<td>66.3 ± 5.6</td>
<td>15.3 ± 1.3</td>
</tr>
<tr>
<td>male</td>
<td>90526</td>
<td>76.9 ± 10.9</td>
<td>54.6 ± 6.0</td>
<td>23.5 ± 5.4</td>
<td>71.5 ± 5.3</td>
<td>18.3 ± 1.6</td>
</tr>
<tr>
<td><strong>Age groups</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young</td>
<td>55627</td>
<td>70.6 ± 14.3</td>
<td>49.8 ± 9.4</td>
<td>23.9 ± 6.0</td>
<td>70.9 ± 5.8</td>
<td>17.2 ± 2.2</td>
</tr>
<tr>
<td>middle-age</td>
<td>72263</td>
<td>71.8 ± 12.1</td>
<td>49.4 ± 8.6</td>
<td>26.0 ± 5.8</td>
<td>68.9 ± 5.6</td>
<td>17.3 ± 1.9</td>
</tr>
<tr>
<td>the elderly age</td>
<td>13503</td>
<td>68.3 ± 11.4</td>
<td>46.0 ± 8.5</td>
<td>27.5 ± 6.9</td>
<td>67.5 ± 6.7</td>
<td>16.8 ± 1.9</td>
</tr>
<tr>
<td>the advanced age</td>
<td>58</td>
<td>65.8 ± 12.7</td>
<td>44.5 ± 8.9</td>
<td>27.9 ± 7.9</td>
<td>67.8 ± 7.6</td>
<td>16.4 ± 2.2</td>
</tr>
<tr>
<td><strong>BMI groups</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>under weight</td>
<td>3677</td>
<td>48.1 ± 4.9</td>
<td>38.2 ± 5.5</td>
<td>15.5 ± 5.7</td>
<td>79.3 ± 5.7</td>
<td>13.8 ± 1.0</td>
</tr>
<tr>
<td>normal</td>
<td>52530</td>
<td>61.0 ± 7.6</td>
<td>44.1 ± 7.2</td>
<td>22.8 ± 5.7</td>
<td>72.1 ± 5.5</td>
<td>15.7 ± 1.4</td>
</tr>
<tr>
<td>overweight</td>
<td>60267</td>
<td>74.3 ± 7.8</td>
<td>51.2 ± 7.4</td>
<td>26.3 ± 5.0</td>
<td>68.7 ± 4.9</td>
<td>17.7 ± 1.4</td>
</tr>
<tr>
<td>I obesity</td>
<td>21221</td>
<td>85.4 ± 8.3</td>
<td>56.3 ± 7.8</td>
<td>29.4 ± 4.9</td>
<td>65.7 ± 4.8</td>
<td>19.3 ± 1.4</td>
</tr>
<tr>
<td>II obesity</td>
<td>3230</td>
<td>96.6 ± 9.8</td>
<td>60.6 ± 8.8</td>
<td>32.6 ± 4.9</td>
<td>62.6 ± 4.7</td>
<td>20.8 ± 1.6</td>
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<tr>
<td>III obesity</td>
<td>526</td>
<td>111.7 ± 13.5</td>
<td>65.9 ± 10.5</td>
<td>36.4 ± 5.3</td>
<td>58.8 ± 4.9</td>
<td>22.5 ± 2.0</td>
</tr>
</tbody>
</table>

BMI: body mass index; BFP: body fat/weight¹00%; SMM: total muscular mass / weight ¹100%; SMH: muscular mass/height²

**Frequency distribution of BMI, BFP, SMM and SMH**
BMI, BFP, SMM and SMH were not normally distributed among the research objects by the Kolmogorov-Smirnov method ($P < .05$). In histograms, the distributions of BMI (Fig. 1. A) and SMM (Fig. 1. C) were very similar to normal distribution, but the distributions of BFP (Fig. 1. B) and SMH (Fig. 1.D) were skewed distribution, especially SMH.

**Frequency distribution of BMI, BFP, SMM and SMH in different genders**

Figure 2 showed frequency distribution of BMI, BFP, SMM and SMH in females. The distribution of SMM (Fig. 2. C) seemed to be closer to the normal distribution than BMI (Fig. 2. A). Figure 3 showed frequency distribution of BMI, BFP, SMM and SMH in males. The four indicators showed an obvious tailing phenomenon in males. Nevertheless, the distribution of SMM (Fig. 3. C) was closer to the normal distribution, followed by SMH.

**The relationship between research indicators in different genders**

The correlation matrix of age, BMI, BFP, SMM and SMH is shown in Supplementary Table 1. In all subjects, BMI, BFP and SMM were significantly correlated with age. BMI and BFP were significantly positively correlated with age, whereas, SMM was significantly negatively correlated with age ($\beta = -0.23$, $P < .001$). There was no significant correlation between SMH and age. There was a significant negative correlation between SMM and BMI ($\beta = -0.53$, $P < .001$), and a significant positive correlation between SMH and BMI ($\beta = 0.79$, $P < .001$). Both SMM ($\beta = -0.98$, $P < .001$) and SMH ($\beta = -0.06$, $P < .001$) were negatively correlated with BFP. Nevertheless, the correlation coefficient of the former was significantly greater than that of the latter.

In females, SMM was significantly negatively correlated with age. However, SMH was significantly positively correlated with age. SMM was still negatively correlated with BFP. Meanwhile, there was a significant negative correlation between SMH and BFP. SMM and SMH also showed significant negative correlation.

In males, there was no significant association between BMI and age. This was different from the female population, where SMM and SMH were significantly negatively correlated with age.

**Trend of BMI, BFP, SMM, and SMH levels in different age groups**

Differences in levels of body composition indices between age groups were compared by one-way analysis of variance and the Bonferroni method, as shown in Supplementary Table 2. In the general population, male or female, there were significant differences in levels of BMI, BFP, SMM and SMH in different age groups.
By pairwise comparison, BMI showed a trend of increasing first and then decreasing, while BFP showed an increasing trend with age increased. With the increasing of age, SMH also showed a firstly increasing trend and then a decreasing trend. SMM in the whole population and female population showed a decreasing trend, while the elderly group had an increasing process in the male population.

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>BMI</th>
<th>BFP</th>
<th>SMM</th>
<th>SMH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI</td>
<td>0.13, &lt; .001</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BFP</td>
<td>0.23, &lt; .001</td>
<td>0.54, &lt; .001</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMM</td>
<td>-0.23, &lt; .001</td>
<td>-0.53, &lt; .001</td>
<td>-0.98, &lt; .001</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>SMH</td>
<td>-0.003, .24</td>
<td>0.79, &lt; .001</td>
<td>-0.06, &lt; .001</td>
<td>0.08, &lt; .001</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>In females</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI</td>
<td>0.34, &lt; .001</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BFP</td>
<td>0.44, &lt; .001</td>
<td>0.83, &lt; .001</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMM</td>
<td>-0.45, &lt; .001</td>
<td>-0.84, &lt; .001</td>
<td>-0.98, &lt; .001</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>SMH</td>
<td>0.16, &lt; .001</td>
<td>0.86, &lt; .001</td>
<td>0.46, &lt; .001</td>
<td>-0.46, &lt; .001</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>In males</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI</td>
<td>0.001, .86</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BFP</td>
<td>0.11, &lt; .001</td>
<td>0.75, &lt; .001</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMM</td>
<td>-0.11, &lt; .001</td>
<td>-0.74, &lt; .001</td>
<td>-0.98, &lt; .001</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>SMH</td>
<td>-0.07, &lt; .001</td>
<td>0.82, &lt; .001</td>
<td>0.27, &lt; .001</td>
<td>-0.24, &lt; .001</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Total: in total subjects; In females: in the female subjects; In males: in the male subjects.
Table 3
Results of research parameters in the different age groups

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>BMI (kg/m²)</th>
<th>BFP(%)</th>
<th>SMM(%)</th>
<th>SMH (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
<td>141451</td>
<td>24.4 ± 3.8</td>
<td>23.9 ± 6.0</td>
<td>70.9 ± 5.8</td>
<td>17.2 ± 2.2</td>
</tr>
<tr>
<td>young group</td>
<td>55627</td>
<td>25.2 ± 3.2 a</td>
<td>26.0 ± 5.8 a</td>
<td>68.9 ± 5.6 a</td>
<td>17.3 ± 1.9 a</td>
</tr>
<tr>
<td>middle-age group</td>
<td>72263</td>
<td>25.1 ± 3.2 a,b</td>
<td>27.5 ± 6.9 a,b</td>
<td>67.5 ± 6.7 a,b</td>
<td>16.8 ± 1.9 a,b</td>
</tr>
<tr>
<td>the elderly group</td>
<td>13503</td>
<td>24.4 ± 3.7</td>
<td>27.9 ± 7.9 a</td>
<td>67.8 ± 7.6 a</td>
<td>16.4 ± 2.2 a</td>
</tr>
<tr>
<td>the oldest group</td>
<td>58</td>
<td>24.4 ± 3.7</td>
<td>27.9 ± 7.9 a</td>
<td>67.8 ± 7.6 a</td>
<td>16.4 ± 2.2 a</td>
</tr>
<tr>
<td><strong>F value</strong></td>
<td>546.4</td>
<td>1853.2</td>
<td>1893.9</td>
<td>219.9</td>
<td></td>
</tr>
<tr>
<td><strong>P value</strong></td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td></td>
</tr>
<tr>
<td><strong>In females</strong></td>
<td>50925</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>young group</td>
<td>19958</td>
<td>22.1 ± 3.3</td>
<td>26.0 ± 5.8</td>
<td>68.9 ± 5.5</td>
<td>15.1 ± 1.3</td>
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<td>middle-age group</td>
<td>24887</td>
<td>23.9 ± 3.2 a</td>
<td>29.9 ± 5.1 a</td>
<td>65.1 ± 4.8 a</td>
<td>15.5 ± 1.3 a</td>
</tr>
<tr>
<td>the elderly group</td>
<td>6068</td>
<td>24.9 ± 3.4 a,b</td>
<td>32.3 ± 5.4 a,b</td>
<td>62.8 ± 5.1 a,b</td>
<td>15.5 ± 1.3 a</td>
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<tr>
<td>the oldest group</td>
<td>12</td>
<td>23.9 ± 3.8 a</td>
<td>35.2 ± 5.8 a</td>
<td>60.9 ± 5.7 a,b</td>
<td>14.5 ± 1.9 b,c</td>
</tr>
<tr>
<td><strong>F value</strong></td>
<td>1742.8</td>
<td>2949.1</td>
<td>3154.0</td>
<td>379.6</td>
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</tr>
<tr>
<td><strong>P value</strong></td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td></td>
</tr>
<tr>
<td><strong>In males</strong></td>
<td>90526</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>young group</td>
<td>35669</td>
<td>25.7 ± 3.5</td>
<td>22.8 ± 5.8</td>
<td>72.1 ± 5.7</td>
<td>18.4 ± 1.6</td>
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<td>middle-age group</td>
<td>47376</td>
<td>25.8 ± 2.9 a</td>
<td>23.9 ± 5.0 a</td>
<td>70.9 ± 4.9 a</td>
<td>18.2 ± 1.5 a</td>
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<td>7435</td>
<td>25.2 ± 3.0 a,b</td>
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<tr>
<td>the oldest group</td>
<td>46</td>
<td>24.6 ± 3.7 b</td>
<td>26.1 ± 7.3 a,c</td>
<td>69.5 ± 6.9 a</td>
<td>16.9 ± 1.9 a,b,c</td>
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<tr>
<td><strong>F value</strong></td>
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<td>307.9</td>
<td>303.1</td>
<td>240.4</td>
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<tr>
<td><strong>P value</strong></td>
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<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td></td>
</tr>
</tbody>
</table>

a: compared with young group; b: compared with middle aged group; c: compared with the elderly group.

Trends in BFP, SMM, and SMH in different BMI groups

No matter in the total, males or females, SMM showed a decline trend from low weight to III degree of obesity \((F = 9528.3, P < .001)\), and pairwise comparisons were statistically significant by the Bonferroni method between every two groups. SMH \((F = 34395.5, P < .001)\) and BFP \((F = 9706.2, P < .001)\) showed the
increasing trends among different BMI groups, and there were significant differences between every two groups \( P < .001 \) (Fig. 4).

**Discussion**

The main method of evaluating skeletal muscle is to detect skeletal muscle mass and muscle strength. Skeletal muscle mass can be measured by anthropometry, endogenous muscle metabolism, computed tomography (CT) \(^2\)\(^1\), magnetic resonance imaging (MRI) \(^2\)\(^2\), dual-energy X-ray absorptiometry (DXA) \(^2\)\(^3\),\(^2\)\(^4\), and bioelectrical impedance analysis (BIA). Among these methods, BIA-derived phase angle measurement is an objective, noninvasive and very convenient method to assess muscle quality \(^2\)\(^5\).

Currently, the percentage of skeletal muscle mass to total body weight (SMM) has been recommended in different consensuses \(^2\)\(^6\),\(^2\)\(^7\). At the same time, there are some applications of skeletal muscle mass divided by the square of height in some studies \(^2\)\(^8\). There are even other methods of calculation \(^2\)\(^9\). These methods are all defined as skeletal muscle mass index (SMI) by international study groups on sarcopenia \(^2\)\(^0\). So far, there is no universal consensus on assessment methods for research in this area or routine clinical practice. This undoubtedly leads to the confusion of SMI concept. Thus, the determination of which operational algorithms are most appropriate to assess skeletal muscle mass remains inconclusive \(^2\)\(^1\),\(^2\)\(^2\). Therefore, it is necessary to compare characteristics of different algorithms. Few available studies had compared SMM with SMH in the same group of subjects. Large-scale study in the Chinese population to address this issue are urgently warranted.

**Theoretical analysis of algorithm comparison**

The measurement of a person's skeletal muscle condition, mainly depends on the quality of skeletal muscle. When weight gains, it may be the increase of skeletal muscle mass, but it also can be the increase of body fat. The change of skeletal muscle can be well reflected by SMM. In theory, given a constant body weight, skeletal muscle mass should be negatively correlated with body fat mass. In the case of an adults' height unchanged, if the total weight is on the increase, which is mainly the increase of body fat, accompanied by a small increase in skeletal muscle mass, SMI will increase. Therefore, it is considered that SMM can better objectively reflect a person's skeletal muscle mass.

**Main findings and comparison with other studies**

From the results of this study, there was a significant difference between SMM and SMH. First of all, the sample data was large enough for normal distribution graphics. However, as can be seen by Fig. 1, Fig. 2 and Fig. 3, the normality, concentration, and stability of the distribution are expressed as SMM > BMI > BFP > SMH, which suggests that SMM is a superior assessment of body composition measurement.

Secondly, age and gender have been confirmed as important covariates in most body composition studies \(^2\)\(^3\). In our study, SMM and SMH showed the significant difference between male and female genders. Compared with different age groups, BMI, BFP, SMM and SMH had different trends with age in
different populations. For example, among different age groups, SMM was the highest in the young group, followed by the middle-aged group, but SMM in the elderly group was higher than that in the middle-aged group. The living habits of people of different ages and genders varied, resulting in different changes in body composition. For example, in the Chinese population, elderly men began to exercise after retirement, and so their SMM would increase. The weight changed with the change of muscle mass, but the height could not change after adulthood, so the trend of SMH was different in males and females. Other authors reported high correlations between skeletal muscle mass and age [34]. According to previous research results, the change in SMM with age is more realistic than that of SMH.

The correlation between SMM and age, BMI, and BFP remained constant throughout, regardless of group. However, there was an inconsistent relationship between age, BMI, BFP, and SMH. These findings suggest that SMM is not only significantly correlated with age, BMI and BFP, but also remained relatively stable in the population with different genders.

As shown previously, SMM was negatively correlated with BMI or BFP, respectively. SMH was inversely correlated with BMI, but negatively correlated with BFP. Generally, as muscle increases, BFP or BMI should decrease. In our study, the higher the body fat, the higher the BFP. Similar correlations of BFP with BMI have been found in other studies [35,36]. SMM is more reasonable than SMH in this regard. Changes in SMM with different BMI groups and BFP is not only in line with the law of nature, but also which is consistent with the existing research and theory in sarcopenia. However, changes in SMH with different BMI groups is completely different from the ones in the existing researches [37,38]. Numerous studies have shown that the incidence of chronic diseases is different with different BMI [39]. Therefore, using different methods to calculate skeletal muscle mass parameters has different clinical guidance significance.

**Strengths and Limitations**

This study had several strengths. First, we included data from a large general population study in China covering all stages of the adult life. Secondly, the biological characteristics of the subjects were relatively comprehensive, including age, gender, and BMI. Thirdly, the number of study subjects was relatively larger than that of previous studies.

Our study also had some limitations. Firstly, the study was limited to Chinese people and did not include other ethnic groups. Secondly, this study was limited to healthy people, excluding patients with serious heart or brain diseases. Thirdly, BFP, SMM, and SMH were based only on BIA measurements, not on more precise methods available to directly measure body composition such as CT or MRI. Finally, this study was a cross-sectional study, selection and loss-to-follow up biases might have influenced accuracy of our conclusion. Ideally, however, future prospective studies should consider optimum sampling strategies when prediction formulas for SMI are developed based on BMI.

**Conclusions**
In conclusion, the findings derived from this study is important both from theoretical and practical standpoints, SMM may be more appropriate to the distribution characteristics of skeletal muscle mass in the population. Men were significantly higher than women in SMM, and young people were the highest. SMM was negatively correlated with BFP, BMI and age. Further studies are needed to confirm the relationship between SMI indices and its risk of various diseases. And further studies with larger patient numbers and prospective design are needed to confirm our findings.

Declarations

Ethics approval and consent to participate

This study was approved (S2017-003-02) by the Chinese People's Liberation Army General Hospital Ethics Committee and complied with the principles of the Declaration of Helsinki and its contemporary amendments.

Consent for publication

All authors of the manuscript have read and agreed to its content and are accountable for all aspects of the accuracy and integrity of the manuscript in accordance with ICMJE criteria. The article is original, has not already been published in a journal, and is not currently under consideration by another journal. We agree to the terms of the BioMed Central Copyright and License Agreement.

Availability of data and material

Not applicable

Competing interests

The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

Funding:

This research received no external funding.

Authors' contributions

Qiang Zeng designed this study. Yan-song Zheng wrote the original drafts. Sheng-yong Dong reviewed and edited the manuscript. Zhen Huang acquired and analyzed the data. Yan-song Zheng and Zhen Huang contributed equally as co-first authors. All authors read and approved the final manuscript.

Acknowledgements

The authors would like to acknowledge the wholehearted support from the faculty of the second medical center & national clinical research center for geriatric diseases, Chinese PLA general hospital.
References


Figures
Figure 1

Frequency distribution of BMI, BFP, SMM and SMH. The distributions of age (Fig. 1. A) and SMM (Fig. 1. C) were very similar to normal distribution, but the distributions of BFP (Fig. 1. B) and SMH (Fig. 1. D) were not standard normal distribution, especially SMH.
Figure 2

Frequency distribution of BMI, BFP, SMM and SMEI in females. The distribution of SMM (Fig.2. C) seemed to be closer to the normal distribution than BMI (Fig.2. A).
Figure 3

Frequency distribution of BMI, BFP, SMM and SMH in males. The four indicators showed obvious tailing phenomenon in males. However, the distribution of SMM (Fig. 3. C) is closer to the normal distribution, followed by SMH (Fig. 3. D).
Figure 4

Distribution trend of BFP, SMM and SMH in different BMI groups. A, In total; B, in females, C in males. It could be seen that, no matter in the total subjects, or in the males or females, SMM presented a gradual downward trend with BMI stratification. However, both BFP and SMH showed an upward trend with the stratification of BMI, and the increase of BFP was higher than that of SMH. All indicators showed significant difference between every two groups by Bonferroni method (P < 0.001).