Reference values of skeletal muscle area for diagnosis of sarcopenia using chest computed tomography in Asian general population

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Abstract

Background   Diagnostic cutoff points for sarcopenia in chest computed tomography (CT) have not been established although CT is widely used for investigating skeletal muscles. This study aimed to determine reference values for sarcopenia of thoracic skeletal muscles acquired from chest CT scans and to analyse variables related to sarcopenia using the cutoff values determined in a general Asian population.

Methods   We retrospectively reviewed chest CT scans of 4470 participants (mean age 54.8 ± 9.9 years, 65.8% male) performed at a check-up centre in South Korea (January 2016–August 2017). To determine cutoffs, 335 participants aged 19–39 years (mean age 35.2 ± 3.6 years, 75.2% male) and 4135 participants aged ≥40 years (mean age 56.4 ± 8.4 years, 65.1% male) were selected as the study group. We measured the following: cross-sectional area (CSA) of the pectoralis, intercostalis, paraspinal, serratus, and latissimus muscles at the 4th vertebral region (T4CSA); T4CSA divided by height2 (T4MI); pectoralis muscle area (PMCSA); and PMCSA divided by height2 (PMI) at the 4th vertebral region. Sarcopenia cutoff was defined as sex-specific values of less than −2 SD below the mean from the reference group.

Results   In the reference group, T4CSA, T4MI, PMCSA, and PMI cutoffs for sarcopenia were 100.06 cm2, 33.69 cm2/m2, 66.93 cm2, 26.01 cm2/m2, 18.29 cm2, and 7.31 cm2/m2 in male, and 66.93 cm2, 26.01 cm2/m2, 18.29 cm2, and 7.31 cm2/m2 in female, respectively. Correlations were observed between appendicular skeletal mass divided by height2 measured by bioelectrical impedance analysis (BIA) and T4CSA (r = 0.82; P < 0.001)/T4MI (r = 0.68; P < 0.001), and ASM/height2 measured by BIA and PMCSA (r = 0.72; P < 0.001)/PMI (r = 0.63; P < 0.001). In the multivariate logistic regression models, sarcopenia defined by T4CSA/T4MI were related to age [odds ratio (95% confidence interval), P-values: 1.09 (1.07–1.11), <0.001/1.05 (1.04–1.07), <0.001] and diabetes [1.60 (1.14–2.25), 0.007/1.47 (1.01–2.14), 0.043]. Sarcopenia defined by PMCSA/PMI were related to age [1.09 (1.08–1.10), <0.001/1.05 (1.03–1.06), <0.001], male sex [0.23 (0.18–0.30), <0.001/0.47 (0.32–0.71), <0.001], diabetes [2.30 (1.73–3.05), <0.001/1.63 (1.15–2.32), 0.007], history of cancer [2.51 (1.78-3.55), <0.001/1.61 (1.04–2.48), 0.033], and sufficient physical activity [0.67 (0.50–0.89), 0.007/0.74 (0.56–0.99), 0.042].

Conclusions   The reference cutoff values of a general population reported here will enable sex-specific standardization of thoracic muscle mass quantification and sarcopenia assessment.

Keywords   Sarcopenia; Thoracic muscle mass; Computed tomography; Cutoff point

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Introduction

The decrease in skeletal muscle function or strength and muscle mass by aging is defined as sarcopenia. Sarcopenia can cause negative outcomes such as physical disability, poor quality of life, and death. The decline in muscle mass is observed not only in older patients but also in younger patients. The diagnosis of sarcopenia requires measurements of muscle quality and quantity. A wide variety of tests, including magnetic resonance imaging (MRI), computed tomography (CT), dual-energy X-ray absorptiometry (DXA), and multifrequency bioelectrical impedance analysis (BIA), are available for the characterization of sarcopenia in practice and research.

Conventionally, when analysing muscle quantity using CT, skeletal muscle measurements at the level of the third lumbar vertebra are used. These are strongly correlated with whole-body muscle mass in healthy adults. A limitation of this method for muscle quantification is that abdominal CT scans are not typically performed in clinical respiratory or cardiac assessment. Thoracic skeletal muscle quantification is clinically important as the muscle quantity is associated with various diseases. Therefore, there have been efforts to measure sarcopenia from thoracic skeletal muscle acquired from chest CT scans. Furthermore, as the thoracic muscle cross-sectional area (CSA) from a single axial CT slice is known to correlate strongly with thoracic muscle volume, measuring CSA of thoracic skeletal muscle using CT has become more common.

Various methods for analysing thoracic skeletal muscles from chest CT scans have shown clinical importance. Among the methods, the CSA of pectoralis, intercostalis, paraspinal, serratus, and latissimus muscles (T4CSA) correlated with quadriceps size and limb muscle strength and have shown a relationship with prognosis in lung transplantation patients. We also have previously described the ability of T4CSA to predict the prognosis in idiopathic pulmonary fibrosis patients. The CSA of pectoralis muscles (PMCSA) have shown a relationship with prognosis in a smoking population, chronic obstructive lung disease, patients with left ventricular assist device implantation, coronavirus disease (COVID-19), patients in intensive care unit, and patients with lung cancer.

Diagnostic indices and diagnostic cutoff points have been established for DXA and BIA. From the abdominal CT scans, Derstine et al. determined reference cutoff points of skeletal muscles at the level of the T10 to L5; the International Consensus of Cancer Cachexia determined reference cutoff points at the level of the third lumbar vertebra to maximize the diagnostic yield for sarcopenia. However, diagnostic cutoff points for the CSA of thoracic skeletal muscles for sarcopenia have not been established in chest CT scans.

Determining appropriate cutoff values for thoracic skeletal muscles is needed to predict and prevent secondary sarcopenia and adverse clinical outcomes in various disease conditions. Furthermore, determining appropriate cutoff values for the diagnosis of sarcopenia may promote further sarcopenia research and treatment. Therefore, examining diagnostic cutoff points for sarcopenia from the CSA of the thoracic skeletal muscles is needed, and it would be useful when considering the cutoff points acquired from DXA and BIA.

The screening programme performed in the Health Promotion Center of the Severance Hospital includes tests such as BIA, chest CT, laboratory blood tests, and pulmonary function tests, as well as questionnaires. Using this data, this study aimed to (i) determine reference values for sarcopenia from thoracic skeletal muscles acquired from chest CT scans, (ii) compare the determined values with those acquired by BIA, and (iii) analyse variables related to sarcopenia, in a general Asian population.

Materials and methods

Study design and population

We performed a retrospective, cross-sectional study based on participants aged 19 years or older who voluntarily visited the Health Promotion Center of the Severance Hospital, Seoul, South Korea and underwent a health checkup programme that included chest CT scans between January 2016 and July 2017. The exclusion criteria were as follows: (i) incomplete past medical history records (n = 122), (ii) incomplete smoking status records (n = 84), (iii) having any current pathological disorders including cancer, liver cirrhosis, chronic renal insufficiency, uncontrolled asthma, cardiovascular disease, or cerebrovascular accident (n = 242), (iv) did not undergo BIA (n = 204), and (v) did not undergo pulmonary function test (n = 24). As a result, 4470 participants were enrolled in our study, of which, 335 participants aged 19–39 years (mean age 35.2 ± 3.6, 75.2% male) were selected as the reference group for determining T4CSA, T4MI, PMCSA, and PMI cutoffs in accordance with previous studies. 4135 subjects aged ≥40 years (mean age 56.4 ± 8.4, 65.1% men) were included in the analysis (Supporting Information, Figure S1). All enrolled patients were Korean.

All participants that underwent our health check-up programme were asked to fill out a questionnaire. Smoking history, alcohol history, past medical and/or surgical history, and whether the participant partakes in regular physical activity (intensity, frequency, and the time of the physical activity) were included in the questionnaire. Smoking history was categorized as ‘never/ex-smoker/current smoker’ and alcohol history was calculated as cc/day. Aerobic exercise was defined as ‘moderate activity that makes you out of breath a little more than usual’, and the examples provided for aerobic exercises included brisk walking, tennis (doubles), cycling at slower than 10 miles per hour, and dancing. Intensive exer-
Exercise was defined as ‘strenuous activity that makes you out of breath much more than usual’, and the examples provided for intensive exercises included running, aerobic dancing, cycling at faster than 10 miles per hour, tennis (singles), and hiking uphill. Sufficient physical activity was considered as performing intensive exercise ≥75 min/week and/or aerobic exercise ≥150 min/week according to the recommendations of WHO and AHA. All participants underwent BIA, pulmonary function tests, and laboratory tests including complete blood count, CRP, blood urea nitrogen, creatinine, total protein, albumin, liver enzymes, total bilirubin, lipid panel tests, fasting glucose, and HbA1c. Body composition was measured with direct segmental multifrequency BIA using the InBody 720 (InBody Co., Ltd., Seoul, Republic of Korea), widely used in the diagnosis of sarcopenia. Measurements were performed with the participants in a standing position grasping the handles of the analyser, providing contact with a total of eight electrodes (two for each foot and hand). The system separately measured the impedance of the participants’ right arm, left arm, trunk, right leg, and left leg at six different frequencies (1, 5, 50, 250, 500, and 1000 kHz). Appendicular skeletal muscle mass (ASM) was calculated as the sum of the lean muscle mass in the bilateral arms and legs. Early morning blood was drawn from an antecubital vein in the arm after overnight fasting, stored in vacuum tubes, and subsequently analysed by a certified, central laboratory at the Health Promotion Center of the Severance Hospital.

**Measurement of cross-sectional area of the skeletal muscle at the level of T4**

We measured CSA of the pectoralis, intercostalis, paraspinal, serratus, and latissimus muscles at the 4th vertebral region (T4_CSA) and CSA of pectoralis muscle area (PM_CSA) at the fourth vertebral region. All chest CT scans were performed in the standardized position with the arms positioned at the sides of the trunk as per the protocol of the Health Promotion Center of the Severance Hospital. Measurements of the skeletal muscles were performed as in our previous study. Quantitative assessment of the CSA was performed semi-automatically using the Aquarius iNtuition Viewer (ver. 4.4.11, TeraRecon Inc., San Mateo, CA, USA) as shown in Figure 1. The T4 level was defined as the slice, which includes the middle of the fourth thoracic vertebrae. The observer visually identified single cross-sectional images. CSAs of tissue in slices were computed automatically by summation of the pixel attenuation of −30 to +150 Hounsfield units for skeletal muscle. After applying the threshold method (with a predefined Hounsfield unit threshold) to slices, boundaries between different tissues were manually corrected additionally. First, muscle CSA combination of the pectoralis, intercostalis, serratus anterior, paraspinal, and latissimus muscles (T4_CSA) was quantified followed by CSA of only the pectoralis muscles (PM_CSA). Second, T4 muscle index (T4MI) was calculated as T4_CSA divided by height^2 and pectoralis muscle index (PMI) was calculated as PM_CSA divided by height^2.

The measurement of CSAs was performed by 3 radiology technicians with 4, 6, and 10 years of experience. Afterwards, 500 samples were randomly selected from the data and another technician performed measurement of CSAs to validate the reliability of the data. The intraclass correlation coefficients for the initial values and the re-measured values were 0.993 (P < 0.001) in the T4CSA and 0.999 (P < 0.001) in the PM_CSA. Radiology technicians measured CSAs without access to patient information. Both contrast-enhanced and non-contrast CT scans were used as there was no difference in muscle CSA measurements between these in the previous study.

We adopted the definition of sarcopenia developed by Baumgartner et al. and recommended by EWGSOP. Sarcopenia cutoff was defined as values less than −2 standard deviations (SD) below the sex-specific mean for a healthy, younger (age 19–39 years) person for T4CSA, T4MI, PMCSA, and PMI.

Figure 1 Sample axial CT images of the fourth thoracic vertebral region. (A) Pectoralis, intercostalis, paraspinal, serratus, and latissimus muscles (T4CSA) are in yellow. (B) Pectoralis muscles (PMCSA) are in green.
Statistical analysis

Descriptive statistics were reported as numbers with proportions or as means with SDs. Chi-square tests were conducted to compare categorical variables; t-tests were conducted to compare continuous variables between the two groups. Pearson’s correlation analysis was used to evaluate the correlation between two continuous variables. To evaluate the relationship between sarcopenia and multiple clinical parameters while controlling potential confounding factors, multivariate logistic regression models were used. In the multivariate logistic regression models for T4MI and PMI, BMI was not included because the value of height\(^2\) would overlap in the calculation of T4MI, PMI, and BMI. An adjusted \(P\)-value \(< 0.05\) was considered statistically significant. Statistical analyses were performed with SPSS version 25.0 (SPSS Inc., Chicago, IL, USA). Receiver operator characteristic (ROC) curves and AUC (area under the ROC curve) were generated using the MedCalc software (version 15.0; MedCalc, Oostende, Belgium).

Results

Baseline characteristics, bioelectrical impedance analysis, laboratory, and pulmonary function test

To determine cutoffs, 335 participants aged 19–39 years (mean age 35.2 ± 3.6 years, 75.2% male) were selected as the reference group. When values less than –2SD below the mean were invested in the reference group as the cutoff for defining sarcopenia, the sex-specific cutoff points of T4\(_{\text{CSA}}\), T4MI, PM\(_{\text{CSA}}\), and PMI were 100.06 cm\(^2\), 33.69 cm\(^2/m\(^2\), 29.00 cm\(^2\), and 10.17 cm\(^2/m\(^2\) in men, respectively and 66.93 cm\(^2\), 26.01 cm\(^2/m\(^2\), 18.29 cm\(^2\), and 7.31 cm\(^2/m\(^2\) in female, respectively. A total of 4135 participants aged ≥40 years (mean age 56.4 ± 8.4 years, 65.1% men) were selected as the study group. Baseline characteristics of the participants in the study group stratified by presence of sarcopenia defined by T4\(_{\text{CSA}}\) and T4MI, and baseline characteristics of the study participants stratified by the presence of sarcopenia defined by PM\(_{\text{CSA}}\) and PMI are provided in Table 1. The prevalence of sarcopenia determined using T4\(_{\text{CSA}}\), T4MI, PM\(_{\text{CSA}}\), and PMI cutoffs was 11.9% (319/2690), 9.4% (252/2690), 6.2% (168/2690), and 8.4% (226/2690) in male, respectively; and 10.7% (154/1445), 7.5% (108/1445), 12.8% (185/1445), and 13.4% (193/1445) in female, respectively. The sarcopenia group had higher BMI than that in the normal group (all \(P < 0.050\)). There was no significant difference in body weight between the sarcopenia group defined by T4MI and the normal group (67.7 ± 11.9 vs. 67.0 ± 11.8, \(P = 0.258\)); additionally, no significant difference in height was found between the sarcopenia group defined by PMI and the normal group (1.67 ± 0.08 vs. 1.67 ± 0.09, \(P = 0.819\)). The proportion of chronic underlying diseases such as hypertension and diabetes was significantly higher in the sarcopenia group compared with that in the normal group (all \(P < 0.050\)). Laboratory and pulmonary function test results of the study patients stratified by presence of sarcopenia defined by T4\(_{\text{CSA}}\), T4MI, PM\(_{\text{CSA}}\), and PMI are provided in Table 2. The sarcopenia group had significantly higher C-reactive protein (CRP), blood urea nitrogen, and haemoglobin A1c and had significantly lower total cholesterol and pulmonary function test results compared to those of the normal group (all \(P < 0.050\)). The distribution of the T4\(_{\text{CSA}}\), T4MI, PM\(_{\text{CSA}}\), and PMI values are shown in Figure 2. T4\(_{\text{CSA}}\), T4MI, PM\(_{\text{CSA}}\), and PMI decreased as age increased. The prevalence of sarcopenia increased with older age in both sexes. High correlations were observed between T4\(_{\text{CSA}}\) and PM\(_{\text{CSA}}\) (\(r = 0.92; P < 0.001\)), and T4MI and PMI (\(r = 0.87; P < 0.001\)). Similarly, correlations were observed between ASM/height\(^2\) measured by BIA and T4\(_{\text{CSA}}\) (\(r = 0.82; P < 0.001\))/T4MI (\(r = 0.68; P < 0.001\)), and ASM/height\(^2\) measured by BIA and PM\(_{\text{CSA}}\) (\(r = 0.72; P < 0.001\))/PMI (\(r = 0.63; P < 0.001\)) (Table S1).

Variables related to sarcopenia

Table 3 shows the result of the logistic regression model to analyse variables related to sarcopenia defined by T4\(_{\text{CSA}}\), T4MI, PM\(_{\text{CSA}}\), and PMI. Sarcopenia defined by T4\(_{\text{CSA}}\) was related to older age [odds ratio (95% confidence interval); \(P\) values: 1.09 (1.07–1.11); \(P < 0.001\)] and diabetes [1.60 (1.14–2.25); \(P = 0.007\)], and was inversely related to body mass index (BMI) [0.80 (0.76–0.84); \(P < 0.001\)] and sufficient physical activity [0.65 (0.49–0.86); \(P = 0.003\)]. Sarcopenia defined by T4MI was related to older age [1.05 (1.04–1.07); \(P < 0.001\)], diabetes [1.47 (1.01–2.14); \(P = 0.043\)], history of liver disease [1.92 (1.16–3.18); \(P = 0.011\)]. Sarcopenia defined by PM\(_{\text{CSA}}\) was related to older age [1.09 (1.08–1.10); \(P < 0.001\)], history of hypertension [1.68 (1.34–2.12); \(P < 0.001\)], diabetes [2.30 (1.73–3.05); \(P < 0.001\)], pulmonary disease [1.50 (1.06–2.13); \(P = 0.023\)], and cancer [2.51 (1.78–3.55); \(P < 0.001\)] and was inversely related to male sex [0.23 (0.18–0.30); \(P < 0.001\)], BMI [0.91 (0.87–0.94); \(P < 0.001\)], alcohol consumption [0.99 (0.98–1.00); \(P = 0.007\)], and sufficient physical activity [0.67 (0.50–0.89); \(P = 0.007\)]. among sarcopenia defined by PMI was related to older age [1.05 (1.03–1.06); \(P < 0.001\)], history of diabetes [1.63 (1.15–2.32); \(P = 0.007\)], cancer [1.61 (1.04–2.48); \(P = 0.033\)], alcohol consumption [1.01 (1.00–1.02); \(P = 0.002\)], and was inversely related to male sex [0.47 (0.32–0.71); \(P < 0.001\)], history of cerebrovascular accident [0.23 (0.06–0.85); \(P = 0.027\)], and sufficient physical activity [0.74 (0.56–0.99); \(P = 0.042\)].
| Subject Characteristics Stratified by Presence of Sarcopenia |
|-------------------------------------------------------------|
| **Defined by T4CSA**                                        |
| **Normal** (*n* = 3662) | **Sarcopenia** (*n* = 473) | **P-value** |
| Age, years | 55.7 ± 8.0 | 62.4 ± 9.4 | <0.001 | 56.1 ± 8.2 | 62.3 ± 9.2 | <0.001 | 56.1 ± 8.2 | 59.9 ± 9.3 | <0.001 |
| Sex, Male | 2371 (64.7%) | 319 (67.4%) | 0.260 | 2432 (66.7%) | 168 (47.6%) | <0.001 | 2464 (66.3%) | 226 (53.9%) | <0.001 |
| Height, m | 1.67 ± 0.08 | 1.63 ± 0.09 | <0.001 | 1.67 ± 0.08 | 1.60 ± 0.08 | <0.001 | 1.67 ± 0.08 | 1.67 ± 0.09 | 0.819 |
| Weight, kg | 68.3 ± 11.8 | 61.4 ± 10.5 | <0.001 | 68.2 ± 11.8 | 59.9 ± 10.4 | <0.001 | 67.9 ± 11.8 | 65.8 ± 12.6 | 0.001 |
| Body mass index, kg/m² | 24.4 ± 3.0 | 23.0 ± 2.8 | <0.001 | 24.3 ± 3.0 | 23.4 ± 3.1 | <0.001 | 24.3 ± 3.0 | 23.6 ± 3.3 | <0.001 |
| **Defined by T4MI<sup>a</sup>**                             |
| **Normal** (*n* = 3775) | **Sarcopenia** (*n* = 360) | **P-value** |
| Age, years | 55.6 ± 8.2 | 60.3 ± 9.6 | <0.001 | 55.9 ± 8.1 | 62.3 ± 9.2 | <0.001 | 56.1 ± 8.2 | 59.9 ± 9.3 | <0.001 |
| Sex, Male | 2438 (64.6%) | 252 (70.0%) | 0.043 | 2522 (66.7%) | 168 (47.6%) | <0.001 | 2464 (66.3%) | 226 (53.9%) | <0.001 |
| Height, m | 1.66 ± 0.08 | 1.69 ± 0.09 | <0.001 | 1.67 ± 0.08 | 1.60 ± 0.08 | <0.001 | 1.67 ± 0.08 | 1.67 ± 0.09 | 0.819 |
| Weight, kg | 67.7 ± 11.9 | 67.0 ± 11.8 | 0.258 | 68.2 ± 11.8 | 59.9 ± 10.4 | <0.001 | 67.9 ± 11.8 | 65.8 ± 12.6 | 0.001 |
| Body mass index, kg/m² | 24.3 ± 2.9 | 23.1 ± 2.8 | <0.001 | 24.3 ± 3.0 | 23.4 ± 3.1 | <0.001 | 24.3 ± 3.0 | 23.6 ± 3.3 | <0.001 |
| **Defined by PMCSA<sup>c</sup>**                            |
| **Normal** (*n* = 3782) | **Sarcopenia** (*n* = 353) | **P-value** |
| Age, years | 55.9 ± 8.1 | 62.3 ± 9.2 | <0.001 | 56.1 ± 8.2 | 59.9 ± 9.3 | <0.001 | 56.1 ± 8.2 | 59.9 ± 9.3 | <0.001 |
| Sex, Male | 2622 (68.6%) | 162 (47.6%) | <0.001 | 2522 (66.7%) | 168 (47.6%) | <0.001 | 2464 (66.3%) | 226 (53.9%) | <0.001 |
| Height, m | 1.67 ± 0.08 | 1.60 ± 0.08 | <0.001 | 1.67 ± 0.08 | 1.60 ± 0.08 | <0.001 | 1.67 ± 0.08 | 1.67 ± 0.09 | 0.819 |
| Weight, kg | 68.2 ± 11.8 | 59.9 ± 10.4 | <0.001 | 67.9 ± 11.8 | 65.8 ± 12.6 | 0.001 | 67.9 ± 11.8 | 65.8 ± 12.6 | 0.001 |
| Body mass index, kg/m² | 24.3 ± 3.0 | 23.4 ± 3.1 | <0.001 | 24.3 ± 3.0 | 23.6 ± 3.3 | <0.001 | 24.3 ± 3.0 | 23.6 ± 3.3 | <0.001 |
| **Defined by PMI<sup>b</sup>**                              |
| **Normal** (*n* = 3716) | **Sarcopenia** (*n* = 419) | **P-value** |
| Age, years | 56.1 ± 8.2 | 59.9 ± 9.3 | <0.001 | 56.1 ± 8.2 | 59.9 ± 9.3 | <0.001 | 56.1 ± 8.2 | 59.9 ± 9.3 | <0.001 |
| Sex, Male | 2464 (66.3%) | 226 (53.9%) | <0.001 | 2464 (66.3%) | 226 (53.9%) | <0.001 | 2464 (66.3%) | 226 (53.9%) | <0.001 |
| Height, m | 1.67 ± 0.08 | 1.67 ± 0.09 | <0.001 | 1.67 ± 0.08 | 1.67 ± 0.09 | <0.001 | 1.67 ± 0.08 | 1.67 ± 0.09 | 0.819 |
| Weight, kg | 68.2 ± 11.8 | 59.9 ± 10.4 | <0.001 | 67.9 ± 11.8 | 65.8 ± 12.6 | 0.001 | 67.9 ± 11.8 | 65.8 ± 12.6 | 0.001 |
| Body mass index, kg/m² | 24.3 ± 3.0 | 23.6 ± 3.3 | <0.001 | 24.3 ± 3.0 | 23.6 ± 3.3 | <0.001 | 24.3 ± 3.0 | 23.6 ± 3.3 | <0.001 |

T4CSA: cross-sectional area of pectoralis, intercostalis, paraspinal, serratus, and latissimus muscles; T4MI, T4 muscle index; PMCSA: cross-sectional area of pectoralis muscles; PMI, pectoralis muscle index.

*P* values are based on the t-tests and χ² tests for continuous and categorical variables, respectively. Continuous variables are presented as mean ± standard deviations and categorical variables are presented as numbers (percentage). T4CSA and T4MI cutoffs for sarcopenia were 100.06 cm² and 33.69 cm²/m² in male participants, respectively, and 66.93 cm² and 26.01 cm²/m² in female participants, respectively.

T4CSA<sub>a</sub> divided by height<sup>2</sup>.

PMCSA<sub>c</sub> divided by height<sup>2</sup>.

Available for 3589 subjects.

Intensive exercise >75 min/week and/or aerobic exercise >150 min/week.
Table 2. Laboratory, bioelectrical impedance analysis, and pulmonary function test results stratified by presence of sarcopenia

| | Defined by T4CSA | Defined by T4MIa | Defined by PMCSA | Defined by PMIb |
|---|---|---|---|---|
| Normal (n = 3758) | Sarcopenia (n = 377) | P-value | Normal (n = 3775) | Sarcopenia (n = 360) | P-value | Normal (n = 3782) | Sarcopenia (n = 353) | P-value | Normal (n = 3716) | Sarcopenia (n = 419) | P-value |
| White blood cell, 10⁹/L | 5.49 ± 1.55 5.45 ± 1.48 | 0.645 | 5.47 ± 1.54 5.59 ± 1.54 | 0.177 | 5.46 ± 1.49 5.67 ± 1.99 | 0.015 | 5.46 ± 1.48 5.68 ± 1.95 | 0.005 |
| Haemoglobin, g/dL | 14.5 ± 1.4 | 0.010 | 14.5 ± 1.41 14.4 ± 1.4 | 0.278 | 14.6 ± 1.4 14.0 ± 1.4 | <0.001 | 14.6 ± 1.4 14.2 ± 1.5 | <0.001 |
| Platelet, 10⁹/L | 232 ± 54 227 ± 55 | 0.036 | 232 ± 53 228 ± 57 | 0.119 | 231 ± 53 238 ± 64 | 0.034 | 231 ± 53 236 ± 62 | 0.120 |
| C-reactive protein, mg/dL | 1.08 ± 3.75 1.79 ± 8.45 | 0.001 | 1.11 ± 4.06 1.86 ± 7.97 | 0.003 | 1.11 ± 4.56 1.64 ± 4.37 | 0.039 | 1.12 ± 4.56 1.65 ± 4.40 | 0.024 |
| Blood urea nitrogen, mg/dL | 14.4 ± 3.4 15.1 ± 4.7 | <0.001 | 14.5 ± 3.5 15.0 ± 5.0 | 0.012 | 14.5 ± 3.5 15.1 ± 5.0 | 0.002 | 14.5 ± 3.5 14.9 ± 4.8 | 0.032 |
| Creatinine, mg/dL | 0.82 ± 0.17 0.82 ± 0.38 | 0.596 | 0.82 ± 0.17 0.83 ± 0.42 | 0.546 | 0.83 ± 0.17 0.78 ± 0.43 | <0.001 | 0.82 ± 0.17 0.79 ± 0.40 | 0.003 |
| Albumin, g/dL | 4.50 ± 0.24 4.48 ± 0.24 | 0.022 | 4.50 ± 0.24 4.49 ± 0.24 | 0.462 | 4.51 ± 0.23 4.46 ± 0.25 | <0.001 | 4.50 ± 0.24 4.47 ± 0.25 | 0.010 |
| Total bilirubin, mg/dL | 1.04 ± 0.39 1.00 ± 0.39 | 0.060 | 1.04 ± 0.39 1.02 ± 0.36 | 0.284 | 1.05 ± 0.40 0.94 ± 0.31 | <0.001 | 1.05 ± 0.39 0.97 ± 0.35 | <0.001 |
| Total cholesterol, mg/dL | 201 ± 38 193 ± 40 | <0.001 | 200 ± 38 194 ± 41 | 0.003 | 200 ± 37 195 ± 44 | 0.008 | 201 ± 38 194 ± 42 | 0.010 |
| Haemoglobin A1c, % | 5.70 ± 0.73 5.91 ± 0.96 | <0.001 | 5.71 ± 0.75 5.86 ± 0.92 | <0.001 | 5.70 ± 0.73 5.99 ± 1.01 | <0.001 | 5.70 ± 0.74 5.91 ± 0.92 | <0.001 |
| ASM/height² in BIA | 7.41 ± 1.06 6.98 ± 0.95 | <0.001 | 7.36 ± 1.06 7.03 ± 1.00 | <0.001 | 7.40 ± 1.05 6.62 ± 0.94 | <0.001 | 7.39 ± 1.05 6.87 ± 1.03 | <0.001 |
| FEV₁/FVC (%) | 78.1 ± 6.2 76.1 ± 7.6 | <0.001 | 78.1 ± 6.3 75.5 ± 7.6 | <0.001 | 78.0 ± 6.3 77.0 ± 7.6 | 0.004 | 78.0 ± 6.3 76.5 ± 7.7 | <0.001 |
| FEV₁ (L) | 2.97 ± 0.65 2.61 ± 0.60 | <0.001 | 2.94 ± 0.65 2.81 ± 0.69 | <0.001 | 2.97 ± 0.64 2.48 ± 0.57 | <0.001 | 2.96 ± 0.64 2.71 ± 0.68 | <0.001 |
| FVC (L) | 3.82 ± 0.83 3.44 ± 0.76 | <0.001 | 3.78 ± 0.83 3.73 ± 0.86 | 0.212 | 3.83 ± 0.82 3.25 ± 0.75 | <0.001 | 3.80 ± 0.82 3.55 ± 0.87 | <0.001 |

T4CSA, cross-sectional area of pectoralis, intercostalis, paraspinal, serratus, and latissimus muscles; T4MI, T4 muscle index; PMCSA, cross-sectional area of pectoralis muscles; PMI, pectoralis muscle index; BIA, Bioelectrical impedance analysis; FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity. Continuous variables are presented as mean ± standard deviations and categorical variables are presented as numbers (percentage). P values are based on the t-tests. T4CSA, T4MI, PMCSA, and PMI cutoffs for sarcopenia were 100.06 cm², 33.69 cm²/m², 29.00 cm², and 10.17 cm²/m² in male participants, respectively, and were 66.93 cm², 26.01 cm²/m², 18.29 cm², and 7.31 cm²/m² in female participants, respectively.

aT4CSA divided by height; ÷PMCSA divided by height².
Discussion

This study attempted to establish reference cutoff values for thoracic skeletal muscles at the level of T4 that can be universally used in clinical settings and other sarcopenia studies. This study validated sarcopenia defined by T4CSA, T4MI, PMCSA, and PMI cutoffs by identifying correlations with BIA results and showing relationships with known variables. The muscle mass estimates by BIA are known to be highly correlated with those measured by DXA and MRI, which are recommended methods for muscle mass evaluation in sarcopenia. The known risk factors of sarcopenia include female sex, alcohol abuse, physical inactivity, starvation, and chronic health conditions including diabetes, and malignancies; these factors also showed a relationship with sarcopenia in this study.

To our knowledge, this is the first study that reports the reference cutoff values of T4CSA, T4MI, PMCSA, and PMI measured on chest CT scans. At the level of L3, the International Consensus of Cancer Cachexia proposed sarcopenia cutoff—defined as L3 muscle CSA divided by height^2—to be less than 55 cm^2/m^2 for men and less than 39 cm^2/m^2 for women. Derstine et al. reported L3 muscle CSA and L3 muscle CSA divided by height^2 cutoff as 144.3 cm^2 and 45.4 cm^2/m^2 in men and 92.2 cm^2, 34.4 cm^2/m^2 in women.

The prevalence of sarcopenia in a healthy general population assessed through the CSA in CT has not yet been reported. Estimates of sarcopenia prevalence vary from 1.7 to 40.4%; in a meta-analysis of 35 studies, the overall estimate of prevalence was 10%. In this study, the overall prevalence of sarcopenia defined by T4CSA, T4MI, PMCSA, and PMI was 11.4%, 8.7%, 8.5%, and 10.1%, respectively. It should also be considered that the sarcopenia study group was set as ≥40 years compared to other studies that set sarcopenia study population at age of 50–70 years.

This study used raw CSAs not divided by height^2 and CSAs divided by height^2 to define sarcopenia. Determining the ideal adjustment method including height has been a long debate in the field of sarcopenia. According to the revised EWGSOP guidelines, muscle mass is correlated with body size and the guidelines identify three examples of body size adjustment: dividing muscle mass by height^2, by weight, or by BMI. Among the studies assessing sarcopenia through chest CT scans, some studies used raw CSA values and some used CSA values divided by height. This study used both raw CSA and CSA divided by height^2 to define sarcopenia.
nia on chest CT, as both these values have shown a relationship with clinical outcomes and/or sarcopenic measures.12,18–22 According to a meta-analysis, 88.4% of studies assessing sarcopenia through abdominal CT scans have used CSA of total skeletal muscle at L3 level divided by height\(^2\). The purpose of height adjustment is to remove the correlation between muscle CSA and height. At the level of L3, Derstine et al. proposed skeletal muscle area divided by height for optimal height adjustment and proposed \(z\)-score for optimal height and BMI adjustment.38 Table S2 shows the relationship between height, weight, and BMI and T4CSA, T4MI, PMCSA, and PMI. This may mean that although the T4CSA, T4MI, PMCSA, and PMI have shown clinical importance, more detailed studies including BMI adjustments may help determine optimal body size-adjusted muscle indexes.

Variables associated with sarcopenia defined by T4CSA, T4MI, PMCSA, and PMI were similar, but there were also some differences. Male sex, history of cancer, and alcohol consumption were associated with sarcopenia defined by PMCSA but were not associated with sarcopenia defined by T4CSA in the multivariate analysis. Male sex, history of cerebrovascular accident, cancer, and sufficient exercise were associated with sarcopenia defined by PMI but were not associated with sarcopenia defined by T4MI in the multivariate analysis. Compared to PMCSA and PMI, T4CSA and T4MI includes the CSA of intercostalis muscles, which are involved in breathing; paraspinal muscles, which support the back; and serratus and latissimus muscles, which are involved in the movement of the scapula and arm; and the differences in the muscles included may be the cause of differences between T4CSA/T4MI and PMCSA/PMI. More detailed studies are therefore needed.

This study has some limitations. First, the study population comprised participants that voluntarily visited one health check-up centre for regular medical check-ups, which can limit generalizability and lead to selection bias. Second, the study population comprised only Asian participants. It is well-established that body composition differs between major races.39 More studies in the multi-race population are thus needed. Third, the physical activity levels of all participants were not directly evaluated. However, based on the survey performed in the study, we could indirectly analyse the relationship between self-reported physical activity and sarcopenia. Fourth, direct functional measures of sarcopenia such as handgrip strength measurement could not be assessed, for they were not included in the checkup pro-

Figure 2 Continued
Table 3  Multivariate logistic regression analysis for variables related to sarcopenia

| Variable                      | Sarcopenia defined by T4CSA | OR (95% CI) | P-value | Sarcopenia defined by T4MI \(^a\) | OR (95% CI) | P-value | Sarcopenia defined by PMCSA | OR (95% CI) | P-value | Sarcopenia defined by PMI \(^b\) | OR (95% CI) | P-value |
|-------------------------------|-------------------------------|-------------|---------|----------------------------------|-------------|---------|-------------------------------|-------------|---------|----------------------------------|-------------|---------|
| Age, years                    | 1.09 (1.07–1.11)              | <0.001      |         | 1.05 (1.04–1.07)                 | <0.001      |         | 1.09 (1.08–1.10)              | <0.001      |         | 1.05 (1.03–1.06)              | <0.001      |         |
| Sex, male                     | 1.28 (0.86–1.91)              | 0.231       |         | 1.10 (0.71–1.69)                 | 0.669       |         | 0.23 (0.18–0.30)              | <0.001      |         | 0.47 (0.32–0.71)              | <0.001      |         |
| Body mass index, kg/m²        | 0.80 (0.76–0.84)              | <0.001      |         | 0.91 (0.87–0.94)                 | <0.001      |         | N/A                           | -           |         | 1.19 (0.89–1.58)              | 0.250        |         |
| Hypertension                  | 1.17 (0.87–1.56)              | 0.310       |         | 0.88 (0.64–1.61)                 | 0.429       |         | 1.68 (1.34–2.12)              | <0.001      |         | 1.63 (1.15–2.32)              | 0.007        |         |
| Diabetes                      | 1.60 (1.14–2.25)              | 0.007       |         | 1.47 (1.01–2.14)                 | 0.043       |         | 2.30 (1.73–3.05)              | <0.001      |         | 1.61 (1.04–2.48)              | 0.033        |         |
| Cardiac disease               | 1.49 (0.98–2.27)              | 0.064       |         | 1.20 (0.74–1.94)                 | 0.453       |         | 1.87 (1.30–2.70)              | 0.001       |         | 1.11 (0.69–1.78)              | 0.667        |         |
| Cerebrovascular accident      | 0.51 (0.19–1.35)              | 0.173       |         | 0.33 (0.10–1.05)                 | 0.061       |         | 1.33 (0.63–2.79)              | 0.456       |         | 0.23 (0.06–0.85)              | 0.027        |         |
| Pulmonary disease             | 1.02 (0.65–1.59)              | 0.938       |         | 1.17 (0.72–1.88)                 | 0.530       |         | 1.50 (1.06–2.13)              | 0.023       |         | 1.04 (0.65–1.69)              | 0.860        |         |
| Liver disease                 | 0.99 (0.58–1.74)              | 0.993       |         | 1.92 (1.16–3.18)                 | 0.011       |         | 1.01 (0.61–1.69)              | 0.962       |         | 2.04 (1.25–3.34)              | 0.004        |         |
| Cancer                        | 0.86 (0.53–1.39)              | 0.544       |         | 1.21 (0.74–1.99)                 | 0.446       |         | 2.51 (1.78–3.55)              | <0.001      |         | 1.61 (1.04–2.48)              | 0.033        |         |
| Fracture                      | 1.13 (0.69–1.86)              | 0.625       |         | 1.24 (0.73–2.12)                 | 0.431       |         | 1.50 (0.98–2.30)              | 0.060       |         | 0.89 (0.52–1.52)              | 0.668        |         |
| Smoking status                | Current                       | Reference   | Reference | Reference | Reference | Reference | Reference | Reference | Reference | Reference | Reference | Reference | Reference |
|                              | Ex-smoker                     | 1.09 (0.75–1.57) | 0.649 | 0.95 (0.65–1.39) | 0.802 | 1.05 (0.75–1.47) | 0.778 | 0.99 (0.67–1.46) | 0.944 |         | 0.91 (0.57–1.45) | 0.679 |         | 1.01 (1.00–1.02) | 0.002 |         |
|                              | Never smoker                  | 0.71 (0.45–1.12) | 0.136 | 0.72 (0.45–1.16) | 0.178 | 1.65 (1.22–2.24) | <0.001 | 0.91 (0.57–1.45) | 0.679 |         | 1.01 (1.00–1.02) | 0.002 |         |                   |                   |
| Alcohol consumption (cc/day)  | 1.00 (0.99–1.01)              | 0.927       |         | 1.00 (0.99–1.01)                 | 0.954       |         | 0.99 (0.98–1.00)              | 0.007       |         | 0.74 (0.56–0.99)              | 0.042        |         |

\(^a\)T4CSA, cross-sectional area of Pectoralis, intercostalis, paraspinal, serratus, and latissimus muscles; T4MI, T4 muscle index; PMCSA, cross-sectional area of pectoralis muscles; PMI, pectoralis muscle index.

\(^b\)T4CSA and PMCSA cutoffs for sarcopenia were 100.06 cm\(^2\) and 29.00 cm\(^2\) in male participants, respectively, and 66.93 cm\(^2\) and 18.29 cm\(^2\) in female participants, respectively.

\(^c\)Intensive exercise >75 min/week and/or aerobic exercise >150 min/week.

\(^d\)Available for 3589 subjects.

\(^e\)Sufficient exercise >75 min/week and/or aerobic exercise >150 min/week.

DOI: 10.1002/jcsm.12946
gramme. Hence, we could only indirectly examine correlation with ASM/height2 measured by BIA but also directly compare the sensitivity and specificity between T4CSA, T4MI, PMCSA, and PMI. Fifth, we could not evaluate the impact of low muscle quantity on long-term clinical outcomes.

In conclusion, this is the first study to report the reference values of T4CSA, T4MI, PMCSA, and PMI measured on CT scans and to suggest cutoff points for diagnosis of sarcopenia in a large population of the general Asian participants. The sex-specific cutoff points of T4CSA, T4MI, PMCSA, and PMI were 100.06 cm², 33.69 cm²/m², 29.00 cm², and 10.17 cm²/m² in men, respectively, and were 66.93 cm², 26.01 cm²/m², 18.29 cm², and 7.31 cm²/m² in women, respectively. Correlation between the BIA results and the values of T4CSA, T4MI, PMCSA, and PMI were observed. The relationship between the variables and sarcopenia defined by T4CSA, T4MI, PMCSA, PMI were similar to known sarcopenia-related factors. Reference cutoff values for thoracic skeletal muscle measured from chest CT scan in a general population reported here will enable sex-specific standardization of thoracic muscle mass quantification and sarcopenia assessment that can be universally used in clinical settings, and this will promote further sarcopenia research.

Conflict of interest

All authors declare that they have no competing interests.

Funding

This research was supported by funds (2019-2) provided by the Department of Internal Medicine, Yonsei University College of Medicine. The funding body had no role in the design of the study, collection, analysis, interpretation of data or writing of the manuscript.

Ethical guidelines statement

The study procedures were approved by the Severance Hospital Institutional Review Board. (https://ocr.yuhs.ac, IRB No. 4-2018-1220) and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. Because this study was a retrospective analysis of existing administrative and clinical data, informed consent was not required.

Acknowledgements

The authors are grateful to the staff of the Radiologic Department of Severance Hospital.

Online supplementary material

Additional supporting information may be found online in the Supporting Information section at the end of the article.

References

1. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T, et al. Sarcopenia: revised European consensus on definition and diagnosis. Age Ageing 2019;48:16–31.
2. Beaudart C, Zaria M, Pasleau F, Regnier J-Y, Bruyère O. Health outcomes of sarcopenia: a systematic review and meta-analysis. PLOS ONE 2017;12:e0169548.
3. Goodpaster BH, Park SW, Harris TB, Kritchevsky SB, Nevitt M, Schwartz AV, et al. The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. J Gerontol A Biol Sci Med Sci 2006;61:1059–1064.
4. Kim YM, Kim JH, Baik SJ, Jung DH, Park JJ, Youn YH, et al. Association between skeletal muscle attenuation and gastroesophageal reflux disease: a health check-up cohort study. Sci Rep 2019;9:20102.
5. Wicks SM, Salamon I, Calderon AI, Carcache de Blanco EJ, Mahady GB. In Bagchi D, Nair S, eds. Chapter 23 - sarcopenia, diabetes, and nutritional intervention. Academic Press; 2018. p 279–292.
6. Chen L-K, Woo J, Assantachai P, Auyeung T-W, Chou M-Y, Iijima K, et al. Asian working group for sarcopenia: 2019 consensus update on sarcopenia diagnosis and treatment. J Am Med Dir Assoc 2020;21:300, e2–307.
7. Fearon K, Strasser F, Anker SD, Bosaeus I, Bruera E, Fainsinger RL, et al. Definition and classification of cancer cachexia: an international consensus. Lancet Oncol 2011;12:489–495.
8. Moisey LL, Mourtzakis M, Cotton BA, Premji T, Heyland DK, Wade CE, et al. Skeletal muscle predicts ventilator-free days, ICU-free days, and mortality in elderly ICU patients. Crit Care 2013;17:R206.
9. Mitsiopoulos N, Baumgartner RN, Heymsfield SB, Lyons W, Gallagher D, Ross R. Cadaver validation of skeletal muscle measurement by magnetic resonance imaging and computerized tomography. J Appl Physiol (1985) 1998;85:115–122.
10. Moon SW, Choi JS, Lee SH, Jung KS, Jung JY, Kang YA, et al. Thoracic skeletal muscle quantification: low muscle mass is related with worse prognosis in idiopathic pulmonary fibrosis patients. Respir Res 2019;20:35.
11. Kumar A, Ansari BA, Kim J, Suri A, Gaddam S, Yenigalla S, et al. Axial muscle size as a strong predictor of death in subjects with and without heart failure. J Am Heart Assoc 2019;8:e010554. https://doi.org/10.1161/JAHA.118.010554.
12. McDonald M-LN, Diaz AA, Ross JC, San Jose Estepar R, Zhou L, Regan EA, et al. Quantitative computed tomography measures of pectoralis muscle area and disease severity in chronic obstructive pulmonary disease. A cross-sectional study. Ann Am Thoracic Soc 2014;11:326–334.
13. Rozenberg D, Mathur S, Herridge M, Goldstein R, Schmidt H, Chowdhury NA, et al. Thoracic muscle cross-sectional area is associated with hospital length of stay post lung transplantation: a retrospective cohort study. Transpul Int 2017;30:713–724.
14. Zuckerman J, Ades M, Mullie L, Trnkus A, Morin JF, Langlois Y, et al. Psoas muscle
area and length of stay in older adults undergoing cardiac operations. Ann Thorac Surg 2017;103:1498–1504.

15. Kottlors J, Zopfs D, Fervers P, Bremm J, Abdullayev N, Maintz D, et al. Body composition on low dose chest CT is a significant predictor of poor clinical outcome in COVID-19 disease—a multicenter feasibility study. Eur J Radiol 2020;132:109274. https://doi.org/10.1016/j.ejrad.2020.109274.

16. Mishra A, Bigam KD, Extermann M, Faramand R, Thomas K, Pidala JA, et al. Sarcopenia and low muscle radiodensity associated with impaired FEV(1) in allogeneic haematopoietic stem cell transplantation recipients. J Cachexia Sarcopenia Muscle 2020;11:1570–1579.

17. Mathur S, Rodrigues N, Mendes P, Rozenberg D, Singer LG. Computed tomography-derived thoracic muscle size as an indicator of sarcopenia in people with advanced lung disease. J Phys Ther Sci 2017;28:99–105.

18. Diaz AA, Martinez CH, Harmouche R, Young TP, McDonald ML, Ross JC, et al. Pectoralis muscle area and mortality in smokers without airflow obstruction. Respir Res 2018;19:62.

19. Teigen LM, John R, Kuchnia AJ, Nagel EM, Earthman CP, Kealhofer J, et al. Preoperative pectoralis muscle quantity and attenuation by computed tomography are novel and powerful predictors of mortality after left ventricular assist device implantation. Circ Heart Fail 2017;10. https://doi.org/10.1161/CIRCHEARTFAILURE.117.004069.

20. Ufuk F, Demirci M, Sagtas E, Akbudak IH, Ugurlu E, Sari T. The prognostic value of muscle area on chest CT in adult COVID-19 patients. Eur J Radiol 2020;131:109271. https://doi.org/10.1016/j.ejrad.2020.109271.

21. Jaitovich A, Khan M, Itty R, Chieng HC, Dumas CL, Nadendla P, et al. ICU admission muscle and fat mass, survival, and disability at discharge: a prospective cohort study. Chest 2019;155:322–330.

22. Kinsey CM, San José Estépar R, van der Velden J, Cole BF, Christiani DC, Washko GR. Lower pectoralis muscle area is associated with a worse overall survival in non–small cell lung cancer. Cancer Cancer Epidemiol Biomarkers Prev 2017;26:38–43.

23. Derstine BA, Holcombe SA, Ross BE, Wang NC, Su GL, Wang SC. Skeletal muscle cutoff values for sarcopenia diagnosis using T10 to L5 measurements in a healthy US population. Sci Rep 2018;8:11369. https://doi.org/10.1038/s41598-018-29825-5.

24. Chen LK, Liu LK, Woo J, Assantachai P, Ayueung TW, Bahyah KS, et al. Sarcopenia in Asia: consensus report of the Asian working group for sarcopenia. J Am Med Dir Assoc 2014;15:95–101.

25. Cho YJ, Lim Y-H, Yun JM, Yoon H-J, Park M. Sex- and age-specific effects of energy intake and physical activity on sarcopenia. Sci Rep 2020;10:9822.

26. Yazar T, Olgun Yazar H. Prevalance of sarcopenia in small cell lung cancer. Respir Care 2019;64:103–107.

27. WHO Guidelines Approved by the Guideline Review Committee. Geneva: World Health Organization. 2010. https://www.who.int/nutrition/publications/WHO_Guidelines_Sarcopenia_GRC_2010.pdf.

28. Piercy KL, Troiano RP. Physical activity guidelines for Americans from the US Department of Health and Human Services. Circ Cardiovasc Qual Outcomes 2018;11:e005263.

29. Tosato M, Marzetti E, Cesari M, Saveria G, Miller RR, Bernabei R, et al. Measurement of muscle mass in sarcopenia: from imaging to biochemical markers. Aging Clin Exp Res 2017;29:19–27.

30. Derstine BA, Holcombe SA, Goulson RL, Ross BE, Wang NC, Sullivan JA, et al. Quantifying sarcopenia reference values using lumbar and thoracic muscle areas in a healthy population. J Nutr Health Aging 2017;21:180–185.

31. Baumgartner RN, Koehler KM, Gallagher D, Romero L, Heymsfield SB, Ross RR, et al. Epidemiology of sarcopenia among the elderly in New Mexico. Am J Epidemiol 1998;147:755–763.

32. Lee SY, Ahn S, Kim YJ, Ji MJ, Kim KM, Choi SH, et al. Comparison between dual-energy X-ray absorptiometry and bioelectrical impedance analyses for accuracy in measuring whole body muscle mass and appendicular skeletal muscle mass. Nutr Metab Cardiovasc Dis 2018;10:738.

33. Janssen I, Heymsfield SB, Baumgartner RN, Ross R. Estimation of skeletal muscle mass by bioelectrical impedance analysis. J Appl Physiol 2000;89:465–471.

34. Cruz-Jentoft AJ, Landi F, Topinkova E, Michel JP. Understanding sarcopenia as a geriatric syndrome. Curr Opin Clin Nutr Metab Care 2010;13:1–7.

35. Mayhew AJ, Amog K, Phillips S, Parise G, McNicholas PD, de Souza RJ, et al. The prevalence of sarcopenia in community-dwelling older adults, an exploration of differences between studies and within definitions: a systematic review and meta-analyses. Age Ageing 2019;48:600–610.

36. Shahtehar G, Keshtkar A, Soltani A, Ahadi Z, Larijani B, Heshmat R. Prevalence of sarcopenia in the world: a systematic review and meta-analysis of general population studies. J Diabetes Metab Disord 2017;16:21.

37. Kim KM, Jang HC, Lim S. Differences among skeletal muscle mass indices derived from height-, weight-, and body mass index-adjusted models in assessing sarcopenia. Korean J Intern Med 2016;31:643–650.

38. Derstine BA, Holcombe SA, Ross BE, Wang NC, Su GL, Wang SC. Optimal body size adjustment of L3 CT skeletal muscle area for sarcopenia assessment. Sci Rep 2021;11:279.

39. Jeng C, Zhao L-J, Wu K, Zhou Y, Chen T, Deng H-W. Race and socioeconomic effect on sarcopenia and sarcopenic obesity in the Louisiana Osteoporosis Study (LOS). JCMS Clin Rep 2018;3:e00027.