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Research Article

Reference Data and T-Scores of Lumbar Skeletal Muscle Area and Its Skeletal Muscle Indices Measured by CT Scan in a Healthy Korean Population

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Abstract

Background: Although computed tomography (CT) is considered the gold standard for investigating skeletal muscles, diagnostic cutoff points for sarcopenia have not been established. We therefore suggested clinically relevant diagnostic cutoff points for sarcopenia based on reference values of skeletal muscle area (SMA) measured by CT scan in a large-sized healthy Asian population.

Methods: This cross-sectional analysis included 11,845 subjects (7,314 men, 4,531 women) who underwent abdominal CT scans in South Korea. SMA including all muscles on the selected axial images of the L3 lumbar vertebrae level was demarcated using predetermined thresholds (−29 to +150 Hounsfield units). SMA indices (height-, weight-, and body mass index [BMI]-adjusted) were calculated.

Results: When T-score < −2.0 was used as the cutoff for defining sarcopenia, the sex-specific cutoff points of SMA, SMA/height^2, SMA/weight, and SMA/BMI were 119.3 and 74.2 cm^2, 39.8 and 28.4 cm^2/m^2, 1.65 and 1.38 cm^2/kg, and 4.97 and 3.46 in men and women, respectively. In both sexes, the SMA/BMI values peaked in the 20s and decreased gradually. The SMA/BMI yielded the highest diagnostic rate of sarcopenia (4.2% in men, 8.7% in women), while SMA/height^2 provided the lowest yield (2.8% in men, 1.0% in women).

Conclusions: This is the first study to report the reference values of SMA and skeletal muscle indices (SMIs) measured on CT scans and to suggest cutoff points for diagnosis of sarcopenia based on T-score in Asian subjects. BMI-adjusted index (SMA/BMI) was the best index of CT-measured SMA to reflect the age-related muscle changes and to maximize the diagnostic yield for sarcopenia.

Keywords: Skeletal muscle area, Skeletal muscle indices, L3 lumbar spine level, CT scan, Asian

Sarcopenia, characterized by decreased skeletal muscle mass and strength/function, is known to be directly related to physical disability, falling, fracture, hospitalization, depression, poor quality of life, adverse metabolic effects, and mortality (1–3). Currently, the most commonly used definition of sarcopenia is from the European Working Group on Sarcopenia in Older People (EWGSOP, the Sarcopenia Working Group) created in 2010 (3); the definition was revised in 2018 through the EWGSOP2 consensus, in which the diagnosis of sarcopenia is based on low muscle strength, low muscle quantity or quality, and low physical performance (4). Diverse methods are

used to evaluate muscle quantity/quality, with the EWGSOP2 consensus recommending the use of dual-energy X-ray absorptiometry (DXA), bioelectrical impedance analysis (BIA), and lumbar muscle cross-sectional area by computed tomography (CT) or magnetic resonance imaging (MRI) in clinical practice according to the healthcare setting and technical resources (4). Appendicular skeletal muscle mass (ASM) measured by DXA is typically used to diagnose sarcopenia (4), and the loss of ASM is regarded as strong evidence of poor physical function in aging (4). Diagnostic indices and diagnostic cutoff points have been established for DXA and BIA (4).

Recently, the measurement of cross-sectional area of specific muscle groups or body locations such as lumbar L3 cross-sectional area by using CT has become more common (5). Moreover, the trunk muscle including abdominal muscle area has a crucial role in performing daily activities, balancing, maintaining mobility, and preventing falls in older adults (6–8). However, there is a lack of evidence to establish diagnostic cutoff points for lumbar L3 cross-sectional area by using CT or MRI (9). Also, CT and MRI are mainly performed in patients and rarely used in healthy subjects, the latter of which is needed to obtain reference values for establishing diagnostic cutoff points. The EWGSOP consensus recommends using cutoff points at –2 *SD* from the mean reference value (ie, T-score ≤ –2.0) (1). In addition, the data of reference values must be comprehensive enough to represent the regional normative population.

From this perspective, the purpose of this study was threefold: (i) to establish a large cohort of healthy subjects to represent the Asian population, (ii) to determine diagnostic cutoff points for sarcopenia based on reference values for abdominal muscle area measured at the L3 lumbar vertebrae level by CT scan, and (iii) to analyze age- and sex-specific percentile distributions so that the data presented as percentiles can serve as references to evaluate the normality of muscle quantity at a given age.

Materials and Methods

Study Population

We performed a retrospective study based on subjects aged 20 years or older who underwent abdominal CT scan during routine health check-up at the Health Screening and Promotion Center of Asan Medical Center (AMC, Seoul, Republic of Korea) between January 2012 and December 2012. Each subject completed a questionnaire regarding medications, history of previous medical and/or surgical diseases, and habits on drinking, smoking, and exercise. Drinking habits were calculated as grams per day and smoking habits were categorized as never, previous, or current. Regular physical activity was defined as engaging in moderate-intensity physical activity for a minimum of 30 minutes for 5 days per week or vigorous-intensity aerobic activity for a minimum of 20 minutes for 3 days per week. We excluded subjects with absence of data as well as those who had any pathological disorders including cancer, liver cirrhosis, chronic renal insufficiency, chronic obstructive lung disease, over thyroid dysfunction, past history of cardiovascular disease or cerebrovascular accident, poorly controlled diabetes mellitus, or currently taking insulin or glucocorticoid. In accordance with previous studies, we selected participants aged 20–44 years as the young reference group (10,11). The study protocol was approved by the Institutional Review Board of AMC (IRB No. 2018–0917) and has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

Laboratory Measurements

After overnight fasting, early morning blood was drawn from an antecubital vein in the arm, stored in vacuum tubes, and subsequently analyzed by a certified, central laboratory at AMC. Levels of fasting total cholesterol, triglycerides, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, aspartate aminotransferase, and alanine aminotransferase were measured using the enzymatic colorimetric method with the Toshiba 200FR Neo analyzer (Toshiba Medical System Co., Ltd., Tokyo, Japan). Creatinine levels were measured using the Jaffe method, and estimated glomerular filtration rate was calculated using the Modification of Diet in Renal Disease Study equation (12). Fasting plasma glucose levels were measured using the immunoturbidimetric method (Toshiba) and the enzymatic colorimetric method with the Toshiba 200 FR autoanalyzer (Toshiba). Serum insulin concentrations were determined with immunoradiometric assay (TFB, Tokyo, Japan). Ion exchange high-performance liquid chromatography (Bio-Rad Laboratories, Inc., Hercules, CA) was used to measure HbA1c levels. All enzymatic activities were measured at 37°C.

Anthropometric and Body Composition Measurements

Trained nurses measured the height and weight of each subject wearing light clothing without shoes. Body mass index (BMI) was calculated by dividing the weight in kilograms by the square of the height in meters. Waist circumference was measured in a horizontal plane at the midway point between the inferior margin of the last rib and the superior iliac crest. Blood pressure was measured on the right arm after a resting period of ≥ 5 minutes using an automatic manometer with an appropriate cuff size.

Body composition was measured with direct segmental multifrequency bioelectrical impedance analysis using the InBody 720 (InBody Co., Ltd., Seoul, Republic of Korea). Measurements were performed with the subjects in a standing position grasping the handles of the analyzer, providing contact with a total of eight electrodes (two per 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 1,000 kHz). ASM was calculated as the sum of the lean muscle mass in the bilateral arms and legs. To obtain more accurate ASM values, we modified the original ASM values using the following formula described in a Korean study by Lee et al. (13): $5.07 + 0.26 \times \text{BMI} + (-1.19) \times \text{gender} + 0.24 \times \text{ASM-by-BIA} + 0.01 \times (\text{ASM-by-BIA})^2 + (-0.06) \times \text{fat percent-by-BIA}$.

CT Image Acquisition

The abdomen and pelvis CT examinations were performed using Somatom Definition (Siemens Healthineers, Erlangen, Germany), Discovery CT750 HD (GE Healthcare, Milwaukee, WI), or LightSpeed VCT scanner (GE Healthcare). All CT examinations were performed with the following parameters: 120 kVp; automated dose modulation (CareDose 4D, Siemens Healthineers; automA and smartmA, GE Healthcare); matrix 512 × 512; collimation of 0.625 mm. All image data were reconstructed with a slice thickness of 5 mm using the filtered back-projection technique with soft tissue reconstruction algorithm (B30f kernel; Siemens Healthineers; Standard kernel, GE Healthcare). For contrast-enhancement, 100–150 mL of iopromide (Ultravist 370 or Ultravist 300; Bayer Schering Pharma, Berlin, Germany) were intravenously administered using an automatic power injector.

Assessment of skeletal muscle area

Body composition was evaluated with abdominal CT using our automated software that was developed by modifying the ImageJ

software (NIH, Bethesda, MD). An abdominal radiologist (K.W.K., 13 years of experience) and an image analyst (J.W.L., 2 years of experience), who were blind to clinical information, reviewed all measured images and corrected the measurement if necessary. The inferior endplate level of the L3 vertebra was chosen as the measurement level. Skeletal muscle areas (SMA), including all muscles on the selected axial images (ie, psoas, paraspinal, transversus abdominis, rectus abdominis, quadratus lumborum, and internal and external obliques) were demarcated using predetermined thresholds (−29 to +150 Hounsfield units) (14). The visceral fat area (VFA) and the subcutaneous fat area (SFA) were also demarcated using fat tissue thresholds (−190 to −30 Hounsfield units) (15). The SMA was adjusted by the square of the height (SMA/height^2), weight (SMA/weight), and body mass index (SMA/BMI), which were collectively referred to as the skeletal muscle indices (SMIs).

Statistical Analysis

All statistical analyses were performed using the SAS software version 9.4 (SAS Institute, Inc., Cary, NC) and R software version 3.6.0 (R Foundation for Statistical Computing, Vienna, Austria). Data are represented as mean ± *SD* or median with interquartile range for continuous variables, and counts and percentages for categorical variables. Correlation between the SMA and ASM was assessed using the Pearson correlation coefficients.

Calculation of T-score and criteria for defining sarcopenia

We defined the T-score for SMA or SMIs (height-, weight-, and BMI-adjusted) by calculating the difference between an individual's measured SMA or SMIs and the mean SMA or SMIs of healthy young adults, and dividing that difference by the *SD* of sex-specific young adults. The formula for T-score calculation is as follows:

$$\text{T} - \text{score} = \frac{\text{Measurement value} - \text{Young adult mean}}{\text{Young adult SD}}$$

We identified the sex-specific mean values of SMA and SMIs and the cutoff points equivalent to T-score −1.0 and −2.0 in the young reference group. Distributions of the T-score values for SMA/BMIs were expressed in density plots in each sex and 10-year age groups. Subjects were classified as "normal" when the T-score was higher than −1.0. Class I and II sarcopenia were defined as −2.0 ≤ T-scores < −1.0 and T-scores less than −2.0, respectively (16,17). The prevalence of class I and II sarcopenia in each sex and 10-year age groups were calculated.

Results

Population Summary

A total of 11,845 subjects (7,314 men and 4,531 women) were included in the analysis (Supplementary Material). Table 1 lists the baseline characteristics of the study population and young adults.

Reference Data for Defining Sarcopenia and Distribution of T-Scores of SMA and SMIs

Table 2 shows the sex-specific mean values of SMA and SMIs and the cutoff points equivalent to T-score −1.0 and −2.0 in the young reference group. When T-score < −2.0 was used as the cutoff for defining sarcopenia, the sex-specific cutoff points of SMA, SMA/height^2, SMA/weight, and SMA/BMI were 119.3 and 74.2 cm^2, 39.8 and 28.4 cm^2/m^2, 1.65 and 1.38 cm^2/kg, and 4.97 and 3.46 in men and women, respectively.

SMA, SMA/height^2, SMA/weight, and SMA/BMI according to age groups are given in Table 3. The SMA in men increased until their 30s and then continuously decreased. The SMA in women increased until the 40s and then decreased. The SMA/height^2 increased until the 40s and then decreased in both sexes. The SMA/weight decreased gradually with age in women, whereas it showed a slight rise in the 40s followed by a gradual decrease in men. The SMA/BMI showed the peak values in the 20s and decreased gradually in both sexes.

Prevalence of sarcopenia

The prevalence of class I and II sarcopenia in each age group are presented in Table 4. The prevalence of class I and II sarcopenia varied from 14.4 to 24.8% and 2.3 to 5.2% in men, respectively, and from 13.8 to 27.2% and 1.0 to 8.7% in women, respectively. When using T-score < −2.0 as the cutoff for sarcopenia, the SMA/BMI provided the highest prevalence of sarcopenia (4.2% in men, 8.7% in women), and SMA/height^2 provided the lowest prevalence (2.8% in men, 1.0% in women). The increasing prevalence of sarcopenia with aging were observed with SMA and all three indices, except in the 20s and 30s age groups due to the small numbers of subjects. The distribution of SMA/BMI in men and women across different age groups are shown in Figure 1A and B.

Correlation between SMA and ASM

Pearson correlation coefficients were used to analyze the relationship between SMA and ASM in the entire population. A statistically significant correlation was found between SMA and ASM (r = .725 in men, r = .659 in women; both p < .001).

Discussion

This is the first study to report the reference values of SMA and SMIs measured on CT scans and suggest cutoff points for diagnosing sarcopenia based on T-score using the data from a large population of healthy Asian subjects. When T-score < −2.0 was used as the cutoff for defining sarcopenia (ie, class II sarcopenia), the sex-specific cutoff points of SMA, SMA/height^2, SMA/weight, and SMA/BMI were 119.3 and 74.2 cm^2, 39.8 and 28.4 cm^2/m^2, 1.65 and 1.38 cm^2/kg, and 4.97 and 3.46 in men and women, respectively.

Determining the ideal adjustment method among height, weight, and BMI has been a long debate in the field of sarcopenia (18). The prevalence of sarcopenia is determined by different definition or cutoff points. In our study, when using T-score < −2.0 as the cutoff, the SMA/BMI provided the highest prevalence of sarcopenia (4.2% in men, 8.7% in women), and SMA/height^2 provided the lowest prevalence (2.8% in men, 1.0% in women). The prevalence is determined by the diagnostic yield of a test that denotes the likelihood that a test provides the information needed to establish a diagnosis (19). Based on its high diagnostic yield, we believe that SMA/BMI may be an ideal index for diagnosing sarcopenia, especially in Asian populations. In addition, adjustment with height is only limited by the possibility that subjects with greater BMIs due to larger amounts of fat are less likely to be diagnosed with sarcopenia (20). Indeed, especially in women, SMA/height^2 yielded 1.0% prevalence of sarcopenia, which may be an underestimation.

Similarly, in a large-sized study (4,486 men and 5,999 women) using data from the Korean National Health and Nutritional Examination Surveys (KNHNES), the prevalence of sarcopenia, defined as ASM measured on DXA below 2 *SD* of the sex-specific mean for healthy young adults, was 12.4% in men and 0.1% in women by height-adjusted ASM and 9.7% in men and 11.8% in women by weight-adjusted ASM;

Table 1. Baseline Characteristics of the Study Population and the Young Adult Reference Group

	Total Study Population		Young Adult Reference Group	
	Men (*n* = 7,314)	Women (*n* = 4,531)	Men (*n* = 1,222)	Women (*n* = 695)
Age, mean ± *SD*	52.6 ± 8.8	52.8 ± 8.8	39.2 ± 4.3	39.5 ± 4.3
Height, cm^2, mean ± *SD*	170.7 ± 0.1	158.2 ± 0.1	173.6 ± 0.1	161.0 ± 0.1
Weight, kg, mean ± *SD*	71.9 ± 10.0	56.7 ± 7.6	75.9 ± 11.4	56.1 ± 8.6
BMI, kg/m^2, mean ± *SD*	24.6 ± 2.9	22.7 ± 3.0	25.2 ± 3.3	21.7 ± 3.3
Waist circumference, mean ± *SD*	87.5 ± 7.8	78.2 ± 8.2	88.0 ± 8.9	74.7 ± 8.2
SBP, mmHg, mean ± *SD*	125.3 ± 13.6	117.9 ± 14.9	126.0 ± 12.6	112.0 ± 12.3
DBP, mmHg, mean ± *SD*	80.6 ± 10.2	73.4 ± 10.6	80.7 ± 10.7	70.3 ± 10.1
Albumin, g/dL, mean ± *SD*	4.4 ± 0.2	4.3 ± 0.2	4.5 ± 0.2	4.3 ± 0.2
BUN, mg/dL, mean ± *SD*	12.9 ± 3.1	12.0 ± 3.2	11.9 ± 2.6	10.3 ± 2.7
Creatinine, mg/dL, mean ± *SD*	0.9 ± 0.1	0.7 ± 0.1	0.9 ± 0.1	0.7 ± 0.1
eGFR, mL/min/1.73cm^2, mean ± *SD*	91.4 ± 14.4	98.3 ± 16.4	97.3 ± 14.4	106.2 ± 16.6
Total cholesterol, mg/dL, mean ± *SD*	193.7 ± 34.5	197.9 ± 34.3	198.9 ± 35.3	184.3 ± 30.0
Triglycerides, mg/dL, median (IQR)	114 (82, 160)	84 (63, 114)	126 (87, 177)	69 (53, 93)
HDL cholesterol, mg/dL, mean ± *SD*	52.1 ± 12.8	62.0 ± 14.6	51.1 ± 12.0	63.9 ± 15.5
LDL cholesterol, mg/dL, mean ± *SD*	121.7 ± 30.4	121.2 ± 30.7	126.1 ± 30.9	108.2 ± 26.9
AST, IU/L, median (IQR)	27 (22, 33)	24 (20, 29)	27 (23, 35)	21 (18, 25)
ALT, IU/L, median (IQR)	24 (18, 34)	17 (14, 24)	28 (20, 42)	15 (12, 19)
Fasting glucose, mg/dL, mean ± *SD*	101.9 ± 18.8	96.2 ± 14.5	98.1 ± 17.9	92.0 ± 11.3
HbA1C, %, mean ± *SD*	5.7 ± 0.7	5.6 ± 0.5	5.5 ± 0.6	5.3 ± 0.4
Insulin, μIU/mL, median (IQR)	4.8 (2.8, 7.2)	4.1 (2.6, 6.4)	4.9 (2.9, 7.7)	3.7 (2.4, 5.9)
Smoking status				
Never, *n* (%)	1,541 (21.1)	4,217 (93.1)	235 (19.2)	580 (83.5)
Ex-smoker, *n* (%)	3,305 (45.2)	151 (3.3)	340 (27.8)	47 (6.8)
Current smoker, *n* (%)	2,465 (33.7)	161 (3.6)	646 (52.9)	68 (9.8)
Alcohol consumption, g/d, median (IQR)	14.4 (4.1, 46.5)	0.4 (0.0, 2.3)	17.8 (6.4, 50.0)	1.3 (0.0, 5.3)
Regular exercise, *n* (%)	4,347 (59.5)	2,604 (57.5)	514 (42.2)	282 (40.6)
ASM, kg, mean ± *SD*	20.4 ± 2.6	15.7 ± 1.5	21.5 ± 2.7	15.8 ± 1.7
ASM/height^2, kg/m^2, mean ± *SD*	7.0 ± 0.7	6.3 ± 0.5	7.1 ± 0.7	6.1 ± 0.6
ASM/weight, %, mean ± *SD*	28.50 ± 1.83	27.83 ± 2.09	28.46 ± 1.97	28.43 ± 2.23
ASM/BMI, mean ± *SD*	0.83 ± 0.08	0.70 ± 0.07	0.86 ± 0.09	0.74 ± 0.08
SMA, cm^2, mean ± *SD*	151.8 ± 21.1	96.8 ± 13.1	161.3 ± 21.0	100.2 ± 13.0
SMA/height^2, cm^2/m^2, mean ± *SD*	52.1 ± 6.8	38.7 ± 5.1	53.6 ± 6.9	38.7 ± 5.1
SMA/weight, cm^2/kg, mean ± *SD*	2.12 ± 0.23	1.72 ± 0.23	2.41 ± 0.24	1.80 ± 0.21
SMA/BMI, mean ± *SD*	6.18 ± 0.72	4.31 ± 0.64	6.45 ± 0.74	4.67 ± 0.61

Note: ALT = alanine aminotransferase; ASM = appendicular skeletal muscle mass; AST = aspartate aminotransferase; BMI = body mass index; DBP = diastolic blood pressure; eGFR = estimated glomerular filtration rate; HbA1c = glycated hemoglobin; HDL = high-density lipoprotein; LDL = low-density lipoprotein; SBP = systolic blood pressure; SMA = skeletal muscle area.

accordingly, the study concluded that the height-adjusted ASM tends to underestimate the prevalence of sarcopenia, especially in women (21). The same issue was also evaluated in other studies in Asian populations including China, which preferred using the weight-adjusted index or combined height- and weight-adjusted indices (22,23). Recently, the Foundation for the National Institutes of Health (FNIH) Sarcopenia Project proposed a consensus and recommended using ASM/BMI for diagnosis of sarcopenia, which was based on large population-based studies as well as statistical classification and regression tree analysis, which determined that muscle mass index is most strongly and directly correlated with weakness and slowness (24).

Although the results of our study did not favor using height-adjustment of muscle measurement on CT, the index adjusted by height squared is widely used. In a healthy European Caucasian population (age 20–40), Werf et al. reported the 5th percentile cutoff values for height-adjusted skeletal muscle index of CT measurement (equivalent to SMA/height^2) as 44.7 cm^2/m^2 in men and 33.0 cm^2/m^2 in women (25). In cancer patients, Prado et al. proposed using sex-specific cutoffs (52.4 cm^2/m^2 in men and 38.5 cm^2/m^2 in women) (26); conversely, Martin et al. proposed sex- and BMI-specific cutoffs: < 41 cm^2/m^2 in women, < 43 cm^2/m^2 in men with BMI < 25 kg/m^2, and < 53 cm^2/m^2 in men with BMI > 25 kg/m^2 (27). The existing studies that used CT muscle measurement were relatively small, and further studies using large sample size are necessary to represent the general population. Also, future studies should consider applying different adjustment methods according to different populations.

In our study, there is an evident sex difference as well as the difference between SMIs regarding the pattern of age-related muscle mass. The SMA/height^2 of men increased until their 30s while the same increased until the 40s in women. In contrast, SMA/weight and SMA/BMI peaked in the 20s and then gradually decreased until the 70s in men and women alike. Age-related muscle loss is a well-known phenomenon, with muscle mass peaking in the 20s and continuously decreasing with age (4,15). In this regard, we believe that SMA/BMI and SMA/weight are better indices for reflecting age-related muscle loss pattern than SMA/height^2. Interestingly, these patterns are very similar to those of the ASM indices in the KNHNES study in that ASM/height^2 peaked in the 30s in men and 40s in women while ASM/weight showed continuous decreases from the 20s to the 80s in both men and women (21).

The protocols for CT acquisition techniques and muscle mass measurement methods have yet to be standardized through international consensus (15). Although the assessment of sarcopenia on whole-body

Table 2. Reference Data from Young Adults Regarding SMA, SMIs, and Cutoff Points Equivalent to T-Scores of −1.0 and − 2.0

	Men (n = 1,222)			Women (n = 695)		
	Mean ± *SD*	T-score = −1.0	T-score = −2.0	Mean ± *SD*	T-score = −1.0	T-score = −2.0
SMA, cm^2	161.3 ± 21.0	140.3	119.3	100.2 ± 13.0	87.2	74.2
SMA/height^2, cm^2/m^2	53.6 ± 6.9	46.7	39.8	38.7 ± 5.1	33.6	28.4
SMA/weight, cm^2/kg	2.14 ± 0.24	1.90	1.65	1.80 ± 0.21	1.59	1.38
SMA/BMI	6.45 ± 0.74	5.71	4.97	4.67 ± 0.61	4.07	3.46

Note: BMI = body mass index; SMA = skeletal muscle area; SMI = skeletal muscle index.

Table 3. Distribution of SMA and SMIs According to Age Groups

		Mean ± *SD*			
Age Group	n (%)	SMA (cm^2)	SMA/height^2 (cm^2/m^2)	SMA/Weight (cm^2/kg)	SMA/BMI
Men	7,314				
20–29	37 (0.5)	157.4 ± 17.7	51.3 ± 5.0	2.21 ± 0.24	6.77 ± 0.75
30–39	497 (6.8)	161.9 ± 22.1	53.1 ± 6.9	2.12 ± 0.25	6.45 ± 0.76
40–49	1,939 (26.5)	158.5 ± 20.5	53.6 ± 6.9	2.16 ± 0.23	6.39 ± 0.69
50–59	3,427 (46.9)	151.8 ± 19.2	52.3 ± 6.5	2.13 ± 0.22	6.19 ± 0.66
60–69	1,179 (16.1)	140.9 ± 19.0	49.8 ± 6.5	2.06 ± 0.23	5.84 ± 0.68
70–79	221 (3.0)	129.1 ± 20.0	45.9 ± 6.7	1.92 ± 0.23	5.40 ± 0.65
≥80	14 (0.2)	119.5 ± 18.7	45.4 ± 7.7	1.98 ± 0.32	5.21 ± 0.81
Women	4,531				
20–29	25 (0.5)	97.7 ± 12.1	36.6 ± 4.8	1.82 ± 0.20	4.87 ± 0.68
30–39	252 (5.6)	98.8 ± 13.0	37.8 ± 5.0	1.81 ± 0.22	4.74 ± 0.63
40–49	1,259 (27.8)	100.5 ± 13.0	39.4 ± 5.2	1.79 ± 0.22	4.58 ± 0.60
50–59	2,105 (46.5)	96.8 ± 12.1	38.8 ± 4.8	1.72 ± 0.21	4.29 ± 0.57
60–69	698 (15.4)	91.5 ± 12.1	37.7 ± 5.2	1.61 ± 0.22	3.91 ± 0.56
70–79	182 (4.0)	88.1 ± 14.3	37.4 ± 6.1	1.54 ± 0.26	3.64 ± 0.60
≥80	10 (0.2)	80.1 ± 10.0	36.0 ± 4.9	1.57 ± 0.25	3.50 ± 0.49

Note: BMI = body mass index; SMA = skeletal muscle area; SMI = skeletal muscle index.

imaging is most accurate, it is not practical. Thus, choosing the optimal level of muscle measurement for representing the total lean body mass is important. Currently, the L3 level of the lumbar vertebra is frequently used as the landmark for the measurement of SMA in sectional body composition studies (28). At the L3 level, CT can measure the major axial muscles including the psoas, erector spinae, quadratus lumborum, and abdominal wall muscles (transversus abdominus, external and internal obliques, and rectus abdominus). Several studies showed that a single scan at the level of L3 is the best compromise site for assessing the total tissue volumes of skeletal muscle, visceral adipose tissue, and subcutaneous adipose tissue (29,30). Nevertheless, psoas muscle measurement has been adopted in many studies, mainly because it is easy to draw the region-of-interest around the psoas muscle. For example, Hamaguchi et al. used the psoas muscle index adjusted by height squared (PMI, cm^2/m^2) in a Japanese population, which peaked in the 20s and then gradually decreased until the 70s (31). Further study is necessary to compare the advantage and drawbacks of SMA measurement and psoas muscle measurement.

Another issue is whether abdominal muscle mass measured on CT can be correlated with ASM measured by DXA or BIA (32). In our study, the correlation coefficients between CT-measured SMA and BIA-measured ASM showed relatively high correlations (r = .725 in men, r = .659 in women). This result may be due to the difference between axial muscle and appendicular muscle or difference in modality. The correlation between thigh muscle mass measured by CT and ASM measured by BIA or DXA should be further explored.

Compared to other methods such as DXA and BIA, CT is limited in that it exposes the subjects to radiation. Therefore, muscle mass measurement is generally analyzed in clinically acquired CT scan for management of diseases. In general, CT is frequently used to evaluate the sarcopenia in cancer patients treated with chemotherapy or major surgery (15,33). After publishing a study (33) in patients with postoperation status, we recognized the need for reference values and sex- and age-related distributions of SMA and SMIs from apparently healthy subjects. However, it is very difficult to collect CT scans of healthy subjects, and there are only few reports on using CT scans from transplantation donor candidates as a representation for healthy population (25,31). In addition, existing studies on healthy subjects had limitations in the number, age groups, and ethnicity of subjects to allow for generalization in Asian populations. In our current study, the subjects were participants in routine health examinations at a private health check-up center of Asan Medical Center, which is the largest hospital in South Korea that provides comprehensive health check-ups for subjects coming from all over the country. Because comprehensive health examinations have been well developed and widely performed in South Korea, we were able to establish a large cohort of healthy subjects. We cannot ensure that these participants are truly representative of the general Korean population because they voluntarily participated during routine health examinations. However, the nationally representative data from the Fourth Korean National Health and Nutrition Examination Surveys (21) showed patterns of body composition according to age and sex that were similar with our data (34). In general, ultrasonography is included for the screening of internal abdominal organs, and in case of abnormal finding that warrants further evaluation, abdominal CT scanning is allowed. In addition, if a

Table 4. Prevalence of Sarcopenia According to Sex and Age Groups

		Class I Sarcopenia (−2.0 ≤ T-score < −1.0)				Class II Sarcopenia (T-score < −2.0)			
Age Group	*n* (%)	SMA	SMA/height^2	SMA/weight	SMA/BMI	SMA	SMA/height^2	SMA/weight	SMA/BMI
Men	7,314	1,812 (24.8)	1,339 (18.3)	1,051 (14.4)	1,555 (21.3)	379 (5.2)	201 (2.8)	167 (2.3)	306 (4.2)
20–29	37 (0.5)	5 (13.5)	4 (10.8)	4 (10.8)	2 (5.41)	1 (2.7)	1 (2.7)	0 (0.0)	0 (0.0)
30–39	497 (6.8)	68 (13.7)	76 (15.3)	65 (13.1)	67 (13.5)	9 (1.8)	10 (2.0)	18 (3.6)	10 (2.0)
40–49	1,939 (26.5)	324 (16.7)	268 (13.8)	200 (10.3)	271 (14.0)	39 (2.0)	27 (1.4)	31 (1.6)	33 (1.7)
50–59	3,427 (46.9)	849 (24.8)	587 (17.1)	457 (13.3)	713 (20.8)	114 (3.3)	59 (1.7)	47 (1.4)	95 (2.8)
60–69	1,179 (16.1)	472 (40.0)	316 (26.8)	254 (21.5)	403 (34.2)	136 (11.5)	62 (5.3)	38 (3.2)	106 (9.0)
70–79	221 (3.0)	88 (39.8)	83 (37.6)	68 (30.8)	93 (42.1)	73 (33.0)	39 (17.7)	30 (13.6)	58 (26.2)
≥80	14 (0.2)	6 (42.9)	5 (35.7)	3 (21.4)	6 (42.9)	7 (50.0)	3 (21.4)	3 (21.4)	4 (28.6)
Women	4,531	932 (20.6)	626 (13.8)	1,021 (22.5)	1,231 (27.2)	128 (2.8)	44 (1.0)	269 (5.9)	395 (8.7)
20–29	25 (0.5)	2 (8.0)	6 (24.0)	3 (12.0)	3 (12.0)	1 (4.0)	0 (0.0)	1 (4.0)	1 (4.0)
30–39	252 (5.6)	44 (17.5)	44 (17.5)	28 (11.1)	32 (12.7)	3 (1.2)	4 (1.6)	6 (2.4)	5 (2.0)
40–49	1,259 (27.8)	165 (13.1)	131 (10.4)	199 (15.8)	210 (16.7)	15 (1.2)	10 (0.8)	23 (1.8)	23 (1.8)
50–59	2,105 (46.5)	423 (20.1)	264 (12.5)	486 (23.1)	620 (29.5)	38 (1.8)	11 (0.5)	100 (4.8)	141 (6.7)
60–69	698 (15.4)	225 (32.2)	141 (20.2)	240 (34.4)	294 (42.1)	43 (6.2)	10 (1.4)	92 (13.2)	149 (21.4)
70–79	182 (4.0)	67 (36.8)	37 (20.3)	64 (35.2)	67 (36.8)	25 (13.7)	8 (4.4)	44 (24.2)	72 (39.6)
≥80	10 (0.2)	6 (60.0)	3 (30.0)	1 (10.0)	5 (50.0)	3 (30.0)	1 (10.0)	3 (30.0)	4 (40.0)

Note: BMI = body mass index; SMA = skeletal muscle area.

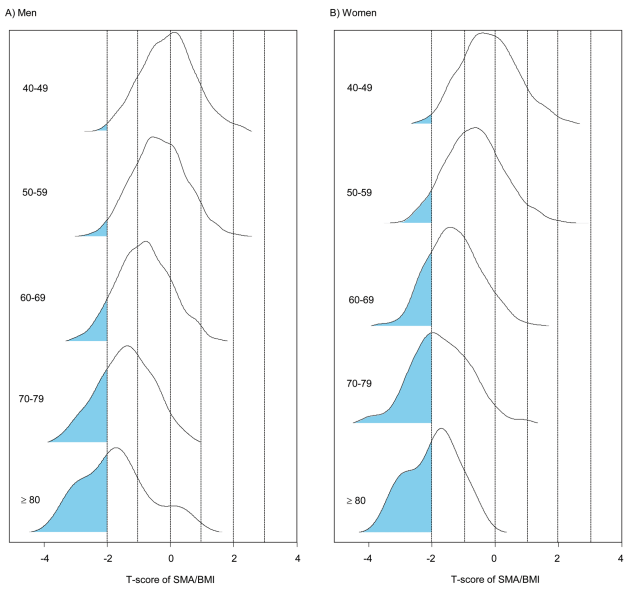

Figure 1. Distribution of SMA/BMI in men and women of different age groups, and the prevalence of class II sarcopenia (blue). SMA = skeletal muscle area; BMI = body mass index.

subject with a family history of cancer wants to take CT scans for screening purpose, CT scans are sometimes allowed after providing warning for the hazard of exposure to radiation. This is why the number of participants in the young age group was small, and we thus decided to set the young reference age at under 44, not 39. This would be reasonable according to the distribution of SMA and SMIs of this study (Table 3) and consistent with other studies (10,11).

Our study has the following limitations. First, the population in this study were subjects who visited one health screening center for regular medical check-ups, which is prone to selection bias and limited generalizability. However, this study population has strengths such as the large sample size, thorough measurements, high reproducibility (use of automated software in measuring the body composition), rigorously controlled data after thorough exclusion of health conditions that may possibly affect the body composition, and similar patterns of body composition to the nationally representative data. Therefore, we believe that our health check-up registry was an adequate source for acquiring data on healthy subjects to represent the general Korean population. Also, we did not evaluate the impact of low muscle quantity on clinical outcomes such as disability, frailty, or mortality. This is an important research topic and we are currently performing a longitudinal study by following up on our subjects.

In summary, this is the first study to report the reference values of SMA and SMIs measured on CT scans and suggest cutoff points for diagnosis of sarcopenia based on T-scores in a large population of healthy Asian subjects. BMI-adjusted index (SMA/BMI) was the best CT index for reflecting the age-related muscle changes and for maximizing the diagnostic yield for sarcopenia. In contrast, height-adjusted index (SMA/height^2) tended to underestimate the prevalence of sarcopenia in our population. Based on our results, we propose using T-score < −2.0 of SMA/BMI (4.97 in men and 3.46 in women) as the standard diagnostic criteria for diagnosing sarcopenia in Asian populations.

Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences* online.

Figure S1. Flow diagram of study subjects.

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reviewed and edited the final manuscript; H.K.K.: designed and conducted the research, contributed to interpretation, discussions about the results, critically revised and edited the final manuscript, and took primary responsibility for the final content; and all authors: read and approved the final version submitted.

Conflict of Interest

None reported.

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