Sarcopenia: Alternative Definitions and Associations with Lower Extremity Function

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OBJECTIVES: To compare two sarcopenia definitions and examine the relationship between them and lower extremity function and other health related factors using data from the baseline examination of the Health Aging and Body Composition (Health ABC) Study.

DESIGN: Observational cohort study.

SETTING: Two U.S. communities in Memphis, Tennessee, and Pittsburgh, Pennsylvania.

PARTICIPANTS: Participants were aged 70 to 79 (N = 2,984, 52% women, 41% black).

MEASUREMENTS: Participants were assessed using dual energy x-ray absorptiometry and were classified as sarcopenic using two different approaches to adjust lean mass for body size: appendicular lean mass divided by height-squared (aLM/ht^2) and appendicular lean mass adjusted for height and body fat mass (residuals).

RESULTS: These methods differed substantially in the classification of individuals as being sarcopenic, especially those who were more obese. The former method was highly correlated with body mass index and identified fewer overweight or obese individuals as sarcopenic. In both men and women, none of the obese group would be considered sarcopenic using the aLM/ht^2 method, compared with 11.5% of men and 21.0% of women using the residuals method. In men, both classifications of sarcopenia were associated with smoking, poorer health, lower activity, and impaired lower extremity function. Fewer associations with health factors were noted in women, but the classification based on both height and fat mass was more strongly associated with lower extremity functional limitations (odds ratio (OR) = 0.9, 95% confidence interval (CI) = 0.7–1.2 for low kg/ht^2; OR = 1.9, 95% CI = 1.4–2.5 for lean mass adjusted for height and fat mass).

CONCLUSION: These findings suggest that fat mass should be considered in estimating prevalence of sarcopenia in women and in overweight or obese individuals. **J Am Geriatr Soc 51:1602–1609, 2003.**

Key words: sarcopenia; muscle mass; physical function

Changes in body composition, including a decrease in bone and muscle mass and an increase in the proportion of fat, accompany aging in humans.[1,2] The age-related loss in skeletal muscle mass reflects muscle remodeling over a lifetime, and the factors that may accelerate this are only recently being examined. Lower muscle mass is associated with lower strength and is thought to contribute to the development of functional limitations and disability in old age.[3] Women have less muscle throughout life, and this may place them at particularly high risk for disability.

Sarcopenia has been increasingly used to describe both the process of age-related muscle loss and the clinical condition of having exceptionally low levels of muscle mass. Despite the existence of the term, "sarcopenia," precise criteria have not been agreed upon. Until the advent of dual-energy x-ray absorptiometry (DEXA) scanning, it has been difficult to reliably quantify lean mass (LM) in large population studies, so the issue of precise clinical definitions had not been paramount. Now that DEXA scanning is widely available for osteoporosis screening, the ability to classify large numbers of persons as sarcopenic is imminent.

At a minimum, it is necessary to account for height in determining whether LM is adequate. In the same way that

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overweight and obesity have been defined by dividing weight by height squared, a commonly used definition of sarcopenia accounts for body size by dividing LM by height squared.[4–6] In the New Mexico Aging Process study,[5] sex-specific cutpoints for kg/m^2 were defined as values that were two standard deviations (SDs) below the mean of a healthy young adult population, similar to the method used to define osteoporosis. It is noteworthy that 2% to 5% met this criterion for sarcopenic obesity, compared with 12% to 30% in normal weight people. Obese individuals who have both higher lean and fat mass may not appear to be sarcopenic even though their muscle mass may be inadequate for their size and their physical functioning. The authors propose that sarcopenia might be better defined by adjusting for body fat mass and height to determine the expected LM. Ultimately, selection of a single standard definition should be based in large part on its relevance to health and physical functioning. It was hypothesized that a definition that could simultaneously account for both height and fat mass would identify a different group as being sarcopenic than when adjusting only for height squared and that such individuals might be at even greater risk for poor lower extremity functioning.

Data relevant to several potential definitions of sarcopenia derived from the baseline of the Health Aging and Body Composition (Health ABC) Study are presented. This is a longitudinal study specifically designed to examine the interrelationships between body composition changes and physical function in 70- to 79-year-old adults initially free of mobility limitations but at high risk for decline. It is hoped that, by examining the relationships between sarcopenia definitions with health and physical functioning, the most scientifically valid and clinically useful definition of sarcopenia can be identified.

METHODS

Population

The Health ABC Study is a longitudinal, observational study of 3,075 well-functioning men and women aged 70 to 79 recruited in 1997–98 from a random sample of Medicare enrollees in Pittsburgh, Pennsylvania, and Memphis, Tennessee. Eligible participants had self-reported no difficulty walking one-quarter of a mile, climbing 10 steps, and performing activities of daily living (ADL); did not report a walking aid; and were free of cancer under active treatment. Analysis was conducted on 2,984 participants (1,435 men and 1,549 women) who had complete data on body composition and physical function. Fifty-two percent were women and 41% were black. Each institutional review board approved the protocol, and all participants gave informed consent for study participation.

Definitions of Sarcopenia

DEXA (QDR 4500A, Hologic, Inc., Waltham, MA) was used to measure whole and regional body composition. Methods and validation data have been previously reported.[7,8] In validation of this model of DEXA against a four-compartment model of body composition, a slight bias in overestimate of fat free mass was detected, resulting in study-wide adoption of a correction factor. Appendicular lean mass (aLM) was calculated as the sum of LM in arms and legs, assuming that all nonfat and nonbone tissue is skeletal muscle. For the purpose of this analysis, two measures of aLM were used to define sarcopenia: aLM relative to height squared and aLM relative to height and total fat mass.

Relative LM was first calculated using the index (aLM/ht^2) proposed by Baumgartner,[5,9] but instead of comparing index values with a cutoff from a younger population, participants were classified as sarcopenic if their value fell into the sex-specific lowest 20% of the distribution of the index in order to compare this method with the alternative below. Of note, these cutpoints of 7.23 kg/ht^2 (men) and 5.67 kg/ht^2 (women) were similar to values previously reported of 7.26 kg/ht^2 (men) and 5.45 kg/ht^2 (women).[5,9]

A second measure of relative LM was derived by adjusting for fat mass in addition to height. Linear regression was used to model the relationship between aLM on height (meters) and fat mass (kg). The residuals of the regression were used to identify those whose LM was much lower or higher than the predicted value. A positive residual would indicate a relatively muscular individual, whereas negative values would indicate relatively sarcopenic individuals. The 20th percentile of the distribution of residuals was used as the cutpoint for sarcopenia. Separate models were fit for men (aLM (kg) = –22.48 + 24.14 × height (m) + 0.21 × total fat mass (kg)) and women (aLM (kg) = –13.19 + 14.75 × height (m) + 0.23 × total fat mass (kg)). A tabulation of LM by height and fat mass in the Health ABC cohort based on these equations is available from the first author.

Physical function

Lower extremity function was assessed using chair stands, gait speed, and standing balance.[10] A total score of 12 was created using the sum of four points for each quartile of chair stands, gait speed, and standing balance derived from the Established Populations for the Epidemiologic Study of the Elderly (EPESE). Impaired lower extremity function was defined as a total score of less than 10.

Potential confounders and effect modifiers of the association between sarcopenia and function were assessed and included race (black or white), age in years, obesity, smoking, alcohol use, comorbidity, and physical activity. Obesity was defined in this report as those with a body mass index (BMI) greater than the sex-specific median to allow comparison with prevalence rates reported elsewhere.[5] As an alternative, the percentage of body fat determined using DEXA was also examined as a measure of overweight. Smoking status was defined as never, previous, and current smoking. Alcohol intake was defined as self-report of less than one drink per week, one to seven drinks per week, more than one drink per day, or none. Comorbidity was examined by summing the total of 11 conditions, assessed by self-report and validated with medication review, and grouping those with none, one, two, or three or more conditions. Physical activity was defined using the caloric expenditure[11] in the past week for self-reported walking, climbing stairs, and exercise. Four categories were created ($<$200 kcal/wk, 200–599 kcal/wk, 600–1,499 kcal/wk, and $\geq$1,500 kcal/wk).[12]

Analysis

Descriptive statistics (means, SDs, proportions) were used to describe demographic and key clinical characteristics of the study population. Because there was little overlap in body composition between men and women, analyses were conducted separately. Interactions were examined for race within sex, and none were noted. Prevalence of sarcopenia by sex was determined, and scatter plots of the two indices of sarcopenia were used to show the correlation and the degree of overlap between them. Two-sample *t* tests were used to test for differences in the distribution of continuous variables, and the chi-square test was used to test for differences in the distribution of categorical variables. The association between sarcopenia and physical function was assessed using logistic regression. Odds ratios (ORs) and 95% confidence intervals (CIs) are reported.

RESULTS

The 2,984 participants from the Health ABC Study in the present analysis included 52% women and 41% blacks (Table 1). Men had greater LM and larger values on measures of lean body mass than women. Total fat mass and percentage of body fat were higher in women than men. Within sex groups, black men tended to have larger values for aLM/ht^2 (8.5 kg/m^2 for black men vs 7.8 kg/m^2 for white men). Similarly, black women had higher total lean body mass (42.5 kg) and aLM/ht^2 (7.3 kg/m^2) than white women (38.1 kg for total lean body mass and 6.1 kg/m^2 for aLM/ht^2) but also had a higher mean BMI (29.7 kg/m^2 for black women vs 26.0 kg/m^2 for white women). Women, especially black women, were more likely to have lower physical function.

Figure 1 shows a comparison of the methods used to define sarcopenia (aLM/ht^2 and regression residuals method including fat mass) in men (Figure 1a) and women (Figure 1b). Using either method, subjects falling in the lowest 20th percentile of the distribution were classified as sarcopenic relative to the rest of the analysis sample. The vertical line indicates the 20th percentile for aLM/ht^2 and the horizontal line the 20th percentile for the residuals. Those who would be classified as being sarcopenic (lowest 20th percentile) are those falling to the left of the line for aLM/ht^2 and below the line for the residual score. The two definitions of sarcopenia were correlated (correlation coefficient $r = 0.88$ in men and $r = 0.71$ in women) but would each classify a different subset of individuals as sarcopenic, although with some overlap. Two hundred two men were classified as sarcopenic by both methods, with 85 classified by one method and not the other (Figure 1a). In women, 155 were classified as sarcopenic by both definitions and 155 by one definition and not the other (Figure 1b).

The prevalence of sarcopenia in those who were overweight (BMI = 25–29) or obese (BMI $\geq$ 30) also varied by definition and sex (Figure 2). Using aLM/ht^2 the prevalence of sarcopenia in the overweight and obese subgroups was 8.9% and 0%, respectively, in men and 0.8% and 0%, respectively, in women. Using the lowest 20th percentile of the residuals for LM adjusted for height and fat mass, the prevalence of sarcopenia in the overweight and obese subgroups was much higher (15.4% and 11.5% in men, and 21.7% and 21% in women). Therefore, when adjusting for height, more thin people would be considered sarcopenic than when accounting for fat and height, where more overweight individuals would be considered sarcopenic. Results were similar when percentage of body fat of greater than the sex-specific median was used to define overweight. The index of aLM/ht^2 was highly correlated with BMI (men, $r = 0.76$, women, $r = 0.85$), whereas the method using the residual of the regression of lean mass on height and fat mass was not (men, $r = 0.38$, women, $r = 0.25$).

Table 1. Characteristics of 2,984 Health Aging and Body Composition Participants by Sex and Race

Characteristic	White Men	White Women	Black Men	Black Women	All
	Mean ± Standard Deviation				
Age	74.0±2.9	73.6±2.8	73.5±2.8	73.4±3.0	73.6±2.9
Height, m	1.7±0.1	1.6±0.1	1.7±0.1	1.6±0.1	1.7±0.1
Weight, kg	81.2±12.3	66.3±12.3	81.0±14.3	75.6±15.4	75.6±14.8
Body mass index, kg/m^2	27.0±3.7	26.0±4.6	27.1±4.3	29.7±5.7	27.4±4.8
Total LBM, kg*	54.8±6.7	38.1±5.1	56.0±7.8	42.5±6.2	47.4±10.0
LBM/height, kg/m	31.6±3.3	23.9±2.9	32.4±4.0	26.6±3.5	28.4±4.9
Relative LBM, kg/m^2	18.2±1.8	15.0±1.8	18.7±2.2	16.7±2.1	17.0±2.4
aLM, kg	23.6±3.2	15.5±2.4	25.5±4.0	18.5±3.3	20.4±5.0
aLM/height, kg/m	13.6±1.6	9.7±1.4	14.7±2.1	11.6±1.9	12.2±2.5
Relative aLM, kg/m^2	7.8±0.9	6.1±0.8	8.5±1.1	7.3±1.1	7.3±1.3
Total fat mass, kg	23.7±6.9	26.4±7.9	22.2±7.4	31.0±9.9	25.9±8.6
Total percentage fat, %	28.7±4.8	39.0±5.6	26.8±5.3	40.1±6.0	34.0±7.9
Total lean mass with bone mineral content, kg	57.3±6.9	39.9±5.3	58.8±8.0	44.4±6.4	49.6±10.5
Established Populations for the Epidemiologic Study of the Elderly score	10.6±1.4	10.1±1.5	9.9±1.7	9.5±1.8	10.0±1.6

* Does not include bone mineral content.
LBM = lean body mass; aLM = appendicular lean mass.

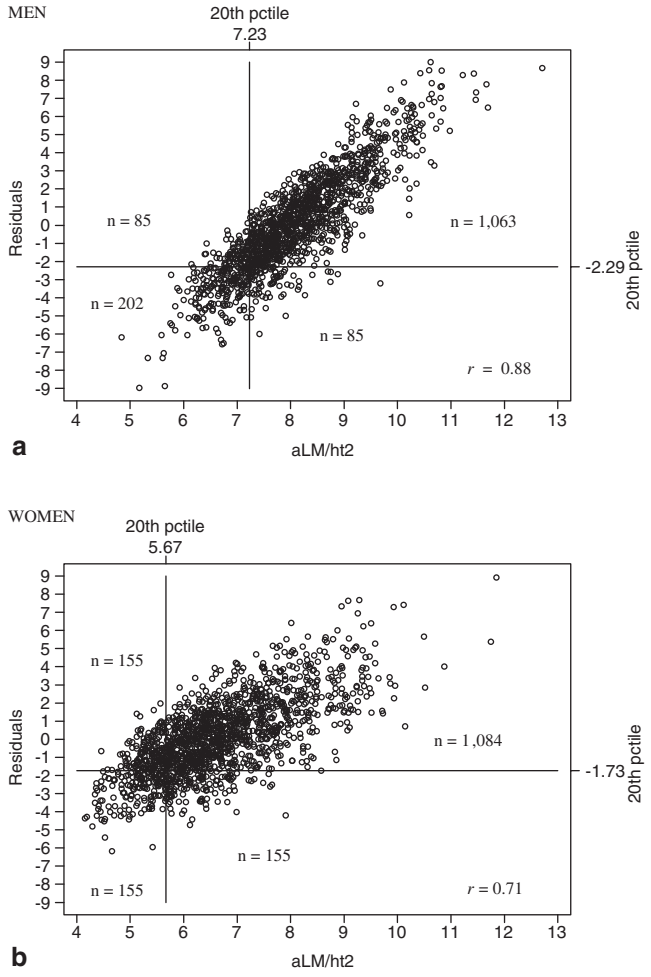

Figure 1. Comparison of the two measures of relative lean mass (a) in men and (b) in women. Residuals (obtained from linear regression of appendicular lean mass (aLM) (kg) on height (meters) and fat mass (kg)) and the ratio (aLM/ht^2) of aLM (kg) and height squared (m^2). Horizontal and vertical lines indicate the 20th percentile of residuals and aLM/ht^2 distributions, respectively. Frequencies in each quadrant are indicated by n, and the correlation coefficient between the two measures is indicated by r.

Differences in the characteristics of men and women classified as sarcopenic using either method are presented in Table 2. There were no age differences between the two groups in either men or women. As would be expected, BMI was lower in those classified as sarcopenic by adjusting for height-squared than with the regression residual method. These differences were more pronounced in women than in men. In men, mean BMI $\pm$ SD was 23.2 $\pm$ 2.5 kg/m^2 for the aLM sarcopenic group and 25.5 $\pm$ 4.09 kg/m^2 for the residual sarcopenic group. In women, mean BMI was 21.9 $\pm$ 2.5 kg/m^2 for the aLM sarcopenic group and 26.6 $\pm$ 4.7 kg/m^2 for the residual sarcopenic group. More black men were classified as sarcopenic using the aLM method (21.6%) than the residual method (14.3%). There was no racial difference observed in women. In women, the proportion with lower extremity functional limitation was higher for the residual sarcopenic group (44.8%) than the aLM sarcopenic group (31.6%). This trend was not observed in men.

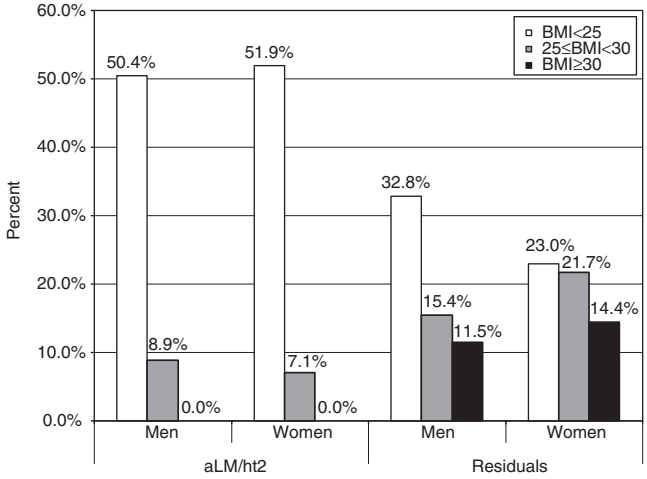

Figure 2. Prevalence of sarcopenia by method (ratio of appendicular lean mass (aLM) (kg) and height squared (m^2) (aLM/ht^2) and residuals obtained from linear regression of aLM (kg) on height (m), fat mass (kg)), sex, and body mass index groups.

The independent associations between selected demographics and other factors within each sarcopenia definition are presented in Table 3. Men aged 75 to 79 were associated with a moderately higher risk of sarcopenia (OR = 1.5, 95% CI = 1.0–2.1 for the aLM/ht^2 and OR = 1.6, 95% CI = 1.2–2.1 for residuals), and black men were less likely to be classified as sarcopenic than white men by either method. Overweight individuals were less likely to be classified as sarcopenic using the aLM/ht^2 method, but for sarcopenia defined using the residuals method, the association with weight was not assessed, because this method takes total fat mass into account. Smoking was associated with sarcopenia, with a similar risk observed for current smokers in both methods. A borderline protective effect was observed for the highest level of physical activity (1,500 kcal/wk) with an OR of 0.7 for the residuals method. Men having three or more comorbid conditions were also more likely to be classified as sarcopenic using either method. Of the 11 conditions assessed individually, only cancer was associated with sarcopenia in men and was similar for each method. In women, black race (OR = 0.2, 95% CI = 0.1–0.3 for both methods) and BMI (OR = 0.5, 95% CI = 0.5–0.6) were inversely associated with sarcopenia. Also, those at the highest level of physical activity were less likely to be sarcopenic for both methods. Although comorbidity of three or more conditions was not associated with sarcopenia in women, diabetes mellitus, when assessed separately, showed a protective effect with both the aLM/ht^2 method (OR = 0.5, 95% CI = 0.2–1.2) and the residual method (OR = 0.6, 95% CI = 0.3–0.9).

The models testing the associations between each index of sarcopenia and impaired lower extremity performance are presented in Table 4. In men, sarcopenia was associated with lower performance score (crude OR = 1.4, 95% CI = 1.0–1.8 for aLM/ht^2 sarcopenics and crude OR = 1.4, 95% CI = 1.1–1.9 for residual sarcopenics). Adjustment for age and race resulted in slightly larger differences between the OR for the two methods. With further adjustment for smoking, alcohol intake, physical activity,

Table 2. Characteristics of Sarcopenic Adults Classified by the Ratio of Appendicular Lean Mass and Height Squared (aLM/ht^2) or Residuals Method

Characteristic	aLM/ht^2 Sarcopenic	Residual Sarcopenic	*P*-value for Difference*
Men			
Age, mean ± SD	74.5 ± 2.75	74.5 ± 2.89	.799
Black, n (%)	62 (21.6)	41 (14.3)	.022
BMI, mean ± SD	23.2 ± 2.49	25.5 ± 4.01	< .001
EPESE score, mean ± SD	10.1 ± 1.70	10.1 ± 1.67	.887
EPESE < 10, n (%)	80 (27.9)	82 (28.6)	.853
Women			
Age, mean ± SD	73.8 ± 2.84	73.7 ± 2.74	.858
Black, n (%)	48 (15.5)	57 (18.4)	.335
BMI, mean ± SD	21.9 ± 2.52	26.6 ± 4.72	< .001
EPESE score, mean ± SD	10.1 ± 1.63	9.6 ± 1.78	.006
EPESE < 10, n (%)	98 (31.6)	139 (44.8)	.001

* *T* test for continuous variables, chi-square test for categorical variables.
SD = standard deviation; BMI = body mass index; EPESE = Established Populations for the Epidemiologic Study of the Elderly.

and comorbidity (for aLM/ht^2 additionally adjusted for BMI), the magnitude of the association changed little, being slightly higher for the residuals methods but with overlapping CIs. In women, a protective effect was noted for the aLM/ht^2 method (crude OR = 0.7, 95% CI = 0.5–0.9). With adjustment for age and race, there was no association between this definition of sarcopenia and low function, and this remained nonsignificant with further adjustment. In contrast, when using the residuals method, there was a statistically significant association between sarcopenia and lower performance score (crude OR = 1.4, 95% CI = 1.1–1.8). As in men, the magnitude of the association was larger in the women after adjustment for age and race and with further adjustment (adjusted OR = 1.9, 95% CI = 1.4–2.5).

DISCUSSION

Two different approaches to defining sarcopenia identify different individuals as sarcopenic. Men identified as sarcopenic using these different methods had similar functional status, and the correlations between the two approaches were high. In women, the correlation was much lower, and the overlap was only about 50%. The classification of sarcopenia based on a low aLM for height and fat mass resulted in a stronger association with lower performance scores than the method adjusting LM for height squared, and only the definition accounting for fat was associated with low function in women. Additionally, this method resulted in a higher prevalence of sarcopenia in those who were more overweight. Using the index of kg/ht^2 in the study's population would classify few of the overweight and none of the obese as sarcopenic. Both methods defined those who had a low LM, and both appeared to be valid in that such individuals tended to have poorer function. In spite of the fact that lower LM with age has been observed both cross-sectionally[2] and longitudinally,[13] there are no criteria for the diagnosis of sarcopenia in older individuals. LM cannot be interpreted in an individual without some indexing to body size. Recent work on indexing percentage of body fat to BMI raises similar issues.[14] More work is needed to validate the optimal criteria for determining a healthy range of LM for a given individual.

The hypothesized relationship between sarcopenia and functional limitation or disability is not well established with data in the published literature. Some have shown that higher fat mass is a more important factor than low LM,[15,16] whereas others have found an independent effect of low lean mass on impaired functional status.[4,5,17] These other studies found more similar associations between kg/ht^2 and function in men and women. Together these studies lend support to the idea that low LM is associated with limitations in lower extremity function whether fat is considered in the definition or with subsequent adjustment for fat mass.[1,4,22,25]

Other analytic approaches to account for both fat mass and LM and the effects on function have been proposed. In a recent study,[18] absolute and relative measures were used to account for the effects of LM and fat mass on functional performance. A lower lean/fat ratio was associated with slower walking speed and more limitation. Obese individuals have, by definition, a lower lean/fat ratio than lean individuals, thus it is not surprising that ratio analysis finds fat mass to be more strongly associated with function than lean mass. Because the current study found that height and weight were related to LM, both were accounted for in estimating a lower-than-predicted LM. Still, this technique has a similar conceptual basis to other approaches, that is, to attempt to capture the effects of low lean and high fat simultaneously. The associations between sarcopenia and impaired function appear to validate this approach, and the simple model for predicting LM allows an expected LM to be easily calculated for an individual. Nevertheless, no one approach has wide acceptance or is without limitations.

Clinicians caring for obese older adults who become ill and cannot support their own body weight recognize the concept of "sarcopenic obesity." Clinically, it is difficult to identify these individuals for treatment because they might not meet criteria for malnutrition, even though many biochemical parameters suggest it. Additionally, absolute

Table 3. Association-Adjusted Odds Ratios (OR)* and 95% Confidence Intervals (CIs) of Selected Demographics and Other Factors with Different Sarcopenia Definitions in 1,435 Men and 1,549 Women from the Health Aging and Body Composition Study

	Men		Women	
	aLM/ht^2	Residuals	aLM/ht^2	Residuals
Characteristic	OR (95% CI)			
Age ≥75	1.5 (1.0–2.1)	1.6 (1.2–2.1)	0.9 (0.6–1.4)	1.1 (0.9–1.5)
Black	0.2 (0.1–0.3)	0.2 (0.1–0.3)	0.2 (0.1–0.3)	0.2 (0.1–0.3)
BMI	0.5 (0.5–0.6)	—	0.5 (0.5–0.6)	—
Drinking				
None	1.0	1.0	1.0	1.0
<1/wk	1.0 (0.6–1.6)	0.7 (0.4–1.0)	1.1 (0.7–1.7)	1.0 (0.8–1.5)
1–7/wk	1.2 (0.8–1.8)	0.8 (0.6–1.2)	0.9 (0.6–1.5)	1.1 (0.8–1.6)
>1/d	1.7 (1.0–3.0)	1.3 (0.8–2.0)	1.2 (0.5–2.8)	0.9 (0.4–1.8)
Smoking				
Never	1.0	1.0	1.0	1.0
Former	1.4 (0.9–2.1)	1.5 (1.1–2.1)	1.1 (0.7–1.6)	1.1 (0.8–1.4)
Current	1.3 (0.7–2.5)	2.6 (1.5–4.4)	1.2 (0.6–2.1)	0.9 (0.6–1.5)
Physical activity				
<200 kcal/wk	1.0	1.0	1.0	1.0
200–599 kcal/wk	1.6 (1.0–2.7)	0.8 (0.5–1.2)	0.7 (0.4–1.1)	0.7 (0.5–1.0)
600–1,499 kcal/wk	1.0 (0.6–1.7)	1.0 (0.7–1.4)	0.7 (0.4–1.0)	0.7 (0.5–1.0)
≥1,500 kcal/week	0.8 (0.5–1.3)	0.7 (0.5–1.0)	0.6 (0.3–1.1)	0.7 (0.4–1.0)
Morbidity				
Cancer	1.8 (1.2–2.6)	1.6 (1.2–2.2)	1.2 (0.8–2.0)	0.9 (0.6–1.3)
Diabetes mellitus	0.8 (0.5–1.3)	0.8 (0.6–1.3)	0.5 (0.2–1.2)	0.6 (0.3–0.9)
Coronary heart disease	1.4 (0.9–2.1)	1.0 (0.7–1.3)	1.3 (0.7–2.3)	1.2 (0.8–1.8)
Coronary heart failure	0.5 (0.1–2.5)	0.5 (0.1–1.6)	—	—
Peripheral arterial disease	1.3 (0.7–2.5)	1.3 (0.8–2.1)	1.1 (0.3–3.6)	0.7 (0.3–1.5)
Hypertension	1.5 (1.1–2.2)	1.1 (0.8–1.4)	1.1 (0.7–1.6)	1.2 (0.9–1.6)
Knee osteoarthritis	1.9 (0.8–4.7)	0.9 (0.4–2.0)	1.5 (0.7–3.3)	1.2 (0.7–1.8)
Osteoporosis	5.8 (0.6–57.7)	3.7 (0.5–29.4)	0.7 (0.4–1.3)	0.8 (0.5–1.2)
Pulmonary disease	1.2 (0.7–2.0)	1.2 (0.8–1.9)	1.4 (0.5–1.6)	1.1 (0.7–1.6)
Ulcer	1.6 (1.1–2.5)	1.4 (1.0–2.0)	0.8 (0.5–1.4)	1.2 (0.8–1.8)
Depression	1.4 (0.6–3.0)	1.8 (1.0–3.1)	0.7 (0.4–1.3)	1.1 (0.7–1.7)
Comorbidity				
None	1.0	1.0	1.0	1.0
1 condition	1.9 (1.2–3.1)	0.9 (0.6–1.4)	1.1 (0.7–1.7)	1.2 (0.8–1.7)
2 conditions	1.9 (1.2–3.2)	1.1 (0.8–1.7)	1.2 (0.8–2.0)	1.3 (0.9–1.9)
≥3 conditions	2.8 (1.7–4.8)	1.5 (1.0–2.3)	0.8 (0.4–1.5)	1.1 (0.7–1.6)

* ORs adjusted for age, race, drinking, smoking, physical activity, and comorbidity. ORs for specific morbidities adjusted for age, race, smoking, drinking, and physical activity. When using aLM/Ht^2, ORs additionally adjusted for body mass index.
aLM/ht^2 = ratio of appendicular lean mass and height squared.

LM in an obese individual is always higher than in a lean person, because both fat and LM increase with weight gain. As noted, the method of determining sarcopenia relative to fat and height resulted in a larger proportion of sarcopenia in those who were more overweight and, in women, a stronger association with lower extremity impairment.

In this study, all participants were free of ADL difficulty and mobility impairment at the baseline assessment of body composition. Nevertheless, on performance testing, a wider range of function was found, including in some participants with early impairment. This allowed us to examine those who were more impaired but not those with frank disability. In addition to validation of definitions using physical functioning, other criterion methods could be used. For example, cutpoints for sarcopenia could be derived from individuals with advanced illness.[19] The cohort in the current study, selected to be free of baseline disability, had few individuals with advanced chronic illness. Expected values for normal young adults have also been proposed as normal values on which to base age-related decline, as has been done with osteoporosis. The sex-specific 20th percentile was arbitrarily chosen because population norms for young adult blacks and whites are not currently available. The prevalence of sarcopenia will vary by race and sex group depending on the criteria, reference populations, and definitions used. As more body composition data from diverse populations with DEXA scanning becomes available, additional validation can be done. Potentially

Table 4. Odds Ratio (OR) of Having an EPESE Score of Less than 10 by Sarcopenia Definition in Men and in Women

	aLM/ht^2 Sarcopenic	Residual Sarcopenic
Model	OR (95% Confidence Interval)	
Men		
Crude	1.4 (1.0–1.8)	1.4 (1.1–1.9)
Age- and race-adjusted	1.6 (1.2–2.2)	1.9 (1.4–2.7)
Adjusted*	1.5 (1.1–2.1)	1.8 (1.3–2.5)
Women		
Crude	0.7 (0.5–0.9)	1.4 (1.1–1.8)
Age- and race-adjusted	0.8 (0.6–1.1)	1.9 (1.4–2.5)
Adjusted*	0.9 (0.7–1.2)	1.9 (1.4–2.5)

* Adjusted for age, race, smoking, drinking, comorbidity, and physical activity. For ratio of appendicular lean mass and height squared (aLM/ht^2), also adjusted for body mass index (BMI) (continuous).
EPESE = Established Populations for the Epidemiologic Study of the Elderly.

more-complex models could be developed to derive expected LM from other body composition parameters. Additionally, some have proposed that the quality of the muscle should be considered in addition to the quantity.[20] It has been reported that the infiltration of muscle with fat is related to strength per unit of muscle mass[21] and to physical function,[22] suggesting the importance of muscle composition to its function and the potential role of muscle quality in defining sarcopenia. Further research is needed to determine whether differences in muscle quality in the weight-bearing (lower extremities) or non-weight-bearing muscles have different patterns of decline in mass or function. For example, human population[23] and animal studies[24] suggest that the quadriceps is more prone to these age-related changes than the upper extremities. Few data have been published describing the predictors of sarcopenia in population studies. In the New Mexico Aging Process study, age of 75 and older, obesity, and current smoking were identified as risk factors in men; in women, only age was identified as a significant predictor of sarcopenia.[5] Physiological studies point to the importance of hormonal factors, especially growth hormone and the sex steroid hormones.[25] Muscle mass and loss of strength have a definite heritable component[26] and are associated with genetic variations in myostatin, ciliary neurotrophic factor, and insulin growth factor-1.[27–29] All of these factors deserve further study, but such studies may be premature given the uncertainty about the best operational definition of sarcopenia. It will also be important to determine what factors accelerate the loss of LM or might preserve LM with weight loss.

In addition to the potential limitations of the restricted age range and functional health status of this cohort, it is important to keep in mind that these analyses are cross-sectional and thus cannot determine causality. Also, the cutpoints chosen were arbitrary and not meant to imply a threshold effect for clinical manifestations of sarcopenia. In fact, the relationship between muscle mass and strength is quite linear,[23] whereas the relationship with function may have a threshold.[30] A cutpoint of function was chosen that should be below the plateau of the mass/strength relationship. It is still possible that the stronger relationship in women may be due to the lower cutpoint used for women. This would not alter the internal consistency of the findings in the women. If a single cutpoint was chosen for men and women, many women and no men would be classified as sarcopenic, because women have lower LM than men at any given height or weight.

Although superior to bioelectric impedance and anthropometric methods such as skin folds or circumferences, determination of body composition using DEXA also has limitations. DEXA has the advantage of quantifying LM more directly and noninvasively than the most accurate techniques, but it does not capture increases in intramuscular fat, which also occur with age. Although body composition scanning is currently widely available using the same DEXA scanners used for bone densitometry, more research is needed to determine whether DEXA body composition scanning can be of clinical utility in geriatric practice.

Because LM is highly correlated with strength, preservation of LM in old age is an important avenue of potential treatment to prevent disability in old age. Interventions under study, including hormonal manipulations and exercise, might be better targeted toward those who are frailer, including those who are sarcopenic but overweight. These data provide another approach to identify those at risk for disability and to further explore the risk factors for low LM. Future studies should examine the role of the quantity of LM in determining important health outcomes, including declines in strength and function as well as mortality to further validate the best approach to defining low LM in an individual.

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