Low Relative Skeletal Muscle Mass (Sarcopenia) in Older Persons Is Associated with Functional Impairment and Physical Disability

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OBJECTIVES: To establish the prevalence of sarcopenia in older Americans and to test the hypothesis that sarcopenia is related to functional impairment and physical disability in older persons.

DESIGN: Cross-sectional survey.

SETTING: Nationally representative cross-sectional survey using data from the Third National Health and Nutrition Examination Survey (NHANES III).

PARTICIPANTS: Fourteen thousand eight hundred eighteen adult NHANES III participants aged 18 and older.

MEASUREMENTS: The presence of sarcopenia and the relationship between sarcopenia and functional impairment and disability were examined in 4,504 adults aged 60 and older. Skeletal muscle mass was estimated from bioimpedance analysis measurements and expressed as skeletal muscle mass index (SMI = skeletal muscle mass/body mass × 100). Subjects were considered to have a normal SMI if their SMI was greater than -one standard deviation above the sex-specific mean for young adults (aged 18–39). Class I sarcopenia was considered present in subjects whose SMI was within -one to -two standard deviations of young adult values, and class II sarcopenia was present in subjects whose SMI was below -two standard deviations of young adult values.

RESULTS: The prevalence of class I and class II sarcopenia increased from the third to sixth decades but remained relatively constant thereafter. The prevalence of class I (59% vs 45%) and class II (10% vs 7%) sarcopenia was greater in the older (≥ 60 years) women than in the older men ($P < .001$). The likelihood of functional impairment and disability was approximately two times greater in the older men and three times greater in the older women with class II sarcopenia than in the older men and women with a normal SMI, respectively. Some of the associations between class II sarcopenia and functional impairment remained significant after adjustment for age, race, body mass index, health behaviors, and comorbidity.

CONCLUSIONS: Reduced relative skeletal muscle mass in older Americans is a common occurrence that is significantly and independently associated with functional impairment and disability, particularly in older women. These observations provide strong support for the prevailing view that sarcopenia may be an important and potentially reversible cause of morbidity and mortality in older persons. **J Am Geriatr Soc 50:889–896, 2002.**

Key words: aging; skeletal muscle; sarcopenia; prevalence; functional impairment; disability; NHANES III

Physical strength, stamina, and balance all depend to some extent on the integrated function of skeletal muscle tissue. After reaching a peak in early adult years, skeletal muscle mass gradually declines beginning at about age 45.[1–3] Referred to as sarcopenia, loss of skeletal muscle mass below a critical threshold may lead to functional impairment and physical disability.[4–6] Advanced skeletal muscle loss may affect quality of life, the need for supportive services, and ultimately the need for long-term care in older persons. The growing older population, combined with the potential reversibility or prevention of skeletal muscle loss, dictates the need for studies aimed at firmly establishing whether sarcopenia is related to functional impairment and disability in the general U.S. population.

Until recently, methods of measuring skeletal muscle mass suitable for large-scale studies were not available. We recently developed and validated an equation for predicting whole-body muscle mass using bioelectrical impedance analysis (BIA).[7] The BIA method provides simple, inexpensive, and reliable estimates of skeletal muscle mass in adult men and women and is appropriate for measuring muscle mass in large cohorts.

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The Third National Health and Nutrition Examination Survey (NHANES III) was conducted to estimate the prevalence of major diseases, nutritional disorders, and risk factors for these diseases in a nationally representative cohort. The NHANES III data set includes BIA measures from approximately 15,000 adults aged 18 and older. Functional impairment and physical disability were also assessed in those subjects aged 60 and older.

The objective of the present investigation was twofold: to establish the prevalence of sarcopenia in older Americans and to test the hypothesis that low skeletal muscle mass, or sarcopenia, is related to functional impairment and physical disability in older persons.

METHODS

Study Population

The National Center for Health Statistics and the Centers for Disease Control and Prevention conducted NHANES III to estimate the prevalence of major diseases and nutritional disorders and potential risk factors for these diseases. NHANES III was a nationally representative, two-phase, 6-year, cross-sectional survey conducted from 1988 through 1994. The complex sampling plan used a stratified, multistage, probability cluster design. The total sample included 33,199 persons. Full details of the study design, recruitment, and procedures are available from the U.S. Department of Health and Human Services.[8,9] The full evaluation included a standardized home interview and a physical examination in a mobile center.

Of the total sample, 14,818 were adults aged 18 and older of non-Hispanic white (n = 6,376), non-Hispanic black (n = 4,295), and Mexican American (n = 4,147) ethnicity in which BIA measures, height, and body weight, which were needed to compute skeletal muscle mass relative to weight, were obtained. Other ethnic groups, in whom the BIA-skeletal muscle method has not been validated, were excluded from the data analysis. Pregnant women were not eligible for the BIA procedure in NHANES III. Data from the young adults (aged 18–39; 3,298 women and 3,116 men) were used as reference data to define cutoff values for normal skeletal muscle mass and sarcopenia. Skeletal muscle mass was determined in 2,278 women and 2,224 men aged 60 and older on whom measures of functional impairment and physical disability were also acquired. Informed consent was obtained from all participants, and the National Center for Health Statistics approved the protocol.

Functional Impairment and Physical Disability

Functional impairment was defined as having limitations in mobility performance (e.g., walking, climbing stairs). The items used to assess functional impairment in NHANES III were selected from the works of Nagi[10] and Rosow et al.[11] Physical disability was defined as having difficulty performing activities of daily living (ADLs) (e.g., shopping, light household chores). The items used to assess disability were selected from the works of Rosow et al.,[11] Lawton et al.,[12] and Katz et al.[13] The agreement between repeated measures of physical function in older persons is approximately 85%.[14]

During the home interview, subjects were asked whether they had no difficulty, some difficulty, much difficulty, or were unable to lift or carry 10 pounds (e.g., sack of rice or potatoes); walk for one-quarter of a mile; walk up 10 steps without resting; stoop, crouch, or kneel; stand up from an armless chair; perform light household chores (e.g., dusting, sweeping); and prepare meals. For each of these measures, those reporting no difficulty were assigned a score of 1, and those reporting any difficulty were assigned a score of 0. The subjects were also asked whether they required help with personal care needs (e.g., eating, bathing, dressing) or routine needs (e.g., household chores, completing necessary business, shopping). Those not requiring help with these tasks were assigned a score of 1, and those requiring help were assigned a score of 0.

Three aspects of physical performance were tested during the physical examination using standardized protocols.[9,15] These tests included the ability to walk 8 feet, complete five chair stands, and stand with the heel of one foot directly in front of the toes of the other foot (tandem stand) for 10 seconds. For each of these physical performance tests, those who completed the task were assigned a score of 1 and those who could not complete the task were assigned a score of 0.

Body Composition

Body weight and height were measured to the nearest 0.1 kg and 0.1 cm using standardized equipment and procedures.[16] Body mass index (BMI) was calculated as weight/height^2 (kg/m^2). BIA resistance (ohms) was obtained using a Valhalla 1990B Bio-Resistance Body Composition Analyzer (Valhalla Medical, San Diego, CA) with an operating frequency of 50 kHz at 800 μA. Whole-body BIA measurements were taken between the right wrist and ankle with the subject in a supine position.[17]

Skeletal Muscle Mass Measurements

Skeletal muscle mass was calculated using the BIA equation of Janssen et al.:[7]

$$\text{skeletal muscle mass (kg)} = [(\text{height}^2/\text{BIA-resistance} \times 0.401) + (\text{gender} \times 3.825) + (\text{age} \times -0.071)] + 5.102$$

where height is in cm; BIA-resistance is in ohms; for gender, men = 1 and women = 0; and age is in years. This BIA equation was developed and cross-validated against magnetic resonance imaging measures of whole-body muscle mass in a sample of 269 men and women varying widely in age (18–86) and adiposity (BMI = 16–48 kg/m^2). In this cohort, the correlation between muscle mass predicted using BIA and muscle mass measured using magnetic resonance imaging was 0.93, and the standard error of the estimate for predicting skeletal muscle mass from BIA was 9%.[7] Absolute skeletal muscle mass (kg) was converted to percentage skeletal muscle mass (muscle mass/body mass × 100) and termed the skeletal muscle index (SMI). SMI was used because it adjusts for stature and the mass of nonskeletal muscle tissues (fat, organ, bone). Most mobility tasks and ADLs are influenced by body size.

Sarcopenia Classification

The distribution of SMI values for those persons aged 18 to 39 from the NHANES III data set was used to develop the classification criteria for muscle loss in the older persons (Figure 1). Subjects were considered to have a normal SMI if their SMI was greater than -one standard deviation above the sex-specific mean for young adults (aged 18–39). Class I sarcopenia was considered present in subjects whose SMI was within -one to -two standard deviations of young adult values, and class II sarcopenia was present in subjects whose SMI was below -two standard deviations of young adult values. This approach is comparable with the use of bone mineral density of a young reference group for classifying normal bone density, osteopenia, and osteoporosis.[18]

Potential Confounders

Age and Race

Age was included in the multivariate analysis as a continuous variable. Race was coded as 0 for non-Hispanic whites, 1 for non-Hispanic blacks, and 2 for Hispanics.

Health Behaviors

Health behaviors were assessed in the home interview. Alcohol consumption was graded as being none (0 drinks/month), moderate (1–15 drinks/month), or heavy (>15 drinks/month). Subjects were considered current smokers if they smoked cigarettes, cigars, or pipe tobacco at the time of the interview; previous smokers if they smoked 100 cigarettes, 20 cigars, or 20 pipefuls of tobacco in their entire life; and nonsmokers if they smoked less than these amounts. Physical activity was graded as being none (<4 times/month), low (4–10 times/month), moderate (11–19 times/month), or high (>19 times/month) based on the subject's reports of their monthly frequency of engaging in leisure-time physical activities. These activities included walking continuously for 1 mile or more, jogging, swimming, cycling, dance, calisthenics, sports, and resistance exercise.

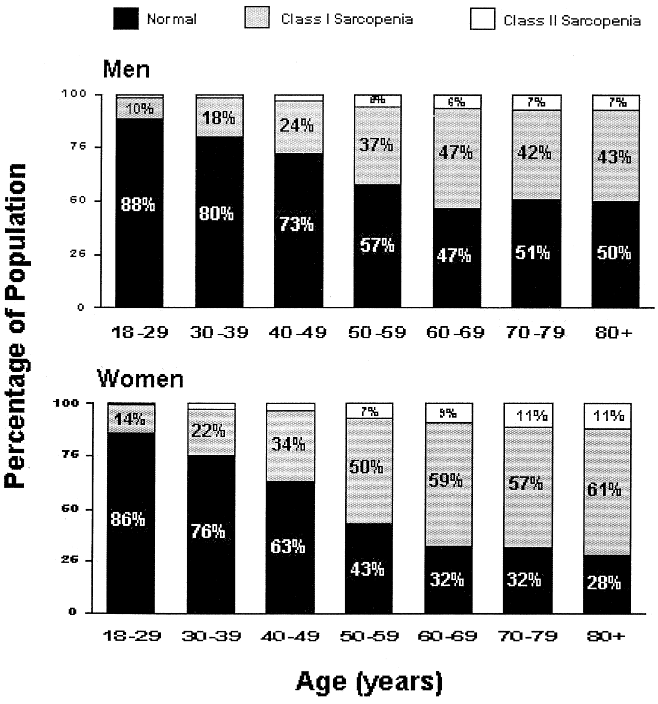

Figure 1. The prevalence of men (top) and women (bottom) with a normal skeletal muscle index (SMI = muscle mass/body mass × 100), class I sarcopenia, and class II sarcopenia according to decade.

Comorbidity

Major chronic illnesses were assessed in the home interview. The chronic illnesses included in the present study were coronary heart disease (myocardial infarction, congestive heart failure), stroke, cancer, lung disease (chronic bronchitis, emphysema), diabetes mellitus other than gestational diabetes, and arthritis (rheumatoid and osteoarthritis). These conditions were considered present for those who had ever been told by a physician that they had the conditions.

Body Mass Index

To determine whether SMI predicts disability beyond that predicted by BMI, we included BMI as a covariate in our analysis. Because both high and low BMI values are associated with functional limitations,[19] BMI could not be analyzed as a continuous variable. Therefore, we classified BMI according to the categories suggested by the World Health Organization[20] and National Institutes of Health[21] (<18.5 = underweight, 18.5–24.9 = normal, 30–34.9 = class I obese, 35.0–39.9 = class II obese, ≥40.0 = class III obese). We then examined the relationship between BMI and function/disability (defined as having any difficulty or being unable to perform one or more self-reported measures of functional impairment or disability) in the NHANES III data set. Based on the results of this analysis (data not shown), the BMI categories were graded as follows: men: underweight = 4.0, normal = 1.0, overweight = 1.0, class I obese = 1.0, class II obese = 1.3, class III obese = 5.3; women: underweight = 1.4, normal = 1.0, overweight = 1.1, class I obese = 1.7, class II obese = 3.1, class III obese = 3.5.

Statistical Analysis

All analyses were conducted using Intercooled Stata 7 (Stata Corporation, College Station, TX) to obtain estimates representative of the U.S. population. Differences in age, BMI, body fat, and SMI were compared between those with a normal SMI and those with class I or class II sarcopenia using analysis of variance (Table 1). Prevalence of functional impairment and physical disability were compared in those with a normal SMI versus those with class I or class II sarcopenia using chi-square statistics (Table 1). Multiple logistic regression analysis was used to examine the associations between sarcopenia with measures of functional impairment and disability (Table 2). Dummy variables (e.g., normal SMI = 2, class I sarcopenia = 1, class II sarcopenia = 0) were created to compute odds ratios (OR) for these factors. Normal SMI was used as the reference category (OR = 1.00). To examine the independent influence of sarcopenia on functional impairment and disability, ORs were also computed after adjusting for the potential influence of age, race, BMI, health behaviors, and comorbidity (Table 2). Because those subjects missing a functional impairment or disability measure were omitted from

Table 1. Comparison of Body Composition Variables and Prevalence of Functional Impairment and Physical Disability According to Skeletal Muscle Index Classification in Older (≥60 years) Men and Women

Variable	Men			Women		
	Normal SMI (n = 1079)	Class I Sarcopenia (n = 978)	Class II Sarcopenia (n = 167)	Normal SMI (n = 630)	Class I Sarcopenia (n = 1374)	Class II Sarcopenia (n = 274)
Body composition variables, means ± standard deviation						
Age, years	70 ± 7	70 ± 7	70 ± 7	71 ± 7	71 ± 7	72 ± 7
Body mass index, kg/m²	24.7 ± 3.3	28.5 ± 3.3*	32.7 ± 5.1†	23.1 ± 3.7	27.9 ± 4.7*	33.6 ± 6.2†
Skeletal muscle mass, kg	29.8 ± 4.2	29.7 ± 4.1	29.0 ± 4.7‡	18.2 ± 3.0	17.8 ± 3.2‡	17.1 ± 3.9§
Skeletal muscle index, %	40.6 ± 2.9	34.4 ± 1.7‡	29.0 ± 1.5§	31.1 ± 2.6	25.3 ± 1.6‡	20.5 ± 1.3§
Prevalence of functional impairment, %						
Any reported difficulty						
Walking 1/4 mile	16.7	20.8	29.6*	20.2	29.9*	46.6*
Climbing 10 stairs	16.2	16.6	18.2*	18.2	29.4*	49.1*
Lifting or carrying 10 pounds	12.0	9.9	17.2*	21.1	27.5*	38.5
Stooping/crouching/kneeling	31.4	41.9*	49.4*	36.6	52.6*	78.2*
Standing up from chair	11.4	14.7	21.0*	14.4	20.6*	37.5*
Unable to						
Walk 8 feet	1.3	1.5	0.8	1.9	2.6	5.8*
Complete 5 chair stands	2.2	2.3	3.2	3.5	3.4	6.9*
Perform tandem stand	0.7	1.9	4.5*	3.8	2.6	4.2
Prevalence of physical disability (%)						
Any reported difficulty						
Performing home chores	11.1	12.5	18.5*	20.2	25.4*	38.5*
Preparing meals	6.1	4.2	7.0	5.1	8.0	14.1*
Require help with						
Personal care needs	3.0	2.9	6.1	5.2	3.6*	8.3*
Routine needs	4.2	3.5	5.0	6.9	9.2*	12.1*

*Significantly greater than normal skeletal muscle index (SMI) within the same gender ($P < .05$).
†Significantly greater than normal SMI and class I sarcopenia within the same gender ($P < .05$).
‡Significantly less than normal SMI within the same gender ($P < .05$).
§Significantly less than normal SMI and class I sarcopenia within the same gender ($P < .05$).

that analysis only, the number of subjects differed slightly for each functional impairment and disability measure.

RESULTS

Subject Characteristics

The mean ± standard deviation SMI in young men (18–39, n = 3,116) was 42.5% ± 5.5%, and corresponding cutoff values for normal SMI, class I, and class II sarcopenia were greater than 37.0%, 37.0% to 31.5%, and less than 31.5%, respectively. The mean SMI in young women (18–39, n = 3,298) was 33.1% ± 5.5%, and corresponding cutoff values for normal SMI, class I, and class II sarcopenia were greater than 27.6%, 27.6% to 22.1%, and less than 22.1%, respectively. To simplify these ranges for potential future applications, the final cutoff levels for normal SMI, class I, and class II sarcopenia were set as follows: men greater than 37%, 37% to 31%, and less than 31%; women greater than 28%, 28% to 22%, and less than 22%.

The distribution of SMI into normal, class I, and class II sarcopenia according to age and sex are summarized in Figure 1. The prevalence of class I and class II sarcopenia increased from the third to sixth decades, but remained relatively constant thereafter (Figure 1). The prevalence of class I (59% vs 45%) and class II (10% vs 7%) sarcopenia was greater in the older (≥60 years) women than in the older men ($P < .001$).

The characteristics of the older subjects, categorized according to gender and SMI category, are shown in Table 1. Independent of gender, age was not different in the three SMI categories (Table 1). Subjects with a normal SMI had lower BMI values than subjects with class I sarcopenia, who in turn had lower BMI values than subjects with class II sarcopenia ($P < .001$, Table 1). Men with a normal SMI had slightly higher absolute muscle mass values than men with class II sarcopenia (29.8 kg vs 29.0 kg, $P = .003$). Women with a normal SMI had slightly higher absolute muscle mass values than women with class I sarcopenia (18.2 kg vs 17.8 kg, $P = .04$), who in turn had slightly higher muscle mass values than women with class II sarcopenia (17.8 kg vs 17.1 kg, $P = .01$). The prevalence of many of the measures of functional impairment and disability were higher in those with class I and class II sarcopenia than in those with a normal SMI (Table 1).

Table 2. Association Between Sarcopenia, Functional Impairment, and Physical Disability in Older (≥60 years) Men and Women

	Men				Women			
	Class I Sarcopenia		Class II Sarcopenia		Class I Sarcopenia		Class II Sarcopenia	
	Unadjusted	Adjusted*	Unadjusted	Adjusted*	Unadjusted	Adjusted*	Unadjusted	Adjusted*
Impairment and Disability	Odds ratio (95% confidence interval)							
Functional impairment								
Any reported difficulty:								
Walking 1/4 mile	1.31 (0.98–1.77)	1.26 (0.90–1.76)	2.10 (1.27–3.47)†	1.59 (0.86–2.94)	1.68 (1.26–2.24)†	1.07 (0.76–1.50)	3.45 (2.28–5.21)†	1.81 (0.87–3.73)
Climbing 10 stairs	1.03 (0.75–1.42)	0.95 (0.67–1.37)	1.15 (0.66–2.02)	0.69 (0.37–1.29)	1.87 (1.40–2.52)†	1.29 (0.92–1.81)	4.35 (2.87–6.58)†	2.02 (1.05–3.87)†
Lifting or carrying 10 pounds	0.81 (0.56– 1.16)	0.70 (0.46–1.03)§	1.53 (0.84–2.77)	0.95 (0.51–1.79)	1.43 (1.07–1.90)†	1.02 (0.73–1.40)	2.34 (1.55–3.54)†	2.58 (1.26–5.28)†
Stoop/crouch/kneel	1.56 (1.21–2.05)†	1.57 (1.17–2.09)†	2.14 (1.35–3.38)†	1.87 (1.17–2.99)†	1.92 (1.49–2.48)†	1.49 (1.12–2.00)†	6.22 (3.99–9.71)†	3.96 (2.03–7.70)†
Stand up from chair	1.35 (0.95–1.93)	1.28 (0.87–1.88)	2.07 (1.14–3.75)†	1.35 (0.71–2.57)	1.54 (1.12–2.12)†	1.12 (0.79–1.60)	3.56 (2.32–5.48)†	2.02 (1.06–3.87)†
Unable to:								
Walk 8 feet	1.16 (0.44–3.10)	1.27 (0.90–1.76)	0.65 (0.18–2.33)	0.47 (0.13–1.77)	1.34 (0.58–3.08)	1.07 (0.76–1.50)	3.11 (1.10–8.78)†	2.20 (0.47–10.40)
Complete 5 chair stands	1.05 (0.46–2.41)	0.87 (0.33–2.29)	1.49 (0.43–5.21)	0.84 (0.21–3.36)	0.98 (0.53–1.81)	0.57 (0.29–1.09)	2.04 (0.94–4.47)	0.90 (0.31–2.65)
Perform tandem stand	2.62 (1.13–6.03)†	2.83 (1.17–6.88)†	6.51 (2.00–21.14)†	4.58 (1.39–15.14)†	0.67 (0.37–1.22)	0.47 (0.24–1.00)§	1.11 (0.53–2.31)	0.30 (0.05–1.91)
Physical disability								
Any reported difficulty:								
Performing home chores	1.15 (0.78–1.68)	1.08 (0.70–1.66)	1.82 (0.95–3.48)†	1.08 (0.54–2.15)	1.35 (0.99–1.83)	0.96 (0.68–1.36)	2.48 (1.62–3.78)†	1.97 (1.02–3.78)†
Preparing meals	0.68 (0.39–1.14)	0.66 (0.36–1.19)	1.16 (0.42–3.17)	0.64 (0.22–1.87)	1.61 (1.02–2.53)†	0.93 (0.55–1.56)	3.05 (1.73–5.36)†	1.79 (0.75–4.26)
Require help with:								
Personal care needs	0.94 (0.52–1.72)	0.97 (0.52–1.81)	2.10 (0.83–5.27)	1.36 (0.45–4.15)	0.69 (0.40–1.21)	0.45 (0.27–0.77)‡	1.68 (0.79–3.54)	2.39 (0.77–7.39)
Routine needs	0.81 (0.45–1.47)	0.75 (0.38–1.49)	1.21 (0.35–4.15)	0.69 (0.20–2.39)	1.38 (0.92–2.06)	1.04 (0.66–1.64)	1.86 (1.06–3.28)†	1.15 (0.53–2.43)

Note: Subjects with a normal skeletal muscle index were used as the reference category (odds ratio = 1.00).
*Adjusted for age, race, BMI, health behaviors, and comorbidity.
†Significantly greater than normal skeletal muscle index within the same gender ($P < .05$).
‡Significantly less than normal skeletal muscle index within the same gender ($P < .05$).
§Significantly less than normal skeletal muscle index within the same gender ($P = .06$).

Functional Impairment and Physical Disability Relations

The associations between sarcopenia, functional impairment, and physical disability are shown in Table 2. ORs were determined before and after adjusting for age, race, BMI, comorbidity, and health behaviors. The unadjusted ORs for some of the measures of functional impairment and disability were higher ($P < .05$) in the older men and women with class I sarcopenia than in the older men and women with a normal SMI (Table 2). After adjusting for the confounding variables, class I sarcopenia was associated with increased ($P < .05$) ORs for having difficulty stooping/crouching/kneeling (men and women) and being unable to perform the tandem stand (men). Surprisingly, after adjusting for the confounding variables, class I sarcopenia was associated with a decreased OR for having difficulty lifting/carrying 10 pounds (men), performing the tandem stand (women), and requiring help with personal care needs (women, Table 2).

Class II sarcopenia was associated ($P < .05$) with an increased OR for many of the measures of functional impairment and disability in both men and women (Table 2). After adjusting for the confounding variables in men, class II sarcopenia was associated ($P < .05$) with increased ORs for having difficulty stooping/crouching/kneeling and not being able to perform the tandem stand (Table 2). After adjusting for the confounding variables in women, class II sarcopenia was associated ($P < .05$) with increased ORs for having difficulty climbing 10 stairs, lifting/carrying 10 pounds, stooping/crouching/kneeling, standing from a chair, and performing household chores (Table 2).

DISCUSSION

In this nationally representative sample of men and women, an approach was developed for classifying sarcopenia based on the distribution of skeletal muscle (percentage of muscle mass, or SMI) in young adults. Using this approach, 45% and 59% of the older (≥60 years) men and women were classified as having class I (moderate) sarcopenia, and 7% and 10%, respectively, of the older men and women were classified as having class II (severe) sarcopenia. The likelihood of functional impairment and physical disability was approximately twice as great in the older men and three times as great in the older women with class II sarcopenia than in the older men and women with a normal SMI. Furthermore, some of the associations between class II sarcopenia, functional impairment, and disability remained after statistical adjustment for the potential confounding variables (age, race, BMI, health behaviors, comorbidity). These results support the view that aging-associated loss of skeletal muscle mass is associated with functional impairment and disability and confirms that sarcopenia is a significant public health problem.

The likelihood of functional impairment and disability was slightly higher in the older men and women with class I sarcopenia than in the older men with a normal relative muscle mass. However, after adjusting for the potential confounding variables such as age, race, health behaviors, and comorbidity; class I sarcopenia was no longer clearly associated with an increased likelihood of functional impairment and disability. In contrast to class I sarcopenia, class II sarcopenia was independently associated with an increased likelihood of functional impairment and disability in older adults, particularly older women. Taken together, these results suggest that modest reductions in skeletal muscle mass with aging do not cause functional impairment and disability. However, if muscle loss progresses to the point where skeletal muscle mass relative to body weight is 30% below the mean of young adults, there is an increased likelihood that functional abilities will be compromised. This reinforces the hypothesis that sarcopenia is a mechanism by which aging influences functional impairment. Considering that the prevalence of class II sarcopenia was 8% in those aged 60 and older, and that there are approximately 42 million Americans within this age group,[22] approximately 3.5 million older Americans are at increased risk of functional impairment and disability consequent to low skeletal muscle mass.

Baumgartner et al.[6] have reported that sarcopenia is independently associated with disability, the use of a cane or walker, and a history of falling in a sample of 808 older non-Hispanic whites and Mexican American men and women. The findings of Baumgartner et al.[6] are consistent with those of Melton et al.,[23] who report that sarcopenia was associated with having difficulty walking in 345 older men and an increase in fractures in 349 older women. In both studies, sarcopenia is defined as having an *absolute* skeletal muscle mass (appendicular) at least two standard deviations below the mean of young adults. The results of the present study demonstrate that low *relative* muscle mass is also an indicator of functional impairment and disability. Had we defined class I and class II sarcopenia based on absolute muscle mass, we would have also seen an independent association between class II sarcopenia, functional impairment, and disability (data not shown). However, because most mobility tasks and ADLs are influence by body size, we feel it is more appropriate to express skeletal muscle mass in relation to body weight.

Many factors are thought to contribute to sarcopenia.[4,5] These include a loss of α-motor neurons,[24] lower levels of steroid hormones,[25,26] a reduction in dietary protein,[27] and a decreased level of physical activity.[28] There is also evidence that catabolic stimuli to muscle increase with advancing age. In particular, increased production of catabolic cytokines such as interleukin-6 is thought to play a role in sarcopenia.[29]

The findings here and elsewhere[1–3] support the view that intervention strategies designed to preserve skeletal muscle mass should be initiated by the fifth decade of life. Because the prevalence of class II sarcopenia was about twice as great in the older persons who were inactive as in the older persons who were at least moderately active (≥3 times/week) it is clear that increasing physical activity should be a fundamental treatment goal. Resistance exercise is particularly beneficial because it can attenuate[30,31] or reverse[32–34] the age-associated decrease in muscle mass and strength. However, few older persons perform adequate levels of resistance exercise. Indeed, fewer than 2% of the older subjects in NHANES III performed resistance exercise on a regular basis (≥1 per week). This observation underscores the need to increase public awareness of including resistance exercise as a fundamental component of a well-balanced physical activity program. The American College of Sports Medicine recommends that older adults perform one to three sets of 10 to 15 repetitions 2 to 3 days/week for all of the major muscle groups to enhance muscular strength, endurance, and size.[35]

Our study has several limitations that should be recognized. First, the cross-sectional nature of this study precludes definitive causal inferences about the relationship between sarcopenia, functional impairment, and disability. It is possible that functional impairment and disability may have preceded sarcopenia rather than the reverse. To our knowledge, no longitudinal studies report that sarcopenia is related to functional impairment and disability. However, muscular strength, which is in large measure determined by muscle mass, is predictive of functional limitations and disability in longitudinal studies.[36] Second, because NHANES III was conducted among the noninstitutionalized U.S. population and because the NHANES III participants who were physically unable to make it to the mobile examination center were not included in our analysis, we may have underestimated the prevalence of sarcopenia. Third, many of the variables examined in NHANES III, including comorbidity, physical activity participation, and physical function were based on self-report. However, studies have shown that self-reported disease is almost as reliable as medical records[37,38] and that the reliability of self-reported physical function in older persons is about 85%.[14] Fourth, our criterion for classifying subjects as sarcopenic was chosen arbitrarily. At present there are insufficient data to determine the exact point at which skeletal muscle mass falls below the threshold at which functional capacity is compromised.

In this study, we employed BIA to estimate skeletal muscle mass. Because the standard error of the estimate for predicting muscle mass from BIA is 9%,[7] some individuals may have been categorized into the wrong SMI category. Despite this limitation, class II sarcopenia predicted from BIA measures was independently associated with an increase in functional impairment. Furthermore, the BIA method[7] is more precise than other methods (e.g., arm girth corrected for skinfold thickness) available for estimating skeletal muscle mass in the clinical setting and epidemiological studies.[6] Finally, the BIA equation used in this study was developed in a heterogenous sample[7] with similar characteristics (e.g., age, BMI) to those in the NHANES III cohort.

In conclusion, this study indicates that there was an increased likelihood of functional impairment in older men and women with a SMI below 31% and 22%, respectively, than in older men and women with normal muscle mass. These observations underscore the need for increased awareness of the public health problems posed by sarcopenia. In this regard, BIA measurements of skeletal muscle[7] could provide medical practitioners with a practical and affordable tool for identifying individuals with class II sarcopenia and thus at increased risk for functional impairment and physical disability.

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