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Epidemiology of Sarcopenia among the Elderly in New Mexico

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Muscle mass decreases with age, leading to "sarcopenia," or low relative muscle mass, in elderly people. Sarcopenia is believed to be associated with metabolic, physiologic, and functional impairments and disability. Methods of estimating the prevalence of sarcopenia and its associated risks in elderly populations are lacking. Data from a population-based survey of 883 elderly Hispanic and non-Hispanic white men and women living in New Mexico (the New Mexico Elder Health Survey, 1993–1995) were analyzed to develop a method for estimating the prevalence of sarcopenia. An anthropometric equation for predicting appendicular skeletal muscle mass was developed from a random subsample (n = 199) of participants and was extended to the total sample. Sarcopenia was defined as appendicular skeletal muscle mass (kg)/height^2 (m^2) being less than two standard deviations below the mean of a young reference group. Prevalences increased from 13–24% in persons under 70 years of age to >50% in persons over 80 years of age, and were slightly greater in Hispanics than in non-Hispanic whites. Sarcopenia was significantly associated with self-reported physical disability in both men and women, independent of ethnicity, age, morbidity, obesity, income, and health behaviors. This study provides some of the first estimates of the extent of the public health problem posed by sarcopenia. *Am J Epidemiol* 1998;147:755–63.

aged; aging; body composition; body mass index; frail elderly; muscles

Human body composition changes with age, but the causes and consequences of these changes are only partly understood (1). A change that is increasingly recognized to have important consequences in old age is the loss of lean tissue, particularly skeletal muscle mass. In 1989, Rosenberg focused renewed attention on this phenomenon by giving it a name, "sarcopenia" (2). "Sarco-," from Greek, denotes "flesh" (muscle), and "-penia" indicates deficiency. Thus, "sarcopenia" translates loosely as "deficiency of muscle," and this term is now used to refer specifically to the gradual loss of skeletal muscle mass and strength that occurs with advancing age.

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Abbreviations: ASM, appendicular skeletal muscle mass; DXA, dual-energy X-ray absorptiometry; IADL, instrumental activities of daily living; SEE, standard error of estimation.

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Possible causal factors for sarcopenia include age-related changes in tissue secretion or responsiveness to trophic hormonal factors, changes in dietary intake and protein metabolism, and "disuse atrophy" (3–5). Possible mechanisms for loss of muscle quality, mass, and strength include decreased skeletal muscle innervation and capillary density and the selective atrophy of type II muscle fibers (6, 7). Although a variety of studies have reported associations of age-related changes in muscle quality, mass, and strength with metabolic/physiologic and functional impairments leading to morbidity and disability in the elderly, the magnitude of the public health problem posed by sarcopenia is not well established (5). A recognized impediment to epidemiologic studies of sarcopenia is the development of suitable approaches for estimating its prevalence in different sex and ethnic groups and determining its association with functional status, morbidity, and other outcomes in elderly populations (8, 9).

The present study was designed to address the following objectives using data from the New Mexico Elder Health Survey, a population-based cross-sectional study of elderly men and women living in Bernalillo County, New Mexico: 1) to develop and test an approach for estimating relative skeletal muscle mass in epidemiologic research; 2) to estimate the

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prevalences of low relative muscle mass, or sarcopenia, in Hispanic and non-Hispanic white elderly men and women in the survey; and 3) to determine whether there are any associations between sarcopenia and health behaviors, chronic morbidity, physical functional impairment, disability, and falls.

MATERIALS AND METHODS

Survey data set

The New Mexico Elder Health Survey (referred to hereafter as "the Survey") was conducted between May 1993 and September 1995. It had a two-tiered design consisting of a standardized home interview and an extensive 4-hour clinical examination. Equal numbers of Hispanic and non-Hispanic white men and women were selected randomly from the Health Care Financing Administration's Medicare listings for Bernalillo County, New Mexico. The GUESS ("Generally Useful Ethnic Search System") computer program was used to make a preliminary identification of ethnicity based on surnames (10). A total of 2,200 subjects were sampled. Of these, 534 had died, had moved, could not be contacted, did not live in Bernalillo County, or were otherwise found to be ineligible. Of the 1,666 eligible subjects contacted, 1,130 (67.8 percent) completed the home interview and 883 (53 percent) completed the full examination. A randomly selected subsample of 199 of the 883 subjects underwent an additional body composition examination by dual-energy X-ray absorptiometry (DXA), as described below. Body composition was measured only for this subsample, because of the high cost and difficulty of obtaining DXA measurements for all Survey participants. All subjects gave informed consent, and all procedures were approved by the Human Research Review Committee of the University of New Mexico School of Medicine.

For the present analyses, 73 subjects were deleted because of missing anthropometric data. Two subjects with artificial limbs whose estimates of muscle mass had doubtful validity were also excluded. Therefore, the data set analyzed included a total of 808 subjects who completed the full examination (426 men and 382 women). Sample sizes were further reduced for some analyses because of additional missing data (noted in the tables or text).

Reference data sets

Data from two independent studies were used as reference data in the present analyses. The first set consisted of data on 301 elderly male and female participants in the New Mexico Aging Process Study. The Aging Process Study is a longitudinal study of nutrition and body composition in a select group of healthy volunteers that has been described in detail elsewhere (1). For the present report, cross-sectional data from 1994 were used to cross-validate equations for predicting muscle mass in the Survey sample. The second data set included 229 non-Hispanic white men and women aged 18–40 years who were participants in the Rosetta Study (1986–1992) (11). This data set was used to help define cutoff values for "sarcopenia" based on comparison of the distributions for muscle mass in young people versus elderly people.

Survey methods

The full examination of subjects included medical histories and questionnaires for assessment of health habits, behaviors and attitudes, and usual dietary intakes, as well as intensive examinations of physical and cognitive functional status, anthropometric measurements, electrocardiograms, glucose tolerance tests, and clinical and biochemical nutrient chemical analyses. Major chronic illnesses were grouped as cancer, stroke, coronary heart disease, non-insulin-dependent diabetes mellitus, gallbladder disease, arthritis (osteoarthritis and rheumatoid), and lung disease (chronic bronchitis, chronic obstructive pulmonary disease). Undiagnosed cases of non-insulin-dependent diabetes mellitus were identified from fasting glucose levels greater than 140 mg/dl or 2-hour serum glucose levels greater than 200 mg/dl following ingestion of 75 g of glucose over a 10-minute period. The Activities of Daily Living (12) and Instrumental Activities of Daily Living (IADL) (13) scales were used to measure self-reported disability. Usual physical activity was graded from subjects' reports of their weekly frequency of engaging in various leisure-time activities, including walking, hiking, jogging, tennis, golf, bicycling, and swimming. Abnormalities of balance and gait were assessed using the instrument developed by Tinetti (14). Participants were asked whether they had experienced one or more falls during the past year, and the use of assistive devices such as a cane or walker was observed and recorded. Hispanic/non-Hispanic white ethnic identification and ancestry were further validated using the reported parents' and grandparents' race/ethnicity, country of birth, preferred language, and language fluency.

A single observer who had been trained by the first author (R. N. B.) took the anthropometric measurements, using standardized techniques (15). Weight was measured to the nearest 0.1 kg using a beam balance scale. Height was measured to the nearest 0.1 cm using a Holtain wall-mounted stadiometer (Holtain Ltd., Crosswell, Wales). Hip circumference was measured using a steel tape at the level of the maximum posterior protrusion of the buttocks. Waist circumfer-

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ence was measured at a level 1 cm above the iliac crests. Triceps and subscapular skinfolds were measured to the nearest 1.0 mm using Holtain calipers on the right side. Grip strength was measured for the dominant hand using a hand dynamometer (Takei Ltd., Tokyo, Japan). A series of three grip strength measurements were taken, and the highest two were averaged.

Body composition

Percentage of body fat and appendicular skeletal muscle mass (ASM) were quantified in the random subsample drawn from the Survey, as well as in subjects from the Aging Process Study and the Rosetta Study, by DXA (Lunar DPX, Madison, Wisconsin). Percentage of body fat was measured using the manufacturer's default definitions. ASM was measured as the sum of the lean soft-tissue masses for the arms and the legs as described by Heymsfield et al. (16). The technical errors of measurement of percentage of body fat and ASM using DXA are less than ±1.5 percent and ±3.0 percent, respectively. DXA measurements of ASM have been validated against corresponding ones from computed tomography and magnetic resonance imaging (17, 18). Differences between DXA, computed tomography, and magnetic resonance imaging measurements are less than 5 percent. The anthropometric measurements taken in the Aging Process Study and the Rosetta Study that correspond to those in the Survey were all made using the same standardized techniques (15).

Statistical methods

Because direct estimates of muscle mass and percentage of body fat by DXA were not obtained for all participants in the Survey, the following approach was used to derive predicted values for the total study sample. The random subsample (n = 199) was further divided randomly into two groups: 1) an equation development group (n = 149) and 2) a cross-validation group (n = 50). Equations for predicting DXA-measured muscle mass and percentage of body fat from anthropometric variables were developed by stepwise regression using data for the 149 subjects in the equation development group. The best predictive equation for muscle mass was

ASM (kg) = 0.2487(weight) + 0.0483(height) − 0.1584(hip circumference) + 0.0732(grip strength) + 2.5843(sex) + 5.8828 [R^2 = 0.91, standard error of estimation (SEE) = 1.58 kg].

The best equation for percentage of body fat was

% body fat = 0.2034(waist circumference) + 0.2288(hip circumference) + 3.6827(ln[triceps skinfold]) − 10.9814(sex) − 14.3341 [R^2 = 0.79, SEE = 3.94 percent].

The accuracy of these predictive equations was tested by comparing the predicted values for percentage of body fat and muscle mass with values measured by DXA in the 50 participants in the cross-validation group. In addition, the predictive accuracy of the equations was further tested by applying them to the independent Aging Process Study sample. Agreement between the predicted and measured values was assessed by regressing the predicted values on the corresponding values measured by DXA. The resulting regression equations were evaluated by testing whether the slope and intercept differed significantly from 1.0 and zero, respectively, and by comparing the standard error of the estimate with that of the original prediction equation. In addition, the difference between the measured and predicted values was regressed on the mean of the values (19). The residuals (differences) from these analyses were further analyzed in relation to ethnicity and age to determine whether these affected the fit of the predictive equations. The cross-validated prediction equations were then applied to derive estimates of percentage of body fat and ASM in the total Survey sample.

To define "sarcopenia," it is necessary to have a measure of relative muscle mass, since absolute muscle mass is correlated strongly with height. ASM (kg)/height^2 (m^2) was calculated as an index of relative skeletal muscle mass, and it is directly analogous to the use of the body mass index (weight (kg)/height^2 (m^2)) for grading relative adiposity. Preliminary analyses established that the square of height in the denominator was the best common power for minimizing the correlation of the index with height across all sex, ethnic, and age groups and study populations. For example, the bivariate correlations between the index and height in the men were 0.03 (Survey), <0.001 (Aging Process Study), and −0.18 (Rosetta Study) (p = 0.06). The corresponding correlations in the women were 0.01 (Survey), −0.05 (Aging Process Study), and −0.03 (Rosetta Study). Within the Survey, the correlation between height and the index was −0.02 in non-Hispanic white men, −0.01 in Hispanic men, 0.09 in non-Hispanic women, and 0.03 in Hispanic women. Thus, the square of height in the denominator of the relative skeletal muscle mass index effectively eliminated differences in ASM associated with greater height in younger adults, as well as with sex and ethnicity.

The term "sarcopenia" refers to a deficiency in relative muscle mass. There are presently no established criteria for identifying the level at which rela-

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tive muscle mass becomes "deficient." To estimate the prevalence of "sarcopenia," we again took an approach directly analogous to that used to define underweight, overweight, and obesity from the body mass index (20). Cutoff values for sarcopenia in each sex were defined as values two standard deviations below the sex-specific means of the Rosetta Study reference data for young adults aged 18–40 years (11). We then estimated the age, sex-, and ethnicity-specific prevalences of sarcopenia in the Survey sample.

Multiple logistic regression was used to examine associations with age, ethnicity, obesity, income, health behaviors, chronic disease, self-reported disability, one or more abnormalities of balance and gait, falls during the past year, use of a cane or walker, and history of bone fracture. Obesity was defined as a percentage of body fat greater than the sex-specific median (38 percent in women and 27 percent in men). Comorbidity was calculated as the sum of all chronic conditions present. "Moderate" physical disability was defined as self-reported difficulty in performing three or more of the six physical activity items on the IADL scale (13): walking distances, shopping for groceries, preparing meals, doing housework, making home repairs, and doing laundry. For the purposes of the present study, we did not analyze associations with individual IADL items, activities of daily living, or measures of cognitive function. We created dummy variables (0,1) to compute odds ratios for these factors in unconstrained analyses. Ethnicity-specific analyses were made within each sex, and ethnicity (Hispanic = 1, non-Hispanic white = 0) was included in all multivariate analyses.

RESULTS

Percentage of body fat from the predictive equation was highly correlated with estimates from DXA in the cross-validation group (R^2 = 0.82, SEE = 4.05 percent), as well as in the independent Aging Process Study sample (R^2 = 0.76, SEE = 4.42 percent). The intercept (a = −4.4) and slope (b = 1.13) of the regression equation for regression of the predicted values on the DXA-measured values in the cross-validation group were not significantly different from zero and 1.0, respectively. However, the slope of the regression of the predicted values on the measured values in the Aging Process Study (b = 1.28) was significantly greater than 1.0, suggesting a tendency for the predictive equation to underestimate actual percentage of body fat at higher levels in this independent sample. Predicted muscle mass was highly correlated with DXA-estimated muscle mass in the cross-validation group (R^2 = 0.86, SEE = 1.72), as well as in the Aging Process Study sample (R^2 = 0.89, SEE = 1.42). The intercept (a = 0.69) and slope (b = 0.97) of the regression equation for regression of the predicted values on the DXA-measured values in the cross-validation group were not significantly different from zero and 1.0. In the Aging Process Study sample, the slope of the regression of the predicted values on the measured values was significantly less than 1.0 (b = 0.94), suggesting a slight tendency for the predictive equation to overestimate actual muscle mass at higher levels in this sample. In summary, the predictive equation for percentage of body fat was found to be accurate within ±4 percent. Similarly, the predictive equation for muscle mass was accurate within ±1.7 kg. Both equations appeared to be unbiased when applied to the cross-validation group, but they displayed slight tendencies to underestimate percentage of body fat and overestimate muscle mass when applied to the independent Aging Process Study sample.

Figure 1 shows the distribution of differences between measured and predicted values for ASM by the mean of the values for each sex in the Survey subsample (n = 199). The differences (errors) ranged from +4.2 kg to −5.1 kg; 83 percent were within ±2 kg. The correlation between the differences and the mean values was 0.14 and was not statistically significant (p = 0.06). The positive slope of the regression of the differences on the means suggests a slight tendency to underestimate ASM in larger people with the Survey subsample. The differences between the

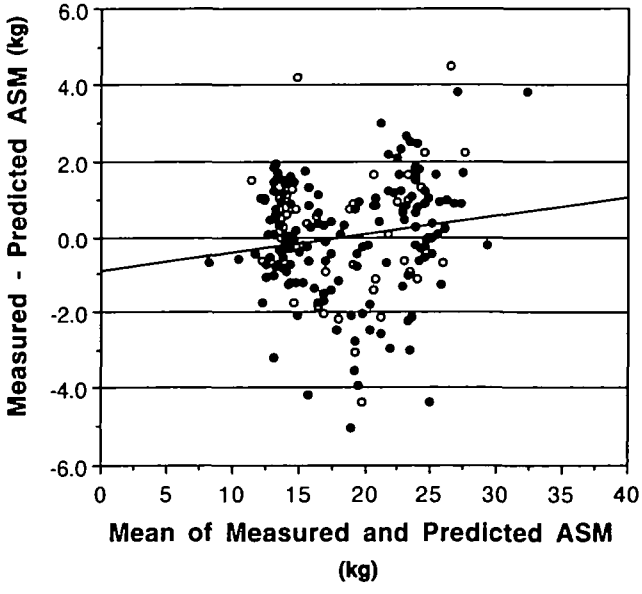

FIGURE 1. Regression of differences between measured and predicted values for appendicular skeletal muscle mass (ASM) on the mean values in a random subsample (n = 199): New Mexico Elder Health Survey, 1993–1995. ○, women; ●, men.

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predicted and measured values for ASM, however, were not significantly associated with age, sex, or ethnicity. Results for corresponding analyses of percentage of body fat did not reveal any significant associations between predictive errors and subject characteristics (data not shown). In summary, we were unable to identify any factors related to body size or composition that affected the accuracy of the equations. The errors of the predictive equations therefore appear to be largely random.

Table 1 compares selected characteristics of members of the Survey sample with members of each of the reference groups, by sex. There were no statistically significant differences between ethnic groups in the Survey for any of the variables shown, with the exception of percentage of body fat, which was significantly ($p < 0.01$) higher in the Hispanic men (28.0 percent vs. 26.8 percent) and women (39.7 percent vs. 37.8 percent). The Survey participants were approximately 3 years younger than the Aging Process Study volunteers, but there were no statistically significant ($p < 0.05$) differences between the Survey and Aging Process Study elderly groups for any other variables. Both Survey and Aging Process Study elderly subjects had significantly less absolute and relative muscle mass than the young adults in the Rosetta Study group, despite having slightly higher body mass indices. Percentage of body fat was subsequently significantly higher in the elderly Survey and Aging Process Study groups than in the young Rosetta group. Mean ASM/height^2 in the elderly men was approximately 87 percent of the mean in the young men. In the women, the corresponding value was approximately 80 percent.

Table 2 shows estimated prevalences of sarcopenia in the Survey sample for each ethnic group, by age and sex. The cutoff values for sarcopenia (ASM/height^2 (kg/m^2) greater than two standard deviations below the sex-specific Rosetta Study means) were 7.26 for men and 5.45 for women. The prevalence of sarcopenia increased significantly with age in both Hispanic and non-Hispanic white men and women. Prevalences increased from 13.5–24 percent in persons under 70 years of age to 60 percent in persons older than 80 years, and were slightly greater in Hispanics than in non-Hispanic whites.

Associations of age (>75 years), ethnicity, obesity, income, health behaviors, and morbidity with sarcopenia are shown in table 3. Among men, sarcopenia was significantly associated with age, obesity, low income (<$15,000/year), current smoking, and lung disease. The odds ratio was increased but not statistically significant ($p > 0.05$) for daily alcohol intake, and the odds ratio for a high level of physical activity, though not statistically significant, suggested a protective effect. Among women, there were no statistically significant associations between any of the variables and sarcopenia, with the exception of age and obesity. Although they were not statistically significant, odds ratios for sarcopenia were greater than 1.5 for stroke and coronary heart disease in the women. There was a significant protective association for obesity (percentage of body fat greater than the sex-specific median) in both the men and the women.

Table 4 shows results from analyses of associations between sarcopenia and indicators of physical functional impairment, falls, and fractures. All odds ratios were

TABLE 1. Characteristics of a New Mexico study sample of elderly persons and two reference groups

	Men			Women		
	New Mexico Elder Health Survey (1993–1995) (n = 426)	Reference group		New Mexico Elder Health Survey (1993–1995) (n = 382)	Reference group	
		Aging Process Study* (elderly persons; 1994) (n = 121)	Rosetta Study† (young adults; 1986–1992) (n = 107)		Aging Process Study* (elderly persons; 1994) (n = 180)	Rosetta Study† (young adults; 1986–1992) (n = 122)
Age (years)	73.6 (5.8)‡	77.2 (5.8)	28.7 (5.1)	73.7 (6.1)	76.4 (6.7)	29.7 (5.9)
Weight (kg)	76.2 (12.1)	76.4 (10.7)	78.3 (12.5)	64.1 (12.7)	63.3 (10.9)	65.0 (15.2)
Height (cm)	171.3 (6.9)	172.9 (7.3)	178.4 (6.6)	156.4 (7.3)	158.0 (6.1)	163.5 (6.7)
Body mass index§	25.9 (3.7)	25.5 (3.1)	24.6 (3.8)	26.2 (4.6)	25.3 (3.9)	24.1 (5.4)
% body fat	27.4 (4.5)¶	26.7 (7.2)	18.2 (6.8)	38.7 (5.8)¶	37.1 (7.5)	26.4 (6.1)
Appendicular skeletal muscle mass (kg)	22.5 (2.6)#	21.6 (3.0)	27.3 (3.6)	14.5 (2.2)#	14.2 (1.9)	17.7 (3.7)
Appendicular skeletal muscle mass/height^2 (kg/m^2)	7.7 (0.7)	7.2 (0.8)	8.6 (1.1)	5.9 (0.7)	5.7 (0.6)	7.3 (0.9)

* Baumgartner et al., 1995 (1).
† Gallagher et al., 1997 (11).
‡ Numbers in parentheses, standard deviation.
§ Weight (kg)/height^2 (m^2).
¶ Percentage of body fat was predicted in the Survey using the formula shown in the text. See text for statistics on cross-validation and prediction errors for the % body fat equation.
# Appendicular skeletal muscle mass (ASM) was predicted in the Survey using the formula shown in the text. See text for statistics on cross-validation and prediction errors for the ASM equation.

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TABLE 2. Prevalences (%) of sarcopenia* in the New Mexico Elder Health Survey, by age, sex, and ethnicity, 1993–1995

Age group (years)	Men		Women	
	Hispanics (n = 221)	Non-Hispanic whites (n = 205)	Hispanics (n = 209)	Non-Hispanic whites (n = 173)
<70	16.9	13.5	24.1	23.1
70–74	18.3	19.8	35.1	33.3
75–80	36.4	26.7	35.3	35.9
>80	57.6	52.6	60.0	43.2

* Appendicular skeletal muscle mass/height² (kg/m²) less than two standard deviations below the mean value for young adults from the Rosetta Study (11).

adjusted for age, ethnicity, obesity, comorbidity, and alcohol intake. Odds ratios for having three or more disabilities on the IADL scale were additionally adjusted for income, physical activity, and smoking, which might influence self-reported disability. In the men, sarcopenia was significantly associated with self-reported physical disability, having one or more balance abnormalities, using a cane or walker, and falling during the past year. In the women, sarcopenia was associated only with having three or more physical disabilities, although odds ratios were greater than 1.5 for having one or more balance abnormalities and using a cane or walker.

TABLE 3. Associations of selected demographic and other factors with sarcopenia* in the New Mexico Elder Health Survey, 1993–1995

	Men			Women		
	%	Odds ratio†	95% CI‡	%	Odds ratio†	95% CI‡
Age >75 years	32	3.28	2.09–5.17	38	2.28	1.41–3.70
Hispanic ethnicity	48	1.09	0.71–1.67	45	1.35	0.84–2.16
Obesity§	50	0.11	0.06–0.19	50	0.07	0.03–0.14
Annual income (dollars)						
>50,000	12	1.00¶		32	1.00	
30,000–50,000	22	0.46	0.21–0.96	29	0.62	0.26–1.46
15,000–30,000	37	1.14	0.62–2.11	20	0.50	0.22–1.14
<15,000	29	3.00	1.45–6.30	19	0.94	0.42–2.15
Frequency of alcohol intake						
None	41	1.00		60	1.00	
<2–5 days/week	41	1.01	0.61–1.68	32	0.53	0.28–0.96
Daily	18	1.57	0.84–2.89	8	1.05	0.38–2.63
Physical activity#						
Low	34	1.00		48	1.00	
Moderate	51	0.97	0.57–1.62	45	0.81	0.48–1.36
High	14	0.62	0.33–1.14	7	0.69	0.30–1.46
Current smoking	14	1.94	1.05–3.51	15	1.76	0.96–3.28
Morbidity						
Cancer	23	1.29	0.66–2.49	15	1.18	0.51–2.65
Stroke	10	1.19	0.49–2.78	9	1.54	0.56–4.06
Coronary heart disease	29	1.18	0.66–2.12	17	1.59	0.73–3.44
Non-insulin-dependent diabetes melitus	24	0.81	0.41–1.55	17	0.99	0.38–2.44
Gallbladder disease	18	0.90	0.45–1.78	26	1.12	0.54–2.27
Arthritis	58	0.69	0.40–1.19	73	0.74	0.36–1.53
Lung disease	9	2.89	1.19–7.02	10	0.70	0.21–2.04
Comorbidity						
None	15	1.00		12	1.00	
1 condition	33	1.03	0.45–2.43	36	0.64	0.24–1.77
2 conditions	27	1.38	0.58–3.35	28	0.92	0.33–2.62
≥3 conditions	25	1.11	0.56–2.75	24	0.87	0.30–2.60

* Appendicular skeletal muscle mass/height² (kg/m²) less than two standard deviations below the mean value for young adults from the Rosetta Study (11).

† Odds ratios for obesity, income, alcohol intake, physical activity, and current smoking were adjusted for age, ethnicity, and comorbidity. Odds ratios for morbidity were adjusted for age, ethnicity, obesity, income, alcohol intake, physical activity score, and current smoking.

‡ CI, confidence interval.

§ Predicted percentage of body fat >27% in men and >38% in women.

¶ Referent.

Self-reported weekly frequency of engaging in selected activities (see text).

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TABLE 4. Associations of sarcopenia* with physical disability or a history of injury, New Mexico Elder Health Survey, 1993–1995

	Men			Women		
	%	Odds ratio†	95% CI‡	%	Odds ratio†	95% CI
≥3 disabilities	16	3.66	1.42–10.02	33	4.08	1.52–11.31
>1 balance abnormality	28	3.23	1.13–9.74	8	1.77	0.48–5.75
>1 gait abnormality	25	1.87	0.94–3.74	21	1.12	0.43–2.73
Use of cane/walker	14	2.29	1.09–4.88	17	1.79	0.67–4.60
Fell during past year	22	2.58	1.42–4.73	31	1.28	0.60–2.67
History of bone fracture	11	0.52	0.20–1.25	24	1.31	0.56–2.89

* Appendicular skeletal muscle mass/height² (kg/m²) less than two standard deviations below the mean value for young adults from the Rosetta Study (11).

† Odds ratios for ≥3 disabilities were adjusted for age, ethnicity, obesity, income, alcohol intake, physical activity score, current smoking, and comorbidity. Odds ratios for all other variables were adjusted for age, ethnicity, obesity, comorbidity, and alcohol intake.

‡ CI, confidence interval.

DISCUSSION

To our knowledge, this is the first epidemiologic study that has developed a method for estimating the prevalence of sarcopenia in a biethnic, population-based sample and that demonstrates an association between low relative muscle mass and functional impairment and disability that is independent of age, ethnicity, obesity, socioeconomic status, morbidity, and health behaviors. Whereas previous studies have established associations between measures of muscle mass and strength (4–6) and between strength and functional performance (21–23), we are aware of few studies that have demonstrated associations between low relative muscle mass and indicators of functional impairment and disability in a population-based sample.

The loss of muscle mass with aging has been documented in a number of studies using a variety of methods, and it appears to occur even in relatively healthy elderly people (1, 11, 24, 25). At present, there are insufficient data for forming any consensus on what constitutes "deficient" muscle mass or sarcopenia. Criteria for estimating prevalences of sarcopenia are needed for public health planning purposes. In the present study, we defined sarcopenia in relation to the distribution of height-adjusted muscle mass in young, healthy adults in a manner analogous to that used for defining population prevalences of overweight and obesity. With this approach, we found that the prevalence of low relative skeletal muscle mass, or sarcopenia, increased with age and exceeded 40 percent among persons older than 80 years in all sex and ethnic groups in our Survey sample. This suggests that substantial numbers of elderly people, especially the "oldest old," may be considered sarcopenic and at risk for associated disability and morbidity. Clearly, our approach requires further refinement; our criterion for classifying subjects as sarcopenic was chosen arbitrarily. The Rosetta Study reference population was small, and its representativeness is not known. Estimates of muscle mass made by DXA are not presently available for larger, population-based samples of younger adults. Different indices might produce different estimated prevalences. In addition, there could be sex-specific thresholds for low relative muscle mass at which risks for various deleterious outcomes increase rapidly. If this is the case, such thresholds could provide less arbitrary, biologically based cutoff values for defining sarcopenia.

In the present paper, values for muscle mass were predicted using an anthropometric prediction equation that was developed and cross-validated in a random subsample of the Survey population, as well as in an independent sample of subjects of similar age from the same geographic region. Although this approach was successful, producing predicted values with relatively modest random errors of ±1.7 kg (±9 percent), it could be argued that the use of simple, conventional indices such as body mass index or mid-arm muscle area would be less costly and would provide equally precise estimates. The use of these simpler alternative indices was examined in the present study. A body mass index less than 22 was associated with relatively small, nonsignificantly increased odds of disability in the men (odds ratio = 2.24, 95 percent confidence interval 0.84–5.87), and there was no association in the women (odds ratio = 1.09, 95 percent confidence interval 0.51–2.30). Although mid-arm muscle area was correlated more strongly with ASM/height^2 (r = 0.77) than was body mass index (r = 0.53), low mid-arm muscle area (less than the sex-specific 25th percentile) was not associated with disability in the men (odds ratio = 1.16, 95 percent confidence interval 0.48–2.66) or the women (odds ratio = 0.80, 95 percent confidence interval 0.21–1.79). These results suggest that neither body mass index nor mid-arm

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muscle area is a sensitive index of sarcopenia in elderly people. Nonetheless, we do not recommend the use of the equations developed in our study to predict muscle mass (or percentage of body fat) in other, independent studies unless a cross-validation or calibration study is performed in a random subsample of that study population to verify their accuracy.

Four additional limitations of the current study should be recognized. First, the study design was cross-sectional, and the results do not establish cause-effect relationships between sarcopenia and morbidity, disability, and falls. Theoretically, certain types of morbidity (e.g., lung disease, stroke, uncontrolled non-insulin-dependent diabetes mellitus) could produce sarcopenia that would result in functional impairment and disability. It is also possible that disability could lead to sarcopenia by limiting physical activity and subsequently predisposing people to some chronic diseases. However, sarcopenia was associated with functional impairment and disability independently of chronic morbidity, which is a potent risk factor for functional impairment (26). In addition, none of the chronic diseases were significantly associated with sarcopenia, with the exception of lung disease in the men. Our data suggest an increased risk of sarcopenia in smokers, which is consistent with the association with lung disease. The sample sizes in our survey may have been insufficient to consider some associations statistically significant.

Second, the rate of response to the full examination was relatively low (53 percent), although it was comparable to response rates in some other surveys of elderly people. It is likely that individuals with more severe impairment, morbidity, and sarcopenia were not included. In addition, the response rate was lower in Hispanics (47 percent) than in non-Hispanic whites (54 percent) and was lowest in Hispanic women (42 percent). This small ethnic difference could have produced bias in the odds ratios for ethnicity, as well as for income, which was highly correlated with ethnicity.

Third, the validity and reliability of the self-reported variables for disability, income, smoking, alcohol intake, and physical activity are not known. Self-reported data may be subject to significant cultural and socioeconomic influences. Our physical activity questionnaire recorded the weekly frequency of engaging in a few types of leisure activities and sports; it did not capture information on a broader array of activities, such as housework or stair-climbing, that may represent important forms of exercise in an elderly population. Nonetheless, there was a consistent linear trend in our study towards a protective effect with increasing physical activity in both sexes.

Fourth, we considered only broad categories of chronic morbidity, and the possible effects of more specific diseases may have been obscured. For example, the category "arthritis" did not differentiate between osteoarthritis and rheumatoid arthritis, which may be associated with significant loss of muscle mass (27). In addition, the potential effect on muscle mass of various medications was not considered. Preliminary analyses revealed no association between dietary energy intake (from food frequency questionnaires) and muscle mass, so dietary variables were not included.

In summary, the present study confirms reports from other, previous studies (1, 11, 24, 25) that relative muscle mass is significantly lower in elderly persons than in younger adults and that it decreases with age among persons older than 65 years. We have provided a method for estimating the prevalence of "deficient" relative muscle mass, or sarcopenia, in population studies that is more sensitive than other approaches currently available. The prevalence of sarcopenia increased with age in both men and women of Hispanic and non-Hispanic white ethnicity. The findings suggest that nearly half of all people older than 80 years may have sarcopenia. In our study, sarcopenia was associated with a three- to fourfold increased likelihood of disability in elderly people, independently of age, sex, obesity, ethnicity, socioeconomic status, chronic morbidity, and health behaviors. These results provide strong evidence that sarcopenia is an important public health problem among the elderly in the United States.

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