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ORIGINAL CONTRIBUTIONS

Associations of Body Composition with Physical Performance and Self-reported Functional Limitation in Elderly Men and Women

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To understand how body composition relates to functional impairment, the authors examined cross-sectional associations of absolute and relative measures of fat and lean mass with physical performance and self-reported functional limitation. The sample consisted of a community-based cohort of 1,655 older women and men from Sonoma, California, who had complete baseline data in 1993–1994 on body composition, physical performance, and functional limitation. Physical performance was assessed by walking speed and grip strength, while global functional limitation, across several domains, was assessed by self-report using standard questions. Lean mass and fat mass were estimated from bioelectric impedance using population-specific prediction equations derived from dual x-ray energy absorptiometry. Higher fat mass was associated with slower walking speed and greater likelihood of functional limitation, while higher lean mass was generally associated only with increased grip strength. A higher lean mass-to-fat mass ratio, a relative measure of body composition, was associated with faster walking speed and less limitation. These findings suggest that fat mass negatively impacts some domains of physical performance and overall functioning, while lean mass is less significant in absolute terms but is important relative to amount of body fat. *Am J Epidemiol* 2002;156:110–21.

aged; body composition; obesity; thinness

Abbreviations: BIA, bioelectric impedance; DEXA, dual energy x-ray absorptiometry; MET, metabolic equivalent; resid, residual variable.

Editor's note: *An invited commentary on this article appears on page 122, and the authors' response appears on page 125.*

Functional limitation, defined as a restriction in the physical (or mental) performance of tasks required for independent living, is a precursor of disability (1) and a significant predictor of morbidity and mortality (2). Although often a direct consequence of pathology, impaired physical performance and functional limitation may also arise as a direct or an indirect result of prior predisposing social and behavioral factors (3). According to this model, factors such as increased physical activity and decreased body mass have the potential to decrease the risk of developing functional limitation, both by delaying the onset of pathology and disease and by lessening the impact of pathology on physical functioning.

A substantial body of evidence exists to support this model. Both cross-sectional and longitudinal studies show that regular exercise is associated with maintenance of physical performance and functional status (4–7). Conversely, low levels of physical activity are associated with loss of function (7, 8). Cross-sectional (5, 9) and longitudinal (8, 10, 11) studies also suggest a direct association between body weight or body mass index and functional limitations. Recently, several studies examined functional limitation in relation to body composition and reported that higher levels

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of fat were associated with a greater likelihood of disability, while lower levels of lean or fat-free mass were not (12–14).

The failure to observe a relation between low lean mass and functional limitation is contrary to the hypothesis that sarcopenia, the age-related loss of muscle mass, decreases physical performance and results in physical impairment (15, 16). It is also contrary to the improvements in physical performance observed after resistance training (17). The purpose of this study was to assess cross-sectional associations of performance-based and self-reported physical function with absolute levels of lean and fat mass independently of each other and of overall body size. In addition, since lean mass and fat mass are not biologically independent, this study also examined the influence of each relative to the other, as defined by the ratio of lean to fat mass. Finally, this study explored the independent relation of fat distribution to physical performance and functional limitation.

MATERIALS AND METHODS

Study sample

The sample consisted of 2,092 men and women aged 55 years and older who resided in or near Sonoma, California, in 1992 and participated in a baseline assessment for a longitudinal investigation of the effect of aging on physiologic capacity and physical function. Details of the study design and sampling procedure have been described elsewhere (18). Briefly, a community-based census identified 3,057 eligible persons at the time of recruitment; 68.4 percent (n = 2,092) agreed to join the cohort and completed a baseline protocol that included an in-home interview and laboratory-based measures. A questionnaire, returned by 44 percent of the nonparticipants, indicated that they were similar to participants in terms of age and number of major chronic medical conditions but were less educated and more likely to be married and former or current smokers. Included in this analysis are 947 women and 708 men (79.1 percent of the cohort) who had complete data on body composition, physical performance, and functional limitation.

Assessment of physical performance and functional limitation

Walking speed was measured by the number of feet walked in 60 seconds, and grip strength in the dominant hand was measured in kilograms with a hydraulic hand grip dynamometer. Participants performed the grip strength test three times, and the mean of the three attempts was used in analysis. Both measures of physical performance were made in the participants' homes by trained interviewers following a standardized protocol.

Self-reported functional limitation was defined from a series of 10 questions (appendix 1) that assessed the degree of difficulty a participant experienced in various domains of physical functioning, such as stooping, crouching, or kneeling; lifting or carrying more than 10 pounds (4.54 kg); and walking up and down stairs. The specific questions were taken from those used in the Framingham Disability Study (19) and Established Populations for Epidemiologic Studies of the Elderly (20) and from the Nagle (21) and Rosow and Breslau (22) scales, all of which have demonstrated reliability and are closely associated with directly measured physical performance (23). Participants who reported "a lot of difficulty" doing one or more functions or not doing at least one function because they were unable or a doctor told them not to were categorized as having a self-reported limitation. All others were defined as having no self-reported limitation. This summary variable represented a broad self-assessment of functional limitation encompassing a range of domains.

Measurement of body composition

Estimates of fat mass and lean mass, considered to be absolute measures of body composition, were derived from reactance and resistance measured with bioelectric impedance (BIA) using the BIA101Q Quantum Body Composition Analyzer System (RJL Systems, Clinton Township, Michigan). With the participant lying supine, bipolar electrodes were placed on the middle finger of the right hand and the lateral aspect of the right ankle. As recommended by Roubenoff et al. (24), fat and lean mass were then estimated from study-specific regression equations predicting lean mass as measured with dual energy x-ray absorptiometry (DEXA). The equations were developed in a validation substudy with 100 men and 100 women randomly selected from the cohort members with no chronic conditions in 10 age- (above and below the median) and gender-specific body mass index strata (<10th, 10th–<50th, 50th–<75th, 75th–<90th, and ≥90th percentiles). These participants had duplicate BIA measurements and a whole-body DEXA scan using a LUNAR DPQIX machine (LUNAR, Madison, Wisconsin). Gender-specific multiple linear regressions, with lean mass measured by DEXA as the dependent variable regressed against the predictor variables suggested by Roubenoff et al. (24), produced the following prediction equations:

$$\text{Lean mass}_{\text{men}}\ (\text{kg}) = 3.587 + 0.326(\text{height}^2/\text{resistance}) + 0.304(\text{weight}) + 0.136 \times \text{reactance}$$

$$\text{Lean mass}_{\text{women}}\ (\text{kg}) = 5.161 + 0.439(\text{height}^2/\text{resistance}) + 0.152(\text{weight}) + 0.053 \times \text{reactance}$$

The total variances in lean mass accounted for by these equations in the validation sample were 0.85 and 0.80, respectively.

Similar regressions were performed for lean plus bone mass. Since total mass is the sum of fat mass plus lean plus bone mass, fat mass (in kilograms) was obtained by subtraction of lean plus bone mass (in kilograms) from weight.

Finally, a relative measure of body composition, the lean-to-fat ratio, was defined by dividing lean mass by fat mass.

Measurement of body size and fat distribution

Measures of body size included height and weight; waist circumference was used as an indicator of fat distribution. Height (in centimeters) was measured on a wall stadiometer with participants in their stocking feet. Weight (in kilograms) was measured on a digital scale. Waist circumference was measured at the location of the natural waist with a Gullick tape measure (Country Technology, Gary Nils, Wisconsin) and recorded to the nearest centimeter.

Other covariates

Age, comorbidity, self-reported physical activity, and smoking status were considered as factors that may confound associations between body composition and physical performance/functional limitation. Age (in years) was calculated as the difference between the date of baseline examination and the reported date of birth. Comorbidity was defined as no chronic condition, one chronic condition, or two or more chronic conditions, based on self-reported physician diagnosis of cardiovascular disease, stroke, cancer, diabetes mellitus, kidney or liver disease, or Parkinson's disease. Recreational physical activity during the previous year was assessed by asking respondents about the average number of times per week they engaged in 22 common activities, such as swimming, bicycling, brisk walking, dancing, and gardening. Activities were assigned standard intensity values in metabolic equivalents (METs) (one MET approximately equals the oxygen consumption required for sitting quietly) (25) multiplied by frequency and summed to create a continuous summary score in METs per week. Smoking status was determined by self-report and categorized as never, former, or current smoker.

Data analysis

The body composition, body size, and fat distribution variables were described by means and standard deviations and treated as continuous variables in all analyses. Walking speed and grip strength were also generally treated as continuous variables, while self-reported functional limitation was dichotomized as described above.

Pearson correlation coefficients provided a crude measure of the collinearity among pairs of body composition, body size, and fat distribution variables. Although a formal evaluation of the eigenvalues and condition indices failed to reveal a high degree of collinearity, the canonic correlation coefficient of lean mass with height and fat mass was 0.85 for both women and men, suggesting a substantial degree of interrelatedness. To minimize this and to allow for an evaluation of the distinct contribution to physical function of that part of each component of body composition or fat distribution that was unrelated to any other body composition or body size factor, three residual variables were defined from linear regression analysis as follows:

Residual variable	Model
lean $mass_{resid}$	lean mass = height + fat mass
$waist_{resid1}$	waist = fat mass + lean mass
$waist_{resid2}$	waist = lean mass/fat mass

Each residual variable specified above represented that part of the dependent variable not accounted for by the independent variables in the corresponding model. No residual variable was defined for the lean-to-fat ratio, the relative measure of body composition, because it was not correlated with height. For that reason, height was also not included in the models defining that part of waist circumference not accounted for by fat and lean mass ($waist_{resid1}$) or the lean-to-fat ratio ($waist_{resid2}$). Appendix 2 presents a mathematical explanation of this approach.

To examine mean differences in body composition and fat distribution by level of physical performance and functional limitation, least-squares means and 95 percent confidence intervals were obtained from analysis of variance, adjusting for age and comorbidity. For these analyses, walking speed and grip strength were dichotomized into high and low at the gender-specific mean.

Estimates of the independent association between physical performance/self-reported functional limitation and fat mass, lean $mass_{resid}$, height, $waist_{resid1}$, and the potentially confounding variables specified above were obtained from multivariable linear or logistic regression models. All variables were entered as either median or mean centered. Weight was not considered in these models, since fat mass and lean mass (plus bone mass) equal weight. A priori hypotheses about possible effect modification of the relation between physical performance or functional limitation and lean mass by age or fat mass were considered by entering terms for lean $mass_{resid}$ × age and lean $mass_{resid}$ × fat mass. Because the age interaction for grip strength was statistically significant ($p < 0.05$) in men, that model was stratified at age 70 years. The fat mass interaction for grip strength was significant in women, and that model was stratified at the gender-specific median of fat mass.

The same approach was used to estimate associations of the relative measure of body composition, the lean-to-fat ratio, with physical performance and functional limitation, with consideration of effect modification by age only. The age interaction for grip strength was again significant in men, and that final model was also stratified at age 70 years.

Goodness-of-fit was evaluated by examination of the residual and predicted values in the linear regression models, and final models were run with and without potentially influential observations (those with a Studentized residual greater than an absolute value of 2). The Hosmer-Lemeshow test provided a measure of goodness-of-fit for the logistic regression models.

All analyses were stratified by gender.

RESULTS

Characteristics of sample

As shown in table 1, women accounted for 57.2 percent of the study sample, and the mean age for both women and men was between ages 69 and 70 years. As expected, the women were, on average, shorter and lighter, with less lean mass and more fat mass and, therefore, a lower lean-to-fat ratio. They also had a smaller mean waist circumference, suggesting less central fat distribution and a smaller overall frame size. Men reported a higher level of physical activity than did women, but the median level was highly active for both. Men had greater grip strength, but there were no differences in average walking speed. Although more than 40 percent of the sample reported at least one chronic condition, only

TABLE 1. Baseline characteristics of the Sonoma, California, aging and physical performance study cohort, 1992

	Women (n = 947)	Men (n = 708)
Age (years) (mean (range))	69.3 (55–95)	69.5 (55–96)
Body composition (mean (SD†))		
Absolute measures (kg)*		
Lean mass	38.4 (4.3)	57.9 (6.5)
Fat mass	27.2 (9.2)	22.4 (7.5)
Relative measure		
Lean/fat ratio*	1.5 (0.46)	2.8 (0.84)
Body size (mean (SD))		
Height (cm)*	160.8 (6.7)	174.7 (6.6)
Weight (kg)*	67.8 (13.0)	83.7 (13.4)
Fat distribution (mean (SD))		
Waist circumference (cm)*	83.7 (11.3)	97.6 (10.6)
Physical activity (METs†/week, median (IQ† range))*	35.0 (18.5–61.0)	44.5 (24.5–71.0)
Physical performance		
Walking speed (feet‡/second) (mean (SD))	2.27 (0.51)	2.28 (0.48)
Grip strength, kg, mean (SD)*	23.6 (6.2)	42.1 (10.3)
Self-reported functional limitation (no. (%))*		
Yes	276 (29.1)	108 (15.3)
Comorbidity (no. of chronic conditions (%))		
1	287 (30.3)	222 (31.4)
2	115 (12.1)	109 (15.4)
Smoking status (no. (%))*		
Former	402 (42.4)	424 (59.9)
Current	82 (8.7)	46 (6.5)

* $p < 0.01$ for difference between men and women.
† SD, standard deviation; MET, metabolic equivalent; IQ, intelligence quotient.
‡ 1 foot = 30.48 cm.

about 30 percent of the women and 15 percent of the men reported any functional limitation. Fewer than 10 percent of the sample were current smokers.

Interrelations of body composition, body size, and fat distribution variables

Given that larger people have more mass and more volume than do smaller people, measures of body composition, body size, and fat distribution are highly correlated with each other. Table 2 presents the correlation coefficients between the measures used in this study. Weight, which was almost entirely collinear with fat mass ($r = 0.97$ and 0.95 in women and men, respectively), was also directly related to lean mass and waist circumference and inversely related to the lean-to-fat ratio. Height, although only minimally correlated with the lean-to-fat ratio and waist circumference, showed a modest correlation with fat mass and a substantial correlation with lean mass ($r = 0.59$ and 0.54 in women and men, respectively). Lean mass and fat mass were also highly positively

TABLE 2. Pearson correlation coefficients between original and residual body composition, body size, and fat distribution variables, stratified by gender, Sonoma, California, 1992

	Weight	Height	Lean mass	Fat mass	Waist circumference	Lean/fat ratio	Lean $mass_{resid}$	$Waist_{resid1}$	$Waist_{resid2}$
Women									
Weight	1.00	0.40	0.88	0.97	0.83	–0.76	0.18	0.00	0.41
Height		1.00	0.59	0.27	0.10	–0.13	0.00	–0.26	0.01
Lean mass			1.00	0.75	0.64	–0.46	0.53	0.12	0.45
Fat mass				1.00	0.86	–0.84	0.00	0.00	0.35
Waist circumference					1.00	–0.73	0.11	0.52	0.68
Lean/fat ratio						1.00	0.24	–0.02	0.00
Lean $mass_{resid}$*							1.00	0.21	0.42
$Waist_{resid1}$								1.00	0.74
$Waist_{resid2}$									1.00
Men									
Weight	1.00	0.43	0.94	0.95	0.85	–0.71	0.27	0.00	0.49
Height		1.00	0.54	0.28	0.12	–0.14	0.00	–0.33	0.01
Lean mass			1.00	0.78	0.71	–0.49	0.53	0.00	0.52
Fat mass				1.00	0.89	–0.00	0.00	0.00	0.41
Waist circumference					1.00	–0.75	0.11	0.45	0.66
Lean/fat ratio						1.00	0.24	–0.04	0.00
Lean $mass_{resid}$							1.00	0.21	0.45
$Waist_{resid1}$								1.00	0.64
$Waist_{resid2}$									1.00

*resid, residual variable.

correlated with each other, and both were substantially related to waist circumference. In contrast, the lean-to-fat ratio was highly correlated in a negative direction with fat mass and waist circumference.

The correlations presented in table 2 further demonstrate the rationale for the use of residual variables by showing the lack of association between the residual variables and the other variables. For instance, even though the correlation between lean mass and lean $mass_{resid}$ remained substantial (0.53 for both women and men), the correlation of lean $mass_{resid}$ with both height and fat mass was, as expected, reduced to zero. Likewise, the correlation between the lean-to-fat ratio and $waist_{resid2}$ was decreased to zero. As a result, the residual variables could be used simultaneously with other body composition or body size variables to examine independent relations of physical performance and functional limitation with that part of each factor that was not accounted for by the other factors.

Associations of body composition and fat distribution with physical performance and self-reported functional limitation

Results of separate analyses of variance, in which the mean level of each body composition or fat distribution variable was compared by level of physical performance or self-reported functional limitation, are presented in table 3. Each comparison was adjusted for age and comorbidity, but not for other body composition or body size variables. In both men and women, fat mass and waist circumference were significantly lower in those with a faster walking speed (above the median) and those with no self-reported functional limitation. Conversely, the lean-to-fat ratio was significantly higher, despite a generally *lower* lean mass. In contrast, greater grip strength (above the median) was significantly associated with greater lean mass, but there were no differences in the lean-to-fat ratio, fat mass, or waist circumference.

These associations, particularly those with lean mass, changed somewhat when the body composition, body size, and fat distribution variables were adjusted for each other by using the residual variables defined above and excluding potentially influential data points (59 women and 50 men). Although the magnitude of the parameter estimates changed slightly when influential data points were included, the direction of the associations and the inferences that could be drawn did not (data not shown).

Although walking speed in women and men remained inversely associated with fat mass and waist circumference (specifically, $waist_{resid1}$ or that part of waist circumference not accounted for by lean mass or fat mass), lean mass (specifically, lean $mass_{resid}$) no longer showed an *inverse*

TABLE 3. Adjusted* least-squares mean and 95% confidence intervals of lean mass, fat mass, waist circumference, lean-to-fat ratio, and height by level of physical performance and self-reported functional limitation, Sonoma, California, 1992

	Lean mass (kg)		Fat mass (kg)		Waist circumference (cm)		Lean mass/fat mass ratio (kg)	
	Mean	95% CI†	Mean	95% CI	Mean	95% CI	Mean	95% CI
				Women				
Walking speed‡								
Low	38.7	38.3, 39.1	28.7	27.8, 29.7	86.3	85.2, 87.5	1.46	1.41, 1.51
High	38.0	37.6, 38.4	26.3	25.3, 27.2	82.6	81.4, 83.8	1.57	1.52, 1.62
p value	0.0142		0.0001		0.0001		0.0010	
Grip strength‡								
Low	37.3	36.9, 37.8	27.1	26.1, 28.0	84.2	83.0, 85.3	1.50	1.46, 1.55
High	39.4	39.0, 39.9	28.1	27.1, 29.0	84.9	83.7, 86.1	1.53	1.48, 1.57
p value	0.0001		0.1109		0.3435		0.4462	
Self-reported functional limitation								
Yes	39.6	39.1, 40.1	31.3	30.2, 32.3	89.3	87.9, 90.6	1.35	1.29, 1.40
No	37.7	37.4, 38.1	25.7	24.9, 26.5	82.2	81.2, 83.2	1.60	1.56, 1.64
p value	0.0001		0.0001		0.0001		0.0001	
				Men				
Walking speed‡								
Low	58.5	57.8, 59.2	24.0	23.2, 24.8	100.3	99.1, 101.5	2.66	2.57, 2.76
High	57.7	57.0, 58.4	21.8	21.0, 22.7	96.6	95.4, 97.8	2.90	2.80, 3.00
p value	0.0786		0.0002		0.0001		0.0005	
Grip strength‡								
Low	56.8	56.2, 57.4	22.4	21.6, 23.3	97.6	96.4, 98.9	2.76	2.66, 2.86
High	59.4	58.7, 60.1	23.4	22.6, 24.3	99.2	98.0, 100.5	2.80	2.70, 2.90
p value	0.0001		0.1039		0.0716		0.5733	
Self-reported functional limitation								
Yes	59.8	58.6, 60.9		24.6, 27.4	103.2	101.2, 105.2	2.49	2.33, 2.64
No	57.7	57.1, 58.3	22.2	21.5, 22.9	97.3	96.3, 98.3	2.85	2.78, 2.93
p value	0.013		0.0001		0.0001		0.0001	

* Adjusted for age and comorbidity.
† CI, confidence interval.
‡ Dichotomized at gender-specific mean.

association and, in men, showed a significant and more expected, direct association (table 4). In the models with a relative measure of body composition, the lean-to-fat ratio continued to be positively related and waist$_{resid2}$ negatively related to walking speed, independent of each other, height, age, and other covariates.

When likelihood of reporting functional limitation was modeled as a function of the absolute measures of body composition, there was no relation with lean mass$_{resid}$, while fat mass and waist$_{resid1}$ were positively related (table 5). In contrast to the lack of an independent relation with the absolute measure of lean mass, the relative measure, the lean-to-fat ratio, was associated with a large decrease in risk (odds ratio = 0.23, 95 percent confidence interval: 0.14, 0.35 for women; odds ratio = 0.45, 95 percent confidence interval: 0.31, 0.68 for men). In these models, waist$_{resid2}$ continued to be related to increased likelihood of functional limitation, independent of body composition and size.

In women, relations between grip strength and absolute measures of body composition varied by fat mass. Although lean mass$_{resid}$ was directly associated with grip strength in all women, the magnitude of the association became less as fat mass increased (p for interaction between lean mass$_{resid}$ and fat mass = 0.0001, beta = –0.025). Stratification at the

TABLE 4. Multivariable adjusted associations between walking speed and absolute or relative measures of body composition and other covariates, stratified by gender, Sonoma, California, 1992

Walking speed (feet†/second)					
Models with absolute measures			Models with relative measure		
	β	(SE‡)		β	(SE)
Women					
Age (years)	–0.026**	(0.002)	Age (years)	–0.026**	(0.002)
Lean mass$_{resid}$‡ (kg)	0.000	(0.006)	Lean/fat ratio	0.156**	(0.027)
Fat mass$_{resid}$ (kg)	–0.009**	(0.001)			
Waist$_{resid1}$ (cm)	–0.006*	(0.002)	Waist$_{resid2}$ (cm)	–0.006**	(0.002)
Height (cm)	0.005*	(0.002)	Height (cm)	0.004*	(0.002)
Chronic conditions§			Chronic conditions§		
None	0.268**	(0.040)	None	0.266**	(0.040)
1	0.135**	(0.043)	1	0.133**	(0.043)
Physical activity (METs‡/week)	0.002**	(0.000)	Physical activity (METs/week)	0.002**	(0.000)
Smoking status¶			Smoking status¶		
Current	–0.126**	(0.047)	Current	–0.127**	(0.047)
Former	–0.004	(0.026)	Former	–0.002	(0.026)
Men					
Age (years)	–0.021**	(0.002)	Age (years)	–0.023**	(0.002)
Lean mass$_{resid}$ (kg)	0.011*	(0.004)	Lean/fat ratio	0.084**	(0.017)
Fat mass$_{resid}$ (kg)	–0.009**	(0.002)			
Waist$_{resid1}$ (cm)	–0.011**	(0.003)	Waist$_{resid2}$ (cm)	–0.006**	(0.002)
Height (cm)	0.006**	(0.002)	Height (cm)	0.007**	(0.002)
Chronic conditions§			Chronic conditions§		
None	0.166**	(0.042)	None	0.176**	(0.042)
1	0.103*	(0.043)	1	0.110*	(0.044)
Physical activity (METs/week)	0.001*	(0.000)	Physical activity (METs/week)	0.001*	(0.000)
Smoking status¶			Smoking status¶		
Current	–0.148*	(0.059)	Current	–0.149*	(0.060)
Former	–0.043	(0.030)	Former	–0.048	(0.029)

* $p < 0.05$, ** $p < 0.01$.
† 1 foot = 30.48 cm.
‡ SE, standard error; resid, residual variable; MET, metabolic equivalent.
§ Reference is two or more chronic conditions.
¶ Reference is never smokers.

gender-specific median of fat mass (26.02 kg) (table 6) showed that a 1-kg increase in lean mass$_{resid}$ was associated with a 0.77-kg increase in grip strength in the leaner women compared with only a 0.33-kg increase in the heavier women. In addition, although fat mass was directly associated and waist$_{resid1}$ was inversely associated with grip strength in the leaner women, neither was associated in the heavier women. Grip strength in women was not associated with the lean-to-fat ratio, although waist$_{resid2}$ was positively associated.

In men, the relations between both absolute and relative measures of body composition and grip strength varied by age (table 7). Models stratified by age showed that the magnitude of the increase in grip strength associated with an increase in lean mass$_{resid}$ was greater in the older men (beta = 0.367 in younger men and 0.865 in older men). Fat mass was not associated in either group, while waist$_{resid1}$ was inversely associated only in the older men. In the models using the relative measure of body composition, neither the lean-to-fat ratio nor waist$_{resid2}$ was associated with grip strength in the younger group but both were positively associated in the older group.

DISCUSSION

This cross-sectional study of body composition, physical performance, and functional limitation found that higher fat mass was associated with slower walking speed and greater

TABLE 5. Multivariable adjusted odds ratio and 95% confidence intervals between self-reported functional limitation and absolute or relative measures of body composition and other covariates, stratified by gender, Sonoma, California, 1992

Self-reported functional limitation (yes/no†)					
Models with absolute measures			Models with relative measure		
	OR‡	95% CI‡		OR	95% CI
Women					
Age (years)	1.10**	1.07, 1.12	Age (years)	1.10**	1.07, 1.12
Lean $mass_{resid}$‡ (kg)	1.00	0.93, 1.07	Lean/fat ratio	0.23**	0.14, 0.35
Fat $mass_{resid}$ (kg)	1.08**	1.06, 1.10			
$Waist_{resid1}$ (cm)	1.03*	1.00, 1.07	$Waist_{resid2}$ (cm)	1.04**	1.02, 1.06
Height (cm)	1.01	0.98, 1.04	Height (cm)	1.01	0.99, 1.04
Chronic conditions§			Chronic conditions§		
0	0.50**	0.31, 0.82	0	0.52**	0.32, 0.84
1	0.63	0.37, 1.06	1	0.65	0.38, 1.08
Physical activity (MET‡/week)	1.00	0.99, 1.00	Physical activity (MET/week)	1.00	0.99, 1.00
Smoking status¶			Smoking status¶		
Current	1.97*	1.0, 3.70	Current	2.00*	1.07, 3.74
Former	1.46*	1.03, 2.06	Former	1.43*	1.01, 2.01
Men					
Age (years)	1.07**	1.03, 1.11	Age (years)	1.07**	1.013, 1.10
Lean $mass_{resid}$ (kg)	0.97	0.90, 1.04	Lean/fat ratio	0.45**	0.31, 0.68
Fat $mass_{resid}$ (kg)	1.09**	1.05, 1.12			
$Waist_{resid1}$ (cm)	1.06*	1.00, 1.12	$Waist_{resid2}$ (cm)	1.05*	1.01, 1.08
Height (cm)	0.99	0.95, 1.03	Height (cm)	0.99	0.95, 1.03
Chronic conditions§			Chronic conditions§		
0	0.28**	0.15, 0.51	0	0.27**	0,14, 0.49
1	1	0.27, 0.89	1	0.48*	0.26, 0.87
Physical activity (METs/week)		0.99, 1.01	Physical activity (METs/week)	1.00	0.99, 1.01
Smoking status¶			Smoking status¶		
Current	2.11	0.69, 6.49	Current	2.07	0.67, 6.38
Former	1.76*	1.02, 3.06	Former	1.78*	1.03, 3.09

* $p < 0.05$; ** $p < 0.01$.
† Modeling having a self-reported functional limitation.
‡ OR, odds ratio; CI, confidence interval; resid, residual variable; MET, metabolic equivalent.
§ Reference is two or more chronic conditions.
¶ Reference is never smoker.

likelihood of functional limitation; that part of lean mass not accounted for by height or fat mass was not associated with these outcomes, except for a small direct association with walking speed in men. In contrast, a higher lean-to-fat ratio was associated with faster walking speed and less likelihood of reported limitation. These findings suggest that absolute amount of fat mass negatively impacts physical performance and functioning, while the impact of lean mass is not as significant in absolute terms but is important relative to amount of body fat.

This suggestion is consistent with previous studies. In the Framingham Heart Study, a higher percentage of body fat, as determined by DEXA, was associated with increased risk of self-reported disability (13), and in the Cardiovascular Health Study cohort, a similar relation was observed with fat mass determined by bioelectric impedance (12). Neither study found any association between disability and lean mass. A comparison of disabled and nondisabled elderly women also reported a significant relation between greater fat mass and disability but no association with lean mass (14). These findings, along with those from this study, may suggest that, contrary to the sarcopenia hypothesis (15), the accumulation of body fat may be more predictive of poor physical performance, functional limitation, and subsequent disability and mortality than loss of muscle mass.

On the other hand, in the domain of muscular strength, as determined in this study by grip strength, the influence of lean mass was apparent, although quite complex. In general, lean mass was directly associated with strength, but the magnitude of the association in women decreased as fat mass

TABLE 6. Multivariable adjusted associations† between grip strength and absolute or relative measures of body composition and other covariates, in women, Sonoma, California, 1992

Grip strength (kg)					
Models with absolute measures			Models with relative measure		
Women with median fat mass (*n* = 440)	β	(SE‡)	All women	β	(SE)
Age (years)	–0.148**	(0.030)	Age (years)	–0.252**	(0.566)
Lean mass$_{resid}$‡ (kg)	0.770**	(0.111)	Lean/fat ratio	–0.012	(0.394)
Fat mass$_{resid}$ (kg)	0.128*	(0.058)			
Waist$_{resid1}$ (cm)	–0.142**	(0.046)	Waist$_{resid2}$ (cm)	0.051*	(0.023)
Height (cm)	0.269**	(0.038)	Height (cm)	0.249**	(0.029)
Chronic conditions†			Chronic conditions†		
0	2.272**	(0.709)	0	1.498**	(0.575)
1	1.510*	(0.749)	1	0.867	(0.610)
Physical activity (MET‡/week)	0.022**	(0.006)	Physical activity (METs/week)	0.013*	(0.005)
Smoking status§			Smoking status§		
Current	2.176**	(0.742)	Current	0.697	(0.674)
Former	0.615	(0.473)	Former	0.372	(0.368)
Women with more than median fat mass (*n* = 448)	β	(SE)			
Age (years)	–0.273**	(0.036)			
Lean mass$_{resid}$ (kg)	0.326**	(0.111)			
Fat mass$_{resid}$ (kg)	0.041	(0.036)			
Waist$_{resid1}$ (cm)	–0.041	(0.044)			
Height (cm)	0.193**	(0.044)			
Chronic conditions†					
0	0.229	(0.879)			
1	–0.107	(0.930)			
Physical activity (METs/week)	–0.000	(0.008)			
Smoking status§					
Current	0.699	(1.247)			
Former	0.672	(0.539)			

* $p < 0.05$; ** $p < 0.01$.
† Reference is two or more chronic conditions.
‡ SE, standard deviation; resid, residual variable; MET, metabolic equivalent.
§ Reference is never smokers.

increased while, in men, the magnitude increased as age increased. This supports the well-known relation between muscle mass and muscular strength but may indicate that absolute strength is not as critical an element for other domains of physical performance or overall functional limitation as other physiologic capacities, such as aerobic capacity. Alternatively, it may be that the contribution of muscle mass, and, therefore, strength, to walking speed, for instance, is not linear and that it is only when muscle mass and strength fall below a certain minimal threshold that its effect in domains other than strength can be observed (26).

The finding that fat mass was directly associated with grip strength in the leaner women is surprising and may be due to chance or may reflect the importance of total body mass to muscular strength, especially at lower levels of total body mass.

This study also found that fat distribution, as measured by waist circumference, was associated with decreased walking speed and increased likelihood of self-reported limitation and with decreased grip strength in leaner women and older men (when absolute measures of body composition were considered). The implication of this finding is that central adiposity, independent of levels of lean mass and fat mass, negatively impacts physical functioning. However, only a few previous reports have examined the impact of central adiposity on functional limitation. One supported the finding of this study (27), while two found no association (12, 13). The direct association between waist circumference and grip strength in women and older men in models using the lean-to-fat ratio is difficult to explain.

This study adds to previous work in several innovative ways. First, consideration of directly observed measures of

TABLE 7. Multivariable adjusted associations† between grip strength and absolute or relative measures of body composition and other covariates, in men, Sonoma, California, 1992

Grip strength (kg)					
Models with absolute measures			Models with relative measure		
Men aged <75 years (*n* = 352)	β	(SE‡)	Men aged <75 years (*n* = 352)	β	SE)
Age (years)	–0.245*	(0.102)	Age (years)	–0.289**	(0.099)
Lean mass $_{resid}$‡ (kg)	0.367*	(0.155)	Lean/fat ratio	–0.910	(0.575)
Fat mass$_{resid}$ (kg)	0.113	(0.063)			
Waist$_{resid1}$ (cm)	0.088	(0.111)	Waist$_{resid2}$ (cm)	0.114	(0.067)
Height (cm)	0.445**	(0.072)	Height (cm)	0.437**	(0.0698)
Chronic conditions†			Chronic conditions†		
0	1.582	(1.649)	0	2.238	(1.637)
1	0.264	(1.745)	1	0.826	(1.743)
Physical activity (METs‡/week)	–0.016	(0.013)	Physical activity (METs/week)	–0.013	(0.013)
Smoking status§			Smoking status§		
Current	–1.319	(1.680)	Current	–1.460	(1.688)
Former	–0.273	(0.972)	Former	–0.427	(0.974)
Men aged >75 years (*n* = 306)	β	(SE)	Men aged >75 years (*n* = 306)	β	(SE)
Age (years)	–0.307**	(0.113)	Age (years)	–0.478**	(0.113)
Lean mass$_{resid}$ (kg)	0.865**	(0.145)	Lean/fat ratio	1.284*	(0.586)
Fat mass$_{resid}$ (kg)	0.035	(0.068)			
Waist$_{resid1}$ (cm)	–0.297**	(0.110)	Waist$_{resid2}$ (cm)	0.151*	(0.070)
Height (cm)	0.448**	(0.084)	Height (cm)	0.474**	(0.832)
Chronic conditions†			Chronic conditions†		
0	1.273	(1.248)	0	1.736	(1.318)
1	1.837	(1.266)	1	2.224	(1.335)
Physical activity (METs/week)	0.006	(0.013)	Physical activity (METs/week)	0.011	(0.014)
Smoking status§			Smoking status§		
Current	–3.628	(2.838)	Current	–1.641	(2.923)
Former	–0.085	(0.996)	Former	–0.393	(1.034)

* $p < 0.05$; ** $p < 0.01$.
† Reference is two or more chronic conditions.
‡ SE, standard error; resid, residual variable; MET, metabolic equivalent.
§ Reference is never smokers.

physical performance as outcomes, in addition to self-reported limitation, may provide insight into how the different components of body composition contribute to intermediate stages of the disablement process, such as decrements in physical performance, as well as to outright limitation and disability (3). Second, examination of both absolute levels of lean and fat mass and lean mass relative to fat mass revealed that fat mass, in and of itself, may be a risk factor for functional limitation, while lean mass may be protective, not in an absolute sense, but in relation to fat mass. Finally, the analytic approach used in this study, which attempted to separate out that part of each body composition and fat distribution variable not accounted for by the other variables and by overall body size perhaps allowed for greater precision of estimates of independent associations. This approach, although typically not used in the analysis of body composition, is well-established in nutritional epidemiology, particularly when it is desirable to assess the effect of fat calories distinct from the effect of total caloric intake (28).

An important limitation of this study is the cross-sectional nature of the data. This makes it impossible to determine whether adverse changes in body composition, such as increased fat mass and waist circumference, were the cause or the effect of decrements in performance or onset of functional limitation. Another important limitation was the inability to assess the impact of diagnosed musculoskeletal diseases on the observed associations. A potential limitation, the assessment of body composition by bioelectric impedance, was overcome by the DEXA validation study that produced population-specific prediction equations and provided a high degree of confidence in the validity of the measures derived from BIA. Another potential limitation might be the ability to generalize the findings to other populations, given the predominantly White (96.6 percent), well-educated (40.4 percent with at least a college degree), and affluent (21.8 percent with incomes of $50,000/year or more) sample. In addition, there could be bias resulting from self-selection into the sample. However, as indicated earlier, the sample showed the full range of functional limitations and medical morbidity expected for the age range under study. In that sense, the cohort is representative of the broad, White middle class that constitutes a large segment of the elderly population in the United States.

In conclusion, this study reinforces the importance of minimizing age-related changes in body composition, particularly increases in fat and central fat deposition and decreases in lean mass to decrease risk of declines in physical performance and development of functional limitation. Unfortunately, the data do not reveal how to accomplish this. Future studies should focus on modifiable behaviors, such as physical activity, that might affect these adverse changes in body composition and prevent or slow the disablement process.

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APPENDIX 1

Questions Used to Assess Functional Limitation

In the past month, what level of difficulty have you had in pushing objects like a living room chair?

In stooping, crouching or kneeling?
In getting up from a stooping, crouching, or kneeling position?
In lifting or carrying items under 10 pounds (4.54 kg), like a bag of potatoes?
In lifting or carrying items over 10 pounds, like a bag of groceries?
In standing in place for 15 minutes or longer?
In sitting for long periods, say 1 hour?
In standing up after sitting in a chair?
In walking alone up and down a flight of stairs?
In walking two to three neighborhood blocks?
Response categories: a lot of difficulty, some difficulty, a little difficulty, no difficulty, don't do on doctor's orders, don't do because unable, never do activity.

APPENDIX 2

Mathematical Justification for Using the Residuals to Mitigate the Problem of Multicollinearity

We examine this problem with two different scenarios. The first is a simple case of having two explanatory variables that are completely dependent on one another. Suppose we have two variables

$$X_1, X_2 \text{ where } X_1 = a + bX_2. \tag{1}$$

Therefore, the correlation between X_1, X_2 is 1. Assuming that the dependent variable Y is normally distributed with mean u and variance σ^2, given a sample of n independently and identically distributed subjects, we are interested in the following regression model :

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + e_i \tag{2}$$

for the ith subject, $1 <= i <= n$, with $e_i \sim N(0,\sigma_e^2)$. However, such a model would result in multicollinearity, and, in fact, using equation 1, we can rewrite equation 2 as follows:

$$\begin{aligned} Y_i &= \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + e_i, \\ Y_i &= \beta_0 + \beta_1(a + bX_{2i}) + \beta_2 X_{2i} + e_i, \\ Y_i &= (\beta_0 + \beta_{1a}) + (\beta_{1b} + \beta_2)X_{2i} + e_i. \end{aligned} \tag{3}$$

In equation 3, the problem of collinearity has been removed, since only X_2 is needed in the regression. In fact, software such SAS (Statistical Analysis Systems, Cary, North Carolina), when faced with this problem, will issue a warning message about the dependency between the two explanatory variables and then assign 0 to one of coefficient estimates and use only one other explanatory variable in the regression model, such as in equation 3.

When the residual method is used in this scenario, instead of model 2, the following model is used:

$$Y_i = \gamma_0 + \gamma_1 X_{1i}^{residual} + \gamma_2 X_{2i} + e_i, \tag{4}$$

where $X_{1i}^{residual}$ is obtained from the regression model where X_1 is the dependent variable and X_2 is the independent variable; however, from equation 1, $X_{1i}^{residual} = 0$, so (4) becomes

$$Y_i = \gamma_0 + \gamma_2 X_{2i} + e_i, \tag{5}$$

which is a regression model where only X_2 is used, as in equation 3.

For the second scenario, suppose we have three variables X_1, X_2, and X_3 with the following constraints:

$$X_1 = a + bX_2 \tag{6}$$

$$X_2, X_3 \text{, so that correlation } (X_2, X_3) = 0 \text{ and } X_1 = X_2 + X_3 \tag{7}$$

(there are two components that explain X_1: X_2 and X_3). Similar to the setup in the first scenario, we are interested in the regression model

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + e_i. \tag{8}$$

However, because of equation 6, a problem of multicollinearity will occur equation 8. Therefore, using equation 6, to avoid collinearity, we rewrite equation 8 as

$$Y_i = \beta_0 + (\beta_1 + \beta_2)X_{2i} + \beta_1 X_{3i} + e_i. \tag{9}$$

Equation 9 is a regression model with X_2 and the other part of X_1 (which is X_3). In the method using the residual, we would also like to obtain a regression model with just X_2 and X_3.

For this scenario, we first obtain the residual from the model in which X_1 is the dependent variable and X_2 and X_3 are the independent variables that is the regression model of form equation 7. Because of equation 6, the residual from such a model would be X_3. Regression model 8, using the residual term $X_{1i}^{residual}$ would become

$$\begin{aligned} Y_i &= \gamma_0 + \gamma_1 X_{1i}^{residual} + \gamma_2 X_{2i} + e_i \\ Y_i &= \gamma_0 + \gamma_1 X_{3i} + \gamma_2 X_{2i} + e_i, \end{aligned} \tag{10}$$

which is equivalent to equation 9, the desired regression model. This shows that the residual method proposed here helps to mitigate the multicollinearity problem. X_2 here could be replaced by a set of explanatory variables, and the interpretation would be similar, as in the case of the single variable. In relation to the data, X_1 here could stand for *lean mass*, X_2 for *height and fat mass* , and X_3 for the *lean mass* part that is not accounted for by *height* and *fat mass* (the residual).