Dietary protein intake is associated with lean mass change in older, community-dwelling adults: the Health, Aging, and Body Composition (Health ABC) Study[1–3]

Denise K Houston, Barbara J Nicklas, Jingzhong Ding, Tamara B Harris, Frances A Tylavsky, Anne B Newman, Jung Sun Lee, Nadine R Sahyoun, Marjolein Visser, and Stephen B Kritchevsky for the Health ABC Study

ABSTRACT

Background: Dietary surveys suggest that many older, community-dwelling adults consume insufficient dietary protein, which may contribute to the age-related loss of lean mass (LM).

Objective: The objective of the study was to determine the association between dietary protein and changes in total LM and nonbone appendicular LM (aLM) in older, community-dwelling men and women.

Design: Dietary protein intake was assessed by using an interviewer-administered 108-item food-frequency questionnaire in men and women aged 70–79 y who were participating in the Health, Aging, and Body Composition study ($n = 2066$). Changes in LM and aLM over 3 y were measured by using dual-energy X-ray absorptiometry. The association between protein intake and 3-y changes in LM and aLM was examined by using multiple linear regression analysis adjusted for potential confounders.

Results: After adjustment for potential confounders, energy-adjusted protein intake was associated with 3-y changes in LM [β (SE): 8.76 (3.00), $P = 0.004$] and aLM [β (SE): 5.31 (1.64), $P = 0.001$]. Participants in the highest quintile of protein intake lost ≈40% less LM and aLM than did those in the lowest quintile of protein intake ($\bar{x} \pm$ SE: -0.501 ± 0.106 kg compared with -0.883 ± 0.104 kg for LM; -0.400 ± 0.058 kg compared with -0.661 ± 0.057 kg for aLM; P for trend < 0.01). The associations were attenuated slightly after adjustment for change in fat mass, but the results remained significant.

Conclusion: Dietary protein may be a modifiable risk factor for sarcopenia in older adults and should be studied further to determine its effects on preserving LM in this population. *Am J Clin Nutr* 2008;87:150–5.

KEY WORDS Body composition, sarcopenia, dietary protein, aging

INTRODUCTION

Aging after middle age is associated with changes in body composition, including increases in fat mass (FM) and decreases in lean mass (LM). Of particular concern is the age-related loss of skeletal muscle (ie, sarcopenia), which may lead to greater risk of functional impairment and mortality (1–3). Although a number of underlying mechanisms contribute to age-related decreases in skeletal muscle, inadequate dietary protein intake may accelerate this process (4). However, many older adults do not consume adequate amounts of dietary protein. Data from the 1996 Continuing Survey of Food Intake by Individuals showed that ≈40% of men and women aged ≥70 y consumed <100% of the recommended dietary allowance (RDA) for protein (0.8 $g \cdot kg^{-1} \cdot d^{-1}$), and ≈16% consumed <75% of the RDA (5). In addition to consuming inadequate amounts of total dietary protein, older adults may be at risk of consuming inadequate animal protein, a source of high-biological-value protein, because of age-associated factors including cost, difficulty in chewing, fear of consuming too much fat or cholesterol, and perceived intolerance of certain foods (6).

Although intervention studies have examined the effect of varying protein intake on changes in body composition and LM over short periods (7, 8), few observational studies have examined the association between dietary protein intake and body composition in older adults. In cross-sectional studies, protein intake was not associated with LM (9, 10). However, in a longitudinal study, Stookey et al (11) found that, among older Chinese adults, those with a higher protein intake lost less midarm muscle area over 4 y of follow-up.

Emerging evidence from intervention studies also suggests that dietary protein may affect the partitioning of fat and LM during intentional weight loss (12–14). This may have important implications for older adults, because weight tends to decline in

[1] From the Sticht Center on Aging, Wake Forest University School of Medicine, Winston-Salem, NC (DKH, BJN, JD, and SBK); the National Institute on Aging, Bethesda, MD (TBH); the University of Tennessee, Memphis, TN (FAT); the University of Pittsburgh, Pittsburgh, PA (ABN); the University of Georgia, Athens, GA (JSL); the University of Maryland, College Park, MD (NRS); and Vrije University, Amsterdam, Netherlands (MV).

[2] Supported by the Intramural Research program of the NIH (contracts no. N01-AG-6-2101, N01-AG-6-2103, and N01-AG-6-2106 from the National Institute on Aging); the American Egg Board/Egg Nutrition Center (to DKH); and the Wake Forest University Claude D Pepper Older Americans Independence Center (P30-AG21332; to DKH).

[3] Reprints not available. Address correspondence to DK Houston, Section on Gerontology and Geriatric Medicine, Department of Internal Medicine, Wake Forest University School of Medicine, Medical Center Boulevard, Winston Salem, NC 27157-1207. E-mail: dhouston@wfubmc.edu.

Received June 12, 2007.

Accepted for publication September 5, 2007.

older age (15). Furthermore, given the high prevalence of obesity in older adults (16), determining the association between dietary protein intake and changes in LM has implications for weight-loss strategies in this group.

The primary objective of the present study was to examine the association between protein intake and LM over 3 y of follow-up among older, community-dwelling adults. A secondary objective was to examine the role of protein intake in preserving LM in older adults assumed to be at greatest risk of loss of LM—ie, those losing weight.

SUBJECTS AND METHODS

Study population

Data for this analysis are from the Health, Aging, and Body Composition (Health ABC) Study, a prospective cohort study investigating the associations among body composition, weight-related health conditions, and incident functional limitation in older adults. The Health ABC Study enrolled 3075 community-dwelling black and white men and women aged 70–79 y between April 1997 and June 1998. Participants were recruited from a random sample of white Medicare-eligible residents and all of the black Medicare-eligible residents in the Pittsburgh, PA, and Memphis, TN, metropolitan areas. Subjects were eligible if they reported no difficulty walking one-fourth of a mile, climbing up 10 steps, or performing basic activities of daily living; were free of life-threatening illness; planned to remain in the geographic area for ≥3 y; and were not enrolled in lifestyle intervention trials. Because the food-frequency questionnaire (FFQ) was administered at the 12-mo follow-up clinic visit (year 2), that visit served as the study baseline for these analyses, and only those participants who attended this visit were eligible for inclusion (n = 2732).

All participants provided written informed consent. All protocols were approved by the institutional review board at each study site (University of Tennessee, Memphis, TN, and the University of Pittsburgh, Pittsburgh, PA).

Exclusions

We excluded participants who missed the FFQ at year 2 (n = 19), those with serious errors on the FFQ (n = 57), and those who reported energy intakes < 500 kcal/d or > 3500 kcal/d (women) or < 800 kcal/d or > 4000 kcal/d (men) (n = 59). Participants who were missing values for LM assessed by dual-energy X-ray absorptiometry (DXA) at year 2 (n = 28) or year 5 (n = 461) were also excluded. Of those participants who were missing LM values at year 5, 188 had died, 140 did not have a clinic visit (home or phone interview only), 41 had a proxy interview, and 21 were lost to follow-up. The remaining 71 participants attended the clinic visit at year 5, but their body composition was not assessed by DXA. Participants missing other pertinent covariates were also excluded (n = 42). The final analysis sample was 2066 participants.

Body composition

Body composition was assessed annually by using DXA (4500A, version 8.20a; Hologic, Waltham, MA). The methods and validation data were previously reported (17, 18). DXA quality-assurance measurements including the use of daily and cross-calibration phantoms were performed at both study sites to ensure scanner reliability, and identical patient scan protocols were employed for all participants. Bone mineral content was subtracted from the total LM to determine total nonbone LM. Appendicular LM (aLM) was calculated as the sum of the LM in arms and legs, under the assumption that all nonfat and nonbone tissue is skeletal muscle. Absolute changes in LM and aLM were calculated with the use of year 2 and year 5 LM and aLM, respectively. Weight was measured in kilograms by using a standard balance-beam scale and height was measured in millimeters by using a Harpenden stadiometer (Holtain Ltd, Crosswell, United Kingdom).

Dietary assessment

To estimate usual nutrient intake, participants completed a 108-item interviewer-administered FFQ (Block Dietary Data Systems, Berkeley, CA) at year 2. The Health ABC Study FFQ food list was developed specifically for the Health ABC Study by using 24-h recalls obtained in the third National Health and Nutrition Examination Survey (NHANES III) from older (>65 y old) non-Hispanic white and black adults residing in the Northeast or the South. Trained interviewers used wood blocks, food models, standard kitchen measures, and flash cards to help participants estimate portion sizes for each food. Interviews were periodically monitored throughout the study to ensure the quality and consistency of the data collection procedures. The Health ABC Study FFQ was analyzed for micronutrient and macronutrient content by Block Dietary Data Systems. In addition to calculations of total protein intake, the source of the protein intake—ie, animal or vegetable—was also determined.

Potential confounders

Demographic characteristics (ie, age, sex, race, and study site), smoking status, alcohol consumption, and physical activity were ascertained by an interviewer-administered questionnaire at baseline. Smoking and alcohol consumption were categorized as never, former, or current. Physical activity was based on the reported time spent in walking for exercise or in other walking (eg, for transportation) over the previous 7 d. The prevalence of physician-diagnosed diabetes, ischemic heart disease (IHD), congestive heart failure (CHF), cerebrovascular disease, cancer (excluding skin), and chronic obstructive pulmonary disease at baseline was determined by using algorithms based on self-reporting and medication use. The use of oral steroids was determined from drug data coded by using the Iowa Drug Information System ingredient codes. Interim hospitalizations, defined as an overnight (ie, >24 h) stay, during the 3 y of follow-up were categorized as 0 or ≥1 hospitalization.

Statistical analysis

Multiple linear regression models were used to examine the associations between protein intake and LM and aLM by using SAS software (version 9.1; SAS Institute, Cary, NC). Protein intake was examined by using the nutrient residual energy-adjustment method, in which the protein residuals obtained by regressing absolute protein intake on total energy intake are used as the independent variables (19). An advantage of this method over others is that it provides a measure of protein intake that is independent of total energy intake (20). Protein intake was evaluated as both a continuous and a categorical variable by using sex-specific quintiles. With the use of the nutrient residual

energy-adjustment method, the quintiles of residual protein represent the variability in absolute protein intake for participants with the same total energy intake. Sex × protein intake and race × protein intake interactions were tested, but they were not significant ($P > 0.15$). Thus, all analyses are presented in the total population. Models were first adjusted for age, sex, race, total energy intake, study site, baseline height, and LM (total or appendicular). Additional models also were adjusted for prevalent health behaviors (ie, smoking, alcohol consumption, and physical activity), health conditions (ie, IHD, CHF, chronic obstructive pulmonary disease, cerebrovascular disease, diabetes, and cancer), use of oral steroids, and interim hospitalizations. To allow determination of whether the associations were independent of change in overall mass, models were also adjusted for changes in FM. Tests for linear trends across quintiles of protein intake were conducted by using the median value in each protein category as a continuous variable in the linear regression models. The association between protein intake and LM was also examined among older adults assumed to be at the greatest risk of loss of LM—ie, those who lost >3% of their weight during the 3-y follow-up (21).

RESULTS

The mean age of the study population was 74.5 y; 53.2% were women, and 35.4% were black. The mean daily protein intake was 70.8 g in men and 60.9 g in women, or ≈0.9 $g \cdot kg^{-1} \cdot d^{-1}$. The mean ± SD change in total and aLM over 3 y of follow-up was a decrease of 0.68 ± 1.94 and 0.48 ± 1.08 kg, respectively. Participants who were excluded were more likely to be men and to be black, to have less than a high school education, and to be older. Participants who were excluded also reported higher total energy and protein intakes; however, protein intake as a percentage of total energy intake did not differ significantly between participants included in the study population and those who were excluded. Baseline LM, aLM, and FM also did not differ significantly between participants included in the study population and those who were excluded.

The descriptive characteristics of the study population by quintile of energy-adjusted total protein intake are shown in **Table 1**. Participants with a higher total protein intake were more likely to be white, less likely to be sedentary, and more likely to have diabetes, and they had a higher body mass index. Over the 3-y follow-up, 28.8% of participants lost >3% of their body weight, 21.7% of participants gained >3% of their body weight, and 49.5% were weight stable (within ±3% of baseline weight). Mean changes in aLM were decreases of 1.30 ± 1.06 kg in weight losers and 0.35 ± 0.81 kg in weight maintainers and an increase of 0.32 ± 0.88 kg in weight gainers. Approximately one-third of participants had an interim hospitalization during the 3-y follow-up.

TABLE 1
Descriptive characteristics at baseline by quintile (Q) of energy-adjusted total protein intake[1]

	Q1	Q2	Q3	Q4	Q5	*P*
Age (y)	74.4 ± 2.8[2]	74.7 ± 2.9	74.5 ± 2.9	74.6 ± 2.9	74.5 ± 2.8	0.74
Female (%)	53.3	53.3	53.1	53.3	53.3	0.99
Black (%)	46.7	36.6	32.4	29.8	31.7	<0.0001
< High school education (%)	25.9	20.8	19.8	20.6	18.2	0.08
Current smoker (%)	9.2	8.5	7.7	7.3	5.3	0.28
Current alcohol consumer (%)	50.8	48.9	51.0	53.3	54.7	0.49
Sedentary (%)	42.9	43.3	35.3	36.1	33.4	0.005
Walking (min/wk)	115.8 ± 185.7	131.5 ± 281.0	137.6 ± 231.5	147.5 ± 298.2	155.7 ± 265.4	0.20
Prevalent health conditions (%)						
Diabetes	15.0	17.0	20.8	20.8	22.8	0.03
Ischemic heart disease	19.4	20.8	17.6	19.8	21.6	0.67
Congestive heart failure	1.7	1.7	2.4	2.9	2.9	0.61
Cerebrovascular disease	7.0	9.2	6.3	6.8	7.5	0.55
COPD	10.9	11.6	12.1	9.9	9.2	0.66
Cancer	16.2	18.4	19.3	18.6	19.4	0.77
Oral steroid use (%)	2.7	2.2	3.6	2.9	3.4	0.75
BMI (kg/m^2)	27.2 ± 4.8	27.1 ± 4.5	27.0 ± 4.6	26.9 ± 4.3	28.0 ± 5.1	0.008
Body composition						
LM (kg)	47.1 ± 9.6	46.9 ± 9.8	46.8 ± 9.9	46.6 ± 10.4	47.6 ± 9.9	0.66
aLM (kg)	20.4 ± 4.9	20.2 ± 4.9	19.9 ± 5.0	19.8 ± 5.1	20.3 ± 5.1	0.42
Fat mass (kg)	26.0 ± 8.9	25.8 ± 8.2	25.5 ± 8.1	25.5 ± 7.7	27.0 ± 9.2	0.08
Dietary intake						
Total energy (kcal/d)	2086 ± 630	1683 ± 604	1680 ± 553	1718 ± 578	1991 ± 638	<0.0001
Fat (% of energy)	34.8	33.2	33.6	32.5	32.1	<0.0001
Carbohydrate (% of energy)	55.1	55.1	53.5	52.7	50.4	<0.0001
Protein (% of energy)	10.9	12.7	14.2	15.9	18.6	<0.0001
Protein (g/d)	56.9 ± 18.6	53.6 ± 19.8	59.2 ± 18.2	67.1 ± 19.2	91.0 ± 27.1	<0.0001
Animal protein (g/d)	27.0 ± 11.0	27.5 ± 12.1	33.1 ± 11.5	40.2 ± 11.9	60.7 ± 20.9	<0.0001
Vegetable protein (g/d)	29.9 ± 11.2	26.0 ± 10.5	26.1 ± 9.7	26.9 ± 10.0	30.3 ± 12.5	<0.0001
Protein ($g \cdot kg^{-1} \cdot d^{-1}$)	0.8 ± 0.3	0.7 ± 0.3	0.8 ± 0.3	0.9 ± 0.3	1.2 ± 0.4	<0.0001

[1] $n = 2066$. Sedentary, 0 min of walking/wk; COPD, chronic obstructive pulmonary disease; LM, lean mass; aLM, appendicular LM. ANOVA or chi-square tests were used to evaluate the distribution.

[2] $\bar{x}$ ± SD (all such values).

We examined associations between dietary protein intake and changes in total LM and aLM by using both continuous and categorical protein variables. The results obtained from the continuous and the categorical models generally agreed; those that were found to have a significant association in the categorical analysis also had a significant association in the analysis that examined protein intake in the continuous form.

Adjusted regression coefficients per unit of energy-adjusted protein intake for change in LM and aLM are shown in **Table 2**. Total protein and animal protein were significantly associated with changes in LM [β (SE): 8.76 (3.00) and 8.82 (3.01), respectively; $P < 0.01$] and aLM [β (SE): 5.31 (1.64) and 5.26 (1.65), respectively; $P < 0.01$] after adjustment for age, sex, race, study site, total energy intake, baseline LM or aLM, height, smoking, alcohol use, physical activity, oral steroid use, prevalent disease, and interim hospitalizations. Further adjustment for changes in FM slightly attenuated the association between total and animal protein intakes and changes in LM and aLM; however, the associations remained significant. Vegetable protein intake was not significantly associated with changes in LM or aLM in the fully adjusted models. Results were similar in analyses that excluded participants with prevalent disease at baseline (data not shown).

The associations between sex-specific quintiles of energy-adjusted total protein intake and changes in LM and aLM in models adjusted for age, sex, race, study site, total energy intake, baseline LM or aLM, height, smoking, alcohol use, physical activity, oral steroid use, prevalent disease, and interim hospitalizations are shown in **Figure 1** (LM) and **Figure 2** (aLM). Participants in the highest protein quintile lost significantly (P for trend < 0.01) less LM (43% less) and aLM (39% less) over the 3-y follow-up than did those in the lowest protein quintile. These associations were attenuated after adjustment for changes in FM over the 3-y follow-up; however, the associations remained significant (P for trend < 0.05; data not shown).

One of our a priori hypotheses was that protein intake may be particularly important in preserving LM in older adults assumed to be at greatest risk of loss of LM—ie, those who were losing weight. However, weight change status × protein intake interactions were tested but were not significant ($P > 0.15$). The association between sex-specific quintiles of energy-adjusted total protein intake and change in aLM in models stratified by weight change and adjusted for age, sex, race, study site, total energy intake, baseline aLM, height, smoking, alcohol use, physical activity, oral steroid use, prevalent disease, and interim hospitalizations is shown in **Figure 3**. Protein intake was associated

TABLE 2
Adjusted regression coefficients (and SE) for change in total lean mass (LM) and appendicular LM (aLM) per unit of energy-adjusted protein intake[1]

	LM		aLM	
	β (SE)	P	β (SE)	P
Total protein				
Model 1	9.02 (2.99)	0.003	5.43 (1.64)	0.0009
Model 2	8.76 (3.00)	0.004	5.31 (1.64)	0.001
Model 3	6.38 (2.74)	0.02	4.10 (1.51)	0.007
Animal protein[2]				
Model 1	8.98 (3.00)	0.003	5.32 (1.65)	0.001
Model 2	8.82 (3.01)	0.003	5.26 (1.65)	0.001
Model 3	6.58 (2.75)	0.02	4.13 (1.52)	0.006
Vegetable protein[3]				
Model 1	9.92 (7.08)	0.16	8.24 (3.89)	0.03
Model 2	7.23 (7.14)	0.31	6.55 (3.92)	0.10
Model 3	1.08 (6.52)	0.87	3.28 (3.61)	0.36

[1] $n = 2066$. LM, aLM, and energy-adjusted protein intake were measured in grams. Multiple linear regression models. Model 1 was adjusted for age, sex, race, study site, total energy intake, baseline LM or aLM, and height. Model 2 was adjusted for variables in model 1 plus smoking, alcohol use, physical activity, oral steroid use, prevalent disease (eg, diabetes, ischemic heart disease, congestive heart failure, cerebrovascular disease, lung disease, or cancer), and interim hospitalizations. Model 3 was adjusted for variables in model 2 plus change in fat mass.

[2] Models for animal protein were also adjusted for vegetable protein intake.

[3] Models for vegetable protein were also adjusted for animal protein intake.

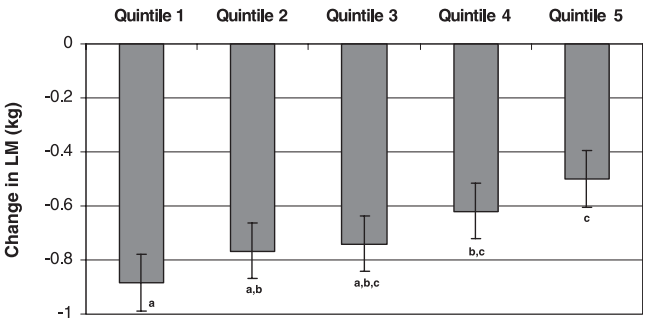

FIGURE 1. Adjusted lean mass (LM) loss by quintile of energy-adjusted total protein intake. $n = 2066$. Adjusted for age, sex, race, study site, total energy intake, baseline LM, height, smoking, alcohol use, physical activity, oral steroid use, prevalent disease (diabetes, ischemic heart disease, congestive heart failure, cerebrovascular disease, lung disease, cancer), and interim hospitalizations. Tests for a linear trend across quintiles of protein intake were conducted by using the median value in each quintile as a continuous variable in the linear regression model; P for trend = 0.002. Least-squares means with different superscript letters are significantly different, $P < 0.05$ (t test). Median total protein intake as a percentage of total energy intake ($g \cdot kg^{-1} \cdot d^{-1}$) by quintile (from quintile 1 to quintile 5) was 11.2% (0.7 $g \cdot kg^{-1} \cdot d^{-1}$), 12.7% (0.7 $g \cdot kg^{-1} \cdot d^{-1}$), 14.1% (0.8 $g \cdot kg^{-1} \cdot d^{-1}$), 15.8% (0.9 $g \cdot kg^{-1} \cdot d^{-1}$), and 18.2% (1.1 $g \cdot kg^{-1} \cdot d^{-1}$).

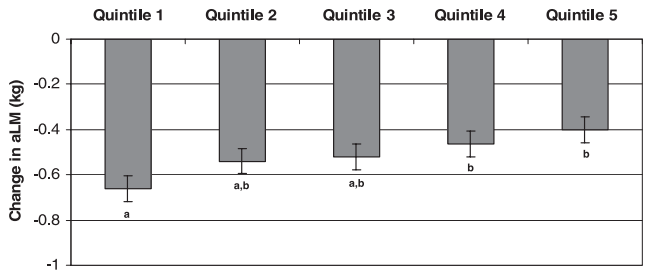

FIGURE 2. Adjusted appendicular lean mass (aLM) loss by quintile of energy-adjusted total protein intake. $n = 2066$. Adjusted for age, sex, race, study site, total energy intake, baseline aLM, height, smoking, alcohol use, physical activity, oral steroid use, prevalent disease (diabetes, ischemic heart disease, congestive heart failure, cerebrovascular disease, lung disease, cancer), and interim hospitalizations. Tests for a linear trend across quintiles of protein intake were conducted by using the median value in each quintile as a continuous variable in the linear regression model; P for trend = 0.0003. Least-squares means with different superscript letters are significantly different, $P < 0.05$ (t test). Median total protein intake as a percent of total energy intake ($g \cdot kg^{-1} \cdot d^{-1}$) by quintile (from quintile 1 to quintile 5) was 11.2% (0.7 $g \cdot kg^{-1} \cdot d^{-1}$), 12.7% (0.7 $g \cdot kg^{-1} \cdot d^{-1}$), 14.1% (0.8 $g \cdot kg^{-1} \cdot d^{-1}$), 15.8% (0.9 $g \cdot kg^{-1} \cdot d^{-1}$), and 18.2% (1.1 $g \cdot kg^{-1} \cdot d^{-1}$).

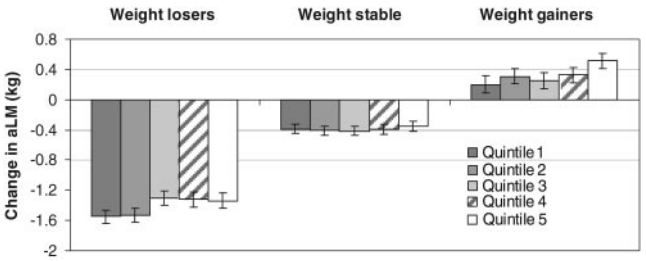

FIGURE 3. Adjusted appendicular lean mass (aLM) loss by quintile of energy-adjusted total protein intake and weight change status. $n = 2066$. Adjusted for age, sex, race, study site, total energy intake, baseline aLM, height, smoking, alcohol use, physical activity, oral steroid use, prevalent disease (diabetes, ischemic heart disease, congestive heart failure, cerebrovascular disease, lung disease, cancer), and interim hospitalizations. Tests for a linear trend across quintiles of protein intake within each strata of weight change were conducted by using the median value in each quintile as a continuous variable in the linear regression model; *P* for trend: weight losers (>3%), 0.03; weight stable (± 3%), 0.60; weight gainers (>3%), 0.02. Median total protein intake as a percentage of total energy intake ($g \cdot kg^{-1} \cdot d^{-1}$) by quintile (from quintile 1 to quintile 5) was 11.2% (0.7 $g \cdot kg^{-1} \cdot d^{-1}$), 12.7% (0.7 $g \cdot kg^{-1} \cdot d^{-1}$), 14.1% (0.8 $g \cdot kg^{-1} \cdot d^{-1}$), 15.8% (0.9 $g \cdot kg^{-1} \cdot d^{-1}$), and 18.2% (1.1 $g \cdot kg^{-1} \cdot d^{-1}$).

with changes in aLM in both weight losers and weight gainers but not in those who were weight stable. Among weight losers, participants in the 3 highest quintiles of protein intake tended to lose less aLM than did those in the lowest quintile (*P* for trend $<$ 0.05). Among weight gainers, participants in the highest quintile of protein intake gained significantly (*P* for trend $<$ 0.05) more aLM than did those in the lowest quintile. Adjustment for changes in FM over the 3-y follow-up attenuated these associations, but they remained significant (*P* for trend $<$ 0.05 among weight losers and weight gainers; data not shown). Similar associations were found for changes in LM (data not shown).

DISCUSSION

Dietary protein intake was associated with changes in LM over 3 y in older, community-dwelling adults in the Health ABC Study cohort. Participants in the highest quintile of energy-adjusted protein intake lost ≈40% less LM and aLM over the 3-y follow-up than did those in the lowest quintile. These associations remained after adjustment for changes in FM over the same period. We also examined the association between protein intake and change in LM in older adults assumed to be at greatest risk of loss of LM—ie, those losing weight. Among those who lost weight over the 3-y period, lower protein intake was associated with greater loss of LM.

Previous observational studies of dietary protein intake and body composition have shown mixed results. Protein intake was not associated with LM in cross-sectional studies (9, 10). However, older adults with higher protein intakes (>12.1% of energy) lost less midarm muscle area over 4 y of follow-up than did those with lower protein intakes (<10.4% of energy) (11). However, midarm muscle area is an imprecise measure of LM. In the Health ABC Study cohort, we found an association between protein intake and changes in LM over 3 y of follow-up: those in the highest quintile of protein intake lost significantly less LM and aLM than did those in the lowest quintile.

In comparison to vegetable proteins, which tend to be deficient in one or more essential amino acids, protein from animal sources provides all essential amino acids and thus is a source of high-biological-value protein. However, few studies have examined the effect of protein source on protein metabolism and body composition in older adults. In older women, protein breakdown in the absorptive state was inhibited in those consuming a high-vegetable-protein diet to a lesser extent than in those consuming a high-animal-protein diet; the result was less net protein synthesis among those in the former group than among those in the latter group (22). In studies contrasting the effect of a lactoovovegetarian diet and a meat-containing diet in combination with resistance training on changes in body composition in older men, results were mixed (23, 24). In the Health ABC Study cohort, we found significant associations between animal protein intake and changes in LM, but no such association with vegetable protein intake. However, the range of intake was much greater for animal protein than for vegetable protein, which may have limited our ability to detect a significant association between vegetable protein intake and changes in LM.

There is some question regarding the adequacy of the current RDA for dietary protein intake (0.8 $g \cdot kg^{-1} \cdot d^{-1}$) in older adults. Dietary protein requirements are based predominately on short-term nitrogen balance (25), not on the maintenance of LM. Some have suggested that the RDA for dietary protein is too low (6, 8, 26, 27), but others maintain that the current RDA is adequate (25, 28). Although nitrogen balance may be achieved at the current RDA level for protein, accommodation may occur, resulting in losses of skeletal muscle and functional impairment. In an intervention study, dietary protein consumed at the RDA level resulted in the loss of midthigh muscle area over a 14-wk period in elderly men and women (8). In the Health ABC Study cohort, participants in the highest quintile of protein intake lost significantly less LM over 3 y of follow-up than did participants in the lowest quintile.

Even if the RDA for protein is adequate for weight-stable older adults, relatively low dietary protein intake may contribute to sarcopenia in the context of weight loss and weight cycling. Layman et al (13) put moderately overweight middle-aged women on 1 of 2 weight-loss regimens; one included protein at the RDA level, and the other provided protein at twice the RDA level (1.6 $g \cdot kg^{-1} \cdot d^{-1}$). After 10 wk, the amount of weight lost did not differ significantly between the 2 groups. However, the partitioning of weight loss was markedly different; the ratio of fat to LM lost in the high-protein group was nearly double the ratio in the low-protein group. Other studies have also observed this difference in the partitioning of weight loss (12, 14). In the Health ABC Study cohort, higher protein intakes were associated with smaller losses of LM in participants who lost weight over the 3-y follow-up. Although protein intakes were not associated with changes in LM in participants who maintained weight, that group lost considerably less LM, on average, than did weight losers. In participants who gained weight over the 3-y follow-up, higher protein intake was associated with a gain in LM. Thus, dietary protein appears to be associated with the partitioning of body mass in those who gain and lose weight. Further research is needed to determine whether higher protein intakes can attenuate the loss of LM in older adults undergoing intentional weight loss.

Strengths of the current study include the large study sample of community-dwelling black and white men and women; the use of dual-energy X-ray absorptiometry to obtain total and regional body-composition measures; the long follow-up (3 y); and the careful adjustment for potential confounders, including lifestyle

factors and prevalent chronic conditions. A limitation of this study is the method used to assess dietary intake. A single, 108-item FFQ was used to characterize the usual intake of food. An FFQ provides an imprecise means of ranking nutrient intakes among persons (29). The imprecision of the dietary data may have reduced the ability of the present study to detect more robust associations between dietary protein intake and changes in LM. In addition, assessment of dietary intake at just one time point may be inadequate to capture important dietary exposures. Analyses were adjusted for smoking, alcohol consumption, physical activity, and other important potential confounders, but diet may serve as a proxy measure for other relevant, healthy lifestyle characteristics. Information on intentionality of weight loss during the 3 y of follow-up was not available; thus, it is possible that those who lost weight over the follow-up period may be in poorer health than those who were weight-stable or who gained weight. Finally, the observational nature of our study did not allow us to evaluate a causal association between dietary protein intake and changes in LM.

To our knowledge, this study is the first longitudinal cohort study to examine the role of dietary protein on changes in body composition by using state-of-the-art body-composition measures. In the Health ABC Study cohort, dietary protein intake was associated with significant changes in LM in older, community-dwelling men and women. These associations remained significant after adjustment for changes in FM, and they were most apparent among those subjects who were in positive or negative energy balance. Although the differences in LM over the 3-y follow-up were small, if compounded over greater lengths of time, they may result in substantial differences in LM. We cannot establish a causal association, but these results suggest that low protein intake may be a modifiable risk factor for sarcopenia among older adults. Thus, dietary protein intake should be further investigated for its potential to attenuate the age-related loss of LM among older adults.

The authors' responsibilities were as follows—DKH: study design, analysis and interpretation of the data, and drafting of the manuscript; SBK: the study design, analysis and interpretation of the data, and critical revision of the manuscript; and BJN, JD, TBH, FAT, ABN, JSL, NRS, and MV: interpretation of the data and critical revision of the manuscript. None of the authors had a personal or financial conflict of interest.

REFERENCES

1. Bales CW, Ritchie CS. Sarcopenia, weight loss, and nutritional frailty in the elderly. Annu Rev Nutr 2002;22:309–23.
2. Janssen I, Heymsfield SB, Ross R. Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. J Am Geriatr Soc 2002;50:889–96.
3. Newman AB, Kupelian V, Visser M, et al. Sarcopenia: alternative definitions and associations with lower extremity function. J Am Geriatr Soc 2003;51:1602–9.
4. Walrand S, Boirie Y. Optimizing protein intake in aging. Curr Opin Clin Nutr Metab Care 2005;8:89–94.
5. USDA Agricultural Research Service. Data tables: results from USDA's 1996 Continuing Survey of Food Intakes by Individuals and 1996 Diet and Health Knowledge Survey. Online ARS Food Surveys Research Group. Internet: http://www.barc.usda.gov/bhnrc/foodsurvey/home.htm (accessed 4 December 2006).
6. Chernoff R. Protein and older adults. J Am Coll Nutr 2004;23(suppl): 627S–30S.
7. Castaneda C, Charnley JM, Evans WJ, Crim MC. Elderly women accommodate to a low-protein diet with losses of body cell mass, muscle function, and immune response. Am J Clin Nutr 1995;62:30–9.
8. Campbell WW, Trappe TA, Wolfe RR, Evans WJ. The recommended dietary allowance for protein may not be adequate for older people to maintain skeletal muscle. J Gerontol: Med Sci 2001;56A:M373–80.
9. Baumgartner RN, Waters DL, Gallagher D, Morley JE, Garry PJ. Predictors of skeletal muscle mass in elderly men and women. Mech Aging Dev 1999;107:123–36.
10. Mitchell D, Haan MN, Steinberg FM, Visser M. Body composition in the elderly: the influence of nutritional factors and physical activity. J Nutr Health Aging 2003;7:130–9.
11. Stookey JD, Adair LS, Popkin BM. Do protein and energy intakes explain long-term changes in body composition? J Nutr Health Aging 2005;9:5–17.
12. Piatti PM, Monti F, Fermo I, et al. Hypocaloric high-protein diet improves glucose oxidation and spares lean body mass: comparison to hypocaloric high-carbohydrate diet. Metabolism 1994;43:1481–7.
13. Layman DK, Boileau RA, Erickson DJ, et al. A reduced ratio of dietary carbohydrate to protein improves body composition and blood lipid profiles during weight loss in adult women. J Nutr 2003;133:411–7.
14. Layman DK, Evans E, Baum JI, Seyler J, Erickson DJ, Boileau RA. Dietary protein and exercise have additive effects on body composition during weight loss in adult women. J Nutr 2005;135:1903–10.
15. Villareal DT, Apovian CM, Kushner RF, Klein S. Obesity in older adults: technical review and position statement of the American Society for Nutrition and NAASO, The Obesity Society. Am J Clin Nutr 2005; 82:923–34.
16. Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM. Prevalence of overweight and obesity in the United States, 1999–2004. JAMA 2006;295:1549–55.
17. Visser M, Fuerst T, Lang T, Salamone L, Harris TB. Validity of fan-beam dual-energy X-ray absorptiometry for measuring fat-free mass and leg muscle mass. Health, Aging, and Body Composition Study–Dual-Energy X-ray Absorptiometry and Body Composition Working Group. J Appl Physiol 1999;87:1513–20.
18. Salamone LM, Fuerst T, Visser M, et al. Measurement of fat mass using DEXA: a validation study in elderly adults. J Appl Physiol 2000;89: 345–52.
19. Willett WC, Stampfer M. Implications of total energy intake for epidemiologic analyses. In: Willett WC, ed. Nutritional epidemiology. 2nd ed. New York: Oxford University Press, 1998:273–301.
20. Willett WC, Howe GR, Kushi LH. Adjustment for total energy intake in epidemiologic studies. Am J Clin Nutr 1997;65(suppl):1220S–8S.
21. Newman AB, Lee JS, Visser M, et al. Weight change and the conservation of lean mass in old age: the Health, Aging and Body Composition Study Am J Clin Nutr 2005;82:872–8.
22. Pannemans DL, Wagenmakers AJ, Westerterp KR, Schaafsma G, Halliday D. Effect of protein source and quantity on protein metabolism in elderly women. Am J Clin Nutr 1998;68:1228–35.
23. Campbell WW, Barton ML Jr, Cyr-Campbell D, et al. Effects of an omnivorous diet compared with a lactoovovegetarian diet on resistance-training-induced changes in body composition and skeletal muscle in older men. Am J Clin Nutr 1999;70:1032–9.
24. Haub MD, Wells AM, Tarnopolsky MA, Campbell WW. Effect of protein source on resistive-training-induced changes in body composition and muscle size in older men. Am J Clin Nutr 2002;76:511–7.
25. Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, Food and Nutrition Board, Institute of Medicine. Dietary reference intakes for energy, carbohydrates, fiber, fat, protein and amino acids. Washington, DC: National Academy Press, 2002.
26. Evans WJ. Protein nutrition, exercise and aging. J Am Coll Nutr 2004; 23(suppl):601S–9S.
27. Dreyer HC, Volpi E. Role of protein and amino acids in the pathophysiology and treatment of sarcopenia. J Am Coll Nutr 2005;24(suppl): 140S–5S.
28. Millward DJ, Fereday A, Gibson N, Pacy PJ. Aging, protein requirements, and protein turnover. Am J Clin Nutr 1997;66:774–86.
29. Willett WC, Sampson L, Stampfer MJ, et al. Reproducibility and validity of a semiquantitative food frequency questionnaire. Am J Epidemiol 1985;122:51–65.