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Research Article

High-Protein Foods and Physical Activity Protect Against Age-Related Muscle Loss and Functional Decline

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Abstract

Background: Some clinical trials suggest that protein supplementation enhances the effects of resistance exercise on skeletal muscle mass (SMM); fewer studies examine the effects of diets rich in protein-source foods on SMM and functional status among community-dwelling adults.

Methods: Data from the Framingham Offspring study including diet (three-day records, exams 3 and 5), physical activity (exams 2 and 4), percent SMM (%SMM) (exams 6 and 7), and functional performance (exams 5 through 8) were used to evaluate independent and combined effects of physical activity and high-protein foods on adjusted mean %SMM (using analysis of covariance) and risk of functional decline (using Cox proportional hazard's models). Analyses were adjusted for such factors as age, education, height, smoking, and fruit and grain consumption).

Results: Higher intakes of protein-source foods (red meat, poultry, fish, dairy, and soy, nuts, seeds and legumes) were associated with higher %SMM over 9 years, particularly among women. Men and women with higher intakes of foods from animal sources had a higher % SMM regardless of activity; beneficial effects of plant-based protein foods were only evident in physically active adults. Active subjects with higher intakes of animal or plant protein-source foods had 35% lowest risks of functional decline. Among less active individuals, only those consuming more animal protein-source foods had reduced risks of functional decline (HR: 0.7l; 95% CI: 0.50–1.01).

Conclusion: Higher intake of animal-protein foods, alone and especially in combination with a physically active lifestyle, was associated with preservation of muscle mass and functional performance in older adults.

Keywords: Exercise—Epidemiology—Functional Performance—Nutrition—Physical Function—Sarcopenia

Age-related loss of the ability to perform basic functional activities is linked with a number of poor health outcomes including chronic disability, diminished quality of life, and premature death (1,2). Functional limitations may result from progressive loss of skeletal muscle mass (SMM) which occurs at higher rates during later adult years due to age-related changes in muscle protein synthesis and breakdown as well as reduced dietary protein intake (3). There is also a greater need for protein to compensate for losses due to underlying illness and associated inflammation (4). Evidence is mounting that the current U.S. Recommended Dietary Allowance (RDA) for protein (0.8 g/kg/d) may not be adequate for the needs of older adults (5,6).

Most short-term clinical trials examining the interplay of protein supplementation and progressive resistance exercise on change in SMM have found a beneficial effect in younger and older subjects (7), although some studies have found the benefit to be minimal (8). Fewer data exist on the long-term effects of dietary protein and protein-source foods in particular on changes in SMM and functional status amongst middle-aged and older community-dwelling subjects. While some studies separate the effects of animal and plant proteins, less consideration has been given to the differential contributions of protein from varying food sources on preservation of SMM and functional status.

The objective of these analyses was to examine the effects of the primary food sources of animal protein (meat, poultry, fish, and dairy) as well as plant protein (legumes, nuts, seeds, soy), alone and in combination with physical activity, on longitudinal changes in SMM and functional decline among middle-aged and older adults in the Framingham Offspring Study (FOS). We hypothesized that active adults who consume more animal protein-source foods would have greater preservation of muscle mass and functional capacity over time.

Methods

Study Population

The FOS began in 1972 with the enrollment of 5,124 offspring (and spouses) from the original Framingham Heart Study. Data on physical status, medical history, laboratory values, and lifestyle habits were collected at approximately 4-year exam intervals. Two different age groups were used for these analyses. For SMM outcomes, subjects 40 years of age or older (median = 52.0 years) at exam 6 or 7 (when bioelectrical impedance analysis [BIA] data were available) were included. For functional status outcomes, subjects aged 50 years or older (median = 55.0 years) at the time of the dietary assessments (exams 3 and 5) were included; follow-up for functional status outcomes continued for up to 16 years (through exam 8). The current analyses were conducted with the approval of the Boston University Institutional Review Board.

Dietary Data

Approximately 16,000 days of dietary records were collected from roughly 70% of subjects at exams 3 and 5. Nutrient content was analyzed using the Nutrition Data System (NDS) of the University of Minnesota (9). Linkage was made between the NDS food codes and United States Department of Agriculture (USDA) food codes to derive servings of red meat (beef, pork, and lamb), poultry and fish, dairy (milk, cheese, and yogurt), and nuts, seeds, soy and legumes using the standard USDA definitions of serving sizes.

Skeletal Muscle Mass

SMM was estimated from BIA using a standard tetrapolar technique in accordance with the manufacturer's instructions (BIA-101; RJL Systems, Detroit). Device calibration was performed weekly (10). The coefficient of variation for repeated BIA measures has been shown to range from 1.8 to 2.9% (11). Further, the correlation between fat free mass measured by dual-energy X-ray absorptiometry (DXA) and BIA in Framingham is 0.85 for men and 0.88 for women (10). SMM was calculated using an equation that was developed and cross-validated by Janssen (12).

Functional Status Outcomes

Functional status was measured at exams 5–8 using standardized instruments. The Rosow–Breslau scale measures gross-mobility capacity (13) while the Nagi scale assesses self-reported functional limitations (14). Tasks most likely to reflect impairment in muscle strength and/or endurance were selected from each scale including (1) doing heavy work at home (2), walking half a mile, and (3) going up and down stairs (from Rosow–Breslau scale) and (1) pushing/pulling heavy objects (eg, heavy living room chair) (2), stooping/crouching/kneeling (3), lifting/carrying weights under 10 lbs., and (4) lifting/carrying objects weighing more than 10 lbs. (from Nagi scale).

Potential Confounders

The following potential confounding variables were included in the final models: age, sex, height, education, current smoking, physical activity, intakes of grains and fruit, and finally, servings of protein-source foods other than those included in each protein exposure category. For example, for the analyses examining effects of red meat intake, the multivariable models included total servings of other protein-source foods such as poultry, fish, dairy, and so on. We explored the inclusion of other dietary factors (eg, fiber, whole grains, and vitamin D) as potential confounders but none were retained in the final models. Height was measured with a standard stadiometer. Mean height was calculated as the average of the exam-specific height measures prior to age 60. Education was determined by self-report and categorized as less than college versus some college or more. Current smoking was expressed as cigarettes smoked per day. Physical activity was self-reported as hours usually spent per day in sleep, sedentary (sitting), slight (standing, walking), moderate (house and yard work, light sports), and heavy activity (vigorous sports, heavy household work). Each subject's mean physical activity was calculated as number of hours/day performing moderate or vigorous activities multiplied by weighted energy expenditure (2.4 for moderate and 5.0 for vigorous).

Statistical Analysis

Sensitivity analyses were used to categorize subjects according to intake in each protein-source food group (1): red meat (beef/lamb/pork) (2), poultry/fish (3), dairy, and (4) legumes/nuts/seeds/soy. Adjusted mean %SMM at the end of follow-up (approximately 9 years) was estimated in each category of intake using analysis of covariance. Analyses was adjusted for confounding by age, sex (for non-sex-specific models), education, height, physical activity, cigarette smoking, and intakes of fruit, grains, and other animal protein-source foods (except those foods comprising the exposure variable). To evaluate synergistic effects of physical activity and protein consumption on %SMM, each protein-source food group was first dichotomized (higher vs. lower intakes) based on results of the above analyses and cross-classified with physical activity (also dichotomized using sensitivity analyses). High activity in this analysis was equivalent to approximately 4.0 hours/day of moderate activity (including work-related activity) or 1.9 hours/day of heavier activity. The cross-classification yielded four exposure groups (1): low physical activity/low protein food intake (control group) (2), low physical activity/high protein food intake (effect of high protein foods alone) (3), high physical activity/low protein food intake (effect of higher physical activity alone), and (4) high physical activity/high protein food intake (synergistic effect of physical activity and protein-source foods).

The same intake categories of high-protein foods were then used to explore the risk of functional decline over a median follow-up time of 13.0 years. Follow-up to the development of limitation in two or more of the functional tasks selected from the Nagi and Rosow–Breslau scales began at exam 5 (when functional status was first measured) and continued until the first of the following: two or more disabilities, lost to follow-up, death, or last available exam with data (exam 8). Cox proportional hazard's models were used to estimate the adjusted hazard ratios for developing two or more functional limitations according to intake of high-protein foods as well as the combination of protein-source foods and physical activity.

Results

Table 1 shows the subject characteristics according to the total number of servings of high-protein animal foods per day for subjects in the analysis cohort examining effects on %SMM. Men and particularly women with lower intakes of animal protein-source foods had

Table 1. Baseline Subject Characteristics by Tertile of Animal Protein Intake

Total animal protein food servings per day[a]

Characteristics	Men			Women		
	<6	6 to <8	≥8	<5	5 to <7	≥7
	n = 287	*n* = 331	*n* = 398	*n* = 342	*n* = 558	*n* = 433
	(*mean* ± *s.d.*)			(*mean* ± *s.d.*)		
Age (years)	53.7 ± 9.6	54.0 ± 9.7	51.5 ± 10.1	53.2 ± 9.6	52.0 ± 9.9	51.5 ± 9.8
BMI (kg/m²)	27.7 ± 3.3	27.1 ± 3.1	26.6 ± 3.1	27.6 ± 5.6	25.4 ± 4.4	24.8 ± 3.7
Physical activity index	13.5 ± 10.1	13.7 ± 9.4	14.6 ± 11.2	13.5 ± 9.2	13.4 ± 9.1	13.4 ± 8.8
Cigarettes/day	3.4 ± 9.0	4.5 ± 10.4	5.1 ± 11.2	4.5 ± 9.5	3.8 ± 9.5	4.1 ± 9.1
Alcohol intake (gm/day)	13.4 ± 18.4	14.6 ± 17.0	16.9 ± 18.0	5.6 ± 9.0	6.8 ± 9.0	8.0 ± 11.7
Grains, servings/day	6.4 ± 2.2	6.7 ± 2.3	7.1 ± 2.4	5.2 ± 1.8	5.1 ± 1.8	5.3 ± 1.9
Fruit, servings/day	1.5 ± 1.2	1.4 ± 1.1	1.4 ± 1.2	1.3 ± 1.0	1.2 ± 0.9	1.3 ± 0.9
Calcium (mg/day)	687 ± 243	761 ± 267	935 ± 370	551 ± 200	638 ± 218	748 ± 310
Vitamin D (mcg/day)	4.49 ± 2.37	5.51 ± 3.54	7.15 ± 3.49	3.48 ± 1.74	4.40 ± 2.04	5.62 ± 3.00
Energy (kcals/day)	1905 ± 423	2138 ± 441	2473 ± 510	1449 ± 316	1609 ± 356	1842 ± 410
Protein (gm/kg)	0.83 ± 0.17	1.04 ± 0.16	1.33 ± 0.23	0.76 ± 0.17	1.01 ± 0.16	1.34 ± 0.25
Leucine (mg/kg)	63.7 ± 13.3	80.3 ± 11.9	103.5 ± 18.4	58.3 ± 12.9	78.6 ± 12.7	104.9 ± 20.1
Fat (% kcals/day)	33.5 ± 6.2	35.1 ± 6.4	35.8 ± 6.1	33.4 ± 6.6	35.1 ± 6.4	35.6 ± 6.9
Carb (% kcals/day)	49.6 ± 7.3	45.7 ± 7.5	42.8 ± 7.3	51.2 ± 8.1	47.0 ± 7.3	43.9 ± 7.3
		column percent			column percent	
Education (% college)	40.1%	38.1%	38.1%	23.4%	22.0%	24.3%

Note: [a]Total animal food servings combined equaling the sum of all servings of red meat, poultry, fish, eggs, milk, yogurt, and cheese.

higher BMIs. Those with the highest intakes of animal foods were slightly younger than those consuming less. Men with the highest intakes of protein-source foods were more active, smoked more, and drank more alcohol. Women consuming the fewest animal protein foods had total protein intakes that were below the current RDA of 0.8 g/kg/day. For both men and women, the leucine content of the diet increased in a linear fashion with increasing intakes of animal source foods. Finally, consumption of more animal protein-source foods in both sexes was associated with consumption of more dietary fat and fewer carbohydrates.

In Table 2, all high protein foods from both animal and plant sources tended to be positively associated with % SMM at the end of follow-up. These effects were generally stronger and more linear for women than for men. For example, women who consumed 2 or more servings of red meat per day had an extra 1.2% SMM (28.1% SMM in highest red meat category vs. 26.9% SMM in lowest intake category, $p < .0001$); men, in contrast, had an extra 0.6% SMM ($p = .0939$) associated with higher red meat intake.

Table 3 examines the independent and combined effects of physical activity and various high-protein foods on % SSM. Both men and women with higher intakes of animal protein foods had higher levels of %SMM, regardless of activity. However, those with higher activity levels did have higher levels of %SMM than those who were less active. In contrast, higher intakes of legumes, soy, nuts, and seeds were associated with beneficial effects on %SMM only among more active individuals. Finally, women with higher intakes of red meats, poultry and fish, and dairy, even when they were less active, had a higher %SMM than those with lower intakes of those foods.

Table 4 shows the multivariable Cox proportional hazards models predicting risk of developing limitation in two or more functional tasks (from the Nagi and Rosow–Breslau scales) over follow-up among adults initially 50 years of age or older. The independent non-dietary positive predictors of developing impairment were age, sex, and cigarette smoking. Physical activity (upper 3 quintiles vs. lower 2) was associated with a 26% reduction in risk. In this model all protein-related foods were considered simultaneously; the strongest protective effects were observed for intakes of dairy and poultry and fish, both of which led to non-statistically significant 20% reductions in risk of functional impairment.

Finally, Table 5 explores possible combined effects of physical activity and various protein-source foods on the risk of developing multiple functional impairments over follow-up. There was no adverse effect of higher intakes of protein derived from animal or plant-based foods. When combined with higher levels of physical activity, however, there were beneficial effects on functional status observed for consumption of red meats, poultry and fish, and dairy. Men consuming 7 or more servings and women consuming 6 or more servings of high protein animal foods were 35% less likely (95% CI: 0.47, 0.89) to develop two or more functional task limitations over follow-up. While there was a non-statistically significant 35% reduction in risk associated with consuming ≥1 ounce of high-protein plant foods among subjects who were the most physically active, there was no beneficial effect among less active subjects (HR: 1.04; 95% CI: 0.69, 1.58).

Discussion

This study provides evidence that higher intakes of a variety of animal protein-source foods (red meats, poultry, fish, and dairy) and higher levels of physical activity were associated with higher levels of SMM, particularly among women. Middle-aged adults at baseline with higher intakes of animal protein foods had higher levels of SMM regardless of activity levels, but beneficial effects of plant-based protein foods were only evident amongst the more physically active adults.

Table 2. Adjusted Mean Percent Skeletal Muscle Mass in Men and Women Associated With Intake of Protein-Source Foods

% Skeletal muscle mass	Men				Women			
Protein foods (servings/day)[a]	*N*	Mean[b]	s.e.	*p*-value	*N*	Mean[b]	s.e.	*p*-value
Beef, Lamb, Pork								
<1 (m); <0.85 (f)	187	36.7	0.27	*Ref*	262	26.9	0.22	*Ref*
1 to <2 (m); 0.85 to <2 (f)	233	36.8	0.24	.8598	491	27.9	0.16	.0002
≥2 (m, f)	596	37.3	0.15	.0939	580	28.1	0.15	<.0001
Poultry & Fish								
<1	167	36.6	0.29	*Ref*	172	26.9	0.27	*Ref*
1 to <3	399	36.9	0.18	.2868	656	27.8	0.14	.0017
≥3	450	37.4	0.17	.0229	505	28.1	0.16	.0001
Dairy								
<1 (m, f)	385	36.7	0.19	*Ref*	559	27.6	0.15	*Ref*
1 to <2 (m); 1 to <1.75 (f)	392	37.3	0.18	.0407	491	27.9	0.16	.1406
≥2 (m); ≥1.75 (f)	239	37.2	0.24	.0955	283	28.2	0.21	.0165
Legumes, Soy, Nuts, Seeds								
<0.25	404	36.8	0.18	*Ref*	575	27.3	0.15	*Ref*
0.25 to <1.25	395	37.1	0.18	.1998	603	28.2	0.14	<.0001
≥1.25	217	37.5	0.25	.0197	155	28.1	0.29	0.0156
Animal Protein Foods								
<6 (m); <5 (f)	287	36.6	0.21	*Ref*	342	27.2	0.19	*Ref*
6 to <8 (m); 5 to <7 (f)	331	36.9	0.20	.3432	558	27.8	0.15	.0078
≥8 (m); ≥7 (f)	398	37.5	0.18	.0023	433	28.3	0.17	<.0001

Notes: [a]One serving for meat, poultry, fish = 1 ounce, cooked; for dairy = 1 cup of milk or yogurt and 1–1.5 ounce cheese; and for legumes, soy, nuts, seeds = 1 cup, cooked. [b]Adjusted for age, education, height, physical activity, cigarette smoking, fruit, grains, and other protein foods not in a given exposure category.

Active adults in this study were generally less likely to develop subsequent functional impairments. When these active men and women also consumed more protein-source foods of any type they were less likely to acquire functional limitations during follow-up. However, there was no beneficial effect of plant protein foods on the risk of developing functional limitations among less active adults while higher intakes of animal protein foods were associated with lower risks of functional decline, regardless of activity level.

Cross-sectional data from the Framingham Study found that higher intakes of total and animal (but not plant) protein were associated with higher appendicular lean mass (15). Similarly, prospective Framingham data found both total and animal protein (but not plant protein) derived from a food frequency questionnaire were linked with the preservation of grip strength in adults ages 29–85 (16). The current analyses extend these results to the examination of longer-term changes in SMM and risk of functional decline associated with dietary patterns derived from protein-source foods. In other prospective studies, dietary protein, particularly from animal sources, has been linked with preservation of total and appendicular lean mass in older adults (17–20). Our results suggest that adequate intakes of protein-source foods during the middle-adult years when individuals are experiencing less anabolic resistance may play an important role in the maintenance of SMM into the older-adult years.

A small number of clinical trials have explored the effects of high-protein foods on SMM. A trial of 132 older men and women found that consuming an additional 210 g of ricotta cheese per day (with 70 g consumed at breakfast, lunch, and dinner) over 12 weeks led to a statistically significant increase in appendicular muscle mass compared with those who followed their habitual diet only (21). Another clinical trial amongst community dwelling older women found that the addition of 160 g per day of lean red meat to the diets of subjects participating in a resistance training program led to greater gains in total body and leg lean mass and strength over four months than did resistance training alone (22). Such studies are consistent with our results that indicate that a variety of protein-source foods may have beneficial effects on muscle mass.

The current analyses focused on the independent and combined effects of physical activity and protein foods. Previous studies have documented beneficial effects of exercise training on SMM (23) but the relevance of these findings to usual physical activity is less clear. One study by Zampieri found that older men who were physically active over 30 years (vs. age-matched sedentary seniors) had greater preservation of muscle fiber size, morphology, and strength (24). Previous studies have also shown that protein supplementation may enhance the effects of resistance exercise on SMM (7,25). A recent review of randomized clinical trials suggests that protein quality may also modify the effects of resistance exercise on SMM; supplementation with essential amino acids (EAAs), especially leucine, has been shown to stimulate muscle protein synthesis and slow breakdown, thereby promoting the hypertrophic effects of resistance exercise and preserving strength (26). Our results are consistent with earlier observations from clinical trials of amino acid supplements in that food sources of high-quality protein were associated with higher levels of SMM.

Age-related skeletal muscle loss is a risk factor for functional decline, likely through effects on muscle strength and endurance (1,27). A few studies have examined the direct relation between dietary protein and functional outcomes. Investigators from the original Framingham Study found only weak beneficial effects of dietary protein on risk of falling (28) while results from the Women's Health Initiative demonstrated that higher protein intakes were associated with higher self-reported physical functioning and slower rates of decline in grip strength and repeated chair stands (29). Similarly, the

Table 3. Adjusted Mean Percent Skeletal Muscle Mass in Men and Women Associated With Physical Activity and Intake of Protein-Source Foods

	Men				Women			
Activity/Food servings[a]	*N*	Mean[b]	s.e.	*p*-value	*N*	Mean[b]	s.e.	*p*-value
Activity[c]/Beef, Lamb, Pork[d]								
Low/Low	168	36.4	0.28	—	127	26.5	0.32	—
Low/High	243	36.7	0.23	.4059	417	27.8	0.17	.0003
High/Low	252	37.0	0.23	.0956	184	27.7	0.27	.0030
High/High	353	37.7	0.19	.0002	605	28.2	0.14	<.0001
Activity[c]/Poultry-Fish[d]								
Low/Low	147	36.2	0.30	—	69	26.3	0.43	—
Low/High	264	36.8	0.22	.1772	475	27.7	0.16	.0033
High/Low	201	37.0	0.26	.0429	103	27.3	0.36	.0671
High/High	404	37.6	0.18	.0002	686	28.1	0.14	<.0001
Activity[c]/Dairy[d]								
Low/Low	163	36.1	0.28	—	243	27.0	0.23	—
Low/High	248	36.9	0.23	.0505	301	27.8	0.21	.0155
High/Low	222	37.1	0.25	.0075	316	27.9	0.20	.0046
High/High	383	37.5	0.19	<.0001	473	28.1	0.16	.0001
Activity[c]/Legumes, Soy, Nuts, Seeds[d]								
Low/Low	297	36.5	0.21	—	443	27.4	0.17	—
Low/High	114	36.7	0.34	.6234	101	27.7	0.35	.4073
High/Low	449	37.2	0.17	.0111	655	27.9	0.14	.0348
High/High	156	37.9	0.29	<.0001	134	28.9	0.31	<.0001
Activity[c]/Animal protein foods[d]								
Low/Low	183	36.0	0.27	—	260	27.2	0.22	—
Low/High	228	37.0	0.24	.0101	284	27.8	0.21	.0516
High/Low	282	37.	0.22	.0024	371	27.7	0.19	.0538
High/High	323	37.7	0.20	<.0001	418	28.3	0.17	<.0001

Notes: s.e. = standard error.
[a]See Table 2 footnote. [b]See Table 2. [c]Low vs. high activity: lowest 2 vs. upper 3 sex-specific quintiles. [d]Cut-off values for low (vs. high) food servings per day: beef, lamb, pork intake = <2 for men, <1 for women; poultry and fish = <2 for men, <1 for women; dairy = <1 for all subjects; legumes, soy, nuts, seeds = <1 for all subjects; total animal protein foods = <7 for men, <6 for women.

Table 4. Multivariable Predictors of the Risk of Developing Two or More Functional Impairments

Predictor variables	HR	95% CI
Red meat (≥2 (m), ≥1 (w) oz. serving/day vs. less)	0.92	(0.70, 1.21)
Poultry, fish (≥2 (m), ≥1 (w) oz. serving/day vs. less)	0.80	(0.64, 1.15)
Dairy (≥1 serving/day vs. less)	0.80	(0.63, 1.01)
Legumes, soy, nuts, seeds (≥1 oz. serving/day vs. less)	0.96	(0.72, 1.30)
Grains (per 1 oz. serving)	0.97	(0.91, 1.03)
Fruits (per 1 cup serving)	1.01	(0.89, 1.15)
Physical activity (quintile 3–5 vs. quintiles 1–2)	0.74	(0.58, 0.93)
Sex (female vs. male)	1.64	(1.10, 2.44)
Age (per year)	1.09	(1.07, 1.11)
Education (some college vs. less)	0.80	(0.62, 1.02)
Height (per inch)	1.01	(0.96, 1.06)
Cigarettes (per pack/day)	1.57	(1.27, 1.96)

Note: CI = Confidence Intervals; HR = Hazards Ratio.

Osteoporosis Risk Factor and Prevention Study found that women who consumed 1.2 g/kg/day or more of dietary protein experienced less decline in grip strength, one-leg stand, and a 6-meter tandem walk than those consuming less (30).

The current study is among the few that have examined the impact of protein-source foods on functional capacities in older adults. Cross-sectional data from older Australian women in the Calcium Intake Fracture Outcome Study (CAIFOS) suggested that higher dairy intakes were associated with better physical performance, including reduced risk of falling, greater hand strength, and better mobility (31). In the Atherosclerosis Risk in Community (ARIC) study amongst middle-aged adults (ages 45–64), baseline intakes of dairy as well as fruits and vegetables were inversely associated with self-reported functional limitations nine years later (32). In a dietary intervention trial, investigators found that adding 210 g/day of ricotta cheese to the diets of older adults led to greater grip strength and better performance on the short physical performance battery and stair-climb power test (21). Our results extend these findings to show that a wide range of protein-source foods, particularly from animal sources, may help to preserve physical functioning in older adults.

There are several important strengths of the current analyses. First, dietary intake was assessed using 6 days of diet records. In addition, two separate measures of SMM derived from BIA were averaged to provide more stable outcome estimates. Another strength of this study is the availability of repeated standardized measures of functional status from four sequential exams. In addition, routine Framingham exams provided carefully collected data on a wide range of potential confounders of interest. While the prospective design of FOS allows for the examination of long-term effects of usual dietary intake, all observational studies are more

Table 5. Relative Risk of Developing Disabilities in Two or More Functional Tasks in Association With Protein-Source Food Intakes and Physical Activity

Activity level/Food servings[a]	*N*	py	Cases	I/1000 py	HR[b]	95% CI
Activity[c]/Beef, Lamb, Pork[d]						
Low/Low	196	2,330	34	14.59	1.00	—
Low/High	438	5,112	92	18.00	0.98	(0.65, 1.48)
High/Low	331	3,764	47	12.49	0.78	(0.50, 1.22)
High/High	702	8,211	111	13.52	0.70	(0.47, 1.05)
Activity[c]/Poultry-Fish[d]						
Low/Low	151	1,690	32	18.94	1.00	—
Low/High	483	5,752	94	16.34	0.77	(0.50, 1.17)
High/Low	231	2,593	35	13.50	0.62	(0.38, 1.00)
High/High	802	9,382	123	13.11	0.60	(0.40, 0.89)
Activity[c]/Dairy[d]						
Low/Low	277	3,252	60	18.45	1.00	—
Low/High	357	4,190	66	15.75	0.78	(0.55, 1.11)
High/Low	405	4,641	69	14.87	0.73	(0.51, 1.03)
High/High	628	7,334	89	12.14	0.58	(0.42, 0.82)
Activity[c]/Legumes, Soy, Nuts, Seeds[d]						
Low/Low	483	5670	95	16.75	1.00	—
Low/High	151	1772	31	17.50	1.04	(0.69, 1.58)
High/Low	816	9460	132	13.95	0.76	(0.59, 1.00)
High/High	217	2515	26	10.34	0.65	(0.42, 1.01)
Activity[c]/All animal protein foods[d]						
Low/Low	303	3563	69	19.37	1.00	—
Low/High	331	3879	57	14.69	0.71	(0.50, 1.01)
High/Low	476	5492	69	12.56	0.68	(0.41, 0.82)
High/High	557	6483	89	13.73	0.65	(0.47, 0.89)

Notes: CI = Confidence Intervals; HR = Hazards Ratio; py = person-years.
[a]See Table 2 footnote. [b]See Table 2 footnote. [c,d]See Table 3 footnote.

subject to potential confounding than are randomized clinical trials. The BIA equation used in this study has been shown to provide valid estimates of SMM in both younger and older healthy adults; however, this method is also subject to greater error (eg, from issues of hydration) than is DXA. Another specific study limitation resulted from the inability to detect change in functional status by sex since insufficient numbers of men in particular reported functional decline over follow-up. The study is also limited by small intakes of plant protein foods (nuts, seeds, soy, legumes). Dietary intakes were self-reported and as such are subject to misreporting of intake of certain foods such as red meat. If these protein-source foods are in fact beneficial and intake was under-reported, the effect on the results would be an attenuation of the true protective effect of high protein-source food intake. Physical activity in this study is also self-reported and thus subject to both differential and non-differential error. Both types of error in this case would likely bias the effects toward the null.

This study makes an important contribution to the understanding of the role of high-protein foods, particularly foods from animal sources (including red meat, poultry, fish, and dairy) and a physically active lifestyle in the preservation of muscle mass and functional independence.

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Conflict of Interest

Authors report no conflict of interest.

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