Amount Rather than Animal vs Plant Protein Intake Is Associated with Skeletal Muscle Mass in Community-Dwelling Middle-Aged and Older Chinese Adults: Results from the Guangzhou Nutrition and Health Study

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ARTICLE INFORMATION

Article history:
Submitted 26 July 2018
Accepted 11 March 2019
Available online 9 May 2019

Keywords:
Skeletal muscle mass
Sarcopenia
Dietary protein
Animal protein
Plant protein

https://doi.org/10.1016/j.jand.2019.03.010

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ABSTRACT

Background Current literature does not indicate if the amount and animal vs plant protein are equally important in the prevention of muscle loss in middle-aged and older Chinese adults.

Objective The aim of the study was to examine the associations between amount or animal vs plant protein and skeletal muscle mass in Chinese adults aged 40 to 80 years.

Design A cross-sectional analysis of a prospective, community-based cohort was performed.

Participants/setting Participants included 1,044 men and 2,169 women aged 40 to 80 years from the Guangzhou Nutrition and Health Study 2011-2013 with body composition measurements by dual-energy x-ray absorptiometry.

Main outcome measure The skeletal muscle index (SMI) was defined as appendicular skeletal muscle mass divided by body weight. Participants in the lowest quartile of the sex-specific SMI were considered to have low muscle mass (LMM).

Statistical analysis Analyses of covariance were performed to estimate the SMI across quintiles of relative dietary intake of total, animal, and plant protein and the ratio of animal-to-plant protein. Logistic regression models were applied to assess the associations between quintiles of protein intake and LMM.

Results The SMI increased significantly across quintiles of relative dietary intake of total, animal, and plant protein (all P trends<0.001). Odds ratios (95% CIs) for LMM among participants in the highest (vs lowest) quintile were 0.3 (0.2, 0.4) for total protein, 0.3 (0.2, 0.5) for animal protein, and 0.4 (0.3, 0.7) for plant protein, respectively (all P trends<0.001). However, the ratio of animal-to-plant protein was not associated with either the SMI or the presence of LMM.

Conclusion Higher dietary intakes of total, animal, and plant protein, regardless of the ratio of animal-to-plant protein, are associated with greater skeletal muscle mass in community-dwelling middle-aged and older Chinese adults with a mean protein intake above the current recommendation for protein of 0.8 g/kg per day.
J Acad Nutr Diet. 2019;119(9):1501-1510.

AGING IS ACCOMPANIED BY A PROGRESSIVE DECLINE in skeletal muscle mass, which in severe cases may result in decreased muscle strength and impaired physical performance (ie, sarcopenia).[1] Low muscle mass (LMM) is strongly linked with fall, fracture, and frailty, which may lead to a loss of mobility and independence.[2-4] Multiple factors are involved in the process of muscle mass loss,[5] and of these, nutrition, especially protein intake, is one of the most important and modifiable factors.[6,7]

Intake and bioavailability of dietary protein appear to decrease with age.[5] An inadequate supply of protein disturbs not only muscle protein metabolism but also skeletal muscle transcription, accelerating muscle mass loss in older adults.[8,9] Therefore, increasing protein intake is considered to be a promising approach to protect against age-related loss of muscle mass through stimulating muscle protein anabolism or suppressing muscle protein degradation.[10,11] However, previous epidemiological studies have produced conflicting results. Higher protein intake was associated with greater muscle mass and less decline in muscle mass in most observational studies[12-16] but not all.[17] In addition, evidence from randomized clinical trials showed either beneficial or no effect of protein supplementation on preserving muscle mass in older adults.[18-21]

Animal and plant protein may have a different effect on muscle health. Dietary protein from different food sources may differ in their protein content, amino acid composition, and protein digestibility.[22] Animal foods are the primary source of high-quality protein.[23] Observational studies have revealed that higher animal protein intake is associated with greater muscle mass and less muscle loss in older Americans and Europeans.[15,24,25] In contrast to the aforementioned studies, Chan and colleagues[26] found that vegetable protein intake but not animal protein intake was associated with reduced muscle loss in community-dwelling older Chinese adults in Hong Kong. Similarly, lower intakes of total and vegetable protein have been reported to be associated with a higher likelihood of LMM in community-dwelling older Chinese adults in Taiwan.[13]

Skeletal muscle mass declines by approximately 0.5% to 1.0% per year beginning at approximately 40 years of age,[5,27] but few population-based studies on the topic of dietary protein and skeletal muscle mass have included middle-aged adults.[24] In addition, few studies have been conducted among adults in mainland China with diets and lifestyles that are different from those of Western populations.[28] In consideration of these points, the primary objective of the present study was to investigate whether amount and animal vs plant protein were associated with skeletal muscle mass in community-dwelling middle-aged and older adults living in mainland China.

RESEARCH SNAPSHOT

Research Question: Are amount and animal vs plant protein intake associated with skeletal muscle mass in Chinese adults aged 40 to 80 years?

Key Findings: The cross-sectional analysis of the Guangzhou Nutrition and Health Study 2011-2013 shows that higher dietary intakes of total, animal, and plant protein, regardless of the ratio of animal-to-plant protein, are significantly associated with greater skeletal muscle mass in a Chinese population who has met the recommendation for protein. The highest protein intake quintiles, compared with the lowest quintiles, are protective against low muscle mass. The trend also indicates that protection increases as the quintiles increase.

MATERIALS AND METHODS

Participants

The current study is a cross-sectional study using data from the Guangzhou Nutrition and Health Study (GNHS) 2011-2013. The GNHS, established in 2008, is an ongoing, community-based prospective cohort study designed to investigate the nutritional factors associated with the development of cardiometabolic diseases and osteoporosis in Chinese adults. The recruitment and enrollment procedures of the GNHS have been previously described in detail.[29] Briefly, 3,169 apparently healthy adults aged 40 to 80 years were enrolled at baseline between July 2008 and June 2010, 2,520 of whom participated in the first follow-up study between April 2011 and March 2013. Moreover, another 879 participants were newly enrolled in the GNHS between March 2013 and August 2013. In the cross-sectional analysis, a total of 3,399 (2,520 plus 879) participants who took part in the GNHS during 2011-2013 were assessed for eligibility. Face-to-face interviews were conducted by well-trained investigators to collect information on demographical characteristics, diet and lifestyles, and personal medical history with structured questionnaires. In the present study, 186 participants were excluded due to (1) missing dietary or body composition data; (2) extreme energy intake (the upper and lower 1% of sex-specific energy intake); and (3) serious disease, including malignancy, hepatic cirrhosis, and renal insufficiency. Ultimately, 3,213 participants, comprising 1,044 (32.5%) men and 2,169 (67.5%) women, were included for analysis (Figure). Study participation was voluntary and all participants provided written informed consent. The GNHS was approved by the Ethics Committee of the School of Public Health at Sun Yat-sen University and was conducted according to the Declaration of Helsinki.

Dietary Assessment

A validated 79-item semiquantitative, interviewer-administered, and paper-based food frequency questionnaire (FFQ) was used to collect dietary information.[30] For each food item, frequency (ie, never, per year, per month, per week, or per day) and amount of food consumption (servings or portion sizes) were recorded according to the choices of the participants during the previous year. Photographs of generic foods and portion sizes were provided to help participants estimate their usual food consumption. Daily dietary intakes of nutrients and energy were calculated according to the China Food Composition Table, 2009.[31] Sources of animal protein included red meat, poultry, fish, shellfish, mollusks, eggs, dairy products, processed meat, and animal giblets, and sources of plant protein included cereals, soybeans, other beans, nuts, vegetables, fruits, and fungi. Relative protein intake was expressed as protein intake per kilogram of body weight per day. The ratio of animal-to-plant protein was calculated as animal protein intake divided by plant protein intake.

Body Composition

The whole-body composition was measured by dual-energy x-ray absorptiometry (DXA) (Discovery W; Hologic Inc). The DXA scanner was calibrated daily. Lean mass, fat mass, and bone mass of the whole body, arms, and legs were analyzed using the Hologic Discovery software version 3.2.[32] Muscle mass was calculated by subtracting bone mass from lean mass. Appendicular skeletal muscle mass included muscle mass of the arms and legs. The intraclass correlation coefficient for the test-retest reliability of the appendicular skeletal muscle mass measurement in 27 participants, after repositioning (measurements were repeated two times for each participant), was 0.98 (95% CI: 0.96, 0.99). The test-retest reliability is excellent. Intraclass correlation coefficient estimates and their 95% CIs were calculated using SPSS statistical package version 20 (SPSS Inc)[33] based on a

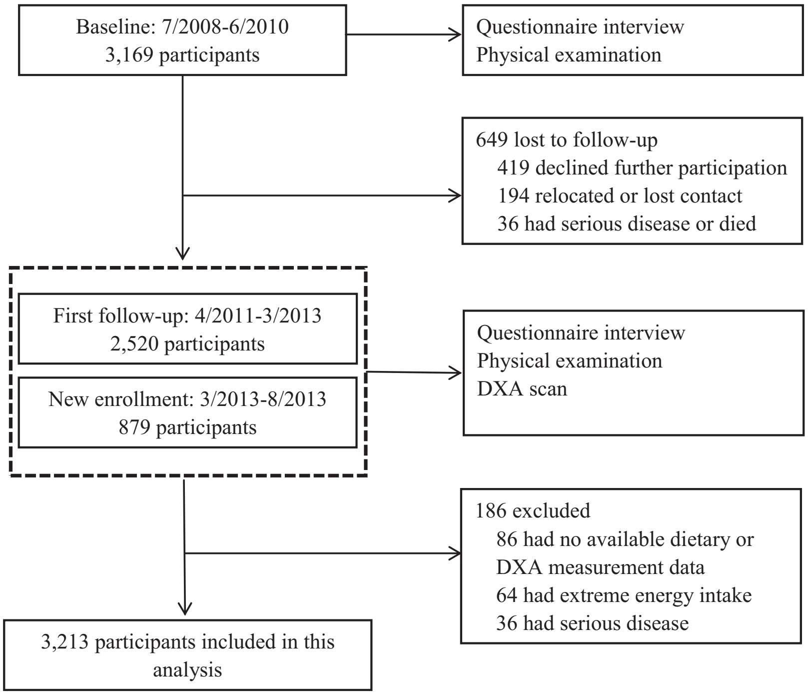

Figure. Flowchart of selection of participants from the Guangzhou Nutrition and Health Study for the cross-sectional analysis of dietary protein intake and skeletal muscle mass. DXA=dual-energy x-ray absorptiometry.

single-measurement, absolute-agreement, two-way mixed-effects model. The skeletal muscle index (SMI), expressed as a percentage, was defined as appendicular skeletal muscle mass divided by body weight.[3,34,35] Participants in the sex-specific lowest quartile of the SMI were considered to have LMM.[36]

Variables

In the present study, the SMI and LMM were used as dependent variables, and relative dietary intake of total, animal, and plant protein, and the ratio of animal-to-plant protein, evaluated both as continuous and categorical variables by using quintiles, were the independent variables of interest. For demographic and general lifestyle characteristics, an interviewer-administered questionnaire was used to collect information on age, sex (men or women), education level (secondary school or below; high school; college or above), smoker (yes or no), alcohol drinker (yes or no), tea drinker (yes or no), and use of multivitamins (yes or no) for men and women, as well as use of oral estrogen (yes or no) and years since menopause for women only. Smokers were defined as participants who smoked at least five packs of cigarettes in the past year. Alcohol drinkers were defined as participants who drank alcohol at least once a week for 6 consecutive months. Tea drinkers were defined as participants who drank tea at least twice a week. Multivitamin use was defined as taking vitamin tablets more than 30 times over the past year. Oral estrogen use was defined as taking estrogen during or after menopause. Years since menopause were calculated as the time between the date of investigation and the date of the last menstruation among women whose menstruation had permanently ceased for natural or surgical reasons (ie, hysterectomy or bilateral oophorectomy). Daily activity was calculated by summing the products of time spent on a variety of activities (eg, work, transportation, housework, physical exercise, and leisure sedentary activity) times the mean metabolic equivalent for that activity.[37] Height was measured barefoot to the nearest 0.1 cm using a Kedao TZCS-4 wall-mounted stadiometer, and weight was measured with light clothing to the nearest 0.1 kg using a Tanita TBF-418B Body Composition Analyzer. Body mass index (BMI) was calculated as body weight (in kilograms) divided by the square of height (in meters). Waist circumference was measured to the nearest 0.1 cm using plastic measuring tapes (Deli) calibrated weekly to a standard tape with the participants standing with feet shoulder width apart and back straight and breathing out normally. All interviewers were trained using standardized protocols to minimize interrater measurement bias.

Statistical Analysis

The interactions between protein intake and sex (men or women) or age (<60 years or ≥60 years) on skeletal muscle mass were not significant (all P>0.15). Thus, all analyses were carried out in the total population. Normality and skewness of continuous variables were assessed by using the Kolmogorov-Smirnov tests. Means and standard deviations (SDs) were reported for normally distributed continuous variables. Categorical variables were presented as numbers and percentages. Analysis of variance (for continuous variables) or Pearson's χ^2 tests (for categorical variables) was used to compare sociodemographic characteristics, lifestyles, and dietary protein intakes. Analysis of covariance was applied to estimate the SMI across quintiles of protein intake. Model 1 was adjusted for age and sex. Model 2 was further adjusted for height, waist circumference, energy intake, daily activity, education level, smoking status, alcohol drinking, tea drinking, and multivitamin use. Models with animal protein included plant protein. Models with plant protein included animal protein. Logistic regression models were used to examine associations between protein intake and the presence of LMM, adjusted for the same covariates as the analysis of covariance. Odds ratios and 95% CIs were calculated according to quintiles of protein intake, with the lowest quintile as the reference group. In women, including years since menopause and estrogen use in the multivariable models only marginally changed the relations and were removed from the models. Tests for linear trend were based on median values of different quintiles of protein intake. All statistical analyses were performed using SPSS statistical package version 20.[33] A two-tailed value of $P<0.05$ was considered indicative of statistical significance.

RESULTS

Participant Characteristics

Mean (SD) age of the study population was 60.7 (6.0) years with a range of 40.5 to 80.0 years, and 67.5% were women. Mean (SD) BMI was 23.6 (3.1). On average, the participants consumed 78.1 (24.1) g protein daily [82.5 (25.6) g/day in men and 75.9 (23.0) g/day in women], corresponding to a mean relative total protein intake of 1.34 (0.45) g/kg per day [1.27 (0.43) g/kg per day in men and 1.38 (0.46) g/kg per day in women]. Overall, 94.3% of the sample met the Recommended Daily Allowance (RDA) for dietary protein of 0.8 g/kg per day,[38] and 61.8% reached the intake level of 1.2 g/kg per day. The participants consumed a 1.2:1 ratio of animal-to-plant protein. Red meat, cereals, vegetables, fish, and dairy products were the top five protein-providing food sources and together contributed more than 70% of the total protein intake in the study population (Table 1).

Baseline characteristics of the 3,213 participants across quintiles of relative total protein intake are shown in Table 2. Participants in higher quintiles of relative total protein intake were younger; had lower weight, height, BMI, waist circumference, and years since menopause; had higher daily activity level and dietary intake of energy, animal protein, and plant protein; and had higher ratio of animal-to-plant protein. Higher quintile participants were less likely to be male participants and smokers, and were more likely to be multivitamin users. However, there were no significant differences in alcohol and tea drinking in the total sample and in estrogen use in women across the quintiles.

Association of Dietary Protein Intake with the SMI

The adjusted mean (SD) SMI by quintiles of protein intake in the study population are shown in Table 3. The SMI increased significantly across quintiles of relative intakes of total, animal, and plant protein after adjusting for age and sex in Model 1 (all P trends<0.001). The associations remained significant after further adjustment for other covariates in Model 2 (all P trends<0.001). Compared with participants in the lowest quintiles of total, animal, and plant protein intake, participants in the highest quintiles had a higher mean SMI of 1%. However, there was no significant difference in the SMI across quintiles of the ratio of animal-to-plant protein in either of the models.

Table 1. Top five food sources of total protein, animal protein, and plant protein among community-dwelling middle-aged and older Chinese adults from the Guangzhou Nutrition and Health Study 2011-2013

Nutrient	Food sources	Percentage contribution to total intake (%)
Total protein	Red meat	26.2
	Cereals	21.1
	Vegetables	9.7
	Fish	9.2
	Dairy products	5.3
	Subtotal	71.6
Animal protein	Red meat	49.1
	Fish	17.2
	Dairy products	10.0
	Poultry	9.8
	Eggs	9.6
	Subtotal	95.7
Plant protein	Cereals	45.3
	Vegetables	20.9
	Soybeans	9.2
	Nuts	8.6
	Other beans	3.3
	Subtotal	87.3

Association of Dietary Protein Intake with the Presence of LMM

The associations between LMM and protein intake are shown in Table 4. Higher relative intakes of total, animal, and plant protein were associated with a lower likelihood of LMM in both Model 1 and Model 2. The odds ratio (95% CIs) for LMM among participants in the highest (vs lowest) quintile was 0.3 (0.2, 0.4) for total protein, 0.3 (0.2, 0.5) for animal protein, and 0.4 (0.3, 0.7) for plant protein, respectively (Model 2, all P trends<0.001). The participants in the highest quintiles of total, animal, and plant protein intake had a 60% to 70% lower likelihood of LMM than those in the lowest quintiles, indicating protection of higher protein intake against LMM. However, no association was found between the ratio of animal-to-plant protein and the presence of LMM.

DISCUSSION

The present study examined the cross-sectional association of amount and animal vs plant protein intake with the SMI and the presence of LMM in community-dwelling middle-aged and older adults in mainland China. In the study population consuming almost a 1:1 ratio of animal-to-plant protein with a mean protein intake above the current RDA for protein of 0.8 g/kg per day, higher dietary intakes of total, animal, and plant protein were associated with a significantly

Table 2. Descriptive characteristics of 3,213 middle-aged and older Chinese adults who participated in the Guangzhou Nutrition and Health Study 2011-2013 by quintiles of relative total protein intake

	Quintiles of Relative Total Protein Intake					
Characteristics	**1 (n=642)**	**2 (n=643)**	**3 (n=643)**	**4 (n=643)**	**5 (n=642)**	***P* for trend**[a]
	←——— *range* ———→					
Relative total protein intake, g/kg per day	≤0.96	0.97-1.16	1.17-1.38	1.39-1.67	≥1.68	—
	←——— *mean±SD*[b] ———→					
Age, y	61.2±6.7	61.2±6.3	60.5±5.7	60.4±5.5	60.1±5.6	<0.001
Weight, kg	65.5±10.0	61.7±9.2	58.8±8.4	57.6±9.1	53.7±8.4	<0.001
Height, cm	160.5±8.0	159.4±7.5	158.2±7.4	158.2±7.3	156.6±7.3	<0.001
BMI[c]	25.4±3.2	24.2±2.9	23.5±2.7	23.0±2.8	21.9±2.7	<0.001
Waist circumference, cm	89.7±8.5	86.9±8.2	84.5±7.5	83.5±8.3	80.1±8.0	<0.001
Daily activity, MET[d]**×h/day**[e]	25.0±5.8	25.4±6.0	25.8±6.3	25.4±6.1	26.6±6.6	<0.001
Years since menopause[f]	10.4±6.7	10.9±6.9	9.6±6.1	9.6±6.1	9.7±6.0	0.02
Dietary intake						
Energy, kcal/day	1,362±263	1,593±294	1,767±308	1,982±366	2,341±480	<0.001
Total protein, g/day	52.7±9.4	65.9±10.3	74.9±11.3	87.7±14.2	109.1±22.7	<0.001
Animal protein, g/day	25.2±7.4	33.9±8.7	39.2±9.3	47.9±12.0	62.1±18.3	<0.001
Plant protein, g/day	27.5±6.5	32.1±7.9	35.6±8.5	39.8±10.2	47.0±15.6	<0.001
Relative total protein, g/kg/day	0.81±0.12	1.07±0.06	1.27±0.06	1.52±0.08	2.04±0.35	<0.001
Relative animal protein, g/kg/day	0.39±0.10	0.55±0.11	0.67±0.12	0.83±0.15	1.16±0.30	<0.001
Relative plant protein, g/kg/day	0.42±0.09	0.52±0.11	0.61±0.12	0.69±0.15	0.88±0.28	<0.001
Ratio of animal to plant protein	0.98±0.42	1.14±0.45	1.18±0.42	1.29±0.47	1.45±0.59	<0.001
	←——— *n (%)* ———→					
Men	256 (39.9)	247 (38.4)	191 (29.7)	186 (28.9)	164 (25.5)	<0.001
Educational level						0.65
Secondary school or below	213 (33.2)	195 (30.3)	174 (27.1)	170 (26.4)	182 (28.3)	
High school	262 (40.8)	270 (42.0)	298 (46.3)	326 (50.7)	309 (48.1)	
College or above	167 (26.0)	178 (27.7)	171 (26.6)	147 (22.9)	151 (23.5)	
Smoker	104 (16.2)	93 (14.5)	72 (11.2)	66 (10.3)	68 (10.6)	<0.001
Alcohol drinker	61 (9.5)	53 (8.2)	47 (7.3)	48 (7.5)	56 (8.7)	0.50
Tea drinker	390 (60.7)	356 (55.4)	356 (55.4)	351 (54.6)	362 (56.4)	0.13
Multivitamin use	98 (15.3)	112 (17.4)	115 (17.9)	143 (22.2)	132 (20.6)	0.002
Estrogen use[f]	26 (6.7)	21 (5.3)	32 (7.1)	33 (7.2)	26 (5.4)	0.67

[a]Tests for linear trend for continuous variables were based on median values of different quintiles of relative protein intake using linear regression models. Tests for linear trend for categorical variables were tested by Jonckheere-Terpstra test.
[b]SD=standard deviation.
[c]BMI=body mass index, calculated as kilograms per square meter.
[d]MET=metabolic equivalent tasks.
[e]Including work, transportation, housework, physical exercise, and leisure sedentary activity.
[f]Women only.

higher mean SMI and a lower likelihood of LMM. However, the ratio of animal-to-plant protein was not associated with either the SMI or the presence of LMM.

The total protein intake in the study population is comparable to or higher than that previously reported among Western populations (78 g/day vs 68 to 93 g/day),[24,25,39,40] and the relative amount of total protein (1.34 g/kg per day vs 0.8 to 1.2 g/kg per day) is likely higher due to the lower BMI (23.6 vs 25 to 30) of the study population in comparison to US and European cohorts.[25,39] In the current study, compared with participants in the lowest quintile whose protein intake (0.81 g/kg per day) is at the current RDA for

Table 3. The skeletal muscle index by quintiles of protein intake in community-dwelling middle-aged and older Chinese adults from the Guangzhou Nutrition and Health Study 2011-2013

Skeletal muscle index	Quintiles of Protein Intake 1 (n=642)	2 (n=643)	3 (n=643)	4 (n=643)	5 (n=642)	*P* for trend[a]
	←——— *g/kg/day* ———→					
Relative total protein	≤0.96	0.97-1.16	1.17-1.38	1.39-1.67	≥1.68	
	←——— *adjusted mean (SE)*[b] ———→					
Model 1[c]	26.7 (0.1)	27.2 (0.1)***	27.4 (0.1)***	27.6 (0.1)***	28.3 (0.1)***	<0.001
Model 2[d]	26.9 (0.1)	27.3 (0.1)**	27.3 (0.1)**	27.6 (0.1)***	28.1 (0.1)***	<0.001
	←——— *g/kg/day* ———→					
Relative animal protein	≤0.45	0.46-0.59	0.60-0.73	0.74-0.94	≥0.95	
	←——— *adjusted mean (SE)* ———→					
Model 1[c]	26.8 (0.1)	27.3 (0.1)***	27.4 (0.1)***	27.6 (0.1)***	28.1 (0.1)***	<0.001
Model 2[de]	27.0 (0.1)	27.4 (0.1)***	27.4 (0.1)***	27.5 (0.1)***	27.9 (0.1)***	<0.001
	←——— *g/kg/day* ———→					
Relative plant protein	≤0.44	0.45-0.54	0.55-0.63	0.64-0.77	≥0.78	
	←——— *adjusted mean (SE)* ———→					
Model 1[c]	26.7 (0.1)	27.2 (0.1)***	27.4 (0.1)***	27.8 (0.1)***	28.1 (0.1)***	<0.001
Model 2[df]	27.0 (0.1)	27.3 (0.1)**	27.3 (0.1)*	27.7 (0.1)***	28.0 (0.1)***	<0.001
	←——— *ratio* ———→					
Ratio of animal-to-plant protein	≤0.79	0.80-1.01	1.02-1.25	1.26-1.57	≥1.58	
	←——— *adjusted mean (SE)* ———→					
Model 1[c]	27.4 (0.1)	27.5 (0.1)	27.3 (0.1)	27.6 (0.1)	27.5 (0.1)	0.14
Model 2[d]	27.4 (0.1)	27.5 (0.1)	27.3 (0.1)	27.5 (0.1)	27.5 (0.1)	0.33

[a]Tests for linear trend were based on median values of different quintiles of relative protein intake using multiple linear regression models.
[b]Analysis of covariance was used.
[c]Adjusted for age and sex.
[d]Adjusted for variables in Model 1 plus height, waist circumference, energy intake, daily activity, education level, smoking status, alcohol drinking, tea drinking, and multivitamin use.
[e]Models for animal protein were also adjusted for relative plant protein intake.
[f]Models for plant protein were also adjusted for relative animal protein intake.
*$P<0.05$ compared with quintile 1.
**$P<0.01$ compared with quintile 1.
***$P<0.001$compared with quintile 1.

protein of 0.8 g/kg per day,[38] participants in the higher quintiles had a significantly higher mean SMI and a lower likelihood of LMM. The higher SMI and lower LMM suggest that protein intake above the RDA may be beneficial in improving muscle health for community-dwelling middle-aged and older adults.

The conclusions of the current study were consistent with those of previous large population-based studies. A cross-sectional study using data from the Women's Health Initiative found that higher dietary protein intake was associated with a higher percentage of lean mass in postmenopausal women (aged 50 to 79 years). Women in the highest quintile of dietary protein intake (1.35 g/kg per day) had 6.5% (95% CI: 6.1%, 6.9%) more lean mass than women in the lowest quintile (0.79 g/kg per day).[39] Cross-sectional data from the Framingham Third Generation Study also showed that participants in the lowest quartile of total dietary protein intake had significantly lower appendicular lean mass compared with those in the upper quartile among 2,986 men and women aged 19 to 72 years.[40] Similarly, the prospective Health, Aging, and Body Composition Study found that participants (aged 70 to 79 years) in the highest quintile of total dietary protein intake (1.1 g/kg per day) lost approximately 40% less lean muscle mass and appendicular lean mass than those in the lowest quintile (0.7 g/kg per day) during a 3-year follow-up.[41] The Framingham Offspring Study further found that higher consumption of protein-rich foods (eg, red meat, poultry, fish, and dairy and soy, nuts, seeds, and legumes) was associated with a higher SMI over 9 years, among men and women with a median age of 52.0 years.[42] It should be noted that the range of relative total protein intake is also quite wide in the present study such that there is a 0.7 g/kg per day difference between the cutoff for the lower and upper quintile—almost a doubling of the current RDA for protein between the upper and lower quintile. Thus, the odds ratios for the upper quintile (vs lower quintile) are relatively low but

Table 4. Odds ratios (95% CIs)[a] for LMM[b] by quintiles of protein intake in community-dwelling middle-aged and older Chinese adults from the Guangzhou Nutrition and Health Study 2011-2013

LMM	Quintiles of Protein Intake					Per 0.1 unit[c]	*P* for trend[d]
	1 (n=642)	2 (n=643)	3 (n=643)	4 (n=643)	5 (n=642)		
	←——— *g/kg/day* ———→						
Relative total protein	≤0.96	0.97-1.16	1.17-1.38	1.39-1.67	≥1.68	—	—
	←——— *n* ———→						
Number of participants with LMM	220	186	163	144	91	804	—
	←——— *odds ratio (95% CI)* ———→						
Model 1[e]	1.0	0.8 (0.6, 0.99)*	0.7 (0.5, 0.8)**	0.6 (0.4, 0.7)***	0.3 (0.2, 0.4)***	0.9 (0.89, 0.9)***	<0.001
Model 2[f]	1.0	0.8 (0.6, 0.997)*	0.7 (0.5, 0.9)*	0.5 (0.3, 0.7)***	0.3 (0.2, 0.4)***	0.9 (0.8, 0.9)***	<0.001
	←——— *g/kg/day* ———→						
Relative animal protein	≤0.45	0.46-0.59	0.60-0.73	0.74-0.94	≥0.95	—	—
	←——— *n* ———→						
Number of participants with LMM	224	166	158	163	93	804	—
	←——— *odds ratio (95% CI)* ———→						
Model 1[e]	1.0	0.6 (0.5, 0.8)***	0.6 (0.5, 0.8)***	0.6 (0.5, 0.8)***	0.3 (0.2, 0.4)***	0.9 (0.87, 0.9)***	<0.001
Model 2[fg]	1.0	0.7 (0.5, 0.9)**	0.6 (0.4, 0.8)***	0.7 (0.5, 0.9)*	0.3 (0.2, 0.5)***	0.9 (0.85, 0.9)***	<0.001
	←——— *g/kg/day* ———→						
Relative plant protein	≤0.44	0.45-0.54	0.55-0.63	0.64-0.77	≥0.78	—	—
	←——— *n* ———→						
Number of participants with LMM	219	181	160	131	113	804	—
	←——— *odds ratio (95% CI)* ———→						
Model 1[e]	1.0	0.7 (0.6, 0.9)*	0.6 (0.5, 0.8)***	0.5 (0.4, 0.6)***	0.4 (0.3, 0.5)***	0.9 (0.8, 0.9)***	<0.001
Model 2[fh]	1.0	0.8 (0.6, 1.1)	0.8 (0.6, 1.03)	0.6 (0.4, 0.8)**	0.4 (0.3, 0.7)***	0.9 (0.8, 0.9)***	<0.001
	←——— *ratio* ———→						
Ratio of animal-to-plant protein	≤0.79	0.80-1.01	1.02-1.25	1.26-1.57	≥1.58	—	—
	←——— *n* ———→						
Number of participants with LMM	181	160	169	146	148	804	—
	←——— *odds ratio (95% CI)* ———→						
Model 1[e]	1.0	0.9 (0.7, 1.1)	0.9 (0.7, 1.2)	0.8 (0.6, 1.01)	0.8 (0.6, 1.03)	0.99 (0.97, 1.002)	0.07
Model 2[f]	1.0	0.9 (0.7, 1.1)	0.9 (0.7, 1.2)	0.8 (0.6, 1.1)	0.8 (0.6, 1.1)	0.98 (0.97, 1.001)	0.12

[a]Logistic regression models were performed.
[b]LMM=low muscle mass, defined as the skeletal muscle index values in the lowest quartile among the participants.
[c]Logistic regression test for per increase in 0.1 unit of every protein intake.
[d]Tests for linear trend were based on median values of different quintiles of relative protein intake.
[e]Adjusted for age and sex.
[f]Adjusted for variables in Model 1 plus height, waist circumference, energy intake, daily activity, education level, smoking status, alcohol drinking, tea drinking, and multivitamin use.
[g]Models for animal protein were also adjusted for relative plant protein intake.
[h]Models for plant protein were also adjusted for relative animal protein intake.
*$P<0.05$ compared with quintile 1.
**$P<0.01$ compared with quintile 1.
***$P<0.001$compared with quintile 1.

likely driven by the large difference in protein intake (Table 4).

The results from epidemiological studies on the relationship between animal vs plant protein intake and muscle mass remain inconsistent. Sahni and colleagues[24] found that leg lean mass was higher in participants in the highest quartile of animal protein intake compared with those in the lowest quartile of intake in both men and women (55 g/day in men and 53 g/day in women), but no association was found between plant protein intake (24 g/day in men and 23 g/day in women) and leg lean mass in either sex, according to a cross-sectional study from the Framingham Offspring Cohort. Houston and colleagues[41] further found that higher animal protein intake (27.0 to 60.7 g/day across quintiles), but not plant protein intake (26.0 to 30.3 g/day across quintiles), was associated with greater lean mass and appendicular lean mass. However, the GNHS showed that higher dietary intakes of both animal and plant protein were associated with a higher SMI and a lower likelihood of LMM. The inconsistent findings of plant protein intake and muscle mass may be due to the different proportion and amount of plant protein in diets. Of note, participants in the GNHS consume almost a 1:1 ratio of animal-to-plant protein and have a much higher and wider plant protein intake (27.5 to 47.0 g/day across quintiles) than Americans and Europeans.[24,25,41] Previous studies have not been able to discover a significant association between plant protein intake and muscle mass in Western populations consuming a much lower plant protein intake with amounts fluctuating in a relatively narrow range.[41] In accordance with the current study, a cross-sectional study from Taiwan reported an association between higher vegetable protein density and a lower likelihood of LMM,[13] and a prospective cohort study from Hong Kong showed an association between higher vegetable protein intake and reduced muscle loss,[26] both of which were conducted in community-dwelling older Chinese populations consuming almost a 1:1 ratio of animal-to-plant protein. However, neither total nor animal protein intake was associated with subsequent decline in muscle mass in the Hong Kong study.[26] A new aspect of the current study is the finding that the ratio of animal-to-plant protein may not be associated with the SMI or the presence of LMM in the GNHS, suggesting that the intake level of dietary protein may be more important than the animal vs plant protein for preserving skeletal muscle mass. Similarly, in the Framingham Third Generation Study, appendicular lean mass increased with dietary protein intake, but no significant differences in appendicular lean mass were observed across different protein food clusters (ie, fast food, full-fat dairy, fish, red meat, chicken, low-fat milk, legumes) after adjusting for other known covariates,[40] indicating that dietary protein food patterns do not further clarify the beneficial effects on muscle mass.

The results of the current study may be of public health significance. Increasing dietary protein intake, regardless of animal or plant protein, may be protective against skeletal muscle loss, even among middle-aged and older adults who have met the current recommendation for protein of 0.8 g/kg per day.

Age-related loss of muscle mass is attributed to a disruption in the regulation of muscle protein turnover, leading to an imbalance between muscle protein synthesis and degradation.[43] Dietary protein directly stimulates muscle protein synthesis and suppresses protein degradation by absorbed amino acids, especially essential amino acids (eg, leucine).[44,45] Essential amino acids can regulate the mammalian target of rapamycin complex 1 (mTORC1) signaling pathway through phosphorylation of ribosomal protein S6 kinase 1 (S6K1) signaling and 4E binding protein 1 (4EBP1) signaling pathways to enhance muscle protein synthesis.[46] In addition, essential amino acids also play a role as building blocks for muscle protein synthesis. Currently available scientific evidence shows that animal protein, which is rich in essential amino acids and exhibits high digestibility, may be better for muscle protein synthesis than plant protein.[47] However, the lower anabolic capacity of plant protein can be compensated for by increasing intake or combining various plant proteins to provide a more favorable amino acid profile,[48] just like the variety of plant protein consumed (from cereals, vegetables, soybeans, nuts, and other beans) in the current study (Table 1). In addition, both animal protein and plant protein from soybeans, peanuts, and lentils are rich in leucine, the most potent amino acid for stimulating muscle protein synthesis.[49]

There are several strengths to the study. First, the present study was conducted in a large community-based cohort of adult men and women with a wide range of age (40 to 80 years). Previous similar studies were largely carried out among older adults >60 years, although the decline in skeletal muscle mass begins at approximately 40 years of age. Second, body composition was measured by DXA, the gold standard for body composition research. Third, the GNHS examined the association between animal vs plant protein intake and muscle mass in a population with almost a 1:1 ratio of animal-to-plant protein. In addition, to our knowledge, it was novel to use the ratio of animal-to-plant protein. And last, the detailed information was collected from participants and was used for important covariates in the analyses.

Nevertheless, several limitations should be acknowledged. First, the cross-sectional design cannot infer causality. Second, recall bias and misreporting of food consumption are possible because self-reported FFQ was administered.[50] However, photographs of generic foods and portion sizes were provided to help participants estimate usual food consumption. Third, the FFQ used in the GNHS was only validated in women but not in men. Fourth, the daily activity questionnaire used in the GNHS was also not validated. Finally, the participants in the GNHS were apparently healthy, ambulant volunteers who were able to walk or take public transport to the study site, so they may be more health conscious and have better physical performance than those who are older, frailer, and less physically active. Therefore, caution should be taken when generalizing the results to the general population.

CONCLUSIONS

In conclusion, higher relative intakes of total, animal, and plant protein, but not the ratio of animal-to-plant protein, are associated with greater skeletal muscle mass in community-dwelling adults 40 to 80 years of age living in mainland China with a mean relative total protein intake of 1.34 g/kg per day. These findings suggest that dietary protein intake level may be more important than animal vs plant protein for preventing sarcopenia. Increasing dietary protein intake, regardless of animal or plant protein, may be beneficial for preserving skeletal muscle mass even among a population who has met the current RDA for protein of 0.8 g/kg per day. Further studies, especially randomized controlled clinical trials, are needed to verify the causal association between amount or animal vs plant protein intake and skeletal muscle mass in community-dwelling middle-aged and older adults.

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STATEMENT OF POTENTIAL CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

FUNDING/SUPPORT

This study was jointly supported by the National Natural Science Foundation of China (No. 81773415 and No. 81472966) and the Key Project of Science and Technology Program of Guangzhou, China (No. 201704020035). The funders had no role in the design, analysis, or writing of this article.

ACKNOWLEDGEMENTS

The authors thank all the people who participated in this study. This study was jointly supported by the National Natural Science Foundation of China (No. 81773415 and No. 81472966) and Key Project of Science and Technology Program of Guangzhou, China (No. 201704020035). The funders had no role in the design, analysis, or writing of this article.

AUTHOR CONTRIBUTIONS

H.-L. Zhu and Y.-M. Chen formulated the research question and designed the study; W.-J. Ma, S.-L. Wu, and C.-L. Li conducted the study; C.-Y. Li and A.-P. Fang analyzed the data; C.-Y. Li wrote the paper; H.-L. Zhu and A.-P. Fang coedited, revised and final reviewed the manuscript critically for important intellectual content. All the authors read and approved the final version of the manuscript.