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Association between plant protein intake and grip strength in Koreans aged 50 years or older: Korea National Health and Nutrition Examination Survey 2016–2018

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Conflict of Interest
The authors declare no potential conflicts of interests.

ABSTRACT

BACKGROUND/OBJECTIVES: We investigated the association of plant and animal protein intake with grip strength in Koreans aged ≥ 50 yrs.
SUBJECTS/METHODS: The data was collected from 3,610 men and 4,691 women (≥ 50 yrs) from the 2016–2018 Korea National Health and Nutrition Examination Survey. We calculated the total energy intake, and the intake of animal and plant protein and collected dietary data using 1-day 24-h dietary recalls. Low grip strength (LGS) was defined as the lowest quintile (men: up to 26.8 kg, women: up to 15.7 kg). The association of protein intake with grip strength was examined using Pearson's correlation and multiple linear regression analysis.
RESULTS: The results proved that participants with LGS had lower daily energy, protein and fat intake, and percent energy from protein than those with normal or high grip strength ($P < 0.0001$). Total energy intake, animal protein, and plant protein were positively associated with grip strength. A higher intake of total plant protein (*P* for trend = 0.004 for men, 0.05 for women) and legumes, nuts, and seeds (LNS) protein (*P* for trend = 0.01 for men, 0.02 for women) was significantly associated with a lower prevalence of LGS. However, non-LNS plant protein intake was not associated with LGS (*P* for trend = 0.10 for men, 0.15 for women). In women, a higher total animal protein intake was significantly associated with decreased LGS (*P* for trend = 0.03).
CONCLUSIONS: Higher total plant protein and LNS protein intake are negatively associated with LGS.

Keywords: Dietary proteins; sarcopenia; food; KNHANES; Koreans

Author Contributions
Conceptualization: Jun SH, Kim Y; Formal analysis: Jun SH, Lee JW, Shin WK; Investigation: Jun SH, Lee JW, Shin WK. Validation: Lee SY; Writing - original draft: Jun SH; Writing- review & editing: Lee JW, Shin WK, Lee SY, Kim Y.

INTRODUCTION

Sarcopenia is a serious health issue among older people that can lead to functional deterioration, physical disability, and increased mortality rates [1,2]. After 50 yrs, muscle strength declines by 1.5% per year, and the decrease accelerates to as much as 3% per year after 60 yrs [3]. Sarcopenia affects a significant percentage of older Koreans. According to a recent nationwide Korean cohort [4], approximately 21% of men and 14% of women aged > 70 yrs were diagnosed with sarcopenia. Sarcopenia has socioeconomic impacts such as increased healthcare costs, institutionalization, reduced workforce participation, increased caregiver burden, and decreased social participation [5]. Adverse outcomes of sarcopenia are directly associated with a decline in muscle strength rather than muscle mass [6,7]. Grip strength indicates the maximum strength drawn from the integrated contraction of the extrinsic and intrinsic hand muscles that induce bending of the hand joints [8]. Grip strength is a reliable surrogate measure of overall muscle strength and is highly correlated with upper limb strength [9], knee extension strength, and peak expiratory flow [4]. It is a simple and non-invasive method for assessing muscle strength and is often used as a screening tool for sarcopenia. Sarcopenia is a multifactorial process influenced by non-modifiable and potentially modifiable factors, including daily lifestyle factors and diet [10,11].

Dietary factors [12], physical activity, and resistance exercise are modifiable lifestyle factors that can minimize muscle mass decline [13]. Previous cohort studies have linked the increased risk of sarcopenia with inadequate protein intake [14,15]. Although animal proteins are considered high-quality proteins due to high quantities of all essential amino acids and greater bioavailability [16], animal protein intake tends to decrease with age for several reasons, such as impaired digestive ability, lack of appetite, and economic feasibility [17]. Plant-based proteins make up a more significant proportion of total protein consumption than animal-based proteins [18] in older people. Plant proteins are generally incomplete; that is, they lack one or more essential amino acids. Legumes, nuts, and seeds (LNS) protein refers to a category of plant-based proteins rich in essential amino acids and considered high-quality proteins. LNS protein are important sources of protein for people who do not consume sufficient amounts of animal-based proteins [19]. Recent studies have indicated that plant-based proteins may have a positive impact on muscle mass and strength [20-23]. However, previous studies have produced conflicting results [24], and the effects of animal- and plant-based proteins, and LNS protein on sarcopenia, have not been adequately assessed. The objective of this study was to explore the potential relationship between various dietary protein sources, as well as total animal and plant protein consumption, and the risk of low grip strength (LGS) in Korean adults aged 50 yrs or older, across different levels of total protein intake.

SUBJECTS AND METHODS

Study design and participants

This study used data from the 7th Korean National Health and Nutrition Examination Survey (KNHANES VII, 2016–2018). The KNHANES is an annual nationwide cross-sectional study carried out by the Korea Disease Control and Prevention Agency [25]. The KNHANES uses a multistage rolling sampling design stratified according to geographic location, sex, and age to represent the South Korean population. The survey included demographic, lifestyle, health status, and dietary intake data. Before participating in the study, all participants provided informed consent. KNHANES VII was approved by the Institutional Review Board of the Korea

Disease Control and Prevention Agency (IRB No. 2018-01-03-P-A, 2018-01-03-C-A). Of 9,135 participants in the 2016–2018 KNHANES aged 50 yrs or older who participated in the 24-h dietary recall, we excluded individuals whose daily energy intake numbers were implausible or fell < 1% or > 99% based on age and sex (n = 74, < 550 kcal/day or > 7,800 kcal/day for men aged < 65 yrs; < 500 kcal/day or > 6,000 kcal/day for men aged ≥ 65 yrs; < 450 kcal/day or > 6,300 kcal/day for women aged < 65 yrs; and < 400 kcal/day or > 4,800 kcal/day for women aged ≥ 65 yrs) and missed grip strength records (n = 760). Therefore, 8,301 participants (3,610 men and 4,691 women) were included in the analysis.

Assessment of dietary intake

Dietary intake was assessed using a trained interviewer's 24-h dietary recall method at each participant's home. The nutritional data for each food item was connected with the Korean Food Composition Table, which was issued by the Rural Development Administration [26], to estimate energy and macronutrient intake, including the amounts of total, animal, and plant proteins. This procedure was repeated for all items and the amounts were summed to compute the average daily nutrient intake for each participant. According to food group classification by KNHANES VII, the total daily plant protein intake includes protein found in cereal, potato or starch, legume, nuts, seeds, vegetables, mushrooms, fruits, seaweeds, or other plant sources and the products made from these foods. LNS protein intake includes proteins found in legumes, nuts, and seeds, whereas excluding legumes, nuts, and seeds (ELNS), protein intake includes plant protein sources other than LNS. The total daily animal protein intake was calculated from any products made from meats, fish, shellfish, eggs, milk or dairy food, and other animal sources. Total daily energy (kcal/day) and macronutrient (g/day) intakes were adjusted by the total energy intake according to the residual method [27]. The percent energy for macronutrients was calculated and compared with the acceptable macronutrient distribution range of the 2020 Dietary Reference Intakes for Koreans (KDRIs) by the Korean Nutrition Society [28]. To evaluate the adequacy of total energy and protein intake, the estimated energy requirement and recommended nutrient intake (RNI) published in the 2020 KDRIs were used [28].

Grip strength

A digital hand grip strength dynamometer (TKK 5401, Japan) was used to measure the grip strength (kg). It was measured in a position of standing, the fore arms far from the waist, and the forearms are measured at the waist level. Grip strength was measured 3 times with both hands, and the highest score was selected for the grip strength data. According to the previous studies [29], LGS was defined as having a grip strength below the gender-specific quintile points (lowest 20%) for healthy elderly individuals aged 65 yrs or older. In this study, the gender-specific quintile points of grip strength of the participants who were 65 yrs or older without diabetes, kidney failure, cirrhosis, stroke, angina pectoris, or cancer were used for the cutoffs. Those with grip strength lower than the cutoff points were defined as LGS. Otherwise, those with grip strength equal to or higher than the cutoffs were designated normal or high grip strength (NHGS).

Assessment of demographics, lifestyles, and health conditions

Qualified interviewers and healthcare experts followed a standardized protocol while carrying out interviews and health evaluations. The interviewer gathered information on various demographic factors, such as age (50–65 yrs, 66–80 yrs, and >80 yrs) [30], gender, education level (high school or lower, college or higher), household income (low, moderate-low, moderate-high, and high), and current medical conditions (presence or absence of hypertension, diabetes, dyslipidemia, osteoarthritis, osteoporosis, or rheumatoid arthritis). Household income was

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divided into quartiles: lowest, lower-middle, upper-middle, or highest. The self-administered questionnaire covered lifestyles, including current smoking, drinking, and resistance exercise. Current smoking was defined as those who had smoked 100 pieces over their lifetime and were currently smoking. Drinking consumption was defined as consuming alcohol more than once per month within the past year. Resistance exercises are defined as muscle exercises that have been practiced for more than 2 days during the past week, such as pushups, sit ups, dumbbells, weights, and iron bars. Health examinations were performed in a mobile examination center, including physical examinations, anthropometric measurements, and laboratory tests (blood and urine). Waist circumference was measured at the end of normal breathing using a standard protocol. Hypertension was defined as having a systolic blood pressure of 140 mmHg or higher, a diastolic blood pressure of 90 mmHg or higher, the use of antihypertensive medications, or a medical diagnosis by a physician [31]. Central obesity was defined as a waist circumference ≥ 80 cm for women and ≥ 90 cm for men [32]. Obesity was defined as body mass index ≥ 25 kg/m^2. Diabetes was defined as fasting serum glucose ≥ 126 mg/dL, the use of diabetes mellitus drug or insulin injection, or a physician's diagnosis [33]. Bone or joint disease was determined by the physician's diagnosis of any of the 3 diseases: osteoporosis, osteoarthritis, and rheumatoid arthritis. High-density lipoprotein (HDL) cholesterol was defined as having serum HDL cholesterol levels equal to or less than 50 mg/dL for women, or equal to or less than 40 mg/dL for men. Dyslipidemia was defined as the occurrence of hyperlipidemia (fasting serum total cholesterol levels of 240 mg/dL or higher, or the use of cholesterol-lowering medications). or hypertriglyceridemia (12 h fasting serum triglyceride ≥ 200 mg/dL).

Statistical analysis

As we accounted for the complex sampling design of the KNHANES VII, the PROC SURVEY procedure with strata, clusters, and sampling weights were applied in the analyses. All variables were reported as either mean ± SE for continuous variables, or as frequency with percentage for categorical variables (95% confidence interval [CI] of the percentage) for categorical variables. The significant differences between the LGS and NHGS groups were determined using either independent *t*-tests to compare means for continuous variables or Rao-Scott χ^2 tests to compare the distribution of categorical variables. Pearson's correlation tests were used to examine the association of grip strength with nutrient intakes, including total, animal-based, plant-based, LNS, and other plant sources ELNS protein intakes. Total protein, animal protein, and plant protein intake were divided into quartiles to examine the variation in grip strength across the intake levels. The odds ratios (ORs) and 95% CIs are estimated using a multivariable logistic regression model to estimate LGS according to the quartiles of protein intake while adjusting for age, household income, resistance exercise, drinking, bone or joint disease, total energy intake, and total plant protein intake for animal protein intake analysis or animal protein intake for total plant protein intake analysis. *P* for trend was obtained using a general linear model procedure with the median values of each quartile while controlling the covariates listed above. Statistical significance was defined as a 2-sided *P*-value of less than 0.05. All statistical analyses were conducted using Statistical Analysis System (SAS) 9.4 (SAS Institute, Cary, NC, USA).

RESULTS

General characteristics and health conditions

Table 1 shows the participants' general characteristics according to the grip strength category. Of enrolled participants, 8.68% of men (n = 414) and 10.65% of women (n = 563)

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were categorized as having LGS. Participants with LGS were more likely to be older, non-resistant exercisers, non-drinkers, and have lower household incomes than those with NHGS. Among men, there were notable differences in the distribution of several age groups between the NHGS and LGS categories, resistance exercise, drinking, and current smoking. The percentage of participants over the age of 80 was significantly higher in the LGS group than in the NHGS group. The proportions of resistance exercise, drinking, and current smoking were significantly higher in the NHGS group than in the LGS group. For women, there were significant differences in the distributions of age groups, resistance exercise, household income, and drinking between the LGS and NHGS groups. There was a higher proportion of individuals with a low household income in the LGS group than in the NHGS group. The proportion of those with age > 80 yrs was greatly higher in the LGS group than in the NHGS group. The proportions of no resistance exercise and monthly drinking were significantly higher in the LGS group than in the NHGS group.

Health conditions by grip strength are shown in **Table 2**. In both men and women, the prevalence of high blood pressure, bone and joint diseases, and low HDL cholesterol was higher than in men and women's NHGS groups. There was a higher prevalence of hypertension, diabetes mellitus, bone or joint diseases, and low HDL cholesterol in the men with LGS than in the men with NHGS. The prevalence rates of obesity and dyslipidemia were lower in men with LGS than in men with NHGS. Diabetes was more prevalent in women with LGS than in women with NHGS.

Nutrient intakes

Participants with LGS consumed lower total daily intakes of energy, protein, and percent energy for protein and fat than those participants with NHGS ($P < 0.0001$) (**Table 3**). However, women and men with LGS consumed more energy from carbohydrates than those with NHGS ($P < 0.0001$).

Participants with NHGS had higher total protein consumption and all different protein sources than those with LGS (**Tables 3** and **4**). For participants with LGS, a higher proportion

Table 1. General characteristics by grip strength and sex

Characteristics	Men					Women				
	LGS		NHGS		*P*-value	LGS		NHGS		*P*-value
	n	Value	n	Value		n	Value	n	Value	
Total	414	8.68	3,196	91.31		563	10.65	4,128	89.34	
Age (yrs)		73.73 ± 0.53		61.38 ± 0.18	< 0.0001		72.51 ± 0.48		62.10 ± 0.17	< 0.0001
Grip strength (kg)		22.45 ± 0.20		38.93 ± 0.14	< 0.0001		13.02 ± 0.10		23.19 ± 0.08	< 0.0001
50–65 yrs	47	23.84 ± 0.51	1,787	40.77 ± 0.16	< 0.0001	80	13.98 ± 0.22	2,384	24.23 ± 0.10	< 0.0001
66–80 yrs	211	22.78 ± 0.26	1,256	35.63 ± 0.18	< 0.0001	292	13.24 ± 0.11	1,505	21.66 ± 0.10	< 0.0001
Over 80 yrs	156	21.57 ± 0.36	144	32.02 ± 0.42	< 0.0001	191	12.13 ± 0.22	239	19.09 ± 0.19	< 0.0001
Resistance exercise[1)]	49	13.64 (9.90–17.37)	898	30.04 (28.12–31.96)	< 0.0001	19	5.49 (2.48–8.51)	564	15.22 (13.85–16.59)	< 0.0001
Household income										
Low	246	55.63 (49.99–61.27)	695	17.93 (16.20–19.66)		328	54.17 (49.07–59.27)	1,176	24.63 (22.73–26.52)	
Moderate low	88	21.28 (16.35–26.22)	845	23.58 (21.84–25.33)		120	22.14 (18.15–26.13)	1,063	24.45 (22.73–26.16)	
Moderate high	53	15.12 (10.72–19.52)	752	25.54 (23.73–27.34)		57	11.00 (7.53–14.47)	909	24.22 (22.65–25.78)	
High	23	7.95 (4.56–11.35)	890	32.93 (30.63–35.24)	< 0.0001	56	12.67 (9.15–16.19)	968	26.69 (24.59–28.80)	< 0.0001
Drinking[2)]	186	44.12 (38.56–49.68)	2,121	68.91 (67.03–70.78)	< 0.0001	95	18.62 (14.48–22.77)	1,148	30.39 (28.66–32.11)	< 0.0001
Current smoking[3)]	93	23.70 (19.00–28.41)	873	29.98 (27.88–32.09)	0.02	15	4.24 (1.37–7.11)	133	3.44 (2.66–4.22)	0.53

Values are presented as mean ± SE or weighted % (95% confidence interval).
LGS, low grip strength; NHGS, normal or high grip strength.
[1)]Those who had practiced muscle exercises such as push-ups, sit-ups, dumbbells, weights, and iron bars for more than 2 days in the past week.
[2)]Those who had drunk alcohol more than once a month over the past year.
[3)]Those who had smoked 100 pieces over a lifetime or now smoking.

Table 2. Health conditions by grip strength and sex

Characteristics	Men					Women				
	LGS		NHGS		*P*-value	LGS		NHGS		*P*-value
	n	Value	n	Value		n	Value	n	Value	
Hypertension[1)]	239	58.65 (53.52–63.78)	1,605	48.26 (46.28–50.24)	0.0005	370	64.83 (60.25–69.40)	1,930	42.03 (40.17–43.89)	< 0.0001
Waist circumference		84.50 ± 0.51		87.04 ± 0.17	< 0.0001		82.63 ± 0.50		81.62 ± 0.19	0.35
Central obesity[2)]	111	25.73 (21.30–30.17)	1,137	34.46 (32.45–36.48)	0.001	347	62.71 (57.62–67.80)	2,353	55.19 (53.18–57.20)	0.007
Obesity[3)]	80	18.64 (14.60–22.68)	1,248	39.53 (37.44–41.62)	< 0.0001	192	35.80 (31.18–40.42)	1,519	35.18 (33.36–37.01)	0.81
Diabetes[4)]	97	24.32 (20.21–29.38)	703	21.13 (19.48–22.78)	0.13	130	25.33 (20.84–29.83)	650	15.38 (14.01–16.75)	< 0.0001
Bone, joint disease[5)]	78	18.39 (14.08–22.69)	337	8.75 (7.68–9.83)	< 0.0001	340	59.26 (54.19–64.34)	1,733	38.61 (36.81–40.40)	< 0.0001
Low HDL cholesterol[6)]	175	44.91 (39.00–50.82)	1,070	31.84 (29.79–33.89)	< 0.0001	363	64.35 (59.45–69.25)	2,017	47.33 (45.47–49.19)	< 0.0001
Dyslipidemia[7)]	47	10.44 (7.19–13.70)	641	20.65 (18.91–22.40)	< 0.0001	86	15.46 (12.01–18.91)	605	14.63 (13.29–15.97)	0.66

Values are presented as mean ± SE or weighted % (95% confidence interval).
LGS, low handgrip strength; NHGS, normal or high grip strength; HDL, high-density lipoprotein.
1)Systolic blood pressure ≥ 140 mmHg, diastolic blood pressure ≥ 90 mmHg, or the use of hypertension drugs.
2)Waist circumference ≥ 80 cm for women and ≥ 90 cm for men.
3)Body mass index ≥ 25 kg/m^2.
4)Fasting serum glucose ≥ 126, diabetes mellitus drug or insulin injection, or physician's diagnosis.
5)Physician's diagnosis for any of the 3 diseases: osteoporosis, osteoarthritis, and rheumatoid arthritis.
6)Serum HDL-cholesterol ≤ 50 mg/dL for women or ≤ 40 mg/dL for men.
7)Hyperlipidemia (fasting serum total cholesterol ≥ 240 mg/dL, the use of cholesterol drug), or hypertriglyceridemia (12 h fasting serum triglyceride ≥ 200 mg/dL).

Table 3. Nutrient intakes by grip strength and sex

Characteristics	Men					Women				
	LGS		NHGS		*P*-value	LGS		NHGS		*P*-value
	n	Value	n	Value		n	Value	n	Value	
Total energy (kcal/day)		1,732.86 ± 33.09		2,217.06 ± 19.82	< 0.001		1,347.99 ± 27.48		1,611.36 ± 12.33	< 0.001
Carbohydrates (%energy)		69.55 ± 0.72		62.96 ± 0.30	< 0.001		73.46 ± 0.46		68.24 ± 0.22	< 0.001
Protein (%energy)		12.57 ± 0.22		13.90 ± 0.08	< 0.001		12.37 ± 0.17		13.79 ± 0.07	< 0.001
Protein (g/day)[1)]		57.06 ± 1.00		62.47 ± 0.36	< 0.001		56.83 ± 0.80		62.86 ± 0.33	< 0.001
Protein (g/kg day)		0.91 ± 0.02		1.13 ± 0.01	< 0.001		0.78 ± 0.01		0.97 ± 0.009	< 0.001
Fat (%energy)		13.31 ± 0.44		16.62 ± 0.17	< 0.001		12.98 ± 0.38		16.88 ± 0.16	< 0.001
Protein ≥ RNI[2)]	132	32.53 (26.96–38.10)	1,972	63.94 (61.74–66.14)	< 0.001	144	26.99 (22.75–31.23)	2,087	52.28 (50.36–54.19)	< 0.001
Total protein intake (g/day)[1)]										
Q1 (11.14–50.20)	146	33.75 (27.97–39.53)	735	22.26 (20.48–24.04)		218	36.16 (31.73–40.59)	976	22.08 (20.47–23.69)	
Q2 (50.20–58.99)	118	28.85 (23.67–34.03)	819	24.15 (22.35–25.95)		147	27.29 (22.93–31.65)	991	23.82 (22.36–25.29)	
Q3 (58.99–69.58)	97	23.49 (19.01–27.96)	824	27.34 (25.59–29.10)		113	20.78 (17.00–24.55)	1,042	26.55 (24.94–28.16)	
Q4 (69.58–257.55)	53	13.89 (10.01–17.78)	818	26.23 (24.40–28.05)	< 0.001	85	15.75 (11.99–19.51)	1,119	27.52 (25.79–29.26)	< 0.001

Values are presented as mean ± SE or weighted % (95% confidence interval). Protein intake amount range (g/day) is shown in parentheses next to the quartile number.
LGS, low grip strength; NHGS, normal or high grip strength; RNI, recommended nutrient intake.
1)Total protein (g/day) and quartiles of total protein (g/day) were total energy-adjusted values by the residual method [23].
2)Total protein intake over the recommended nutrient intake in the Dietary Reference Intake for Koreans 2020 [37], men: 60 g/day and women: 50 g/day.

was in the lowest quartile than those in the other quartiles in any protein source intakes. Participants with NHGS were more often in the highest quartile than in the other quartiles of animal protein intake. However, no significant differences were observed between plant-based protein intake quartiles.

Correlation between grip strength and nutrient intakes

Moderate negative associations between age and grip strength were found in both men (r = −0.56) and women (r = −0.49) (**Table 5**). In addition, weak significant correlations between total energy, percent energy for fat, total protein, total animal protein, total plant protein, LNS protein, and ELNS protein intake with grip strength were found in both men (ranging from r = 0.05 for LNS protein to r = 0.24 for total energy) and women (ranging from r = 0.06 for L.N.S. protein to r = 0.18 for animal protein). The percent energy of carbohydrates was negatively associated with grip strength (r = −0.21 for men, −0.19 for women).

Table 4. Protein intakes from different food sources by grip strength and sex

Characteristics	Men					Women				
	LGS		NHGS		*P*-value	LGS		NHGS		*P*-value
	n	Value	n	Value		n	Value	n	Value	
Plant[1)] protein (g/day)		32.34 ± 0.87		37.22 ± 0.37	< 0.001		25.75 ± 0.56		29.91 ± 0.28	< 0.001
Plant protein (% protein)		63.79 ± 0.01		55.58 ± 0.00	< 0.001		69.91 ± 0.01		60.29 ± 0.00	< 0.001
LNS protein (g/day)		7.34 ± 0.50		8.61 ± 0.18	0.002		5.21 ± 0.27		6.60 ± 0.13	< 0.001
ELNS protein (g/day)		26.57 ± 0.68		30.64 ± 0.30	< 0.001		21.76 ± 0.50		24.51 ± 0.22	< 0.001
Animal[2)] protein (g/day)		19.86 ± 1.16		35.98 ± 0.64	< 0.001		13.98 ± 0.70		23.47 ± 0.38	< 0.001
Plant[1)] protein intake (g/day)										
Q1 (0–25.56)	157	38.18 (32.92–43.44)	745	24.02 (22.00–26.05)		188	33.49 (29.22–37.76)	984	23.67 (22.09–25.25)	
Q2 (25.56–33.97)	103	25.17 (20.48–29.87)	799	24.81 (22.91–26.71)		168	30.99 (26.06–35.92)	1,005	25.17 (23.58–26.75)	
Q3 (33.97–44.76)	91	22.62 (17.99–27.26)	812	25.31 (23.49–27.14)		117	19.51 (15.44–23.57)	1,056	25.34 (23.72–26.96)	
Q4 (44.76–170.59)	62	14.00 (10.24–17.76)	840	25.84 (23.88–27.79)	< 0.001	90	15.99 (12.27–19.72)	1,082	25.81 (24.08–27.54)	< 0.001
LNS protein intake (g/day)										
Q1 (0–2.28)	131	31.32 (25.88–36.77)	769	24.65 (22.85–26.44)		177	31.08 (26.62–35.54)	995	24.34 (22.79–25.90)	
Q2 (2.28–5.77)	99	25.12 (20.01–30.22)	803	25.65 (23.92–27.37)		150	26.06 (21.88–30.23)	1,023	25.35 (23.75–26.95)	
Q3 (5.77–11.32)	101	24.45 (19.16–29.74)	802	24.89 (23.06–26.72)		122	23.56 (18.97–28.16)	1,051	25.54 (23.97–27.10)	
Q4 (11.32–102.74)	80	19.09 (14.74–23.44)	822	24.80 (23.05–26.54)	0.05	114	19.28 (15.47–23.09)	1,058	24.75 (23.16–26.35)	0.008
ELNS protein intake (g/day)										
Q1 (0–21.53)	152	36.50 (31.38–41.61)	750	24.08 (22.09–26.07)		183	33.85 (29.46–38.23)	989	23.84 (22.26–25.42)	
Q2 (21.53–28.12)	104	25.89 (20.89–30.89)	798	24.41 (22.52–26.30)		154	26.10 (21.88–30.31)	1,019	25.30 (23.72–26.88)	
Q3 (28.12–36.54)	93	21.54 (17.29–25.79)	810	25.10 (23.31–26.89)		126	22.76 (18.14–27.38)	1,047	25.05 (23.58–26.52)	
Q4 (36.54–147.82)	64	16.06 (11.67–20.45)	838	26.39 (24.40–28.37)	< 0.001	100	17.27 (13.48–21.07)	1,072	25.79 (24.10–27.47)	< 0.001
Animal[2)] protein intake (g/day)										
Q1 (0–12.40)	183	43.32 (37.61–49.03)	719	19.95 (18.23–21.66)		236	40.16 (35.61–44.70)	992	20.29 (18.79–21.78)	
Q2 (12.40–25.12)	115	28.05 (22.89–33.21)	787	22.99 (21.24–24.74)		131	22.73 (18.69–26.77)	1,018	24.39 (22.76–23.03)	
3 (25.12–43.57)	72	17.46 (13.55–21.38)	831	26.65 (24.77–28.53)		101	19.95 (15.72–24.18)	1,081	26.16 (24.55–27.78)	
Q4 (43.57–427.43)	43	11.14 (7.49–14.80)	859	30.39 (28.48–32.31)	< 0.001	95	17.14 (13.38–20.91)	1,106	29.14 (27.44–30.84)	< 0.001

Values are presented as mean ± SE or weighted % (95% confidence interval). Protein intake range (g/day) is shown in parentheses next to the quartile number.
LGS, low grip strength; NHGS, normal or high grip strength; LNS, legumes, nuts, and seeds; ELNS, other plant sources except legumes, nuts, and seeds.
1)Plant sources: cereal, potato or starch, LNS, vegetables, mushrooms, fruits, seaweeds, and other plant sources.
2)Animal sources: meats, eggs, fishes and shellfish, milk and dairy products, and other animal sources.

Table 5. Correlation coefficients between hand grip strength and nutrients intakes

Characteristics	Men		Women	
	r	*P*-value	r	*P*-value
Age (yrs)	−0.56	< 0.001	−0.49	< 0.001
Total energy (kcal/day)	0.24	< 0.001	0.17	< 0.001
Fat (%kcal)	0.2	< 0.001	0.18	< 0.001
Carbohydrate (%kcal)	−0.21	< 0.001	−0.19	< 0.001
Protein (%kcal)	0.13	< 0.001	0.14	< 0.001
Protein[1)] (g/day)	0.12	< 0.001	0.13	< 0.001
Total plant[2)] protein (g/day)	0.14	< 0.001	0.11	< 0.001
LNS protein	0.05	0.007	0.06	0.0006
ELNS protein	0.13	< 0.001	0.11	< 0.001
Total animal[3)] protein (g/day)	0.22	< 0.001	0.18	< 0.001

LNS, legumes, nuts, seeds; ELNS, other plant sources, except legumes, nuts, and seeds.
1)Protein (g/day) energy adjusted protein intake by residual method.
2)Animal sources: meats, eggs, fishes and shellfish, milk and dairy products, and other animal sources.
3)Plant sources: cereal, potato or starch, LNS, vegetables, mushrooms, fruits, seaweeds, and other plant sources.

Association between grip strength and protein intakes

A higher total protein intake was significantly associated with a lower prevalence of LGS showing a declining trend (*P* for trend = 0.005 for men, 0.004 for women) (**Table 6**). Men participants in the highest protein intake quartile had a 71% lower OR of LGS than those in the lowest quartile (OR, 0.29; 95% CI, 0.12–0.68). Participants with protein intake over the RNI showed a 29% lower OR of LGS than those with protein intake below the RNI in women (OR, 0.71; 95% CI, 0.51–0.99).

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Table 6. ORs and 95% CIs of low hand grip strength according to various protein intake quartiles

Characteristics	Men		Women	
	n	OR (95% CI)	n	OR (95% CI)
Total protein intake[1)] (g/day)				
Q1	146	1.00	218	1.00
Q2	118	0.84 (0.55–1.29)	147	0.68 (0.45–1.01)
Q3	97	0.57 (0.34–0.97)	113	0.75 (0.41–1.37)
Q4	53	0.29 (0.12–0.68)	85	0.47 (0.20–1.12)
P for trend		0.01		0.00
Protein intake (g/day) > RNI[2)]	132	0.68 (0.46–1.01)	144	0.71 (0.51–0.99)
Plant[3)] protein intake (g/day)				
Q1	157	1.00	188	1.00
Q2	103	0.80 (0.54–1.18)	168	0.98 (0.71–1.36)
Q3	91	0.82 (0.55–1.20)	117	0.68 (0.45–1.01)
Q4	62	0.62 (0.35–1.11)	90	0.90 (0.53–1.54)
P for trend		0.00		0.05
LNS protein intake (g/day)				
Q1	131	1.00	177	1.00
Q2	99	0.76 (0.53–1.10)	150	0.86 (0.64–1.15)
Q3	101	0.88 (0.58–1.34)	122	0.78 (0.56–1.10)
Q4	80	0.66 (0.41–1.04)	114	0.86 (0.59–1.24)
P for trend		0.01		0.02
ELNS protein intake (g/day)				
Q1	152	1.00	183	1.00
Q2	104	0.79 (0.53–1.18)	154	0.69 (0.51–0.95)
Q3	93	0.76 (0.51–1.17)	126	0.81 (0.53–1.26)
Q4	64	0.94 (0.53–1.67)	100	0.84 (0.51–1.39)
P for trend		0.10		0.15
Animal[4)] protein intake (g/day)				
Q1	183	1.00	236	1.00
Q2	115	1.17 (0.74–1.84)	131	0.96 (0.64–1.45)
Q3	72	1.02 (0.54–1.92)	101	0.83 (0.48–1.44)
Q4	43	1.11 (0.41–2.99)	95	0.76 (0.36–1.58)
P for trend		0.08		0.03

OR adjusted for total covariates: age, household income, resistance exercise, drinking, bone joint disease, total energy intake, total plant protein intake (for animal protein intake analysis), or animal protein intake (for total plant, LNS, and ELNS protein intake analysis). *P* for trend was calculated using a general linear model procedure with the median values of each quartile and total covariates.
LNS, legumes, nuts, seeds; ELNS, except legumes, nuts, and seeds; OR, odds ratio; CI, confidence interval; RNI, recommended nutrient intake.
1)Total protein intakes over the estimated average requirement in Dietary Reference Intake for Koreans 2020, male: 50 g/day, female: 40 g/day [24].
2)Total protein intake over the recommended nutrient intake in Dietary Reference Intake for Koreans 2020, males: 60 g/day, females: 50 g/day [24].
3)Plant sources: cereal, potato or starch, LNS, vegetables, mushrooms, fruits, seaweeds, and other plant sources.
4)Animal sources: meats, eggs, fishes and shellfish, milk and dairy products, other animal sources.

A higher intake of total plant (*P* for trend = 0.004 for men, 0.05 for women) and LNS proteins (*P* for trend = 0.01 for men, 0.02 for women) was associated with a lower prevalence of LGS in both men and women. However, no significant association was observed between the ELNS intake and LGS. Higher total animal protein intake was significantly associated with a decrease in LGS only in women (*P* for trend= 0.03).

The association between protein intake and LGS varied depending on the proportion of protein intake to total energy intake, the ratio of plant protein intake to animal protein intake (**Table 7**), and the presence of bone joint disorders (**Table 8**). Increased total plant protein intake in proportion to total energy intake (*P* for trend = 0.007 for men), LNS plant protein intake in proportion to total energy intake (*P* for trend = 0.006 for men, 0.01 for women), total animal protein intake in proportion to total energy intake (*P* for trend = 0.01 for men, 0.003 for women), and ratio of total plant protein intake to total animal protein intake (*P* for trend = 0.03 for women) were all associated with a lower trend of LGS. Among participants without bone joint diseases, increasing protein intake, including total protein intake (*P* for

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Table 7. ORs and 95% CIs of low hand grip strength according to proportion of protein intake to total energy intake and ratio of total plant protein intake to total animal protein intake

Characteristics	Men		Women	
	n	OR (95% CI)	n	OR (95% CI)
Quartiles of total plant protein intake proportion in total energy intake				
Q1	80	1.00	104	1.00
Q2	96	0.53 (0.28–0.98)	157	1.37 (0.91–2.06)
Q3	116	0.66 (0.38–1.14)	140	1.12 (0.73–1.71)
Q4	122	0.43 (0.24–0.78)	162	1.02 (0.65–1.61)
P for trend		0.01		0.29
Quartiles of LNS plant protein intake proportion in total energy intake				
Q1	117	1.00	166	1.00
Q2	94	0.79 (0.48–1.30)	132	0.72 (0.48–1.09)
Q3	95	0.55 (0.34–0.90)	124	0.64 (0.41–1.01)
Q4	108	0.54 (0.32–0.90)	141	0.71 (0.49–1.03)
P for trend		0.01		0.01
Quartiles of ELNS plant protein intake proportion in total energy intake				
Q1	78	1.00	108	1.00
Q2	92	0.50 (0.28–0.87)	105	0.65 (0.41–1.03)
Q3	124	0.76 (0.41–1.41)	168	0.99 (0.62–1.58)
Q4	120	0.54 (0.29–1.01)	182	1.01 (0.64–1.57)
P for trend		0.15		0.59
Quartiles of total animal protein intake proportion in total energy intake				
Q1	113	1.00	155	1.00
Q2	76	0.91 (0.58–1.42)	100	0.93 (0.65–1.34)
Q3	51	0.55 (0.34–0.89)	65	0.77 (0.50–1.20)
Q4	35	0.47 (0.27–0.82)	56	0.64 (0.41–1.00)
P for trend		0.01		0.00
Quartiles of ratio of total plant protein intake over total animal protein intake				
Q1	38	1.00	56	1.00
Q2	47	1.05 (0.57–1.92)	63	1.10 (0.66–1.83)
Q3	76	1.32 (0.73–2.38)	89	1.26 (0.81–1.98)
Q4	98	1.29 (0.76–2.20)	135	1.32 (0.84–2.09)
P for trend		0.95		0.03

OR adjusted for total covariates: age, household income, resistance exercise, drinking, bone joint disease, total energy intake, total plant protein intake (for animal protein intake analysis), or animal protein intake (for total plant, LNS, and ELNS protein intake analyses). *P* for trend was calculated using a general linear model procedure with the median values of each quartile and total covariates.
LNS, legumes, nuts, seeds; ELNS, except legumes, nuts, and seeds; OR, odds ratio; CI, confidence interval.

trend=0.007 for men, 0.03 for women), plant protein intake (*P* for trend = 0.02 for men), LNS protein intake (*P* for trend = 0.01 for men), and animal protein intake (*P* for trend = 0.03 for women), was associated with decreased prevalence of LGS. In contrast, participants with bone joint diseases had lower grip strength with higher total protein intake (*P* for trend = 0.03 for women), plant protein intake (*P* for trend = 0.002 for men), and animal protein intake (*P* for trend = 0.02 for women).

DISCUSSION

The findings of this study indicate that a higher intake of total plant protein and LNS protein was associated with a lower prevalence of LGS. However, the ELNS protein intake was not associated with LGS. Therefore, a diet that includes plant-based proteins may help maintain muscle health in older individuals.

Our results are consistent with existing evidence that the total amount of energy and protein consumed in food is protective against muscle weakness in older adults [8,34]. Regarding amino acid profile and better availability, animal proteins are generally regarded as more

Table 8. ORs and 95% CIs of low hand grip strength according to protein intake stratified by physician's diagnosis of any of 3 bone joint diseases (osteoporosis, rheumatoid arthritis, and osteoarthritis)

Characteristics	No bone joint diseases				Bone joint diseases			
	Men (n = 3,195)		Women (n = 2,618)		Men (n = 415)		Women (n = 2,073)	
	n	OR (95% CI)	n	OR (95% CI)	n	OR (95% CI)	n	OR (95% CI)
Total protein intake (g/day)								
Q1	105	1.00	112	1.00	19	1.00	196	1.00
Q2	104	1.03 (0.57–1.85)	60	0.64 (0.32–1.26)	25	1.60 (0.45–5.72)	78	0.79 (0.42–1.49)
Q3	68	0.70 (0.34–1.45)	35	0.51 (0.17–1.50)	24	2.97 (0.61–14.29)	52	1.14 (0.41–3.18)
Q4	59	0.84 (0.24–2.86)	16	0.56 (0.10–3.02)	10	2.31 (0.14–36.00)	14	0.84 (0.14–5.07)
P for trend		0.01		0.03		0.37		0.03
Plant protein intake (g/day)								
Q1	132	1.00	75	1.00	25	1.00	115	1.00
Q2	81	0.58 (0.36–0.93)	54	0.67 (0.33–1.36)	24	0.73 (0.20–2.55)	112	1.13 (0.70–1.80)
Q3	74	0.72 (0.41–1.24)	45	0.41 (0.16–1.01)	17	0.49 (0.10–2.42)	64	0.59 (0.28–1.22)
Q4	49	0.38 (0.18–0.80)	49	0.63 (0.21–1.86)	12	0.60 (0.04–7.94)	49	0.62 (0.24–1.56)
P for trend		0.00		0.07		0.00		0.06
LNS protein intake (g/day)								
Q1	108	1.00	63	1.00	26	1.00	114	1.00
Q2	80	0.74 (0.44–1.24)	55	0.58 (0.30–1.14)	19	0.37 (0.13–1.08)	95	0.92 (0.59–1.43)
Q3	81	0.77 (0.43–1.36)	52	0.90 (0.43–1.90)	20	0.99 (0.32–3.04)	70	0.58 (0.36–0.93)
Q4	67	0.56 (0.29–1.06)	53	0.56 (0.29–1.07)	13	0.29 (0.05–1.60)	61	0.73 (0.46–1.18)
P for trend		0.01		0.21		0.19		0.07
ELNS protein intake (g/day)								
Q1	128	1.00	68	1.00	24	1.00	115	1.00
Q2	84	0.97 (0.59–1.59)	59	0.65 (0.33–1.30)	21	0.87 (0.20–3.66)	95	0.74 (0.47–1.18)
Q3	74	0.70 (0.41–1.18)	53	0.65 (0.25–1.63)	19	0.98 (0.16–5.98)	73	0.87 (0.42–1.82)
Q4	50	0.87 (0.38–2.01)	43	0.58 (0.17–1.95)	14	0.79 (0.12–5.17)	57	0.79 (0.31–1.96)
P for trend		0.15		0.10		0.65		0.60
Animal protein intake (g/day)								
Q1	95	1.00	54	1.00	25	1.00	112	1.00
Q2	67	0.82 (0.51–1.33)	39	0.93 (0.46–1.88)	14	1.27 (0.37–4.31)	62	0.88 (0.53–1.45)
Q3	44	0.64 (0.36–1.13)	23	0.62 (0.28–1.35)	7	0.70 (0.22–2.26)	39	0.78 (0.42–1.43)
Q4	18	0.41 (0.17–0.98)	20	0.51 (0.23–1.11)	5	0.63 (0.10–3.83)	27	0.62 (0.27–1.43)
P for trend		0.13		0.03		0.14		0.02

LNS, legumes, nuts, seeds; ELNS, except legumes, nuts, and seeds; OR, odds ratio; CI, confidence interval.

favorable for maintaining muscle health. However, there have been some contradictory reports. Chan *et al.* [21] reported that the consumption of a higher amount of protein derived from vegetables was linked to a decrease in muscle loss among older individuals residing in Hong Kong communities. There was no observed correlation between the intake of animal protein and changes in physical performance measures and skeletal muscle mass [21]. A Japanese group reported that the animal protein to vegetable protein ratio was negatively correlated with skeletal muscle mass in elderly diabetic patients [22]. According to a recent meta-analysis of randomized controlled trials, animal protein intake was found to have no significant effect on improving lean mass and muscular strength in individuals over the age of 50 [23]. These findings suggest the presence of physiologic factors that offset the advantages of animal proteins in older adults. The metabolites of animal protein can promote atherosclerosis [35] and may lead to an increased risk of sarcopenia [36]. It could obstruct the positive relationship between animal proteins and muscular strength. On the contrary, phytochemicals in plants can prevent the adverse effects of oxidative stress and minimize skeletal muscle breakdown by reducing inflammatory molecules, such as tumor necrosis factor-alpha, interleukin-6, C-reactive protein, and nuclear factor kappa B [37]. Non-radical derivatives and free radicals produced by exogenous or endogenous processes may oxidize proteins, disrupt their composition, impair their beneficial activities, and disturb DNA transcription [38]. They may also damage the gene system and stimulate mutations, leading to

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the deterioration of nuclear and corporal activities, programmed cell death, and inflammation [38], substantially contributing to sarcopenia [39]. Moreover, plant products, such as fiber and low-digestible proteins, can also benefit the gut microbiota and enable distant intestinal microbial fermentation [40], which can affect mechanisms such as inflammation, short-chain fatty acid production, and protein anabolism [41]. Fatty acids modulate molecular signaling, which may affect longitudinal muscle maintenance and regeneration [42].

We found that a higher intake of LNS protein is positively associated with a lower LGS. LNS proteins are an important sources of essential amino acids including leucine, lysine, and valine [43,44]. Previous investigations have shown that leucine is a key regulator of protein synthesis in skeletal muscles. Leucine stimulates human muscle protein synthesis through multiple pathways, including the rapamycin protein kinase pathway [45]. A simulation study based on French national dietary survey data showed that LNS protein could more efficiently substitute animal protein than other plant sources, maintaining protein and amino acid adequacy [46]. A recent meta-analysis also demonstrated that soybean supplementation produced similar gains in muscular strength and muscle mass as whey protein [47]. A dose-response meta-analysis of prospective cohort studies revealed a notable link between the consumption of nuts or legumes and a reduced risk of chronic heart disease and all-cause mortality [48,49], the mechanism and role of LNS protein in muscular health warrants further investigation. A possible reason for this is that LNS protein has a higher protein-energy ratio than grains, which are the main sources of ELNS [46]. Similarly, a simulation study of the isocaloric substitution of animal protein with plant protein revealed that adequate protein and amino acids were efficiently secured when LNS was favored over other plant sources. Moreover, a meta-analysis indicated no between-group differences in the influence of several animal or soy protein supplements on muscle strength [47]. Additionally, studies have indicated that even small servings of mixed nuts and legume seeds can provide health benefits such as reducing DNA damage and inflammation markers [50].

We found that a higher total intake of animal proteins was associated with a significantly lower prevalence of LGS in women. These results are consistent with those of previous studies [51,52] that reported a significant positive association between grip strength and energy, protein, and animal-based protein intakes in older Korean women. Individual differences in factors such as age, sex, and physical activity levels may also play a role in the relationship between protein intake and muscle health; however, further research is needed to fully understand the relationship between animal and plant protein intakes and their effects on muscle health.

The present study has several limitations. First, a causal relationship could not be determined since our study was cross-sectional in design. Second, we categorized the plant protein as LNS and ELNS. Each plant protein might have a differential impact on grip strength. Third, all participants aged 50 or older were analyzed together. Age groups were not analyzed separately. Finally, protein intake was measured through dietary recall for a single day; it may not represent typical eating patterns. Despite these limitations, the strengths of this study are as follows: First, this study was a large-scale and nationally representative study in Korean. Second, this study used the first study in which plant protein was found to be related to muscle strength in older Koreans.

Finally, we suggest that total plant or legume, nut, and seed protein intake were positively associated with grip strength in men and women. A longitudinal study should confirm the relationship between the intake of plant protein and muscle strength in middle-aged and elderly adults.

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