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Relationship between dietary protein and amino acid intake and handgrip strength in Korean adults: data from the 2014–2019 Korea National Health and Nutrition Examination Survey

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Abstract

Background Sarcopenia contributes to an increased risk of falls and fractures, and reduced mobility, and mortality. Supplementation with dietary protein and amino acids has been suggested as a potential strategy to slow or prevent the associated loss of muscle mass and strength. However, most previous studies have focused on dietary protein or limited populations, such as older adults. Therefore, this study aimed to investigate the relationship between dietary protein and amino acid intake and handgrip strength (HG) in Korean adults.

Methods This study used data from the 2014–2019 Korea National Health and Nutrition Examination Survey. A total of 18,565 adults who participated in a 1-day 24-hour recall method were included. Protein intake was calculated as a percentage of total energy intake from food sources (animal and plant). Amino acid intake (g/day), including essential amino acids (EAAs), branched-chain amino acids (BCAAs), and non essential amino acids (NEAAs), was assessed using a database expanded based on amino acid composition databases constructed by national institutions. Low HG was diagnosed based on the 2019 guidelines of the Asian Working Group on Sarcopenia.

Results In the fully adjusted model, total and plant protein intakes were positively associated with HG levels (kg) (β = 0.04 and 0.07 per 1% increase, respectively; $p < 0.05$ for both). Participants aged ≥ 65 years in the highest NEAA intake group had a 42% lower risk of low HG compared to those in the lowest intake group (odds ratio 0.58; 95% confidence interval 0.35–0.97; p for trend = 0.1026). A lower risk of HG was observed in older participants whose plant protein intake ranged from 8 to 10% of energy, compared to those consuming less than 7%. However, no association was found when intake exceeded 10% of energy.

This study is based on a master thesis 'Relationship between dietary protein intake and grip strength in Korean Adults: Data from the 2014 ~ 2019 Korea National Health and Nutrition Examination Survey' submitted to the Graduate School, Jeju National University.

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Conclusions These findings suggest that a high intake of NEAAs and a moderately high intake of plant protein may be associated with a lower risk of low HG among Korean older adults. Further prospective studies are needed to explore the effects of protein and amino acid intake on muscle mass and strength.

Keywords Protein, Amino acid, Handgrip strength, Sarcopenia, KNHANES

Background

Sarcopenia, an age-related loss of skeletal muscle mass, along with decreased muscle strength and/or physical performance [1], is associated with an increased risk of falls and fractures and reduced mobility. Ultimately, this leads to a decline in quality of life [2–4]. Furthermore, sarcopenia is associated with increased mortality [5]. Known causes of sarcopenia include aging, diseases such as cancer, diabetes, osteoporosis, and endocrine disorders, and lifestyle factors such as low physical activity, sedentary lifestyle, and oral health issues [6]. Nutritional factors, specifically inadequate protein and energy intake and micronutrient deficiencies, have also been identified as contributors to sarcopenia risk [7].

Adequate dietary protein intake can help prevent the loss of muscle mass and strength and enhance muscle fiber production [8]. Recent meta-analyses of randomized controlled trials (RCTs) and observational studies have shown that protein supplementation or a high-protein diet can improve lean body mass (LBM), muscle strength, and physical function [9–11]. Another meta-analysis of 28 RCTs found that, in older adults performing resistance exercise, increased protein intake was associated with higher appendicular lean mass and handgrip strength (HG), compared to low-protein intake [12]. However, in the absence of resistance exercise, there were no additional benefits in LBM, appendicular muscle mass, or HG.

Both dietary protein quality and quantity are important [13], and protein quality can be determined by amino acid composition and food source (e.g., animal vs. plant) [14–16]. Several RCTs have reported the beneficial effects of essential amino acid (EAA) supplementation, including increased muscle mass in obese older adults in the United States [17] and improved HG in institutionalized older patients in Italy [18]. Additionally, branched-chain amino acids (BCAAs) - leucine, isoleucine, and valine - may promote protein anabolism by enhancing protein synthesis and inhibiting its degradation [19]. An RCT that involved ten adults aged 20 years or older in the UK found that BCAA supplementation stimulated muscle protein synthesis following resistance exercise, compared to a control group [20]. Furthermore, a 12-week RCT in Korea reported that leucine-rich supplementation increased LBM among 111 adults aged ≥ 50 years compared with a control group [21].

Previous epidemiological findings regarding the relationship between dietary protein sources and HG levels, as indicators of muscle strength, have been inconsistent [22–25]. For example, a prospective study using the Framingham Offspring cohort found that total and animal protein intakes were associated with increased HG in older adults, whereas plant protein intake showed no such association [22]. However, a cross-sectional study in older adults in New Zealand reported a positive correlation between HG and protein from plant sources, dairy products, and eggs (but not all animal protein) [23]. Additionally, another cross-sectional study of American adults found that both animal and plant protein intake was significantly associated with higher HG [24].

Despite the recognized importance of protein quality, epidemiological evidence on the relationship between overall dietary amino acid intake in the usual diet and muscle mass or strength remains limited. A few cross-sectional studies conducted in the United States [24, 26] and Korea [27, 28] have investigated the association between amino acid intake and HG, and these studies were limited to specific amino acids or age groups. Thus, this study aimed to investigate the association between dietary protein quantity and quality, defined by food sources (animal vs. plant protein) and amino acid intake, and HG in Korean adults using national survey data, including its relationship with low HG in older individuals.

Methods

Data source and study participants

This study used the data from the 2014 to 2019 Korea National Health and Nutrition Examination Survey (KNHANES), an annual national survey conducted by the Korea Centers for Disease Control and Prevention (KCDC). The survey targeted a nationally representative sample of non-institutionalized individuals. A detailed explanation of the KNHANES data can be found elsewhere [29]. Among the 47,309 participants, exclusions were made for individuals under 19 years of age (n = 8,804), those who did not participate in a 24-hour dietary recall (n = 4,613), those without HG measurements (n = 2,549), those lacking height and body weight data (n = 2,472), those reporting implausible energy intake (< 500 kcal/day or > 5000 kcal/day) (n = 594) [30–32], pregnant or lactating women (n = 310), and those diagnosed with renal failure (n = 64), cirrhosis (n = 58), or hypertension, diabetes, and dyslipidemia (n = 9,280). Consequently, 18,565 participants were included in the final analysis (Fig. 1).

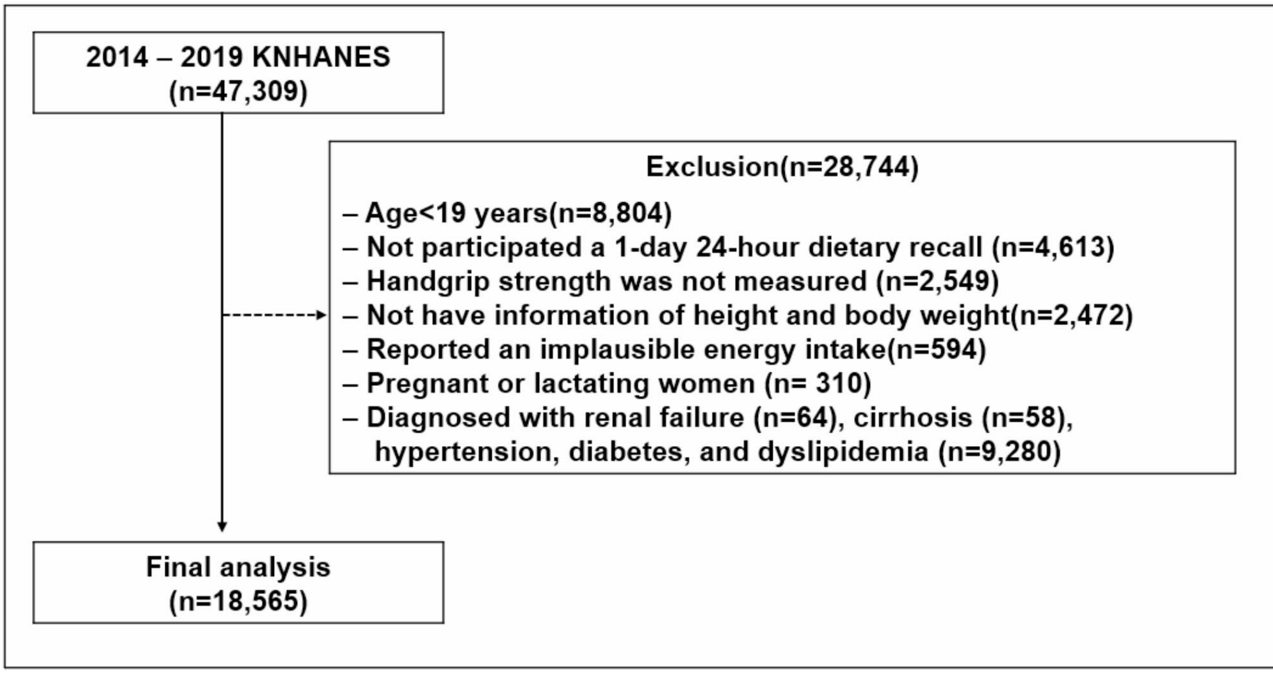

Fig. 1 The flow chart for selecting study participants

The KNHANES was approved by the KCDC Institutional Review Board through 2014 (approval number: 2013-12EXP-03–5 C) and was conducted under the Bioethics Act without deliberation from 2015 to 2017. Approval was required again from 2018 onward (approval numbers: 2018-01-03-P-A, 2018-01-03-C-A). Informed consent was obtained from all the participants.

Dietary intake

Dietary intake was assessed using a 1-day 24-hour dietary recall method. A trained interviewer recorded all foods and beverages consumed by the participants within a 24-hour period in their homes. Protein quantity was evaluated in terms of absolute intake (g/day) and as a percentage of total energy from protein (% of energy), while protein intake from animal and plant sources, along with amino acid intake, was assessed as indicators of protein quality. Daily amino acid intake (g) was estimated by linking the 24-hour dietary recall data to an amino acid content database (DB). This DB was expanded by the research team using the Korean Standard Food Composition Table, published by the Rural Development Administration, the Ministry of Food and Drug Safety's food nutrient database, and research reports from the Korea Health Industry Development Institute [33–35]. This study evaluated 18 amino acids, comprising EAAs such as isoleucine, leucine, valine, methionine, threonine, tryptophan, lysine, phenylalanine, and histidine, and nonessential amino acids (NEAAs), including arginine, tyrosine, cysteine, alanine, aspartic acid, glutamic acid, glycine, serine, and proline, as per the 2020 Dietary Reference Intakes for Koreans [8]. EAA density was estimated as the amount of EAA intake relative to total protein intake (EAAs/total protein) [36].

Assessment of HG

HG was measured three times for each hand, starting with the dominant hand, in a standing position, using a digital HG dynamometer (T.K.K 5401, Takei Scientific Instruments Co., Ltd., Niigata City, Japan). The participants were allowed 60 s of rest between each round of measurements, for both hands. In this study, the highest of the six values measured by both hands was used [37]. Additionally, in participants aged ≥ 65 years, low HG was diagnosed based on the 2019 Asian Working Group on Sarcopenia criteria [1], defined as < 28 kg for males and < 18 kg for females.

Sociodemographic and lifestyle factors

The sociodemographic variables that were evaluated in this study included sex, age, educational level, household income, marital status, and region. The lifestyle factors included smoking status, alcohol consumption, and physical activity. The age groups were divided into 19–64 years and 65 years or older. Educational level was categorized as middle school or less, high school, or college or above. Household income levels were classified as low, lower middle, upper middle, and high using quartiles of monthly equivalized household income, which was calculated by dividing monthly household income by the square root of the number of household members [38–40]. Marital status was categorized as unmarried, married (living with a spouse), or married (separated, widowed, or divorced). Region was divided into urban and rural areas, and current smoking was defined as "yes" if the individual had smoked more than five packs (100 cigarettes) in their lifetime and was currently smoking. Alcohol consumption was categorized as "none" for individuals who never drank or drank less than once per month over the past year; "moderate" for those who drank more than once per month; and "high" for those who drank more than seven glasses of alcoholic beverages per occasion for males and more than five for females, more than twice a week [41–43]. Resistance exercise was defined as performing activities such as push-ups, sit-ups, dumbbell exercises, weightlifting, or iron bar exercises for more than two days in the past week.

Statistical analysis

Statistical analyses were performed using SAS 9.4 (SAS Institute, Cary, NC, USA). The complex sample design factors of KNHANES, including strata, clusters, and weights, were incorporated into the PROC SURVEY procedure. All continuous variables were presented as mean ± standard error (SE), and categorical variables were reported as frequency (%). Dietary protein and amino acid intakes (g/day) were energy-adjusted using the residual method. Differences in general characteristics and dietary protein and amino acid intakes by sex and age group were tested using a chi-square test for categorical variables and a t-test for continuous variables. Differences in HG levels across quintiles and per unit of dietary protein intake (% of energy) and amino acid intake (g/day) were examined using a general linear model (GLM), with adjustments for confounding variables. Tukey's post-hoc analysis was performed to test statistically significant differences in HG between quintiles. Multiple logistic regression analysis was used for participants aged 65 years or older to estimate the odds ratio (OR) and 95% confidence interval (CI) for low HG across quintiles of dietary protein and amino acid intake, with the first quintile as the reference group. In the GLM and multiple logistic regression analyses, Model 1 adjusted for age, sex, total energy intake, educational level, household income, marital status, region, alcohol consumption, smoking status, and body mass index, while Model 2 further included resistance exercise. Additionally, because protein intake is related to other macronutrients, carbohydrate intake (% of energy) was adjusted for in Model 3. Linear trends across quintiles were assessed using the median value of each quintile as a continuous variable. Stratified analyses by sex and age group (19–64 years and ≥ 65 years) were also conducted. All statistical tests were two-tailed, and statistical significance was set at $p < 0.05$.

Results

General characteristics of the study participants by sex and age group

The general characteristics of the study participants stratified by sex and age group are shown in Table 1. The average age of the participants was 41.8 years, and the study participants were comprised of 50.9% males and 49.1% females. About half of the participants (49.2%) had attained a college degree or higher. The proportion of current smokers was 22.0%, and high-risk drinkers accounted for 12.4% of the total. Additionally, 23.4% of the participants performed resistance exercise for more than two days in the past week. The average HG of the participants was 33.8 kg, and approximately 4.9% of the study participants had low HG. All socioeconomic and lifestyle factors showed significant differences by sex and age group ($p < 0.05$ for all).

Dietary protein and amino acid intake by sex and age group

Table 2 presents dietary protein and amino acid intake by sex and age group. The average protein intake of all the participants was 72.5 g/day, accounting for 15.3% of their energy intake. Energy-adjusted total protein intake was highest in males aged 19–64 years (90.7 g/day) and lowest in females aged ≥ 65 years (46.0 g/day). Animal protein intake (% of energy) was higher in both males and females aged 19–64 years compared to those aged 65 years, whereas plant protein intake was higher in those aged ≥ 65 years ($p < 0.001$ for all). The average total amino acid intake was 62.1 g/day, including 24.9 g/day of EAAs and 37.3 g/day from NEAAs. Overall, amino acid intake was highest in males aged 19–64 years and lowest in females aged ≥ 65 years ($p < 0.001$ for all).

Association between protein and amino acid intake and HG

Table 3 presents HG levels according to quintiles of protein intake (% of energy) and amino acid intake, as well as the estimated HG change per one-unit increase based on the GLM. Among all participants, HG was slightly higher in higher quintiles of total and plant protein intake in Model 1 (p for trend = 0.0067 for total protein and 0.0131 for plant protein). These associations remained significant after further adjustments for resistance exercise (Model 2) and carbohydrate intake (Model 3). The effect sizes (β) for a 1% increase in total and plant protein intake were 0.04 and 0.07, respectively ($p < 0.05$ for both). Regarding amino acids, the p for trend across quintiles of EAAs and NEAAs was significant in the fully adjusted model. Nonetheless, neither EAA nor NEAA intake, as continuous variables, showed a significant association with HG levels.

Table 1 General characteristics of study participants from the 2014–2019 KNHANES[1)]

Characteristic	Total (*n* = 18,565)	Sex			Age group		
		Males (*n* = 7,886)	Females (*n* = 10,679)	*P* value	19–64 years (*n* = 16,095)	≥ 65 years (*n* = 2,470)	*P* value
Sex							0.0189
Male	7,886 (50.9)	-	-		6,595 (50.7)	1,291 (53.5)	
Female	10,679 (49.1)	-	-		9,500 (49.3)	1,179 (46.5)	
Age (years)	41.8 ± 0.2	41.5 ± 0.2	42.1 ± 0.2	0.0216	-	-	
Educational level				< 0.001			< 0.001
Middle school or less	2,911 (11.5)	1,110 (9.4)	1,801 (13.6)		1,473 (7.3)	1,438 (65.2)	
High school	6,248 (39.3)	2,682 (40.7)	3,566 (37.9)		5,865 (40.8)	383 (19.7)	
College or above	7,951 (49.2)	3,370 (50.0)	4,581 (48.5)		7,664 (51.9)	287 (15.2)	
Household income				0.0429			< 0.001
Low	2,314 (10.4)	995 (9.9)	1,319 (10.9)		1,234 (7.7)	1,080 (42.7)	
Lower middle	4,477 (23.5)	1,904 (23.2)	2,573 (23.9)		3,756 (23.1)	721 (29.2)	
Upper middle	5,538 (30.9)	2,372 (31.7)	3,166 (30.1)		5,161 (32.1)	377 (15.9)	
High	6,179 (35.2)	2,588 (35.3)	3,591 (35.1)		5,900 (37.1)	279 (12.2)	
Marital status				< 0.001			< 0.001
Unmarried	4,142 (30.4)	2,140 (35.4)	2,002 (25.2)		4,132 (32.9)	10 (0.4)	
Married	12,769 (63.1)	5,351 (60.9)	7,418 (65.4)		10,991 (62.3)	1,778 (73.1)	
Separated, widowed, or divorced	1,648 (6.5)	395 (3.7)	1,253 (9.4)		966 (4.8)	682 (26.5)	
Region				< 0.001			< 0.001
Urban	15,468 (87.1)	6,457 (86.3)	9,011 (87.9)		13,728 (88.0)	1,740 (76.5)	
Rural	3,097 (12.9)	1,429 (13.7)	1,668 (12.1)		2,367 (12.0)	730 (23.5)	
Current smoking[2)]				< 0.001			< 0.001
Yes	3,305 (22.0)	2,748 (37.5)	557 (6.1)		3,051 (22.9)	254 (11.4)	
No	14,835 (78.0)	4,935 (62.5)	9,900 (93.9)		12,767 (77.1)	2,068 (88.6)	
Alcohol consumption[3)]				< 0.001			< 0.001
None	7,629 (37.8)	2,187 (27.0)	5,442 (48.9)		6,218 (36.0)	1,411 (59.6)	
Moderate	8,517 (49.8)	4,128 (54.8)	4,389 (44.6)		7,715 (50.9)	802 (35.3)	
High	1,999 (12.4)	1,371 (18.2)	628 (6.5)		1,888 (13.0)	111 (5.1)	
Resistance exercise[4)]				< 0.001			0.0010
Yes	3,726 (23.4)	2,159 (30.7)	1,567 (16.0)		3,304 (23.7)	422 (20.1)	
No	13,670 (76.6)	5,151 (69.3)	8,519 (84.0)		11,925 (76.3)	1,745 (79.9)	
Handgrip strength (kg)	33.8 ± 0.1	42.2 ± 0.1	25.2 ± 0.1	< 0.001	34.4 ± 0.1	27.4 ± 0.2	< 0.001
Low handgrip strength[5)]				< 0.001			< 0.001
Yes	1,198 (4.9)	408 (3.5)	790 (6.4)		568 (3.3)	630 (24.9)	
No	17,367 (95.1)	7,478 (96.5)	9,889 (93.6)		15,527 (96.7)	1,840 (75.1)	

Values are presented as n (weighted %) or mean ± SE

*Number of missing values: educational level (1,455), household income (57), marital status (6), current smoking (425), alcohol consumption (420), and resistance exercise (1,169)

1) KNHANES, Korea National Health and Nutrition Examination Survey

2) Yes: smoked more than 5 packs (100 cigarettes) in one's lifetime and currently smoking

3) None: never consumed alcoholic beverage or drank less than once per month in the past year; moderate: drank more than once per month; high: consumed over seven glasses of alcoholic beverages per occasion (males) or over five (females), more than twice per week

4) Yes: performed activities such as push-ups, sit-ups, dumbbell exercises, weightlifting, or iron bar exercises for more than two days in the past week

5) Yes: handgrip strength was less than 28 kg for males and less than 18 kg for females

In participants aged 19–64 years, total protein intake in males and plant protein intake in females were positively associated with HG ($\beta = 0.07$ for males and 0.06 for females; $p < 0.05$ for both) (Supplemental Table 1). No significant differences were observed in adults aged ≥ 65 years for either sex. When stratified by resistance exercise status, plant protein intake in females were positively associated with HG among those who did not perform resistance exercise ($\beta = 0.07$; $p = 0.0107$) (Supplemental Table 2). Supplemental Tables 3 and 4 present HG levels according to amino acid intake, and no significant differences were found by age group and resistance exercise status in either sex.

Table 2 Dietary protein and amino acid intake of study participants according to sex and age group[1)]

Protein/amino acid[2)]	Total (n = 18,565)	Males (n = 7,886)		Females (n = 10,679)		P value
		19-64 years (n = 6,595)	≥ 65 years (n = 1,291)	19-64 years (n = 9,500)	≥ 65 years (n = 1,179)	
Protein (g/day)						
Total protein	72.5 ± 0.2	90.7 ± 0.4	63.9 ± 0.5	63.8 ± 0.2	46.0 ± 0.4	< 0.001
Animal protein	41.9 ± 0.4	56.8 ± 0.7	37.0 ± 1.8	38.0 ± 0.4	22.4 ± 1.3	< 0.001
Plant protein	34.6 ± 0.1	40.5 ± 0.2	39.1 ± 0.3	30.6 ± 0.1	30.3 ± 0.2	< 0.001
Protein (% of energy)						
Total protein	15.3 ± 0.0	15.9 ± 0.1	14.1 ± 0.1	15.0 ± 0.1	12.9 ± 0.1	< 0.001
Animal protein	8.0 ± 0.1	8.7 ± 0.1	5.5 ± 0.1	7.8 ± 0.1	4.4 ± 0.1	< 0.001
Plant protein	7.3 ± 0.0	7.2 ± 0.0	8.6 ± 0.1	7.2 ± 0.0	8.5 ± 0.1	< 0.001
Total amino acids	62.1 ± 0.2	78.5 ± 0.4	54.1 ± 0.5	54.4 ± 0.2	38.4 ± 0.4	< 0.001
EAAs	24.9 ± 0.1	31.6 ± 0.2	21.5 ± 0.2	21.7 ± 0.1	15.2 ± 0.2	< 0.001
BCAAs	11.8 ± 0.0	14.9 ± 0.1	10.8 ± 0.1	10.2 ± 0.0	7.8 ± 0.1	< 0.001
Isoleucine	2.9 ± 0.0	3.7 ± 0.0	2.6 ± 0.0	2.5 ± 0.0	1.9 ± 0.0	< 0.001
Leucine	5.2 ± 0.0	6.6 ± 0.0	4.7 ± 0.0	4.5 ± 0.0	3.4 ± 0.0	< 0.001
Valine	3.7 ± 0.0	4.6 ± 0.0	3.5 ± 0.0	3.2 ± 0.0	2.5 ± 0.0	< 0.001
Lysine	3.7 ± 0.0	4.8 ± 0.0	2.8 ± 0.0	3.2 ± 0.0	1.9 ± 0.0	< 0.001
Methionine	1.3 ± 0.0	1.7 ± 0.0	1.0 ± 0.0	1.1 ± 0.0	0.7 ± 0.0	< 0.001
Phenylalanine	3.0 ± 0.0	3.8 ± 0.0	2.7 ± 0.0	2.6 ± 0.0	2.0 ± 0.0	< 0.001
Threonine	2.5 ± 0.0	3.2 ± 0.0	2.0 ± 0.0	2.2 ± 0.0	1.4 ± 0.0	< 0.001
Tryptophan	0.6 ± 0.0	0.8 ± 0.0	0.5 ± 0.0	0.5 ± 0.0	0.4 ± 0.0	< 0.001
Histidine	1.9 ± 0.0	2.5 ± 0.0	1.5 ± 0.0	1.7 ± 0.0	1.1 ± 0.0	< 0.001
NEAAs	37.3 ± 0.1	46.9 ± 0.2	32.6 ± 0.3	32.7 ± 0.1	23.3 ± 0.2	< 0.001
Arginine	4.1 ± 0.0	5.2 ± 0.0	3.8 ± 0.0	3.6 ± 0.0	2.6 ± 0.0	< 0.001
Tyrosine	2.0 ± 0.0	2.5 ± 0.0	1.6 ± 0.0	1.7 ± 0.0	1.1 ± 0.0	< 0.001
Cysteine	0.7 ± 0.0	0.9 ± 0.0	0.7 ± 0.0	0.7 ± 0.0	0.5 ± 0.0	< 0.001
Alanine	3.8 ± 0.0	4.8 ± 0.0	3.5 ± 0.0	3.2 ± 0.0	2.5 ± 0.0	< 0.001
Aspartic acid	6.0 ± 0.0	7.5 ± 0.0	5.4 ± 0.1	5.3 ± 0.0	3.9 ± 0.0	< 0.001
Glutamic acid	11.1 ± 0.0	14.0 ± 0.1	9.2 ± 0.1	9.9 ± 0.0	6.6 ± 0.1	< 0.001
Glycine	2.6 ± 0.0	3.4 ± 0.0	2.0 ± 0.0	2.3 ± 0.0	1.4 ± 0.0	< 0.001
Proline	4.2 ± 0.0	5.2 ± 0.0	4.0 ± 0.0	3.6 ± 0.0	3.0 ± 0.0	< 0.001
Serine	2.7 ± 0.0	3.4 ± 0.0	2.3 ± 0.0	2.4 ± 0.0	1.6 ± 0.0	< 0.001

Values are presented as mean ± SE

1) EAA, essential amino acid; BCAA, branched-chain amino acid; NEAA, nonessential amino acid

2) Protein and amino acid intake (g/day) were energy-adjusted using the residual method

Association between protein and amino acid intake and low HG

In Model 2, older participants in the highest quintile groups had a lower risk of low HG compared to those in the lowest quintile groups for total protein (OR: 0.54, 95% CI: 0.35–0.84, p for trend = 0.0362), EAA (OR: 0.59, 95% CI: 0.38–0.90, p for trend = 0.0294), and NEAA (OR: 0.52, 95% CI: 0.34–0.79, p for trend = 0.0098) intake (Table 4). However, these significant associations disappeared after further adjustment of carbohydrate intake for total protein and BCAA intake (Model 3). In the fully adjusted model, the highest NEAA intake group had a lower OR for low HG than the lowest intake group, but the linear trend across quintiles was not significant. Additionally, participants in quintiles 3 and 4 of plant protein intake had a lower risk of low HG compared to those in the lowest quintile group, whereas the OR for quintile 5 was not significant (OR for quintile 3: 0.51, 95% CI: 0.33–0.77; OR for quintile 4: 0.62, 95% CI: 0.40–0.98). In the sex-stratified analysis, a significant association between NEAA intake and low HG was observed only in males in the fully adjusted model (Supplementary Tables 5 and 6).

Discussion

In a representative sample of 18,565 Korean adults, higher total and plant protein intakes, expressed as percentages of total energy, were positively associated with HG levels after adjusting for confounding variables, though the effect sizes were relatively small. Among older adults, those in the highest quintile of NEAA intake had a lower risk of low HG compared to those in the lowest quintile; however, no significant linear trend was observed. In contrast, animal protein intake was not

Table 3 Handgrip strength levels (kg) according to quintiles of dietary protein and amino acids[1)]

Total (*n* = 18,565)	**Quintile of dietary protein intake (% of energy)**							**Per 1% increase**		
	Quintile 1 (*n* = 3,713)	**Quintile 2 (*n* = 3,713)**	**Quintile 3 (*n* = 3,713)**	**Quintile 4 (*n* = 3,713)**	**Quintile 5 (*n* = 3,713)**	***P* value**	***P* for trend**	**β**	**SE**	***P* value**
Total protein										
Median (range)	10.3 (1.4–11.5)	12.5 (11.5–13.4)	14.3 (13.4–15.3)	16.5 (15.3–18.0)	20.7 (18.0-62.7)					
Model 1[2)]	33.0 ± 0.2	33.2 ± 0.2	33.1 ± 0.2	33.2 ± 0.1	33.4 ± 0.2	0.0614	0.0067	0.04	0.01	0.0030
Model 2[3)]	33.5 ± 0.2	33.7 ± 0.2	33.6 ± 0.2	33.7 ± 0.2	33.9 ± 0.2	0.1995	0.0293	0.03	0.01	0.0150
Model 3[4)]	33.4 ± 0.2	33.6 ± 0.2	33.6 ± 0.2	33.7 ± 0.2	33.9 ± 0.2	0.0881	0.0084	0.04	0.01	0.0027
Animal protein										
Median (range)	1.9 (0.0-3.3)	4.5 (3.3–5.5)	6.7 (5.5–7.9)	9.3 (7.9–11.1)	14.3 (11.1–60.3)					
Model 1	33.1 ± 0.2	33.3 ± 0.2	33.0 ± 0.2	33.2 ± 0.2	33.3 ± 0.2	0.2670	0.2772	0.02	0.01	0.0796
Model 2	33.6 ± 0.2	33.8 ± 0.2	33.5 ± 0.2	33.7 ± 0.2	33.7 ± 0.2	0.3639	0.5309	0.01	0.01	0.2294
Model 3	33.6 ± 0.2	33.7 ± 0.2	33.5 ± 0.2	33.7 ± 0.2	33.8 ± 0.2	0.3064	0.3755	0.02	0.01	0.1020
Plant protein										
Median (range)	4.9 (0.1–5.7)	6.3 (5.7–6.8)	7.3 (6.8–7.9)	8.4 (7.9–9.1)	10.2 (9.1–24.1)					
Model 1	32.9 ± 0.2	33.1 ± 0.2	33.3 ± 0.2	33.3 ± 0.2	33.3 ± 0.2	0.0561	0.0131	0.06	0.03	0.0359
Model 2	33.3 ± 0.2	33.6 ± 0.2	33.8 ± 0.2*	33.8 ± 0.2*	33.8 ± 0.2	0.0329	0.0085	0.06	0.03	0.0215
Model 3	33.3 ± 0.2	33.6 ± 0.2	33.8 ± 0.2*	33.8 ± 0.2*	33.8 ± 0.2	0.0198	0.0064	0.07	0.03	0.0178
Total (*n* = 18,565)	**Quintile of dietary amino acid intake (g/day)[5)]**							**Per 1 g increase[6)]**		
	Quintile 1 (*n* = 3,713)	**Quintile 2 (*n* = 3,713)**	**Quintile 3 (*n* = 3,713)**	**Quintile 4 (*n* = 3,713)**	**Quintile 5 (*n* = 3,713)**	***P*value**	***P*for trend**	***β***	**SE**	***P*val-ue**
EAAs										
Median (range)	15.3 (0.3–17.7)	19.6 (17.7–21.3)	23.1 (21.3–24.9)	27.1 (24.9–30.0)	34.9 (30.0-260.9)					
Model 1	33.1 ± 0.2	33.1 ± 0.2	33.1 ± 0.2	33.2 ± 0.2	33.4 ± 0.2	0.2950	0.0297	0.011	0.006	0.0642
Model 2	33.6 ± 0.2	33.6 ± 0.2	33.6 ± 0.2	33.6 ± 0.2	33.8 ± 0.2	0.5824	0.0999	0.007	0.006	0.2009
Model 3	33.5 ± 0.2	33.6 ± 0.2	33.6 ± 0.2	33.7 ± 0.2	33.9 ± 0.2	0.3834	0.0460	0.010	0.007	0.1162
BCAAs										
Median (range)	7.7 (0.1–8.9)	9.7 (8.9–10.5)	11.2 (10.5–12.0)	12.8 (12.0–14.0)	16.0 (14.0-123.7)					
Model 1	33.2 ± 0.2	32.9 ± 0.2	33.2 ± 0.2	33.2 ± 0.2	33.3 ± 0.2	0.2431	0.2154	0.020	0.014	0.1468
Model 2	33.7 ± 0.2	33.4 ± 0.2	33.7 ± 0.2	33.7 ± 0.2	33.7 ± 0.2	0.3755	0.4302	0.013	0.013	0.3476
Model 3	33.7 ± 0.2	33.4 ± 0.2	33.7 ± 0.2	33.7 ± 0.2	33.7 ± 0.2	0.3386	0.3373	0.017	0.015	0.2586
NEAAs										
Median (range)	24.2 (0.6–27.7)	30.4 (27.8–32.8)	35.2 (32.8–37.6)	40.4 (37.6–44.1)	50.5 (44.1-331.4)					
Model 1	32.9 ± 0.2	33.2 ± 0.2	33.2 ± 0.2	33.3 ± 0.2	33.4 ± 0.2	0.1317	0.0153	0.008	0.004	0.0493
Model 2	33.4 ± 0.2	33.7 ± 0.2	33.7 ± 0.2	33.7 ± 0.2	33.8 ± 0.2	0.3114	0.0641	0.006	0.004	0.1466
Model 3	33.4 ± 0.2	33.6 ± 0.2	33.7 ± 0.2	33.8 ± 0.2	33.8 ± 0.2	0.2055	0.0316	0.008	0.005	0.0892
EAAs/Total protein										
Median (range)	0.28 (0.04–0.30)	0.32 (0.30–0.33)	0.34 (0.33–0.35)	0.36 (0.35–0.37)	0.39 (0.37–2.30)					
Model 1	33.3 ± 0.2	33.1 ± 0.2	33.3 ± 0.2	33.2 ± 0.2	33.0 ± 0.2	0.3235	0.0767	-0.124	0.082	0.1303
Model 2	33.8 ± 0.2	33.6 ± 0.2	33.8 ± 0.2	33.6 ± 0.2	33.5 ± 0.2	0.3218	0.0936	-0.122	0.082	0.1359
Model 3	33.8 ± 0.2	33.6 ± 0.2	33.8 ± 0.2	33.6 ± 0.2	33.5 ± 0.2	0.2329	0.0931	-0.123	0.083	0.1388

Values are presented as adjusted mean ± SE

1) EAA, essential amino acid; BCAA, branched-chain amino acid; NEAA, nonessential amino acid

2) Adjusted for age, sex, total energy intake, educational level, household income, marital status, region, alcohol consumption, smoking, and body mass index

3) Additionally adjusted for resistance exercise

4) Additionally adjusted for carbohydrate intake (% of energy)

5) Amino acid intake (g/day) was energy-adjusted using the residual method

6) Per 0.1 g increase for EAAs/Total protein

Table 4 Multivariable-adjusted odds ratios and 95% confidence intervals of low handgrip strength according to quintiles of dietary protein and amino acid intake among participants aged 65 years or older[1)]

Dietary protein intake (% of energy)	**Quintile 1 (*n* = 494)**	**Quintile 2 (*n* = 494)**	**Quintile 3 (*n* = 494)**	**Quintile 4 (*n* = 494)**	**Quintile 5 (*n* = 494)**	***P* for trend**
Total protein						
Median (range)	9.34 (5.81–10.40)	11.29 (10.41–12.15)	12.96 (12.15–13.77)	14.72 (13.77–15.95)	18.14 (15.95–38.43)	
Model 1[2)]	1.00	0.61 (0.42–0.89)	0.84 (0.56–1.26)	0.71 (0.46–1.09)	0.52 (0.34–0.81)	0.0203
Model 2[3)]	1.00	0.61 (0.42–0.89)	0.86 (0.57–1.29)	0.74 (0.48–1.13)	0.54 (0.35–0.84)	0.0362
Model 3[4)]	1.00	0.63 (0.43–0.94)	0.91 (0.58–1.42)	0.82 (0.50–1.33)	0.62 (0.36–1.09)	0.2519
Animal protein						
Median (range)	0.31 (0.00-1.23)	2.23 (1.23–3.11)	3.99 (3.11–5.02)	6.08 (5.04–7.55)	10.22 (7.56–28.37)	
Model 1	1.00	0.85 (0.58–1.25)	0.83 (0.54–1.27)	0.92 (0.63–1.34)	0.71 (0.46–1.09)	0.1929
Model 2	1.00	0.85 (0.58–1.25)	0.85 (0.55–1.30)	0.97 (0.66–1.41)	0.73 (0.47–1.13)	0.2695
Model 3	1.00	0.90 (0.61–1.33)	0.95 (0.61–1.49)	1.16 (0.76–1.76)	1.02 (0.61–1.72)	0.6540
Plant protein						
Median (range)	6.32 (1.74–7.02)	7.50 (7.02–7.95)	8.49 (7.95–8.97)	9.53 (8.97–10.20)	11.21 (10.21–19.51)	
Model 1	1.00	0.93 (0.60–1.42)	0.61 (0.41–0.93)	0.75 (0.48–1.16)	0.84 (0.57–1.24)	0.2912
Model 2	1.00	0.92 (0.59–1.42)	0.60 (0.39–0.91)	0.73 (0.47–1.13)	0.83 (0.56–1.23)	0.2689
Model 3	1.00	0.80 (0.52–1.22)	0.51 (0.33–0.77)	0.62 (0.40–0.98)	0.75 (0.50–1.11)	0.1546
Dietary amino acid intake (g/day)[5)]	Quintile 1 (*n* = 494)	Quintile 2 (*n* = 494)	Quintile 3 (*n* = 494)	Quintile 4 (*n* = 494)	Quintile 5 (*n* = 494)	*P* for trend
EAA						
Median (range)	14.62 (3.24–16.42)	17.95 (16.42–19.36)	20.84 (19.37–22.38)	24.08 (22.38–26.31)	30.74 (26.32-128.56)	
Model 1	1.00	0.85 (0.58–1.24)	0.78 (0.52–1.17)	0.86 (0.57–1.29)	0.56 (0.37–0.86)	0.0140
Model 2	1.00	0.83 (0.57–1.21)	0.81 (0.54–1.21)	0.88 (0.58–1.32)	0.59 (0.38–0.90)	0.0294
Model 3	1.00	0.86 (0.58–1.25)	0.85 (0.56–1.30)	0.95 (0.61–1.49)	0.68 (0.40–1.14)	0.2430
BCAA						
Median (range)	7.91 (1.38–8.82)	9.53 (8.82–10.13)	10.76 (10.13–11.37)	12.03 (11.37–12.94)	14.63 (12.94–54.99)	
Model 1	1.00	1.28 (0.86–1.91)	1.08 (0.71–1.64)	1.16 (0.76–1.76)	0.67 (0.44–1.02)	0.0285
Model 2	1.00	1.30 (0.87–1.95)	1.10 (0.72–1.68)	1.18 (0.77–1.80)	0.71 (0.46–1.08)	0.0542
Model 3	1.00	1.30 (0.87–1.94)	1.12 (0.73–1.72)	1.24 (0.80–1.90)	0.78 (0.49–1.26)	0.3194
NEAA						
Median (range)	22.76 (6.97–25.44)	27.83 (25.44–30.03)	32.17 (30.03–34.41)	36.64 (34.42–39.57)	45.49 (39.57-226.46)	
Model 1	1.00	0.72 (0.49–1.08)	0.73 (0.50–1.07)	0.80 (0.53–1.21)	0.50 (0.33–0.75)	0.0038
Model 2	1.00	0.73 (0.49–1.08)	0.76 (0.52–1.12)	0.83 (0.55–1.25)	0.52 (0.34–0.79)	0.0098
Model 3	1.00	0.74 (0.50–1.11)	0.80 (0.53–1.20)	0.88 (0.56–1.39)	0.58 (0.35–0.97)	0.1026
EAA/Total protein						
Median (range)	0.28 (0.07–0.31)	0.32 (0.31–0.33)	0.34 (0.33–0.35)	0.36 (0.35–0.37)	0.38 (0.37–2.30)	
Model 1	1.00	1.11 (0.73–1.67)	1.15 (0.75–1.77)	0.95 (0.62–1.47)	1.51 (0.99–2.31)	0.1441
Model 2	1.00	1.09 (0.72–1.65)	1.16 (0.75–1.80)	0.96 (0.62–1.48)	1.52 (0.99–2.34)	0.1311
Model 3	1.00	1.08 (0.71–1.62)	1.16 (0.75–1.79)	0.94 (0.61–1.44)	1.54 (1.00-2.36)	0.1274

Values are presented as odds ratio (95% confidence intervals)

1) EAA: essential amino acid, BCAA: branched-chain amino acid, NEAA: nonessential amino acid

2) Adjusted for sex, age, total energy intake and educational level, household income, marital status, region, alcohol, smoking, and body mass index

3) Additionally adjusted for resistance exercise

4) Additionally adjusted for carbohydrate intake (% of energy)

5) Amino acid intake (g/day) was energy-adjusted using the residual method

significantly associated with HG levels or the risk of low HG.

Animal protein, which are considered as high-quality protein owing to their abundance in EAAs including BCAAs, are known to support increased muscle strength and mass by promoting muscle protein synthesis [44]. However, contrary to our expectations, this study did not find a significant association between animal protein intake and HG levels or low HG risk. Conversely, a 1% increase in plant protein intake was associated with a 0.07 kg increase in HG levels among all participants. Additionally, a lower risk of low HG was found in older adults whose plant protein intake ranged 8–10% of total energy (quintiles 3 and 4) compared to those consuming less than 7% (quintile 1), but no association was observed when intake exceeded 10% (quintile 5). This may partly be related to the types of plant foods consumed at different levels of plant protein intake. In Koreans, grains are the major source of plant protein [45]. A previous study found that protein intake from legumes, nuts, and seeds was inversely associated with the risk of low HG, whereas plant protein intake from other sources was not associated in Korean adults aged ≥ 50 years [46].

Previous cross-sectional studies examining the association between protein intake from different food sources and HG have reported inconsistent findings [24, 25, 46–48]. These discrepancies may be due to variations in dietary assessment methods, how protein intake is measured (e.g., g/day or % of energy), differences in participant age or country, survey periods, and confounding variables such as sociodemographic and lifestyle factors, including resistance exercise. In Korean adults aged 60 years and older, the risk of low HG decreased with increased total protein intake measured as g/kg/day after adjusting for confounding variables, such as sex, body mass index, education level, and smoking [47]. Another study found associations between both animal and plant protein intake (measured in g/day) and low HG among men aged 50 years or older [46]. Conversely, some studies in the Korean population identified a significant inverse association between animal protein intake and low HG in women aged 65 years or older [25, 48]. In the United States, among adults over 19 years of age, both animal and plant protein intakes were positively associated with HG levels after adjusting for sex, age, and race [24].

An RCT conducted on 24 adults in the United States found that both whey protein and rice protein reduced fat mass and increased LBM and skeletal muscle hypertrophy following periodic resistance exercise [49]. Similarly, in vegetarians aged 18 years or older in the United States, mung bean protein intake was shown to increase HG compared to that in the control group [50]. Furthermore, a recent prospective study of older Chinese adults found that higher plant protein intake was associated with less decline in lean mass and gait speed, as well as a reduced risk of incident sarcopenia among sarcopenia-free participants, but not total or animal protein [51]. In a cross-sectional Japanese study [52], vegetable protein intake was positively associated with SMI in patients with type 2 diabetes mellitus. These findings suggest that plant protein may have beneficial effects on muscle mass; however, further prospective and intervention studies are needed to elucidate the underlying mechanisms.

Additionally, this study evaluated dietary amino acid intake by type as an index of protein quality. A 1 g increase in energy-adjusted EAA, BCAA, and NEAA intake was not significantly associated with HG levels. However, significant linear trends were observed across quintiles of EAA and NEAA intake. Previously, BCAA intake was not associated with HG in Korean older adults, whereas only leucine showed a positive association [28]. In contrast, EAA and BCAA intake per kg of body weight were positively associated with HG in American adults aged 33–71 years [26].

Meanwhile, the group with the highest NEAA intake had a lower risk of low HG among older people, but there was no significant association with EAA or BCAA intake. These findings could be partly explained by the food sources of amino acids in Korean adults. Although animal foods are well-known sources of EAAs, including BCAAs [53], our supplementary analysis revealed that the primary source of amino acids was grains, followed by meat and seafood, regardless of the type of amino acid (data not shown). Similarly, grain-based foods have been reported to be major sources of BCAAs in older Koreans [28]. A recent cross-sectional study of 5,971 Korean older adults categorized EAA by food source (animal/plant) and found a significant association between HG and EAAs from animal sources, but not from plant sources [27]. These findings suggest that the quality of EAA may vary by food source, and further prospective studies are needed to investigate the effects of amino acids on muscle mass and strength in Korean populations, considering the type, food sources, and interactions with other macronutrients.

The average protein intake of the study participants was 15.3% of the total energy intake, similar to the 15.2% reported in a previous study using 1998–2018 KNHANES data [54]. Compared to other countries, the protein intake of Koreans was higher than that of the Chinese (13.1%) according to the 1991–2015 China Health and Nutrition Survey (CHNS) [55], but slightly lower than that of Americans (16.4%) based on 1999–2016 NHANES data [56]. Approximately 87.6% of the participants in this study consumed protein within the acceptable macronutrient distribution range (7–20% of energy) [57], while 11.9% exceeded 20% of their energy intake from protein. Despite a continuous increase in animal food consumption in Korea [58], plant protein still constitutes a relatively high proportion of the total protein intake. Therefore, protein and amino acid intake patterns in the Korean diet should be considered when developing recommendations for improving muscle health and preventing sarcopenia.

The strengths of this study are as follows. First, it used a large, nationally representative sample of Koreans. Second, although most previous studies focused on the relationship between protein intake and HG among older adults, this study included all adults over the age of 19 years. Finally, this study examined the comprehensive aspects of dietary protein by considering food sources and amino acids based on the amino acid DB. However, this study has several limitations that should be considered when interpreting the findings. First, the cross-sectional study design did not allow for the determination of causal relationships between protein and amino acid intake and HG. Second, estimating the participants' usual intake based on a 1-day 24-hour dietary recall is challenging. Third, the findings may not be generalizable to other populations as the study focused solely on Koreans. Fourth, the incompleteness of the amino acid DB may have led to an underestimation of amino acid intake. However, because the DB covers the amino acid content of 84.9% of food consumption, this may reduce the likelihood of underestimation. Lastly, although the study carefully adjusted for confounding variables, potential biases may still exist.

Conclusion

These study findings suggest that a high intake of NEAAs and a moderately high intake of plant protein may be associated with a lower risk of low HG among Korean older adults. Further prospective studies are necessary to explore the effects of protein and amino acids on muscle mass and strength in Koreans, considering the types of protein, food sources, and interactions with other macronutrients.

Abbreviations

KNHANES	Korea National Health and Nutrition Examination Survey
HG	Handgrip strength
EAA	Essential amino acid
BCAA	Branched-chain amino acid
NEAA	Non essential amino acid

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12937-025-01131-7.

Supplementary Material 1

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Not applicable.

Author contributions

H.H. and K.H. designed the study. H.H. analyzed the data and drafted the manuscript. H.H. and S.K. constructed the amino acid database. K.H. supervised the project. All authors read and approved the final manuscript.

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Data availability

The datasets analyzed during the current study are available in the KNHANES website, https://knhanes.kdca.go.kr.

Declarations

Ethical approval

The KNHANES was approved by the KCDC Institutional Review Board through 2014 (approval number: 2013-12EXP-03–5 C) and was conducted under the Bioethics Act without deliberation from 2015 to 2017. Approval was required again from 2018 onward (approval numbers: 2018-01-03-P-A, 2018-01-03-C-A). Informed consent was obtained from all the participants.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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