CLINICAL INVESTIGATION

Prospective Associations of Diet Quality With Incident Frailty in Older Adults: The Health, Aging, and Body Composition Study

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OBJECTIVE: To examine associations of diet quality indicators with 4-year incidence of frailty in community-dwelling older adults.

DESIGN: Prospective cohort study.

SETTING: Health, Aging, and Body Composition Study, United States.

PARTICIPANTS: Community-dwelling men and women, aged 70 to 81 years in 1998 to 1999 (first follow-up, present study's baseline; n = 2154).

MEASUREMENTS: At first follow-up, dietary intake over the preceding year was assessed with a food frequency questionnaire. Indicators of diet quality include the Healthy Eating Index (categorized as poor, medium, and good), energy intake, and protein intake (a priori adjusted for energy intake using the nutrient residual model). Frailty status was determined using Fried's five-component frailty phenotype and categorized into "robust" (0 components present), "pre-frailty" (1 - 2 components present), or "frail" (3-5 components present). Cox proportional hazards analysis was used to examine associations of the diet quality indicators with 4-year incidence of (1) frailty and (2) pre-frailty or frailty. Competing risk analysis was used to examine associations with frailty by accounting for competing risks of death.

RESULTS: During the 4-year follow-up, 277 of the 2154 participants, robust or pre-frail at baseline, developed frailty, and 629 of the 1020 participants, robust at baseline, developed pre-frailty or frailty. Among the robust and pre-frail, after adjustment for confounders including energy intake, those consuming poor- and medium-quality diets had a higher frailty incidence than those consuming good-quality diets (hazard ratio [HR] = 1.92 [95% confidence interval {CI} = 1.17-3.17] and HR = 1.40 [95% CI = 0.99-1.98], respectively). No associations for energy or protein intake were observed. Competing risk analyses yielded similar results. Among the robust, those with lower vegetable protein intake had a higher "pre-frailty or frailty" incidence (per −10 g/d: HR = 1.20; 95% CI = 1.04-1.39). No other associations were observed.

CONCLUSION: Poorer overall diet quality and lower vegetable protein intake may increase the risk of becoming frail in old age. We found no association for intakes of energy, total protein, or animal protein. **J Am Geriatr Soc 00:1-8, 2019.**

Key words: dietary intake; energy; frailty phenotype; old age; protein

With the older population growing rapidly, an increase in the prevalence of frailty is to be expected. Given the components of frailty (ie, weight loss, weakness, exhaustion, slowness, and physical inactivity),[1] diet is considered an important determinant of its development. Older adults especially may benefit from dietary strategies as their diet is commonly observed to be of insufficient overall quality[2-4] or low in protein.[3,5]

Four prospective studies showed that better adherence to a Mediterranean diet, as assessed with the Mediterranean Diet Score (MDS) or the Elderly Dietary Index, was associated with lower frailty risk in older adults,[6-9] whereas one study[10] showed no association. Prospective studies investigating associations with adherence to general dietary guidelines, as assessed with the Diet Quality Index or the Healthy Diet Indicator, showed both inverse[10,11] and no associations.[7] Few studies have examined single dietary components. Lower energy intake was associated with higher risk of (pre-)

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frailty,[12] and lower protein intake was associated with higher risk of frailty in two[13,14] but not all prospective studies.[11,12]

None of the previous studies considered time to onset of frailty nor potential competing risks of death. The latter is especially important in older adults given their high mortality rate.[15] This study examines associations of diet quality indicators relevant in old age with 4-year incidence of frailty (accounting for competing risks) and pre-frailty in community-dwelling older adults. To explore underlying pathways, we examined associations with the individual frailty components as secondary analyses.

METHODS

Study Population

Data are from the Health, Aging, and Body Composition (Health ABC) Study, which consists of 3075 US community-dwelling black and white older adults, aged 70 to 79 years at baseline (1997-1998). Detailed information on recruitment can be found elsewhere.[5] All participants provided written informed consent. The institutional review boards of the University of Tennessee, Memphis, TN, and the University of Pittsburgh, Pittsburgh, PA, approved the study.

At the Health ABC Study's baseline, participants underwent a home interview and a clinical examination. Follow-up data were collected annually. Dietary intake was assessed at the 12-month follow-up examination (1998-1999), which serves as baseline for the present study.

Analytic Sample

Participants were excluded for the following reasons (Supplementary Figure S1): dropped out before the present study's baseline examination (n = 77); missing (n = 285) or invalid (n = 57) dietary data; high energy intakes (ie, greater than 3500 kcal/d [women] or greater than 4000 kcal/d [men])[16] (n = 41); unknown baseline frailty status (n = 28); frail at baseline (n = 175); or no or insufficient follow-up data on frailty (n = 258). In total, 2154 robust or pre-frail participants were included in the analyses of time to frailty. For the analyses of time to pre-frailty or frailty, we additionally excluded participants who were pre-frail at baseline (n = 1134), leaving 1020 robust participants. For the secondary analyses, the analytic samples comprised the 2154 participants minus the participants for whom the respective component was present or unknown at baseline or missing at all follow-up examinations (Supplementary Figure S2).

Frailty Assessment

Frailty was operationalized according to the frailty phenotype of Fried et al,[1] which consists of five components: weight loss, weakness, exhaustion, slowness, and physical inactivity (all: yes or no). Three states were distinguished: robust (0 components present), pre-frail (1-2 components present), and frail (3-5 components present). We operationalized each component using the most commonly used measures and literature-based cutoff values,[17] which was possible for all components except physical inactivity.

Weight loss was defined as unintentional weight loss of 5% or more in the preceding 12 months, using measured body weight (BW) of two consecutive annual follow-up examinations.[3] Weight loss was considered "unintentional" if the participant reported not having tried to lose weight or not having lost weight in the past 12 months. Weakness was defined as mean handgrip strength of 30 kg or less (men) and of 20 kg or less (women).[18,19] Grip strength was measured twice per hand using a Jamar handheld dynamometer (TEC). We used the mean of the best measurement from each hand. In the years that grip strength was not assessed (first and third follow-up years), we calculated the mean of the preceding and following year. If grip strength was missing due to pain or surgery on both hands, the participant was considered weak. Exhaustion was determined by the question "In the past month, on the average, have you been feeling unusually tired during the day?" Two categories were distinguished: present ("Yes, most of the time" or "Yes, all of the time") and absent ("Yes, some of the time," "No", or "Do not know"). Slowness was defined as usual walking speed over 20 m of 1.0 m/s or less.[20,21] Physical inactivity was determined by the total amount of kcal/wk spent on three commonly performed physical activities: (exercise or other) walking, climbing stairs, and doing major chores, as measured using a modified leisure-time physical activity questionnaire.[22] Because the Health ABC Study data were not suitable to compare with general physical activity guidelines, we used a population-derived cutoff value. As proposed by Fried et al,[1] we determined the lowest quintile for men (134 kcal/wk or less) and women (34 kcal/wk or less) at baseline, and applied those cutoff values to all follow-up examinations. Participants who had one missing physical activity variable and were considered "physically inactive" were coded as missing for this component due to the uncertainty about the number of kilocalories spent on the unknown activity.

Dietary Assessment

At baseline (1998-1999), habitual dietary intake over the preceding year was assessed with a 108-item modified version of the Block food frequency questionnaire (FFQ),[23] administered by trained interviewers. Intakes of energy, macronutrients, and food groups were calculated by Block Dietary Data Systems.

Three indicators of diet quality were examined: overall diet quality, energy intake, and protein intake.[3] Overall diet quality was expressed by the 10-component 1994-1996 Healthy Eating Index (HEI),[24] a score that reflects compliance with the 1995 Dietary Guidelines for Americans[25] and the Food Guide Pyramid[26] and variety in the diet. A sum score of 0 to 100 can be obtained; higher scores reflect better diet quality. The HEI was categorized into poor (less than 51), needs improvement (51-80), hereafter referred to as medium, and good (greater than 80).

Energy intake was expressed in kcal/d, and total protein intake in g/d and g/kg adjusted BW (aBW) per day. The latter approach controls for the deficit and excess in BW of underweight and overweight people, respectively, as proposed by Berner et al.[27] For participants with an undesirable body mass index (BMI), BW was recalculated to a BMI of 18.5 to 24.9 (those aged 70 years or younger) or 22.0 to 27.0 (those aged 71 years or older). Protein intake (g/kg aBW per day) was dichotomized according to the current Recommended Dietary Allowance[28] into low (less than 0.8) and high (0.8 or greater). We examined associations of animal and vegetable protein intake (g/d) separately because animal proteins may stimulate muscle protein synthesis to a greater extent than vegetable proteins.[29] As energy intake is related to weight loss,[30,31] and we aimed to

Table 1. Baseline Characteristics of the Non-frail Community-Dwelling Older Adults of the Health ABC Study Cohort, According to Baseline Frailty Status

	Frailty status at baseline[a]		
Characteristics	Robust (n = 1020)	Pre-frail (n = 1134)	Robust or pre-frail (n = 2154)
Age, y[b]	74.2 ± 2.7	74.8 ± 2.9	74.5 ± 2.8
Female sex, No. (%)	422 (41.4)	687 (60.6)	1109 (51.5)
White, No. (%)	704 (69.0)	692 (61.0)	1396 (64.8)
Memphis study site, No. (%)	504 (49.4)	536 (47.3)	1040 (48.3)
High education level, No. (%)	499 (49.0)	496 (43.8)	995 (46.3)
Family income, No. (%)			
<$50 000	691 (67.7)	858 (75.7)	1549 (71.9)
≥$50 000	210 (20.6)	145 (12.8)	355 (16.5)
Unknown	119 (11.7)	131 (11.6)	250 (11.6)
Living alone, No. (%)	259 (25.5)	355 (31.4)	614 (28.7)
Body mass index, kg/m^{2}[b]	27.0 ± 4.1	27.4 ± 5.1	27.2 ± 4.6
Fat mass index, kg/m[b]	9.2 ± 3.0	10.3 ± 3.7	9.8 ± 3.4
Current smoker, No. (%)	57 (5.6)	109 (9.6)	166 (7.7)
Current alcohol drinker, No. (%)	406 (39.8)	408 (36.0)	814 (37.8)
No. of chronic diseases, No. (%)			
0	179 (17.5)	111 (9.8)	290 (13.5)
1-2	609 (59.7)	682 (60.1)	1291 (59.9)
≥3	232 (22.7)	341 (30.1)	573 (26.6)
Estimated glomerular filtration rate, mL/min/1.73 m^{2}[b]	73.0 ± 13.9	72.7 ± 16.0	72.9 ± 15.1
Depression (CES-D scale score ≥16), No. (%)	27 (2.7)	50 (4.4)	77 (3.6)
Cognitive function (3MS score) [b]	92 ± 7	91 ± 7	91 ± 7
No. of medications, No. (%)			
0	228 (22.4)	180 (15.9)	408 (19.0)
1-4	578 (56.9)	647 (57.3)	1225 (57.1)
≥5	210 (20.7)	302 (26.7)	512 (23.9)
Healthy Eating Index score, No. (%)			
Poor (<51)	61 (6.0)	79 (7.0)	140 (6.5)
Medium (51-80)	737 (72.3)	833 (73.5)	1570 (72.9)
Good (>80)	222 (21.8)	222 (19.6)	444 (20.6)
Energy intake, kcal/d[b]	1869 ± 652	1800 ± 636	1833 ± 644
Total protein intake, g/d[b,c]	66.9 ± 15.1	66.1 ± 13.3	66.5 ± 14.2
Total protein intake <0.8 g/kg aBW per day, No. (%)[c]	308 (30.2)	263 (23.2)	571 (26.5)
Animal protein intake, g/d[b,c]	37.8 ± 15.9	37.2 ± 14.2	37.5 ± 15.0
Vegetable protein intake, g/d[b,c]	27.3 ± 6.5	27.0 ± 6.1	27.1 ± 6.3
Frailty component fulfilled at baseline, No. (%)			
Weight loss		95 (8.4)	95 (4.4)
Weakness		565 (49.9)	565 (26.2)
Exhaustion		100 (8.8)	100 (4.6)
Slowness		390 (34.6)	390 (18.2)
Physical inactivity		325 (28.7)	325 (15.1)

Abbreviations: 3MS, Modified Mini-Mental State Examination; aBW, adjusted body weight; CES-D, Center for Epidemiological Studies Depression; Health ABC, Health, Aging, and Body Composition.
[a]Frailty status was categorized into robust (score = 0 of 5), pre-frail (score = 1-2 of 5), and frail (score = 3 or greater of 5).
[b]Data are given as mean ± SD.
[c]Protein intake was adjusted for energy intake by using the nutrient residual model.

examine the independent association between protein intake and frailty, all protein intake indicators were a priori adjusted for energy intake by applying the nutrient residual model.[16]

Assessment of Covariates

Detailed information on assessment and categorization of age, sex, race, study site, education level, family income, living arrangement, smoking status, number of chronic diseases, alcohol consumption, estimated glomerular filtration rate (eGFR), depression, cognitive function, medication use, and BMI can be found elsewhere.[3] Total body fat mass was obtained from whole-body scans using dual-energy X-ray absorptiometry (Hologic QDR 4500A). Fat mass index was calculated as measured fat mass (kg) divided by measured height (m) squared.

Statistical Analyses

Cox proportional hazard analysis was used to examine associations of the diet quality indicators with 4-year incidence of (1) frailty, (2) pre-frailty or frailty (to explore if associations differ between the early and late phase of the frailty process), and (3) components of frailty. The scale of continuous independent variables was reversed by multiplying all individual values by −1, to examine associations for lower intakes. Follow-up time was defined, for each outcome separately, as the time between the baseline examination and (1) the first diagnosis of (pre-)frailty, (2) the last examination attended, or (3) the fourth (last) follow-up examination, whichever came first.

Competing risk analysis, using the subdistribution hazard model proposed by Fine and Gray,[32] was used to examine associations of the diet quality indicators with 4-year incidence of frailty by accounting for competing risks of death. This method adjusts for the potential preclusion of the occurrence of the event of interest by another event occurring earlier, the competing event.[33] People who became frail were considered as cases, and people who died were considered as competitors. We did not apply competing risk analyses to investigate associations with incident "pre-frailty or frailty" because we expected the robust participants (included in these analyses) to be at lower risk of death than the pre-frail participants also included in the analyses for incident frailty. As a post-hoc analysis, we repeated the analyses using a more conservative cutoff value for the weight loss component: 10% instead of 5% over 12 months.

Three models were built. In addition to a crude model, model 1 was adjusted for age, sex, race, study site, education level, family income, living arrangement, smoking status, alcohol consumption, fat mass index, and energy intake. Model 2 was additionally adjusted for number of chronic diseases, eGFR, depression, cognitive function, and number of medications. Animal and vegetable protein intakes were mutually adjusted.

Tests for trend were performed by modeling the median values of each category continuously. For all analyses, statistical significance was set at $P < .05$ (two sided). Interaction by age, sex, race, and physical activity was tested ($P < .01$ because of multiple testing) by adding an interaction term to the crude model. No interactions were observed. Cox proportional hazard analyses were performed by SPSS Statistics, version 25 (IBM Corp), and competing risk analyses were performed by R package *cmprsk*, version 1.1456 (RStudio).

RESULTS

Characteristics of study population

Of the 2154 participants, 1020 were robust and 1134 were pre-frail at baseline (Table 1). Mean ± SD age at baseline was 74.5 ± 2.8 years, 51.5% were female, 64.8% were white, and mean BMI was 27.2 ± 4.6 kg/m^2. Diet was graded as "poor" or "medium" in 6.5% and 72.9% of the participants, respectively, and protein intake less than 0.8 g/kg aBW per day was present in 26.5%. Weakness (26.2%), slowness (18.2%), and physical inactivity (15.1%) were the most prevalent frailty components among the pre-frail participants.

Compared to the participants included (n = 2154), those excluded because of missing or unknown frailty status during follow-up (n = 258; Supplementary Figure S1) were slightly older ($P < .01$), more often male ($P < .01$), and current smokers ($P < .001$); and they had more chronic diseases ($P < .05$) at baseline. Furthermore, they were more likely to have slowness ($P < .001$) and be physically inactive ($P < .05$) at baseline. No differences were observed for the HEI, energy intake, or protein intake.

Associations with incident frailty and "pre-frailty or frailty"

During the 4-year follow-up (mean = 3.5 years), 277 of the 2154 robust or pre-frail participants developed frailty. After full adjustment for confounders (model 2), poor- and medium-quality diets were associated with a 92% and a 40% higher incidence of frailty compared to good-quality diets, respectively (Figure 1A). Similar results were observed when death was considered a competing risk (Figure 1B).

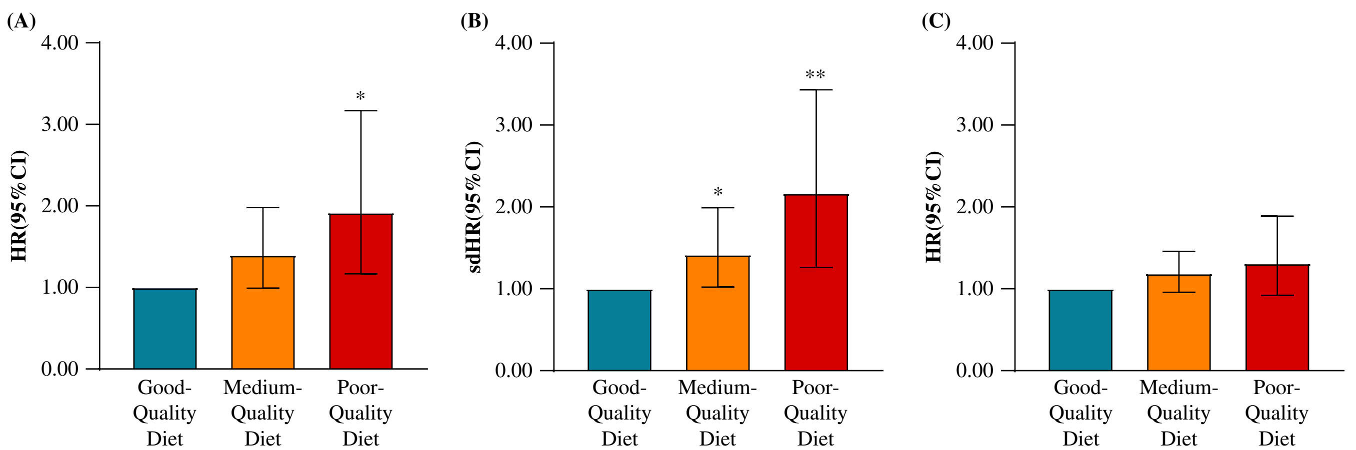

Figure 1. Associations of consumption of medium- and poor-quality diets compared to good-quality diets with 4-year incidence of frailty (A), frailty accounting for competing risks of death (B), and pre-frailty or frailty (C) among community-dwelling older adults of the Health, Aging, and Body Composition Study cohort who were robust and pre-frail (A and B) or robust (C) at baseline. Abbreviations: CI, confidence interval; HR, hazard ratio; sdHR, subdistribution HR. *$P < .05$, **$P < .01$.

No associations were observed with energy or (total, animal, or vegetable) protein intake (Table 2).

During the 4-year follow-up (mean = 2.7 years), 629 of the 1020 robust participants developed pre-frailty or frailty. The associations of overall diet quality with incident pre-frailty or frailty were in the same direction as for frailty, but not statistically significant (Figure 1C). A 10-g lower vegetable protein intake was associated with a 20% higher incidence of pre-frailty or frailty. No associations were observed with energy intake, total protein intake, or animal protein intake (Table 3).

Post-hoc analyses showed that the hazard ratio (HR) for poor- compared to good-quality diets with incident frailty decreased when frailty was operationalized using a cutoff value of 10% for the weight loss component (HR = 1.69; 95% confidence interval [CI] = 1.50-1.96; *P* = .08). The HRs for total, animal, and vegetable protein intake (continuously analyzed) increased; and they were statistically significant for total and vegetable protein intake. Associations only marginally changed for incident pre-frailty or frailty.

Secondary Analyses

Poor- and medium-quality diets were associated with a 74% and 30% higher incidence of physical inactivity, respectively (*P* = .003 for trend), but not with any other frailty component (Supplementary Table S1). Lower energy intake was associated only with a lower incidence of weight loss. Lower total protein intake (g/d) was associated only with a higher incidence of physical inactivity (*P* = .049 for trend). No associations were observed for low compared to high protein intake. Lower animal protein was associated only with a higher incidence of physical inactivity, whereas lower vegetable protein intake was associated with higher incidences of physical inactivity, weight loss, and slowness.

DISCUSSION

Consumption of poor- and medium-quality diets was associated with a higher 4-year incidence of frailty—with and without accounting for competing events—but not with incident pre-frailty or frailty among non-frail community-dwelling older adults. Lower vegetable protein intake was associated with a higher incidence of pre-frailty or frailty, but not frailty. No associations were observed with total or animal protein intake, or energy intake.

Our study confirms results from prospective studies among Western populations[6-9,11] that poorer overall diet quality is associated with higher frailty risk (determined using the frailty phenotype). The one prospective study showing no association[10] included Chinese older persons and used the FRAIL scale (Fatigue, Resistance, Ambulation, Illnesses, and Loss of Weight) to determine frailty, which may explain the discrepancy. We also showed that the associations for overall diet quality remain similar when competing risks of death were taken into account and after additional adjustment for baseline frailty status or score (data not shown).

Our secondary analyses suggest that the association of overall diet quality (HEI) with frailty was mostly driven by the physical inactivity component. This finding is similar to that in the Three-City-Bordeaux cohort,[8] but different from the Seniors-Study on Nutrition and Cardiovascular Risk in Spain (ENRICA) cohort,[6] in which the MDS was not associated with any single frailty component. The Seniors-ENRICA study used the frailty phenotype, but assessment and operationalization of the underlying components differed. Furthermore, the Seniors-ENRICA cohort was, on average, younger than the Health ABC Study cohort (mean age = 68 vs 75 years, respectively), which may have contributed to the inconsistent findings.

Our null findings for protein intake with (pre-)frailty were in contrast to two,[13,14] but in line with two other prospective studies.[11,12] In the Women's Health Initiative Observational Study (WHI-OS),[13] however, only protein intake expressed in energy % and g/kg BW per day but not g/d was associated with frailty risk. This may be due to the different cutoff values used for weight loss (WHI-OS, greater than 5% in 3 years; our study, 5% or greater in 1 year) as we observed that the association between protein intake and frailty risk became stronger when frailty was operationalized based on weight loss of 10% or more (HR per −10 g/d = 1.12; 95% CI = 1.00-1.25; *P* = .04) compared to 5% or more (data not shown). Furthermore, we applied the nutrient residual model to adjust for energy intake, while other studies only adjusted for energy intake in their regression models. However, reanalyzing our data by applying this latter procedure resulted in the same study conclusions. Other studies reported prospective associations of lower protein intake with higher risks of lean mass loss,[5] mobility limitations,[34] and disability,[35] all suggesting a protein intake of greater than 1.0 g/kg aBW per day to be most optimal.[34,35] We found, however, also no associations when using a cutoff value of 1.0 or 1.2 g/kg aBW per day (data not shown). Current findings suggest that the role of protein in the development of frailty remains unclear.

We expected to find stronger associations for animal than vegetable protein because of the higher biological quality[36] of the former. We found, however, only an association of vegetable (but not animal) protein intake with incident pre-frailty or frailty, and also with weight loss, slowness, and physical inactivity. This contrasts with a study among Spanish older adults[14] showing that higher animal but not vegetable protein intake was associated with lower frailty risk. The much lower intake of animal protein in our population than in the Spanish sample (38 vs 61 g, respectively) may explain the discrepancy in part. We do not expect that the type of meat consumed would explain differences in observed associations because the types and amounts of amino acids in various types of meat are largely comparable. Furthermore, although our observed association between vegetable protein intake and physical inactivity disappeared after adjustment for HEI, the associations with pre-frailty or frailty, weight loss, and slowness remained (data not shown). Our associations for overall diet quality and vegetable protein intake may suggest that poorer diet quality is indicative of a less healthy lifestyle in general. This needs further exploration.

Strengths of our study include the prospective design, consideration of time to onset of (pre-)frailty, and use of population-independent cutoff values (except for physical inactivity) to enhance comparability with other studies.[17] Furthermore, we applied advanced statistical analyses, thereby reducing the risk of bias due to competing risks of death.[15] Some limitations should also be mentioned. First, the validity

Table 2. Hazard Ratios and 95% Confidence Intervals for the Associations of Indicators of Diet Quality with 4-Year Incidence of Frailty (by Accounting for Competing Risks of Death) in Robust or Pre-frail (n = 2154 or n = 2270, Respectively, in Competing Risk Analysis) Community-Dwelling Older Adults of the Health ABC Study Cohort

	Risk of developing frailty (4-y follow-up)[a,b]			Risk of developing frailty by accounting for competing risks of death (4-y follow-up)[a,c]		
Variable	Crude model	Model 1[d]	Model 2[e]	Crude model	Model 1[d]	Model 2[e]
Healthy Eating Index score						
Poor (<51)	2.21 (1.37-3.57)**	1.73 (1.05-2.84)*	1.92 (1.17-3.17)*	2.31 (1.43-3.73)***	1.90 (1.17-3.11)*	2.17 (1.26-3.43)**
Medium (51-80)	1.44 (1.03-2.00)*	1.28 (0.91-1.80)	1.40 (0.99-1.98)	1.44 (1.04-2.00)*	1.31 (0.94-1.83)	1.42 (1.02-1.99)*
Good (>80)	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
P value for trend	.001	.032	.009	.001	.013	.004
Energy intake per 100-kcal/d lower intake	1.01 (0.99-1.03)	1.00 (0.98-1.02)	1.00 (0.98-1.02)	1.01 (0.99-1.03)	1.01 (0.99-1.03)	1.01 (0.99-1.03)
Energy intake, kcal/d						
Q1: ≤1360.6	1.04 (0.75-1.44)	0.97 (0.70-1.35)	0.96 (0.69-1.34)	1.07 (0.77-1.48)	1.03 (0.74-1.44)	1.03 (0.73-1.43)
Q2: 1360.7-1742.4	0.90 (0.64-1.27)	0.93 (0.66-1.32)	0.88 (0.62-1.24)	0.91 (0.65-1.28)	0.96 (0.68-1.37)	0.92 (0.64-1.31)
Q3: 1742.5-2217.1	0.82 (0.58-1.16)	0.87 (0.62-1.24)	0.80 (0.56-1.14)	0.82 (0.58-1.16)	0.89 (0.62-1.26)	0.81 (0.57-1.16)
Q4: ≥2217.2	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
P value for trend	.806	.885	.850	.694	.826	.849
Total protein intake per 10-g/d lower intake	1.08 (0.99-1.17)	1.05 (0.96-1.14)	1.06 (0.97-1.16)	1.07 (0.98-1.17)	1.05 (0.95-1.16)	1.06 (0.96-1.17)
Total protein intake, g/d						
Q1: ≤57.16	1.31 (0.95-1.80)	1.18 (0.85-1.63)	1.24 (0.89-1.72)	1.23 (0.94-1.78)	1.19 (0.85-1.65)	1.22 (0.87-1.70)
Q2: 57.17-64.18	0.78 (0.55-1.12)	0.72 (0.50-1.04)	0.75 (0.52-1.09)	0.78 (0.55-1.12)	0.73 (0.51-1.04)	0.75 (0.53-1.08)
Q3: 64.19-73.19	0.87 (0.62-1.23)	0.83 (0.58-1.18)	0.82 (0.58-1.17)	0.88 (0.62-1.24)	0.84 (0.60-1.18)	0.83 (0.59-1.17)
Q4: ≥73.20	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
P value for trend	.193	.535	.330	.243	.520	.400
Total protein intake <0.8 g/kg aBW per day[f]	0.95 (0.72-1.24)	1.02 (0.76-1.37)	1.09 (0.82-1.47)	0.93 (0.71-1.22)	0.99 (0.74-1.31)	1.03 (0.77-1.37)
Animal protein intake per 10-g/d lower intake	1.05 (0.96-1.13)	1.03 (0.94-1.12)	1.06 (0.96-1.15)	1.04 (0.96-1.13)	1.03 (0.94-1.13)	1.06 (0.96-1.17)
Vegetable protein intake per 10-g/d lower intake	1.14 (0.93-1.39)	1.10 (0.89-1.36)	1.19 (0.94-1.50)	1.13 (0.91-1.41)	1.09 (0.85-1.40)	1.18 (0.89-1.55)

Note. For risk of developing frailty (4-year follow-up), data are given as hazard ratio (95% confidence interval); for risk of developing frailty by accounting for competing risks of death (4-year follow-up), data are given as subdistribution hazard ratio (95% confidence interval).

Abbreviations: aBW, adjusted body weight; Health ABC, Health, Aging, and Body Composition; Q, quartile; Ref, reference.

*$P < .05$, **$P < .01$, ***$P < .001$.

[a]Frailty status was categorized into robust (score = 0 of 5), pre-frail (score = 1-2 of 5), and frail (score = 3 or greater of 5).

[b]Cases/total = 269/2082 (differs from original sample size due to missing covariates).

[c]Cases/total = 458/2196 (differs from original sample size due to missing covariates).

[d]Adjusted for age, sex, race, study site, education level, income, living arrangement, smoking status, alcohol consumption, fat mass index, and energy intake. By using energy intake as the independent variable, models were not additionally adjusted for energy intake.

[e]Additionally adjusted for number of chronic diseases, estimated glomerular filtration rate, depression, cognitive function, and number of medications. Animal and vegetable protein were mutually adjusted.

[f]The hazard ratio reflects the association for low (less than 0.8 g/kg aBW per day) compared to high (0.8 or greater g/kg aBW per day) protein intake.

Table 3. Hazard Ratios and 95% Confidence Intervals for the Associations of Indicators of Diet Quality with 4-Year Incidence of Pre-frailty or Frailty in Robust (n = 1020) Community-Dwelling Older Adults of the Health ABC Study Cohort

	Risk of developing pre-frailty or frailty (4-y follow-up)[a,b]		
Variable	Crude model	Model 1[c]	Model 2[d]
Healthy Eating Index score			
Poor (<51)	1.44 (1.02-2.03)*	1.23 (0.86-1.76)	1.31 (0.92-1.89)
Medium (51-80)	1.15 (0.95-1.41)	1.10 (0.90-1.35)	1.19 (0.96-1.46)
Good (>80)	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
P value for trend	.037	.226	.076
Energy intake per 100-kcal/d lower intake	1.00 (0.99-1.01)	0.99 (0.98-1.01)	0.99 (0.98-1.01)
Energy intake, kcal/d			
Q1: ≤1360.6	0.99 (0.79-1.25)	0.93 (0.73-1.18)	0.92 (0.72-1.16)
Q2: 1360.7-1742.4	1.09 (0.87-1.36)	1.06 (0.84-1.33)	1.04 (0.83-1.31)
Q3: 1742.5-2217.1	1.12 (0.90-1.40)	1.13 (0.90-1.41)	1.12 (0.90-1.40)
Q4: ≥2217.2	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
P value for trend	.944	.602	.520
Total protein intake per 10-g/d lower intake	1.03 (0.98-1.09)	1.02 (0.96-1.08)	1.03 (0.98-1.09)
Total protein intake, g/d			
Q1: ≤57.16	1.14 (0.90-1.43)	1.07 (0.84-1.35)	1.12 (0.88-1.42)
Q2: 57.17-64.18	1.13 (0.90-1.42)	1.13 (0.89-1.42)	1.11 (0.88-1.41)
Q3: 64.19-73.19	1.26 (1.01-1.58)*	1.28 (1.02-1.61)*	1.29 (1.02-1.62)*
Q4: ≥73.20	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
P value for trend	.332	.665	.457
Total protein intake <0.8 g/kg aBW per day[e]	0.92 (0.78-1.10)	0.91 (0.76-1.09)	0.94 (0.78-1.14)
Animal protein intake per 10-g/d lower intake	1.00 (0.95-1.05)	1.00 (0.95-1.05)	1.03 (0.97-1.09)
Vegetable protein intake per 10-g/d lower intake	1.19 (1.04-1.36)**	1.14 (1.00-1.31)	1.20 (1.04-1.39)*

Note. Data are given as hazard ratio (95% confidence interval).
Abbreviations: aBW, adjusted body weight; Health ABC, Health, Aging, and Body Composition; Q, quartile; Ref, reference.
*$P < .05$, **$P < .01$.
[a]Frailty status was categorized into robust (score = 0 of 5), pre-frail (score = 1-2 of 5), and frail (score = 3 or greater of 5).
[b]Cases/total = 613/991 (differs from original sample size due to missing covariates).
[c]Adjusted for age, sex, race, study site, education level, income, living arrangement, smoking status, alcohol consumption, fat mass index, and energy intake. By using energy intake as the independent variable, models were not additionally adjusted for energy intake.
[d]Additionally adjusted for number of chronic diseases, estimated glomerular filtration rate, depression, cognitive function, and number of medications. Animal and vegetable protein were mutually adjusted.
[e]The hazard ratio reflects the association for low (less than 0.8 g/kg aBW per day) compared to high (0.8 or greater g/kg aBW per day) protein intake.

of our dietary data may be limited because FFQs have a moderate ability to estimate absolute dietary intake and recalling dietary intake over the previous year is difficult, especially in old age.[37,38] However, FFQs are considered suitable for ranking individuals according to their average dietary intake.[37] We expect that any arising misclassification was nondifferential and may have attenuated the associations.[38] Second, our cohort included white and African American persons, so we cannot ascertain whether our findings apply to other races. Third, although we used a prospective study design, reverse causation cannot be ruled out. This may explain the unexpected finding of lower energy intake with lower risk of weight loss. Fourth, residual confounding (by other lifestyle factors) may still be present, even though we adjusted for a wide range of confounders.

The present study confirms current evidence from prospective studies that an overall unhealthy diet may increase the risk of frailty in community-dwelling older adults, even when accounting for competing risks of death and using time to onset. Although some prospective studies[13,14] showed that higher protein intake may lower frailty risk, our study indicates that the quality of the overall diet may be more important than protein intake for reducing the development of frailty in old age.

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initial manuscript; all authors: contributed to the interpretation of the data, critically revised the manuscript, and gave final approval.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article.

Supplementary Table S1. Hazard Ratios and 95% Confidence Intervals for the Associations of Indicators of Diet Quality with 4-Year Incidence of the Single Components of the Frailty Phenotype in Robust or Pre-frailty Community-Dwelling Older Adults of the Health ABC Study Cohort.

Supplementary Figure S1. Flowchart of Participants Included in the Analytic Samples for Time to Frailty and Time to Pre-Frailty or Frailty.

Supplementary Figure S2. Flowchart of Participants Included in the Analytic Samples for Time to the Individual Frailty Components (i.e., Weight Loss, Weakness, Exhaustion, Slowness, and Physical Inactivity).