The Impact of High Carbohydrate Intake on Physical Frailty in Older Korean Adults: a Cohort-based Cross-sectional Study

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Abstract

Background: The relationship between macronutrients and frailty is unclear. Previous studies have confirmed the relationships between energy and protein intake and physical frailty, while few studies have examined the role of carbohydrate or fat intake in the prevalence of frailty. The aim of this study is to investigate the relationship of energy and macronutrients with physical frailty in the Korean elderly population who had a high proportion of energy intake from carbohydrates.

Methods: This study included 954 adults aged 70 to 84 years who have completed the assessment of frailty and 24-h recall upon enrolment in the Korean Frailty and Aging Cohort Study and have no extreme intake under 400 kcal ($n = 2$). The relationship between energy or macronutrients and frailty was evaluated using multivariate logistic regression models and multivariate nutrient density models.

Results: In the subjects with low energy intake (odds ratio [OR] = 2.94, 95% confidence interval [CI] = 1.34–6.45) and total subjects (OR = 2.01, 95% CI = 1.03–3.93), consuming carbohydrates above the acceptable macronutrient distribution range (65% of energy) was related to a higher risk of frailty. Substituting the energy from fat with carbohydrates was related to a higher risk of frailty (1%, OR = 1.05, 95% CI = 1.00–1.09; 5%, OR = 1.26, 95% CI = 1.02–1.56; 10%, OR = 1.59, 95% CI = 1.03–2.43).

Conclusions: This study showed that the proportion of energy intake from carbohydrates and fats may be an important nutritional intervention factor for reducing the risk of frailty.

Background

Life expectancy has been steadily increasing [1]. It is estimated to be 65.2 years for those born in 2000 and 71.9 years for those born in 2016 [1]. However, the healthy life expectancy (HALE) without disability for those born in 2016 is 64.6 years, indicating a gap between life expectancy and HALE [1]. The gap between life expectancy and HALE means an unhealthy survival period, and closing this gap has recently become a global goal [2]. Since mobility and disability are factors that affect life satisfaction and quality of life, it is necessary to manage these factors to increase HALE [3, 4].

The state of reduced reserve capacity and vulnerability to stress can be defined as frailty, which has been reported to be related to a high risk of falls, hospitalization, disability, and death [5–8]. Nutritional, physical, and medical interventions could prevent or delay the deterioration of physiological function related to physical frailty [9–11]. Moreover, even in the already frail state, it is possible to recover to the prefrail stage depending on the intervention and nutritional intake level [12], so the need for intervention is emphasized at all stages of prevention, delay, and recovery of physical frailty in the elderly.

Since the Fried frailty index examines the physical functions, such as muscle strength [7], previous research has mainly focused on protein as a nutritional factor related to frailty [12–24]. In a multicenter cross-sectional study conducted on 2,108 elderly people living in a community in Japan, higher protein intake was negatively related to frailty prevalence [22]. The relationship between relative protein intake and frailty has also been investigated in other studies, for example, 1 g/kg body weight (BW) [18] and 1.1 g/kg BW [23] were related to low prevalence of frailty.

The Korean Nutrition Society recommends a total protein intake of 55 g for men and 45 g for women or 0.91 g/kg for individuals aged ≥ 65 years, which is established as the minimum amount of protein that an adult should consume to maintain nitrogen balance. However, the recommended protein intake (0.91 g/kg BW) is the minimum value for maintaining nitrogen balance in adults and does not reflect the metabolic characteristics of older adults, so consuming at least 1.0 g/kg of protein has been recommended [25–27], and 1.2 g/kg BW is also proposed by the Korean Geriatrics Society and the Korean Nutrition Society to prevent sarcopenia [28].

However, inconsistent results have been found regarding the relationship between protein intake and frailty and muscle strength [12–24]. Moreover, insufficient energy intake leads to a decrease in protein synthesis even if amino acids are adequately provided. Therefore, a sufficient energy intake is an important nutritional factor in the prevention of frailty [29]. The study have also reported that low energy intake increased the risk of frailty, but discrepancies of the results also exist [18, 20, 21].

Carbohydrate intake is positively related to the prevalence of metabolic syndrome and diabetes [30, 31], and since these chronic diseases are factors influencing the prevalence of frailty, not only protein but also carbohydrates and fats should be considered integrally. Studies have shown that the Korean elderly population consumed more than the acceptable macronutrient distribution range (AMDR) in carbohydrate energy consumption [32–34]. Therefore, understanding the high carbohydrate diet affecting frailty in the elderly is crucial.

To our knowledge, only a few studies have investigated the relationship between high carbohydrate diet and frailty. Furthermore, the elderly is at risk of low energy and food intake due to anorexia of aging, chronic diseases, decreased physical activity, and decreased masticatory function [35, 36], but these characteristics of the elderly are not considered, and simply high intake levels of quantity tend to be recommended to prevent frailty [25–27]. However, additional information is necessary to confirm the intake level of macronutrients related to the prevalence of frailty in subjects with low energy intake. Therefore, the aim of this study is to identify energy and macronutrient intake level that may be related to the frailty status among the older adults who tended to have a high energy intake from carbohydrates in Korea.

Methods

Study population

Data were retrieved from the baseline surveys of the Korean Frailty and Aging Cohort Survey (KFACS), which were conducted from May to November 2016 [37, 38]. KFACS enrolled 1,559 Korean community-dwelling elderly people aged 70 to 84 years. The participants were recruited according to age- and gender-specific strata, and the surveys were conducted across eight university-affiliated hospitals and two public health centers. Out of 1,559 individuals, 1,002 attended the nutrition sub-cohort. Forty-eight participants were excluded from the analysis, especially those with an energy intake under 400 kcal (n = 2), and the missing values for the components of frailty (n = 46) were also excluded. The final analytical sample included 954 subjects. This study was performed in accordance with the Declaration of Helsinki, and it was approved by the Institutional Review Board of Dankook University, Hanyang University, and Kyung Hee University. Written informed consent was obtained from all participants.

General characteristics

Information on age, sex, educational attainment, house income, living situation (living alone or not), physician-diagnosed chronic disease (hypertension, dyslipidemia, or type 2 diabetes), number of prescription drugs, chewing status, and smoking status was obtained after face-to-face interviews. Height and weight were measured by a trained staff. Body mass index (BMI) was calculated as weight (kg) divided by height squared (m²). BMI was categorized as underweight (<18.5 kg/m²), normal weight (≥18.5 to <23 kg/m²), overweight (≥23 to <25 kg/m²), and obese (≥25 kg/m²) according to the Asia-Pacific classification of BMI [39].

Definition of frailty

We used a modified version of the Fried frailty phenotype [7, 40], which has the following five components: unintended weight loss, weakness (poor grip strength), self-assessed exhaustion, slow walking speed, and low physical activity. Weakness was measured using a hand dynamometer (Takei TKK 5401, Takei Scientific Instruments, Tokyo, Japan). The grip strength of each hand was measured, and the measurement was repeated after 3 min; the highest value among the averages of each measurement was used for analysis. Exhaustion was assessed using the Center for Epidemiological Studies-Depression scale. Walking speed was measured while walking 4 m at a normal rhythm. Physical activity was measured using the International Physical Activity Questionnaire–Short Form (Korean version) [41]. Table 1 shows the information of components and criteria for adding 1 point. The frailty scores ranged from 0 to 5, and frailty status was categorized as robust (0), prefrail (1–2), and frail (3–5).

Table 1
Fried frailty index and criteria for adding 1 point.

Components	Criteria for adding 1 point
Unintended weight loss [40]	Unintended weight loss of 4.5 kg or more in the last year
Weakness [40]	Grip strength lower than 26 kg for men and lower than 18 kg for women
Exhaustion [42]	“I felt that everything I did was an effort” or “I could not get going” was yes for three or more days in a week
Slow walking speed [40]	Walking speed below 1 m/s after walking 4 m at a normal rhythm
Low physical activity [43]	Metabolic equivalent of task in minutes per week (MET-min/week) was below 494.65 kcal for men and below 283.50 kcal for women

Dietary intake assessment

The interviewers were trained with the standardized protocol for the 24-h recall method. Interviews were conducted based on home visiting, and visual aids, which were developed by the Korea Disease Control and Prevention Agency, were used to estimate the quantity of the food consumed during a day. Nutrient intake was calculated using the 24-h recall dietary assessment system of the National Institute of Health and the Korea Disease Control and Prevention Agency [44].

Total energy and macronutrient intake

Total energy was calculated as the sum of carbohydrate (4 kcal * g/d), protein (4 kcal * g/d), and fat (9 kcal * g/d) kcal. Carbohydrates, protein, and fat were expressed as the percentage of energy to evaluate the adequacy of macronutrient intake using the AMDR (carbohydrate, 55–65%; protein, 7–20%; fat, 15–30%) [32]. The participants were categorized by the AMDR of each macronutrient.

The estimated energy requirement (EER) was calculated using the formula for estimating the energy requirements suggested by the Dietary Reference Intakes for Koreans {men: 662 – 9.53 × age + value of physical activity level (PA) [15.91 × weight (kg) + 539.6 × height (m)]; women: 354 – 6.91 × age + PA [9.36 × weight+ 726 × height (m)]}. The PA value was determined for all subjects to be 1.11 for men and 1.12 for women in consideration of the PA from the International PA Questionnaire [32]. Energy intake was dichotomized at the cut-off point of EER.

The relationship of protein intake with the prevalence of prefrailty and frailty was identified using four types of cutoffs: (1) AMDR (7–20% of energy from protein) [32], (2) the age- and gender-specific recommended nutrient intake (RNI) (elder men, 55 g/d; elder women, 45 g/d) [32], (3) the RNI cut-off for dietary protein (0.91 g/kg BW/d) [32], and (4) cut-off suggested by the Korean Geriatrics Society and the Korean Nutrition Society for the prevention of sarcopenia (1.2 g/kg BW/d) [28].

Blood tests

Blood samples were taken after an 8-h fast and were brought to a commercial laboratory. The serum levels of triglycerides, HDL cholesterol, LDL cholesterol, FBS, HbA1c, and hs-CRP were measured.

Statistical analysis

Energy intake (kcal/d, 100 kcal/d) and each macronutrient intake (g/d, 10 g/d, % from energy, kcal/d, and 100 kcal/d) were used as continuous variables, and energy and macronutrient cutoffs were used as categorical variables. Categorical variables were presented as n (%), whereas continuous variables were presented as means $\pm$ standard deviations or means $\pm$ standard errors. P-values for the differences in frail status were obtained using a chi-square test or Fisher's exact test for qualitative variables or analysis of variance for continuous variables. The differences among the groups were determined using the Scheffé post hoc test.

The p-values for differences between the frail status were obtained using the Cochran–Mantel–Haenszel test for qualitative variables or the general linear model for continuous variables. Values were adjusted for age and sex.

Adjusted multinomial logistic regression analysis was conducted to compare the energy and macronutrient intake of frail and prefrail older adults with those of the robust older adults. We tried to confirm the relationship between the prevalence of frail status and sufficient energy intake, but because of the small number of subjects with sufficient energy intake, irregularities appeared in the Hessian matrix, and the validity was uncertain, so those with sufficient energy intake were excluded from the multinomial logistic regression analysis. Odds ratios (ORs) and their corresponding 95% confidence intervals (CIs) were derived, after adjusting for age, sex, education attainment, house income, living situation (alone or not), hypertension, triglyceride, number of prescription drugs, chewing status, alcohol, and PA in Model 1. Model 2 was adjusted for Model 1 covariates and total energy.

Multivariate nutrient density models were conducted to examine the relationship between macronutrients and frailty status in total subjects as well as subjects who consumed the unmet intake with the standard energy intake criteria. Detailed information on the multivariate nutrient density models is available elsewhere [45]. Briefly, in logistic regression analysis, total energy intake and macronutrient of interest were included as independent variables, and frail status was included as a dependent variable. With the total energy intake adjusted, the increase in the energy of the macronutrient of interest can be interpreted as a decrease in the iso-energy of other nutrients not included in the model. For example, to examine the substitution of fat with carbohydrates, the model includes carbohydrates, protein, total energy intake, and covariates but excludes fat. The OR for carbohydrates represents substituting fat with the same energy from carbohydrates. All statistical analyses were conducted using the IBM SPSS Statistics 25.0 Program (IBM SPSS INC, Armonk) and were tested at a P-value below 0.05.

Results

Of the 1,002 participants recruited to KFACS, 954 (95%) had complete data for all the variables of interest. Table 2 shows the relationship between the aspects of general characteristics and frailty status. The participants had an average age of 76.3 years (70–84). The proportion of women was 51.7%, of which 10.9% were frail and 50.2% prefrail. After adjusting for age and sex, frail older adults were less educated, had low income, and presented with a high prevalence of physician-diagnosed hypertension. Frail older adults also had lower HDL cholesterol and marginally higher triglyceride levels. The proportion of polypharmacy and chewing discomfort according to frail status were significantly different, showing a higher proportion in frail older adults. The level of PA was lower in frail older adults than in prefrail and robust older adults.

Table 2
The relationship between the aspects of general characteristics and frailty status ¹⁾

	All	Robust (n=371)	Prefrail (n=479)	Frail (n=104)	p ²⁾	p ³⁾
Age (year)	76.3 ± 3.9	75.5 ± 3.7 ^a	76.4 ± 3.9 ^b	78.7 ± 3.8 ^c	<0.001	-
Sex, n (%)						
Men	461(48.3)	232(61.2)	202(42.9)	27(26.0)	<0.001	-
Women	493(51.7)	147(38.8)	269(57.1)	77(74.0)		
Educational attainment, n (%)						
≤ 6 years	436(45.8)	121(32.0)	229(48.6)	86(82.7)	<0.001	<0.001
≥ 7 years	517(54.2)	257(68.0)	242(51.4)	18(17.3)		
House income (per a month), n (%)						
Unknown	80(8.4)	24(6.3)	41(8.7)	15(14.4)	<0.001	<0.001
< 1 million won	388(40.7)	123(32.5)	198(42.0)	67(64.4)		
1-2 million	218(22.9)	88(23.2)	118(25.1)	12(11.5)		
≥ 2 million	268(28.1)	144(38.0)	114(24.2)	10(9.6)		
Living alone or living with partner, n (%)						
Living alone	245(25.7)	73(19.3)	133(28.2)	39(37.5)	<0.001	0.691
Living with partner	709(74.3)	306(80.7)	338(71.8)	65(62.5)		
BMI (kg/m ²), n (%)						
< 18.5, underweight	16(1.7)	6(1.6)	8(1.7)	2(1.9)	0.999	0.862
18.5-22.9, normal	285(29.9)	109(28.8)	145(30.8)	31(29.8)		
23-24.9, overweight	251(26.3)	107(28.2)	114(24.2)	30(28.8)		
≥ 25, obese	402(42.1)	157(41.4)	204(43.3)	41(39.4)		
Disease (Yes)						
Hypertension, n (%)	566(59.3)	190(50.1)	302(64.1)	74(71.2)	<0.001	<0.001
Dyslipidemia, n (%)	294(30.8)	110(29.0)	153(32.5)	31(29.8)	0.502	0.6
Type 2 diabetes, n (%)	216(22.7)	77(20.4)	110(23.4)	29(28.2)	0.224	0.165
Total cholesterol (mg/dL)	171.6 ± 1.2	173 ± 1.9	170.2 ± 1.6	172.7 ± 3.1	0.481	0.107
Triglyceride (mg/dL)	122.2 ± 2.0	118.4 ± 3.1 ^a	121.9 ± 2.7 ^{ab}	137.4 ± 7.7 ^{bc}	0.022	0.055
HDL-cholesterol (mg/dL)	51.4 ± 0.5	52.2 ± 0.8	51 ± 0.6	50.1 ± 1.2	0.289	0.032
LDL-cholesterol (mg/dL)	107.9 ± 1.0	109 ± 1.7	106.8 ± 1.4	108.4 ± 3.0	0.606	0.289
FBS (mg/dL)	104.3 ± 21.4	104.6 ± 21.4	104.1 ± 20.9	104.4 ± 23.6	0.942	0.919
HbA1c (%)	6.0 ± 0.8	6.0 ± 0.7	6.1 ± 0.9	5.9 ± 0.7	0.235	0.202
hs-CRP (mg/dL)	1.3 ± 0.1	1.3 ± 0.1	1.3 ± 0.1	1.1 ± 0.1	0.583	0.811
Number of prescription drugs, n (%)						
≥ 4	458(48.3)	150(39.6)	243(52.0)	65(63.1)	<0.001	<0.001
≤ 3	491(51.7)	229(60.4)	224(48.0)	38(36.9)		
Chewing status, n (%)						
Uncomfortable	376(39.5)	108(28.5)	209(44.4)	59(57.3)	<0.001	<0.001
Comfortable(moderate)	577(60.5)	271(71.5)	262(55.6)	44(42.7)		
Alcohol (g/d)	29.7 ± 4.2	43.8 ± 7.8 ^a	23.3 ± 5.6 ^{ab}	7.1 ± 3.8 ^b	0.012	0.518
Smoking status, n (%)						
Everyday	44(4.7)	15(4)	22(4.7)	7(6.7)	0.747	0.141

Sometimes	3(0.3)	1(0.3)	2(0.4)	0(0.0)		
None	897(95.0)	359(95.7)	441(94.8)	97(93.3)		
Physical activity	458.1 ± 21.8	592.3 ± 42.5 ^a	414.4 ± 25.6 ^b	166.6 ± 34.4 ^c	<0.001	0.003
1) Qualitative variables are presented as n (%), continuous variables are presented as means ± standard deviations or means ± standard errors. 2) p-values for differences between the frail status were obtained by a chi-square test or fisher's exact test for qualitative variables, or by ANOVA for continuous variables, superscript letters were significantly different among the groups by Scheffé post hoc test 3) Values were adjusted for age and sex, p-values for differences between the frail status were obtained by the Cochran-Mantel-Haenszel test for qualitative variables, or by GLM for continuous variables						

Table 3 shows the macronutrient intake of the participants according to frail status and level of energy intake. In all participants, those who were frail had, on average, lower energy intake and lower carbohydrate, protein, and fat intake than those who were prefrail and robust. Regarding the percentage of energy from macronutrients, frail participants had higher energy intake from carbohydrates and lower energy intake from protein and fat than those who were prefrail or robust. The prevalence of frailty was significantly high in participants with high energy intake from carbohydrates (>65%) and low energy intake from fat (<15%). A similar relationship was observed in subjects who consumed less than the EER, but not in subjects who consumed energy adequately.

Table 3

The macronutrient intake of the participants according to frail status and level of energy intake¹⁾

	All	≥ Calculated EER					< Calculated EER					
	All	Robust	Prefrail	Frail	p ²⁾	All	Robust	Prefrail	Frail	p ²⁾	All	Robus
		(n=371)	(n=479)	(n=104)			(n=81)	(n=87)	(n=13)			(n=29)
Energy (kcal/d)	1461.4 ± 16.6	1566.0 ± 26.7 ^a	1439.4 ± 22.6 ^b	1179.1 ± 43.8 ^c	<0.001	2174.2 ± 34.6	2270.2 ± 51.5 ^a	2124.9 ± 50.3 ^{ab}	1906.1 ± 78.3 ^b	0.012	1294.4 ± 12.7	1374.6 ± 19.6 ^a
Carbohydrate (g/d)	248.5 ± 2.8	263.0 ± 4.6 ^a	244.4 ± 3.9 ^b	213.9 ± 7.8 ^c	<0.001	361.8 ± 6.4	375.5 ± 10.1	354.9 ± 8.7	322.4 ± 17.8	0.067	221.9 ± 2.3	232.4 ± 3.5 ^a
Protein (g/d)	54.4 ± 0.8	59.0 ± 1.3 ^a	53.7 ± 1.1 ^b	41.1 ± 2.0 ^c	<0.001	79.8 ± 2.1	84.6 ± 3.1	77.2 ± 3	67.9 ± 7.4	0.064	48.5 ± 0.7	52 ± 1
Fat (g/d)	27.8 ± 0.6	30.9 ± 1.0 ^a	27.5 ± 0.9 ^b	17.7 ± 1.3 ^c	<0.001	45.3 ± 1.9	47.8 ± 2.9	44.1 ± 2.8	38.3 ± 5.3	0.384	23.7 ± 0.5	26.3 ± 0.9 ^a
Energy from carbohydrate (%)	68.8 ± 0.3	67.9 ± 0.5 ^a	68.5 ± 0.5 ^a	73.3 ± 0.9 ^b	<0.001	67 ± 0.8	66.5 ± 1.2	67.3 ± 1.1	68 ± 3.2	0.836	69.2 ± 0.4	68.2 ± 0.6 ^a
Energy from protein (%)	14.8 ± 0.1	15.0 ± 0.2 ^a	14.9 ± 0.2 ^a	13.7 ± 0.3 ^b	0.006	14.6 ± 0.2	14.8 ± 0.4	14.4 ± 0.3	14.1 ± 1.2	0.652	14.9 ± 0.1	15 ± 0
Energy from fat (%)	16.4 ± 0.3	17.2 ± 0.4 ^a	16.6 ± 0.4 ^a	13.0 ± 0.7 ^b	<0.001	18.4 ± 0.7	18.7 ± 1	18.2 ± 1	17.9 ± 2.2	0.931	15.9 ± 0.3	16.7 ± 0.5 ^a
Energy intake cut-off, n (%)												
< Calculated EER	773(81.0)	298(78.6)	384(81.5)	91(87.5)	0.115						-	-
AMDR for carbohydrate (%), n (%)												
< 55	92(9.6)	45(11.9)	42(8.9)	5(4.8)	0.001	29(16.0)	13(16.0)	13(14.9)	3(23.1)	0.922	63(8.2)	32(10.0)
55-65	214(22.4)	87(23.0)	117(24.8)	10(9.6)		38(21.0)	16(19.8)	20(23.0)	2(15.4)		176(22.8)	71(23.0)
≥ 65	648(67.9)	247(65.2)	312(66.2)	89(85.6)		114(63.0)	52(64.2)	54(62.1)	8(61.5)		534(69.1)	195(61.0)
Protein intake cut-off, n (%)												
< age- and gender-specific RNI	453(47.5)	165(43.5)	212(45.0)	76(73.1)	<0.001	11(6.1)	5(6.2)	3(3.4)	3(23.1)	0.035	442(57.2)	160(50.0)
< 0.91 g/kg	554(58.1)	203(53.6)	274(58.2)	77(74.0)	0.001	17(9.4)	7(8.6)	8(9.2)	2(15.4)	0.739	537(69.5)	196(61.0)
< 1.2 g/kg	783(82.1)	293(77.3)	395(83.9)	95(91.3)	0.002	68(37.6)	27(33.3)	34(39.1)	7(53.8)	0.337	715(92.5)	266(80.0)
AMDR for protein (%), n (%)												
< 7	1(0.1)	1(0.3)	0(0.0)	0(0.0)	0.571	1(0.6)	1(1.2)	0(0.0)	0(0.0)	0.433	0(0.0)	0(0.0)
7-20	881(92.3)	348(91.8)	434(92.1)	99(95.2)		171(94.5)	75(92.6)	84(96.6)	12(92.3)		710(91.8)	273(90.0)
≥ 20	72(7.5)	30(7.9)	37(7.9)	5(4.8)		9(5.0)	5(6.2)	3(3.4)	1(7.7)		63(8.2)	25(8.4)
AMDR for fat (%), n (%)												
< 15	456(47.8)	170(44.9)	221(46.9)	65(62.5)	0.007	73(40.3)	33(40.7)	35(40.2)	5(38.5)	0.624	383(49.5)	137(40.0)
15-30	430(45.1)	176(46.4)	216(45.9)	38(36.5)		84(46.4)	36(44.4)	40(46.0)	8(61.5)		346(44.8)	140(41.0)
≥ 30	68(7.1)	33(8.7)	34(7.2)	1(1.0)		24(13.3)	12(14.8)	12(13.8)	0(0.0)		44(5.7)	21(7.0)
1) Qualitative variables are presented as n (%), continuous variables are presented as means ± standard errors. 2) p-values for differences between the frail status test or fisher's exact test for qualitative variables, or by ANOVA for continuous variables, superscript letters were significantly different among the groups by S adjusted for age and sex, p-values for differences between the frail status were obtained by the Cochran- Mantel-Haenszel test for qualitative variables, or by												

Table 4 shows the adjusted multinomial logistic regression models comparing the nutrient intakes for frail and prefrail subjects with those for the robust subjects comprising the reference group. In the entire study population, energy and macronutrients were related to the risk of frailty, but after adjusting for

energy intake in Model 2, most of these relationships were no longer significant. In the participants with low energy intake, relationships of macronutrients with physical frailty were still significant, even after adjusting for energy. In Model 2, the risk of frailty per 10 g increase in carbohydrates (OR = 1.14, 95% CI = 1.02–1.27) and per 100 kcal increase from carbohydrates (OR = 1.38, 95% CI = 1.05–1.80) increased significantly. The risk of frailty decreased with the increase in the same amount of fat (OR = 0.67, 95% CI = 0.50–0.91) and energy from fat (OR = 0.64, 95% CI = 0.46–0.90). In the same model, the increase in protein intake and energy intake from protein did not show a significant relationship with physical frailty, but the recommended protein intake in consideration of sex and age showed a positive relationship with the prevalence of prefrailty. Notably, in both groups of subjects with low energy intake (OR = 2.94, 95% CI = 1.34–6.45) and total subjects (OR = 2.01, 95% CI = 1.03–3.93), consuming carbohydrates above the AMDR (65% of energy) was related to a higher risk of frailty, even after adjusting for energy.

Table 4
The relationship between the nutrient intakes and frail status^{1), 2)}

	All		< calculated EER													
	Model 1 ³⁾				Model 2 ⁴⁾				Model 1 ³⁾				Model 2 ⁴⁾			
	Prefrail		Frail		Prefrail		Frail		Prefrail		Frail		Prefrail		Frail	
	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)
Energy (100kcal/d)	0.99	0.96–1.02	0.92	0.87–0.98	–	–	–	–	0.98	0.93–1.03	0.89	0.82–0.98	–	–	–	–
Carbohydrate (per 10 g/day)	0.99	0.97–1.01	0.97	0.94–1.00	0.98	0.95–1.02	1.07	0.98–1.16	0.99	0.96–1.02	0.97	0.93–1.02	0.99	0.94–1.04	1.14	1.02–1.27
Protein (per 10 g/day)	0.99	0.93–1.06	0.84	0.73–0.96	1.04	0.94–1.16	0.92	0.74–1.15	1.00	0.91–1.11	0.80	0.67–0.97	1.06	0.92–1.21	0.90	0.69–1.19
Fat (per 10 g/day)	1.00	0.92–1.08	0.76	0.63–0.92	1.04	0.93–1.15	0.83	0.66–1.05	0.98	0.87–1.10	0.63	0.49–0.82	1.00	0.87–1.15	0.67	0.50–0.91
Carbohydrate energy (100kcal/d)	0.98	0.94–1.02	0.92	0.85–1.00	0.96	0.88–1.06	1.17	0.95–1.45	0.97	0.91–1.04	0.93	0.83–1.05	0.98	0.86–1.11	1.38	1.05–1.80
Protein energy (100kcal/d)	0.98	0.84–1.15	0.64	0.46–0.90	1.11	0.85–1.44	0.81	0.47–1.41	1.01	0.79–1.28	0.58	0.37–0.92	1.15	0.82–1.62	0.78	0.39–1.54
Fat energy (100kcal/d)	1.00	0.92–1.09	0.74	0.60–0.91	1.04	0.93–1.17	0.81	0.63–1.06	0.98	0.86–1.11	0.60	0.45–0.81	1.00	0.86–1.17	0.64	0.46–0.90
Energy intake cut-off, n (%)																
≥ Calculated EER	0.91	0.63–1.30	0.70	0.34–1.43	–	–	–	–	–	–	–	–	–	–	–	–
Energy from carbohydrate cut-off (%)																
< 55 (vs ≥ 55)	0.85	0.53–1.37	0.55	0.19–1.61	0.87	0.54–1.40	0.61	0.21–1.79	0.73	0.41–1.27	0.24	0.05–1.14	0.73	0.41–1.27	0.24	0.05–1.14
≥ 65 (vs < 65)	0.88	0.64–1.20	2.18	1.12–4.22	0.86	0.62–1.18	2.01	1.03–3.93	0.97	0.68–1.37	3.16	1.45–6.86	0.94	0.66–1.35	2.94	1.34–6.45
Protein intake cut-off, n (%)																
≥ age- and gender-specific RNI	1.19	0.88–1.60	0.52	0.30–0.90	1.47	1.02–2.14	0.72	0.36–1.45	1.22	0.87–1.71	0.54	0.29–1.02	1.49	0.99–2.25	0.79	0.37–1.67
≥ 0.91 g/kg	1.04	0.77–1.40	0.77	0.44–1.35	1.18	0.82–1.69	1.38	0.68–2.80	1.09	0.77–1.55	0.88	0.45–1.75	1.20	0.81–1.78	1.45	0.66–3.17
≥ 1.2 g/kg	0.83	0.58–1.21	0.54	0.24–1.21	0.88	0.56–1.37	0.93	0.37–2.37	0.71	0.39–1.29	0.65	0.17–2.51	0.73	0.40–1.36	0.92	0.23–3.69
Energy from fat cut-off (%)																
< 15 (vs ≥ 15)	0.86	0.63–1.16	1.25	0.74–2.12	0.83	0.61–1.13	1.12	0.65–1.92	0.91	0.65–1.28	1.46	0.81–2.62	0.89	0.63–1.25	1.32	0.73–2.40
≥ 30 (vs < 30)	0.97	0.56–1.65	0.22	0.03–1.75	1.00	0.58–1.71	0.25	0.03–1.96	0.88	0.46–1.71	0.29	0.04–2.31	0.89	0.46–1.73	0.29	0.04–2.38
1) Reference category: Robust. 2) Odds ratio and 95% confidence interval were obtained by the multinomial logistic regression analysis. 3) Model 1 was adjusted for age, sex, education attainment, house income, living alone or with partner, hypertension, triglyceride, number of prescription drugs, chewing status, alcohol, physical activity. 4) Model 2 was adjusted for Model 1 covariates and total energy.																

Table 5 shows the relationship between the replacement of energy from macronutrients with other macronutrients and frail status. For the group with low energy intake, replacing energy from carbohydrates with energy from fat was negatively related to the prevalence of frailty (1%, OR = 0.96, 95% CI = 0.92–1.00; 5%, OR = 0.79, 95% CI = 0.64–0.98; 10%, OR = 0.63, 95% CI = 0.41–0.97). Substituting the energy from fat with carbohydrates was related to a higher risk of frailty (1%, OR = 1.05, 95% CI = 1.00–1.09; 5%, OR = 1.26, 95% CI = 1.02–1.56; 10%, OR = 1.59, 95% CI = 1.03–2.43). However, substituting the energy from carbohydrates or fat with protein showed no significant relationship with risk of frailty among the low energy intake groups.

Table 5

The relationship between the replacement of energy from macronutrients with other macronutrients and frail status^{1), 2), 3)}

	All				< calculated EER			
	Prefrail		Frail		Prefrail		Frail	
	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)
Replacement of energy from carbohydrate with other macronutrients								
Protein for carbohydrate (1% of energy)	1.03	0.98–1.07	0.99	0.92–1.07	1.03	0.98–1.08	1.01	0.93–1.10
Protein for carbohydrate (5% of energy)	1.14	0.92–1.42	0.97	0.65–1.43	1.17	0.92–1.49	1.04	0.68–1.59
Protein for carbohydrate (10% of energy)	1.30	0.84–2.02	0.93	0.42–2.06	1.38	0.85–2.23	1.08	0.46–2.53
Fat for carbohydrate (1% of energy)	1.00	0.98–1.02	0.97	0.94–1.01	1.00	0.98–1.02	0.96*	0.92–1.00
Fat for carbohydrate (5% of energy)	1.01	0.92–1.11	0.87	0.72–1.05	0.99	0.88–1.10	0.79*	0.64–0.98
Fat for carbohydrate (10% of energy)	1.02	0.84–1.24	0.76	0.52–1.11	0.97	0.78–1.22	0.63*	0.41–0.97
Replacement of energy from fat with other macronutrients								
Protein for fat (1% of energy)	1.02	0.97–1.08	1.02	0.92–1.13	1.04	0.98–1.10	1.06	0.95–1.18
Protein for fat (5% of energy)	1.13	0.86–1.48	1.11	0.67–1.83	1.19	0.88–1.60	1.31	0.76–2.25
Protein for fat (10% of energy)	1.28	0.74–2.19	1.23	0.45–3.34	1.41	0.78–2.57	1.72	0.58–5.05
Carbohydrate for fat (1% of energy)	1.00	0.98–1.02	1.03	0.99–1.07	1.00	0.98–1.03	1.05*	1.00–1.09
Carbohydrate for fat (5% of energy)	0.99	0.90–1.09	1.15	0.95–1.39	1.01	0.91–1.13	1.26*	1.02–1.56
Carbohydrate for fat (10% of energy)	0.98	0.81–1.19	1.32	0.90–1.94	1.03	0.82–1.29	1.59*	1.03–2.43
Replacement of energy from protein with other macronutrients								
Carbohydrate for protein (1% of energy)	0.97	0.93–1.02	1.01	0.93–1.09	0.97	0.92–1.02	0.99	0.91–1.08
Carbohydrate for protein (5% of energy)	0.88	0.70–1.09	1.04	0.70–1.54	0.85	0.67–1.09	0.96	0.63–1.47
Carbohydrate for protein (10% of energy)	0.77	0.49–1.19	1.07	0.49–2.36	0.73	0.45–1.18	0.92	0.39–2.16
Fat for protein (1% of energy)	0.98	0.92–1.03	0.98	0.89–1.08	0.97	0.91–1.03	0.95	0.85–1.06
Fat for protein (5% of energy)	0.88	0.68–1.16	0.90	0.55–1.48	0.84	0.62–1.13	0.76	0.44–1.31
Fat for protein (10% of energy)	0.78	0.46–1.34	0.81	0.30–2.20	0.71	0.39–1.29	0.58	0.20–1.71
* p value < 0.005 1) Reference category: Robust. 2) Odds ratio and 95% confidence interval were obtained by the multinomial logistic regression analysis. 3) Models were adjusted for macronutrients, age, sex, education attainment, house income, living alone or with partner, hypertension, triglyceride, number of prescription drugs, chewing status, alcohol, physical activity, total energy.								

Discussion

In this study comprising community-dwelling older-aged people, our findings show that the risk of frailty was positively related to the high level of energy intake from carbohydrates (>65% energy). Particularly, for the group with low energy intake, we found that a high energy intake from carbohydrates was related to an increased prevalence of frailty, whereas high energy intake from fat was related to a decreased prevalence in multivariate nutrient density models.

The Fried frailty phenotype includes the components for assessing physical abilities, which are related to muscle mass and strength [7]. Muscle protein is regulated and metabolized depending on the intake of protein and amino acids [46, 47]. Studies on the relationship between protein intake and the prevalence of frailty have been conducted considering protein intake as the main nutritional factor, but inconsistent results have been obtained [12–24]. In the present study, high protein intake was related to a lower prevalence of frailty, but this was not significant after adjusting for total energy. This finding is consistent with the results from the study on the relationship between protein intake and grip strength in Korean elderly women, in which total protein intake had a positive relationship with grip strength, but no significant results were found after adjusting for energy [33]. A lower protein effect after energy adjustment may partially indicate the relationship between energy intake and frailty [18, 21, 48]. Previous studies have suggested that low energy intake is positively related to the prevalence of frailty [20, 21].

Several studies have shown a 5–17.9% prevalence of anorexia in the elderly [49, 50]. Anorexia has been known to occur owing to various causes, such as reduction of PA, decrease in mastication function, increased levels of cholecystokinin and leptin hormones, decrease in digestive function, and drug intake, which leads to decreased nutritional intake [35, 36]. Therefore, it may be important to determine the intake levels associated with the prevalence of frailty in older adults with low energy intake. In this study, the relationship between the level of macronutrient intake and the prevalence of frailty was different depending on whether the energy intake criteria were met or not. In the group with insufficient energy intake, high energy intake from carbohydrates showed a positive relationship with the prevalence of frailty, which was significant even after adjusting for total energy.

In the present study, high energy intake from carbohydrates was positively associated with the prevalence of frailty. Previous studies have reported the carbohydrate intake effect on chronic disease and mortality [30, 31, 51, 52]. The Atherosclerosis Risk in Communities study reported a U-shaped association between energy intake from carbohydrates and mortality as well as a significantly lower risk of death, particularly with a carbohydrate energy intake of 50–55% [51]. A meta-analysis of 432,179 people from different countries (e.g., the US, Sweden, Japan, and Greece) has also shown a U-shaped association between energy intake from carbohydrates and mortality (energy from carbohydrates of <40%, OR = 1.20, 95% CI = 1.09–1.32; energy from carbohydrates >70%, OR = 1.23, 95% CI = 1.11–1.36) [51]. The Prospective Urban Rural Epidemiology (PURE) study found that high carbohydrate energy intake was associated with an increased risk of death, but no significant association with hypertension prevalence was found [52]. High carbohydrate intake was associated with low LDL cholesterol but was also associated with low HDL cholesterol, high triglyceride levels, and an increase in the apo B/apo A1 ratio, which is known to be a strong predictor of myocardial infarction [53]. High carbohydrate intake was also associated with elevated inflammatory responses in the skeletal muscle [54], increased insulin resistance [55], mitochondrial damage in the muscle cells [56], and chronic low levels of inflammation that contribute to sarcopenia [57].

Frailty has been reported to be associated with higher oxidative stress and lower antioxidant markers in the body [21, 58, 59]. Low energy intake might reflect low overall nutrient intake [34]. In this study, the high prevalence of frailty in elderly subjects with low energy intake and high carbohydrate intake may be due to their poor diet quality, accompanying the low intake of antioxidant nutrients. Higher scores on the Alternate Mediterranean Diet, the Dietary Approaches to Stop Hypertension (DASH) diet, and the alternate Healthy Eating Index-2010 were reported to be associated with a lower risk of frailty in the Nurses' Health Study (relative risk [RR] = 0.87, 95% CI = 0.85–0.90; RR = 0.93, 95% CI = 0.91–0.95; RR = 0.90, 95% CI = 0.88–0.92, respectively) [60]. Another study on men has shown that the highest quintiles of the alternative Healthy Eating Index, Mediterranean diet score, and DASH score were associated with 40%, 46%, and 43% lower rates of frailty, respectively, compared with the lowest quintile [61]. These data suggest that the quality of diet might be related to physical frailty.

We found that frailty was decreased when carbohydrates were exchanged for fat in the low energy intake group. A previous meta-analysis showed the negative association between the substitution of carbohydrate with protein or fat and mortality [51]. The risk of mortality was different according to food source; substituting the carbohydrate with plant-based protein or fat was negatively associated with mortality (hazard ratio [HR] = 0.82, 95% CI = 0.78–0.87) and replacing the carbohydrates with animal-based protein or fat were positively associated with mortality (HR = 1.18, 95% CI = 1.08–1.29) [51]. These results suggest that it may be appropriate to recommend the intake of plant-based proteins or fats instead of carbohydrates. In the present study, the proportion of energy from fat in subjects with low energy intake was 13% for energy and below the lowest AMDR for fat. The PURE study represented that the highest quintile of total fat (median = 35.3%) was associated with less risk of total mortality when compared with the lowest quintile (median = 10.6%) and the highest intake of saturated fat, monounsaturated fat, and polyunsaturated fat was related to less risk of total mortality [52]. However, in a cross-sectional study of 4,724 people aged 50 years and older who participated in the US National Health and Nutrition Examination Survey, consuming more than 20% of energy from saturated fatty acids was associated with higher morbidity and mortality [62]. Therefore, the type of fat as well as the energy intake from fat within the AMDR should be considered in preventing frailty.

However, our study has some limitations. First, this is a cross-sectional study, so causality between dietary intake and frailty may not be verified. Second, a single 1-day 24-h recall may not be representative of the usual intake. However, the within-person variances of the energy and macronutrients have shown to be relatively low among the elderly [63, 64]. Future studies will be needed to clarify the relationship between macronutrient intake and frailty by using the repeated 24-h recall survey and prospective longitudinal data. Third, this study population included ambulatory older adults who lived near the center. Our results could not be fully representative of the older adults in Korea. Fourth, in this study, we were unable to gather information on the subtypes of dietary fat associated with physical frailty because no nutrient database for each subtype of fat was available. Since the health effects of intake levels according to dietary fat subtypes are different, studies suggesting the appropriate types of fats are needed. Fifth, in this study, the statistical test for subjects who consumed the recommended energy level was limited because of the small sample size. Therefore, the analysis of the relationship between energy and macronutrients and the prevalence of frailty in these subjects could not be performed. Nevertheless, our study has shown that the intake levels of carbohydrates and fats may be important factors in preventing the risk of frailty in older adults with low energy intake.

Conclusions

In this study, we found that the inappropriate proportion of energy from carbohydrates and fat was related to a higher prevalence of frailty in the elderly with low energy intake. It was also indicated that the proportion of energy intake from carbohydrates and fats may be an important nutritional intervention factor in reducing the risk of frailty, as well as protein as previously emphasized.

Declarations

Ethics approval and consent to participate

This study was performed in accordance with the Declaration of Helsinki, and it was approved by the Institutional Review Board of Dankook University, Hanyang University and Kyung Hee University. Written informed consent was obtained from all participants.

Consent for publication

Not Applicable.

Availability of data and materials

Data are available upon reasonable request. All published articles and news articles using the KFACS database, data provision manuals and contact information are available at the KFACS website (<http://www.kfacs.kr>). The KFACS cohort database and blood samples are available to researchers, and the authors anticipate collaboration even with international researchers, although approval from the Kyung Hee University Hospital IRB is required to share the dataset or banked blood samples for all the researchers.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

KK conceived and designed the study. MKK & YL acquired data. NY & KK analyzed and interpreted the data. NY wrote the first draft of the manuscript. MKK & YL provided critical comments for important intellectual content and approved the final submission.

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