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Association of the dietary inflammatory index with sarcopenic obesity and frailty in older adults

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Abstract

Objectives This study examined whether a higher dietary inflammatory index (DII®) is associated with the risk of sarcopenic obesity (SO) and frailty among Korean older adults.

Methods A total of 950 participants aged 70–84 years, who completed the baseline nutrition survey of the Korean Frailty and Aging Cohort Study, were included in the analysis. The DII, quantifying the dietary inflammatory potential, was calculated using 23 foods and nutrients as assessed by a 24-h dietary recall. SO was defined as the coexistence of sarcopenia (dual-energy X-ray absorptiometry-measured appendicular skeletal muscle mass index of < 7.0 for males; <5.4 for females) and abdominal obesity (waist circumference of ≥ 90 cm for males; ≥85 cm for females). Frailty status was assessed using the Fried frailty index (range, 0–5), a simple tool for defining frailty that consists of three or more of five frailty items. Multinomial logistic regression models were used to estimate odds ratios (ORs) with 95% confidence intervals (CIs), adjusting for confounders.

Results The prevalence of SO and frailty was 9.8% and 10.8%, respectively. The DII was significantly higher in the frail group (2.7) compared to the robust and SO groups (2.0 vs. 1.8) ($P < 0.001$). Among nutrients and foods included in the DII, the frail group exhibited lower vitamin E, niacin, vitamin B_6, energy, and protein intakes than the robust and SO groups. Multivariable-adjusted OR (95% CI) for frailty versus robust (comparing DII tertile 3 to tertile 1) was 2.3 (1.1–4.8; *P*-trend = 0.02). However, no significant association was observed between the DII and SO (OR, 1.1; 95% CI, 0.5–2.1; *P*-trend = 0.6).

Conclusions A higher DII score was associated with increased odds of frailty but not with SO in Korean older adults, suggesting that proinflammatory diets have a greater impact on frailty than that on SO in the older population.

Keywords Dietary inflammatory index, Frailty, Sarcopenic obesity, Aging, Korean older adults

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Introduction

The proportion of the population aged 65 years and older has increased over the past six decades, both on a global scale (from 5.5% in 1960 to 9.6% in 2021) and in South Korea (from 3.3% in 1960 to 16.7% in 2021) [1]. Notably, South Korea has experienced a remarkably rapid transition to an aged society [2]. Aging is known to result in impairments across various musculoskeletal systems, including the joints, bones, muscles, and multiple body areas or systems [3]. Additionally, aging is associated with an elevation in total body fat mass and increase in visceral fat depots may occur redistributing fat into the abdominal region [4]. These age-related changes in body composition may be linked to reduced mobility, decreased functional capacity [3], and an increased risk of cardiovascular diseases, diabetes, and metabolic syndrome [4].

To assess age-related changes in body composition, several phenotypes have been identified. Sarcopenic obesity (SO) is characterized by the coexistence of sarcopenia, which refers to the "age-related loss of skeletal muscle mass plus loss of muscle strength and/or reduced physical performance" [5], along with obesity [6]. Frailty has been defined as "a state of vulnerability to poor homeostasis resolution following a stressor event and is a consequence of a cumulative decline in several physiological systems during a lifetime [7]". Frailty can be considered an umbrella term that encompasses sarcopenia. Globally, frailty affects 12–24% of older adults [8], whereas in South Korea, its prevalence stands at 8% [9]. The global SO prevalence is approximately 11% [10], whereas in South Korea, it is approximately 4% [11]. Although these conditions are distinct, low-grade inflammation, as indicated by elevated inflammatory markers including interleukin-6, high-sensitivity C-reactive protein (hs-CRP), and tumor necrosis factor alpha, is believed to be a common biological mechanism underlying both phenotypes [7, 12].

Diet plays a significant role in modulating low-grade inflammation [13], and the dietary inflammatory index (DII) has been widely used for assessing the inflammatory potential of diets [14]. Extensive evidence supports a positive association between the DII and several health outcomes, including metabolic risk markers, cancer risk, cardiovascular diseases, and mortality [15], as well as phenotypes including sarcopenia [16], abdominal obesity [17], and frailty [18]. However, owing to the scarcity of studies conducted in South Korea, generalizing these findings to the Korean population is challenging. Although two studies have been conducted in the Korean context, one is limited to postmenopausal women [19], and the other has a relatively small sample size [20]. Furthermore, to date, no study has directly investigated the association between the DII and SO. Frailty and SO are common conditions among older adults, and previous studies indicated that several characteristics, including metabolic, inflammatory, and hematologic markers, are shared between the two conditions [21–23]. It would be more meaningful to understand these two conditions in relation to the DII rather than examining each condition separately.

Considering these gaps, the present study aimed to examine the association of the dietary inflammatory potential, as measured by the DII, with SO and frailty, among Korean older adults. We hypothesized that Korean older adults with higher DII scores would exhibit increased odds of having both SO and frailty compared with those with lower DII scores.

Methods

Study Population

The Korean Frailty and Aging Cohort Study (KFACS) is a population-based prospective cohort study that aims to investigate frailty status and changes in frailty states over time among community-dwelling older adults in Korea [24]. From May to November 2016, a total of 1,559 community dwellers aged 70–84 years were recruited using quota sampling stratified by age and sex from 10 study centers located in different regions [24].

Among 1,002 (64%) participants who completed nutrition surveys, we excluded those with the following conditions: total energy intake of <400 kcal (n=3), missing data on dual-energy X-ray absorptiometry (DEXA) (n=5), and missing frailty component data (n=44). Due to the limited sample size, we did not exclude participants with missing covariates (n=17). The final analytical sample included 950 participants (459 males and 491 females) (Supplemental Fig. 1).

Data Collection

Face-to-face interviews were conducted to gather information on demographics (e.g., age, sex, education level, monthly household income, and family structure [living alone or not]), health status (e.g., comorbidity and number of prescription drugs), and health behaviors (e.g., chewing status, smoking status, alcohol consumption, and physical activity level). Trained staff performed measurements of anthropometrics (e.g., height, weight, and waist circumference), body composition (e.g., muscle mass), and physical function (e.g., hand grip strength, chair-stand time, and walking speed). Body mass index (BMI) was calculated as the ratio of weight (kg) to height squared (m^2). Waist circumference was measured at the midpoint between the lowest rib margin and the upper ridge of the iliac crest using an inelastic tape. Muscle mass (kg) was measured using DEXA (GE Healthcare Lunar, Madison, WI, USA; and Hologic DXA Systems, Hologic Inc., Bedford, MA, USA). Grip strength (kg) was

measured using a hand grip dynamometer (T.K.K.5401; Takei Scientific Instruments Co., Tokyo, Japan). The handgrip strength was measured twice for each hand over a 3-min interval. We used the highest value among the averages of each measurement for further analysis. Walking speed over a 4-m distance was assessed using an automatic timer (Gait Speedometer; Dynamic Physiology, Daejeon, Korea). Blood samples were collected following an 8-h fasting and transported to a commercial laboratory for analysis. This study utilized serum total cholesterol (mg/dL), triglycerides (mg/dL), high-density lipoprotein (HDL) cholesterol (mg/dL), low-density lipoprotein (LDL) cholesterol (mg/dL), fasting blood glucose (mg/dL), hemoglobin A1C (HbA1C) (%), and hs-CRP (mg/dL) [24].

To collect detailed dietary information, trained interviewers administered a 24-h dietary recall in the participant's home. Participants reported the description, quantity, and time and place of consumption for all foods and beverages consumed within the previous 24 h, with the assistance of visual aids developed by the Korea Disease Control and Prevention Agency (KDCA) [25]. Nutrient intakes were estimated using the 24-h dietary recall assessment system of the National Institute of Health and the KDCA [25].

DII

As the main exposure, the DII was calculated to comprehensively assess the inflammatory potential of diets [14]. This composite index was developed and validated using a comprehensive review of 1,943 articles published from 1950 to 2010. Briefly, the inflammatory potential of 45 food, nutrient, and bioactive compound parameters was scored on the basis of their effects on inflammatory biomarkers (interleukin-1β, interleukin-4, interleukin-6, interleukin-10, tumor necrosis factor-α, and hs-CRP). The range for overall DII score in the DII development study was −8.87 to +7.98 [14]. The DII calculation in this study followed the same approach as that described in the original DII development study [14]. Originally, 45 parameters were included in the DII calculation, but *the following 23 foods and nutrients, which were only available to use, were included in this study*: beta-carotene, carbohydrate, cholesterol, energy, fiber, folic acid, garlic, ginger, green/black tea, vitamin A, vitamin B_1, vitamin B_2, vitamin B_6, vitamin C, vitamin D, vitamin E, iron, niacin, vitamin B_{12}, onion, pepper, protein, and total fat. *Owing to insufficient data, the following 22 foods and nutrients were not included in the calculation*: caffeine, alcohol, eugenol, magnesium, MUFA, n-3 fatty acid, n-6 fatty acid, PUFA, saffron, saturated fat, selenium, trans fat, turmeric, zinc, flavan-3-ol, flavones, flavonols, flavonones, anthocyanidins, isoflavones, thyme/oregano, and rosemary.

First, Z-scores were computed for each of the 23 parameters by subtracting the standard global mean (derived from the representative global diet database) from the actual consumption and subsequently dividing by the global standard deviation. Second, the estimated Z-scores were converted into percentiles to minimize the effect of skewness or outliers. These percentiles were centered on 0 (yielding a symmetrical distribution) by doubling each percentile value and subtracting 1. Lastly, parameter-specific DII scores were determined by multiplying the centered percentile values by the corresponding overall food parameter-specific inflammatory effect score, and the overall DII score was obtained by summing across all parameter-specific DII scores. A higher DII score indicates a more proinflammatory diet, while a lower score suggests a more anti-inflammatory diet. In this study, DII scores ranged from −3.07 to 4.39.

Assessment of outcomes

SO

We used the appendicular skeletal muscle mass index (ASMI) for sarcopenia diagnosis. The appendicular skeletal muscle mass (ASM) was defined as the sum of lean muscle mass in both the arms and legs, and the ASMI was obtained by dividing the ASM by the square of the height (kg/m^2). Sarcopenia was defined as an ASMI of <7.0 and <5.4 for males and females, respectively, which is a diagnostic criterion for sarcopenia proposed by the Asian Working Group for Sarcopenia (AWGS) [5]. Abdominal obesity was defined as a waist circumference of ≥ 90 and ≥ 85 cm for males and females, respectively, according to the criteria set by the Korean Society for the Study of Obesity [26]. Finally, SO was defined as the presence of both sarcopenia and abdominal obesity.

Frailty

To assess frailty status, a modified version of the Fried frailty index was used [27]. The Fried frailty index included the following five components: unintended weight loss, weakness, self-assessed exhaustion, slow walking speed, and low physical activity. In the modified Fried frailty index, the physical activity component was assessed using the Korean version questionnaire to better represent the physical activity levels of the Korean population, and the remaining components were assessed using the same criteria as the original Fried frailty index. (1) Unintended weight loss component was defined as an affirmative answer to "Have you experienced unintended weight loss of 4.5 kg or more during the last year?" (2) Weakness component was defined as a grip strength of <26 and <18 kg for males and females, respectively [28]. (3) The exhaustion component was assessed on the basis of responses to questions from the Center for Epidemiological Studies-Depression scale: "I felt that everything I

did was an effort" or "I could not get going." Exhaustion was defined as an affirmative answer to the above mentioned questions for three or more days in a week. (4) Slow walking speed component was defined as <1 m/s after walking 4 m at a normal rhythm. (5) The physical activity component was evaluated using the International Physical Activity Questionnaire–Short Form (Korean version) [29]. The metabolic equivalent of task (MET)-minutes was quantified by multiplying the frequency, duration, and intensity of physical activities engaged during a week. "Low physical activity" was defined as <494.65 and <283.50 MET-min/week for males and females, respectively (Supplemental Table 1).

Each frailty index component received a score of 1 if the criteria were met; otherwise, it received a score of 0. The final modified frailty index score was calculated by summing the scores of each component (range, 0–5), with a score of 3–5 defining frailty.

Assessment of covariates

Covariates included age (years), sex (male or female), education level (<7 or ≥7 years of education), monthly household income (unknown, <1, 1–2, or ≥2 million Korean won), family structure (living alone or living with a partner), number of chronic diseases (counts), number of prescribed drugs (<4 or ≥4), chewing status (uncomfortable or comfortable), smoking status (everyday, sometimes, or none), alcohol consumption (g/day), physical activity level (MET-min/week), and total energy intake.

Statistical analysis

The normality of all continuous variables was evaluated both visually using histograms and Q–Q plots and using skewness and kurtosis values. Variables that did not follow a normal distribution were log-transformed for the statistical test (physical activity level, repeated five-chair stands, triglyceride, fasting blood glucose, HbA1C, and hs-CRP). The characteristics of study participants by SO and frailty status were described using means and standard deviations for continuous variables and frequencies and proportions for categorical variables. The significance of differences in characteristics between the robust (neither have SO nor frailty), SO, and frailty groups was examined using analysis of variance and a chi-square test for continuous and categorical variables, respectively. Age- and sex-adjusted anthropometric and metabolic characteristics between the robust, SO, and frailty groups were presented as means and standard errors using the general linear model. Except for energy and cholesterol intake, all nutrient intakes used in the DII calculation were expressed as percentages of the age- and sex-specific recommendations based on the Dietary Reference Intakes for Koreans (KDRI) 2020 [30]. Total energy intake was expressed as a percentage of the estimated energy requirement, calculated using the following formula {male: 662 − 9.53 × age + value of physical activity level (PA) [15.91 × weight (kg) + 539.6 × height (m)]; female: 354 − 6.91 × age + PA [9.36 × weight + 726 × height (m)]} [30]. PA values of 1.11 and 1.12 for males and females, respectively, were assigned [30]. The dietary characteristics between the robust, SO, and frailty groups were tested using the general linear model after adjusting for age, sex, and total energy intake. To determine group differences, we performed Tukey's multiple comparison test.

For categorical analysis, the DII was classified into tertiles, with tertile 1 serving as the reference (range: -3.07–1.46 for tertile 1; 1.46–2.83 for tertile 2; 2.84–4.39 for tertile 3). Multinomial logistic regression models were used to estimate the odds ratios (ORs) and 95% confidence intervals (CIs) for the presence of SO and frailty versus robust by comparing tertiles 2 and 3 with tertile 1 of the DII as the exposure variables. We presented the following two adjustment models: (1) an age- and sex-adjusted model; and (2) model 1, with the inclusion of age, sex, education, monthly household income, family structure, number of chronic diseases, number of prescription drugs, chewing status, smoking status, alcohol consumption, physical activity, and total energy intake as covariates. We tested for the presence of multicollinearity using the variance inflation factor (VIF) and found no evidence of multicollinearity among the covariates (VIF < 10). The potential linear trends across increasing DII tertiles were tested by assigning the medians to each DII tertile as a continuous variable. All statistical tests were two-sided with a statistical significance level of 0.05. All statistical analyses were performed using SAS software version 9.4 (SAS Institute, Cary, NC, USA).

Results

Participant characteristics

The characteristics of study participants in the robust, SO, and frailty groups are presented in Table 1. Among 950 participants, 93 (9.8%) and 103 (10.8%) had SO and frailty, respectively. Participants in the frailty group were more likely to be older females with lower education levels, household income, and physical activity levels than those in the robust and SO groups. Furthermore, they were more likely to live alone, have a higher number of chronic diseases and prescribed drugs, and refer uncomfortable chewing status.

Participants in the SO group had lower ASM measures (ASM, ASM/height^2, and ASM/weight) and HDL-cholesterol levels as well as higher waist circumference and BMI than those in the frailty and robust groups. Participants with frailty had the lowest hand grip strength, the longest time for repeated five-chair stands, and the highest triglycerides and hs-CRP levels (Table 2).

Table 1 General characteristics of study participants in the robust, SO, and frailty groups ($n=950$)

	Robust group	Sarcopenic obesity group	Frailty group	*P* value [a]
n (%)	754 (79.4)	93 (9.8)	103 (10.8)	
Age (years)	75.9 ± 0.1[c]	77.0 ± 0.4[d]	78.8 ± 0.4[e]	0.01
Age				
<75 years	312 (41.4)	30 (32.3)	17 (16.5)	< 0.0001
≥75 years	442 (58.6)	63 (67.7)	86 (83.5)	
Sex				
Males	382 (50.7)	50 (53.8)	27 (26.2)	< 0.0001
Females	372 (49.3)	43 (46.2)	76 (73.8)	
Education level				
<7 years	321 (42.6)	25 (26.9)	85 (82.5)	< 0.0001
≥7 years	432 (57.3)	68 (73.1)	18 (17.5)	
Monthly household income				
Unknown	62 (8.2)	3 (3.2)	15 (14.6)	< 0.0001
<1 million won	282 (37.4)	36 (38.7)	66 (64.1)	
1–2 million won	189 (25.1)	16 (17.2)	12 (11.7)	
≥2 million won	221 (29.3)	38 (40.9)	10 (9.7)	
Family structure				
Living alone	178 (23.6)	27 (29.0)	39 (37.9)	0.01
Living with a partner	576 (76.4)	66 (71.0)	64 (62.1)	
Number of chronic diseases	2.1 ± 0.1[c]	2.6 ± 0.2[d]	2.8 ± 0.1[d]	< 0.0001
Number of prescribed drugs				
≥4	343 (45.5)	50 (53.8)	64 (62.1)	0.01
<4	408 (54.1)	42 (45.2)	38 (36.9)	
Chewing status				
Uncomfortable	285 (37.8)	30 (32.3)	58 (56.3)	< 0.0001
Comfortable (moderate)	469 (62.2)	63 (67.7)	44 (42.7)	
Smoking status				
Everyday	33 (4.4)	4 (4.3)	7 (6.8)	0.44
Sometimes	2 (0.3)	1 (1.1)	0 (0.0)	
None	709 (94.0)	88 (94.6)	96 (93.2)	
Alcohol consumption (g/day)	35.1 ± 4.9	27.0 ± 13.9	7.5 ± 13.2	0.14
Physical activity level [b]	514.1 ± 24.1[c]	312.3 ± 68.7[c]	165.0 ± 65.2[d]	< 0.0001

Abbreviations: SO, sarcopenic obesity

Data source: Korean Frailty and Aging Cohort Survey (KFACS)

Note: Data are presented as means and standard errors for continuous variables and sample sizes and percentages for categorical variables.

[a] *P* values for differences in characteristics between the robust, frailty, and sarcopenic obesity groups are obtained using analysis of variance (ANOVA) for continuous variables and the chi-square test for categorical variables. Mean values with different superscripts ([c, d, e]) within a row are significantly different among the exposure groups on Tukey's multiple comparison test.

[b] For the significance test, the physical activity level is log-transformed owing to a non-normal distribution, and the mean value is an original value.

DII and Individual DII component characteristics

The total mean DII scores were 2.67, 1.96, and 1.82 in the frailty, robust, and SO groups, respectively. Most nutrient intakes, except for vitamin A, vitamin C, vitamin B_1, niacin, carbohydrate, vitamin B_{12}, and iron, were below the recommended nutrient intake (RNI) or adequate intake (AI) levels based on the KDRI 2020. Among individual nutrients and foods included in the DII, vitamin E, niacin, vitamin B_6, energy, and protein intakes were lower in the frailty group than those in the robust and SO groups (Table 3).

DII in relation to SO and frailty

The associations between the DII and SO as well as frailty are shown in Fig. 1. Participants with higher DII scores had a higher frailty prevalence (4.4%, 8.8%, and 19.2% in tertiles 1 [T1], 2 [T2], and 3 [T3], respectively). Participants in DII T2 had higher SO prevalence than those in T1 and T3 (9.5%, 13.6%, and 6.3% in T1, T2, and T3, respectively). After adjusting for age and sex, OR (95% CI) for frailty versus robust (comparing DII tertile 3 to tertile 1) was 3.35 (1.78–6.29; *P*-trend < 0.0001), whereas no association between DII and SO was observed. A positive association between the DII and frailty remained consistent in multivariable-adjusted models (T3 vs. T1, OR, 2.26; 95% CI, 1.07–4.80; *P*-trend = 0.02) (Fig. 1) and

Table 2 Anthropometric and metabolic characteristics of study participants in the robust, SO, and frailty groups ($n=950$)

	Robust group	Sarcopenic obesity group	Frailty group	*P* value [a]
ASM (kg)	17.2 ± 0.1^{c}	14.6 ± 0.3^{d}	16.0 ± 0.3^{e}	< 0.0001
ASM/height^2 (kg/m^2)	6.8 ± 0.03^{c}	5.7 ± 0.1^{d}	6.5 ± 0.1^{e}	< 0.0001
ASM/weight (%)	28.0 ± 0.1^{c}	23.0 ± 0.3^{d}	26.6 ± 0.3^{e}	< 0.0001
Hand grip strength (kg)	24.6 ± 0.2^{c}	23.0 ± 0.5^{d}	19.5 ± 0.5^{e}	< 0.0001
Repeated five-chair stands (s)	11.3 ± 0.2^{c}	11.4 ± 0.4^{c}	16.0 ± 0.4^{d}	< 0.0001
Frailty score [b]	0.75 ± 0.03^{c}	0.94 ± 0.07^{d}	3.08 ± 0.07^{e}	< 0.0001
Waist circumference (cm)	87.0 ± 0.3^{c}	93.3 ± 0.9^{d}	88.9 ± 0.8^{c}	< 0.0001
Body mass index (kg/m^2)	24.3 ± 0.1	25.1 ± 0.3	24.7 ± 0.3	0.04
Total cholesterol (mg/dL)	171.5 ± 1.3	173.5 ± 3.6	170.7 ± 3.6	0.84
Triglyceride (mg/dL)	119.3 ± 2.2	128.6 ± 6.4	136.9 ± 6.3	0.03
HDL-cholesterol (mg/dL)	52.0 ± 0.5	48.6 ± 1.4	48.9 ± 1.4	0.02
LDL-cholesterol (mg/dL)	107.6 ± 1.2	110.6 ± 3.3	107.7 ± 3.3	0.70
Fasting blood glucose (mg/dL)	103.9 ± 0.8	107.0 ± 2.2	105.1 ± 2.2	0.30
HbA1C (%)	6.0 ± 0.03	6.1 ± 0.1	6.0 ± 0.1	0.32
hs-CRP (mg/dL)	1.29 ± 0.08^{c}	2.02 ± 0.23^{d}	2.06 ± 0.22^{d}	0.002

Abbreviations: ASM, appendicular skeletal muscle mass; HDL, high-density lipoprotein; LDL, low-density lipoprotein; HbA1C, hemoglobin A1C; hs-CRP, high-sensitive C-reactive protein

Data source: Korean Frailty and Aging Cohort Survey (KFACS)

Note: Means and standard errors are obtained using the linear regression model after adjusting for age and sex.

[a] *P* values for differences in characteristics between the robust, frailty, and sarcopenic obesity groups are obtained using the general linear model after adjusting for age and sex. Mean values with different superscripts ($^{c, d, e}$) within a row are significantly different among the exposure groups on Tukey's multiple comparison test. For the significance test, repeated five-chair stands, triglyceride, fasting blood glucose, HbA1C, and hs-CRP are log-transformed owing to non-normal distributions, and the mean values of these variables are original values.

[b] A composite frailty score (range: 0–5) is calculated using a modified version of the Fried frailty phenotype (unintended weight loss, weakness [poor grip strength], self-assessed exhaustion, slow walking speed, and low physical activity).

further adjustment for blood markers (T3 vs. T1, OR, 2.43; 95% CI, 1.13–5.23; *P*-trend=0.02) (Supplemental Fig. 2).

Discussion

In this cross-sectional study of 950 Korean older participants, we observed that individuals with frailty had the highest DII score, indicating a higher proinflammatory diet consumption, whereas those with SO had the lowest DII score, indicating a lower proinflammatory diet consumption. Our findings showed a significant positive association between the DII and frailty, which remained statistically significant even after controlling for demographic and lifestyle variables. However, no meaningful association was observed between the DII and SO.

In our study, the positive association between the DII and frailty is consistent with previous studies. Five cross-sectional studies conducted on individuals aged 60 years and older demonstrated that those with higher DII scores had a 1.7–3.6 times greater likelihood of being frail than those with lower DII scores [20, 31–34]. Furthermore, a prospective study conducted in US adults with or at a high risk of knee osteoarthritis (age range: 45–85 years) showed that individuals with higher DII scores had a 1.4 times higher risk of developing frailty [35]. Collectively, these findings suggest that diets with a higher proinflammatory potential, as indicated by higher DII scores, have negative impacts on frail status, particularly in older adult populations.

Although our study identified a positive association between the DII and frailty, the results did not support our hypothesis regarding the association between the DII and SO. In the older adult population, SO may be a more significant predictor of age-related changes in body composition than sarcopenia or obesity alone [36]. This is because these changes frequently occur simultaneously and have a synergistic adverse effect on cardiometabolic health and mortality risk with aging [36]. Several factors might explain our findings. First, variations in body composition measurement techniques and the definition of sarcopenia and obesity across studies may contribute to inconsistent results [37]. Owing to the lack of the use of different equipment, accurately and consistently assessing both conditions is challenging [37]. We used the ASMI for sarcopenia definition as recommended by the AWGS [5] and waist circumference for obesity definition to better reflect visceral adiposity [38]. However, neither of these measures was based on gold standard measures of body composition. Furthermore, we observed no significant differences when comparing different definitions of sarcopenic obesity based on BMI or percent body fat (Supplemental Fig. 3). To address this issue, future studies should strive for the use of more precise body composition assessment techniques including computed

Table 3 Mean and standard error of the dietary inflammatory index (DII) and relative consumption of individual DII components in the robust, SO, and frailty groups ($n=950$)

	Robust group	Sarcopenic obesity group	Frailty group	*P* value [a]
Total mean DII score	1.96 ± 0.05[c]	1.82 ± 0.14[c]	2.67 ± 0.14[d]	< 0.0001
Individual components of DII consumption				
Anti-inflammatory effect				
Fiber (% intake to AI)	27.0 ± 0.4[c]	27.5 ± 1.2[c]	24.1 ± 1.2[d]	0.0002
Vitamin A (% intake to RNI)	105.0 ± 3.2[c]	100.6 ± 9.1[c]	95.4 ± 9.0[d]	0.0004
Vitamin D (% intake to AI)	36.0 ± 1.8	40.3 ± 5.2	27.2 ± 5.2	0.09
Vitamin E (% intake to AI)	65.9 ± 1.0[c]	64.3 ± 2.8[cd]	56.3 ± 2.8[d]	0.01
Vitamin C (% intake to RNI)	99.9 ± 2.3[c]	99.3 ± 6.7[c]	90.2 ± 6.6[d]	0.003
Vitamin B_1 (% intake to RNI)	139.2 ± 26.7[c]	106.7 ± 76.0[c]	107.1 ± 75.1[d]	0.01
Vitamin B_2 (% intake to RNI)	81.0 ± 1.4[c]	85.5 ± 4.0[c]	75.4 ± 4.0[d]	0.003
Niacin (% intake to RNI)	111.5 ± 1.4[c]	125.1 ± 3.9[d]	110.1 ± 3.8[c]	0.004
Vitamin B_6 (% intake to RNI)	95.3 ± 1.3[c]	108.2 ± 3.8[c]	91.0 ± 3.7[d]	0.0001
Folate (% intake to RNI)	73.2 ± 1.3[c]	74.8 ± 3.7[c]	68.0 ± 3.7[d]	0.0003
Beta-carotene (μg/day)	3563 ± 110[c]	3582 ± 313[c]	3412 ± 310[d]	0.001
Garlic (g/day)	5.7 ± 0.2[c]	5.3 ± 0.5[cd]	4.3 ± 0.5[d]	0.01
Ginger (g/day)	0.9 ± 0.1	0.6 ± 0.4	0.8 ± 0.4	0.51
Onion (g/day)	14.2 ± 0.8[c]	15.4 ± 2.3[cd]	10.7 ± 2.3[d]	0.03
Green tea (g/day)	0.8 ± 0.5[c]	5.4 ± 1.5[d]	0.3 ± 1.5[c]	0.01
Pepper (g/day)	7.6 ± 0.6	6.1 ± 1.7	4.6 ± 1.7	0.11
Proinflammatory effect				
Energy (% intake to EER)	83.4 ± 0.1[c]	82.7 ± 0.4[cd]	82.2 ± 0.4[d]	0.001
Carbohydrate (% intake to RNI)	191.2 ± 1.1	187.6 ± 3.2	197.1 ± 3.1	0.09
Protein (% intake to RNI)	99.0 ± 0.9[c]	107.0 ± 2.7[c]	94.4 ± 2.7[d]	0.0002
Fat (g/day)	54.5 ± 0.5[c]	59.6 ± 1.5[d]	52.5 ± 1.5[c]	**0.002**
Vitamin B_{12} (% intake to RNI)	224.9 ± 11.4[c]	321.9 ± 32.4[d]	230.5 ± 32.1[cd]	0.02
Iron (% intake to RNI)	154.6 ± 2.6[c]	159.8 ± 7.5[c]	150.2 ± 7.4[d]	0.01
Cholesterol (mg/day)	62.5 ± 1.9	69.5 ± 5.4	52.7 ± 5.3	0.08

Abbreviations: DII, dietary inflammatory index; KDRI, Dietary Reference Intakes for Koreans; AI, adequate intake; RNI, recommended nutrient intake; EER, estimated energy requirement

Data source: Korean Frailty and Aging Cohort Survey (KFACS)

[a] *P* values for differences in dietary characteristics between the robust, frailty, and sarcopenic obesity groups are obtained using the general linear model after adjusting for age, sex, and total energy intake. Mean values with different superscripts ([c, d, e]) within a row are significantly different among the exposure groups on Tukey's multiple comparison test. Variables except for vitamin E, niacin, energy, carbohydrate, vitamin B_{12}, and cholesterol are log-transformed owing to non-normal distributions, and the mean values of these variables are original values

tomography (CT) or magnetic resonance imaging (MRI) is encouraged.

Alternatively, it is plausible that frailty may be an inclusive concept that encompasses both sarcopenia and obesity. The definitions and diagnostic criteria for sarcopenia and frailty share several similarities [39], and sarcopenia, obesity, and frailty share common underlying mechanisms, particularly involving low-grade inflammation [7, 12, 21]. However, notably, sarcopenia or obesity may precede frailty development but not vice versa [39, 40]. Moreover, considering that diet represents a long-term habitual exposure, detecting associations with relatively short-term outcomes including body composition may be insufficient. Also, diet could reflect possible impairments in the overall health status besides the SO of frailty.

Another potential explanation is that the SO group in our study exhibited better oral health, healthier lifestyle habits, and higher education and income levels. These characteristics might also influence the consumption of healthy food, which could have a positive impact on anti-inflammatory effects [41, 42]. Although confounding variables were adjusted in the analysis model, it is possible that unmeasured positive factors in this group may have diluted the association between the DII and SO.

In our study, participants in the SO group showed more favorable dietary intake profiles overall than those in the frailty and robust groups (Tables 3and Supplemental Table 2). Among those in the SO group, the proportion of participants who did not meet the Dietary Reference Intakes for Koreans recommendations for vitamins E, C, B_1, B_2, B_3, B_6, and folate was the lowest, whereas the proportion with inadequate protein intake was the highest. This finding contradicts a previous study that reported negative associations between several nutrient intakes and SO [43]. Conversely, the frailty group had lower vitamin E, B_3, B_6, energy, and protein intakes than the

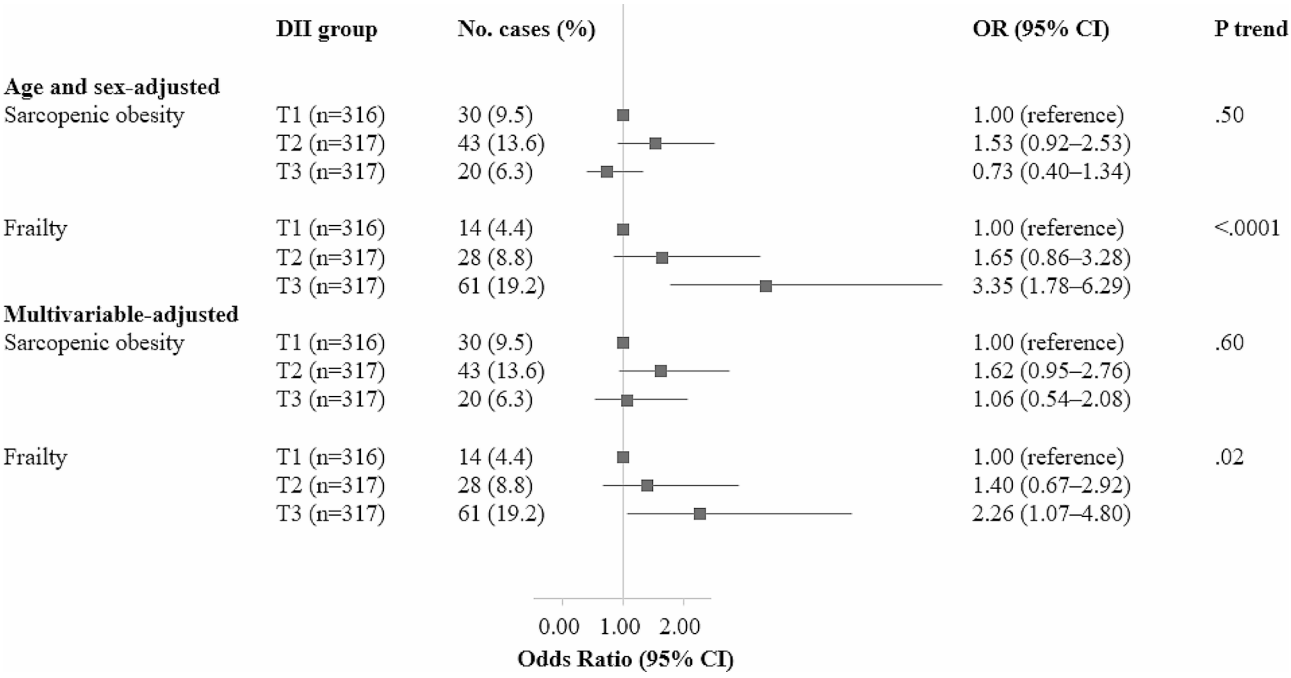

Fig. 1 Odds ratios (95% confidence intervals) for sarcopenic obesity and frailty by tertiles of the dietary inflammatory index score Abbreviations: T, tertile; DII, dietary inflammatory index; OR, odds ratio; CI, confidence interval

Data source: Korean Frailty and Aging Cohort Survey (KFACS)

Note: Multinomial logistic regression models are used to estimate odds ratios and their corresponding 95% confidence intervals for the presence of SO and frailty versus robust by comparing tertile 2 and 3 with tertile 1 of the DII as the exposure variables. The number of each SO and frailty cases and their percentages are presented as No. cases (%) according to the DII tertile. *P* for trends is determined by treating the median value of the DII score as a continuous variable using multinomial logistic regression models. The multivariable-adjusted model is adjusted for age, sex, education level, monthly household income level, family structure, number of chronic diseases, number of prescribed drugs, chewing status, smoking status, alcohol consumption, physical activity level, and total energy intake

robust group, which aligns with previous knowledge [44]. Collectively, it is possible that the pathophysiology of SO may be inadequately explained by dietary intake. To further investigate this possibility, future studies using repeated dietary measures are required.

This study had several strengths. To our knowledge, this is the first study to simultaneously examine the association between dietary inflammatory potential and two age-related conditions. Second, the KFACS provided a wide range of data necessary for assessing multiple phenotypes. Body composition data from DEXA and comprehensive physical examination data allowed us to assess two frequently examined phenotypes, including SO and frailty, respectively. However, our study also had several limitations. First, owing to its cross-sectional design, we cannot establish a strong causal relationship between proinflammatory diets and frailty incidence. Second, as our study focused on Korean adults aged 70–84 years, our findings may not be applicable to other populations. Third, a single 24-h dietary recall may not fully capture individuals' dietary habits and may poorly represent usual individual intake owing to day-to-day variations in nutrients or foods consumed [45]; however, compared with other methods, the 24-h recall method is considered to have the least bias. Fourth, while the original DII included 45 components, only 23 of them were included in the DII calculation owing to data availability, leaving behind 22 components. It is possible that the results might differ if these remaining components were added. However, of note, most of the missing components are not commonly consumed in the Korean diet. Additional studies are needed to explore this issue by including a broader range of dietary components in the DII calculation. Finally, obesity misclassification may have occurred as waist circumference may not fully capture adiposity compared with direct measures, including CT or MRI [38].

In conclusion, our findings indicate that a higher DII score is associated with increased odds of having frailty but not with SO in Korean older adults. These results suggest that proinflammatory diets have a greater impact on frailty than that on SO in the older adult population. This finding may be explained by the fact that frailty could be a more comprehensive condition that is primarily related to advanced age, whereas sarcopenia and obesity are not exclusively related to advanced age [39]. To confirm the replicability of these results, further large-scale studies based on a prospective cohort study design

and randomized controlled trials are needed. Furthermore, to gain a better understanding of the observed associations, studies exploring the underlying mechanisms should be conducted.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12877-024-05239-z.

Supplementary Material 1

Author contributions

S.J. contributed to data curation, formal analysis, visualization, original draft preparation and Y.L. contributed to research funding, original draft preparation, reviewing and editing. K.K. and S.P. contributed to conceptualization, writing, reviewing and editing. All authors gave final approval and agreed to be accountable for all aspects of ensuring integrity and accuracy.

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Data availability

The data used in the study is not publicly available, but the data used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval and consent to Participate

The study was reviewed and approved by the Institutional Review Boards of Dankook University, Hanyang University and Kyung Hee University, and was conducted in accordance with the Declaration of Helsinki. All participants provided written informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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