Review

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The Implication of Nutrition on the Prevention and Improvement of Age-Related Sarcopenic Obesity: A Systematic Review

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Abstract

OBJECTIVES: Nutrition plays a pivotal role in the initiation and progression of sarcopenic obesity, making it a critical focus for preventing and treating this condition. However, the specific dietary components that effectively combat sarcopenic obesity remain poorly understood. The objective of this systematic review was to examine the potential nutritional and dietary factors that may play a role in the development of sarcopenic obesity in the elderly population.

METHODS: To identify relevant studies investigating the association/effects of dietary pattern/single foods/nutrients or supplements with sarcopenic obesity-related outcomes, a comprehensive literature search was conducted until April 2023. The search encompassed multiple databases including PubMed, Scopus, EMBASE, and Google Scholar. Two researchers performed rigorous assessments that included screening titles and abstracts, reviewing full-text studies, extracting data, and evaluating the quality of the studies. The Newcastle-Ottawa Scale was used for observational studies, while the Jadad-Oxford Scale was employed for clinical trials.

RESULTS: Twenty-three studies (14 observational studies and 9 trials) with 37078 participants, published between 2012 and 2022, were eligible for the systematic review. Of the 14 observational articles, two focused on dietary patterns and 12 on food/calorie/macro- and micronutrient intake. The nutritional interventions included the intake of supplements (i.e., protein, amino acids, tea catechin, and vitamin D) and dietary management (calorie restriction, very low-calorie ketogenic diet, and high-protein diet). Appropriate dietary factors, such as appropriate intake of calories, macronutrients, micronutrients, antioxidant nutrients, vegetables, fruits, and overall dietary quality, have been shown to be effective in preventing and treating sarcopenic obesity-related parameters. A combined approach of hypocaloric diet and high protein intake may be necessary for managing both obesity and sarcopenia in older individuals.

CONCLUSION: Studies suggest that dietary factors, such as overall dietary quality, appropriate intake of calories and protein, consumption of antioxidant nutrients, vegetables, fruits, and protein, may be linked to sarcopenic obesity.

Key words: Nutrition, diet, sarcopenic obesity, obesity, sarcopenia.

Introduction

Globally, the number of adults aged 65 and over is growing rapidly. As of 2019, there were approximately 700 million individuals aged 65 years or older worldwide (1). According to estimates, there will be 2.1 billion people 65 and older in the world by 2050, an increase of approximately 10% from the current levels (2).

As our society ages, there is a rapid increase in various health issues affecting the older populations. Among the elderly, sarcopenia is considered one of the most significant health issues. Sarcopenia is a condition observed in older individuals and is characterized by loss of muscle mass and strength that can contribute to physical limitations in older individuals (3). In addition to sarcopenia, obesity is another significant health concern that can lead to metabolic and cardiovascular diseases (CVDs). Sarcopenic obesity (SO), representing the simultaneous occurrence of sarcopenia and obesity, has a synergistic effect that can worsen metabolic and cardiovascular diseases as well as mortality rates (4, 5). Furthermore, there is evidence to suggest that SO may increase the likelihood of physical disabilities, gait and balance abnormalities, and a higher risk of falls in older individuals when compared to either sarcopenia or obesity occurring alone (6). In a notable study by Rolland et al. (7) involving an older female cohort, it was found that the Odds Ratio (OR) for reduced ability to perform the task of climbing stairs was 1.47 for women with sarcopenia compared to healthy peers, 1.79 for purely obese women, and 3.60 for women with sarcopenic obesity. This vicious cycle can persist because the accumulation of fat tissue and reduction of muscle mass are interrelated (8). As a result, the prevention and management of SO hold immense significance in promoting public health and ensuring optimal well-being during the aging process.

Dietary modifications, along with other lifestyle changes, are fundamental to managing sarcopenic obesity (2). While some previous reviews have touched upon the aspects of nutritional interventions and their impact on sarcopenic obesity, our systematic review aimed to provide a comprehensive assessment of the collective evidence in this area. By synthesizing findings from studies focusing on individual foods, food groups, nutrient intake or status, nutritional supplementation, and dietary patterns, the objective of this study is to systematically gather the current evidence of the associations of nutrition with sarcopenic obesity in older people.

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Method

Search strategy

We systematically searched PubMed, Scopus, EMBASE, and Google Scholar databases until April 2023, encompassing a comprehensive range of languages and publication dates. The following search terms were used: ('sarcopenic obesity' OR 'sarcobesity' OR 'sarcopenic obese' OR 'obese sarcopenia') AND ('nutrition' OR 'diet' OR 'dietary pattern' OR 'dietary determinants' OR 'nutritional risk factors' OR 'food' OR 'nutrient'). For this review, we included all potentially relevant studies regardless of their main outcome or language. We performed a manual search by reviewing the references of key articles to identify any potential studies that were not captured by the electronic database searches. All the articles included in this review were published in English. Figure 1 illustrates the selection process used in this review. Due to the diversity in the comparisons made across the included studies (including variations in outcomes, exposures/interventions, participants, and settings), as well as the insufficiency of data appropriate for quantitative analysis and pooling, we conducted a qualitative systematic review. The systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (9). Pre-registration code of the systematic review and meta-analysis protocols in PROSPERO is 461337.

Eligibility criteria

Randomized clinical trials and observational studies were included in this review. Conversely, we excluded reviews, editorials, studies involving non-human models, and studies lacking full-text access or written in languages other than English. The studies involved the assessment of individuals with sarcopenic obesity, in which participants were required to meet the criteria for both sarcopenia and obesity. The diagnostic criteria for sarcopenia included the evaluation of muscle quantity or quality, whereas the diagnostic criteria for obesity included indicators such as BMI, body fat percentage, or waist circumference (WC). To be eligible for inclusion in this review, studies were required to investigate the association/effects of dietary pattern/single food/calorie intake/nutrients or supplements with sarcopenic obesity-related outcomes in individuals with sarcopenic obesity. We excluded studies involving participants with cachexia or severe mental and cognitive conditions that could prevent adherence to a structured nutritional regimen, such as Alzheimer's disease or dementia. Additionally, studies evaluating participants with sarcopenia or obesity alone were excluded.

Table 1 displays the PICOS (population, intervention, comparator, outcome, and setting) items utilized during this systematic review. Given the methodological approach employed, ethical approval was not necessary for this study.

Table 1. PICOS (population, intervention/exposure, comparator, outcome, and setting) criteria used to perform the systematic review

PICOS	Criteria
Population	Community-dwelling individuals with sarcopenic obesity in various age groups
Intervention/exposure	Any nutritional exposure/intervention
Comparator	Control group (if applicable)
Outcome	Body composition (eg, fat mass, muscle mass, lean mass), anthropometric indices, muscle strength, muscle function
Setting	Observational studies and clinical trials

Study selection

After removing duplicates, two authors (BA and ZS) independently evaluated the titles and abstracts obtained from the initial search. The two authors assessed the full-text articles to ensure that they met the eligibility criteria. In the event of any discrepancies between the researchers, a third reviewer (SA) was consulted to resolve them.

Data extraction and quality assessment

We developed a data mining sheet to document details pertaining to: first author, year of publication, country, study design, Sample size, age and sex of participants, definition of sarcopenic obesity, nutrient(s) or food or dietary pattern exposure (for observational studies), study groups and intervention duration (for clinical trials) sarcopenic obesity-related outcomes, and main findings. The Newcastle-Ottawa scale (10) was utilized to assess the quality of observational studies, while the Jadad-Oxford scale (11) was employed to evaluate randomized clinical trials. The NOS evaluates three fundamental aspects of the methodology: the selection of study participants (0–4 points), the adjustment of confounders (0–2), and the determination of outcome indicators (0–3). A study with a score of 7–9 points was classified as high quality (10). The Jadad-Oxford scale awarded 0 or 1 points for each of five criteria: 1) the presence of randomization, 2) the method of randomization, 3) double-blinding, 4) the method of double-blinding, and 5) the description of withdrawals and dropouts. Scores of ≥3 and ≤2 were considered high and low quality, respectively (11).

Tables 2 and 3 provide details of the included studies.

Results

Selected studies

Upon evaluating 3276 abstracts sourced from databases, excluding duplicates, and conducting screening based on titles and abstract contents, as well as identifying additional records from other sources, a comprehensive assessment of 66 articles in full text was conducted.

Of these, 43 studies were deemed irrelevant to the current systematic review and were therefore excluded from further

Table 2. Characteristics of the observational studies investigating the association between dietary determinants and sarcopenic obesity-related outcomes (presented in chronological order, starting with the most recent)

First author, year (Reference No)	Country	Study design	Sample size (male/female)	Age of participants*	Definition of sarcopenic obesity	Nutrient(s) or food or dietary pattern	Sarcopenic obesity-related outcomes	Main findings	Study quality (NOS)
Eglseer, 2022 (12)	Germany	Cross-sectional	5362 (2308/3054)	62 (50–70)	Low hand grip strength (< 35 kg for men and < 22 kg for women) coexisting with obesity (≥ 30 kg/m^2)	Different protein sources were clustered into three categories: dairy products, meat and fish, and eggs and legumes.	Hand grip strength	Daily intake of meat/fish is associated with lower odds of suffering from obesity with low handgrip strength in retirement-aged persons.	8
Jia, 2022 (13)	China	Cross-sectional	3713 (1351/2362)	61.9 ± 8.0	Sarcopenia: Low MM (ASMI < 7.0 kg/m2 for male, 5.7 kg/m2 for female) and low muscle strength (handgrip < 28 kg for male, < 18 kg for female) (or low physical performance (SPPB ≤ 9)). Obesity: a) BMI ≥ 28.0 kg/m^2; b) FM% ≥ 60th percentile of the weighted sample distribution, adjusting for sex.	25(OH)D status	Hand grip strength, SMI and SPPB	The role of vitamin D in obesity and sarcopenia was different between men and women, and the relationship between PA and sarcopenia was modified by serum vitamin D status.	7
Kim, 2022 (14)	South Korea	Cross-sectional	932 (319/613)	71.8 ± 0.1	Sarcopenia: SMA <7.0kg/m^2 for men and <5.7 kg/m^2 for women; handgrip strength < 28.0 kg for men and < 18.0 kg for women or the lowest quintile of muscle strength among the study participants indicated low muscle strength. Obesity: BMI ≥ 25 kg/m^2 or the upper two quintiles for FM% for each sex.	Calorie, macronutrients, micronutrients, fiber. Foods were classified into carbohydrate-rich (white rice, mixed rice, noodles, and wheat) or protein-rich (beans, nuts, tofu, fish, meat, and poultry eggs) group.	Hand grip strength, body composition, prevalence of SO.	Overconsumption of wheat and meat negatively impacted the development of SO, while protein intake was positively associated with grip strength and skeletal muscle mass in elderly Koreans.	5
Lee, 2021 (15)	Korea	Cross-sectional	3828 (1635/2193)	≥ 65 years	Combination of body mass index (BMI) _ 25 kg/m^2 and BMI adjusted-appendicular skeletal muscle mass <0.789 for men and <0.512 for women.	Daily total calorie intake (kcal/day), protein intake (g/day), carbohydrate intake (g/day), and fat intake (g/day).	Predicting SO	Total calorie intake and carbohydrate intake (g/kg/day) are inversely related to SO in women. carbohydrate intake (g/kg/day) could be the best index for determining SO.	7
Chen, 2021 (16)	China	Cross-sectional	3795 males and females	≥ 60 years	Sarcopenia: low SMI (<5.78 kg/m^2 in males and <4.58 kg/m2 in females), low muscle strength (HGS <28 kg in males and <18 kg in females), or low physical performance (GS <1.0 m/s for both sexes). Obesity: WC ≥85 cm in males and ≥80 cm in females.	The dietary patterns were determined by principal component analysis (PCA).	The occurrence and progression of SO.	The elderly should have a balanced daily diet such as lacto-ovo vegetarian dietary pattern to prevent the occurrence and progression of SO.	7
Mendham, 2021 (17)	South Africa	Cross-sectional	122 females	60–85 years	Sarcopenia: Grip strengthBMI of < 0.56, and ASMBMI of < 0.512. Obesity: BMI of ≥ 30.0 kg/m^2.	Energy, macronutrients, and 12 food groups.	Body composition, grip strength, gait speed, agility/dynamic balance.	Consumption of cooked porridge correlated with a higher grip strengthBMI, while consumption of animal protein foods, cholesterol and fibre correlated with a lower grip strengthBMI.	4
Yang, 2020 (18)	Korea	Cross-sectional	3815 (1960/1855)	≥ 60 years	Sarcopenia: the lowest 20th percentile of handgrip strength of people without other comorbidities (34.5 kg in men and 20.0 kg in women). obesity: BMI ≥ 25 kg/m^2.	Ratio of daily omega-3 fatty acid consumption to daily energy intake	Prevalence of SO.	The omega-3 fatty acid ratio was significantly higher in older females without SO than in older females with SO. The ratio was associated with the prevalence of SO in elderly females, but not in males.	7

Table 2 (continued). Characteristics of the observational studies investigating the association between dietary determinants and sarcopenic obesity-related outcomes (presented in chronological order, starting with the most recent)

First author, year (Reference No)	Country	Study design	Sample size (male/female)	Age of participants*	Definition of sarcopenic obesity	Nutrient(s) or food or dietary pattern	Sarcopenic obesity-related outcomes	Main findings	Study quality (NOS)
Yoo, 2020 (19)	Korea	Cross-sectional	3937 (1615/2322)	≥ 65 years	Sarcopenia: ASMM divided by weight (%) of < 1 SD below the sex-specific mean for young adults. Obesity: BMI ≥ 25 kg/m^2.	Energy, macronutrients, eight micronutrients, diet quality.	Prevalence of SO.	The SO group had insufficient energy intake, protein, and antioxidant micronutrients, and lower overall dietary quality than the non-SO group.	7
Rasaei, 2019 (20)	Iran	Cross-sectional	301 females	18-48 years	Two lower quintiles of SMM and two highest quintiles of FM.	Using principal component analysis three major dietary patterns were determined: the DASH, western and unhealthy dietary pattern.	The association between SO and major dietary pattern.	Adherence of the DASH Diet, has a significant effect on reducing the risk of SO.	5
Son, 2019 (21)	Korea	Cross-sectional	3367 males and females	≥ 65 years	Sarcopenia: ASMM < 1SD below the gender-specific mean ASMM for healthy young adults. Obesity: WC > 90 cm for men or > 85 cm for women.	Nutrient intake level or recommended nutrient intake was analyzed.	Odds ratio of sarcopenic obesity	The risk of SO in subjects not meeting the recommended intakes of energy, riboflavin, and vitamin C increased significantly by 25.4%, and 36.6%, and 32.6%, respectively, compared to that in the those meeting the recommended nutrient intake.	6
Oh, 2016 (22)	Korea	Cross-sectional	4452 (1929/2523)	≥ 60 years	Sarcopenia: ASM/Wt (%) > 1SD below the mean value of normal young people with the same gender. Obesity: BMI ≥ 25 kg/m^2.	Vitamin D concentration and protein intake	Prevalence of SO.	The prevalence of sarcopenic obesity relatively increased as a diet deficient of protein intake and vitamin D.	8
Barbat-Artigas, 2016 (23)	France	Retrospective	146 females	53±9 years	Sarcopenia: Lowest tertile of LMI. Obesity: BMI ≥ 30 kg/m^2 and FM ≥40%.	Calorie restriction (1400 ± 200 kcal/day) and aerobic exercise.	Body composition	Caloric restriction and aerobic exercise may reduce fat mass in obese women, independently of their sarcopenic status.	5
Kim, 2013 (24)	Korea	Cross-sectional	493 (180/313)	≥ 20 years	Sarcopenia: SMI of 1 SD below the sex-specific mean value for a young reference group. Obesity: visceral fat area ≥100 cm^2.	Serum 25(OH)D levels	Body composition	25(OH)D levels were positively correlated with SMI in both men and women. Vitamin D deficiency was associated with SO.	5
Hwang, 2012 (25)	Korea	Cross-sectional	2221 males and females	> 60 years	Sarcopenia: ASM divided by body weight (%) more than 2 SD below mean value of sex-specific young normal people Obesity: WC ≥ 90 cm in men and ≥ 85 cm in women.	carbohydrate, protein, lipid, mineral, and vitamin intake.	Body composition	Vitamin D was negatively associated with SO in both men and women. Vitamin A intake in SO men and potassium in SO women were lower than ones in control.	6

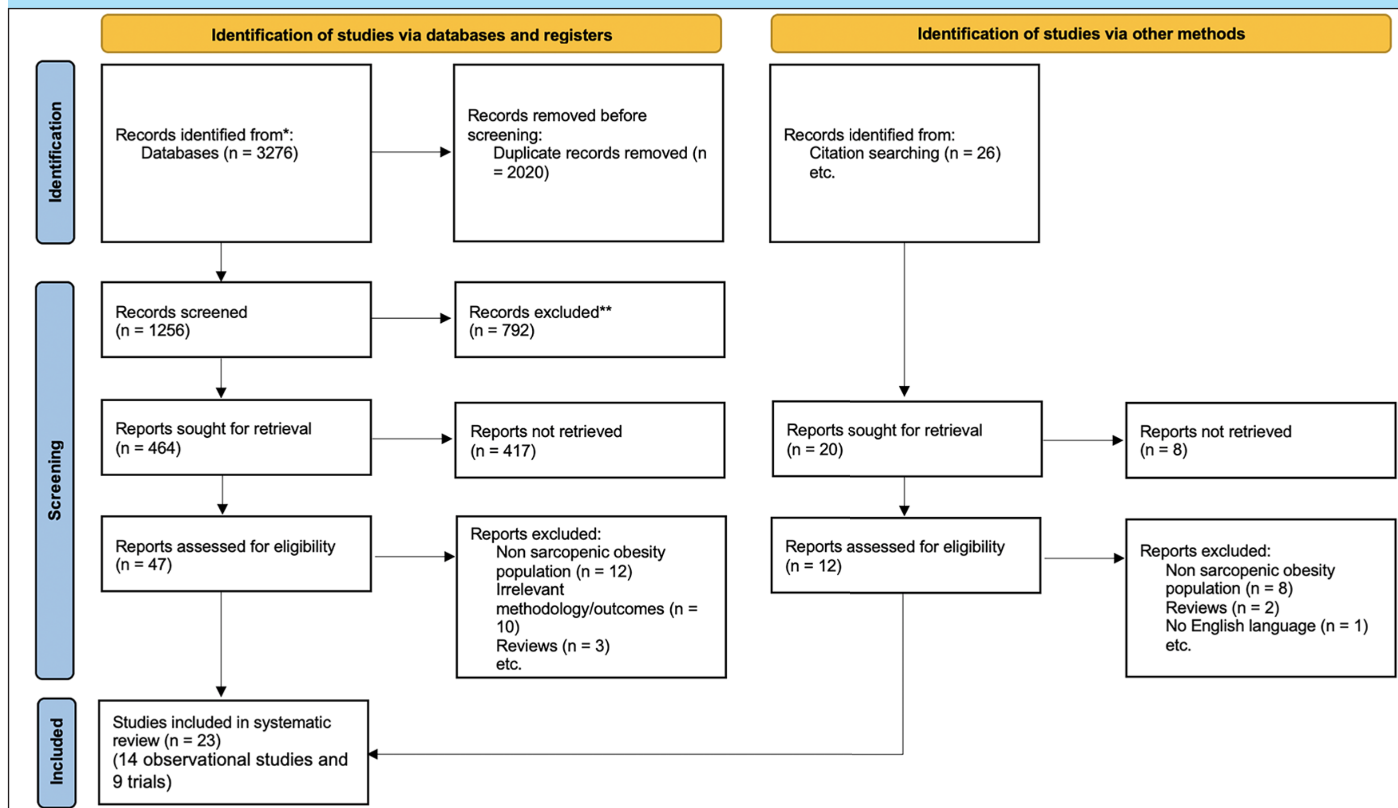
* Values reported as mean±SD or median (interquartile range) or range. Abbreviations: SO, sarcopenic obesity; FM, fat mass; FFM, fat free mass; SMI, skeletal muscle mass index; SPPB, short physical performance battery; VLCKD, vary low calorie ketogenic diet; IT, interval training; LCD, low calorie diet; ALST, appendicular lean soft tissue; RT, resistance training; WB-EMS, whole body electromyostimulation; ASMM, appendicular skeletal muscle mass; MMI, muscle mass index; SD, standard deviation; FMI, fat mass index; BMI, body mass index; WC, waist circumference; aa, amino acid.

Table 3. Characteristics of the interventional studies investigating the association between dietary determinants and sarcopenic obesity-related outcomes (presented in chronological order, starting with the most recent).

First author, year (Reference No)	Country	Sample size (male/female)	Age of participants*	Definition of sarcopenic obesity	Study groups (n)	Intervention duration	Sarcopenic obesity-related outcomes	Main findings	Study quality (Jadad-Oxford Scale)
Camajani, 2022 (26)	Italy	24 (3/21)	56.3±5.3	FM > 39–41% for woman and > 29–31% for man; Five times Sit-to-Stand Chair test > 15 s; SPPB < 8.	VLCKD (12); VLCKD + IT (12)	6 weeks	Body composition; physical performance (chair stand test)	VLCKD is effective in terms of body weight loss, particularly FM; moreover, the combination of VLCKD and IT could determine a better preservation of FFM.	4
Camajani, 2022 (27)	Italy	16 hyperinsulinemic and post-menopausal women	Range: 50-70	Fat mass > 38%; Handgrip < 16 Kg; Chair stand test > 15 s; SPPB < 8.	All patients followed an LCD combined with supplementation with whey protein and leucine.	45 days	Body composition; functional tests (handgrip and SPPB)	LCD with adequate protein intake and supplementation with whey protein and leucine should be promoted to maintain muscle mass andimprove muscle strength in women with SO.	4
Nabuco, 2019 (28)	Brazil	26 females	≥ 60 years	FM ≥ 35% combined with ALST <15.02 kg	Whey protein + RT (13); Placebo + RT (13)	12 weeks	Body composition; muscle strength; functional capacity	Whey protein combined with RT increased ALST, and decreased total and trunk fat mass, improving sarcopenia and decreasing SO in older women.	5
Kemmler, 2018 (29)	Germany	100 males	≥ 70 years	SMI < 0.789; FM > 27%	WB-EMS & whey protein (33); whey protein (33); control (34)	16 weeks	Body composition	Moderate-high dosed whey protein supplementation, may be a feasible choice to address obesity and cardiometabolic risk in older men with SO unable or unmotivated to exercise conventionally.	5
Kemmler, 2018 (30)	Germany	67 males	≥ 70 years	SMI < 0.789; FM > 27%	WB-EMS & protein (33); control (34)	16 weeks	Body composition, dynamic strength of the leg and hip extensors, gait velocity, lower extremity function favorably affects local and overall muscle/fat distribution and lower limb functioning in older men with SO.	WB-EMS combined with whey protein supplements	5
Sammarco, 2017 (31)	Italy	18 females	41–74	FM > 34.8%; FFM <90% of subject's ideal FFM.	LCD & placebo (9); LCD high protein diet	4 months	Body composition, handgrip test, SPPB	Sarcopenic obese patients with high-protein diet showed an improvement in muscle strength. Furthermore, dietary protein enrichment may represent a protection from the risk of sarcopenia following a hypocaloric diet.	4
Kemmler, 2017 (32)	Germany	100 males	≥ 70 years	SMI < 0.789; FM > 27%	WB-EMS & protein (33); protein (33); control (34)	16 weeks	Body composition, SMI, handgrip strength	WB-EMS plus protein is a safe and efficient method for tackling sarcopenia and SO in older men.	5
Muscariello, 2016 (33)	Italy	104 females	> 65 years	Two MMI SD below the obesity-derived cutoff score(7.3kg/m^2); The cutoffs for obesity: 1) BMI ≥ 30.0 kg/m^2, 2) WC > 88.0 cm, 3) FM% ≥ 35.0%, and 4) FMI ≥ 9.5kg/m^2.	Hypocaloric diet containing 1.2 g/kg desirable body weight/ day of proteins (54); normal protein intake (50).	3 months	Body composition, handgrip strength	A diet moderately rich in proteins was able to preserve MM in sarcopenic women. Therefore, adequate protein intake could contribute to the prevention of lean-mass loss associ¬ated with weight reduction in obese older people.	6
Kim, 2016 (34)	Japan	139 females	> 70 years	FM ≥ 32% and SMI < 5.67 kg/m^2; FM ≥ 32% and grip strength < 17.0 kg; and FM ≥ 32% and walking speed < 1.0 m/s.	Exercise and nutritional supplementation (aa+catechin) (n= 36); exercise (n=35); nutritional supplementation (n = 34); health education (n = 34).	3 months	Body composition, SMI, grip strength, knee extension strength, usual walking speed, walking pa-rameters.	Exercise and nutrition had beneficial effects on body composition, and physical function, but improvements in muscle mass and variable combinations such as FM% and SMI or FM% and physical functions were not observed.	6

* Values reported as mean±SD or range. Abbreviations: SO, sarcopenic obesity; SMM, skeletal muscle mass; ASMM, appendicular skeletal muscle mass; ALST, appendicular lean soft tissue; ASMI, appendicular skeletal muscle mass index; VLCKD, very low calorie ketogenic diet; IT, interval training; LCD, low calorie diet; SPPB, short physical performance battery; BMI, body mass index; WC, waist circumference; FM, fat mass; FFM, fat free mass; MM, muscle mass; SMI, skeletal muscle mass index; DASH, dietary approach to stop hypertension; HGS, handgrip strength; GS, gait speed; ASM, appendicular skeletal muscle mass; LMI, lean body mass index; WB-EMS, whole body electromyostimulation; RT, resistance training; IT, interval training; aa, amino acid; n, number of participants in each group.

Figure 1. PRISMA flow diagram for selection process of the studies



evaluation. Overall, 23 studies (14 observational studies and 9 trials) (12-34) with 37078 participants, published between 2012 and 2022, were eligible for the systematic review. Figure 1 shows the flow diagram of the literature search process.

Characteristics of the observational studies

Table 2 presents a chronological summary of the descriptive details of the included studies arranged in order from the most recent. In the 14 observational studies (12-25) included in this systematic review, a total of 36,484 participants were involved. Eight studies were conducted in Korea (14, 15, 18, 19, 21, 22, 24, 25), two in China (13, 16), one in Germany (12), one in South Africa (17), one in Iran (20), and another one in France (23). Studies published between 2012 and 2022. Of the 14 observational articles, two focused on dietary patterns (16, 20) and 12 on foods/calorie/macro- and micronutrient intakes. One study had a retrospective cohort design (23), whereas the remaining studies utilized a cross-sectional design. Three studies included only females (17, 20, 23) and the other included both females and males. The sample sizes ranged from 122 to 5362 participants. BIA was used for sarcopenic obesity screening in five articles (13, 14, 16, 20, 23), eight studies employed DEXA (15, 17-19, 21, 22, 24, 25), and one study did not assess body composition (12).

Observational studies on the association between nutritional factors and sarcopenic obesity

Barbat-Artigas et al. (2016) (23) conducted an observational study involving 146 obese women who participated in a three-week, institution-based weight-reducing program. The program consisted of a dietary plan (1400 ± 200 kcal/day) and daily aerobic exercises at a specialized medical institution. Women with and without SO experienced significant reductions in fat mass (P<0.05) following the weight-reducing program. However, differences in the lean body mass index between the two groups persisted even after completing the program. Interestingly, non-sarcopenic obese women experienced a significant loss of lean mass (P<0.05), whereas sarcopenic obese women did not experience a similar loss.

In a study by Eglseer et al. (2022) (12), significantly lower protein intake was observed in participants with low handgrip strength, and this trend was more pronounced in participants with both obesity and low handgrip strength (P < 0.001). Regular consumption of meat/fish (0.56, CI 0.40–0.79) was identified as a significant factor associated with obesity in conjunction with low handgrip strength.

According to a cross-sectional study by Jia et al. (13), the relationship between vitamin D and both obesity and sarcopenia exhibits sex-specific differences. Furthermore, the effect of serum vitamin D status on the relationship between physical activity and sarcopenia was established.

In a study of 2221 Koreans aged 60 years or older conducted by Hwang et al. (25) using data from the Fourth Korea National Health and Nutrition Examination Survey (2009), vitamin D was found to be inversely associated with sarcopenic obesity in both male and female participants.

Yang et al. (2020) (18) analyzed data from the KNHANES (2014-2018) and found that the omega-3 fatty acid ratio in individuals with and without SO was 1.0% and 0.9% in

men (P = 0.271) and 0.8% and 1.0% in women (P = 0.017), respectively. Compared with Q1, OR (95% CI) of Q2, Q3, and Q4 of omega-3 fatty acid ratios were 1.563 (0.802–3.047), 1.246 (0.611–2.542), and 0.924 (0.458–1.864) respectively, in men and 0.663 (0.379–1.160), 0.640 (0.372–1.102), and 0.246 (0.113–0.534) respectively, in women, following the complete adjustment for confounding variables.

Son et al. (21) showed that the average daily energy intake was greater in the group without sarcopenia than in that with sarcopenia. Participants who fell short of the recommended intake levels for energy, riboflavin, and vitamin C were found to have a significantly higher risk of SO, with increased risks of 25.4%, 36.6%, and 32.6%, respectively, compared to those who met the recommended nutrient intake levels.

According to another cross-sectional study (19), individuals with sarcopenic obesity had an inadequate intake of energy, protein, and antioxidant micronutrients, as well as lower overall dietary quality (P < 0.05).

In a study by Oh et al. (2016) (22), insufficient dietary protein intake and inadequate levels of vitamin D were linked to a relatively higher occurrence of obesity, sarcopenia, and SO.

Kim et al. (14) conducted a study involving 932 rural Korean residents aged 65 years or older, who were categorized into two groups according to their cardiometabolic status: the cardiometabolic multimorbidity (CM) group and non-CM group. After adjusting for covariates, a positive association was observed between dietary fat and protein intake and handgrip strength in women with CM (P = 0.001). There was a positive correlation between protein intake (g/kg) and appendicular skeletal muscle mass (ASM; kg/m2) and ASM (%) in both males and females, irrespective of their cardiometabolic status. Individuals in the highest tertile of wheat intake (269.1 g/d) had a 2.1-fold increased prevalence ratio of sarcopenic obesity in the CM group, compared to those in the lowest tertile (8.6 g/d). Participants in the highest tertile of meat intake (T2:34.8 g/d, T3:99.5 g/d) exhibited a twofold increase in the prevalence of sarcopenic obesity (PR:1.932, CIs:1.066–3.500) compared to those in the lowest tertile (T1:9.2 g/d) in the CM group.

According to Rasaei et al. (2019) (20), individuals in the highest category of the DASH dietary pattern had lower odds of SO (OR = 0.27, 95% CI = 0.08 to 0.96, P = 0.04). Even after controlling for age, total energy intake, and physical activity, a significant negative association between DASH diet and SO remained (OR = 0.20, 95% CI = 0.05 to 0.77, P = 0.01).

Mendham et al. (17) conducted a cross-sectional study involving 122 black South African women aged 60-85 years, which indicated that the consumption of cooked porridge was linked to higher grip strength BMI, while the consumption of animal protein foods, cholesterol, and fiber was linked to lower grip strength BMI.

According to another cross-sectional study conducted by Chen et al. (16), among older Chinese individuals living in the community, the lacto-ovo vegetarian dietary pattern was associated with a lower risk of SO [OR 0.79, 95% CI (0.65, 0.97); P = 0.027], while the meat-fish and junk food dietary patterns were not significantly associated with the risk of SO.

In a representative Korean nationwide population-based study conducted by Lee et al. (15) that included 3828 older adults, it was found that the OR (95% CI) for SO in women was 0.95 (0.91-0.99) per 100 increment of total calorie intake and 0.83 (0.74-0.94) per 1 increment of carbohydrate intake (g/kg/day), after adjusting for confounding variables. In both men and women, carbohydrate intake had a greater predictive power for SO than other patterns of macronutrient intake.

In the Korean Sarcopenic Obesity Study, a total of 493 seemingly healthy adults were enrolled for analysis (24), and it was found that in men, the levels of 25(OH)D were significantly lower in the SO group with SO compared to the group without SO. There was a positive correlation between 25(OH)D levels and the skeletal muscle mass index (SMI) in both men and women. Additionally, 25 (OH) D levels were independently associated with SO in men.

Characteristics of the interventional studies

Table 3 presents a chronological list of descriptive details of the included interventional studies. A total of 594 participants participated in nine interventional studies included in the systematic review (26-34). Four studies were conducted in Italy (26, 27, 31, 33), three in Germany (29, 30, 32), one in Brazil (28) and another one in Japan (34). These studies were published between 2016 and 2022. Five trials included only females (27, 28, 31, 33, 34), three studied only males (29, 30, 32), and one study included both females and males (26). The age of the subjects in the included studies was greater than 41 years; sample sizes ranged between 16 and 139 participants.

The nutritional interventions encompassed the consumption of supplements such as protein, amino acids, vitamin D, and tea catechins, as well as dietary management (calorie restriction, very low-calorie ketogenic diet, and high-protein diet). Four of the articles employed a combination of physical exercise and nutritional supplementation (28-30, 32). The exercises utilized in the studies included resistance training, aerobic training (either individually or in combination), whole-body electromyostimulation (WB-EMS), and either conventional strength/hypertrophy training with 1-2 minutes of recovery between sets or high-speed circuit training without recovery between sets. The duration of interventions ranged from 6 to 16 weeks.

These studies did not include any information regarding adverse effects.

Interventional studies investigating the effects of nutritional factors on sarcopenic obesity

In 2022, Camajani et al. (26) conducted a study involving 24 men and women aged 50-70 years with SO to evaluate the efficacy of a very low-calorie ketogenic diet (VLCKD) alone versus a VLCKD combined with interval training. The study found that VLCKD was effective in reducing body weight, especially fat mass (FM). Furthermore, combining the VLCKD with interval training was found to be more effective in preserving fat-free mass (FFM).

In a 12-week clinical trial (28) involving 26 older women with SO, the group that received 35 g of whey protein combined with supervised resistance training showed greater

improvements in appendicular lean soft tissue and reductions in total and trunk fat mass than the placebo group. Both groups demonstrated enhanced muscular strength, waist/hip ratio, functional capacity, and other plasma metabolic biomarkers, with no significant differences observed between the two conditions. Muscariello et al. (33) conducted a study on 104 sarcopenic obese females aged over 65 years and divided them into two subgroups: the first group (normal protein intake (NPI), n=50) was given a hypocaloric diet containing 0.8 g/kg desirable body weight/day of proteins, and the second group (high protein intake (HPI), n=54) was given a hypocaloric diet containing 1.2 g/kg desirable body weight/day of proteins for three months. After the diet intervention, both groups showed significant reductions in BMI (NPI: 30.7±1.3 vs 32.0±2.3 kg/m^2, HPI: 30.26±0.90 vs 31.05±2.90 kg/m^2; P<0.01 vs baseline). The muscle mass index also showed significant variations in both the NPI and HPI sarcopenia groups (NPI: 6.98±0.1 vs 7.10±0.2 kg/m^2, HPI: 7.13±0.4 vs 6.96±0.1 kg/m^2; P<0.01 vs baseline).

The study (29) enrolled 100 community-dwelling men aged ≥ 70 years with SO and randomly assigned them to one of three groups: whey protein supplementation (WPS), WB-EMS combined with protein supplementation (WB-EMS&P), or a control group without any intervention. Both the WB-EMS&P (P < 0.001) and WPS groups (P = 0.011) demonstrated significant differences in changes compared with the control group. The WB-EMS&P group demonstrated a significant reduction in trunk fat mass (P < 0.001), whereas the WPS group showed a non-significant decrease (P = 0.117). In contrast, the control group experienced an increase in trunk fat mass, although the difference was not statistically significant (P = 0.159). Significant reductions in WC were observed in the treatment groups, whereas the WC of the control group remained unchanged. Only WC showed significant differences between the WB-EMS&P and WPS groups (P = 0.015).

Kemmler et al. (32) conducted a 16-week study involving 100 men aged 70 years or older who had both sarcopenia and obesity. Participants were randomly allocated to one of three groups: WB-EMS and protein supplementation (WB-EMS & P), isolated protein supplementation, or a control group with no intervention. Both intervention groups showed significant reductions in body fat and an increase in the skeletal muscle mass index. The differences between the intervention and control groups were statistically significant.

Kemmler et al. (30) conducted another 16-week trial in which community-dwelling men aged ≥ 70 years with SO were randomly allocated to receive either WB-EMS and protein supplementation or no intervention (control group). The intervention group showed significant increases in thigh lean muscle mass and positive changes in appendicular skeletal muscle mass, trunk fat, gait velocity, leg extensor strength, and advanced lower extremity function, whereas the control group showed little to no changes. Additionally, fat mass significantly increased in the control group, but was maintained in the intervention group.

In a randomized controlled trial conducted by Kim et al. (34), 139 older Japanese women with SO were enrolled to explore the effects of exercise and/or nutritional supplementation on body composition and physical function. The exercise and nutrition groups showed significantly decreased total body fat mass and increased stride, whereas the exercise group showed significant reductions in trunk fat compared to the control group. Both intervention groups were more than four times more likely to have reduced body fat mass than the control group. Exercise and nutritional interventions also significantly improved walking speed.

Camajani et al. (27) conducted a study in which 16 post-menopausal women with SO and hyperinsulinemia were assigned to a low-calorie diet supplemented with whey proteins and leucine for 45 days. All participants showed significant reductions in BMI and WC and preserved total lean body mass. Women also showed significantly improved muscle strength and function.

Sammarco et al. (31) conducted a trial in 18 sarcopenic obese women and randomly assigned them to a hypocaloric diet plus placebo (group A) or a hypocaloric high-protein diet (group B). While both groups experienced significant weight loss, the women in group B exhibited retention of lean body mass and improvements in muscle strength. The Short Physical Performance Battery score did not change in either group, but the SF-36 test showed a significant improvement in general health after four months in group B.

Discussion

The objective of this systematic review was to provide a summary of nutritional exposures/interventions which have been shown to be effective in preventing and treating SO and parameters related to SO. The findings of these studies add to the growing body of evidence indicating that various dietary factors, such as appropriate calorie intake, macronutrient and micronutrient consumption, antioxidant nutrient intake, consumption of fruits and vegetables, and overall dietary quality, are linked to SO.

Weight loss may be sufficient to improve metabolic health in older obese individuals. However, in the case of SO, weight loss alone may have adverse effects on muscle function and increase the risk of frailty, as highlighted in a study (35). Weight management in older adults requires careful consideration, and diets with very low energy intake (<1000 kcal/d) for weight loss are strongly discouraged (36). It is not advisable to rely solely on energy-restricted diets for the treatment of SO without incorporating complementary dietary modifications such as increased protein intake and nutritional counseling. Implementing such an approach may exacerbate the depletion of lean muscle mass in these patients, and is typically less efficacious than a comprehensive combined approach (36). It is recommended to follow a moderate energy restriction of 500-750 kcal/day, targeting a weight loss of 0.5-1 kg/week or 8%-10% of the initial body weight within 6 months. In the case of older individuals with SO, it is suggested to adopt an even more conservative energy restriction approach, starting at 200 kcal/day. Simultaneously, it is important to ensure a protein intake of at least 1 g/kg body weight per day and an appropriate intake of essential micronutrients (36). The definitive establishment of the potential additional benefit

of high protein intake in preserving lean mass during energy restriction and training in older adults remains unclear (37).

The efficacy of isolated protein and amino acid supplementation in increasing lean body mass (LBM) in older individuals remains a topic of debate (38). Xu et al. (39) conducted a meta-analysis of nine studies and reported a non-significant overall increase in LBM of 0.34 (95% CI: -0.42 to 1.10) kg in older individuals (≥ 65 years). In another meta-analysis (40) by the same research group, a low effect (0.18; -0.18 to 0.54 kg) of leucine supplementation on LBM in people aged approximately 65 years and older was observed. Unlike the aforementioned meta-analyses, Komar et al. (41) performed a meta-analysis comprising 16 studies that specifically examined the impact of leucine supplementation (at a minimum dosage of 2 g/day) on individuals aged ≥ 65 years. The study revealed a substantial and statistically significant mean difference of 0.99 kg (0.43-1.55 kg) in LBM between the groups receiving the intervention and the placebo groups. Another systematic review (42) found that combining protein supplements with resistance training effectively increased muscle mass and strength in older individuals irrespective of their body weight. The only systematic review that exclusively focused on individuals with SO (43) included only two randomized controlled trials (RCTs) that examined the effectiveness of nutritional intervention or exercise. However, none of the included studies reported significant reductions in body fat or increases in skeletal muscle or lean mass.

The protein source may be critical for retaining muscle mass, as there is evidence suggesting that proteins derived from animal-based sources have more anabolic effects than proteins derived from plant-based sources (44). The disparity in anabolic effects between plant-based proteins and animal-based proteins may be due to differences in the type and quantity of essential amino acids, particularly the relatively lower levels of leucine in plant-derived proteins. However, an important limitation of the identified studies is the absence of data on total protein intake, which comprises both dietary and supplemental protein. Moreover, studies often exhibit noticeable differences with respect to protein source and dosage, and frequently have an inadequate sample size.

In addition, reports suggest that omega-3 fatty acids may prevent and treat SO. Research has demonstrated that omega-3 fatty acids can augment the functioning of peroxisomal and mitochondrial enzymes responsible for beta-oxidation of fatty acids. The primary effect of omega-3 fatty acids is to stimulate the expression of the acyl-CoA oxidase gene, which is the main enzyme responsible for beta-oxidation of fatty acids in peroxisomes (45). Omega-3 fatty acids increase the activity of carnitine palmitoyltransferase II, which facilitates the transport of fatty acids into the mitochondria for beta oxidation. This enhances lipid oxidation in both peroxisomes and mitochondria, leading to overall acceleration of the process (18).

Notably, inadequate intake and low levels of certain micronutrients have been associated with the onset of sarcopenia in older individuals. A systematic review by Muir and Montero-Odasso (46) demonstrated that vitamin D supplementation at daily doses of 800–1000 IU improves various sarcopenic parameters in older individuals. In general, micronutrient deficiencies are linked to heightened susceptibility to frailty and sarcopenia in older individuals (47). Obese individuals, in particular, are at a relatively high risk of developing micronutrient deficiencies.

According to a study (21), failing to meet the recommended intake for riboflavin was associated with a 1.366-fold increase in the risk of SO, and a negative correlation was observed between vitamin C intake and the risk of SO. Additionally, a lower intake of vitamin A has been reported in men with SO than in those without SO. Furthermore, the Women's Health and Aging Study revealed an association between blood carotenoid concentration and indicators of muscle mass loss in older women (48). According to Ashoori and Saedisomeolia (49), riboflavin, an antioxidant, has the potential to alleviate inflammation in the body. Numerous studies have shown that ROS buildup of reactive oxygen species may lead to oxidative stress, causing a decline in muscle mass and strength in older adults (48). Additionally, there is a connection between oxidative stress, muscle function, and walking impairment in older adults (21).

Kim and colleagues (50) discovered that older men who frequently consumed vegetables and fruits had a 68% lower prevalence of sarcopenia, based on data from KNHANES 2008-2009. Vegetables and fruits are the primary sources of antioxidants such as carotenoids and vitamin C, which can decrease oxidative stress in the skeletal muscle. This reduction in oxidative stress is linked to a reduced risk of sarcopenia (51), as oxidative stress can have catabolic effects on the skeletal muscle (52). Yoo and colleagues (19) found a positive association between nutrient adequacy ratios (NAR) of antioxidant nutrients, including vitamin A, thiamin, riboflavin, niacin, and vitamin C, and the risk of SO in older adults. Therefore, monitoring the intake of antioxidant nutrients in individuals with SO is recommended to ensure adequate consumption. Although the exact mechanisms are still not fully understood and the existing literature provides conflicting findings, some evidence indicates that green tea may enhance fat oxidation (53). This potential effect could have played a role in the observed changes in body composition, as demonstrated in a study conducted by Kim et al. (34).

Regarding the diets, a study proposes that the satiety-enhancing effect of higher protein intake, regulated by appetite-mediating hormones such as leptin, could be the underlying mechanism by which ketogenic diets result in visceral fat loss. Leptin is produced by adipose cells and plays a role in regulating the energy balance and fat storage by suppressing hunger (54). The DASH diet is effective in reducing and controlling weight and body fat in overweight and obese individuals (55), which could lead to an increase in resting metabolic rate.

Collectively, the findings from these studies add to the growing body of evidence indicating that dietary factors, such as overall dietary quality and consumption of antioxidant nutrients, vegetables, fruits, and protein, are linked to the risk of SO.

It is important to consider that complex interventions aimed at preventing and treating SO should prioritize older women, as they generally have lower muscle mass and strength than men

(56). Furthermore, due to the greater rate of change in fat-free muscle mass to fat muscle mass associated with weight gain, women face a heightened risk of developing SO compared to men (57). Furthermore, women represent the majority of the older population, and in terms of demographics, they typically have longer life expectancies and bear a higher burden of disability (58).

As far as we know, this is the first systematic review to investigate nutritional exposures and interventions that influence sarcopenic obesity and outcomes related to sarcopenic obesity. This review stands out for its comprehensive evaluation of dietary patterns, calorie intake, nutrients/food groups, and nutrition supplementation through the inclusion of both observational and interventional studies. However, this systematic review has some limitations. The studies included in this systematic review exhibited significant heterogeneity regarding the diverse exposures or interventions employed, variations in the definition of SO, and differences in the outcomes examined. Furthermore, in some studies that examined the effects of the combination of nutrition and exercise on sarcopenic obesity or sarcopenic obesity-related outcomes, we could not disentangle the effects of nutrition from those of exercise. To advance research in this field, it is crucial to establish a widely accepted definition of SO as well as clear cutoff values. The same is true for sarcopenia and obesity that require treatment in older individuals.

Conclusion

This review highlights the role of proper calorie intake, balanced macronutrient distribution, sufficient micronutrients, and antioxidant-rich foods in preserving muscle mass and in managing obesity. The reviewed studies emphasized balanced energy restriction with adequate protein intake as a potential strategy for addressing SO. However, varied interventions and methodologies suggest the need for standardized research approaches. Although some interventions target sarcopenia or obesity, few have focused on SO, indicating a research gap.

Understanding the intricate role of nutrition in muscle and adiposity interactions is therefore crucial. Future research should define SO, use consistent assessment and outcome measures, and explore the long-term effects of nutritional interventions combined with exercise. This review highlights the importance of nutrition in SO prevention and management. Challenges persist, but this insight guides further research to refine interventions and improve the well-being of older individuals affected by or at risk for sarcopenic obesity.

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Author contributions: BA and MV conceived and designed the study. BA and SA conducted the systematic search, screened articles, and read the full texts for eligibility. BA and ZS extracted data from the original studies and evaluated the studies for risk of bias. BA, and FH contributed to the interpretation of the results and wrote the first draft of the manuscript. MV, and FH contributed to the interpretation of the results and critically revised the manuscript. All authors have read and approved the final manuscript. MV is the guarantor. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

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