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REVIEW ARTICLE

Implication of diet and exercise on the management of age-related sarcopenic obesity in Asians

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The incidence of sarcopenic obesity among adults aged ≥65 years is rising worldwide. Sarcopenic obesity is a high-risk geriatric syndrome defined as a gain in the amount of adipose tissue along with the age-related loss of muscle mass and strength or physical performance. Sarcopenic obesity is associated with increased risks of falls, physical limitations, cardiovascular diseases, metabolic diseases, and/or mortality. Thus, the identification of preventive and treatment strategies against sarcopenic obesity is important for healthy aging. Diet and exercise are the reasons for the development of sarcopenic obesity and are key targets in its prevention and treatment. Regarding weight reduction alone, it is most effective to maintain a negative energy balance with dietary calorie restriction and aerobic exercise. However, it is important to preserve skeletal muscle mass while reducing fat mass. Resistance exercise and appropriate protein supply are the main ways of preserving skeletal muscle mass, as well as muscle function. Therefore, in order to improve sarcopenic obesity, a complex treatment strategy is needed to limit energy ingestion with proper nutrition and to increase multimodal exercises. In this review, we focus on recently updated interventions for diet and exercise and potential future management strategies for Asian individuals with aging-related sarcopenic obesity. **Geriatr Gerontol Int 2022; 22: 695–704**.

Keywords: diet, exercise, obesity, sarcopenia, skeletal muscle mass.

Introduction

Globally, the number of adults over the age of 65 is increasing rapidly. In 2019, there were approximately 700 million adults aged ≥65 years. In the next 30 years, the global older population will more than double, to over 1.5 billion adults in 2050.[1] With an aging society, various health problems among the older population are rapidly increasing. Sarcopenia is one of the most important health problems among the elderly. Sarcopenia is the loss of muscle mass and strength with aging that might contribute to physical limitations in the elderly.[2] Along with sarcopenia, obesity is an important health problem causing metabolic and cardiovascular diseases (CVDs). Sarcopenic obesity, the coexistence of sarcopenia and obesity, has a synergistic effect in exacerbating metabolic and cardiovascular diseases and mortality.[3,4] This vicious cycle may continue because the accumulation of fat tissue and the decrease in muscle mass are interdependent.[5] Therefore, the prevention and treatment of sarcopenic obesity in the elderly is important for healthy aging. Lifestyle modifications, including diet and exercise, are fundamental for the treatment of sarcopenic obesity. In this narrative review, we review updated diet and exercise strategies for sarcopenic obesity and propose future management strategies.

Definition and diagnosis of sarcopenic obesity

In current studies, sarcopenic obesity is defined as a combination of the individual definitions of sarcopenia and obesity. The diagnosis of sarcopenia has been diverse, with no consensus on the definition. The first definition was that of Baumarterner *et al.* were the first to diagnose sarcopenia in terms of the appendicular skeletal muscle mass (ASM) divided by height squared (ASM [kg]/height^2 [m^2]), with sarcopenia being taken to be present when this value is less than two standard deviations (SD) lower than the average value of a young reference group, as determined using dual-energy-X-ray absorptiometry (DXA).[6] Janssen *et al.* defined sarcopenia as a skeletal muscle mass index (SMI = SMM [kg]/weight [kg] × 100) one or two SDs lower than the reference value measured by bioelectrical impedance analysis (BIA).[7] Newman *et al.* demonstrated other criteria of appendicular lean mass adjusted for height and fat mass, especially fat mass should be considered in women or in obese adults.[8] In addition, we presented a cost-effective screening tool for the Z-score of the log-transformed A Body Shape Index (LBSIZ) and its cut-off values for assessing sarcopenia in American and Korean populations with central obesity.[9] The European Working Group on Sarcopenia in Older People (EWGSOP) defined sarcopenia as the presence of low muscle mass combined with low muscle function (muscle strength or physical performance) based on a large number of previous studies.[2] Later, EWGSOP2 emphasized low muscle strength as the primary parameter for defining sarcopenia,[10] as it plays a crucial role in predicting mortality.[11,12] Handgrip strength is generally used to evaluate muscle strength because it closely reflects the area of the calf section and lower limb muscle power.[13] Moreover, EWGSOP2 assessed the decreases in muscle strength and muscle quantity (or mass) as diagnostic criteria and also assessed physical performance to evaluate the severity of sarcopenia.[10]

Along with these various definitions of sarcopenia, previous studies have also used various definitions of obesity. The World Health Organization (WHO) suggested a body mass index (BMI) ≥ 30 kg/m^2 as a cutoff value for obesity and a BMI ≥ 25 kg/m^2 for overweight.[14] Even with the same BMI, however, Asians have a higher body fat percentage than non-Asians.[15] Therefore, the cutoff value is 25 kg/m^2 for obesity and 23 kg/m^2 for overweight in the Asian population, which are lower values than those for the general population.[16] Alternatively, waist circumference (WC) is used as a parameter for obesity because abdominal fat is more closely related to CVD than total body fat.[17] The WHO uses cutoff levels of ≥ 102 cm for men and ≥ 88 cm for women in Westernized populations, and the cutoff values differ according to ethnic group.[14,18] In the International Diabetes Federation criteria for Asians, WC ≥ 90 cm for men, and ≥ 85 cm for women are used to identify abdominal obesity,[19] because Asians show lower cutoff levels for WC in mortality and morbidity than other ethnic groups.[16] In addition, measurements of percentage body fat have suggested other definitions of obesity.[20] Moreover, percentage body fat has also been shown to be a useful predictor of muscle strength rather than ASM in obese elderly individuals.[21] A retrospective Japanese study of inpatients with post-acute rehabilitation suggested that percentage body fat > 35% in women and > 30% in men were meaningful criteria for defining obesity in diagnosing sarcopenic obesity as predicting worse rehabilitation outcomes.[22]

Very recently, the European Society for Clinical Nutrition and Metabolism (ESPEN) and the European Association for the Study of Obesity (EASO) jointly announced a consensus on a two-stage algorithm (screening and diagnosis) for sarcopenic obesity.[23] The screening process consists of both the assessment of elevated BMI (or WC) and the presence of surrogate parameters of sarcopenia (e.g., clinical symptoms, suspicion factors, or validated questionnaires).[23] An individual with a positive screening result for both conditions must consider the diagnostic evaluation to confirm sarcopenic obesity, which primarily estimates decreased skeletal muscle function, and then measure altered body composition including increased fat mass and reduced muscle mass.[23] In the future, it will be necessary to verify these diagnostic criteria for sarcopenic obesity and to establish universal reference values according to the measurement method and ethnic group.

Causes of sarcopenic obesity

Aging-related changes in body composition and metabolism

Decreases in muscle mass and increases in body fat are common with aging.[24,25] One of the key factors causing sarcopenia with age is a decline in physical activity. This exacerbates a decrease in muscle mass and strength, further reinforcing physical inactivity. Muscle mass and strength decrease more rapidly after 65 years of age, with peak levels at approximately 40 years of age.[26] Muscle mass loss with age is mainly caused by a decrease in size rather than a decrease in the number of type II muscle fibers.[27] The decline in muscle mass leads to a decrease in basal metabolic rate.[28] In addition, physical inactivity, limited oxidative capacity, and mitochondrial dysfunction also contribute to a lower basal metabolic rate in the elderly.[29] The decrease in the resting metabolic rate accounts for the accumulation of fat mass. Body fat mass increases gradually until the age of 70 years, mainly in the form of visceral fat mass that is strongly correlated with CVD and type 2 diabetes mellitus.[30,31]

Hormonal changes due to aging

Aging-related declines in the productions of testosterone, estrogen, and growth hormones contribute to changes in body composition.[32] Testosterone enhances muscle synthesis and regeneration by activating amino acid utilization.[33] Testosterone decreases by 1.6–3% per year of age, and this has a detrimental effect on muscle and fat distribution.[34] Women experience an increase in visceral fat during menopause.[35,36] The decline in estrogen is also attributed to sarcopenia owing to the increase in pro-inflammatory cytokines such as IL-6 and tumor necrosis factor-α (TNF-α).[37] Estrogen may interact with skeletal muscle directly via estrogen beta receptors on the muscle cell membrane.[38] In addition, insulin-like growth factor (IGF-1) and growth hormone stimulate muscle protein synthesis and enhance muscle strength.[32] The decreased levels of testosterone, estrogen, and growth hormone with aging play an important role in accelerating the decrease in muscle mass/strength and increase in fat mass.

Moreover, aging-induced muscle atrophy worsens, irisin levels decrease, and myostatin levels increase.[39,40] Simultaneously, these changes in irisin and myostatin are closely associated with reductions in white fat browning and energy expenditure, resulting in increased fat tissue.[40]

Several hormone-related pharmaceutical therapies, including myostatin inhibitors, testosterone, growth hormone, growth hormone-releasing hormone analogs, and dehydroepiandrosterone, have been tried for counteracting sarcopenia, but their use was limited owing to their ineffectiveness and side effects in humans.[41,42]

Low-grade inflammation

Aging and physical inactivity lead to sarcopenic obesity, which decreases the size and number of muscle fibers and increases the number of adipocytes. Both skeletal muscle and adipose tissue act as central endocrine organs and secrete messenger peptides such as myokines and adipokines.[43] Myokines and adipokines interact with each other and modulate chronic low-grade inflammation through endocrine, paracrine, and autocrine pathways.[43] In particular, obesity induces inflammation by activating macrophages and T lymphocytes.[44] The activation of these immune cells promotes the secretion of pro-inflammatory hormones such as leptin, resistin, chemerin, TNF-α, and interleukin-6 (IL-6).[45–47] Increased leptin levels result in leptin resistance, causing free fatty acid deposition in the visceral areas, and thus accelerating insulin resistance and muscle catabolism.[48] The decreased consumption of free fatty acids increases oxidative stress, which contributes to proteolysis and systemic inflammation.[49] The increased secretion of TNF-α impairs skeletal muscle synthesis and causes mitochondrial dysfunction.[50] In contrast, irisin, a peroxisome proliferator-activated receptor gamma co-activator 1-a (PGC1α)-dependent myokine, acts as an anti-inflammatory cytokine and is stimulated by cold exposure and exercise.[43] Irisin regulates adipocyte browning and IGF-1 production, resulting in improved energy expenditure, reduced white adipose tissue, and increased muscle growth.[43] Therefore, because the low-grade inflammation of sarcopenic obesity promotes the vicious cycle of loss of muscle mass and the accumulation of fat mass, the downregulation of inflammatory pathways through weight reduction, nutritional support, and exercise are strategies to prevent or attenuate age-induced sarcopenic obesity.

Treatment strategy

Owing to the lack of randomized controlled trials addressing the treatment of sarcopenic obesity, there are no clear guidelines. However, lifestyle modifications, including dietary interventions and increased physical activity, are key components in the treatment of sarcopenic obesity (Fig. 1).

Dietary strategy

Low-calorie diet

Weight loss in the obese elderly population has been controversial owing to the coexistence of the beneficial aspects of reducing obesity-related complications and concerns about the detrimental effects on health.[51] Weight-loss interventions in elderly obese individuals improved physical function and quality of life.[52–54] A longitudinal study suggested that a calorie-restricted diet (1200–1800 kcal/day) with moderate physical activity (indoor cycling, outdoor walking, five sessions per week) for 3 weeks improved stair-climbing performance, especially in elderly (≥50 years old) obese women (BMI ≥ 40).[52] A prospective study with a 3-month-long weight-loss program showed that community-dwelling older women (≥ 60 years old) with obesity (BMI ≥ 30) who had reduced calorie intakes (1200–1500 kcal/day) and performed physical activity (at least 5000 steps per day) achieved moderate weight loss (mean ± standard deviation [SE], 4.3 ± 5.5 kg) and improved physical performance and quality of life.[53] A randomized controlled trial among obese older adults (BMI 27–41, age ≥ 55 years) with osteoarthritis reported that the calorie-restriction-with-exercise (energy-intake deficit of 800 to 1000 kcal per day) and the calorie-restriction groups had significant weight losses (mean value −10.6 kg, −8.9 kg, respectively) and decreased inflammatory markers as compared with the exercise-only group.[54]

A randomized controlled trial of weight-loss interventions among obese older adults recommended a 500–1000 kcal/day-deficit diet.[55] The aim of weight loss is a decrease in body weight by 0.5 kg per week, finally approaching an 8%–10% reduction from the basal body weight at 6 months, followed by weight-loss maintenance.[56,57] It is possible for a hypocaloric diet to lead to a not only the loss of fat mass but also lean body mass, which exacerbates sarcopenia.[58] The "Quarter fat-free mass rule" suggests that approximately 75% of the weight loss in dietary restriction is composed of the loss of fat mass, whereas 25% is that of fat-free mass (muscle mass).[59] The decline in muscle mass and strength could adversely affect functional capacity and quality of life in the elderly population.[60] Several studies have suggested that adequate protein intake may prevent declines in muscle mass and strength during calorie restriction for sarcopenic obesity.[61,62] In addition, calorie restriction is associated with a decrease in bone mass and with impaired bone microstructure.[63] Therefore, with regard to the weight-loss strategy, calorie restriction should be combined with adequate protein supply and exercise training to attenuate the harmful effects on muscle and bone.[41,58]

High protein intake

Dietary protein intake plays an important role in the synthesis of muscle protein. Dietary proteins supply amino acids that are essential for promoting protein anabolism, while also acting as raw materials for muscle protein synthesis.[64,65] With aging, the muscle protein synthetic response to anabolic stimuli is blunted, and more dietary protein is needed to maintain muscle mass; this is referred to as anabolic resistance.[66] Muscles in the elderly are less sensitive to lower amounts of amino acids than those in young adults, and they require a higher amount of protein to stimulate synthesis and accrue muscle protein.[67] Furthermore, older adults with chronic diseases such as congestive heart failure, chronic kidney disease, and diabetes mellitus also have higher protein requirements to keep up with an increased metabolism due to inflammatory conditions.[68] For older adults (≥65 years old), evidence-based recommendations suggested daily protein intakes of 1.0 to 1.2 g/kg body weight per day to maintain and accrue lean body mass. For older adults with chronic disease or acute illness, an even higher amount of daily protein intake (1.2 to 1.5 g/kg weight per day) is recommended.[69,70] An intervention study in 104 older women (≥ 65years old) with sarcopenic obesity showed that a hypocaloric diet with high protein intake (≥1.2 g/kg body weight per day) is associated with the preservation of muscle mass as compared with a hypocaloric diet with low protein intake (≤0.8 g/kg body weight per day).[71] In addition, a longitudinal study of 304 older adults (mean age 72 years) reported that those with protein intakes of 1.2 to 1.76 g/kg body weight per day had fewer health problems than those with protein intakes of less than 0.8 g/kg body weight per day.[72] Moreover, the Women's Health Initiative, a prospective cohort study of 24 000 women with a 3-year follow-up, suggested that older women (aged 65 to 79 years) with a 20% higher intake of dietary protein (protein intake defined as percentage of total kilocalories) had a 12% lower risk of frailty.[73]

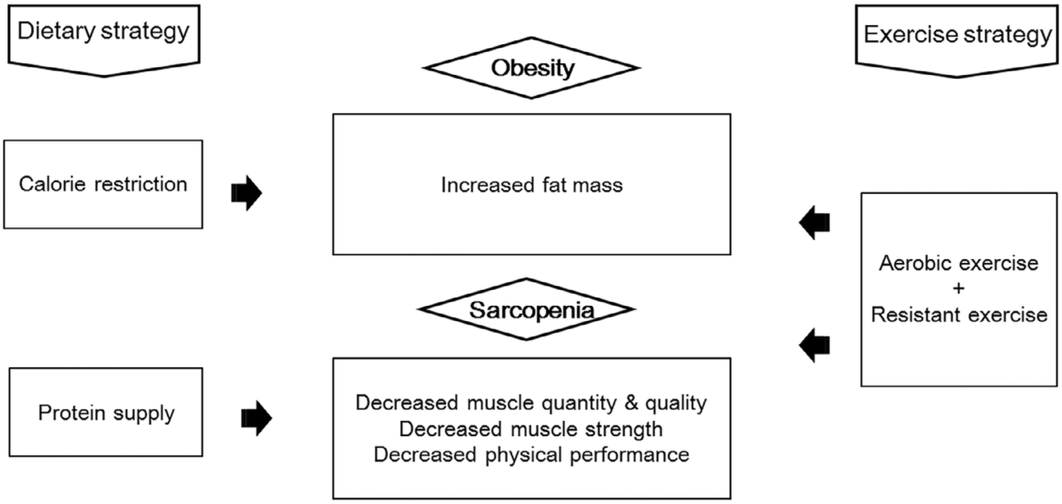

Figure 1 Treatment strategies for age-related sarcopenic obesity. Black arrows refer to the main targets of dietary and exercise strategies.

Source of protein intake

Protein sources may also be crucial for muscle mass retention. A previous study showed that a hypocaloric diet with a high protein intake from dairy foods promoted fat mass loss and the preservation of lean body mass.[73] In particular, whey protein from milk is considered to be an important component contributing to the preservation of muscle mass during weight-loss intervention.[74,75] Whey protein, which is quickly digested and absorbed, promotes muscle protein anabolism better than casein, which is slowly digested and absorbed.[76] Leucine, which is present at high concentrations in whey protein, is known to play a key role in augmenting the muscle protein synthetic response to food intake.[77] A meta-analysis of randomized controlled trials that investigated the effect of leucine supplementation on body composition showed that leucine had beneficial effects on the increase in lean body mass among elderly individuals with sarcopenia.[78] In addition, healthy older women (aged 65–75 years) who consumed a high-protein diet containing more than 4 g of leucine had greater increases in myofibrillar protein synthesis than those who consumed an isocaloric mixed protein beverage containing 1.3 g of leucine.[79] Likewise, there is evidence that dietary protein derived from animal-based sources has more anabolic effects than that derived from plant-based sources.[80] This may be attributed to the differences in the type and content of essential amino acids in plant-based proteins as compared with animal-based proteins, especially the relatively low leucine content in plant-derived proteins.

Vitamin D supplementation

Vitamin D deficiency is reported to be associated with low muscle mass, weak muscle strength, and decreased physical performance.[81–83] A 2.6-year follow-up prospective study of community-dwelling older adults reported that both baseline and changes in 25-hydroxyvitamin D levels are crucial for the maintenance of muscle mass, function, and physical activity.[81] Additionally, a previous longitudinal study among community-dwelling adults (70–89 years old) showed that an increase in the 25-hydroxyvitamin D level (≥20 ng/mL) was correlated with substantial improvement in physical performance.[82] In general, vitamin D deficiency is highly prevalent in older adults owing to insufficient exposure to sunlight and a decrease in dietary intake.[84] The American Geriatrics Society recommended the supplementation of 1000 IU/day of vitamin D3 with calcium and the maintenance of over 30 ng/mL serum vitamin D in older subjects aged ≥ 65 years.[85] However, when serum vitamin D levels exceed the target, the effectiveness of vitamin D supplementation in improving sarcopenia is questionable. For example, a previous meta-analysis of 17 randomized controlled trials involving 5072 participants showed that vitamin D supplementation had no positive effect on the increase in muscle strength among adults with sufficient vitamin D levels (25-hydroxyvitamin D > 25 nmol/L).[86] In contrast, an analysis of studies in adults with vitamin D deficiency showed that vitamin D supplementation improved proximal muscle strength.[86] Meanwhile, a previous meta-analysis of randomized controlled trials reported that vitamin D supplementation of 800 to 1000 IU in older adults had beneficial effects on balance and muscle strength.[87] Hence, vitamin D supplementation in the elderly with sarcopenic obesity who live indoors may help to reduce the risk of falls and fractures[88] and improve muscle capability and physical performance.[81,87]

Exercise strategy

Exercise has been reported to have a profound effect on both sarcopenia and obesity multifariously. In particular, exercise has a profound effect on the promotion of muscle mass and function by stimulating muscle protein synthesis,[89] improving mitochondrial synthesis and function,[90] decreasing myostatin expression[91] and skeletal muscle inflammatory gene expression,[92] enhancing intramuscular IGF-1,[93] improving insulin sensitivity of muscle protein metabolism,[94] and activating skeletal muscle satellite cells.[95] A recent meta-analysis of randomized controlled trials with sarcopenic obese populations showed that exercise strategy was more effective and coincident with fat mass loss and the enhancement of muscle functions such as gait speed and muscle strength than nutritional strategy, but its influence on increasing skeletal muscle mass was discordant.[96] These inconsistent findings may be related to different exercise intensities and modalities, study durations, and participant characteristics, including age or previous training history. Aerobic and resistance exercises are major interventions in exercise strategies.

Aerobic exercise

Aerobic exercise has shown beneficial effects on skeletal muscle by improving insulin sensitivity[97] and reducing oxidative stress.[98] It also improves cardiovascular function,[99] skeletal muscle mitochondrial adaptation,[100] and skeletal muscle blood flow capacity,[101] thereby resulting in increased aerobic capacity. Therefore, with the increasing aerobic capacity of the muscle, aerobic exercise might be the main target for improving muscle quality, metabolic rate, and physical function in the elderly.[102,103] Aerobic exercise generally includes large-muscle activities such as walking, stair stepping, running, rowing, swimming, and cycling. Recently, some studies have suggested that aerobic exercise also has anabolic potential. Harber *et al.* reported significantly increased quadriceps muscle mass after 12 weeks of progressive cycling in older adults.[104,105] In addition, high-intensity interval training (HIT), namely repeated short bursts of intense exercise that last from seconds to minutes between breaks or recovery periods, is a possible exercise regimen with proven advantages in muscle protein synthesis[106,107] and skeletal muscle health.[102] Although there is little evidence in patients with obesity and sarcopenia, a number of studies have suggested that HIT might be a valuable exercise regimen as it upregulates PGC-1a[108] and mitochondrial biogenesis[109] and improves insulin sensitivity.[110]

Furthermore, aerobic exercise with/without a calorie-restricted diet is a potential treatment strategy for weight loss.[111] In a randomized controlled trial of 60 obese subjects with sarcopenia aged 65–75 years, Chen *et al.* showed that the aerobic exercise group had a significant reduction in visceral fat and body fat mass along with the preservation of skeletal muscle mass during 8 weeks compared with the non-exercise group.[112] Nonetheless, studies on aerobic exercise are limited in the population with sarcopenic obesity, despite its being a significant therapeutic intervention for sarcopenic obesity that enhances muscle function and weight control.

Resistance exercise

Resistance exercise, as a single intervention, may be the most effective strategy to reverse aging-related sarcopenic obesity, because it promotes muscle hypertrophy, muscle strength, flexibility, and fat mass loss.[92] The effect of resistance exercise for ≥3 months on increases in muscle mass, strength, and physical performance has also been reported in a geriatric population.[113–115] Resistance exercise increased lean body mass and the cross-sectional areas of both type I and type II muscle fibers in older adults.[116,117] In particular, a longitudinal study also reported that resistance exercise contributed to the increase in muscle mass mainly through type II muscle fiber hypertrophy.[27] This may be due to increased anabolic hormone production,[118] decreased catabolic cytokine activity,[119] enhanced muscle protein synthesis,[120] and the activation of satellite cells.[121] Furthermore, resistance exercises downregulate the pathological progression of sarcopenic obesity by decreasing inflammatory cytokines, reducing oxidative stress, and increasing mitochondrial function.[113]

Slow-velocity resistance exercise is a safe and effective traditional way to increase muscle quality and quantity in older populations.[116,122,123] In addition, an emerging regimen to improve muscle function in terms of both strength and speed of contraction effectively is fast-velocity resistance exercise, which could improve daily-life activities in older adults.[124,125] Recently, Balachandran *et al*. showed that fast-velocity circuit exercise significantly increased physical performance measured by short physical performance battery (SPPB) in obese patients with sarcopenia.[126] Furthermore, Candow *et al*. reported that short-term heavy resistance training for 22 weeks in healthy older men (60–71 years) resulted in significant increases in lean body mass, local muscle size, and muscle strength to a level similar to that in younger men.[124]

Regarding the geriatric population with sarcopenic obesity, little is known about the efficacy of resistance exercise on body composition, muscle strength, and physical function. In a randomized controlled trial with obese women with sarcopenia, Gadelha *et al*. showed significant increases in skeletal muscle mass, strength, and functional capacity after 24 weeks of progressive resistance training.[127] Additionally, in obese elderly women with sarcopenia, resistance exercise with an elastic band for 12 weeks improved body composition by preserving lean muscle mass and reducing fat mass as compared with the no-exercise group.[128] Similarly, the beneficial influence of elastic resistance exercise for 12 weeks on body composition, muscle function (ratio of muscular strength to muscle mass), and physical capacity in obese older women with sarcopenia has been reported.[129] Therefore, resistance exercise may be a potential and meaningful strategy for enhancing body composition and physical function in relation to sarcopenic obesity.

Combination of aerobic and resistance exercise

The professional societies' guidelines strongly recommend that older adults, like healthy young adults, should perform at least 150–300 min of (moderate to intense) aerobic exercise per week, with moderate- to high-intensity resistance exercises involving all major muscles at least 2 days per week.[130–132] Recently, functional balance training and strength training have been considered important in improving functional ability and reducing falls in an elderly population.[131] However, since these guidelines are based on healthy elderly people, more evidence is needed to elucidate their efficacy and safety in order to apply them to populations with sarcopenic obesity.

Theoretically, a combination of aerobic and resistance exercises seems ideal for improving body composition and muscle function simultaneously in a population with sarcopenic obesity. In the Lifestyle Interventions and Independence for Elders Pilot (LIFE-P) study with an older population aged 70–89 years, Manini *et al*. showed that multimodal exercise including aerobic, strength, and balance exercises in subjects with/without obesity improved overall physical function as measured by SPPB scores as compared with the no-exercise group, but this improvement was blunted in obese adults.[133] However, in a post-hoc stratified analysis using the LIFE study (the same group), physical activity intervention showed the greatest benefit for major mobility disability in extremely obese participants (BMI ≥ 35 kg/m^2), although there were no statistically significant benefit differences between obesity categories, using BMI and/or waist circumference.[134] Moreover, in a randomized controlled trial with obese older subjects, a combination of aerobic and resistance exercise reduced body weight and promoted physical functions such as strength, balance, and gait more effectively than in the no-exercise group.[135] Among the aerobic, resistance and combination exercise groups, the physical performance test score was the best in the combination exercise group; strength, in the resistance exercise group; and peak oxygen consumption, in the aerobic exercise group.[135] With weight loss, lean body mass decreased in all the exercise groups.[135] However, the loss of lean body mass was less in the resistance exercise (2% decrease) and combination exercise (3% decrease) groups than that in the aerobic exercise group (5% decrease).[135] This suggests the importance of accompanying aerobic exercises with resistance exercise during weight-loss treatment, because resistance exercise attenuated the effect of muscle mass loss according to weight loss and improved muscle strength, despite muscle loss, which indicates an enhancement in muscle function.[135] Furthermore, in a randomized controlled trial of Japanese women with sarcopenic obesity, 3 months of aerobic and resistance exercise demonstrated a significant decrease in total body fat mass and trunk fat mass and increases in knee extension strength and arm and leg muscle mass.[136] Thus, these pieces of evidence suggest that the combination of aerobic and resistance exercise is the most effective and harmonious exercise strategy targeting all components of sarcopenic obesity.

Coupling of dietary intervention with exercise strategy

To manage sarcopenic obesity, it is crucial to maintain a negative energy balance for weight loss while preserving muscle mass. Although, as mentioned above, calorie restriction alone appears to lead to a distinct reduction in body weight, this result may be accompanied by a loss in skeletal muscle mass.[59] In order to manage both obesity and sarcopenia, a combined strategy of exercise and hypocaloric diet with high protein intake (≥1.2 g/kg body weight per day) may be effective in older subjects.[137,138] In particular, an acute increase in exercise with amino acid supplementation synergistically stimulates skeletal muscle synthesis by increasing the nutritive flow to the muscle.[139] For instance, in a meta-analysis of 52 studies, Weinheimer *et al*. showed that a combination of energy restriction and exercise may be more suitable than treatment alone in a population with sarcopenic obesity in terms of effective weight loss and fat-free mass conservation.[140]

In a meta-analysis of 22 randomized controlled trials, Cermak *et al*. reported that dietary protein supplementation had an effect on the additional increase in skeletal muscle mass and strength during prolonged resistance exercise in both healthy younger and healthy older people.[141] In a meta-analysis of randomized controlled trials in a population with sarcopenic obesity, Hita-Contreras *et al*. reported that dietary protein supplements combined with exercise induced beneficial effects on fat mass and appendicular skeletal muscle mass as well as on physical function (grip strength and gait speed).[142] Similarly, protein supplement interventions along with aerobic and resistance exercise conferred additional benefits to physical function in healthy older subjects with sarcopenic obesity.[143] A recent meta-analysis study in a population with sarcopenic obesity reported that the combination of exercise and nutritional strategy (dietary and/or supplementary intervention) significantly increased skeletal muscle mass, whereas an exercise strategy alone did not.[96] In addition, exercise with/without nutritional strategies greatly improved hand grip strength and gait speed.[96] However, Hsu *et al*. reported no extra benefit of the protein-based nutritional intervention during exercise intervention with respect to body composition, walking speed, or grip strength in the population with sarcopenic obesity in a meta-analysis.[144] Although the effects of protein supply on muscle mass or function are not constant, the role of protein, which stimulates muscle protein synthesis, cannot be disregarded.

Meanwhile, a recent meta-analysis study of older adults showed that resistance exercise in conjunction with vitamin D3 supplementation had additional advantages for muscle strength compared with resistance exercise only.[145] Furthermore, a randomized controlled trial with sarcopenic older subjects showed that the combination of resistance exercise and nutritional supplementation (vitamin D3 and protein) was more effective for muscle strength and quality compared with each of them alone.[146] Overall, a calorie-restricted diet with appropriate nutritional supplementation plus combined exercise may be the most effective way to improve sarcopenic obesity.

Conclusions

Sarcopenic obesity is defined as the coexistence of sarcopenia and obesity, namely decreased skeletal muscle mass with low muscle function and excess body fat. It is becoming a public health concern that is associated with significant immobility, comorbidity, mortality, and societal costs. Different from sarcopenia or obesity alone, sarcopenic obesity exacerbate each other synergistically leading to the loss of skeletal muscle mass and gain in adipose tissue mass occurs through disability, dependency, and reduced mobility.[3] On the need for universally established diagnostic criteria of sarcopenic obesity, ESPEN and EASO recently reported a two-step algorithm (screening and diagnosis) for evaluating sarcopenic obesity.[23] Identifying sarcopenic obesity and applying an ideal approach to improving muscle mass and function along with reducing fat mass is necessary in the frail elderly population. Energy restriction without exercise could result in body weight loss, but this loss could be accompanied by muscle mass loss.[140] Nevertheless, weight loss itself seems to have a positive effect through the improvement of relative sarcopenia (greater loss of fat mass than lean body mass), frailty, and the reduction of obesity-induced low-grade chronic inflammation.[41,58,147] Moreover, the addition of aerobic and resistance exercises with energy restriction can help to maintain skeletal muscle mass as well as enhance physical performance and muscle strength, which are the main components of sarcopenia. In particular, appropriate dietary proteins, including essential amino acids, can promote muscle protein synthesis and affect muscle health. Although great efforts have been made to identify effective drugs for muscle loss, there has been no successful pharmacological treatment.[148] In the absence of effective drugs for sarcopenia, the best effect on sarcopenic obesity is obtained by combining proper dietary intervention (e.g. a low-calorie and high-protein diet) with regular physical activity based on aerobic and resistance exercise (e.g. using body weight: chair-stand exercise, planks, lunges, squats, etc.; using machines; using elastic bands, etc.) according to the individual's health condition. Further research is required to determine the most effective strategy to prevent or treat sarcopenic obesity, such as ways to combine exercise and dietary intervention and the exercise strategies (i.e., the ratio of aerobic to resistance exercise or the types of exercise). In addition, more investigations are needed to develop and commercialize potential drugs to improve muscle function and mass in older populations with physical limitations.

Author contributions

Yoon Jung Kim, Shinje Moon, and Jae Myung Yu contributed to the literature search and the original draft preparation. Hye Soo Chung contributed to the study conceptualization, text review, and editing. All authors have read and agreed to the published version of the manuscript.

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Indicate sponsor's role in the design, methods, subject recruitment, data collections, analysis and preparation of paper. If there is no sponsor, indicate "none".

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Disclosure statement

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Data availability statement

Data sharing is not applicable to this narrative review article as no new data were generated or analyzed in this study.

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