



Current perspectives on sarcopenia: diagnosis and therapeutic approaches

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Korea is experiencing rapid population aging and entered a super-aged society in December 2024. This demographic shift underscores the growing prevalence of sarcopenia, a progressive skeletal muscle disorder related to aging, characterized by reduced muscle mass, strength, and function, which significantly affects the morbidity and quality of life of older adults. Although sarcopenia is defined as a medical condition (ICD-10-CM M62.84; KCD-8 M62.5), no effective pharmacological treatment exists, emphasizing the importance of non-pharmacological prevention and management strategies. Definitions of sarcopenia have been proposed by the European Working Group on Sarcopenia in Older People (EWGSOP), the Asian Working Group for Sarcopenia (AWGS), and the Korean Working Group on Sarcopenia (KWGS). The current interventions focus on exercise and nutritional supplementation. Protein intake above the generally recommended dietary allowance, along with resistance exercise, is strongly recommended for the prevention and management of sarcopenia. Asian intervention studies have highlighted the benefits of multimodal programs that combine exercise, nutrition, and geriatric care. However, standardized protocols remain inconclusive. Variations in diagnostic criteria and ethnic differences further complicate the management of sarcopenia. Future large-scale studies are needed to establish effective preventive measures and therapeutic strategies for sarcopenia with a focus on tailored interventions and standardized protocols for Asians.

Keywords: Sarcopenia; Exercise; Nutrition; Proteins

INTRODUCTION

Population aging in Korea is progressing at an unprecedented rate, making it one of the most rapidly aging countries worldwide. This demographic shift is driven by the combination of increased life expectancy and one of the lowest fertility rates worldwide [1]. As the older population has continued to grow, the country has already entered a super-aged society as of December 2024, with the proportion of the older population surpassing 20% of the total population. The aging population also highlights the need for policies to support active aging, improve the infrastructure of older patient care, and address potential intergenerational economic imbalances [2]. The growing older population

requires increased attention to various diseases such as sarcopenia, which is prevalent among older adults.

Sarcopenia is a progressive and generalized skeletal muscle disorder characterized by the loss of muscle mass, strength, and function [3]. This condition, which is closely associated with aging, significantly affects mobility, physical performance, and the overall quality of life, particularly among older adults [4,5]. Notably, sarcopenia, as an independent medical condition, is now classified (M62.84) under the International Classification of Diseases, Tenth Revision, Clinical Modification (ICD-10-CM), code by the Centers of Disease Control and Prevention [6]. Revised Korean Standard Classification of Diseases-8 (KCD-8) also included sarcopenia as a clinical condition in 2021, with the diagnos-

tic code M62.5. Sarcopenia is increasingly recognized as a major public health concern because of its strong correlation with frailty, disability, and mortality [7]. Understanding the underlying mechanisms and clinical implications of sarcopenia is essential to develop effective prevention and management strategies to address its growing prevalence in aging populations.

EPIDEMIOLOGY OF SARCOPENIA

As the prevalence of sarcopenia varies between studies depending on the characteristics of the study population and the definition used, the prevalence of sarcopenia among older populations is estimated to be 10–16% worldwide [8]. According to the Asian Working Group of Sarcopenia 2019 diagnostic criteria, the incidence of sarcopenia in Chinese older males aged 60–69 years, 70–79 years and > 80 years was 1.5%, 9.6%, and 33.1%, respectively [9]. According to a previous analysis utilizing the 2022 Korea National Health and Nutrition Examination Survey dataset, the prevalence of sarcopenia was 5.5% in the ≥ 60 years group, 9.6% in the ≥ 70 years group, and 21.5% in the ≥ 80 years group among men. Among women, the prevalence rates were 7.9%, 10.5%, and 25.9%, respectively [10]. Physical inactivity, alcohol consumption, obesity, malnutrition, smoking, extreme sleep duration, and diabetes are associated with an increased risk of sarcopenia. Vitamin D, adiponectin, pulse wave velocity, and gut microbiota are known to be associated with sarcopenia [8]. Owing to these various risk factors and pathophysiological mechanisms, sarcopenia should be approached and addressed as a geriatric syndrome requiring tailored intervention strategies.

Previous research on the economic burden associated with sarcopenia estimated a direct expenditure of 1.5% of the total national healthcare costs in the United States. The excess healthcare cost was estimated to be \$860 for every man with sarcopenia and \$933 for every woman with sarcopenia, and a 10% reduction in sarcopenia prevalence would result in savings of \$1.1 billion every year in the United States of America [11]. Additionally, sarcopenia is associated with many chronic diseases, including diabetes, non-alcoholic fatty liver disease, and hypertension [12–14].

PATHOPHYSIOLOGY OF SARCOPENIA

Aging disrupts skeletal muscle homeostasis by shifting the balance between the anabolic and catabolic processes in protein metabolism towards catabolism. In sarcopenic muscles, cellular alterations include a reduction in both the size and number of type II muscle fibers, along with increased intramuscular and intermuscular fat infiltration. Additionally, the number of satellite cells, which play a key role in the regeneration and repair of damaged muscle fibers, is diminished. In sarcopenia, the function of satellite cells may be impaired due to changes in systemic regulatory factors, such as those within the muscle stem cell niche, including transforming growth factor-beta (TGF- β). Other factors contributing to muscle atrophy include neuromuscular junction dysfunction, reduced motor unit numbers, chronic inflammation, insulin resistance, mitochondrial impairment, and oxidative stress [15].

Many international pharmaceutical companies have attempted to develop drugs to treat sarcopenia. These molecular targets, including myostatin, activin receptors, exercise mimetics, and hormones, are correlated with the etiology of sarcopenia [16]. However, none of these drugs have been proven to improve exercise performance, strength, or overall quality of life while simultaneously increasing muscle mass. Therefore, sarcopenia is currently considered to be difficult to treat with medication. Therefore, proper assessment, prevention, and management of sarcopenia are important for healthy aging.

DIAGNOSIS OF SARCOPENIA

In 1989, Irwin Rosenberg proposed the term ‘Sarcopenia’ (Greek ‘sarx’ or flesh + ‘penia’ or loss) to identify age-related decrease of muscle mass [17]. The European Working Group on Sarcopenia in Older People (EWGSOP) published a European consensus regarding the definition and diagnosis of sarcopenia in 2010 [3], defining sarcopenia as the presence of both low muscle mass and function (strength or performance). In 2019, the EWGSOP revised the consensus on the definition and diagnosis of sarcopenia (EWGSOP2) [18], which focused on low muscle strength as a key characteristic of sarcopenia, used the detection of low muscle quantity or quality to confirm the diagnosis of sarcopenia, and identified poor physical performance as an indicator of

severe sarcopenia. The EWGSOP2 provided clinical algorithms for sarcopenia case finding, diagnosis, and identification of severity, while also describing tools for measurements and cutoff points for each measurement. It defined low muscle strength as a handgrip strength of < 27 kg for men and < 16 kg for women, and low physical performance was defined as a 5-time chair stand test result of > 15 s. A slow gait speed was defined as ≤ 0.8 m/s. The EWGSOP2 also defined low muscle quantity as an appendicular muscle mass/height² < 7.0 kg/m² for men and that < 5.5 kg/m² for women. Muscle quality (muscle architecture and composition) was measured using computed tomography or magnetic resonance imaging. The EWGSOP initially proposed the definition and diagnostic criteria for sarcopenia primarily based on European populations. However, there are concerns regarding its applicability to Asian populations, owing to differences in physical and demographic characteristics.

To address this issue, the Asian Working Group for Sarcopenia (AWGS) published a consensus in 2014, specifically tailored to Asian populations, and updated it in 2019 [19,20]. The Asian Working Group for Sarcopenia (AWGS) 2019 consensus adjusted the definition and diagnostic criteria for sarcopenia, considering the unique physical characteristics of Asians. For example, low muscle strength was defined as a handgrip strength < 28 kg for men and < 18 kg for women, and low physical performance was defined as a 5-time chair stand test result of > 12 s. Additionally, poor physical performance was defined as a gait speed of < 1.0 m/s over a 6-m distance [20]. The AWGS 2019 differs from the EWGSOP2 in its approach to cutoff values for muscle mass measurement. Specifically, the AWGS 2019 provides distinct cutoff points based on two measurement methods: dual-energy X-ray absorptiometry (DXA) and bioelectrical impedance analysis (BIA). The criteria for defining low muscle mass differed slightly. The AWGS 2019 adopted a revised algorithm for sarcopenia diagnosis, emphasizing practicality and accessibility. In primary health care and community preventive service settings, after case-finding with a self-reported questionnaire, muscle strength with handgrip strength tests or physical performance with 5-time chair stand test is sufficient to determine possible sarcopenia and recommend lifestyle modifications in diet and exercise. To confirm the clinical diagnosis, the appendicular skeletal muscle mass should be measured to define sarcopenia or severe sarcopenia.

Recent statements from the Sarcopenia Definitions and

Outcomes Consortium (SDOC) and the European Society for Clinical and Economic Aspects of Osteoporosis, Osteoarthritis, and Musculoskeletal Diseases (ESCEO) emphasize the importance of muscle function over muscle mass in defining sarcopenia and measuring clinical improvement during intervention [21,22].

The Korean Working Group on Sarcopenia (KWGS) published guidelines and an expert consensus on sarcopenia screening and diagnosis in 2023 [23]. The KWGS provides two-phase Delphi interviews comprising 19 questions, conducted by 40 expert panelists. The KWGS recommends at least two screening tools to identify the possible sarcopenia status. After measuring physical performance, muscle mass, and muscle strength, sarcopenia was diagnosed based on the decrease in the said parameters. Severe sarcopenia is defined as a significant decrease in muscle mass and strength and physical performance. The KWGS introduced the concept of "functional sarcopenia," which refers to a condition wherein the muscle mass is normal, but both physical performance and muscle strength are reduced. This reflects a shift from the traditional definition of sarcopenia, focused primarily on muscle mass, to a concept that recognizes muscle strength and function as being equally important as muscle quantity. Additionally, for any condition diagnosed as being related to sarcopenia, it is recommended to perform a comprehensive geriatric assessment and address the burden of multidomain sarcopenia by focusing on nutrition, physical performance, comorbidities, polypharmacy, and social support.

The definitions and diagnostic criteria for sarcopenia vary according to guidelines. The definitions and diagnostic methods used in the major guidelines are summarized in Table 1. Different guidelines have proposed various algorithms for screening and diagnosing sarcopenia. Consequently, clinicians who aim to apply these guidelines may experience confusion regarding screening tests and assessments. Moreover, different institutions may diagnose sarcopenia using distinct methods, leading to variability in a person's sarcopenia diagnosis depending on the institution where the evaluation was conducted. This inconsistency also poses challenges in conducting multicenter research on sarcopenia.

Table 1. Definition and diagnostic criteria of sarcopenia according to guidelines

Guideline	Definition	Diagnosis criteria and cut-off levels	Diagnosis algorithm
EWGSOP2 (2019)	Sarcopenia is a muscle disease associated with adverse outcomes, characterized by loss of muscle strength and mass.	1. Muscle strength: - Grip strength: men < 27 kg, women < 16 kg / - Chair stand test for five rises: > 15 s 2. Muscle quantity/quality: - Appendicular skeletal muscle mass (ASM/Height ²): men < 7.0 kg/m ² , women < 5.5 kg/m ² (measured via DXA) / - Muscle quality (muscle architecture and composition) measured with CT or MRI 3. Physical performance: - Gait speed: ≤ 0.8 m/s / - SPPB: ≤ 8 points / - Timed up and go: ≥ 20 s / - 400 m walk test: non-completion or ≥ 6 min	If sarcopenia is suspected, muscle strength is measured first. If muscle strength is reduced, muscle quantity or quality is assessed to confirm the diagnosis of sarcopenia, and physical performance is evaluated to determine the severity of sarcopenia.
AWGS (2019)	Sarcopenia is a loss of skeletal muscle mass and function associated with aging.	1. Muscle strength: - Grip strength: men < 28 kg, women < 18 kg 2. Muscle mass: - ASM/Height ² : men < 7.0 kg/m ² , women < 5.7 kg/m ² (BIA) ASM/Height ² : men < 7.0 kg/m ² , women < 5.4 kg/m ² (DXA) 3. Physical performance: - Gait speed: < 1.0 m/s - SPPB: ≤ 9 points - 5-time chair stand test: ≥ 12 s	In primary care, suspected sarcopenia is defined by abnormalities in muscle strength or physical performance, prompting lifestyle education. Definitive diagnosis requires clinical assessment of muscle strength, performance, and mass.
KWGS (2023)	Sarcopenia is an age-related condition characterized by decreased muscle mass and impaired muscle strength or physical performance.	1. Muscle strength: - Grip strength: men < 28 kg, women < 18 kg 2. Muscle mass: - ASM/Height ² : men < 7.0 kg/m ² , women < 5.7 kg/m ² (BIA) ASM/Height ² : men < 7.0 kg/m ² , women < 5.4 kg/m ² (DXA) 3. Physical performance: - Gait speed: < 1.0 m/s - SPPB: ≤ 9 points - 5-time chair stand test: ≥ 12 s	Individuals with positive screening test are classified with possible sarcopenia. Subsequently, muscle mass, physical performance, and muscle strength are measured to diagnose functional sarcopenia, sarcopenia, or severe sarcopenia.

EWGSOP2, European Working Group on Sarcopenia in Older People revised the consensus on the definition and diagnosis of sarcopenia; AWGS, Asian Working Group for Sarcopenia; KWGS, Korean Working Group on Sarcopenia; DXA, dual-energy X-ray absorptiometry; CT, computed tomography; MRI, magnetic resonance imaging; SPPB, short physical performance battery; BIA, bioelectrical impedance analysis.

PREVENTION AND MANAGEMENT OF SARCOPENIA

The pathophysiology of sarcopenia is multifactorial and has not yet been overcome using specific therapeutic agents. Therefore, most studies on the prevention and management of sarcopenia have focused on exercise, nutritional supplementation, or a combination of both. Sarcopenia is an age-related disease. Muscle mass declines by 1.5% per year after the age of 50 years and by 3% per year after the age of 80 years [24]. Though only exercise and nutritional support through increased protein intake are known to improve sarcopenia, older people with sarcopenia often have coexisting musculoskeletal or other chronic diseases or various age-related syndromes along with impaired digestive capacity, making it challenging to provide appropriate interventions. Several systematic reviews (SRs) have evaluat-

ed the effects of exercise and nutrition on sarcopenia [25-30]. According to previous SRs, exercise is the most effective intervention for improving sarcopenia-related outcomes. Although nutritional supplementation alone has limited effects, it may provide additional benefits when combined with exercise. However, further high-quality, targeted, and randomized controlled trials are needed, particularly in high-risk or malnourished populations. Physiologically, older adults may experience reduced responsiveness to the beneficial effects of dietary protein on muscle protein synthesis, a phenomenon known as 'anabolic resistance,' which make the maintenance and enlargement of muscles difficult [31].

Medications for sarcopenia

Besides exercise and nutritional support as frontline treatment strategies for sarcopenia, some emerging medications for sarcopenia have also been proposed. Angiotensin-con-

verting enzyme inhibitors, angiotensin receptor blockers, perindopril, enalapril, and losartan were used to improve muscle mass, muscle strength, and physical performance but did not show improvement [32-34]. Several randomized controlled trials have investigated the effects of vitamin D supplementation on sarcopenia. It was difficult to identify the sole effect of vitamin D supplementation on sarcopenia because most studies reported a combined treatment with exercise or protein supplementation. A meta-analysis concluded that combining vitamin D supplementation with protein supplementation and exercise can significantly increase grip strength and showed a trend toward increasing muscle mass [35]. Omega-3 polyunsaturated fatty acids have anti-inflammatory properties and may also have an anabolic effect on muscles through the activation of mTOR signaling and reduced insulin resistance [36]. Omega-3 supplementation significantly increased gait speed, thigh muscle volume, and strength in previous randomized controlled trials [37,38]. Among nutritional supplementation that promote muscle protein synthesis, branched chained amino acids (BCAA) and β -hydroxy β -methylbutyric acid (HMB) were shown to improve muscle mass, function, and strength [39,40]. Antibodies such as bimagrumab or trevogrumab, which target myostatin or activin receptors, were developed but failed to prove sufficient efficacy and safety profile [16]. Testosterone, a selective androgen receptor

modulator, dehydroepiandrosterone, insulin growth factor 1 mimetic, growth hormone (GH), and GH secretagogue have also been used to manage sarcopenia; however, the outcomes have been inconsistent [41,42]. Treatment with a β -adrenoceptor antagonist resulted in bradycardia, reduced endurance capacity, attenuation of muscle adaptive mechanisms to exercise, and poor mitochondrial bioenergetics and protein synthesis [43]. A non-specific β -adrenoceptor antagonist may be more effective as it not only reduces catabolic mechanisms by blocking the β -1 adrenergic receptors but also induces an anabolic effect by stimulating the β -2 adrenergic receptors [44]. β -adrenoceptor antagonists have demonstrated weight gain in patients with cancer cachexia and heart failure cachexia [45,46]. The HMB has been shown in resistance trained athletes for muscle mass, strength, and performance [40,47,48]. Antibody target to myostatin or activin receptor showed increased muscle mass, strength and mobility in those with slow gait speed [49]. The candidate substances that have been investigated as therapeutic agents for sarcopenia and require further research in the future are summarized in Table 2.

Protein intake for the prevention and management of sarcopenia

Older individuals have higher protein needs than younger ones owing to disease-related catabolism, decreased mus-

Table 2. Potential medications for sarcopenia

Medication / Substance	Mechanism of effects	Outcomes	Reference
BCAA	Stimulates muscle protein synthesis via the mTORC1 pathway	Both pre-sarcopenic and sarcopenic subjects showed improved SMI, gait speed, and grip strength at 5 weeks. However, all three parameters progressively declined at 17 weeks	[39,47]
HMB	Metabolite of leucine, promotes muscle protein synthesis	Positive results were also disclosed in resistance trained athletes for muscle mass, strength and performance	[40,47,48]
Omega-3 fatty acids	Anti-inflammatory effects with modulation of muscle protein synthesis in response to resistance exercise	Improve gait speed, thigh muscle volume and strength	[37,38]
Vitamin D	Enhance muscle protein synthesis	Combining vitamin D supplementation with protein supplementation and exercise can significantly increase grip strength	[35]
β -adrenoceptor antagonist	Reduce catabolic mechanisms by blocking the β -1 adrenergic receptors	Weight gain on cancer cachexia and heart failure cachexia patients	[45,46]
Antibody target to myostatin or activin receptor	Enhance muscle protein synthesis	Bimagrumab increased muscle mass and strength and improved mobility in those with slow walking speed	[49]

BCAA, branched-chain amino acids; HMB, β -hydroxy β -methylbutyric acid; SMI, Skeletal Muscle Index.

cle perfusion, low amino acid availability, and anabolic resistance; however, protein intake decreases with age owing to medical conditions, physical or mental disabilities, and socioeconomic conditions. Despite significant differences in the overall health and physiology between older and younger adults, the recommended dietary allowance (RDA) for protein has traditionally been set uniformly at 0.8 g per kilogram of body weight per day for healthy adults of all ages [50]. However, various expert groups and geriatric/sarcopenia-related societies recommend a higher level of protein intake beyond the RDA.

The PROT-AGE working group, an international study group that reviews dietary protein needs based on aging, supports the concept that lean muscle mass can be better maintained if an older person consumes dietary protein at a level higher than that of the general RDA. Major recommendations for protein intake for healthy older people are (1) older people should consume an average daily intake of 1.0–1.2 g/kg body weight per day, (2) the per-meal anabolic threshold of dietary protein/amino acid intake is higher in older individuals (i.e., 25–30 g protein per meal, containing approximately 2.5–2.8 g leucine) in comparison with young adults, (3) protein source, timing of intake, and amino acid supplementation may be considered when making recommendations for dietary protein intake by older adults. The PROT-AGE group suggests that further research is needed to determine the optimal types of proteins and timing of protein intake [51].

In 2013, the European Society for Clinical Nutrition and Metabolism (ESPEN) hosted a Workshop on Protein Requirements of older people. Based on the evidence, the ESPEN recommended that healthy older individuals should take at least 1.0–1.2 g protein/kg body weight/day. For those who are malnourished or at a risk of malnutrition because they have acute or chronic illness, protein should be consumed at 1.2–1.5 g protein/kg body weight/day, with even higher intake for individuals with severe illness or injury. The ESPEN guidelines also recommend daily exercise (resistance or aerobic) along with adequate protein intake to promote muscle health [52]. BCAA, especially leucine, positively regulate the signaling pathways involved in the synthesis of muscle proteins [53]. In a previous study on exercise and nutrition in older Japanese community-dwelling women with sarcopenia, individuals who exercised and consumed leucine showed increased leg muscle mass and strength and faster gait speed [54]. β -HMB, an active metabolite of leucine, in-

creased muscle protein synthesis and reduced muscle protein breakdown in young adults in an insulin-independent manner [47]. However, clinical evidence regarding the benefits of leucine or β -HMB in older adults with sarcopenia remains controversial.

Dietary protein intake in Korean older adults aged ≥ 60 years was assessed using a 24-h recall nutrition survey in the 6th Korean National Health and Nutrition Survey (KNHANSE) from 2013–2014. The protein intakes were 1.03 and 0.90 g/kg/day in men and women, respectively. Among them, 47.9% of men and 60.1% of women had insufficient protein intake based on the RDA [55]. The Korean Geriatric Society and the Korean Nutrition Society have also released recommendations for Korean older adults to prevent sarcopenia [56]. This expert consensus recommends a dietary protein intake of > 1.2 g/kg and 20 g of essential amino acids per day for community-dwelling older adults. Leucine or other BCAA and β -HMB enrichment may be beneficial but clinical evidence remains insufficient. Fast protein (whey protein) may be more beneficial than slow protein (casein protein), and proteins of animal origin may be better than plant-based proteins in promoting muscle mass synthesis. Protein intake during exercise may synergistically stimulate muscle protein synthesis, leading to improved muscle mass and strength in older adults. A tailored approach is recommended for patients with acute or chronic diseases.

Observational studies have suggested that older adults who consume more protein can maintain their muscle mass and strength [57,58]. According to a systematic review identifying which interventions effectively improves sarcopenia-related components, compared to the control group, nutritional intervention only improved handgrip strength but not skeletal muscle index or gait speed [29]. In Korea, a community-based randomized controlled trial demonstrated that providing protein-energy supplements (an additional 400 kcal of energy and 25 g of protein, including 9.4 g of essential amino acids per day) to older adults with a low socioeconomic status over a 12-week period led to significant improvements in the intervention group. Compared with the control group, these participants showed better outcomes in the short physical performance battery (SPPB), usual gait speed, and timed up-and-go test by the end of the study [59].

Table 3. Previous Asian studies on sarcopenia intervention

Author (publication year)	Country	Participants eligibility	Group	Age (yr)	Total number	Intervention	Follow up (wk)	Outcome
Kim et al. (2021) [65]	Japan	≥ 65 yr; older women with muscle mass decline	Combined	74.9 ± 5.4	65	Exercise + 3 g of amino acid	12	No change of muscle mass and strength
			Exercise	74.6 ± 4.9	65	60-min comprehensive exercise program once a week and were encouraged to perform a home-based exercise program + 3 g of placebo		Beneficial effect on low back discomfort in combined group
Li et al. (2021) [66]	China	≥ 60 yr; older adults with sarcopenia	Combined	71.5 ± 5.3	48	Exercise and nutrition	12	Compared with controls,
			Exercise	73.7 ± 5.7	37	Resistance and walking for 60 min and 3 days/ week		appendicular muscle mass and grip strength were significantly higher in nutrition, exercise and combined group
			Nutrition	70.0 ± 4.0	51	Supply whey protein 30 g/day, daily		
			Control	72.9 ± 6.3	33			
Osuka et al. (2021) [48]	Japan	≥ 65 yr; older women with sarcopenia	Combined	73.5 ± 4.2	39	Exercise + β-HMB	12	Exercise appeared to be the only
			Exercise	71.8 ± 4.1	39	Resistance exercise for 60 min and 3 days/week		effective intervention to improve outcomes in older women with
			β-HMB	71.5 ± 4.5	39	Supply β-HMB 1,500 mg/ day daily		low muscle mass (gait speed, knee extensor and hip adduction)
			Control	71.6 ± 4.2	39			Combination of β-HMB did not improve outcome
Yamada et al. (2019) [67]	Japan	≥ 70 yr; older adults with sarco- and dynapenia	Combined	84.9 ± 5.6	28	Exercise + nutrition	12	Participants in the combined
			Exercise	84.7 ± 5.1	28	Resistance exercise for 30 min and 2 days/week		group had a significantly greater improvement in rectus femoris
			Nutrition	83.2 ± 5.7	28	Supply whey protein 10 g/day daily and vitamin D supplement		echo intensity, knee extension torque and appendicular muscle mass than those in the other groups
			Control	83.9 ± 5.7	28			

Table 3. Continued

Author (publication year)	Country	Participants eligibility	Group	Age (yr)	Total number	Intervention	Follow up (wk)	Outcome
Seino et al. (2018) [68]	Japan	≥ 65 yr; sedentary older adults	Combined	73.4 ± 4.3	40	Exercise + supply protein fortified milk 10.5 g/day and and micronutrients (8.0 mg zinc, 12 mug vitamin B12, 200 mug folic acid, 200 IU vitamin D, and others/day) daily	12	Low-dose dairy protein plus micronutrient supplementation during resistance exercise significantly increased muscle mass in older adults but did not further improve physical performance
			Exercise	73.7 ± 4.3	40	Resistance exercise for 60 min and 2 days/week		
Kim et al. (2012) [54]	Japan	≥ 75 yr; older adults with sarcopenia	Combined	79.5 ± 2.9	38		12	Combined intervention may be effective in enhancing not only muscle strength, but also combined variables of muscle mass and walking speed and of muscle mass and strength in sarcopenic women
			Exercise	79.0 ± 2.9	39	Resistance exercise for 60 min and 2 days/week		
			Nutrition	79.2 ± 2.8	39	Supply amino acid 6 g/day daily		
			Control	78.9 ± 2.8	39			

Exercise for the prevention and management of sarcopenia

The International Conference on Sarcopenia and Frailty Research (ICSFR) advocates resistance exercise as the primary strategy for sarcopenia treatment. Protein supplementation or a protein-rich diet is conditionally recommended for exercise. The ICSFR suggests that vitamin D supplementation or anabolic hormones should not be recommended because of a lack of robust evidence [60]. According to systematic review aiming to identify which intervention effectively improves sarcopenia related component, compared to control group, exercise intervention only improved handgrip strength and gait speed, both of the muscle strength and function, without increasing skeletal muscle index [29]. On comparing exercise and nutrition, there was an improvement in gait speed with exercise alone [29].

An observational study conducted in Korea using data from the 2008–2011 and 2014–2018 KNHANSE concluded that moderate-to-vigorous physical activity was highly correlated with the skeletal muscle index, hand grip strength, and sarcopenia [61]. A recent multicomponent interventional study from Korea, the Aging Study of the Pyeongchang Rural Area, implemented a 24-week program consisting of 60-min group exercise sessions, daily nutritional support with 26 g of protein and 11.26 g of essential amino acids, psychiatric care for depression, and geriatric interventions to discontinue potentially inappropriate medications. This program resulted in a 3.2-point increase in the SPPB score (from a baseline of 7.4) by the end of the intervention, with the positive effects persisting for six months post-intervention [62].

Regarding the specific modality of exercise, most studies on improving sarcopenia in older patients reported resistance exercise, while others reported aerobic exercises such as walking. Resistance exercises were sometimes provided independently; however, in many cases, they were offered as part of a multimodal exercise program that included aerobic or balance exercises [29]. A previous SR examined randomized controlled trials that identified the effectiveness of exercise intervention on important outcomes in older adults with sarcopenia. It concluded that resistance exercise with or without nutrition and the combination of resistance exercise with aerobic and balance exercises were the most effective for improving physical function. However, adding nutritional interventions alongside exercise led to a greater improvement in handgrip strength compared with exercise

alone, while having a comparable effect on other physical function measures [63].

PREVIOUS INTERVENTION STUDIES ON SARCOPENIA CONDUCTED IN ASIA

Sarcopenia was initially identified in 1989, but was officially recognized by the World Health Organization in 2016 [17,64]. The primary challenge in managing sarcopenia is that no curative drug has been discovered yet. Efforts to develop effective therapies have faced numerous obstacles globally; however, none have been successful [16]. Presently, proper exercise and protein intake are recommended for the prevention and management of sarcopenia [18]. In this review, we briefly discussed the interventions and outcomes of sarcopenia-related intervention studies conducted in Asia (Table 3). Previous studies conducted among older adults with sarcopenia in Asia predominantly implemented exercise and nutritional interventions that were generally well-tolerated and effective [54,65-68].

CONCLUSION

Sarcopenia has been defined differently by various research groups, and no definite consensus has been reached until recently. The definition of sarcopenia may be influenced by differences between ethnic groups, highlighting the need to establish a definition specifically for the Korean population. Additionally, the measurement values vary depending on the modality used, leading to the application of diverse diagnostic criteria across studies. Although SRs have shown that exercise and protein supplementation can help in muscle synthesis and improve sarcopenia, standardized protocols are still unknown. Additionally, no consensus exists on the most appropriate age to begin preventive activities; or on the optimal type, duration, frequency, and intensity of exercise; or the ideal type, dosage, and frequency of protein intake. Developing standardized protocols for sarcopenia intervention in older adults is challenging owing to the heterogeneity of the aging population, which includes variations in health status, comorbidities, and functional capacity. In addition, intervention studies differ widely in terms of exercise type, intensity, duration, and nutritional components, making it difficult to compare outcomes. The lack

of consensus on diagnostic criteria and outcome measures further complicates the establishment of universal guidelines. Furthermore, most previous studies did not include a sufficient number of large-scale randomized controlled trials to independently assess the distinct effects of exercise and nutritional interventions on sarcopenia. Therefore, future studies should focus on large-scale interventional studies to establish robust evidence for the diagnosis, prevention, and treatment of sarcopenia.

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