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Review article

Lifestyle approaches to prevent and retard sarcopenia: A narrative review

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ABSTRACT

Sarcopenia, with its high prevalence and its adverse health outcomes, amongst older adults is considered a major public health problem. Its primary, secondary and tertiary preventions are therefore very important. Our objective was to review the effects of lifestyle factors, including not only dietary habits and exercise but also social use of substances such as alcohol and tobacco, on the incidence of sarcopenia and on its health outcomes. We found that the effect of lifestyle on muscle parameters or physical function has been investigated in many trials of heterogeneous design and quality. However, based on data from interventional studies, we can be confident that loss of physical function and its consequences can be counteracted by physical activity. There are some interesting data, mainly evident from observational studies, suggesting that healthier dietary patterns may improve muscle health. The combination of exercise with dietary supplement has more conflicting results and the effect of other lifestyle changes, such as cessation of alcohol or tobacco use, is difficult to establish clearly. Further high-quality trials are needed to substantiate the mechanism of action of each intervention as well as to determine the optimal modalities of these in older adults.

1. Introduction

Sarcopenia, formally recognised as a muscle disease with an ICD-10-MC Diagnosis Code, is characterized by low muscle strength and low muscle quantity and quality according to the recent publication of the European Working Group on Sarcopenia in Older People (EWGSOP2), physical performance being used to assess the severity of this muscle disease [1]. Its prevalence (from 3.2 to 26.3% with the EWGSOP2 definition) and adverse consequences (e.g. mortality and institutionalization) increase with age. All the more, considering the global ageing of the population, sarcopenia can be considered a major public health concern [2]. Its prevention and global management are therefore of primary importance. Currently, no pharmacological treatment is available to prevent or cure this disease and most of the interventions susceptible to reduce its incidence or progression are non-pharmacological (e.g. resistance training, nutritional supplementation) even if the severity of sarcopenia may influence the benefits of interventions. Importantly, with adequate interventions, sarcopenia may be reversed. Lifestyle, defined as the set of habits and customs that is influenced by the life-long process of socialization, including social use of substances such as alcohol and tobacco, dietary habits, and exercise, is known to affect global health of the general population but it could potentially affect more specifically sarcopenic populations [3–5]. Many studies have already shown the effects of some lifestyle changes on different individual parameters of sarcopenia (i.e. muscle mass, muscle strength, physical performance) but fewer trials have investigated lifestyle changes in specific sarcopenic populations or their influence on the incidence of sarcopenia. The objective of this paper is to review the lifestyle factors that could potentially affect the incidence of sarcopenia or its health outcomes.

2. Methods

The present narrative review was organized through the "Narrative Review Checklist" proposed by the Academy of Nutrition and Dietetics. First, systematic reviews, meta-analyses, randomized controlled studies and observational studies, published in English from January 2011 until December 2021 were searched on PubMed using the following search terms: sarcopenia, nutrition, physical activity, lifestyle, exercise, alcohol and smoking. A manual search of the references of the included articles was also performed to complete the literature search. All published papers retrieved were sorted by date and type of intervention. Then, a

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selection of the most recent articles on each topic was done, giving priority to meta-analyses, systematic reviews and clinical trials but also on large epidemiological studies and recommendations guidelines. However, for some specific topics where the literature is more limited, studies with a small sample size or with an original study design have been have been considered for inclusion. Animal and experimental model studies were excluded from the review. At last, case reports, editorials, letters to the editor and conference proceedings were also excluded from the review.

3. Summary of the literature search

A total of 30 relevant papers were selected and sorted by type of intervention. Based on this sorting, we will discuss them in four main topics: physical activity, nutrition, the combination of physical activity with nutrition and other interventions.

3.1. Physical activity

3.1.1. Observational studies

3.1.1.1. Sedentary behaviour. Sedentary behaviour, distinct from physical inactivity, refers to certain activities requiring very low energy expenditure [6]. It is an independent predictor of poor health outcomes (e.g. obesity, blood pressure, total cholesterol, fatal and non-fatal cardiovascular diseases, type 2 diabetes, metabolic syndrome, some cancers and all-cause mortality) even when meeting physical activity guidelines [7]. In a cross-sectional study, including 162 community dwelling men and women aged 60 to 86 years, it was shown that for each one-hour increment in sitting time, the risk of being diagnosed with sarcopenia was significantly increased by 33%, independently of physical activity and confounding factors [8]. In another cross-sectional study, involving 1286 men aged 70 to 92 years, recruited from UK Primary Care Centres, the authors observed that sedentary time was marginally but not significantly associated with an increased risk of sarcopenic obesity, independently of physical activity level (RR 1.18 [95% CI 0.99, 1.40]) [9]. Another study, using the same study design, including 14,585 participants aged over 65 years from low- and middle-income countries, showed that one-hour increase in sedentary behaviour per day was associated with 1.06 (95% CI = 1.04–1.10) times higher odds for sarcopenia [10]. At last, in a prospective study of 18 months, following a small institutionalized population ($n = 58$), sitting time was not associated with the incidence of sarcopenia with only 8 of the participants who developed the disease during the follow-up [11].

3.1.1.2. Physical activity. Physical activity is defined by the World Health Organization (WHO) as any bodily movement produced by skeletal muscles that requires energy expenditure (https://www.who.int/news-room/fact-sheets/detail/physical-activity). Physical activity has been shown to be associated with body composition and functional capacities in older adults [12]. In 2017, a systematic review and meta-analysis described the relationship between physical activity and the presence of sarcopenia from cross-sectional and cohort studies [13]. The authors included 25 articles in their systematic review and observed that a statistically significant association between physical activity and sarcopenia prevention was documented in most of the studies. Importantly, the different longitudinal studies included revealed a protective role of physical activity against sarcopenia development. From their systematic review, they included 9 studies in a meta-analysis and showed that physical activity reduces the odds of suffering from sarcopenia (OR 0.45; 95%CI 0.37–0.55).

3.1.2. Intervention studies

Many clinical trials have assessed the effect of exercise programs on muscle parameters in older adults with or without sarcopenia. Most of these studies have been summarized through different systematic reviews and/or meta-analyses that differ slightly, mainly in inclusion and exclusion criteria. First, a systematic review included 12 clinical trials on subjects with sarcopenia aged over 65 years [14]. Authors of this systematic review reported that high intensity strength exercise alone or combined with aerobic exercise, improved muscle mass, muscle strength, and functional performance. A dose-response effect was found for muscle mass; for individuals who exercised more frequently (more than two sessions per week), a higher increase of muscle mass was highlighted. Then, a meta-analysis published in 2020, including 22 clinical trials exploring exercise in older adults with sarcopenia, showed that exercise treatment improved various components of sarcopenia [15]. The calculated standardized mean difference was 0.57 for grip strength, 0.56 for timed five chair stands, 0.44 for gait speed and 0.97 for the timed up and go test. However, no difference was observed for muscle mass. It should be pointed out that the authors observed, as anticipated, a huge heterogeneity in the exercise programs which ranged from 30 to 80 min of training, 1 to 5 training sessions weekly during 6 to 36 weeks. Another very recent meta-analysis, published in 2021, including adults older than 60 years suffering from sarcopenia diagnosed with the EWGSOP criteria, included 7 clinical trials [16]. The authors confirmed the importance of exercise on physical performance (with a standardized mean difference of 1.21, 95%CI [0.79 to 1.62]) and on muscle strength (0.51, 95%CI [0.25 to 0.76]). They also confirmed results from the previous cited meta-analysis and showed no effect on muscle mass. Regarding recommendations for older adults, the expert consensus guidelines of the ICFSR propose the following program to counteract sarcopenia: (A) resistance and power training with 2 to 3 sessions per week, combining slower and faster (power training) muscle actions at intensities of 40 – 80% of 1RM; (B) functional exercises e.g., standing from a chair with progressive increases in loading/speed; (C) balance and gait exercises progressing in complexity: line walking, tandem foot standing, standing on one leg, heel-toe walking [17].

3.1.3. Modelisation studies

Recently, isotemporal substitution models were proposed to analyse the potential effect of physical activity modification. Isotemporal substitution modelling estimates the effect of replacing time spent doing one activity type with time spent doing another activity. An interesting study, modelling the data of more than 500 subjects aged over 65 years, showed that replacing 1 h/day of sedentary behaviour by 1 h/day of moderate to vigorous physical activity could be associated with greater gait speed and grip strength [18]. The reallocation of 15 min/day of time spent to moderate to vigorous physical activity yielded a significant lower sarcopenia risk by 15% ($P < 0.001$). However, no significant effect was observed if sedentary behaviour was replaced by light physical activity. These results were confirmed very recently in a population of 885 older adults where the isotemporal substitution models showed that replacing sedentary behaviour with an equivalent duration of moderate to vigorous intensity physical activity was associated with faster gait speed, higher skeletal muscle mass, and a lower prevalence of sarcopenia and that the effect of light-intensity physical activity on sarcopenia may be insufficient [19].

4.1. Nutrition

In this specific section, we have decided to focus on whole foods, micro or macro nutrients or diets, but not on dietary supplements (essential amino acids, creatine, vitamin D, etc.).

4.1.1. Observational studies

A recent, important and well-conducted systematic review (with a search date up to March 2020) investigated the effect of whole foods (i.e. meat, fish, eggs, fruit and vegetables, and non-liquid dairy) on the ageing muscle and sarcopenia in adults aged over 50 years [20]. The authors included 19 observational studies (i.e. cross-sectional or

prospective) out of which 10 had a low risk of bias and 8 a medium risk of bias. The synthesis of findings showed consistent evidence of a beneficial effect of lean red meat on muscle mass or lean tissue mass, of higher intake of fruit and vegetables for better muscle function and of dairy products (semi-solid and cheese) on appendicular muscle mass. There was moderate evidence concerning the role of these foods in muscle strength and sarcopenia, and limited or inconclusive evidence regarding the benefits of other whole foods (e.g., white meat, fish, eggs, soy products) on muscle health and sarcopenia.

Over the last few years, the association between food patterns, particularly the Mediterranean diet, and physical function has gathered considerable interest. A recent systematic review and meta-analysis in older adults has shown that high adherence to Mediterranean diet was cross-sectionally associated with better physical performance but that no significant association was observed with the incidence of mobility problems [21]. With a more specific focus on muscle health, a longitudinal study in 554 women aged 65–72 years showed that a higher adherence to Baltic Sea diet and Mediterranean diet was associated with a lower relative skeletal muscle index and total body lean mass loss over a 3-year follow-up, compared to lower adherence [22].

Our group has also investigated the effect of nutritional status on different muscle parameters in the SarcoPhAge study, a cohort of more than 500 community dwelling older adults aged over 65 years [23]. First, we showed that sarcopenic subjects seem to consume significantly reduced amounts of many micronutrients and macronutrients compared to non-sarcopenic subjects [24]. Next, prospectively, we showed that the 3-year changes in daily macro- and micronutrient intakes were not significantly associated with the changes over the same period in gait speed or muscle strength [25]. Then, we showed a significantly higher risk of developing sarcopenia during the 4-year follow-up in patients diagnosed with malnutrition (i.e. GLIM criteria) at baseline (adjusted hazard ratio = 3.23 (95%CI 1.73–6.05)) compared to well-nourished participants [26]. At last, we confirmed that malnourished subjects, diagnosed with the GLIM criteria, had a higher risk of developing sarcopenia after a follow-up of 5 years [27].

4.1.2. Intervention studies

Experimental assessment of the effect of dietary patterns or whole food is quite complex and scarce. Nonetheless, some trials have been published in that field. The systematic review presented above also summarized all clinical trials assessing the myoprotective effect of whole foods [20]. The authors included 9 studies from which only 3 had low risk of bias. The authors summarized that (1) more lean red meat (beef, veal, and lamb) could increase lower-body strength; (2) higher intake of fruit and vegetables (over 5 portions a day) showed a trend in greater increase in muscle strength; (3) more cheese intake could increase muscle mass; and (4) other whole foods have no consistent effect on muscle parameters. However, the authors noted that the small number of high quality studies limits the generalization of the results.

The potential different effect on muscle function between animal proteins versus plant proteins has also been investigated. A meta-analysis of 16 randomized controlled trials found that protein source did not affect changes in absolute lean mass or muscle strength [28]. These results were confirmed in the sensitivity analysis based on studies including subjects aged over 50 years. However, it should be noted that in studies including subjects below the age of 50 years, animal proteins tend to be more beneficial for lean mass than plant proteins. Another point to be taken into account is that the source of animal proteins in most of the studies included in this meta-analysis was derived from dairy, while for plant proteins a majority of the studies utilized some form of soy proteins. At last, the authors noted a huge heterogeneity in subjects and interventions in the included studies limiting the extrapolation to clinical practice. Consequently, there is a debate regarding whether source of proteins differentially affects musculoskeletal health in older adults.

4.2. Combination of physical activity and nutrition

As shown above, most of the trials evaluate separately the effects of exercise from those of food intake on muscle parameters but the question remains about to which extent some benefits could be enhanced when these interventions are combined. Very few studies have assessed the added value of exercises with a supplementation of whole food. Much more data is available regarding the added value of food supplement (e.g. protein drink, hydroxymethylbutyrate capsule, powdered amino acid, etc.). In a comprehensive review of the literature including 17 studies on older adults over 65 years in which combined nutrition and exercise interventions were used, enhanced benefits of exercise training, when combined with dietary supplementation, have been shown in some but not all trials [29]. The authors however noted two important points: (1) the existing evidence is inconsistent and (2) the studies were diverse in terms of participants, supplementation strategies, exercise training and design. In another systematic review including randomized controlled trials in subjects aged 60 years and over, Beaudart et al. showed that muscle strength increased in 82.8% of the studies (29/35) following exercise intervention but that dietary supplementation showed additional benefits in only a small number of studies (8/35, 22.8%) [30]. The authors also showed that the majority of studies showed an increase in physical performance following exercise intervention (26/28 RCTs, 92.8%) but interaction with nutrition supplementation was only found in 14.3% of these studies (4/28 RCTs). They concluded that the interactive effect of dietary supplementation with exercise on muscle function appears limited but they also noted as an important limitation that most of these studies were performed on well-nourished subjects. At last, it is important to note that in all these individual studies the nature of the nutritional supplement used varied in terms of type of supplement, additional nutrients provided, frequency of consumption and timing of supplementation (at the same time as the exercises or not). For the latter, although authors of a meta-analysis in healthy adults found no influence of intake timing on muscle strength and synthesis, it could be different in older adults with suboptimal dietary intakes [31].

4.3. Other lifestylesi

Some observational studies have assessed the relationship between lifestyle and sarcopenia. For example, an original Chinese study showed amongst community-dwelling people aged 60 years and older that participants with sarcopenia had lower family function scores (assessed using the Family APGAR scale) than those without sarcopenia, even after adjustment for all potential confounding covariates, highlighting the importance of a well-functioning family [32]. In an interesting analysis of the Korea National Health and Nutrition Examination Survey including 3937 Korean individuals aged 40 years or older, it was observed that positive psychological health was associated with a low prevalence of sarcopenic obesity, particularly in middle-aged adults [33].

Some data from the SarcoPhAge cohort could also bring some interesting information about the associations between lifestyle and sarcopenia. For example, we showed recently that there were significantly more smokers than non-smokers who developed sarcopenia in our cohort followed over a 5-year period (35.9% vs 16.8%, P-value = 0.003) [34]. After adjustment of potential confounders, it was observed that smokers have a 2.36-fold higher risk of developing sarcopenia (95% CI 1.31–4.26), highlighting, once again, that tobacco use is a major public health problem.

The data regarding alcohol is much more complex to interpret. Indeed, a meta-analysis of 13 studies published in 2016, found out that alcohol consumption was not a risk factor for the development of sarcopenia [35]. Even more, alcohol consumption could have a protective character against sarcopenia, with odds ratio for sarcopenia amongst alcohol drinkers of 0.77 (0.67–0.88) for the overall population.

However, the authors of this meta-analysis noted a huge heterogeneity in the definition of sarcopenia in the studies, an important variability and a lack of objectivity in the description of alcohol exposure. They also noted that no study had a primary focus on the relationship between sarcopenia and alcohol consumption.

The effect of a 6-month duration multi-domain lifestyle intervention (with physical exercise, nutritional enrichment, cognitive training or a combination of those interventions) has been recently investigated in a randomized standard care control trial [36, 37]. In this study, involving 246 community-dwelling pre-frail and frail older adults aged ≥65 years with and without sarcopenia, multi-domain interventions were associated with significant ($p<0.001$) reduction of sarcopenia at 3 and 6 months of follow-up and were also associated with an improved gait speed and an enhanced lower limb strength.

Other interventions could have some potential in sarcopenia, sun exposure, for example, through its effect on vitamin D status. However, to our knowledge, no well-designed study has investigated its real effect in this disease [38].

5. Conclusion

The effect of lifestyle on muscle parameters or physical function has been investigated in numerous observational and interventional trials of heterogeneous design and quality. Despite the fact that long-term trials are clearly lacking in this field, we can conclude that (1) an important strategy to combat the loss of physical function and its consequences for older adults is physical activity; (2) the importance of 'healthier' dietary patterns to fight the loss of muscle health is mainly evident from observational studies but more well-designed interventional studies are needed; (3) the results of the combination of exercise with dietary supplement are conflicting and; (4) the effect of other lifestyle changes are lacking. As already proposed, further high-quality trials, particularly in more diverse populations (including low-income countries), but with more precision when selecting the population, are needed to enable an understanding of dose and duration effects of lifestyle changes (physical activity, nutrition, cognitive training, alcohol, smoking, etc.) on the muscle and on physical function of older adults [39,40]. More studies are also needed to substantiate the mechanism of action of each intervention as well as to determine the optimal modalities of these in older adults.

Contributors

Olivier Bruyère contributed to the literature search and review, preparation of the original draft, and revision of the draft.

Jean-Yves Reginster contributed to the literature search and review, and revision of the draft.

Charlotte Beaudart contributed to the literature search and review, preparation of the original draft, and revision of the draft.

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The authors declare that they have no competing interests.

References

[1] A.J. Cruz-Jentoft, et al., Sarcopenia: revised European consensus on definition and diagnosis, Age Ageing 48 (1) (2019) 16–31.
[2] L.V. Fernandes, et al., Prevalence of sarcopenia according to EWGSOP1 and EWGSOP2 in older adults and their associations with unfavorable health outcomes: a systematic review, Aging Clin. Exp. Res. (2021).
[3] A. Menotti, P.E. Puddu, G. Catasta, Lifestyle as determinant of all-cause mortality and age at death. A middle-aged male population followed-up 60 years until the survivors were aged 100 years, Aging Clin. Exp. Res. 33 (11) (2021) 3091–3098.
[4] O. Rom, et al., Lifestyle and sarcopenia-etiology, prevention, and treatment, Rambam Maimonides Med. J. 3 (4) (2012) e0024.
[5] P.L. Tzeng, et al., Daily lifestyle behaviors and risks of sarcopenia among older adults, Arch. Public Health 78 (1) (2020) 113.
[6] S. Panahi, A. Tremblay, Sedentariness and health: is sedentary behavior more than just physical inactivity? Front. Public Health 6 (2018) 258.
[7] L.F. de Rezende, et al., Sedentary behavior and health outcomes: an overview of systematic reviews, PLoS One 9 (8) (2014), e105620.
[8] J. Gianoudis, C.A. Bailey, R.M. Daly, Associations between sedentary behaviour and body composition, muscle function and sarcopenia in community-dwelling older adults, Osteoporos. Int. 26 (2) (2015) 571–579.
[9] D.A. Aggio, et al., Cross-sectional associations of objectively measured physical activity and sedentary time with sarcopenia and sarcopenic obesity in older men, Prev. Med. 91 (2016) 264–272.
[10] L. Smith, et al., The Association Between Sedentary Behavior and Sarcopenia Among Adults Aged ≥65 Years in Low- and Middle-Income Countries, Int. J. Environ. Res. Public Health 17 (5) (2020).
[11] N. Reid, et al., The Association of Sitting Time With Sarcopenia Status and Physical Performance at Baseline and 18-Month Follow-Up in the Residential Aged Care Setting, J. Aging Phys. Act 26 (3) (2018) 445–450.
[12] F. Buckinx, et al., Impact of current or past physical activity level on functional capacities and body composition among elderly people: a cross-sectional analysis from the YMCA study, Arch. Public Health 79 (1) (2021) 50.
[13] M. Steffl, et al., Relationship between sarcopenia and physical activity in older people: a systematic review and meta-analysis, Clin. Interv. Aging 12 (2017) 835–845.
[14] D.E. Barajas-Galindo, et al., Effects of physical exercise in sarcopenia. a systematic review, Endocrinol. Diabetes Nutr. (Engl. Ed.) 68 (3) (2021) 159–169.
[15] W. Bao, et al., Exercise programs for muscle mass, muscle strength and physical performance in older adults with sarcopenia: a systematic review and meta-analysis, Aging Dis. 11 (4) (2020) 863–873.
[16] A. Escriche-Escuder, et al., Effects of exercise on muscle mass, strength, and physical performance in older adults with sarcopenia: a systematic review and meta-analysis according to the EWGSOP criteria, Exp. Gerontol. 151 (2021), 111420.
[17] M. Conneely, et al., A physiotherapy-led transition to home intervention for older adults following emergency department discharge: protocol for a pilot feasibility randomised controlled trial, Pilot Feasibility Stud. 8 (1) (2022) 3.
[18] J.L. Sánchez-Sánchez, et al., Sedentary behaviour, physical activity, and sarcopenia among older adults in the TSHA: isotemporal substitution model, J. Cachexia Sarcopenia Muscle 10 (1) (2019) 188–198.
[19] K. Nagai, et al., Impact of isotemporal substitution of sedentary time with physical activity on sarcopenia in older Japanese adults, J. Am. Med. Dir. Assoc. 22 (4) (2021) 876–878.
[20] A. Granic, et al., Myoprotective whole foods, muscle health and sarcopenia: a systematic review of observational and intervention studies in older adults, Nutrients 12 (8) (2020).
[21] H.J. Coelho-Júnior, A. Trichopoulou, F. Panza, Cross-sectional and longitudinal associations between adherence to Mediterranean diet with physical performance and cognitive function in older adults: a systematic review and meta-analysis, Ageing Res. Rev. 70 (2021), 101395.
[22] M. Isanejad, et al., Association of the Baltic Sea and Mediterranean diets with indices of sarcopenia in elderly women, OSPTRE-FPS study, Eur. J. Nutr. 57 (4) (2018) 1435–1448.
[23] C. Beaudart, et al., Quality of life and physical components linked to sarcopenia: the SarcoPhAge study, Exp. Gerontol. 69 (2015) 103–110.
[24] C. Beaudart, et al., Association between dietary nutrient intake and sarcopenia in the SarcoPhAge study, Aging Clin. Exp. Res. 31 (6) (2019) 815–824.
[25] L. Lengelé, et al., Association between changes in nutrient intake and changes in muscle strength and physical performance in the sarcophage cohort, Nutrients 12 (11) (2020).
[26] C. Beaudart, et al., Malnutrition as a strong predictor of the onset of sarcopenia, Nutrients 11 (12) (2019).
[27] L. Lengelé, et al., Malnutrition, assessed by the Global Leadership Initiative on Malnutrition (GLIM) criteria but not by the mini nutritional assessment (MNA), predicts the incidence of sarcopenia over a 5-year in the SarcoPhAge cohort, Aging Clin. Exp. Res. 33 (6) (2021) 1507–1517.
[28] M.T. Lim, et al., Animal protein versus plant protein in supporting lean mass and muscle strength: a systematic review and meta-analysis of randomized controlled trials, Nutrients 13 (2) (2021).
[29] H.J. Denison, et al., Prevention and optimal management of sarcopenia: a review of combined exercise and nutrition interventions to improve muscle outcomes in older people, Clin. Interv. Aging 10 (2015) 859–869.
[30] C. Beaudart, et al., Nutrition and physical activity in the prevention and treatment of sarcopenia: systematic review, Osteoporos. Int. 28 (6) (2017) 1817–1833.

[31] J. Wirth, E. Hillesheim, L. Brennan, The role of protein intake and its timing on body composition and muscle function in healthy adults: a systematic review and meta-analysis of randomized controlled trials, J. Nutr. 150 (6) (2020) 1443–1460.
[32] S. Hai, et al., Association between sarcopenia with lifestyle and family function among community-dwelling Chinese aged 60 years and older, BMC Geriatr. 17 (1) (2017) 187.
[33] S. Yoo, D.Y. Kim, H. Lim, Sarcopenia in relation to nutrition and lifestyle factors among middle-aged and older Korean adults with obesity, Eur. J. Nutr. 59 (8) (2020) 3451–3460.
[34] M. Locquet, et al., Relationship between smoking and the incidence of sarcopenia: the SarcoPhAge cohort, Public Health 193 (2021) 101–108.
[35] M. Steffl, et al., Alcohol consumption as a risk factor for sarcopenia - a meta-analysis, BMC Geriatr. 16 (2016) 99.
[36] Y. Lu, et al., Effects of multi-domain lifestyle interventions on sarcopenia measures and blood biomarkers: secondary analysis of a randomized controlled trial of community-dwelling pre-frail and frail older adults, Aging (Albany NY) 13 (7) (2021) 9330–9347.
[37] Y. Lu, et al., Assessment of sarcopenia among community-dwelling at-risk frail adults aged 65 years and older who received multidomain lifestyle interventions: a secondary analysis of a randomized clinical trial, JAMA Netw. Open 2 (10) (2019), e1913346.
[38] D. Scott, et al., The epidemiology of sarcopenia in community living older adults: what role does lifestyle play? J. Cachexia Sarcopenia Muscle 2 (3) (2011) 125–134.
[39] M. Billot, et al., Preserving mobility in older adults with physical frailty and sarcopenia: opportunities, challenges, and recommendations for physical activity interventions, Clin. Interv. Aging 15 (2020) 1675–1690.
[40] S.M. Robinson, et al., Does nutrition play a role in the prevention and management of sarcopenia? Clin. Nutr. 37 (4) (2018) 1121–1132.