Clinical Nutrition 41 (2022) 2308–2324

Contents lists available at ScienceDirect

Clinical Nutrition

journal homepage: http://www.elsevier.com/locate/clnu

Meta-analyses

Antioxidant-rich foods, antioxidant supplements, and sarcopenia in old-young adults ≥55 years old: A systematic review and meta-analysis of observational studies and randomized controlled trials

Maria Besora-Moreno [a], Elisabet Llauradó [a, b, *], Rosa M. Valls [a, **], Lucia Tarro [a, b], Anna Pedret [a], Rosa Solà [a, b, c]

[a] Universitat Rovira i Virgili, Facultat de Medicina i Ciències de la Salut, Functional Nutrition, Oxidation, and Cardiovascular Diseases Group (NFOC-Salut), 43201 Reus, Spain
[b] Institut Investigació Sanitària Pere i Virgili (ISPV), 43204, Reus, Spain
[c] Hospital Universitari Sant Joan de Reus, 43204, Reus, Spain

ARTICLE INFO

Article history:
Received 21 January 2022
Accepted 26 July 2022

Keywords:
Antioxidants
Sarcopenia
Muscle mass
Muscle strength
Physical function
Older adults

SUMMARY

Background & aims: Sarcopenia is a disabling muscular multifactorial disease involving the oxidation process in old-young adults. We aimed to evaluate the relationship between antioxidant-rich foods (A-RF) and sarcopenia (muscle mass, strength, and function) based on observational studies (OS), and to assess the effectiveness of antioxidant interventions in ≥55-year-old adults via randomized controlled trials (RCTs). Moreover, to confirm if the OS results were in accordance with the RCTs results.
Methods: We searched in the MEDLINE®/PubMed, Cochrane Library, and CINAHL databases from 2000 to 2020 about sarcopenia and specific nutrients/foods. The risk of bias was assessed and meta-analyses were performed using the Review Manager program.
Results: The systematic review included 28 studies (19 OS, 9 RCTs), whereas the meta-analysis included 4 RCTs. Results of the systematic review of OS revealed that higher A-RF consumption was associated with better sarcopenia outcomes. Results of the RCTs meta-analysis indicated that higher fruit/vegetable consumption, supplementation with magnesium, and vitamin E plus vitamin D and protein significantly reduced the time to complete 5 stands (mean difference; 95% CI; −1.11 s; 1.70, −0.51; $p < 0.01$). Additionally, including tea catechin supplementation significantly increased handgrip strength (1.02 kg; 0.60, 1.44; $p < 0.01$).
Conclusions: In sum, A-RF or antioxidant supplementation could be effective tools for sarcopenia, especially improving muscle strength and function. The best interventions according to the meta-analysis of the RCTs were supplementation of vitamin E in combination with vitamin D and protein, magnesium, tea catechins, and increasing fruit and vegetable consumption.
Registration number: PROSPERO (CRD42020183045).

1. Introduction

The elderly population undergoes biological changes throughout the aging process [1] such as sarcopenia, which is a multifactorial disease involving the oxidation process, characterized by progressive, generalized skeletal muscle disorder [2].

According to the recent revised consensus of the European Working Group on Sarcopenia in Older People (EWGSOP2), 2019, sarcopenia is defined by 3 criteria: 1) low muscle strength (MS) based on grip strength (<27 kg for men, <16 kg for women); 2) low muscle quantity or quality based on the appendicular skeletal muscle mass (ASM) (the sum of the MM of the four limbs; <20 kg for men, <15 kg for women); and 3) low physical performance based on gait speed (≤0.8 m/s) [2]. Thus, MS is the first parameter used to diagnose probable sarcopenia because it is a more reliable measure of muscle function and is better at predicting adverse outcomes [2]. Sarcopenia diagnosis is confirmed by low muscle quantity or quality [2]. Moreover, if the three criteria are identified sarcopenia is considered severe [2]. The most used tools to assess

* Corresponding author. Functional Nutrition, Oxidation, and Cardiovascular Diseases Group (NFOC-Salut), Universitat Rovira i Virgili, Facultat de Medicina i Ciències de la Salut, C/Sant Llorenç 21, 43201, Reus, Spain.
** Corresponding author. Functional Nutrition, Oxidation, and Cardiovascular Diseases Group (NFOC-Salut), Universitat Rovira i Virgili, Facultat de Medicina i Ciències de la Salut, C/Sant Llorenç 21, 43201, Reus, Spain.
E-mail addresses: elisabet.llaurado@urv.cat (E. Llauradó), rosamaria.valls@urv.cat (R.M. Valls).

https://doi.org/10.1016/j.clnu.2022.07.035

sarcopenia were a calibrated handheld dynamometer, magnetic resonance imaging (MRI) and computer tomography (CT), gait speed, the Short Physical Performance Battery (SPPB), the Timed Up and Go (TUG) test, and the 400-m walk test [2–4].

The sarcopenia prevalence ranges from 1% to 33%, depending on age and geographic region [5]. The prevalence in Europe was 11.1% in 2016 and is expected to increase to 22.3% by 2045 [6]. Sarcopenia can also be developed in adults [7], since beyond the age of 50, leg muscle mass (MM) is reduced by 1%–2% per year, and MS declines by 1.5%–5% annually [8]. Sarcopenia has negative consequences for health status, affecting the incidence or prognosis of certain comorbidities [9], increasing the risk of falls [2,10] and fractures [2], hospitalization [9], and mortality [2,9,11], being a determinant of loss of independence [9] and impacting in health care costs [9,12]. Factors that cause and worsen muscle quantity and quality are disease; inactivity; malnutrition [2], genetics, hormonal factors, and a decrease in protein synthesis [13–15]. Another factor is the excessive production of reactive oxygen species (ROS) in skeletal muscle, which results in a loss of MM and muscle function during the aging process [16]. In particular, mitochondrial damage stimulates the accumulation of ROS [17,18], which could be considered key to sarcopenia development.

Thus, antioxidants can reduce oxidative damage and improve the loss of MM and MS generated by ROS in sarcopenic subjects [16]. Physical activity and/or nutrition are promising tools to prevent or treat sarcopenia [5]. Until now, there have been no systematic reviews or meta-analyses studying the connection and effects between antioxidant-rich foods (A-RF) and antioxidant supplements and sarcopenia. Therefore, the main objective of the present systematic review and meta-analysis was to evaluate the relationship between A-RF and sarcopenia or the risk of low MM, MS, and physical function (PF) based on observational studies, and to assess the effectiveness of A-RF and antioxidant supplements in different parameters of sarcopenia in people ≥55 years old via RCTs. Moreover, to confirm if the results of observational studies were in accordance with the effects of A-RF and antioxidant supplements on sarcopenia in RCTs.

2. Material and methods

We performed a systematic review and meta-analysis of observational studies and RCTs regarding the impact of A-RF and antioxidant supplements on sarcopenia or the risk of low MM, MS, and PF. The present review was in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines (Supplemental Table 1) [19]. Additionally, the review was registered in the International Prospective Register of Systematic Reviews (PROSPERO) as CRD42020183045.

2.1. Search strategy

We conducted a systematic search in the MEDLINE®/PubMed, Cochrane Library, and CINAHL electronic databases using the following keywords for sarcopenia and specific nutrients/foods: sarcopenia, MM, MS, PF, antioxidants, ascorbic acid, vitamin A, vitamin E, carotenoids, copper, selenium, zinc, magnesium, iron, phenols, diet, vegetables, fruit, fabaceae/legumes, nuts, seeds, tea, chocolate/cacao, and oils. Additionally, Supplemental Table 2 outlines the search strategies in detail, including keywords. We limited the search strategy to the years of publication from 2000 to 2020, the English language, human studies, and publication type.

2.2. Eligibility criteria and study selection

The inclusion criteria were as follows: a) observational studies (case–control, cohort, cross-sectional) and RCTs; b) with a target population ≥55 years old and elderly individuals; c) about A-RF or antioxidant supplements and their association and/or effects on sarcopenia, MM, MS, and PF; d) limited to the English language and human studies; e) published from 2000 to 2020; f) studies conducted worldwide with the general population, probably with some comorbidities; g) assessed only one, two, or all of the sarcopenia variables; and h) with different sarcopenia assessment tools. In contrast, the exclusion criteria were as follows: a) studies that only included individuals with a specific health condition (cancer, kidney disease, gastrointestinal disease, cardiovascular disease, etc.); b) when the target population only consisted of frail individuals; c) about sarcopenic obesity (because sarcopenia and obesity together increase the risk of falls, fractures, comorbidities, and osteoporosis risk because of the reduction of bone density; obesity could alter the natural behavior of sarcopenia); d) and studies that did not meet all the inclusion criteria mentioned above.

The observational studies included in the systematic review focused on dietary patterns including A-RF or the consumption of specific A-RF and sarcopenia, MM, MS, and PF. The RCTs were defined by the Population, Intervention, Comparison, Outcomes, and Study (PICOS) criteria (Supplemental Table 3).

2.3. Data extraction

We selected the studies included in the systematic review using the Rayyan QCRI web application, which automates systematic reviews [20]. The first step for considering the inclusion of the studies involved title and abstract screening according to the inclusion and exclusion criteria. The second step entailed the full-text assessment of the studies that had passed the first round of screening. Finally, in the third step, we only included for data extraction and quality assessment the observational studies and RCTs that met all the criteria described previously. Two researchers performed the data extraction (M.B.-M., E.L.L.). Any disagreement or discrepancies were resolved through discussion with the third author (R-M.V.). When any necessary information for inclusion was missing from any study, we contacted the authors to request it.

We defined the data extraction and collection based on the following variables: a) authors; b) title; c) year of publication; d) type of study; e) country; d) number of participants; f) age; g) gender of participants; h) follow-up; i) type of intervention; j) duration of the intervention; k) sarcopenia assessment (or MM, MS, and PF as sarcopenia variables); l) antioxidant assessment tool; m) antioxidants or source of antioxidants; and n) antioxidant outcomes. The sources of antioxidants were dietary patterns including A-RF, the consumption of specific A-RF (vegetables, fruits, beans, nuts, seeds, tea, cacao, and oils), and antioxidant supplementation. Of all sources, the most common antioxidants were vitamins (vitamins C, A, and E), minerals (copper, zinc, magnesium, selenium, and iron), phenolic compounds, and carotenoids [21]. We included all relevant study details, such as the results of each variable, the association of sarcopenia with A-RF or antioxidant supplements, the effects of A-RF or antioxidant supplements on sarcopenia, and the risk of bias in the studies. Moreover, observational studies assessed A-RF consumption using intake assessment methods (e.g., food frequency questionnaires or dietary records) or assessing plasma or serum concentrations.

2.4. Quality assessment based on risk of bias in individual studies

We employed two different tools to evaluate the quality of each included study depending on the type of study (either observational or RCT).

For observational studies, we used the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies to evaluate

the risk of bias [22]. This quality tool was based on 14 questions, and the quality classification was divided into three categories: high; medium; and low [22]. For cohort studies (evaluated based on 14 questions equivalent to 14 points), the cutoff points were low quality (≤5 points), medium quality (6–9 points), and high quality (10–14 points). For cross-sectional studies (evaluated based on 10 questions equivalent to 10 points, because questions 6, 7, 12, and 13 were specific for cohort studies), the cutoff points were low quality (≤3 points), medium quality (4–7 points), and high quality (8–10 points). We defined these cutoff points as suggested by the tool [22].

For the RCTs, we employed the Cochrane risk of bias tool, RoB 2 [23]. This quality tool assesses the risk of bias in 5 domains; the risk of bias classification was a) low risk of bias (there is a low risk of bias for all 5 domains); b) some concerns (if there are some concerns in at least one domain, but it is not a high risk of bias for any domain); and c) high risk of bias (if there is high risk of bias in at least one domain or if there are some concerns about multiple domains that reduce confidence in the results).

2.5. Data synthesis

We synthesized the data based on the data reviewed depending on the type of study. We performed a systematic review of observational studies to assess the association between dietary patterns including A-RF or the consumption of specific A-RF and sarcopenia variables. Meanwhile, we conducted a systematic review and meta-analysis of RCTs to confirm whether the results of the observational studies were in accordance with the effects of antioxidant supplements or interventions based on the consumption of A-RF on sarcopenia.

2.6. Statistical analysis

We performed all statistical analyses using Review Manager (RevMan) ([Computer program], Version 5.4, the Cochrane Collaboration, 2020). Regarding the systematic review, the outcomes of observational studies were expressed as odds ratio (OR) or hazard ratio (HR) and 95% confidence interval (CI). In addition, the RCT results were expressed as the mean and standard deviation (SD), median and interquartile ranges, and mean difference (MD) and 95% CI. To determine the change in RCTs, it is preferable to use MD and 95% CI whenever possible. If MD and 95% CI information did not appear in the study, we carried out the calculation with the RevMan program, if possible, leading to enough information for comparison to other studies included. Moreover, the p-value employed to establish the effectiveness of the RCT intervention was Group x time. If this value was not available, we asked the authors of the publication, and if the authors did not respond, we calculated it with RevMan.

Focusing on the meta-analysis, the RCTs included in the meta-analysis were all the studies with the most commonly used tool to assess each sarcopenia variable and with complete information about the outcome. We only analyzed sarcopenia variables with at least 3 RCTs that met the inclusion criteria mentioned above. For the meta-analysis, the means and SD or the change of the sarcopenia variables from baseline to the end of intervention of the control and intervention groups were required. The effect size was represented by MD and the 95% CI from continuous outcomes and risk ratio (RR) for dichotomous outcomes. A p-value of <0.05 was considered statistically significant. We evaluated the heterogeneity in RCTs using the I^2 statistic obtained from the RevMan program. When the heterogeneity was over 85% (high heterogeneity), we analyzed them using randomized and non-fixed effects.

3. Results

A total of 2172 articles were identified through databases, 742 were excluded due to duplicity, and 1234 were excluded for not meeting the inclusion criteria in the title and abstract screening. The remaining 196 articles were full-text assessed for eligibility, and 168 were excluded for the following reasons: different study outcomes (n = 81), population not following the inclusion criteria (n = 53), study design not accepted according to the eligibility criteria (n = 28), and full-text not being available (n = 6). Ultimately, 28 studies were included in the systematic review [24–51], 19 were observational studies [24–34,36,45–51] and 9 were RCTs [35,37–44]. Additionally, 4 RCTs were included in the meta-analysis [37–39,42] (Fig. 1), 4 RCTs in the MS meta-analysis [37–39,42], and 3 RCTs in the PF meta-analysis [37,38,42].

3.1. Characteristics of the observational studies included in the systematic review

Of the 19 observational studies, there were 13 cross-sectional studies [25–28,31,32,34,45–47,49–51], 5 cohort studies [24,30,33,36,48], and one study that conducted cohort and cross-sectional analyses [29] (Tables 1, 3, 5 and 7; Supplemental Tables 4, 5, 7, 8, 10, 11, 13, and 14). The study population consisted of men and women in 16 studies, only women in 2 studies, and only men in one study. The subjects were ≥55 years old, and the sample size of the studies ranged from 84 to 14,585. The studies were carried out on the following continents: Europe, Asia, Africa, and America. In the cohort studies, the follow-up duration ranged from 3 to 7.2 years. Of the 19 observational studies, 15 were about dietary patterns including A-RF such as the Mediterranean diet, a diet rich in fruits, or a healthy diet, and 4 were about the consumption of specific A-RF such as fruits, vegetables, or nuts.

3.2. Characteristics of the RCTs included in the systematic review

In the 9 RCTs (Tables 2, 4 and 6; Supplemental Tables 6, 9, and 12), the study population was of both genders in 5 studies, with only women in 3 studies and only men in one study. The subjects were ≥59 years old in all the studies, and the sample size of the studies ranged from 30 to 139. The duration of the intervention ranged from 12 weeks (3 months) to 24 weeks (6 months). The studies were carried out on the following continents: Europe, Asia, and America. Of the 9 RCTs, 7 were about antioxidant supplementation, such as resveratrol, vitamin C, vitamin E, tea catechins, or magnesium, and 2 were about interventions based on the consumption of A-RF, such as fruits and vegetables, and a healthy diet. In addition, 6 RCTs also included physical activity interventions apart from nutritional intervention.

3.3. Sarcopenia assessment

Of the 19 observational studies, 12 assessed MS, 10 MM, and 10 PF. Additionally, of these observational studies, 6 evaluated all three sarcopenia variables. Of the 9 RCTs, 8 studies assessed the MM, 7 MS, and 5 PF. Additionally, of these RCTs, 3 studies assessed all three sarcopenia variables.

Regarding the sarcopenia evaluation of observational studies and RCTs, specifically, for the MM measure, bioelectrical impedance (BIA) and dual-energy X-ray absorptiometry (DXA) were the most

commonly used tools. BIA was used in 5 observational studies and 2 RCTs, and DXA was employed in 4 observational studies and 4 RCTs. Nearly all studies (11 observational studies and 5 RCTs) assessed MS using a dynamometer. Related to PF assessment tools, gait speed or walking speed was the most commonly used tool in 8 observational studies and 3 RCTs.

3.4. Associations between MM and antioxidants in the observational studies

A total of 4 cross-sectional studies evaluated the relationship between antioxidants and MM, and all of them demonstrated a significantly positive association between both variables [28,32,50,51] (Table 1; Supplemental Table 4).

One cross-sectional study from the Fourth and Fifth Korea National Health and Nutrition Examination Survey (KNHANES IV-V) concluded that women with higher vegetable consumption (≥5 servings/day) had 48% lower odds of dropped MM than women with less vegetable consumption (<5 servings/day) after adjusting for confounding factors [50]. Another cross-sectional study from the KNHANES IV, adjusted for confounding factors, determined that the higher quintile of vegetable (median: 6.6 times/day), fruit (median: 1.9 times/day), and vegetable and fruit (median: 7.9 times/day) consumption, compared to the lowest quintile (2.2, 0.2, and 2.8 times/day, respectively), was significantly associated with 52%, 70%, and 68% lower risk of sarcopenia in men measured as low MM, respectively [51]. In addition, higher consumption of fruits (median: 1.9 times/day) in women was significantly associated with a 61% lower risk of sarcopenia [51].

In addition, one cross-sectional study established that the higher quartile of plasma vitamin C concentrations (39.61–447.92 μmol/L), compared to the lowest quartile (0–13.81 μmol/L), was associated with 29% lower odds of dropped fat-free mass index (FFMI) in a fully adjusted model in the British Regional Heart Study [32]. One cross-sectional study showed that low serum selenium levels (<0.90–1.08 μmol/L) were associated with a 2.30- to 4.62-fold increased risk of low MM in elderly residents of Taipei (in Taiwan) in a fully adjusted model [28].

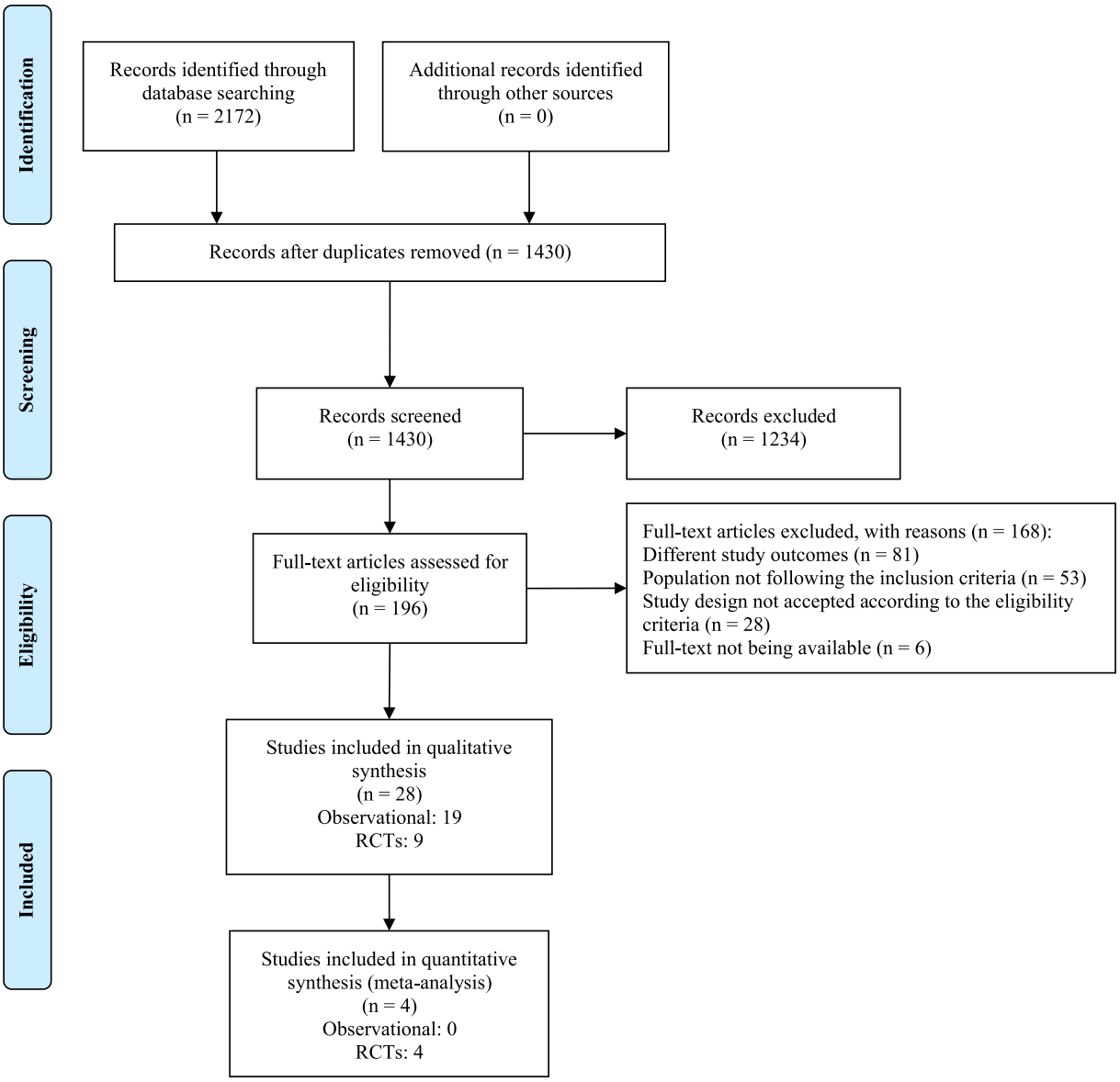

Fig. 1. PRISMA flow diagram of the studies selected for the systematic review and meta-analysis.

Table 1
Characteristics from each included cross-sectional and cohort studies on the relationship between antioxidants and MM.

Cross-sectional studies									
Study; year	Country	Total, n	Gender; age (y)	Type of assessment	Antioxidant assessment		Sarcopenia assessment tool	A higher level of antioxidants (A-RFC; DPDA-RF) is associated with …	
					Type or source	Tool		… an improvement of MM	… a decline in MM
Atkins JL et al., 2014 [32]	United Kingdom	4252	M 60-79 y	DPA-RF	Vitamin C Vitamin E Iron Fruits Vegetables	FFQ BS	MAMC BIA	X Vitamin C	
Chen YL et al., 2014 [28]	Taiwan	327	M/W ≥65 y	DPA-RF	Selenium	BS	BIA	X	
Kim J et al., 2015 [50]	Korea	3285	M/W ≥65 y	DPA-RF	Vegetables Fruits	FFQ	DXA	X Vegetables	
Kim J et al., 2015 [51]	Korea	1912	M/W ≥65 y	A-RFC	Vegetables Fruits	FFQ	DXA	X Fruits, vegetables	

Cohort studies										
Study; year	Country	Total, n	Follow-up	Gender; age (y)	Type of assessment	Antioxidant assessment		Sarcopenia assessment tool	A higher level of antioxidants (A-RFC; DPDA-RF) is associated with …	
						Type or source	Tool		… an improvement of MM	… a decline in MM
Yokoyama Y et al., 2017 [24]	Japan	935	4 years	M/W ≥65 y	DPA-RF	Diet variety	DVS	BIA	–	–

MM: muscle mass; DPA-RF: dietary patterns including antioxidant-rich foods; A-RFC: antioxidant-rich food consumption; M: men; W: women; BS: blood sample; FFQ: food frequency questionnaire; DVS: dietary variety score; BIA: bioelectrical impedance; DXA: dual-energy X-ray absorptiometry; MAMC: midarm muscle circumference.

One cohort study assessed the relationship between diet variety rich in antioxidants and MM; it did not show significant results [24] (Table 1; Supplemental Table 5).

3.5. Antioxidant effects on MM in the RCTs

A total of 8 RCTs evaluated different interventions focused on MM [35,38–44] (Table 2; Supplemental Table 6). Of the 8 RCTs, one showed statistically significant results for MM favoring intervention [41], one revealed a tendency favoring intervention [42], one demonstrated significant results opposed to the intervention [43], and 5 did not show significance [35,38–40,44].

The effective intervention was a 24-week, 3-arm RCT: a) resistance training twice a week, b) resistance training twice a week with a healthy diet composed of whole-grain cereals; fruits, vegetables and berries (≥600 g/day); rape seed oil, olive oil, nuts, and seeds; fish and seafood (≥500 g/day); lean meat, low-fat dairy products (≤0.5 L/day); soft drinks/juice (be avoided/<1.5 dL juice/day); and c) a control group without any intervention [41]. At 24 weeks, the results of this RCT signaled that leg lean mass was significantly increased in the resistance training with healthy diet intervention group in comparison to the control group (MD [95% CI]: 0.41 kg [0.12, 0.70]; p[Group x time] = 0.027) [41].

Similarly, a 6-month, 2-arm RCT: a) vitamin E supplementation in combination with vitamin D and protein (218 mg/day of vitamin E, 1404 IU/day of vitamin D, and 44 g/day of protein in a powder mix to be reconstituted) or b) an isocaloric control product. This RCT showed a trend related to improvement in ASM in the intervention group compared to the control group (MD [95% CI]: 0.48 kg [0.00, 0.96]; p[Group x time] = 0.05) [42].

In contrast, a 12-week, 2-arm RCT: a) vitamin C and E supplementation (500 mg/day and 117.5 mg/day, respectively) and strength training three times a week or b) a control group with a placebo and strength training, had opposite results [43]. The results indicated that changes in total lean mass were significantly greater in the control group than in the vitamin supplementation group (median [interquartile range]: 2191 g [1,517, 3296] vs. 867 g [0, 2799]; p[Group x time] = 0.04) [43].

Additionally, 5 studies did not show significant differences among groups over time [35,38–40,44]. First, a 12-week, 2-arm RCT: a) resistance training with resveratrol supplementation (500 mg/day) or b) a control group with resistance training and 500 mg/day of corn starch [40]. Second, a 6-month, 4-arm RCT: a) a vitamin group: only with vitamin E supplementation (900 mg/day), b) an exercise group: only participating in a walking program three times a week, c) an exercise-vitamin group: with vitamin E supplementation (900 mg/day) and a walking program, and d) a control group without exercise or vitamin E supplementation [35]. Third, a 12-week, 2-arm RCT: a) magnesium oxide supplementation (900 mg/day, magnesium oxide equivalent to 300 mg bioavailable magnesium) or b) a control group [38]; both groups were involved in a twice-weekly fitness program at public gyms. Fourth, a 6-month, 4-arm RCT: a) resistance training three times a week, b) antioxidant supplementation (vitamin C 1000 mg/day and vitamin E 400 IU/day), c) antioxidant supplementation combined with resistance training three times a week, and d) a control group with a placebo. This RCT seems to have a significant treatment effect, but there were no differences among the groups [44]. Finally, a 3-month, 4-arm RCT: a) tea catechin supplementation (350 mL/day of tea with 540 mg of catechin), b) exercise based on stretching, muscle strengthening, balance and gait training twice a week, c) exercise and tea catechin supplementation, and d) a control group with health education [39].

3.6. Associations between MS and antioxidants in the observational studies

A total of 4 cross-sectional studies assessed the association between antioxidants and MS; all of them demonstrated a significantly positive association between both variables [26,31,45,47] (Table 3; Supplemental Table 7).

Table 2
Characteristics from each included RCTs on the relationship between antioxidants and MM.

Study; year	Study design; duration; country	Total, n	Gender; age (y)	Type of intervention	Antioxidant assessment		Sarcopenia assessment tool	There is a significant improvement in MM in …	
					Type or source	Tool		… antioxidant supplementation or antioxidant-rich diet group	… control or placebo group
Alway SE et al., 2017 [40]	R, DB, PC 12 weeks United States of America	30	M/W ≥65 y	AS	Resveratrol (500 mg/day)	Blood samples	ADP	–	–
Bjørnsen T et al., 2016 [43]	R, DB, PC 12 weeks Norway	34	M ≥60 y	AS	Vitamin C, vitamin E (500 mg/day, 117.5 mg/day)	Blood samples	DXA		X
Bo Y et al., 2019 [42]	R, DB, PC 6 months China	60	M/W ≥60 y	AS	Whey protein, vitamin D, vitamin E (218 mg/day vitamin E)	Self-recorded intake dairy 3-day dietary record Blood samples	BIA	Tendency	
Bobeuf F et al., 2011 [44]	R, DB, PC 6 months Canada	57	M/W ≥59 y	AS	Vitamin C, vitamin E (1000 mg/day, 400 IU/day)	Blood samples	DXA UEC	–	–
Kim H et al., 2013 [39]	R, CT[a] 3 months Japan	128	W ≥75 y	AS	Tea catechins (540 mg/day)	Record volume of tea consumed, bottle caps	BIA	–	–
Nalbant Ö et al., 2009 [35]	R, CT 6 months Turkey	57	M/W ≥61 y	AS	Vitamin E (900 mg/day)	Blood samples	Tanita BCA	–	–
Strandberg E et al., 2015 [41]	R, CT 24 weeks Sweden	63	W ≥65 y	A-RFC	Healthy diet (rich in whole-grain cereals; fruits, vegetables and berries (≥600 g/day); rape seed oil, olive oil, nuts, and seeds; fish and seafood (≥500 g/day); lean meat, dairy products (≤0.5 L/day (low fat)); soft drinks/juice (be avoided <1.5 dL juice/day))	6-day dietary record	DXA	X	
Veronese N et al., 2014 [38]	R, CT, PG[a] 12 weeks Italy	139	W ≥65 y	AS	Magnesium oxide (900 mg/day)	Blood samples Urine samples	DXA	–	–

All RCTs were analyzed per-protocol.
MM: muscle mass; R: randomized; DB: double blind; PC: placebo controlled; M: men; W: women; AS: antioxidant supplementation; A-RFC: interventions based on antioxidant-rich food consumption; ADP: air displacement plethysmography; DXA: dual-energy X-ray absorptiometry; BIA: bioelectrical impedance; UEC: urinary excretion of creatinine; CT: controlled trial; Tanita BCA: Tanita body composition analyzer.
[a] Outcome assessors were blind.

Table 3
Characteristics from each included cross-sectional and cohort studies on the relationship between antioxidants and MS.

Cross-sectional studies									
Study; year	Country	Total, n	Gender; age (y)	Type of assessment	Antioxidant assessment		Sarcopenia assessment tool	A higher level of antioxidants (A-RFC; DPDA-RF) is associated with …	
					Type or source	Tool		… an improvement of MS	… a decline in MS
Barrea L. et al., 2019 [31]	Italy	84	W ≥60 y	DPA-RF	MDP	7-day DR PREDIMED	Dyn	X EVOO, vegetables, fruits, nuts, Mediterranean diet	
Kim H. et al., 2019 [26]	Korea	3675	M/W ≥65 y	DPA-RF	Diet quality	KHEI aMED DASH	Dyn	X	
Lauretani F. et al., 2007 [47]	Italy	891	M/W ≥65 y	DPA-RF	Selenium	BS	Dyn	X	
Semba RD. et al., 2003 [45]	United Stated of America	669	W 70–79 y	DPA-RF	Carotenoids Vitamin E	BS	Dyn	X α-carotene, β-carotene, β-cryptoxanthin, lutein/zeaxanthin, total carotenoids, α-tocopherol	

Cohort studies										
Study; year	Country	Total, n	Follow-up	Gender; age (y)	Type of assessment	Antioxidant assessment		Sarcopenia assessment tool	A higher level of antioxidants (A-RFC; DPDA-RF) is associated with …	
						Type or source	Tool		… an improvement of MS	… a decline in MS
Arias-Fernández L. et al., 2019 [33]	Spain	3,289	7.2 y[a]	M/W ≥60 y	A-RFC	Nuts	CDH	Dyn	–	–
Lauretani F. et al., 2008 [48]	Italy	948	6 years	M/W ≥65 y	A-RFC	Carotenoids	BS	Dyn	X	
Yokoyama Y. et al., 2017 [24]	Japan	935	4 years	M/W ≥65 y	DPA-RF	Diet variety	DVS	Dyn	X	

MS: muscle strength; DPA-RF: dietary patterns including antioxidant-rich foods; A-RFC: antioxidant-rich food consumption; M: men; W: women; MDP: Mediterranean dietary pattern; DR: dietary registration/record; PREDIMED: cuestionario de prevención con dieta mediterránea; BS: blood sample; KHEI: Korean healthy eating index; aMED: alternate Mediterranean diet score; DASH: dietary approaches to stop hypertension score; DVS: dietary variety score; Dyn: dynamometer; CDH: computerized diet history; DVS: dietary variety score.
[a] Mean.

Table 4
Characteristics from each included RCTs on the relationship between antioxidants and MS.

Study; year	Study design; duration; country	Total, n	Gender; age (y)	Type of intervention	Antioxidant assessment		Sarcopenia assessment tool	There is a significant improvement in MS in …	
					Type or source	Tool		… antioxidant supplementation or antioxidant-rich diet group	… control or placebo group
Alway SE. et al., 2017 [40]	R, DB, PC 12 weeks United States of America	30	M/W ≥65 y	AS	Resveratrol (500 mg/day)	Blood samples	Dyn	X	
Bjørnsen T. et al., 2016 [43]	R, DB, PC 12 weeks Norway	34	M ≥60 y	AS	Vitamin C, vitamin E (500 mg/day, 117.5 mg/day)	Blood samples	1RM	–	–
Bo Y. et al., 2019 [42]	R, DB, PC 6 months China	60	M/W ≥60 y	AS	Whey protein, vitamin D, vitamin E (218 mg/day vitamin E)	Self-recorded intake dairy 3-day dietary record Blood samples	Dyn	X	
Kim H. et al., 2013 [39]	R, CT[a] 3 months Japan	128	W ≥75 y	AS	Tea catechins (540 mg/day)	Record volume of tea consumed, bottle caps	Dyn	–	–
Neville CE. et al., 2013 [37]	R, CT, PG[a] 16 weeks United Kingdom	83	M/W ≥65 y	A-RFC	Fruits and vegetables (5 portions/day)	7-day dietary record Blood samples	Dyn	–	–
Strandberg E. et al., 2015 [41]	R, CT 24 weeks Sweden	63	W ≥65 y	A-RFC	Healthy diet (rich in whole-grain cereals; fruits, vegetables and berries (≥600 g/day); rape seed oil, olive oil, nuts, and seeds; fish and seafood (≥500 g/day); lean meat, dairy products (≤0.5 L/day (low fat)); soft drinks/juice (be avoided <1.5 dL juice/day))	6-day dietary record	1RM MIQS	–	–
Veronese N. et al., 2014 [38]	R, CT, PG[a] 12 weeks Italy	139	W ≥65 y	AS	Magnesium oxide (900 mg/day)	Blood samples Urine samples	Dyn	X	–

All RCTs were analyzed per-protocol.
MS: muscle strength; R: randomized; DB: double blind; PC: placebo controlled; M: men; W: women; AS: antioxidant supplementation; A-RFC: interventions based on antioxidant-rich food consumption; Dyn: dynamometer; 1RM: one-repetition maximum; CT: controlled trial; MIQS: maximal isometric quadriceps strength.
[a] Outcome assessors were blind.

Table 5
Characteristics from each included cross-sectional and cohort studies on the relationship between antioxidants and PF.

Cross-sectional studies										
Study; year	Country	Total, n	Gender; age (y)	Type of assessment	Antioxidant assessment		Sarcopenia assessment tool	A higher level of antioxidants (A-RFC; DPDA-RF) is associated with …	
					Type or source	Tool		… an improvement	… a decline in PF of PF
Zbeida M. et al., 2014 [34]	Israel United States of America	4577	M/W ≥60 y	DPA-RF	MDP	MDS	PFQ T20ft	–	–
Cohort studies									
Study; year	Country	Total, n	Follow-up	Gender; age (y)	Type of assessment	Antioxidant assessment		Sarcopenia assessment tool	A higher level of antioxidants (A-RFC; DPDA-RF) is associated with …	
						Type or source	Tool		… an improvement	… a decline in PF of PF
Arias-Fernández L. et al., 2019 [33]	Spain	3289	7.2 y[a]	M/W ≥60 y	A-RFC	Nuts	CDH	GSP R–BSPF	X	
Bartali B. et al., 2008 [30]	Italy	698	3 years	M/W ≥65 y	DPA-RF	Vitamin E Iron	BS	SPPB	X Vitamin E	
Struijk EA. et al., 2018 [36]	Spain	1630	4 years	M/W ≥60 y	DPA-RF	MDP	MDS MEDAS	R–BSPF	X Fruits, nuts, Mediterranean diet	
Yokoyama Y. et al., 2017 [24]	Japan	935	4 years	M/W ≥65 y	DPA-RF	Diet variety	DVS	UGSP	X	

PF: physical function; DPA-RF: dietary patterns including antioxidant-rich foods; A-RFC: antioxidant-rich food consumption; M: men; W: women; MDP: Mediterranean dietary pattern; BS: blood sample; DVS: dietary variety score; MDS: Mediterranean diet score; GSP: gait speed; PFQ: physical function questionnaire; T20ft: time to complete 20 ft walk; CDH: computerized diet history; R-BSRF: Rosow and Breslau scale of self-reported physical function; MEDAS: Mediterranean diet adherence screener; SPPB: short physical performance battery; UGSP: usual gait speed.
[a] Mean.

One cross-sectional study showed that handgrip strength was 1.59-, 1.12-, 1.11-, and 1.09-fold significantly increased due to the consumption of extra virgin olive oil for culinary use, vegetables (≥2 servings/day), fruits (≥3 servings/day), and nuts (≥3 servings/week) after adjusting for body mass index (BMI) in old-young adult women from Italy [31]. Additionally, this cross-sectional study established that low adherence to the Mediterranean diet was significantly associated with a reduction of 27% in handgrip strength, whereas higher adherence was associated with a 1.14-fold increase in handgrip strength [31]. In addition, one cross-sectional study indicated that the highest tertiles of different diet quality scores (Korean Healthy Eating Index [KHEI], 58.57–94.22, score of 100 points; the alternate Mediterranean diet score [aMED], 5–8, score of 9 points; and the dietary approaches to stop hypertension score [DASH], 24–34, score of 40 points), compared to the lowest tertiles of KHEI (15.0–49.86 score), aMED (0–3 score), and DASH (8–20 score), were significantly associated with 32%–53% lower odds of dropped MS (borderline in the case of KHEI women) in a fully adjusted model in Korean old-young adults [26].

Moreover, one cross-sectional study indicated that old-young adults from Italy in the lowest quartile of plasma selenium (<0.8 μmol/L), compared to the highest quartile (>1.0 μmol/L), were significantly associated with 1.69-, 1.94- and 1.94-fold increased low grip, hip, and knee strength, respectively, in a fully adjusted model [47]. Another cross-sectional study that included women from the Women's Health and Aging Studies (WHAS) I and II, described in an adjusted model that the three highest quartiles of plasma α-carotene were significantly associated with 45%–70% lower risk of dropped grip strength, 55%–72% lower risk of dropped hip strength, and 43%–62% lower risk of dropped knee strength [45]. Additionally, the two highest quartiles of plasma β-carotene were significantly associated with 54%–66% lower risk of dropped grip strength, 47%–64% lower risk of dropped hip strength, and 52%–53% lower risk of dropped knee strength [45]. Moreover, the two highest quartiles of plasma β-cryptoxanthin were significantly associated with 39%–48% lower risk of dropped grip strength, 41%–59% lower risk of dropped hip strength, and a 46% lower risk of dropped knee strength [45]. Also, the three highest quartiles of plasma lutein/zeaxanthin were significantly associated with 58%–71% lower risk of dropped grip strength, 52%–74% lower risk of dropped hip strength, and 56%–61% lower risk of dropped knee strength [45]. Further, the three highest quartiles of total plasma carotenoids were significantly associated with 39%–63% lower risk of dropped grip strength, 44%–69% lower risk of dropped hip strength, and 46%–56% lower risk of dropped knee strength [45]. Finally, the highest quartile of plasma α-tocopherol was significantly associated with a 56% lower risk of dropped grip strength, and a 48% lower risk of dropped knee strength [45].

A total of 3 cohort studies assessed the relationship between antioxidants and MS in old-young adults; 2 had significantly positive associations between both variables [24,48], and one was not significant [33] (Table 3; Supplemental Table 8). In particular, a 4-year cohort study showed that the highest (≥7 points) and middle (4–6 points) dietary variety score (DVS), compared to the lowest score (0–3 points), were significantly associated with 40%–57% lower risk of decline in grip strength in a fully adjusted model in community-dwelling old-young Japanese individuals [24]. In addition, another 6-year cohort study determined that the

Table 6
Characteristics from each included RCTs on the relationship between antioxidants and PF.

Study; year	Study design; duration; country	Total, n	Gender; age (y)	Type of intervention	Antioxidant assessment		Sarcopenia assessment tool	There is a significant improvement in PF in …	
					Type or source	Tool		… antioxidant supplementation or antioxidant-rich diet group	… control or placebo group
Bo Y. et al., 2019 [42]	R, DB, PC 6 months China	60	M/W ≥60 y	AS	Whey protein, vitamin D, vitamin E (218 mg/day vitamin E)	Self-recorded intake dairy 3-day dietary record Blood samples	6-m GSP TUG CHST	–	–
Kim H. et al., 2013 [39]	R, CT[a] 3 months Japan	128	W ≥75 y	AS	Tea catechins (540 mg/day)	Record volume of tea consumed, bottle caps	WA TUG BA	X	
Nalbant Ö. et al., 2009 [35]	R, CT 6 months Turkey	57	M/W ≥61 y	AS	Vitamin E (900 mg/day)	Blood samples	SFT	X	
Neville CE. et al., 2013 [37]	R, CT, PG[a] 16 weeks United Kingdom	83	M/W ≥65 y	A-RFC	Fruits and vegetables (5 portions/day)	7-day dietary record Blood samples	SPPB	–	–
Veronese N. et al., 2014 [38]	R, CT, PG[a] 12 weeks Italy	139	W ≥65 y	AS	Magnesium oxide (900 mg/day)	Blood samples Urine samples	SPPB	X	

All RCTs were analyzed per-protocol.
PF: physical function; R: randomized; DB: double blind; PC: placebo controlled; M: men; W: women; AS: antioxidant supplementation; A-RFC: interventions based on antioxidant-rich food consumption; GSP: gait speed; TUG: time-up–and-go test; CHST: chair stand test; CT: controlled trial; WA: walking ability; BA: balance ability; SFT: senior fitness test; SPPB: short physical performance battery.
[a] Outcome assessors were blind.

lowest plasma carotenoid quartile (<1.37 μmol/L), compared to the highest quartile (>2.16 μmol/L), was significantly associated with a 2.25-fold increased risk of poor hip strength and a 2.12-fold increased risk of knee strength in a fully adjusted model in old-young adults from Italy [48].

3.7. Antioxidant effects on MS in the RCTs

A total of 7 RCTs evaluated different interventions focused on MS [37–43] (Table 4; Supplemental Table 9). Of the 7 RCTs, 3 revealed statistically significant results favoring intervention [38,40,42], and 4 did not show significance [37,39,41,43].

One effective intervention involving resveratrol supplementation (500 mg/day) and exercise demonstrated a significant increase of 14.0% in knee extensor power at 60°/s after the intervention ($p < 0.05$), whereas the placebo group was unchanged [40]. Moreover, the Group × time interaction was significant in the average power knee extensor at 60°/s ($p = 0.004$) [40].

Another effective intervention, mentioned above, based on vitamin E supplementation (218 mg/day of vitamin E) in combination with protein and vitamin D, significantly increased the handgrip strength in the intervention group compared to the placebo group (MD [95% CI]: 2.68 kg [0.71, 4.65]; p[Group x time] = 0.009) [42]. The last effective intervention, referred to before, was magnesium supplementation (900 mg/day), which showed a significant increase in handgrip strength in the magnesium supplementation group compared to the control group (MD [95% CI]: 1.33 kg [0.12, 2.54]; p[Group x time] = 0.03), whereas the change between groups at 12 weeks was not significant [38].

Further, 4 RCTs did not demonstrate significant differences among the groups [37,39,41,43]. Three of them were about the supplementation of tea catechins (540 mg/day) [39], vitamin C and vitamin E (500 mg/day vitamin C and 117.5 mg/day vitamin E) [43], and following a healthy diet rich in whole-grain cereals; fruits, vegetables and berries (≥600 g/day); rape seed oil, olive oil, nuts, and seeds; fish and seafood (≥500 g/day); lean meat, low-fat dairy products (≤0.5 L/day); soft drinks/juice (be avoided/<1.5 dL juice/day) [41]. Moreover, there was another RCT involving a 16-week, 2-arm intervention based on the consumption of A-RF: a) ≥5 portions of fruits and vegetables/day and b) a control group of approximately ≤2 portions of fruits and vegetables/day, which did not show significant differences [37].

3.8. Associations between PF and antioxidants in the observational studies

One cross-sectional study assessed the relationship between antioxidants and PF, but did not show significant results [34] (Table 5; Supplemental Table 10). Instead, a total of 4 cohort studies evaluated the relationship between antioxidants and PF, and all of them noted a significant, positive association in old-young adults [24,30,33,36] (Table 5; Supplemental Table 11).

One 4-year cohort study, mentioned before, signaled that the highest (≥7 points) and middle (4–6 points) DVS, compared to the lowest score (0–3 points), were significantly associated with a 41%–57% lower risk of decline in usual gait speed in a fully adjusted model [24].

Another cohort study (over a mean of 7.2 years) from Spain indicated that higher nut consumption (≥11.5 g/day), in comparison with no nut consumption, was significantly associated with a 41% lower risk of self-reported impaired agility and a 50% lower risk of self-reported impaired mobility in men, and a 35% lower risk of self-reported impaired overall PF in a fully adjusted model in women [33].

Table 7
Characteristics from each included cross-sectional and cohort studies on the relationship between antioxidants and sarcopenia status.

Cross-sectional studies

Study; year	Country	Total, n	Gender; age (y)	Type of assessment	Antioxidant assessment		Sarcopenia assessment tool	A higher level of antioxidants (A-RFC; DPDA-RF) is associated with …	
					Type or source	Tool		… an improvement of sarcopenia status	… a decline in sarcopenia status
Results classified according to the level of antioxidants									
Hashemi R et al., 2015 [27]	Iran	300	M/W ≥55 y	DPA-RF	MDP vs. WDP	FFQ	DXA Dyn GSP	X MDP	
Koyanagi A et al., 2020 [49]	China, Ghana, India, Mexico, Russia, South Africa	14,585	M/W ≥65 y	A-RFC	Vegetables Fruits	S/D	SMM ASM SMI GSP[a]	X Fruits	
Li C et al., 2020 [46]	China	861	M/W ≥65 y	DPA-RF	DP1, DP2, DP3	FFQ DVS DPS	BIA Dyn GSP	X DP2	
ter Borg S et al., 2019 [25]	Netherlands	227	M/W ≥65 y	DPA-RF	α-tocopherol/ cholesterol Magnesium	BS	BIA Dyn GSP CHST	–	–

Studies with cohort and cross-sectional analyses

Study; year	Country	Total, n	Follow-up	Gender; age (y)	Type of assessment	Antioxidant assessment		Sarcopenia assessment tool	A higher level of antioxidants (A-RFC; DPDA-RF) is associated with …	
						Type or source	Tool		… an improvement of sarcopenia status	… a decline in sarcopenia status
Results classified according to the level of antioxidants										
Chan R et al., 2016 [29]	China	3,957 CS 2,948 CH	4 years	M/W ≥65 y	DPA-RF	Diet quality MDP Vegetables Fruits	FFQ DQI-I MDS	DXA Dyn GSP	–	–

DPA-RF: dietary patterns including antioxidant-rich foods; A-RFC: antioxidant-rich food consumption; M: men; W: women; MDP: Mediterranean dietary pattern; WDP: western dietary pattern; DP1: cereal-tubers-animal oils; DP2: mushrooms-fruits-milk; DP3: animal foods; S/D: servings/day; FFQ: food frequency questionnaire; DVS: dietary variety score; DPS: dietary pattern score; Dyn: dynamometer; GSP: gait speed; CHST: chair stand test; DXA: dual-energy X-ray absorptiometry; SMM: skeletal muscle mass; ASM: appendicular skeletal muscle mass; SMI: skeletal muscle mass index; BIA: bioelectrical impedance; BS: blood sample; CS: cross-sectional; CH: cohort; DQI-I: dietary quality index-international; MDS: Mediterranean diet score.

[a] The muscle strength assessment tool was not reported.

Another 4-year cohort study from Spain showed that an optimal consumption of nuts (≥3 times/week) was significantly associated with a 32% lower risk of impairment in agility and a 28% lower risk of impairment in overall PF in a fully adjusted model [36]. Additionally, an optimal consumption of fruits (≥3 servings/day) according to the Mediterranean diet adherence screener (MEDAS) score was associated with a 34% lower risk of impairment in overall PF [36]. The same cohort study demonstrated that the 2-point increase in the MEDAS score (ranging from 0 to 14) was significantly associated with a 16% lower risk of impairment in agility, a 20% lower risk of impairment mobility, a 16% lower risk in overall PF, and a 13% lower risk of impairment in any PF domain in a fully adjusted model [36]. Further, one cohort study established that low serum concentrations of vitamin E (1.1 μg/mL) were significantly associated with a 1.62-fold increase in PF decline in a fully adjusted model in old-young adults from the InCHIANTI study from Italy [30].

3.9. Antioxidants effects on PF in the RCTs

A total of 5 RCTs evaluated different interventions focused on PF [35,37–39,42] (Table 6; Supplemental Table 12). Of the 5 RCTs, 3 showed statistically significant results favoring intervention [35,38,39], and 2 did not show any significant results [37,42].

One effective intervention involving vitamin E supplementation (900 mg/day) and exercise revealed that the chair stand test (MD [95% CI]: 4.30 repetitions [3.56, 5.04]; $p < 0.016$) and arm curl test (MD [95% CI]: 2.2 repetitions [1.37, 3.03]; $p < 0.016$) were significantly increased in comparison to the control group [35]. Additionally, in the same RCT, the chair stand test was significantly increased in the exercise group in comparison to the control group (MD [95% CI]: 4.40 repetitions [3.59, 5.21; $p < 0.016$) [35].

Other effective RCT intervention involving tea catechin supplementation (540 mg/day) and exercise determined that the TUG test was significantly decreased (MD [95% CI]: −1.76 s. [−2.01, −1.51]; p [Group x time]<0.001), and usual and maximum walking speed were significantly increased (MD [95% CI]: 0.13 m/s [0.10, 0.16]; p [Group x time] = 0.007; 0.35 m/s [0.31, 0.39]; p[Group x time] <0.001, respectively) in comparison to the health education control group [39].

The last effective RCT intervention based on magnesium supplementation (900 mg/day) showed that SPPB walking (MD [95% CI]: 0.52 points [0.28, 0.76]; p[Group x time]<0.0001) and walking speed (MD [95% CI]: 0.19 m/s [0.11, 0.27]; p[Group x time] <0.00001) were significantly increased in comparison to the control group [38]. Additionally, compared to the control group, chair stand time was significantly reduced (MD [95% CI]: −1.16 s. [−1.81, −0.51]; p[Group x time] = 0.0005) in the magnesium intervention group [38]. However, one RCT intervention about diets including A-RF such as increasing fruit and vegetable consumption (increasing ≥5 portions of fruits and vegetables/day) [37], and another RCT based on vitamin E supplementation (218 mg/day of vitamin E) in combination with protein and vitamin D [42], did not reveal significant results between the intervention and placebo groups over time.

3.10. Associations between sarcopenia status and antioxidants in the observational studies

Of the 19 observational studies, 5 studies (4 cross-sectional studies [25,27,46,49] and one study with cross-sectional and cohort analyses [29]) assessed two or more sarcopenia variables, such as MM, MS, and PF, and exhibited the results focused on sarcopenia status.

A total of 4 cross-sectional studies evaluated the relationship between dietary patterns including A-RF and the consumption of specific A-RF and sarcopenia status in old-young adults [25,27,46,49]; 3 of them observed significant negative associations [27,46,49], and one did not demonstrate significant results [25] (Table 7; Supplemental Table 13).

One cross-sectional study indicated that the three highest fruit consumption quartiles (1 to >4 servings/day), compared to the lowest quartile (0 servings/day), were significantly associated with a 26%–40% lower risk of sarcopenia, especially in women with a 44%–62% lower risk, after adjusting for confounding variables in old-young adults from middle-income countries [49]. Another cross-sectional study signaled that the highest quartile of antioxidant-rich dietary pattern score (0.49–6.12 score from −2.09 to 6.12) rich in mushrooms, fruits, and milk, compared to the lowest quartile (−2.09 to −0.66 score), was significantly associated with a 67% lower likelihood of sarcopenia in a fully adjusted model in Chinese old-young adults [46].

Another cross-sectional study found that elderly individuals in the highest tertile of the Mediterranean dietary pattern were significantly associated with a 60% lower likelihood of sarcopenia in a fully adjusted model in old-young Iranian adults [27].

One study that performed cross-sectional and cohort analyses evaluating dietary patterns including A-RF and sarcopenia status, did not observe any significant results [29] (Table 7; Supplemental Table 14).

3.11. Antioxidant effects on sarcopenia status in the RCTs

No RCT exhibited results based on sarcopenia status.

3.12. Quality of the observational studies included in the systematic review

Table 8 outlines the quality of the observational studies included in the systematic review. According to the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies [22], the quality of the 13 cross-sectional studies included in the present systematic review was high in 3 studies [26,31,45] and medium in 10 studies [25,27,28,32,34,46,47,49–51]. Additionally, all 5 cohort studies were of medium quality [24,30,33,36,48]. Furthermore, the quality of the one study that involved both cohort and cross-sectional analyses was medium–high [29].

The most reported questions by all 19 cohort and cross-sectional studies were question 1 (research question) and question 14 (statistical analyses). Specifically, all observational studies clearly stated a research question, measured the potential confounding variables, and adjusted the results. Instead, question 5 (sample size justification), question 10 (repeated exposure assessment), and question 13 (follow-up rate) were less reported by the studies. No study reported question 7 (sufficient timeframe to see an effect) or question 12 (the blinding of outcome assessors).

3.13. Quality of the RCTs included in the systematic review

According to the Cochrane risk of bias tool RoB2 [23], of the 9 RCTs included, 4 were classified as having a high risk of bias [35,39,41,44], 3 with some concerns [37,38,43], and 2 as having a low risk of bias [40,42] (Fig. 2). Of the 4 RCT studies with a high risk of bias, one had high risk in domain 2 (deviations from the intended interventions) [44], one in domain 3 (missing outcome data) [39], one in domain 4 (measurement of the outcome) [41], and one in domains 2 and 4 [35].

Table 8
Quality of the cohort and cross-sectional studies included in the systematic review.

	Type of study	1. Research question	2. Study population	3. Participation rate	4. Participants selection and eligibility criteria	5. Sample size justification	6. Exposure assessment	7. Sufficient timeframe to see and effect	8. Different levels of exposure	9. Exposure measures and assessment	10. Repeated exposure assessment	11. Outcome measures	12. Blinding of outcome assessors	13. Follow-up rate	14. Statistical analyses	Quality:
Arias-Fernández L et al., 2019 [33]	Cohort	Yes	Yes	Yes	NR	No	Yes	NR	Yes	Yes	Yes	No	No	CD	Yes	Medium
Atkins JL et al., 2014 [32]	Cross-sectional	Yes	Yes	Yes	NR	No	No	No	No	Yes	No	Yes	NA	NA	Yes	Medium
Barrea L et al., 2019 [31]	Cross-sectional	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	No	Yes	NA	NA	Yes	High
Bartali B et al., 2008 [30]	Cohort	Yes	No	Yes	NR	No	Yes	NR	No	Yes	No	Yes	No	No	Yes	Medium
Chan R et al., 2016 [29]	Cohort and cross-sectional	Yes	Yes	Yes	Yes	No	Yes	NR	No	Yes	No	Yes	No	No	Yes	Medium-High
Chen YL et al., 2014 [28]	Cross-sectional	Yes	Yes	CD	Yes	No	No	No	Yes	Yes	No	Yes	NA	NA	Yes	Medium
Hashemi R et al., 2015 [27]	Cross-sectional	Yes	Yes	CD	Yes	No	No	No	Yes	Yes	No	Yes	NA	NA	Yes	Medium
Kim H et al., 2019 [26]	Cross-sectional	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No	Yes	NA	NA	Yes	High
Kim J et al., 2015 [50]	Cross-sectional	Yes	Yes	Yes	NR	No	No	No	NA	Yes	No	Yes	NA	NA	Yes	Medium
Kim J et al., 2015 [51]	Cross-sectional	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	NA	NA	Yes	Medium
Koyanagi A et al., 2020 [49]	Cross-sectional	Yes	Yes	CD	NR	No	No	No	Yes	No	No	NR	NA	NA	Yes	Medium
Lauretani F et al., 2007 [47]	Cross-sectional	Yes	No	Yes	NR	No	No	No	Yes	Yes	No	Yes	NA	NA	Yes	Medium
Lauretani F et al., 2008 [48]	Cohort	Yes	Yes	Yes	NR	No	Yes	NR	Yes	Yes	Yes	Yes	No	No	Yes	Medium
Li C et al., 2020 [46]	Cross-sectional	Yes	Yes	CD	No	No	No	No	Yes	Yes	No	Yes	NA	NA	Yes	Medium
Semba RD et al., 2003 [45]	Cross-sectional	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No	Yes	NA	NA	Yes	High
Struijk EA et al., 2018 [36]	Cohort	Yes	Yes	Yes	Yes	No	Yes	NR	Yes	Yes	No	No	No	Yes	Yes	Medium
ter Borg S et al., 2019 [25]	Cross-sectional	Yes	Yes	CD	Yes	No	No	No	Yes	Yes	No	Yes	NA	NA	Yes	Medium
Yokoyama Y et al., 2017 [24]	Cohort	Yes	Yes	CD	No	No	Yes	NR	Yes	No	No	Yes	No	No	Yes	Medium
Zbeida M et al., 2014 [34]	Cross-sectional	Yes	Yes	CD	NR	No	No	No	Yes	No	No	No	NA	NA	Yes	Medium
TOTAL OF AFFIRMATIVE RESULTS		19	17	11	9	1	6	0	14	15	2	15	0	1	19	

CD: cannot determine; NA: not applicable; NR: not reported.
Questions 6, 7, 12, and 13 are only for cohort studies. The cross-sectional studies answers were: No (questions 6 and 7) and NA (questions 12 and 13).
Cohort studies: low quality (≤5 points), medium quality (6–9 points), and high quality (10–14 points). Cross-sectional studies: low quality (≤3 points), medium quality (4–7 points), and high quality (8–10 points).

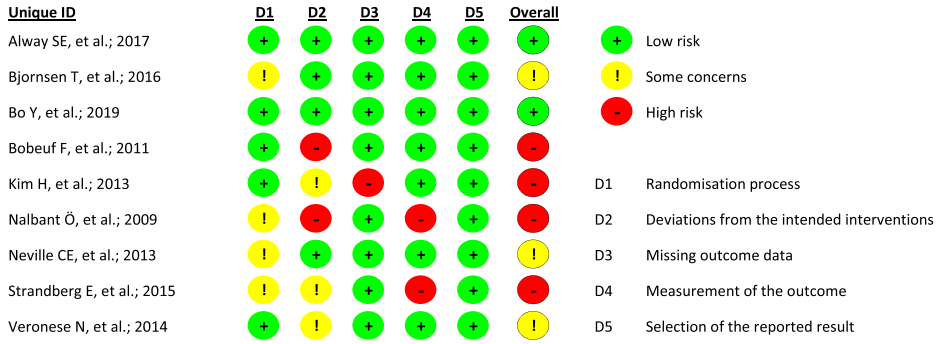

Fig. 2. Quality of the RCTs included in the systematic review.

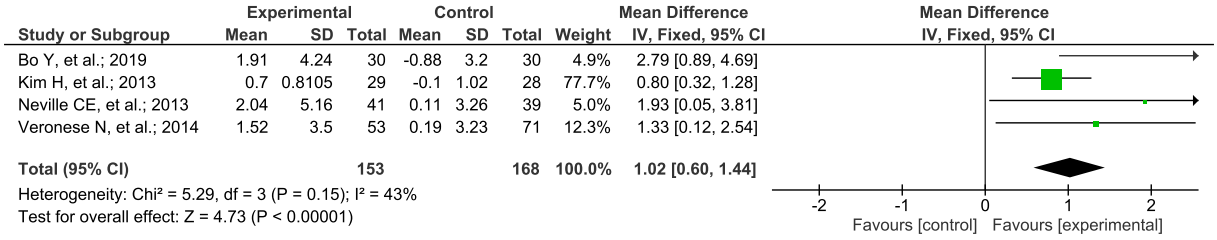

Fig. 3. Forest plot of the meta-analysis of RCTs that evaluated the effect of antioxidant supplementation and A-RF supplementation in relation to handgrip strength (kg).

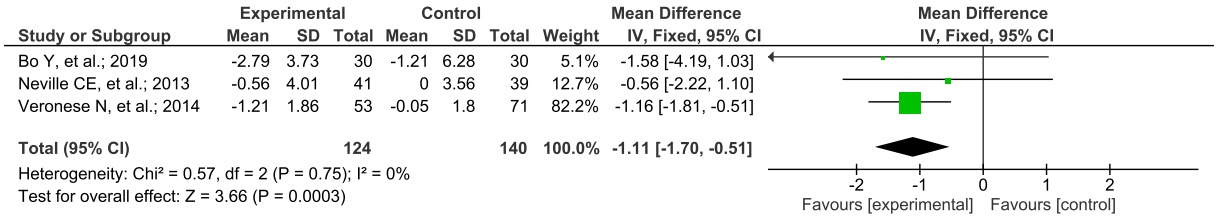

Fig. 4. Forest plot of the meta-analysis of RCTs that evaluated the effect of antioxidant supplementation and A-RF supplementation in relation to the time to complete 5 stands (s).

3.14. Meta-analysis of the RCTs

A total of 4 RCTs were included in the meta-analysis [37–39,42]. Four RCTs contained data about MS as handgrip strength [37–39,42] (Fig. 3), and 3 RCTs were about PF measured as time to complete 5 stands, which consisted of getting up from a chair without armrests five times with the arms against the chest [37,38,42] (Fig. 4). Regarding MM in the RCTs, it was not possible to conduct a meta-analysis because outcomes were expressed in different units and measured with different tools, so not enough RCTs could be included.

The meta-analysis of 4 RCTs [37–39,42] that assessed the effect of antioxidant supplementation and interventions based on the consumption of A-RF on MS revealed a significant increase in handgrip strength (kg) (1.02 MD; 95% CI 0.60, 1.44; $p < 0.01$; $I2 = 43\%$) (Fig. 3). The present meta-analysis of 4 RCTs included a sample of 321 individuals. The 4 RCT interventions included in the meta-analysis were about magnesium supplementation (900 mg/day of oral magnesium oxide equivalent to 300 mg bioavailable magnesium for 12 weeks [3 months]) [38], vitamin E supplementation (218 mg/day of vitamin E) in combination with vitamin D (1404 IU/day) and protein (44 g/day), for 6 months in a powder mix to be reconstituted [42], tea catechin supplementation (540 mg/day of catechin for 3 months) [39], and increasing fruit and vegetable consumption to 5 portions/day for 16 weeks (4 months) [37].

The meta-analysis of 3 RCTs [37,38,42] that evaluated the effect of antioxidant supplementation and A-RF supplementation in relation to PF revealed a significant reduction in the time to complete 5 stands (sec) (−1.11 MD; 95% CI -1.70, −0.51; $p < 0.01$; $I2 = 0\%$) (Fig. 4). The present meta-analysis of 3 RCTs included a sample of 264 individuals. Additionally, the interventions included were magnesium supplementation [38], vitamin E supplementation in combination with vitamin D and protein [42], and increasing fruit and vegetable consumption [37], as explained in the above meta-analysis of MS.

4. Discussion

The present systematic review of observational studies determined that A-RF were associated with better MM, MS, PF, and overall sarcopenia status in old-young adults. In addition, the present meta-analysis of RCTs showed that interventions based on

the supplementation of antioxidants such as magnesium, vitamin E in combination with vitamin D and protein, tea catechins, and increasing daily fruit and vegetable consumption produced an improvement in MS and PF, especially in handgrip strength and the time to complete 5 stands. However, there was not enough evidence neither to make associations nor to conduct a meta-analysis about MM. Additionally, to answer the objective, only the positive association of fruit and vegetable consumption with MM obtained via the observational studies were confirmed by the RCTs.

The systematic review of cross-sectional studies indicated that higher consumption of vitamin C [32], selenium [28], and fruits and vegetables [50,51] was significantly associated with higher MM in old-young adults. Further, the vitamin C results can be confirmed by a cross-sectional study with ≥42-year-old population [52]. In addition, one literary review established that vitamin E could reverse muscle damage [53]. In contrast, the systematic review of RCTs only showed an improvement in MM by following a diet rich in A-RF [41], and was not enough to determine any relationship between MM and antioxidants. However, a review suggests that a healthy diet could be as effective or more effective than supplementation to preserve MM in the elderly [54]. In addition, the positive association of fruit and vegetable consumption with MM, detected in observational studies from Korea [50,51], was confirmed on a Swedish RCT based on the consumption of ≥600 g/day of fruits, vegetables, and berries [41]. This confirmation was justified because the portion size in Korean observational studies (40 g of vegetables and 100 g of fruits for each serving [55]) applied to their daily fruit and vegetable consumption, was similar to the RCT intervention [41] and Swedish recommendations [56]. Additionally, it was not possible to estimate the clinical impact of MM improvement in the RCTs.

The systematic review of cross-sectional and cohort studies indicated that higher consumption of selenium [47], carotenoids [45,48] and α-tocopherol [45], extra virgin olive oil, vegetables, fruits, and nuts, following the Mediterranean dietary pattern [31], and having higher scores of diet quality [26] or diet variety [24], reflected better MS. On this line, these results were confirmed by a recent cohort study with ≥33-year-old subjects [57] and a literary review [58]; it showed that the intake of carotenoids or carotenoid-rich foods protects against the decline in MS in old-young adults. The present meta-analysis of RCTs showed that antioxidant supplementation of vitamin E (218 mg/day) in combination with vitamin D and protein [42], tea catechins (540 mg/day) [39], magnesium (900 mg/day) [38], and increasing fruit and vegetable consumption (to 5 portions/day) [37] improved handgrip strength by 1.02 kg, but it was not possible to quantify the clinical impact of handgrip strength improvement [59].

In the present systematic review no cross-sectional studies showed significant results about PF, but some cohort studies determined favorable associations related to vitamin E [30], fruits [36], nuts [33,36], Mediterranean dietary pattern [36], and diet variety [24]. One cohort study [57] and a literary review [58] indicated that carotenoids and carotenoid-rich food consumption protects against walking disability [58] and improves gait speed [57]. Moreover, the cohort study determined that vitamin E consumption improves gait speed too [57]. Further, the meta-analysis of RCTs revealed that antioxidant supplementation of vitamin E (218 mg/day) in combination with vitamin D and protein [42], magnesium (900 mg/day) [38], and an increase in fruit and vegetable consumption (to 5 portions/day) [37] improved PF, reducing the time to complete 5 stands by 1.11 s. Unfortunately, no interval related to the time to complete 5 stands has been described to determine the clinical impact of these interventions. Nevertheless, an increase of 0.1 m/s in gait speed, a 1-point increase in SPPB score, or an increase of at least 50 m in the 6-min walk test could be used as a reference to assess the clinical impact of the different interventions [59–61]. Two RCTs about exercise and tea catechin supplementation [39] and magnesium supplementation [38], had an improvement of walking speed with clinical relevance from baseline to the end of the intervention. Finally, another RCT showed an improvement in the 6-min walk test over 50 m with clinical relevance from baseline to the end of the intervention in the exercise and exercise-vitamin groups [35].

According to the antioxidant recommendations for increasing MS and PF based on the meta-analysis of RCTs (Table 9), interventions between 3 and 6 months could be enough [37–39,42].

The current systematic review of cross-sectional studies determined that higher consumption of fruits [49] and following the Mediterranean dietary pattern [27], or a diet rich in antioxidants [46], can improve overall sarcopenia status in old-young adults. One systematic review concluded that magnesium and selenium are the most useful minerals for preventing and treating sarcopenia [62]. Additionally, the Mediterranean diet contains many A-RF, specially highlighting nuts and olive oil due to their ability to modulate oxidative processes [63]. Further, in combination with resistance training, was associated with greater antioxidant capacity [64].

Thus, based on the present systematic review and meta-analysis, it is possible to grasp the importance of antioxidants as a tool to improve MS and PF. However, more research is needed to determine the impact of other antioxidants such as vitamins (in particular vitamin A), minerals (iron, zinc, and copper), and phenolic compounds, or A-RF such as beans, seeds, and cacao on sarcopenia status. Moreover, should be performed future meta-analysis about MM and observational studies.

4.1. Limitations

The present systematic review and meta-analysis faced some limitations. First, it was difficult to unify the results due to the use of different antioxidant intake and sarcopenia assessment tools and their respective units. Second, 3 observational studies [26,30,51],

Table 9
Antioxidant recommendations to improve MS and PF according to the meta-analysis of RTCs.

Study	Sarcopenia parameters	Type of source or supplementation	Dosage	Exercise or physical activity	Duration
Bo Y et al., 2019 [42]	MS PF	Vitamin E supplementation in combination with vitamin D and protein	218 mg/day of vitamin E 1404 IU/day of vitamin D 44 g protein/day	No	24 weeks (6 moths)
Veronese N et al., 2014 [38]	MS PF	Magnesium oxide	900 mg/day	Yes	12 weeks (3 months)
Kim H et al., 2013 [39]	MS	Tea catechins	540 mg/day	Yes	12 weeks (3 months)
Neville CE et al., 2013 [37]	MS PF	Fruit and vegetable	5 portions/day	No	16 weeks (4 months)

MS: muscle strength; PF: physical function.

involved individuals who consume nutritional supplements, and 5 RCTs did not exclude volunteers who had taken supplements before the intervention started [38,39,41,42,44]. Additionally, some RCT studies included protein supplements or physical activity in the interventions, two aspects that can be involved in the results observed. Thus, the results could not be fully attributed to A-RF or interventions. This was a major limitation. Third, in observational studies, a dietary pattern could indeed include different antioxidants with synergistic influence and it was not possible to isolate the individual antioxidant power. Fourth, we included articles from different countries showing different lifestyles and eating habits, and this could affect in a different way on sarcopenia management. Fifth, there are fewer RCTs about antioxidant supplementation on sarcopenia and the interventions are different among them; for this reason, future RCTs meta-analysis should be classified considering A-RF interventions and antioxidant supplementation. Sixth, it was not possible to conduct a RCT meta-analysis about MM and a meta-analysis of observational studies. Seventh, some RCTs were not significant in the results tables, but by contrast, there were significant in the meta-analysis forest plot, probably due to the RevMan calculator estimation. Eighth, it was not possible to verify the associations of MS and PF from observational studies by RCTs because the variables were different (plasma or serum concentrations vs. mg/day of supplementation) or the food portion size was different among the countries. Finally, it was not possible to estimate the clinical impact of MM and MS outcomes because there is no clinical reference point [59].

5. Conclusion

The present systematic review of observational studies and meta-analysis of RCTs established that A-RF or antioxidant supplementation could be a good tool to enhance and treat age-related sarcopenia, especially MS and PF. The best interventions according to the meta-analysis of the RCTs were supplementation of vitamin E in combination with vitamin D and protein, magnesium, tea catechins, and increasing fruit and vegetable consumption. Meanwhile, more research is required about other antioxidants.

Acknowledgments

The FOOP-Sarc project (PID2019-105164RB-I00) was funded by MCIN/AEI/10.13039/501100011033.

Funding

This article in journal has been possible with the support of the Secretaria d'Universitats i Recerca del Departament d'Empresa i Coneixement de la Generalitat de Catalunya, the European Union (UE) and the European Social Fund (ESF) (2022 FI_B2 00011).

Author contributions

Maria Besora-Moreno: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Visualization; Roles/Writing - original draft.

Elisabet Llauradó: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Supervision; Validation; Visualization; Roles/Writing - original draft.

Rosa M. Valls: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Supervision; Validation; Visualization; Roles/Writing - original draft.

Lucia Tarro: Writing - review & editing.

Anna Pedret: Writing - review & editing.

Rosa Solà: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Supervision; Validation; Visualization; Roles/Writing - original draft.

Declaration of competing interest

No potential conflict of interest is reported by the authors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clnu.2022.07.035.

References

[1] World Health Organization (WHO). Ageing and health. 2018. https://www.who.int/news-room/fact-sheets/detail/ageing-and-health. [Accessed 9 December 2020].
[2] Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T, et al. Sarcopenia: revised European consensus on definition and diagnosis. Age Ageing 2019;48:16–31. https://doi.org/10.1093/ageing/afy169.
[3] Beaudart C, McCloskey E, Bruyère O, Cesari M, Rolland Y, Rizzoli R, et al. Sarcopenia in daily practice: assessment and management. BMC Geriatr 2016;16:1–10. https://doi.org/10.1186/s12877-016-0349-4.
[4] Roberts HC, Denison HJ, Martin HJ, Patel HP, Syddall H, Cooper C, et al. A review of the measurement of grip strength in clinical and epidemiological studies: towards a standardised approach. Age Ageing 2011;40:423–9. https://doi.org/10.1093/ageing/afr051.
[5] Cruz-Jentoft AJ, Landi F, Schneider SM, Zúñiga C, Arai H, Boirie Y, et al. Prevalence of and interventions for sarcopenia in ageing adults: a systematic review. Report of the International Sarcopenia Initiative (EWGSOP and IWGS). Age Ageing 2014;43:48–759. https://doi.org/10.1093/ageing/afu115.
[6] Ethgen O, Beaudart C, Buckinx F, Bruyère O, Reginster JY. The future prevalence of sarcopenia in Europe: a claim for public health action. Calcif Tissue Int 2017;100:229–34. https://doi.org/10.1007/s00223-016-0220-9.
[7] Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, et al. Sarcopenia: European consensus on definition and diagnosis: report of the European working group on sarcopenia in older people. Age Ageing 2010;39:412–23. https://doi.org/10.1093/ageing/afq034.
[8] Keller K, Engelhardt M. Strength and muscle mass loss with aging process. Age and strength loss. Muscles Ligaments Tendons J 2013;3:346–50. https://doi.org/10.11138/mltj/2013.3.4.346.
[9] Beaudart C, Rizzoli R, Bruyère O, Reginster JY, Biver E. Sarcopenia: burden and challenges for public health. Arch Publ Health 2014;72:45. https://doi.org/10.1186/2049-3258-72-45.
[10] Schaap LA, Van Schoor NM, Lips P, Visser M. Associations of sarcopenia definitions, and their components, with the incidence of recurrent falling and fractures: the longitudinal aging study Amsterdam. J Gerontol - Ser A Biol Sci Med Sci 2018;73:1199–204. https://doi.org/10.1093/gerona/glx245.
[11] de Buyser SL, Petrovic M, Taes YE, Toye KRC, Kaufman JM, Lapauw B, et al. Validation of the FNIH sarcopenia criteria and SOF frailty index as predictors of long-term mortality in ambulatory older men. Age Ageing 2016;45:603–9. https://doi.org/10.1093/ageing/afw071.
[12] Antunes AC, Araújo DA, Veríssimo MT, Amaral TF. Sarcopenia and hospitalisation costs in older adults: a cross-sectional study. Nutr Diet 2017;74:46–50. https://doi.org/10.1111/1747-0080.12287.
[13] Dhillon RJS, Hasni S. Pathogenesis and management of sarcopenia. Clin Geriatr Med 2017;33:17–26. https://doi.org/10.1016/j.cger.2016.08.002.
[14] Marzetti E, Calvani R, Tosato M, Cesari M, Di Bari M, Cherubini A, et al. Sarcopenia: an overview. Aging Clin Exp Res 2017;29:11–7. https://doi.org/10.1007/s40520-016-0704-5.
[15] Dodds RM, Roberts HC, Cooper C, Sayer AA. The epidemiology of sarcopenia. J Clin Densitom 2015;18:461–6. https://doi.org/10.1016/j.jocd.2015.04.012.
[16] Damiano S, Muscariello E, La Rosa G, Di Maro M, Mondola P, Santillo M. Dual role of reactive oxygen species in muscle function: can antioxidant dietary supplements counteract age-related sarcopenia? Int J Mol Sci 2019;20. https://doi.org/10.3390/ijms20153815.
[17] Kadoguchi T, Shimada K, Miyazaki T, Kitamura K, Kunimoto M, Aikawa T, et al. Promotion of oxidative stress is associated with mitochondrial dysfunction and muscle atrophy in aging mice. Geriatr Gerontol Int 2020;20:78–84. https://doi.org/10.1111/GGI.13818.
[18] Lourenço dos Santos S, Baraibar MA, Lundberg S, Eeg-Olofsson O, Larsson L, Friguet B. Oxidative proteome alterations during skeletal muscle ageing. Redox Biol 2015;5:274. https://doi.org/10.1016/J.REDOX.2015.05.006.
[19] Hutton B, Salanti G, Caldwell DM, Chaimani A, Schmid CH, Cameron C, et al. The PRISMA extension statement for reporting of systematic reviews incorporating network meta-analyses of health care interventions: checklist and explanations. Ann Intern Med 2015;162:777–84. https://doi.org/10.7326/M14-2385.

[20] Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan-a web and mobile app for systematic reviews. Syst Rev 2016;5:210. https://doi.org/10.1186/s13643-016-0384-4.
[21] Harvard TH. Chan School of Public Health. Antioxidants | the nutrition source n.d. https://www.hsph.harvard.edu/nutritionsource/antioxidants/. [Accessed 4 January 2021].
[22] National Heart Lung, Blood Institute. Study quality assessment tools n.d. https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools. [Accessed 10 May 2020].
[23] Sterne JAC, Savović J, Page MJ, Elbers RG, Blencowe NS, Boutron I, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. BMJ 2019;366:l4898. https://doi.org/10.1136/bmj.l4898.
[24] Yokoyama Y, Nishi M, Murayama H, Amano H, Taniguchi Y, Nofuji Y, et al. Dietary variety and decline in lean mass and physical performance in community-dwelling older Japanese: a 4-year follow-up study. J Nutr Health Aging 2017;21:11–6. https://doi.org/10.1007/s12603-016-0726-x.
[25] ter Borg S, Luiking YC, van Helvoort A, Boirie Y, Schols JMGA, de Groot CPGM. Low levels of branched chain amino acids, eicosapentaenoic acid and micronutrients are associated with low muscle mass, strength and function in community-dwelling older adults. J Nutr Health Aging 2019;23:27–34. https://doi.org/10.1007/s12603-018-1108-3.
[26] Kim H, Kwon O. Higher diet quality is associated with lower odds of low hand grip strength in the Korean elderly population. Nutrients 2019;11:1487. https://doi.org/10.3390/nu11071487.
[27] Hashemi R, Motlagh AD, Heshmat R, Esmaillzadeh A, Payab M, Yousefinia M, et al. Diet and its relationship to sarcopenia in community dwelling iranian elderly: a cross sectional study. Nutrition 2015;31:97–104. https://doi.org/10.1016/j.nut.2014.05.003.
[28] Chen YL, Yang KC, Chang HH, Lee LT, Lu CW, Huang KC. Low serum selenium level is associated with low muscle mass inthe community-dwelling elderly. J Am Med Dir Assoc 2014;15:807–11. https://doi.org/10.1016/j.jamda.2014.06.014.
[29] Chan R, Leung J, Woo J. A prospective cohort study to examine the association between dietary patterns and sarcopenia in Chinese community-dwelling older people in Hong Kong. J Am Med Dir Assoc 2016;17:336–42. https://doi.org/10.1016/j.jamda.2015.12.004.
[30] Bartali B, Frongillo EA, Guralnik JM, Stipanuk MH, Allore HG, Cherubini A, et al. Serum micronutrient concentrations and decline in physical function among older persons. JAMA 2008;299:308–15. https://doi.org/10.1001/jama.299.3.308.
[31] Barrea L, Muscogiuri G, Di Somma C, Tramontano G, De Luca V, Illario M, et al. Association between Mediterranean diet and hand grip strength in older adult women. Clin Nutr 2019;38:721–9. https://doi.org/10.1016/j.clnu.2018.03.012.
[32] Atkins JL, Whincup PH, Morris RW, Wannamethee SG. Low muscle mass in older men: the role of lifestyle, diet and cardiovascular risk factors. J Nutr Health Aging 2014;18:26–33. https://doi.org/10.1007/s12603-013-0336-9.
[33] Arias-Fernández L, Machado-Fragua MD, Graciani A, Guallar-Castillón P, Banegas JR, Rodríguez-Artalejo F, et al. Prospective association between nut consumption and physical function in older men and women. J Gerontol - Ser A Biol Sci Med Sci 2019;74:1091–7. https://doi.org/10.1093/gerona/gly171.
[34] Zbeida M, Goldsmith R, Shimony T, Yardi H, Naggan L, Shahar DR. Mediterranean diet and functional indicators among older adults in non-mediterranean and mediterranean countries. J Nutr Health Aging 2014;18:411–8. https://doi.org/10.1007/s12603-014-0003-9.
[35] Ö Nalbant, Toktaş N, Toraman NF, Öğüş C, Aydin H, Kaçar C, et al. Vitamin E and aerobic exercise: effects on physical performance in older adults. Aging Clin Exp Res 2009;21:111–21. https://doi.org/10.1007/BF03325218.
[36] Struijk EA, Guallar-Castillón P, Rodríguez-Artalejo F, López-García E. Mediterranean dietary patterns and impaired physical function in older adults. J Gerontol - Ser A Biol Sci Med Sci 2018;73:333–9. https://doi.org/10.1093/gerona/glw208.
[37] Neville CE, Young IS, Gilchrist SECM, McKinley MC, Gibson A, Edgar JD, et al. Effect of increased fruit and vegetable consumption on physical function and muscle strength in older adults. Age (Omaha) 2013;35:2409–22. https://doi.org/10.1007/s11357-013-9530-2.
[38] Veronese N, Berton L, Carraro S, Bolzetta F, De Rui M, Perissinotto E, et al. Effect of oral magnesium supplementation on physical performance in healthy elderly women involved in a weekly exercise program: a randomized controlled trial. Am J Clin Nutr 2014;100:974–81. https://doi.org/10.3945/ajcn.113.080168.
[39] Kim H, Suzuki T, Saito K, Yoshida H, Kojima N, Kim M, et al. Effects of exercise and tea catechins on muscle mass, strength and walking ability in community-dwelling elderly Japanese sarcopenic women: a randomized controlled trial. Geriatr Gerontol Int 2013;13:458–65. https://doi.org/10.1111/j.1447-0594.2012.00923.x.
[40] Alway SE, McCrory JL, Kearcher K, Vickers A, Frear B, Gilleland DL, et al. Resveratrol enhances exercise-induced cellular and functional adaptations of skeletal muscle in older men and women. J Gerontol - Ser A Biol Sci Med Sci 2017;72:1595–606. https://doi.org/10.1093/gerona/glx089.
[41] Strandberg E, Edholm P, Ponsot E, Wåhlin-Larsson B, Hellmén E, Nilsson A, et al. Influence of combined resistance training and healthy diet on muscle mass in healthy elderly women: a randomized controlled trial. J Appl Physiol 2015;119:918–25. https://doi.org/10.1152/japplphysiol.00066.2015.
[42] Bo Y, Liu C, Ji Z, Yang R, An Q, Zhang X, et al. A high whey protein, vitamin D and E supplement preserves muscle mass, strength, and quality of life in sarcopenic older adults: a double-blind randomized controlled trial. Clin Nutr 2019;38:159–64. https://doi.org/10.1016/j.clnu.2017.12.020.
[43] Bjørnsen T, Salvesen S, Berntsen S, Hetlelid KJ, Stea TH, Lohne-Seiler H, et al. Vitamin C and E supplementation blunts increases in total lean body mass in elderly men after strength training. Scand J Med Sci Sports 2016;26:755–63. https://doi.org/10.1111/sms.12506.
[44] Bobeuf F, Labonte M, Dionne IJ, Khalil A. Combined effect of antioxidant supplementation and resistance training on oxidative stress markers, muscle and body composition in an elderly population. J Nutr Health Aging 2011;15:883–9. https://doi.org/10.1007/s12603-011-0097-2.
[45] Semba RD, Blaum C, Guralnik JM, Moncrief DT, Ricks MO, Fried LP. Carotenoid and vitamin E status are associated with indicators of sarcopenia among older women living in the community. Aging Clin Exp Res 2003;15:482–7. https://doi.org/10.1007/BF03327377.
[46] Li C, Kang B, Zhang T, Gu H, Song P, Chen J, et al. Dietary pattern and dietary energy from fat associated with sarcopenia in community-dwelling older Chinese people: a cross-sectional study in three regions of China. Nutrients 2020;12:3689. https://doi.org/10.3390/nu12123689.
[47] Lauretani F, Semba RD, Bandinelli S, Ray AL, Guralnik JM, Ferrucci L. Association of low plasma selenium concentrations with poor muscle strength in older community-dwelling adults: the InCHIANTI Study. Am J Clin Nutr 2007;86:347–52. https://doi.org/10.1093/ajcn/86.2.347.
[48] Lauretani F, Semba RD, Bandinelli S, Dayhoff-Brannigan M, Giacomini V, Corsi AM, et al. Low plasma carotenoids and skeletal muscle strength decline over 6 years. J Gerontol - Ser A Biol Sci Med Sci 2008;63:376–83. https://doi.org/10.1093/gerona/63.4.376.
[49] Koyanagi A, Veronese N, Solmi M, Oh H, Shin JI, Jacob L, et al. Fruit and vegetable consumption and sarcopenia among older adults in low- and middle-income countries. Nutrients 2020;12:706. https://doi.org/10.3390/nu12030706.
[50] Kim J, Lee Y, Kye S, Chung YS, Kim KM. Association between healthy diet and exercise and greater muscle mass in older adults. J Am Geriatr Soc 2015;63:886–92. https://doi.org/10.1111/jgs.13386.
[51] Kim J, Lee Y, Kye S, Chung YS, Kim KM. Association of vegetables and fruits consumption with sarcopenia in older adults: the fourth Korea national health and nutrition examination survey. Age Ageing 2015;44:96–102. https://doi.org/10.1093/ageing/afu028.
[52] Lewis LN, Hayhoe RPG, Mulligan AA, Luben RN, Khaw KT, Welch AA. Lower dietary and circulating vitamin C in middle- and older-Aged men and women are associated with lower estimated skeletal muscle mass. J Nutr 2020;150:2789–98. https://doi.org/10.1093/jn/nxaa221.
[53] Khor SC, Abdul Karim N, Wan Ngah WZ, Mohd Yusof YA, Makpol S. Vitamin E in sarcopenia: current evidences on its role in prevention and treatment. Oxid Med Cell Longev 2014:914853. https://doi.org/10.1155/2014/914853.
[54] Ganapathy A, Nieves JW. Nutrition and sarcopenia—what do we know? Nutrients 2020;12:1–25. https://doi.org/10.3390/NU12061755.
[55] Choi MK, Hyun WJ, Lee SY, Park HJ, Kim SN, Song KH. One portion size of foods frequently consumed by Korean adults. Nutr Res Pract 2010;4:82–8. https://doi.org/10.4162/NRP.2010.4.1.82.
[56] Livsmedelsverket. Find your way to eat greener, not too much and be active. 2015.
[57] Sahni S, Dufour AB, Fielding RA, Newman AB, Kiel DP, Hannan MT, et al. Total carotenoid intake is associated with reduced loss of grip strength and gait speed over time in adults: the Framingham Offspring Study. Am J Clin Nutr 2021;113:437–45. https://doi.org/10.1093/ajcn/nqaa288.
[58] Semba RD, Lauretani F, Ferrucci L. Carotenoids as protection against sarcopenia in older adults. Arch Biochem Biophys 2007;458:141–5. https://doi.org/10.1016/j.abb.2006.11.025.
[59] Cruz-Jentoft AJ, Sayer AA. Sarcopenia. Lancet 2019;393:2636–46. https://doi.org/10.1016/S0140-6736(19)31138-9.
[60] Morley JE, Abbatecola AM, Argiles JM, Baracos V, Bauer J, Bhasin S, et al. Sarcopenia with limited mobility: an international consensus. J Am Med Dir Assoc 2011;12:403–9. https://doi.org/10.1016/J.JAMDA.2011.04.014.
[61] Perera S, Mody SH, Woodman RC, Studenski SA. Meaningful change and responsiveness in common physical performance measures in older adults. J Am Geriatr Soc 2006;54:743–9. https://doi.org/10.1111/J.1532-5415.2006.00701.X.
[62] van Dronkelaar C, van Velzen A, Abdelrazek M, van der Steen A, Weijs PJM, Tieland M. Minerals and sarcopenia; the role of calcium, iron, magnesium, phosphorus, potassium, selenium, sodium, and zinc on muscle mass, muscle strength, and physical performance in older adults: a systematic review. J Am Med Dir Assoc 2018;19:6–11. https://doi.org/10.1016/j.jamda.2017.05.026. e3.
[63] Bullo M, Lamuela-Raventos R, Salas-Salvado J. Mediterranean diet and oxidation: nuts and olive oil as important sources of fat and antioxidants. Curr Top Med Chem 2011;11:1797–810. https://doi.org/10.2174/156802611796235062.
[64] Panagiotakos DB, Kavouras SA, Pitsavos C, Chrysohoou C, Arnaoutis G, Skoumas Y, et al. Physical activity and adherence to mediterranean diet increase total antioxidant capacity: the ATTICA study. Cardiol Res Pract 2011;1. https://doi.org/10.4061/2011/248626.