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Research Article

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Nutritional and Exercise Interventions for Sarcopenia in Older Adults: A Systematic Review and Network Meta-Analysis

Maximiliano Arlettaz[1*], Daniel Jesus Garcia Martinez[2], Pratyush Kumar[3], Amrit Sharma[4], Kumar Abhishek[5], Ronahy Haidar[6], Sneha Kurian[7], Pratibha Thomas[8], Roberta Voci[9], Sukanya Nachimuthu[10], Mohamed Khaled Al-Haggagi[11], Asmitha Prabhakara Reddy[12] and Ewelina Bagińska[13]

[1]*National University of Entre Rios, Faculty of Health Sciences, Villaguay, Entre Ríos, Argentina*

[2]*Francisco de Vitoria University, Madrid, Spain*

[3]*Dr Baba Saheb Ambedkar Medical College and Hospital, India*

[4]*Department of Gastroenterology and Human Nutrition Unit, All India Institute of Medical Sciences, New Delhi, India*

[5]*Internal Medicine, Centerpoint Medical Center, HCA Healthcare Midwest, USA*

[6]*Faculty of Medicine, University of Aleppo, Aleppo, Syria*

[7]*Dermatology Resident, Christian Medical College, Vellore, India*

[8]*Rajiv Gandhi University of Health Sciences, India*

[9]*Magna Græcia University of Catanzaro, Italy*

[10]*Prof. M. Viswanathan Diabetes Research Centre, India*

[11]*Faculty of Physical Therapy, South Valley University, Qena, Egypt*

[12]*Internal Medicine, Southern Illinois University School of Medicine, USA*

[13]*Ex Pomeranian Medical University, Szczecin, Poland*

[*]Corresponding Author
Maximiliano Arlettaz, National University of Entre Rios, Faculty of Health Sciences, Argentina.

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Abstract

Background and Purpose

Sarcopenia is a progressive condition that impairs strength, physical function, and quality of life in older adults. Both nutritional and exercise interventions have been proposed, but their comparative effectiveness remains unclear. This systematic review and *network meta-analysis aimed to evaluate the effects of these interventions on muscle strength, mass, and physical performance in older adults with sarcopenia.*

Methods

Electronic databases (PubMed, Embase, Scopus, Cochrane CENTRAL, and Web of Science) were searched from inception to February 2024 for randomized controlled trials including adults aged ≥60 years with sarcopenia. Eligible studies evaluated nutritional or exercise interventions and reported outcomes on handgrip strength, appendicular muscle mass, or gait speed. A frequentist random-effects model was used to conduct the network meta-analysis. Treatment effects were expressed as standardized mean differences with 95% confidence intervals and ranked using P-scores. Publication bias and heterogeneity were assessed.

Results and Discussion

Twenty studies were included. For handgrip strength, no intervention produced significant effects. Vitamin C (treatment effect [TE]: 0.148, P-score: 0.65) and vitamin E (TE: 0.091, P-score: 0.64) ranked highest, followed by resistance training (TE: 0.081, Pscore: 0.62). For appendicular muscle mass, resistance training showed the most favorable trend (TE: 0.436, P-score: 0.66), while protein supplementation was associated with a negative effect (TE: –0.235, P-score: 0.23). Gait speed improved significantly only with calcium supplementation (TE: 1.174; 95% CI: 0.294 to 2.053; p = 0.009; P-score: 0.89).

Conclusions

Calcium supplementation demonstrated a significant improvement in gait speed, while resistance training showed favorable trends across multiple outcomes. These findings underscore the clinical importance of promoting resistance exercise and highlight calcium as a potential adjunct to enhance physical performance in older adults with sarcopenia.

Keywords: Calcium, Muscle Strength, Nutritional Supplementation, Older Adults, Resistance Training, Sarcopenia

1. Introduction

Sarcopenia is a progressive and generalized skeletal muscle disorder that increases the risk of falls, physical disability, and mortality in older adults [1]. Although primarily agerelated, sarcopenia can also affect younger individuals with chronic comorbidities such as inflammatory conditions, congenital heart disease, and type 2 diabetes mellitus [2-4]. The term “sarcopenia,” coined by Rosenberg in 1989, literally means “loss of flesh” [5]. Its prevalence ranges from 10% to 27%, with higher rates in men [6]. Diagnostic criteria vary across studies, with key components including muscle strength, muscle mass, and physical performance. These factors may present independently or in combination, leading to variability in diagnosis. In response to this variability, multiple expert groups have proposed definitions to standardize the diagnosis of sarcopenia: the European Working Group on Sarcopenia in Older People (EWGSOP), the European Society for Clinical Nutrition and Metabolism (ESPEN), and the International Working Group on Sarcopenia (IWGS), among others [7-9]. While details differ, all definitions highlight low muscle mass and strength or performance as central features.

Sarcopenia is further categorized as primary (age-related) or secondary (associated with inactivity, malnutrition, or disease) [10]. Various tools are available for diagnosis depending on clinical context and resources. Screening instruments include the SARC-F questionnaire and the Ishii score [11-13]. Objective assessments encompass handgrip strength, chair stand test, dual-energy X-ray absorptiometry (DXA), bioelectrical impedance analysis, gait speed, and the short physical performance battery (SPPB). Additional methods such as mid-thigh imaging, CT-based muscle analysis, ultrasound, creatinine dilution, and quality-of-life questionnaires like SarQoL are increasingly being explored [14,15]. Multiple pathophysiological mechanisms contribute to sarcopenia, including motor neuron loss, hormonal imbalances, chronic inflammation, mitochondrial dysfunction, and reduced muscle regenerative capacity [16]. Adipocyte infiltration may also occur, leading to sarcopenic obesity. These factors collectively disrupt muscle protein synthesis and accelerate catabolism [17].

Among the most studied treatment approaches are nutritional interventions and exercise regimens. Skeletal muscle is the primary site of protein storage and turnover, and its maintenance depends on a balance between synthesis and degradation [18,19]. Nutritional strategies often focus on protein and amino acid supplementation, particularly whey protein and leucine. Whey protein is favored for its high biological value, rapid digestion, and leucine content. It has demonstrated antioxidant, anti-inflammatory, and muscle-protective properties [20-24]. Exercise, especially resistance training and multimodal regimens combining aerobic, balance, and flexibility components, has consistently shown benefits in muscle strength and function. These interventions may reduce inflammation and improve body composition in older adults with sarcopenia [24].

Given the substantial clinical and economic burden of sarcopenia, identifying the most effective and feasible treatment options is a priority [25,26]. Sarcopenia is also associated with cardiovascular disease, respiratory conditions, neuropsychiatric disorders, and postoperative complications, contributing to increased morbidity, mortality, and healthcare costs [27-30]. This review aims to synthesize available evidence on nutritional and exercise interventions to determine their comparative effectiveness in improving muscle related outcomes in older adults with sarcopenia.

2. Methods

This systematic review and network meta-analysis was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and MetaAnalyses (PRISMA) guidelines [31]. The PRISMA checklist is provided in Table S1. The review was structured using the PICO framework, detailing the participants, interventions, comparisons, outcomes, and study designs of the included studies.

2.1 Search Strategy

A comprehensive literature search was conducted using five databases: PubMed (MEDLINE), Embase, Scopus, Cochrane CENTRAL, and Web of Science, covering the period from database inception to February 2024. The search strategy included terms related to sarcopenia, older adults populations, and nutritional or physical interventions, using both keywords and MeSH terms. Additionally, the reference lists of all included studies and relevant systematic reviews were manually screened. The screening process was performed independently by two reviewers using Rayyan.ai. Duplicate records were removed both automatically and manually. Details of the full search strategy are available in Supplementary Table S2.

2.2 Eligibility Criteria

Eligible studies included only randomized controlled trials. Other study designs, unpublished articles, and preprints were excluded. Only articles published in English were considered. Studies were required to involve older adults aged 60 years or older diagnosed with sarcopenia based on recognized diagnostic criteria (EWGSOP, EWGSOP2, IWGS, or AWGS). To be included, studies had to evaluate either nutritional or physical interventions and report at least one of the primary outcomes of interest. Two types of interventions were considered: nutritional and physical. Nutritional interventions included studies assessing whey protein supplementation at a dose of ≥1.2 g protein/kg body weight/day for a minimum of 8 weeks, as well as other nutritional approaches such as multivitamins, alternative protein sources, and leucine-based supplements. Physical interventions included exercise-based programs involving resistance training or multimodal regimens that combined aerobic, resistance, balance, and flexibility components.

2.3 Study Selection and Data Extraction Process

Study selection was conducted independently by two reviewers, who screened titles and abstracts for relevance, followed by full-text review of potentially eligible studies. Disagreements were resolved through discussion or consultation with a third reviewer. The selection process followed PRISMA guidelines and was documented using a standardized flow diagram.

Data were extracted independently by two reviewers using a predefined extraction form. Extracted information included publication year, country of study, sample characteristics (e.g., age, diagnostic criteria, baseline functional status), intervention details (e.g., type, duration, dosage), outcome measures, and follow-up duration. Any discrepancies in data extraction were resolved by consensus. If necessary, corresponding authors were contacted for clarification or missing data.

2.4 Risk of Bias Assessment

The risk of bias was assessed using the Cochrane risk-of-bias tool, which evaluates domains such as selective outcome reporting and missing data. Two reviewers conducted the assessments independently, and disagreements were resolved through discussion or consultation with a third reviewer. Publication bias was assessed qualitatively based on study characteristics and reporting completeness.

2.5 Outcomes

Eligible studies had to report at least one of the following outcomes: handgrip strength, appendicular muscle mass (AMM), or gait speed, based on standardized assessment protocols.

2.6 Statistical Analysis

For dichotomous outcomes, treatment effects were calculated using log odds ratios. For continuous outcomes, standardized mean differences (SMDs) were used as effect sizes. All analyses were conducted using a frequentist approach. A network meta-analysis was performed to synthesize direct and indirect evidence, provided that the distribution of potential effect modifiers across comparisons was sufficiently similar. Random-effects network meta-analyses were conducted using the netmeta package in R. Results were presented as network plots, forest plots, league tables, and ranking plots based on Pscores. Inconsistency between direct and indirect evidence was assessed globally using the design-by-treatment interaction model. When inconsistency was detected, sidesplitting analysis was applied using the netmeta package to identify specific loops contributing to inconsistency.

3. Results

A total of 5285 studies were identified during the databases search and 20 were included after the selection process in this systematic review and network meta-analysis [32-51].

More details are available on PRISMA flowchart (Figure 1).

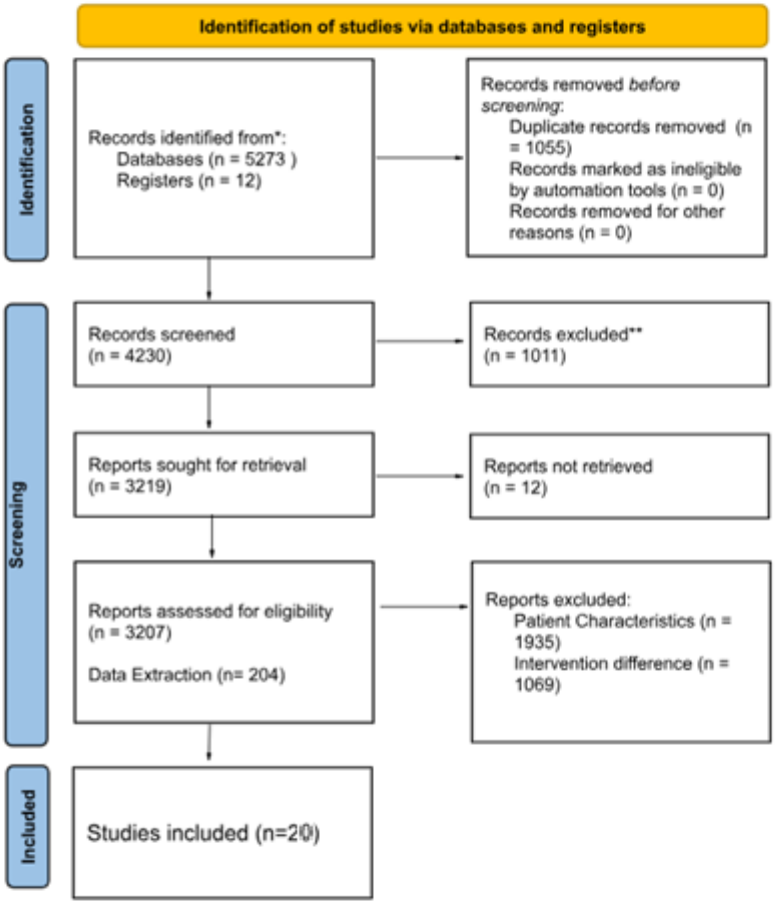

Figure 1: PRISMA Flowchart

The studies spanned across multiple geographic regions, with a significant number originating from Europe and Asia. The average age of participants was 68.5 years, with a nearly equal distribution of males and females. The characteristics of included studies are available in Supplementary Table S3.

3.1 Handgrip Strength

The network meta-analysis included fifteen interventions assessing their effects on handgrip strength (Figure 2). Vitamin C supplementation showed a small positive effect (treatment effect [TE]: 0.148; 95% confidence interval [CI]: –0.463 to 0.759; p = 0.636), with a P-score of 0.65. Vitamin E supplementation produced a similarly small, non-significant effect (TE: 0.091; 95% CI: –0.492 to 0.824; p = 0.806), and a Pscore of 0.64. Resistance training demonstrated a modest positive effect (TE: 0.081; 95% CI: –0.165 to 0.326; p = 0.521), with a P-score of 0.62. Aerobic exercise did not contribute to strength improvement (TE: –0.004; 95% CI: –0.864 to 0.856; p = 0.993), with a Pscore of 0.49. Fatty acid supplementation showed no meaningful effect (TE: –0.052; 95% CI: –0.963 to 0.858; p = 0.910), with a P-score of 0.45. Protein supplementation was associated with a slight negative effect (TE: –0.079; 95% CI: –0.357 to 0.200; p = 0.580), with a P-score of 0.38. Vitamin D supplementation had a negligible impact on handgrip strength (TE: –0.19; 95% CI: –0.604 to 0.223; p = 0.944), with a P-score of 0.28.

Despite none of the interventions reaching statistical significance, vitamin C and vitamin E ranked highest based on P-scores, suggesting a higher probability of being among the most effective interventions. Resistance training, although not top-ranked, consistently showed a modest positive effect and remains clinically relevant due to its broader impact on musculoskeletal function. The wide confidence intervals observed across interventions reflect underlying heterogeneity and highlight the need for further high-quality trials focusing specifically on handgrip strength as a primary outcome. No evidence of publication bias was detected based on funnel plot symmetry and Egger’s test (p = 0.5959).

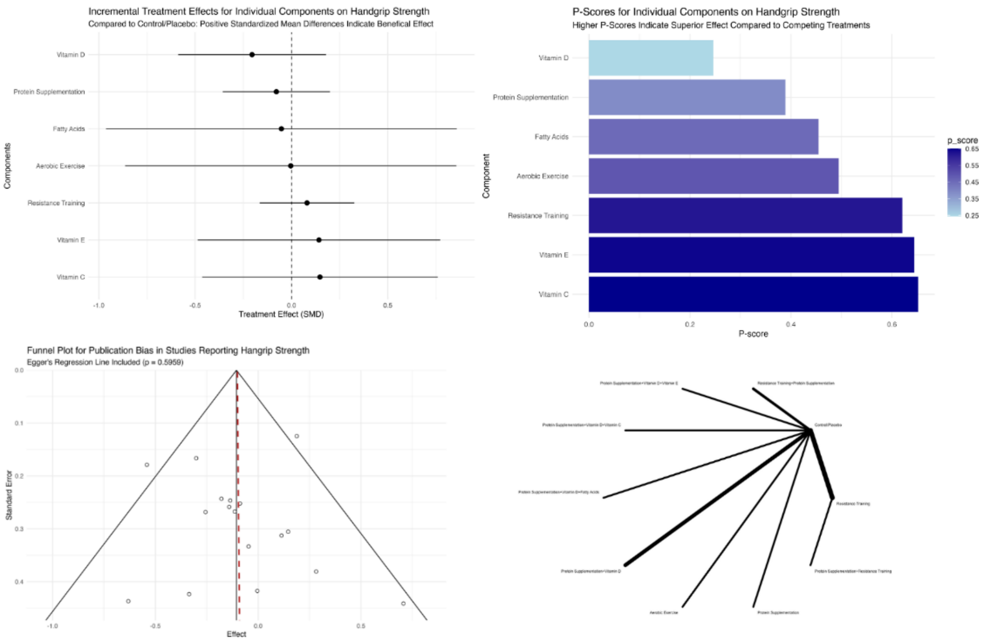

Figure 2: Treatment Effects, P-scores, Funnel Plot and Network Meta-Analysis for Handgrip Strength

3.2 Appendicular Muscle Mass (AMM)

The network meta-analysis included eleven interventions assessing their effects on AMM (Figure 3) [32-42]. Resistance training demonstrated the highest treatment effect on appendicular muscle mass (treatment effect [TE]: 0.436; 95% confidence interval [CI]: – 0.286 to 1.157; p = 0.236), and had the highest P-score (≈0.66). Vitamin C supplementation also showed a positive, but non-significant effect (TE: 0.223; 95% CI: – 0.978 to 1.424; p = 0.716), with a P-score of approximately 0.57. Aerobic exercise showed a similar effect size (TE: 0.195; 95% CI: –0.873 to 1.263; p = 0.720), with a P-score of 0.56. Vitamin D supplementation yielded a smaller positive effect (TE: 0.089; 95% CI: – 0.946 to 1.124; p = 0.866), with a P-score of 0.46. Vitamin E had a minimal effect on muscle mass (TE: 0.009; 95% CI: –1.228 to 1.127; p = 0.860), with a P-score of 0.44. Protein supplementation was associated with a slight negative effect (TE: –0.235; 95% CI: –0.808 to 0.338; p = 0.421), ranking lowest with a P-score of approximately 0.23.

None of the interventions reached statistical significance in improving appendicular muscle mass. However, resistance training and vitamin-based interventions exhibited positive trends. The ranking probabilities based on P-scores suggest that resistance training may be the most promising strategy, although the wide confidence intervals indicate substantial uncertainty. No evidence of publication bias was observed (Egger's test, p = 0.2931), and the network plot showed well-connected comparisons among interventions.

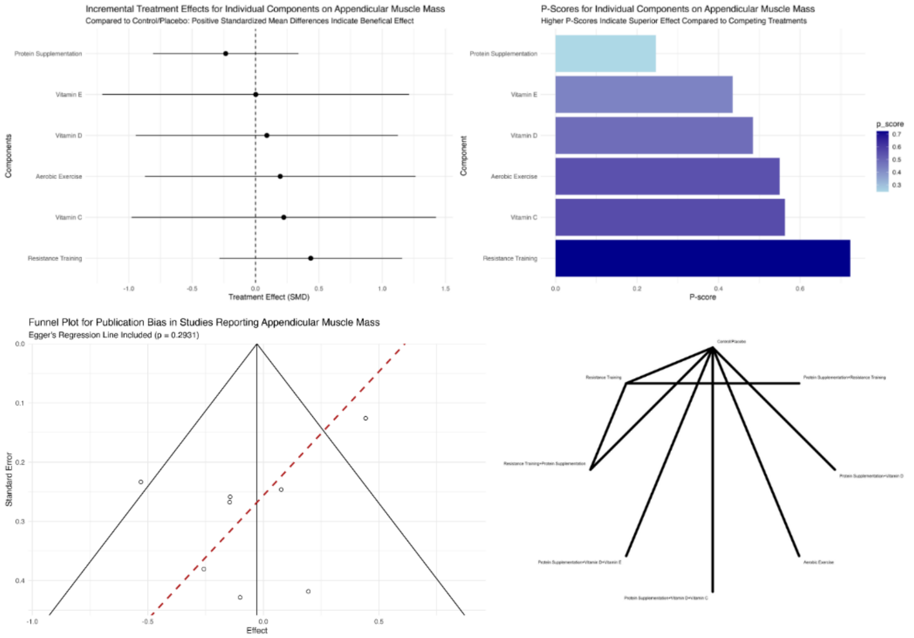

Figure 3: Treatment Effects, P-scores, Funnel Plot and Network Meta-Analysis for Appendicular Muscle Mass

3.3 Gait Speed

The network meta-analysis included twelve interventions assessing their effects on gait speed (Figure 4) [33,36-40,42-47]. Calcium supplementation demonstrated the strongest effect on gait speed (treatment effect [TE]: 1.174; 95% confidence interval [CI]: 0.294 to 2.053; p = 0.009), and had the highest P-score (0.89). Fatty acid supplementation showed a positive but non-significant effect (TE: 0.778; 95% CI: –0.485 to 2.041; p = 0.227), with a P-score of approximately 0.66. Vitamin C was also associated with a non-significant positive trend (TE: 0.587; 95% CI: –0.324 to 1.498; p = 0.207), with a P-score of 0.57. Vitamin E yielded a non-significant modest effect (TE: 0.449; 95% CI: –0.524 to 1.422; p = 0.368), with a P-score of 0.53. Resistance training had an, also non-significant small effect (TE: 0.031; 95% CI: –0.253 to 0.316; p = 0.828), with a P-score of 0.35. Vitamin D supplementation showed minimal non-significant benefit (TE: 0.174; 95% CI: –0.842 to 0.529; p = 0.707), with a P-score of 0.18. Protein supplementation was the least effective, but also non-significant (TE: –0.146; 95% CI: –0.468 to 0.176; p = 0.374), with the lowest P-score (0.16).

Among the evaluated interventions, only calcium supplementation resulted in a statistically significant improvement in gait speed. Other strategies, such as fatty acid and vitamin C and E supplementation, exhibited positive trends but did not reach statistical significance. Resistance training, while effective in other functional domains, showed limited benefit for gait speed. The network was well connected, and there was no evidence of publication bias based on funnel plot symmetry and Egger's test (p = 0.7358).

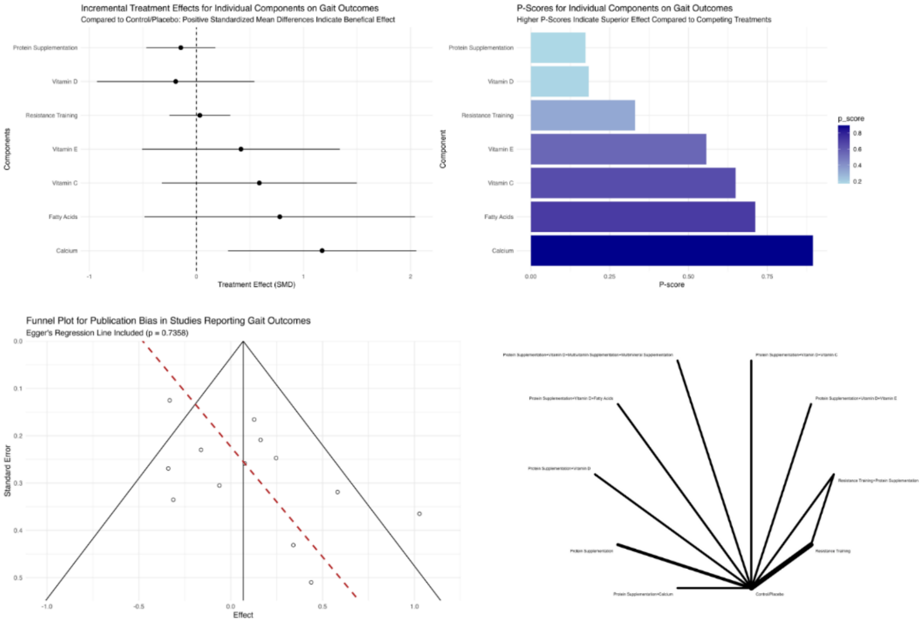

Figure 4: Treatment Effects, P-scores, Funnel Plot and Network Meta-Analysis for Gait Speed

4. Discussion

Sarcopenia is a multifactorial condition that significantly impairs quality of life and functional independence among older adults. This systematic review and network metanalysis aimed to compare the effects of nutritional and exercise interventions on muscle strength, mass, and physical performance in older adults diagnosed with sarcopenia. While most interventions did not reach statistical significance, several demonstrated promising trends consistent with prior literature, underscoring the potential of combined approaches to manage sarcopenia effectively.

Among all interventions, calcium supplementation showed a statistically significant improvement in gait speed. While calcium is traditionally associated with bone health, it may also influence neuromuscular function, excitation-contraction coupling, and neurotransmission, which could explain the observed improvements in mobility [52,53]. Although few studies have evaluated calcium supplementation alone in the context of sarcopenia, some evidence suggests it may improve physical performance in this population [54]. Our finding highlights the need to further investigate its potential role as part of a multimodal therapeutic strategy.

Resistance training consistently demonstrated favorable trends across multiple outcomes, including handgrip strength and appendicular muscle mass, although none of the effects reached statistical significance. These findings align with previous studies reporting improvements in muscle strength, mass, and overall function in older adults with sarcopenia [19,55]. Given its accessibility, low cost, and additional benefits for balance and metabolic health, resistance training remains a cornerstone in the management of muscle loss in aging populations.

Nutritional interventions such as protein and vitamin D supplementation also showed variable, non-significant effects in our analysis. Nevertheless, previous evidence suggests their effectiveness in enhancing strength, muscle mass, and/or physical performance when used alone or in combination with physical training [56,57]. On the other hand, there is some evidence that whey protein, leucine, and vitamin D supplementation can increase appendicular muscle mass in patients with sarcopenia, but a physical program is necessary to improve both muscle strength and physical function [58].

Other interventions—such as fatty acid supplementation, vitamins C and E, and aerobic training—demonstrated modest, non-significant improvements. While these strategies ranked lower in the network analysis, they may still provide ancillary benefits, especially when integrated into holistic care models that include resistance training and targeted nutritional support. Fatty acid, like omega-3, has been suggested to benefit muscle mass (with high doses) and improve muscle function, although the changes are small and unlikely to be clinically meaningful, and the interpretation of the findings is limited by the small number of participants, heterogeneity of supplementation regimens, and different measuring protocols [59]. Antioxidant vitamins, like vitamin C and E, are thought to prevent oxidative stress and may be able to play a role in the treatment of sarcopenia. However, there is not enough convincing evidence to support the use of vitamin E and vitamin C for the prevention and treatment of sarcopenia [60].

This study has several limitations. Heterogeneity in study design, diagnostic criteria, intervention duration, and population characteristics may have influenced effect estimates. Additionally, some interventions were underrepresented, limiting the statistical power and precision of comparisons. Pharmacological therapies, although discussed in the context of sarcopenia, were not included in this analysis and should be examined in future studies. Variability in baseline nutritional status and incomplete reporting of adherence also limit the generalizability of our findings. Despite these limitations, this network meta-analysis contributes to the growing evidence base supporting non-pharmacological interventions for sarcopenia. The findings highlight calcium supplementation as a promising strategy to improve gait speed and reinforce the value of resistance training in preserving muscle strength and mass. Future research should focus on determining the most effective combinations of nutritional and exercise based interventions, ensuring scalability, adherence, and long-term sustainability in real-world clinical settings.

5. Conclusion

This systematic review and network meta-analysis highlights the potential of nonpharmacological interventions to address sarcopenia in older adults. Although most interventions did not reach statistical significance, resistance training and calcium supplementation showed the most promising trends in improving muscle-related outcomes. Calcium supplementation was the only intervention associated with a significant improvement in gait speed. Resistance training, despite non-significant results, demonstrated consistent benefits across strength and muscle mass outcomes. These findings underscore the importance of exploring combined nutritional and physical strategies and emphasize the need for further high-quality trials to optimize treatment approaches for sarcopenia.

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