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REVIEW

Effect of protein and amino acids supplements on muscle strength and physical performance: A scoping review of randomized controlled trials

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Abstract

Protein and amino acid supplementation is an effective intervention that significantly enhances physical function and reduces frailty and sarcopenia in older adults. This scoping review aims to map and synthesize the available evidence on the effects of various types of protein and amino acid supplementation in this population. Following the PRISMA-ScR guidelines, we conducted a literature search to identify clinical trials examining the effects of protein and amino acid supplementation, with or without physical exercise, on muscle strength, physical performance, and body composition in healthy, frail, or sarcopenic older adults. Our analysis of 80 trials with a total of 5290 participants examines the evidence for the effectiveness of protein supplementation in enhancing muscle strength and body composition. Whey protein, creatine, milk protein, leucine, essential amino acids, and soy protein were the most used types of protein, and our findings indicate that whey protein, creatine, and milk protein yield the best results when used in conjunction with resistance training. Additionally, leucine and milk protein have shown the potential to enhance body composition even without concurrent resistance training. In conclusion, studies on the effectiveness of whey protein in improving muscle strength and body composition in older adults with resistance training are inconsistent. More research is required to explore the potential benefits of soy and leucine-enriched supplements. Protein supplementation's impact on physical performance remains inconclusive. Further studies are needed to determine the effects of protein types and supplementation on muscle-related parameters in older adults.

KEYWORDS

essential amino acids, muscle strength, protein, physical performance, supplementation

INTRODUCTION

The process is linked to a gradual reduction in muscle mass and strength, accompanied by broader declines in other physiological functions. This multifaceted decline ultimately contributes to functional limitations, more pronounced disability, and an increased reliance on assistance.[1] Over the past few decades, the older adult population has experienced an escalating increase in the risks of falls, loss of independence, and even premature death.[2] This situation is further exacerbated by the higher economic burden placed on the healthcare system.[2] Frailty is a complex, multidimensional syndrome characterized by a reduction in physiological reserve across several body systems, leading to an increased vulnerability to stressors and adverse outcomes such as falls, disability, and hospitalization.[3] Sarcopenia, on the other hand, refers specifically to the progressive loss of skeletal muscle mass and strength, which directly impacts physical performance.[4] Frailty and sarcopenia are significant public health problems in older adults; these issues affect their physical function and quality of life, and increase their risk of falls, fractures and hospitalization.[5] As the world population continues to age, there is a growing need for interventions that can prevent or treat frailty and sarcopenia and improve the health and independence of older adults.

As a modifiable lifestyle factor, nutrition holds the potential to promote active and healthy.[6] Notably, a protein intake exceeding the current recommended dietary allowance (RDA) of 0.8 g/kg/day has been suggested as a viable approach to safeguard physical function in older adults.[7] Protein is essential for maintaining muscle mass and function, and sufficient protein intake is crucial for preventing muscle loss and functional decline in older adults.[8] However, older adults often have a decreased appetite and decreased ability to absorb protein, which can lead to protein malnutrition and an increased risk of frailty and sarcopenia.[9]

Protein supplementation has been shown to increase muscle mass, strength and physical function in older adults.[10,11] Furthermore, protein supplementation improves physical function,[12,13] body composition[14–16] and muscle strength[17–20] during physical exercise. The effects of protein supplementation on frailty and sarcopenia are thought to be due to increased muscle protein synthesis and improved muscle function, which can lead to improved physical performance and reduced risk of falls and fractures.[21]

Despite the evidence that protein supplementation can improve physical function and reduce frailty in older adults, there is still a need for more research to fully understand the effects of different types of protein on frailty and sarcopenia. Different sources of protein, such as whey, soy and milk, have distinct amino acid profiles and rates of digestion, and they may exert dissimilar effects on muscle protein synthesis and physical performance.[5] Furthermore, it is not clear which type of protein is the most effective or safe for older adults, and what the optimal amount of protein supplementation is for reducing the risk of frailty and sarcopenia.

This scoping review specifically aims to provide a comprehensive overview of the available literature on the effects of various protein supplementation strategies on sarcopenia-related outcomes, such as muscle strength, muscle mass, and physical performance in older adults. This approach was chosen to map the existing evidence, explore the types of protein studied, and identify gaps in the literature. By synthesizing the available evidence, this scoping review aims to guide healthcare professionals and researchers in understanding the current landscape of protein supplementation research and highlight areas that require further investigation to support older adults in reducing the risk of frailty and sarcopenia.

MATERIALS AND METHODS

We completed this review in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR).

Data resources and search strategy

We conducted this review by performing thorough automated online searches. We searched the following online databases for articles: PubMed, EMBASE, the Cochrane Library Database, Scopus, and Google Scholar. The search covered RCTs published in English between January 1, 2000, and July 1, 2022. Our search strategy incorporated keywords related to the target population (eg, frailty, older adults), interventions (eg, protein supplementation), and outcomes (eg, muscle strength, physical performance). The full search strategies for each database are detailed in (Table S1).

The initial step involved reviewing the titles and abstracts retrieved from the searches. Two independent reviewers (AHA and ZAZ) conducted the abstract screening. In instances where there was disagreement about whether a study should be included or excluded, a third reviewer (SAA) was consulted to reach a consensus. Abstracts that lacked sufficient information to determine eligibility were flagged for full-text retrieval and further evaluation.

For the full-text screening phase, two independent reviewers (AHA and NMY) assessed each article. Any disagreements during this stage were resolved through discussion with the third reviewer (SAA). The full-text articles were evaluated for relevance based on the eligibility criteria outlined in the following section. To ensure no relevant studies were overlooked, we manually examined the reference lists of included articles to identify any additional studies that might have been missed during the initial database searches. The study selection process is illustrated in (Figure 1), which provides a flowchart of the studies selection.

Eligibility criteria

We applied the following inclusion criteria: (1) complete, peer-reviewed studies published in English; (2) randomized controlled trials (RCTs) conducted in humans that investigated the effects of protein or amino acid supplementation alone or in combination with

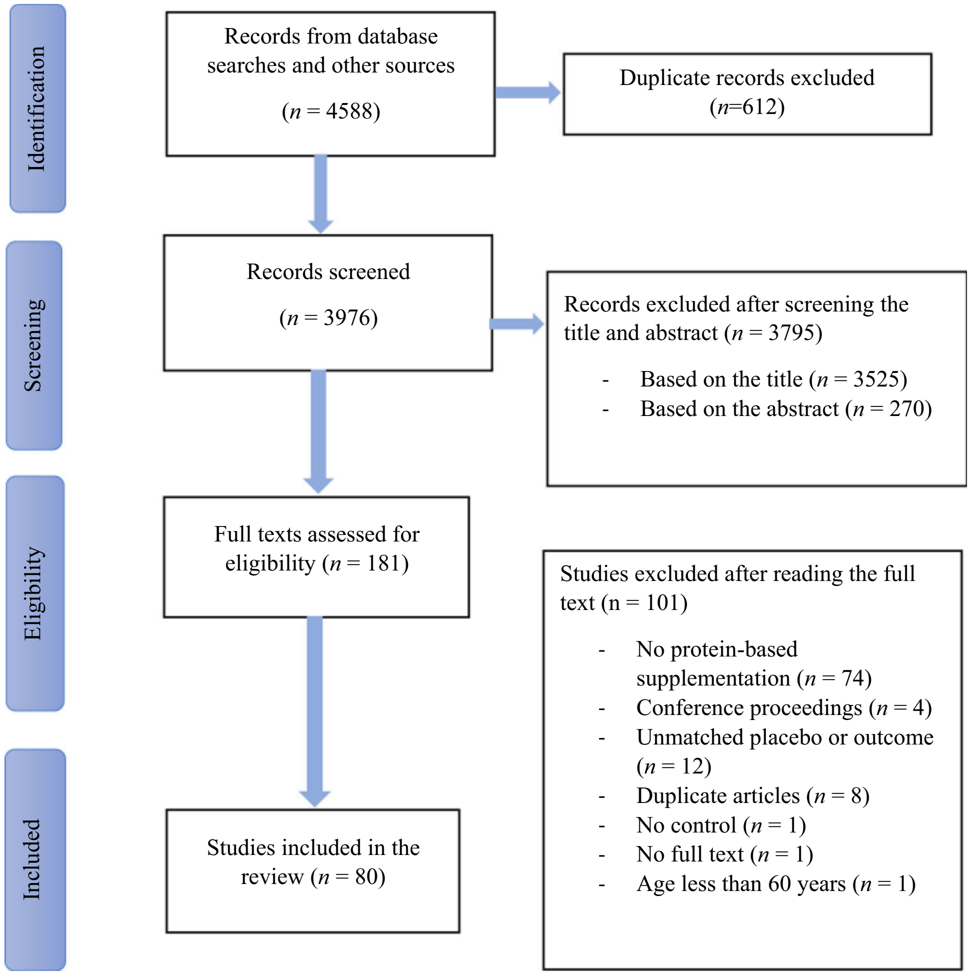

FIGURE 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart of the study selection process.

resistance training (RT) or compared protein or amino acid supplementation with a nonprotein control or placebo during resistance training; (3) studies including male and female participants with a mean age of ≥60 years, regardless of living setting (eg, community-dwelling, nursing homes, outpatient settings); and (4) studies that assessed at least one of the primary or secondary outcomes of this review, including muscle strength (upper and lower extremities), physical performance (e.g., gait speed, chair-stand test), and body composition (eg, lean body mass, fat-free mass, muscle mass, total body fat) measured using dual-energy X-ray absorptiometry or bioelectrical impedance analysis. We excluded publications not written in English, studies available only as abstracts, conference proceedings, and research protocols.

Data collection and synthesis

Two authors conducted the full-text screening, and any disagreements regarding the inclusion of studies were resolved through discussion. If a consensus could not be reached, a third reviewer was consulted to resolve the discrepancy. To streamline the subsequent steps, all selected articles and their corresponding key categories were organized into a single Excel file. The relevant outcome data from each study were extracted and grouped according to the type of supplement used.

RESULTS

After conducting the literature search across the aforementioned databases, we initially identified 4588 studies. Following the elimination of 612 duplicate studies, we reviewed 3976 studies. Nine studies were found through manual searches of the reference lists of the full-text publications we included. Ultimately, we included a total of 80 articles that examined the effect of various types of protein supplementation in this review (Figure 1).

Study characteristics

The 80 included trials used 11 different types of protein and amino acid supplements and included a total of 5290 participants. The median number of participants per trial is 48, indicating that half of the trials had <48 participants and half had more. The IQR (31 to 99) shows that the middle 50% of trials had between 31 and 99 participants. This suggests that most trials in this review were relatively small, with a few larger trials (eg, 200, 208, and 218 participants) skewing the upper range. The population areas included the Americas (34 trials), Europe (32 trials), Asia (12 trials), and Oceania (two trials). Regarding the population types, 43 trial populations were healthy community dwellers; 12 trials targeted prefrail, frail (according to Fried criteria), malnourished, or sarcopenic older adults; 11 trials focused on older adults with special conditions or diseases such as arthritis, osteopenia, osteoporosis, type 2 diabetes, heart failure, or obesity; seven trials examined postmenopausal women; six trials examined low-activity or sedentary older adults; and three trials evaluated inpatient, posthospitalized, or residential care centre patients. Twenty-three trials only included older women, 13 trials only included older men, and the remaining 46 trials targeted older men and women.

The interventions in the included studies varied in duration. Eleven studies focused on periods up to 10 weeks, 32 studies had durations of 12 to 14 weeks, 23 studies spanned 4 to 6 months, six studies lasted 8 to 12 months, and four studies extended beyond 1 year. The outcomes measured in the included studies were mostly muscle strength, whether upper or lower extremity strength (*n* = 54), and body composition (*n* = 55). The last and least measured is physical performance (*n* = 25). Of the included trials, 59 included RT. Thirty-eight of these trials applied supervized whole-body RT, which was graded into low, moderate, and high-intensity training based on the intensity of the exercises performed. Low-intensity RT typically involved light resistance with higher repetitions (eg, <50% of one-repetition maximum), moderate-intensity RT used moderate resistance with moderate repetitions (eg, 50%–70% of one-repetition maximum), and high-intensity RT involved heavy resistance with fewer repetitions (eg, >70% of one-repetition maximum). Seven trials conducted training programs exclusively targeting the upper and/or lower limbs. Seven trials used different types of training such as exergames which are defined as exercise programs that incorporate interactive video games, walking, balance training and endurance training, among others, and four trials applied self-administered, home-based training. Twenty-four trials tested the effect of protein supplementation alone without training. Other specific characteristics of the studies are described in Table S2.

Supplement characteristics

Types of protein and amino acid supplements

The studies investigated the following protein and amino acid supplements, grouped into categories based on the most commonly used types: whey protein (*n* = 32); creatine (*n* = 12); milk protein (*n* = 11); leucine (*n* = 8); essential amino acids (*n* = 6); and other types such as soy protein (*n* = 4), citrulline (*n* = 2), L-carnitine (*n* = 2), collagen peptides (*n* = 1), L-arginine (*n* = 1), and beta-alanine (*n* = 1), as shown in (Figure 2).

Supplement dosage and timing and RT

Whey protein

Eight studies investigated the effects of whey protein on muscular strength, physical performance, and body composition, and 24 studies examined the effect of whey protein supplementation alongside resistance exercise on the aforementioned measures. Eleven studies

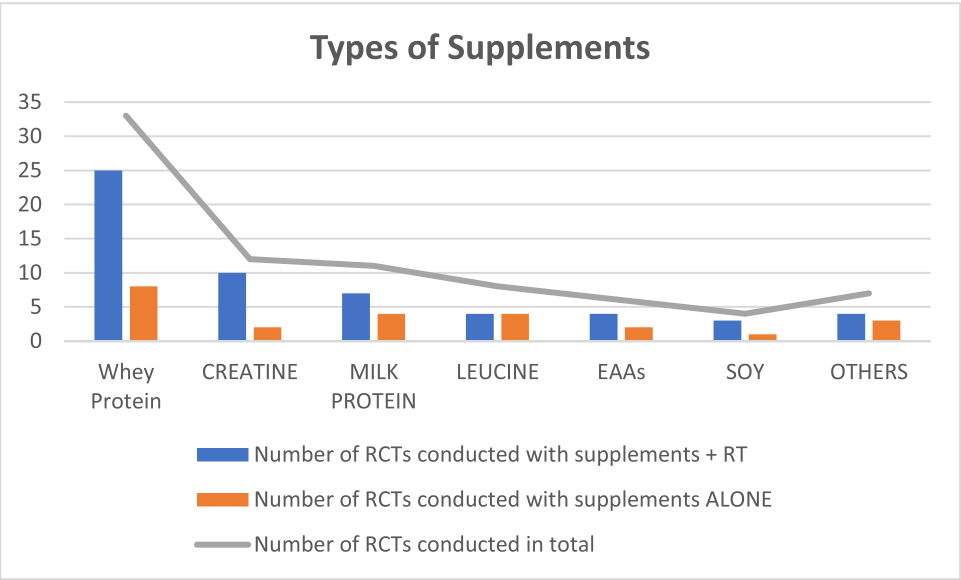

FIGURE 2 The number of studies that evaluated different types of protein supplements. EAAs, essential amino acids; RCT, randomized controlled trial; RT, resistance training.

employed 40 g or more of whey protein per day,[17,21–30] whereas seven trials used an amount of 30–39 g/day[16,30–35] and 11 trials used <30 g/day.[11,13,18,36–43] Additionally, three trials employed a technique to determine protein consumption to achieve whey protein supplementation of 1.2–1.5 g/kg/day.[10,44,45]

The studies that tested the effect of whey protein supplements combined with RT mostly applied full-body training ($n = 19$). Another three studies focused on upper and lower extremities in their training programmes[13,36,40] and two studies applied home-based training.[22,38] Biesek et al. (2021) investigated the effectiveness of exergames when combined with whey protein on muscle strength and physical performance of older adults.[43] Whey protein supplement timing was linked to the RT programme in 15 of the 32 studies. In eight of them, supplements were consumed after training on the training days only,[16,22,31,32,35–37,42] whereas, in the remaining seven studies, the researchers instructed the participants to also consume whey protein supplement either after training or during meal times on nontraining days.[18,23,30,33,39,40,43] Moreover, 11 studies linked the intake of whey protein supplement with regular meal times.[11,17,24,27,28,34,38,44–47]

Creatine

Twelve studies tested the effect of creatine supplementation on muscle strength and physical performance. Most of these studies applied RT combined with creatine supplementation ($n = 10$); however, two trials tested the effect of creatine alone.[48,49] Creatine supplementation was combined with whole-body exercises,[50–55] upper limb RT,[56] lower-limb RT,[57] high-velocity RT[58] or chest and leg press exercise.[59] The creatine dose was 0.1 g/kg,[50–53,58] 5 g/day,[54–57] 3 g/day[49] or 1 g/day.[48] Baker et al. (2015) used a 20 g creatine bolus delivered on two occasions 7 days apart.[59] The timing of creatine supplement consumption in seven studies was connected with training time (before or after),[50–54,56,59] whereas, in three studies, the participants consumed the supplements during meal times.[49,51,55]

Milk protein

Eleven studies evaluated the effect of milk protein either combined with RT or alone on muscle strength and body composition. Four studies tested the effect of milk protein in older adults alone,[60–63] six studies combined milk protein supplementations with RT,[64–69] and one study applied walking exercise.[15] The dosage of milk protein supplementation varied widely, from ≤10 g/day,[65,68,69] 11–30 g/day approximately,[61,67] 30–35 g/day,[15,63,64,66] or >35 g/day.[60,62] The timing of supplement intake was mostly at meal times, especially breakfast and lunch,[60–64,66,67] and after training,[69] or with meals on nontraining days in the trials with RT.[66,68,70]

Leucine

Eight studies investigated the effect of leucine on frailty functions[12,14,19,71–75]; four studies administered leucine supplementation without concomitant RT.[12,71,72,75] The RT programme in most of the studies was low-to-moderate intensity[14,19,74] or involved lower-limb exercises alongside balance training.[73] Leucine was consumed either as a single component[71,73] or as leucine-enriched amino acids[12,14,19,74] or protein supplementation.[72,75] The daily dosage of leucine or leucine-enriched supplement was 2.4–8.4 g in most trials, except for one that administered 10 g per day.[73] Most of the researchers instructed the participants to consume leucine or leucine-enriched supplements during meal times. However, in one study, the participants consumed leucine-enriched amino acid supplements after performing sit-to-stand exercises.[14]

Essential amino acids

Six studies assessed the effect of essential amino acids on frailty functions in older adults. Four studies applied full-body training throughout the weeks,[76–79] and another two studies included home-based exercises for women with osteoarthritis[20] and older adults with heart failure.[80] The dosage of the mixed amino acid supplements ranged from 3 to 6 g,[20,78,79] 10 g[76,80] and 15 g[81] per day. These participants were instructed to take the supplements after breakfast or between meals.[78,80,81] In two studies, supplementation only occurred on training days, either before[20] or after training.[76]

Other supplements

Four studies tested the effect of soy protein on muscle strength and body composition of postmenopausal women[82,83] or sarcopenic older adults.[4,84] The soy protein dose was 40 g,[84] 20–25 g[82,83] or 1.5 g/kg[4] per day. Two studies applied full-body training 3 days[82] or 4 days[84] per week, whereas one study applied home-based exercises.[4]

Citrulline[85] and L-citrulline[86] supplementation was explored in two studies, with a dosage of 10 and 3 g per day, respectively to evaluate their effect on muscle strength and physical performance in older adults. One study applied high-intensity RT 3 days per week for sedentary older adults with obesity,[85] whereas the other study used balance and aerobic exercises.[86]

Two studies examined L-carnitine supplementation with no concomitant RT to test its effect on older adults' muscle strength and body composition. The dosage was 1.5 g/kg[87] or 1500 mg[88] per day. Collagen peptides,[89] L-arginine,[90] and beta-alanine[91] were applied at 15, 8, and 3.2 g per day, respectively. Collagen peptides were used in combination with full-body training 3 days per week.[89] Beta-alanine was combined with endurance exercises,[91] whereas Aguiar et al. tested the effect of L-arginine supplementation alone on muscle strength of older adults.[90]

THE EFFECT OF PROTEIN SUPPLEMENTATION ON THE OUTCOME MEASURES

Whey protein

Whey protein supplementation did not increase the adaptive response to RT in terms of muscle strength (one-repetition maximum of chest press, bench press, leg press or knee extension)[16,23,24,27–29,33,39,44] or handgrip strength.[22,36,38,40,43,46] However, several studies reported significant improvements in muscle strength, as measured by tests such as the leg press, knee extension, chest press, and handgrip strength, following RT combined with whey protein supplementation.[13,17,18,35,41,42] For example, Bell et al. found that the addition of a multiingredient nutrition supplement containing whey protein significantly increased strength during both the first phase of supplementation alone and the later phase in combination with exercise, particularly in upper-body strength.[17] Similarly, Karelis et al. demonstrated that cysteine-rich whey protein combined with RT resulted in a 39.3% increase in muscle strength compared with the control group.[18] The timing of protein supplementation varied across studies: some studies, such as Atherton et al., Junior et al., and Bell et al., administered protein immediately postexercise,[17,35,42] whereas others, like Mori et al. and Mertz et al., provided protein before exercise or twice daily as part of the supplementation regimen.[13,41]

In terms of physical performance, gait speed tended to improve after whey protein supplementation combined with RT,[13,24] but there were no advancements in the Timed Up and Go test, the 30-s chair-stand test, and the 6-min walk test.[28,37,44,92] In addition, many studies showed that lean body mass,[18,23,28,33,37,40,46] lean soft tissues,[27,30] muscle mass,[39,43,45] and fat mass[33,45] did not change when combining whey protein supplementation and RT. However, other studies showed whey protein supplementation and RT improved lean body mass,[17] lean soft tissues,[16,31,32] muscle mass,[13,35,38] and fat mass.[16,32,42,46]

Regarding the studies without RT, most studies reported that whey protein supplementation did not enhance handgrip strength[10,25,34] or knee extension.[34] However, one study found significant improvements in both measures, with the whey protein supplementation (WPS) group showing greater increases in grip strength and knee extensor force compared with the control group.[11] Physical performance, measured by the short physical performance battery test (SPPBT) (which compromises three tests, balance test, gait speed test, and chair-stand test), walking test, and the Timed Up and Go test, showed no improvements in older adults consuming whey protein despite the duration or the dose.[10,11,25,34] However, whey protein significantly improved fat-free mass at 45 g/day in healthy older adults.[26] Moreover, gait speed and appendicular skeletal muscle mass were enhanced after consuming 1.5 g/kg/day of whey protein in undernourished older adults.[10]

Creatine

Regarding muscle strength, creatine supplementation combined with full-body RT (3 days/week) improved upper-body strength, as measured by one-repetition maximum for chest press with 0.1 g/kg/day,[50,53] biceps curl with 5 g/day,[54] and bench press with 5 g/day.[54,55] Similarly, lower-body strength improved in terms of one-repetition maximum for leg press with 0.1 g/kg/day and full-body RT (3 days/week)[50,53,58] and knee extension with 5 g/day and 2–3 days of RT[54,58] in healthy men and postmenopausal women. However, in other studies, creatine supplementation did not provide additional benefits to RT at 0.1 g/kg and 20 g per day in terms of upper muscular strength measured by one-repetition maximum for chest press,[52,59] bench press, biceps curl, and knee extension after receiving 5 g of creatine supplement along with upper and lower extremities training in healthy men.[56]

Four studies evaluated the effects of creatine supplementation on physical function. Two studies reported positive effects when creatine was combined with high-velocity RT: one study[58] in healthy older men found that a creatine dose of 0.1 g/kg/day improved the peak torque of the knee flexors and extensors. It also enhanced balance board time-to-completion, a test where participants walked backwards (toe to heel) along a narrow board, with faster times indicating better balance. Another study[57] in older women with knee osteoarthritis observed improvements in the 30-s sit-to-stand test, using a higher creatine dose of 20 g/day alongside lower-limb RT. In contrast, creatine supplementation alone did not improve muscle function as assessed by the Timed Up and Go test and the timed-stand test[48,49] in osteopenic postmenopausal women, in which the creatine dose was significantly lower (1 or 3 g/day).

Studies that combined creatine supplementation with full-body training demonstrated improvements in some body composition measures such as lean body mass at 5 and 8 g/day,[53,55] muscle mass, and bone mineral density at 5 g per day[51] in healthy older adults. On the other hand, in other studies there were no significant changes in lean body mass and bone mineral density with 1 or 3 g of creatine supplementation either alone osteopenic postmenopausal women[48,49] or when combined with full-body training and upper limps training[52,56] in older adults. In addition, compared with placebo, 0.1 g/kg/day of creatine supplementation alongside full-body training did not improve fat mass or bone mineral density in healthy men.[52]

Milk protein

Milk protein supplementation alone[63] or combined with RT[67] had a positive effect in terms of physical performance for leg press[66] and knee extension.[67] However, in another study, milk protein supplementation did not improve these measures.[62] Moreover, pulse-feeding milk protein did not improve handgrip strength in malnourished or at-risk patients in an inpatient rehabilitation unit.[60]

Regarding body composition, milk protein significantly improved lean mass,[15,60,61,63,69] fat-free mass[68] and leg tissue mass.[67] Appendicular skeletal muscle mass was also improved following pulse-feeding of milk protein in malnourished older adults in an inpatient rehabilitation setting.[60] Another study showed a significant improvement in muscle mass of sedentary older adults when consuming 10 g of milk protein alongside full-body training.[68] Two studies, however, did not report any additional effect of milk protein with high-intensity functional training on muscle mass in older adults[65] or when consumed alone.[62,65] Finally, in three studies involving older adults who consumed milk protein at 10 g[68,69] per day and 31 g per day[15] with low-to-moderate-intensity exercises, fat mass improved significantly.

Leucine

The effect of leucine or leucine-enriched supplements on muscle strength or physical performance in the included studies is inconsistent. Significant improvements in handgrip strength were observed with leucine supplementation alone at 0.2 g/kg/day[12] and when combined with low-intensity training at 3 g/day[14] or lower-limb training at 10 g/day.[73] However, other studies reported no muscle strength improvement in terms of handgrip strength and knee extension with leucine doses of 21 g/day and 6 g/day[72,74] or in leg press strength at 7.5 g per day.[71]

Two studies reported no significant effect of leucine consumption on physical performance in terms of gait speed at 6 g/day with home-based training[74] or the SPPBT and the Timed Up and Go test at 6 g/day.[72] However, two studies found that leucine supplementation improved functional independence measure performance with 3 g/day and low-intensity RT[14] and upper-body and lower-body functional tests (eg, 30-s arm-curl test, 30-s chair-stand test, and 6-min walk test) with 11–21 g/day and no training.[12]

For body composition, leucine supplementation significantly improved lean body mass with 3 g/day,[75] lean tissue mass with 11–21 g/day,[12] and appendicular skeletal muscle mass with 3 g/day and low-intensity training[14] in community-dwelling older adults. On the other hand, leucine had no effect on fat-free mass with 7.5 g/day,[71] muscle mass in older adults with type 2 diabetes receiving 6 g/day and home-based RT,[74] or lean body mass in community-dwelling older adults consuming 6 g/day.[72]

Essential amino acids

The primary outcome in trials investigating essential amino acids (EAAs) was walking speed, which significantly improved in healthy older adults who participated in full-body RT (2 days/week) with 6 g/day EAAs[78] and in those undergoing home-based training with 10 g/day of EAAs.[76] However, no improvement was observed in women with arthritis performing self-administered training with 6 g/day EAAs.[20] In addition, walking time was improved in sarcopenic women after receiving 6 g per day of essential amino acids supplements alongside full-body training.[79] In terms of muscle strength, significant improvements were observed in knee extension in sarcopenic women consuming 6 g EAAs per day with 2 days of full-body training,[79] supplementing with 15 g/day EAAs and progressive aerobic RT,[81] and hip abductor strength in women with arthritis supplementing with 6 g/day EAAs, although handgrip strength did not improve.[20] For body composition, lean body mass did not improve in nonfrail, independent, healthy older adults who consumed 15 g/day EAAs alongside aerobic exercise.[81] However, leg muscle mass significantly increased in sarcopenic women after full-body training plus 6 g of essential amino acids supplementation.[79]

Other supplements

Soy protein supplementation at 20 g/day reduced total and subcutaneous abdominal fat in postmenopausal women.[83] When combined with full-body training, soy protein at 25 g/day and 40 g/day improved muscle strength measured by knee extension,[82,84] whereas a dose of 1.5 g/kg/day enhanced bench press and arm-curl test performance in older adults.[4]

Regarding other amino acid supplements, L-carnitine at 1500 mg/day,[88] L-arginine at 8 g/day[90] and beta-alanine at 3.2 g/day combined with endurance RT[91] did not improve muscle in healthy older adults. However, one study reported that 500 mg/day of L-carnitine improved handgrip strength in prefrail older adults.[87] Collagen peptides at 15 g/day, when consumed during or after full-body RT, improved body composition in sarcopenic older men by increasing fat-free mass and reducing fat mass.[89] For L-citrulline, 10 g/day showed beneficial effects on handgrip strength, knee extension, and fat mass reduction in sedentary older adults with obesity when paired with high-intensity training[85] and improved the walking speed of older adults when combined with balance and aerobic exercises at 3 g/day.[86]

DISCUSSION

This scoping review addresses the lack of a comprehensive synthesis of evidence on the effects of different types of protein supplementation on muscle strength, physical performance, and body composition in older adults. By mapping and summarizing findings from 80 trials, this review provides an overview of the current research landscape and highlights gaps that require further investigation.

Twenty studies examined the effects of protein supplementation alone on muscle strength, body composition, and functional ability in older adults, whereas 60 studies assessed its impact when combined with RT of varying types and intensity.

WPS was the most frequently utilized type of protein, applied by itself or in conjunction with home-based exercise interventions (in nine trials). However, our analysis indicates that in all but one study,[11] WPS does not significantly enhance muscle strength or physical performance.[10,22,25,34,38,40] These results coincide with two meta-analyses that evaluated the effect of increased protein intake beyond the RDA. The authors found that high protein intake has limited effects on muscle strength when not associated with physical training.[93,94] Furthermore, the impact of whey protein appears to be more evident in terms of body composition improvements, including enhancements in muscle mass[10,38] and fat-free mass.[26] Nevertheless, there remains a certain degree of contradiction within the literature concerning the effects of WPS on body composition.[10,21,25,34,40] Intriguingly, studies have highlighted that milk and leucine-rich protein supplements have superior effects compared with WPS over a relatively short duration (3–6 months) on the body composition of older adults.[12,14,15,60,61,75]

The reviewed studies exhibited substantial variability in RT intensity, ranging from low-intensity home-based exercises and upper/lower-limb resistance training to full-body RT and high-velocity RT. The training frequency also varied, with studies implementing 2–5 sessions per week, leading to differences in observed outcomes. Higher-intensity protocols, such as full-body training performed at least three times per week in combination with protein the supplement, were generally associated with greater improvements in muscle strength, body composition (including lean body mass and fat mass), and functional performance (eg, gait speed, chair-stand test, Timed Up and Go test).[17,18,54,68,81] However, some studies did not observe significant gains in certain measures, such as handgrip strength, and physical functions despite RT,[23,33,51,52] suggesting that total training volume, progression, and individual response may influence outcomes.

In contrast, moderate-intensity training (full-body RT or upper/lower-limb RT at 2–3 sessions per week) showed inconsistent results, with some studies reporting increases in muscle mass, fat mass reduction, and functional improvements,[13,58,64,79] whereas others found no significant effects compared with placebo.[24,28,36] Lower-intensity training with protein supplementation, such as home-based or light RT, generally resulted in minimal or no improvements across multiple outcomes, including muscle function or body composition, further underscoring the importance of progressive overload and training intensity in older adults.[20,27,40,69,74]

These findings align with previous systematic review and meta-analysis that emphasized the necessity of progressive, high-intensity training (≥3 days per week) combined with protein supplementation to maximize muscle strength, body composition improvements, and functional gains in aging populations.[95] However, in contrast to previous reviews that primarily focused on moderate-to-high-intensity RT, the current analysis incorporates a broader range of training intensities and frequencies, providing a more comprehensive perspective on the interaction between exercise load, supplementation, and aging-related musculoskeletal changes. Importantly, the findings suggest that less frequent or lower-intensity RT alone may be insufficient to induce significant changes across multiple health outcomes, even when combined with supplementation, reinforcing the need for structured, progressive RT in this population.

In the studies that included RT, WPS was the most frequently employed protein supplement (25 trials). When combined with supervised training, it led to positive effects on muscle strength[13,17,18,35,42,47] and body composition,[13,16,32,35,42,46] particularly in terms of lean body mass enhancements.[16,17,31,32] However, the consistency of these results is not definitive because several studies presented contradictory findings. Specifically, certain investigations indicated no significant changes in muscle strength[23,24,27–29,32,33,36,39,40,44,46,92] or body composition[23,24,27,28,30,33,36,37,39,40,43,45,46,92] when incorporating WPS alongside RT programmes. The addition of whey protein to RT does not seem to significantly enhance physical performance; however, two studies reported improved gait speed when WPS was combined with RT compared with RT alone.[13,24] These outcomes contrast with the findings of a systematic review and meta-analysis of WPS; the authors highlighted a notable impact of WPS on lean mass and gait speed among individuals with sarcopenia.[96]

Creatine supplementation was the second most use type of protein supplementation combined with RT (10 trials). It predominantly had a positive impact on body composition[50,51,53–55,58] and also improved muscle strength[50,53–55,58] within a supervised training context. Interestingly, milk protein exhibited a superior effect in terms of body composition improvement compared with whey protein,[64,67–69] This observation aligns with the findings of a systematic review and meta-analysis that compared the effects of milk protein vs whey protein on resistance training-induced lean body mass or fat-free mass gains among older adults.[97] Moreover, the effect of protein supplementation on the physical performance of older adults remains uncertain, as suggested by the findings from the trials we included in this review, mainly owing to the scarcity of studies that have directly investigated this aspect. Another meta-analysis conducted on a distinct cohort of middle-aged to older adults, with or without existing sarcopenia, also yielded inconclusive results regarding the impact of dairy protein supplementation.[98]

Soy and leucine supplementation appears to exhibit a potentially beneficial impact on muscle strength and physical performance in conjunction with training programmes. Nevertheless, the findings from a comprehensive meta-analysis suggest some beneficial effects of dietary protein on physical function measures of older adults.[99] However, it is important to acknowledge that further research is required to substantiate this assertion, given the limited number of conducted trials exploring this area.

Protein supplementation may benefit older adults with special conditions such as arthritis,[20,57] osteopenia, or osteoporosis;[55,84] inpatient older adults;[11,60] or poststroke sarcopenic adults.[14] Furthermore, we did not find any discernible correlation between the timing or duration of supplement intake and its impact on the outcome measures in older adults. This observation aligns with the findings of a systematic review, which similarly indicated the absence of a favorable effect from specific timing of protein intake on metrics such as lean body mass, handgrip strength, and leg press strength.[100]

CONCLUSION

This scoping review highlights the variable and conflicting results regarding the impact of protein supplementation on muscle strength and body composition in older adults. Although whey protein, creatine, and milk protein have been most commonly studied in conjunction with RT and show promising effects, the evidence remains inconsistent. Further research is needed to determine the potential benefits of soy and leucine-enriched supplements for improving muscle strength in older adults. Notably, protein supplementation without concurrent RT may still lead to improvements in body composition, particularly with leucine, milk protein, and whey protein, although the impact on muscle strength is less certain. Additionally, the effects of protein supplementation on physical performance in older adults remain inconclusive. These findings underscore the need for further, more comprehensive studies to clarify the effects of various protein types and supplementation regimens on muscle strength, body composition, and physical performance in the aging population.

AUTHOR CONTRIBUTIONS

Alaa H. Al‐Rawhani conducted the literature search, writing, reviewing, and editing of the manuscript; Siti Nur'Asyura Adznam assisted with the literature search and manuscript writing' Zalina Abu Zaid, Nor Baizura Md. Yusop, Hakimah M. Sallehuddin, and Mohammed A. Alshawsh, reviewed, edited, and approved the final manuscript.

CONFLICT OF INTEREST STATEMENT

None declared.

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REFERENCES

1. Janssen I, Heymsfield SB, Ross R. Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *J Am Geriatr Soc*. 2002;50:889‐896.
2. Moreland B, Kakara R, Henry A. Trends in nonfatal falls and fall‐related injuries among adults aged ≥65 years—United States, 2012–2018. *MMWR Morb Mortal Wkly Rep*. 2020;69(27):875‐881.
3. Hanlon P, Nicholl BI, Jani BD, Lee D, McQueenie R, Mair FS. Frailty and pre‐frailty in middle‐aged and older adults and its association with multimorbidity and mortality: a prospective analysis of 493 737 UK Biobank participants. *Lancet Public Health*. 2018;3(7):e323‐e332.
4. Shahar S, Norshafarina NS, Badrasawi M, et al. Effectiveness of exercise and protein supplementation intervention on body composition, functional fitness, and oxidative stress among elderly Malays with sarcopenia. *Clin Interv Aging*. 2013;8:1365‐1375.
5. Coelho‐Junior HJ, Marzetti E, Picca A, Cesari M, Uchida MC, Calvani R. Protein intake and frailty: a matter of quantity, quality, and timing. *Nutrients*. 2020;12:2915.
6. Chan R, Leung J, Woo J. Associations of dietary protein intake on subsequent decline in muscle mass and physical functions over four years in ambulant older Chinese people. *J Nutr Health Aging*. 2014;18(2):171‐177.
7. Bauer J, Biolo G, Cederholm T, et al. Evidence‐based recommendations for optimal dietary protein intake in older people: a position paper from the prot‐age study group. *J Am Med Dir Assoc*. 2013;14(8):542‐559.
8. Wolfe RR, Miller SL, Miller KB. Optimal protein intake in the elderly. *Clin Nutr*. 2008;27(5):675‐684.
9. Norman K, Haß U, Pirlich M. Malnutrition in Older Adults‐Recent Advances and Remaining Challenges. *Nutrients*. 2021;3(8):2764.
10. Park Y, Choi JE, Hwang HS. Protein supplementation improves muscle mass and physical performance in undernourished prefrail and frail elderly subjects: a randomized, double‐blind, placebo‐controlled trial. *Am J Clin Nutr*. 2018;108(5):1026‐1033.
11. Niccoli S, Kolobov A, Bon T, et al. Whey protein supplementation improves rehabilitation outcomes in hospitalized geriatric patients: a double blinded, randomized controlled trial. *J Nutr Gerontol Geriatr*. 2017;36(4):149‐165.
12. Ispoglou T, White H, Preston T, McElhone S, McKenna J, Hind K. Double‐blind, placebo‐controlled pilot trial of L‐Leucine‐enriched amino‐acid mixtures on body composition and physical performance in men and women aged 65–75 years. *Eur J Clin Nutr*. 2016;70(2):182‐188.
13. Mori H, Tokuda Y. Effect of whey protein supplementation after resistance exercise on the muscle mass and physical function of healthy older women: a randomized controlled trial. *Geriatr Gerontol Int*. 2018;18:1398‐1404.
14. Yoshimura Y, Bise T, Shimazu S, et al. Effects of a leucine‐enriched amino acid supplement on muscle mass, muscle strength, and physical function in post‐stroke patients with sarcopenia: a randomized controlled trial. *Nutrition*. 2019;58:1‐6.
15. ten Haaf DSM, Eijsvogels TMH, Bongers CCWG, et al. Protein supplementation improves lean body mass in physically active older adults: a randomized placebo‐controlled trial. *J Cachexia Sarcopenia Muscle*. 2019;10(2):298‐310.
16. Nabuco HCG, Tomeleri CM, Fernandes RR, et al. Effect of whey protein supplementation combined with resistance training on body composition, muscular strength, functional capacity, and plasma‐metabolism biomarkers in older women with sarcopenic obesity: a randomized, double‐blind, placebo‐control. *Clin Nutr ESPEN*. 2019;32(2019):88‐95.
17. Bell KE, Snijders T, Zulyniak M, et al. A whey protein‐based multi‐ingredient nutritional supplement stimulates gains in lean body mass and strength in healthy older men: a randomized controlled trial. *PLoS One*. 2017;12(7):e0181387.
18. Karelis A, Messier V, Suppère C, Briand P, Rabasa‐Lhoret R. Effect of cysteine‐rich whey protein (Immunocal®) supplementation in combination with resistance training on muscle strength and lean body mass in non‐frail elderly subjects: a randomized, double‐blind controlled study. *J Nutr Health Aging*. 2015;19(5):531‐536.
19. Reule CA, Scholz C, Schoen C, Brown N, Siepelmeyer A, Alt WW. Reduced muscular fatigue after a 12‐week leucine‐rich amino acid supplementation combined with moderate training in elderly: a randomised, placebo‐controlled, double‐blind trial. *BMJ Open Sport Exerc Med*. 2017;2(1):e000156.
20. Ikeda T, Jinno T, Masuda T, et al. Effect of exercise therapy combined with branched‐chain amino acid supplementation on muscle strengthening in persons with osteoarthritis. *Hong Kong Physiother J*. 2018;38(1):23‐31.
21. Oikawa SY, Kamal MJ, Webb EK, Mcglory C, Baker SK, Phillips SM. Whey protein but not collagen peptides stimulate acute and longer‐term muscle protein synthesis with and without resistance exercise in healthy older women: a randomized controlled trial. *Am J Clin Nutr*. 2020;111(3):7‐11.
22. Björkman MP, Suominen MH, Kautiainen H, et al. Effect of protein supplementation on physical performance in older people with sarcopenia—a randomized controlled trial. *J Am Med Dir Assoc*. 2020;21(2):226‐232.e1.
23. Chalé A, Cloutier GJ, Hau C, Phillips EM, Dallal GE, Fielding RA. Efficacy of whey protein supplementation on resistance exercise‐induced changes in lean mass, muscle strength, and physical function in mobility‐limited older adults. *J Gerontol A Biol Sci Med Sci*. 2012;68:682‐690.
24. Griffen C, Duncan M, Hattersley J, Weickert MO, Dallaway A, Renshaw D. Effects of resistance exercise and whey protein supplementation on skeletal muscle strength, mass, physical function, and hormonal and inflammatory biomarkers in healthy active older men: a randomised, double‐blind, placebo‐controlled trial. *Exp Gerontol*. 2022;158(2021):111651.
25. Jadczak AD, Visvanathan R, Barnard R, Luscombe‐Marsh N. A randomized controlled pilot Exercise and Protein Effectiveness Supplementation Study (EXPRESS) on reducing frailty risk in community‐dwelling older people. *J Nutr Gerontol Geriatr*. 2021;40(1):26‐45.

26. Kerstetter JE, Bihuniak JD, Brindisi J, et al. The effect of a whey protein supplement on bone mass in older Caucasian adults. *J Clin Endocrinol Metab*. 2015;100(6):2214-2222.
27. Mojtahedi MC, Thorpe MP, Karampinos DC, et al. The effects of a higher protein intake during energy restriction on changes in body composition and physical function in older women. *J Gerontol A Biol Sci Med Sci*. 2011;66A(11):1218-1225.
28. de Azevedo Bach S, Radaelli R, Schemes MB, et al. Can supplemental protein to low-protein containing meals superimpose on resistance-training muscle adaptations in older adults? A randomized clinical trial. *Exp Gerontol*. 2022;162(2022):111760.
29. Weisgarber KD, Candow DG, Farthing JP. Whey protein and high-volume resistance training in postmenopausal women. *J Nutr Health Aging*. 2015;19(5):511-517.
30. Michel J, Lievense K, Norton S, et al. The effects of graded protein intake in conjunction with progressive resistance training on skeletal muscle outcomes in older adults: a preliminary trial. *Nutrients*. 2022;14(13):2739.
31. Fernandes RR, Nabuco HCG, Sugihara Junior P, et al. Effect of protein intake beyond habitual intakes following resistance training on cardiometabolic risk disease parameters in pre-conditioned older women. *Exp Geront*. 2018;110(March):9-14.
32. Nabuco HCG, Tomeleri CM, Sugihara Junior P, et al. Effects of pre- or post-exercise whey protein supplementation on body fat and metabolic and in flammatory profile in pre-conditioned older women: a randomized, double-blind, placebo-controlled trial. *Nutr Metab Cardiovasc Dis*. 2019;29(3):290-300.
33. Villanueva MG, He J, Schroeder ET. Periodized resistance training with and without supplementation improve body composition and performance in older men. *Eur J Appl Physiol*. 2014;114(5):891-905.
34. Zhu K, Kerr DA, Meng X, et al. Two-year whey protein supplementation did not enhance muscle mass and physical function in well-nourished healthy older postmenopausal women. *J Nutr*. 2015;145(11):2520-2526.
35. Sugihara Junior P, Ribeiro AS, Nabuco HCG, et al. Effects of whey protein supplementation associated with resistance training on muscular strength, hypertrophy and muscle quality in pre-conditioned older women. *Int J Sport Nutr Exerc Metab*. 2018;28(5): 528-535.
36. Amasene M, Cadenas-sanchez C, Echeverria I, et al. Effects of resistance training intervention along with leucine-enriched whey protein supplementation on sarcopenia and frailty in post-hospitalized older adults: preliminary findings of a randomized controlled trial. *J Clin Med*. 2022;11:97.
37. Arnarson A, Geirsdottir OG, Ramel A, Briem K, Jonsson PV, Thorsdottir I. Effects of whey proteins and carbohydrates on the efficacy of resistance training in elderly people: double blind, randomised controlled trial. *Eur J Clin Nutr*. 2013;67(8):821-826.
38. Björkman MP, Pilvi TK, Kekkonen RA, Korpela R, Tilvis RS. Similar effects of leucine rich and regular dairy products on muscle mass and functions of older polymyalgia rheumatica patients: a randomized crossover trial. *J Nutr Health Aging*. 2011;15(6):462-467.
39. Holwerda AM, Overkamp M, Paulussen KJM, et al. Protein supplementation after exercise and before sleep does not further augment muscle mass and strength gains during resistance exercise training in active older men. *J Nutr*. 2018;148(11):1723-1732.
40. Gade J, Beck AM, Andersen HE, et al. Protein supplementation combined with low-intensity resistance training in geriatric medical patients during and after hospitalisation: a randomised, double-blind, multicentre trial. *Br J Nutr*. 2019;122(9):1006-1020.
41. Mertz KH, Reitelseder S, Bechshoeft R, et al. The effect of daily protein supplementation, with or without resistance training for 1 year, on muscle size, strength, and function in healthy older adults: a randomized controlled trial. *Am J Clin Nutr*. 2021;113(4):790-800.
42. Atherton C, McNaughton LR, Close GL, Sparks A. Post-exercise provision of 40g of protein during whole body resistance training further augments strength adaptations in elderly males. *Res Sports Med*. 2020;28(4):469-483.
43. Biesek S, Vojciechowski AS, Filho JM, et al. Effects of exergames and protein supplementation on body composition and musculoskeletal function of prefrail community-dwelling older women: a randomized, controlled clinical trial. *Int J Environ Res Public Health*. 2021;18(9324):9324.
44. Kirk B, Mooney K, Amirabdollahian F, Khaiyat O. Exercise and dietary-protein as a countermeasure to skeletal muscle weakness: Liverpool Hope University—Sarcopenia aging trial. *Front Physiol*. 2019;10(445):1-11.
45. Kirk B, Mooney K, Cousins R, et al. Effects of exercise and whey protein on muscle mass, fat mass, myoelectrical muscle fatigue and health-related quality of life in older adults: a secondary analysis of the Liverpool Hope University–Sarcopenia Trial (LHU–SAT). *Eur J Appl Physiol*. 2020;120(2):493-503.
46. Krause M, Crognale D, Cogan K, et al. The effects of a combined bodyweight-based and elastic bands resistance training, with or without protein supplementation, on muscle mass, signaling and heat shock response in healthy older people. *Exp Geront*. 2019; 115(2018):104-113.
47. Mertz KH, Reitelseder S, Bechshoeft R, et al. The effect of daily protein supplementation, with or without resistance training for 1 year, on muscle size, strength, and function in healthy older adults: a randomized controlled trial. *Am J Clin Nutr*. 2021;113(4):790-800.
48. Lobo DM, Tritto AC, da Silva LR, et al. Effects of long-term low-dose dietary creatine supplementation in older women. *Exp Geront*. 2015;70:97-104.
49. Sales LP, Pinto AJ, Rodrigues SF, et al. Creatine supplementation (3 g/day) and bone health in older women: a 2-year, randomized, placebo-controlled trial. *J Gerontol A Biol Sci Med Sci*. 2019;75(5): 931-938.
50. Candow D, Vogt E, Johannsmeyer Sarah. Strategic ingestion of creatine supplementation and resistance training in healthy older adults. *Appl Physiol Nutr Metab*. 2015;13(306):1-27.
51. Johannsmeyer S, Candow DG, Brahms CM, Michel D, Zello GA. Effect of creatine supplementation and drop-set resistance training in untrained aging adults. *Exp Geront*. 2016;83:112-119.
52. Candow DG, Chilibeck PD, Gordon J, et al. Effect of 12 months of creatine supplementation and whole-body resistance training on measures of bone, muscle and strength in older males. *Nutr Health*. 2021;27(2):151-159.
53. Candow DG, Zello GA, Ling B, et al. Comparison of creatine supplementation before versus after supervised resistance training in healthy older adults. *Res Sports Med*. 2014;22(1):61-74.
54. Aguiar AF, Januário RSB, Junior RP, et al. Long-term creatine supplementation improves muscular performance during resistance training in older women. *Eur J Appl Physiol*. 2013;113(4):987-996.
55. Gualano B, Macedo AR, Alves CRR, et al. Creatine supplementation and resistance training in vulnerable older women: a randomized double-blind placebo-controlled clinical trial. *Exp Geront*. 2014;53:7-15.
56. Bemben MG, Witten MS, Carter JM, Eliot KA, Knehans AW, Bemben DA. The effects of supplementation with creatine and protein on muscle strength following a traditional resistance training program in middle-aged and older men. *J Nutr Health Aging*. 2010;14(2):155-159.
57. Neves M, Gualano B, Roschel H, et al. Beneficial effect of creatine supplementation in knee osteoarthritis. *Med Sci Sports Exerc*. 2011;43(8):1538-1543.
58. Bernat P, Candow DG, Geryzb K, Butchart S, Schoenfeld BJ, Bruno P. Effects of high-velocity resistance training and creatine supplementation in untrained healthy aging males. *AIDS Res Hum Retroviruses*. 2012;2016(133):1-28.

59. Baker TP, Candow DG, Farthing JP. Effect of preexercise creatine ingestion on muscle performance in healthy aging males. *J Strength Cond Res*. 2016;30(6):1763-1766.
60. Bouillanne O, Curis E, Hamon-Vilcot B, et al. Impact of protein pulse feeding on lean mass in malnourished and at-risk hospitalized elderly patients: a randomized controlled trial. *Clin Nutr*. 2013; 32(2):186-192.
61. Norton C, Toomey C, McCormack WG, et al. Protein supplementation at breakfast and lunch for 24 weeks beyond habitual intakes increases whole-body lean tissue mass in healthy older adults. *J Nutr*. 2016;146(1):65-69.
62. Ottestad I, Løvstad AT, Gjevestad GO, et al. Intake of a protein-enriched milk and effects on muscle mass and strength. A 12-week randomized placebo controlled trial among community-dwelling older adults. *J Nutr Health Aging*. 2017;21(10):1160-1169.
63. Tieland M, van de Rest O, Dirks ML, et al. Protein supplementation improves physical performance in frail elderly people: a randomized, double-blind, placebo-controlled trial. *J Am Med Dir Assoc*. 2012;13(8):720-726.
64. Tieland M, Dirks ML, van der Zwaluw N, et al. Protein supplementation increases muscle mass gain during prolonged resistance-type exercise training in frail elderly people: a randomized, double-blind, placebo-controlled trial. *J Am Med Dir Assoc*. 2012;13(8): 713-719.
65. Carlsson M, Littbrand H, Gustafson Y, et al. Effect of high-intensity exercise and protein supplementation on muscle mass in adl dependent older people with and without malnutrition—a randomized controlled trial. *J Nutr Health Aging*. 2011;16(8):736.
66. Aas SN, Seynnes O, Benestad HB, Raastad T. Strength training and protein supplementation improve muscle mass, strength, and function in mobility-limited older adults: a randomized controlled trial. *Aging Clin Exp Res*. 2020;32(4):605-616.
67. Francis P, Mc Cormack W, Toomey C, et al. Twelve weeks' progressive resistance training combined with protein supplementation beyond habitual intakes increases upper leg lean tissue mass, muscle strength and extended gait speed in healthy older women. *Biogerontology*. 2017;18(6):881-891.
68. Gryson C, Ratel S, Rance M, et al. Four-month course of soluble milk proteins interacts with exercise to improve muscle strength and delay fatigue in elderly participants. *J Am Med Dir Assoc*. 2014;15(12):958.e1-e9.
69. Nakayama K, Saito Y, Sanbongi C, Murata K, Urashima T. Effects of low-dose milk protein supplementation following low-to-moderate intensity exercise training on muscle mass in healthy older adults: a randomized placebo-controlled trial. *Eur J Nutr*. 2021;60(2): 917-928.
70. Ten Haaf DSM, Bongers CCWG, Hulshof HG, Eijsvogels TMH, Hopman MTE. The impact of protein supplementation on exercise-induced muscle damage, soreness and fatigue following prolonged walking exercise in vital older adults: a randomized double-blind placebo-controlled trial. *Nutrients*. 2020;12(6):1806.
71. Leenders M, Verdijk LB, van der Hoeven L, et al. Prolonged leucine supplementation does not augment muscle mass or affect glycemic control in elderly type 2 diabetic men. *J Nutr*. 2011;141(6): 1070-1076.
72. Murphy CH, Flanagan EM, De Vito G, et al. Does supplementation with leucine-enriched protein alone and in combination with fish-oil-derived n−3 PUFA affect muscle mass, strength, physical performance, and muscle protein synthesis in well-nourished older adults? A randomized, double-blind, placebo-controlled trial. *Am J Clin Nutr*. 2021;113(6):1411-1427.
73. Trabal J, Forga M, Leyes P, et al. Effects of free leucine supplementation and resistance training on muscle strength and functional status in older adults: a randomized controlled trial. *Clin Interv Aging*. 2015;10:713-723.
74. Yamamoto Y, Nagai Y, Kawanabe S, et al. Effects of resistance training using elastic bands on muscle strength with or without a leucine supplement for 48 weeks in elderly patients with type 2 diabetes. *Endocr J*. 2021;68(3):291-298.
75. Kang Y, Kim N, Choi YJ, et al. Leucine-enriched protein supplementation increases lean body mass in healthy Korean adults aged 50 years and older: a randomized, double-blind, placebo-controlled trial. *Nutrients*. 2020;12(6):1816.
76. Bonnefoy M, Mercier C, Carre C, Guetemme G, Laville M, Cornu C. Efficacy of home-based intervention programme on physical activity and ability older people. *J Nutr Health Aging*. 2012;16(4): 370-377.
77. Jonker R, Deutz NE, Erbland ML, Anderson PJ, Engelen MP. Effectiveness of essential amino acid supplementation in stimulating whole body net protein anabolism is comparable between COPD patients and healthy older adults. *Metabolism*. 2017;69:120-129.
78. Kawada S, Okamoto Y, Ogasahara K, Yanagisawa S, Ohtani M, Kobayashi K. Resistance exercise combined with essential amino acid supplementation improved walking ability in elderly people. *Acta Physiol Hung*. 2013;100(3):329-339.
79. Kim HK, Suzuki T, Saito K, et al. Effects of exercise and amino acid supplementation on body composition and physical function in community-dwelling elderly Japanese sarcopenic women: a randomized controlled trial. *J Am Geriatr Soc*. 2012;60(1):16-23.
80. Pineda-Juárez JA, Sánchez-Ortiz NA, Castillo-Martínez L, et al. Changes in body composition in heart failure patients after a resistance exercise program and branched chain amino acid supplementation. *Clin Nutr*. 2016;35(1):41-47.
81. Markofski MM, Jennings K, Timmerman KL, et al. Effect of aerobic exercise training and essential amino acid supplementation for 24 weeks on physical function, body composition, and muscle metabolism in healthy, independent older adults: a randomized clinical trial. *J Gerontol Series A Biol Sci Med Sci*. 2019;74(10):1598-1604.
82. Orsatti FL, Maestá N, de Oliveira EP, et al. Adding soy protein to milk enhances the effect of resistance training on muscle strength in postmenopausal women. *J Diet Suppl*. 2018;15(2):140-152.
83. Christie DR, Grant J, Darnell BE, Chapman VR, Gastaldelli A, Sites CK. Metabolic effects of soy supplementation in postmenopausal Caucasian and African American women: a randomized, placebo-controlled trial. *Am J Obstet Gynecol*. 2010;203(2):153.e1-e9.
84. Shenoy S, Bedi R, Sandhu JS. Effect of soy isolate protein and resistance exercises on muscle performance and bone health of osteopenic/osteoporotic post-menopausal women. *J Women Aging*. 2013;25(2):183-198.
85. Buckinx F, Marcangeli V, Pinheiro Carvalho L, et al. Initial dietary protein intake influence muscle function adaptations in older men and women following high-intensity interval training combined with citrulline. *Nutrients*. 2019;11(7):1685.
86. Caballero-García A, Pascual-Fernández J, Noriega-González DC, et al. L-citrulline supplementation and exercise in the management of sarcopenia. *Nutrients*. 2021;13(9):3133.
87. Badrasawi M, Shahar S, Abd Manaf Z, RajabFadilah, NF, KAS D. Efficacy of L-carnitine supplementation on frailty status and its biomarkers,nutritional status,and physical and cognitive function among prefrail older adults: a double-blind,randomized,placebo-controlled clinical trial. *Clin Interv Aging*. 2016;11:1675-1686.
88. Sawicka A, Hartmane D, Lipinska P, Wojtowicz E, Lysiak-Szydlowska W, Olek R. L-carnitine supplementation in older women. A pilot study on aging skeletal muscle mass and function. *Nutrients*. 2018;10(2):255.
89. Zdzieblik D, Oesser S, Baumstark MW, Gollhofer A, König D. Collagen peptide supplementation in combination with resistance training improves body composition and increases muscle strength in elderly sarcopenic men: a randomised controlled trial. *Br J Nutr*. 2015;114(8):1237-1245.

90. Aguiar AF, Balvedi MCW, Buzzachera CF, et al. l-Arginine supplementation does not enhance blood flow and muscle performance in healthy and physically active older women. *Eur J Nutr*. 2016;55(6):2053-2062.
91. Bailey CH, Signorile JF, Perry AC, Jacobs KA, Myers ND. Beta-alanine does not enhance the effects of resistance training in older adults. *J Diet Suppl*. 2018;15(6):860-870.
92. Amasene M, Besga A, Echeverria I, et al. Effects of leucine-enriched whey protein supplementation on physical function in post-hospitalized older adults participating in 12-weeks of resistance training program: a randomized controlled trial. *Nutrients*. 2019;11:2337.
93. Hengeveld LM, Boer JMA, Gaudreau P, et al. Prevalence of protein intake below recommended in community-dwelling older adults: a meta-analysis across cohorts from the PROMISS consortium. *J Cachexia Sarcopenia Muscle*. 2020;11(5):1212-1222.
94. Nunes EA, Colenso-Semple L, Mckellar SR, et al. Systematic review and meta-analysis of protein intake to support muscle mass and function in healthy adults. *J Cachexia Sarcopenia Muscle*. 2022;13(2):795-810.
95. Liao C, DeLee, Hsiao PH, et al. Effects of protein supplementation combined with resistance exercise on body composition and physical function in older adults: a systematic review and meta-analysis. *Nutrients*. 2017;10(12):1916.
96. Nasimi N, Sohrabi Z, Nunes EA, et al. Whey protein supplementation with or without vitamin D on sarcopenia-related measures: a systematic review and meta-analysis. *Adv Nutr*. 2023;14(4):762-773.
97. Huang LP, Condello G, Kuo CH. Effects of milk protein in resistance training-induced lean mass gains for older adults aged ≥60 y: a systematic review and meta-analysis. *Nutrients*. 2021;13(8):2815.
98. Hanach NI, Mccullough F, Avery A. The impact of dairy protein intake on muscle mass, muscle strength, and physical performance in middle-aged to older adults with or without existing sarcopenia: a systematic review and meta-analysis. *Adv Nutr*. 2019;10(1):59-69.
99. Cawood AL, Elia M, Stratton RJ. Systematic review and meta-analysis of the effects of high protein oral nutritional supplements. *Res Rev*. 2012;11(2):278-296.
100. Wirth J, Hillesheim E, Brennan L. The role of protein intake and its timing on body composition and muscle function in healthy adults: a systematic review and meta-analysis of randomized controlled trials. *J Nutr*. 2020;150(6):1443-1460.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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