Accepted Article

Journal of Frailty, Sarcopenia and Falls

Review Article

The Use of Electrical Stimulation for Older Adults at Risk for Developing Sarcopenia: A Systematic Review

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Abstract

This study aimed to compile evidence on the effectiveness of neuromuscular electrical stimulation (NMES) for improving muscle strength in older adults, with or without systemic pathologies. A systematic search of PubMed, Cochrane Library, and Scopus databases was conducted for randomized controlled trials (RCTs) published between 2017 and 2023. Eligible studies included: older adults over 55 years, the use of either static stimulation (neuromuscular electrical stimulation NMES) in a stationary position or dynamic stimulation (functional electrical stimulation - FES applied during single or multi-joint movement), examined at least one muscle strength outcome, reported stimulation parameters (e.g., frequency, duration, amplitude), and involved participants with or at risk for sarcopenia. This review included 12 RCTs with Physiotherapy Evidence Database (PEDro) scores ranging from 5-9 (good quality). 9 studies reported significant increase in isometric muscle strength following electrical stimulation. Common parameters were 50-100 Hz with variable intensity and pulse duration. The findings suggest that both dynamic stimulation, or static stimulation delivered prior to strength or endurance training, respectively, proved more effective than static stimulation alone. However, parameter selection varied widely and was often unjustified, highlighting the need for standardization to optimize outcomes in community-dwelling older adults.

Keywords: Dynamometer, Functional electrical stimulation, Muscular strength, Parameter, Quadriceps

Introduction

Sarcopenia is a progressive and generalized skeletal muscle disease characterized by low muscle quality and quantity resulting in muscle weakness[1]. Once an individual develops sarcopenia, the likelihood of adverse outcomes including falls, fractures, physical disability, and mortality increases[2-4]. The original definition sought improved clinical parameters and updated the requirements for diagnosis to include low levels of measurement for muscle strength, muscle quantity/quality, and physical performance to characterize the severity of the sarcopenia[1,5].

At the muscle fiber level, sarcopenia is characterized by specific type II muscle fiber atrophy, fiber necrosis, and decreased type II muscle fiber satellite cell content[6-10]. This is largely driven by disruption in the regulation of skeletal muscle protein turnover, leading to a structural imbalance between muscle protein synthesis and degradation[11]. Moderate to high-intensity resistance training has been shown to stimulate protein anabolism as well as morphologic and metabolic muscular adaptations to produce hypertrophy in individuals with sarcopenia[12].

Previous evidence has shown that moderate to high-intensity resistance training (RT, e.g., 2-3 sets of 8-15 repetitions at 50-80% 1 repetition maximum) effectively prevents and reverses sarcopenia, improving muscle mass and strength within 12 weeks[13,14]. Older adults (65-75 years) can achieve muscle gains comparable to younger adults with consistent training over six months[15]. RT is more effective than aerobic exercise for increasing muscle

The authors have no conflict of interest.

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Edited by: *Yannis Dionyssiotis*

Accepted *18 May 2025*

Search domain	Keywords/MeSH Terms	Boolean Operators
Intervention	"Neuromuscular" AND "Functional" ("electric stimulation" OR ("electric" AND "stimulation"))	OR, AND
Muscle-related outcomes	"Muscular strength", "Muscle strength", "Sarcopenia"	OR
Population	"Aged", "Older adults", "Elderly", "Seniors", "Aging populations"	OR
Study design	"Randomized controlled Trail", "RCT", "Clinical trial", "Controlled clinical trial"	OR

Table 1. Search strategy.

mass, particularly in older women and enhances protein synthesis without increasing muscle breakdown[16,17]. Despite its benefits, high-intensity training is often avoided by those with sarcopenia[18,19].

Individuals with sarcopenia face barriers to regular exercise, including fear of falling, discomfort, transportation issues, cost, lack of support and reduced functional capacity[20,21]. Traditional exercise programs often require access to gyms or clinics, limiting participation for those with mobility or social constraints[22-24]. Enhancing access and efficiency of exercise programs is essential to reduce the prevalence of sarcopenia.

Electrical stimulation (ES) is a widely used clinical modality to enhance muscle function during neurological and orthopedic rehabilitation[25,26]. For clarity of terminology used during this review, static stimulation will refer to when neuromuscular electrical stimulation (NMES) is applied while the individual is stationary, while dynamic stimulation will refer to when NMES or functional electrical stimulation (FES) is applied during single or multi-joint movement[27]. NMES is a commonly used form of static stimulation for restoring muscle function in the clinical rehabilitation and research setting[28]. NMES is utilized in both young and aging populations to improve muscle activation and strength following neurologic injuries, as well as following orthopedic surgeries or in the management of chronic orthopedic conditions, with a focus on improving muscle function to support recovery and enhance rehabilitation outcomes[29-32]. Increasingly, evidence also supports its application in healthy populations[33-35]. NMES is typically delivered in a static position, using repetitive, preset on-off stimulation cycles at the individual's maximum tolerated intensity. When NMES is delivered to large functional lower extremity muscle groups, it has been shown to be as effective as voluntary exercise to improve strength in older adults[36-38]. This makes NMES a home-based option to address muscle weakness associated with sarcopenia, allowing NMES to serve as a viable rehabilitation alternative to combat barriers previously mentioned[39].

Alternatively, functional electrical stimulation (FES) involves repetitive stimulation where on-off cycles are synchronized with muscle activation during a single and/or multi-joint/functional movement, also at an intensity sufficient to elicit a motor response[40]. Alongside NMES research, studies on FES have shown benefits beyond muscle strength, including improved motor learning, movement control and neuroplasticity[41-43]. Repetitive, experience-based motor learning can lead to lasting functional gains[44]. With aging, type 2 muscle fibers are denervated and reinnervated by type 1 fibers, leading to 40% reduction in motor units and enlarged, unstable low-threshold units. This contributes to muscle atrophy and reduces the strength needed for mobility. Static and dynamic stimulation can specifically target type 2 fibers to promote hypertrophy, but stimulation parameters vary widely in the literature[45]. Applying dynamic stimulation during movement that is typically challenging for sarcopenic individuals, such as a sit-to-stand, can enhance muscle strength and promote greater engagement in daily activities, ultimately improving quality of life[46]. Currently, there is promising research involving both static and dynamic stimulation in sarcopenic populations, however there is no systematic review summarizing evidence from the existing studies.

This review aims to examine current evidence on the utility and effectiveness of static and dynamic stimulation among community dwelling older adults with non-neurological or non-orthopedic conditions on outcomes of strength and sarcopenia and identify commonly used stimulation parameters.

Methods

Protocol Registration

The current systematic review has been registered in PROSPERO (CRD42024582725).

Search process and Strategy

To investigate the outlined research aims, we employed three databases: PubMed, Cochrane and Scopus. Key terms for the database search were in the Title, Abstract, or Keywords sections of research articles. The keywords included in the search criteria were 'Electrical stimulation', 'Neuromuscular electrical stimulation', 'Functional

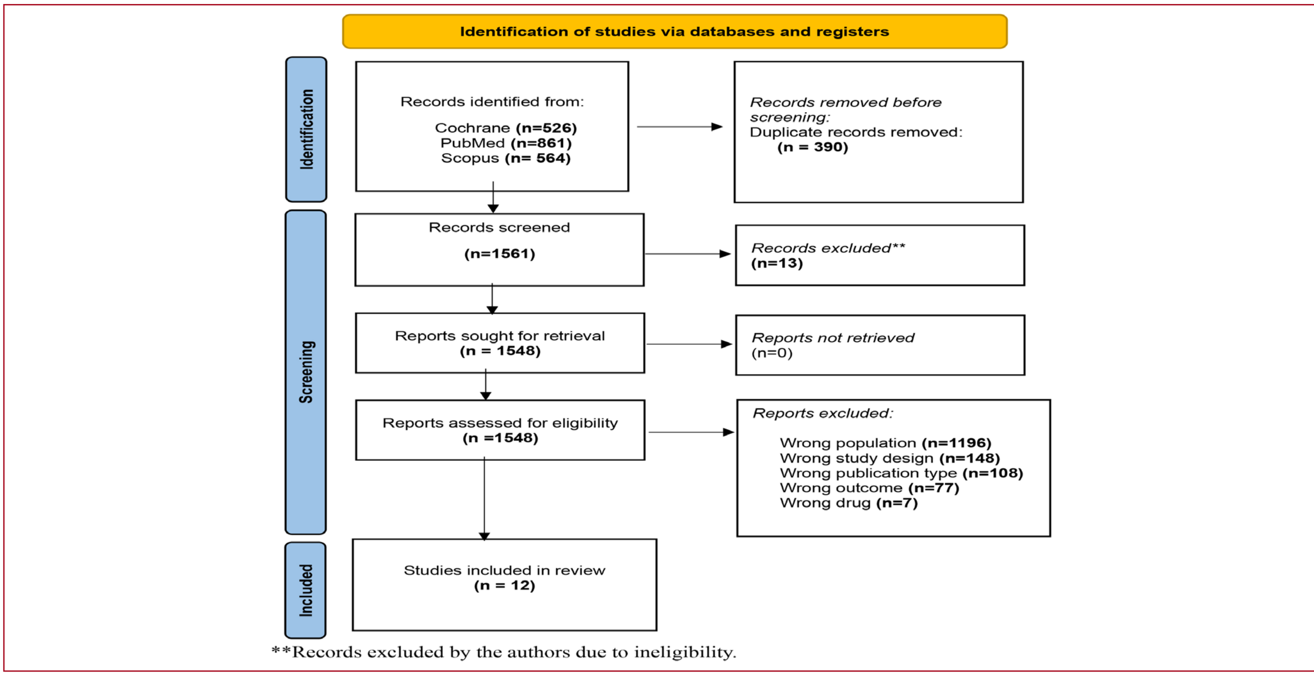

Figure 1. PRISMA 2020 flow diagram for new systematic reviews, which included searches of databases.

electrical stimulation', 'sarcopenia', and 'older adults. The detailed search strategy is presented in Table 1.

Eligibility Criteria

Studies were included if: 1) the study was a randomized controlled trial (RCT); 2) the study used NMES or FES as an intervention tool; 3) the study examined muscle strength as one of its outcome measures; 4) the study was published in or after 2017; 5) the age of the study cohort must include individuals >55 years of age; 6) included participants with sarcopenia or at risk for sarcopenia. The studies were excluded if they included any neurologic or orthopedic conditions or included healthy young cohorts (i.e., < 45 years of age).

Quality of included studies

The quality of the studies was determined using the Physiotherapy Evidence Database (PEDro) scale. Two authors (SD and GM) conducted blinded PEDro scoring seperately and disagreements were resolved upon discussion with the third author (RP).

Software Utilized

After searching, EndNote 20 was utilized to identify and eliminate any duplicate studies. Next, the duplicates were removed and the studies were imported into Rayyan, an Intelligent Systematic Review software. Each author independently assessed and determined the inclusion or exclusion of research studies, with decisions made in isolation and without knowledge of the choices made by other authors.

Study	Quality assessment	
	Author 1	Author 2
Esteve V et al. [2017][50]	Good	Fair
Brüggemann AK et al. [2017][48]	Good	Excellent
Hanada et al. [2019][51]	Good	Good
Acaroz et al. [2019][49]	Fair	Good
Acheche et al. [2020][53]	Good	Good
Jang et al. [2021][58]	Good	Good
Bondi et al. [2022][47]	Good	Good
Ramezani et al. [2023][54]	Excellent	Good
Schinner et al. [2023][56]	Good	Fair
Sumin et al. [2020][52]	Excellent	Good
Thapa et al. [2022][55]	Good	Good
Suzuki et al. [2018][57]	Good	Good

Table 2. Quality assessments of the included studies (PEDro).

Results

After conducting the initial search, 1,951 studies were collected and transposed to EndNote 20 for further analysis. After removing duplicates and screening the title, abstracts, and eligibility criteria, 12 studies were included in the review. Figure 1 illustrates the Preferred Items for Systematic Reviews and Meta-analyses (PRISMA) flowchart.

The PEDro scores were within the range of 5-9, which is interpreted as fair to good quality of studies included (Table 2).

A pooled sample of 435 participants aged 45-70 years was included. Four out of 12 studies included adults undergoing hemodialysis, 4 studies included healthy middle-aged and older adults, and others included adults with liver transplant, chronic obstructive pulmonary disease, and post-COVID-19, post-cardiovascular surgery. Of the 12 studies, 9 demonstrated a significant improvement in muscle strength within the targeted muscle group with the use of static or dynamic stimulation[47,48,50,52-57]. In comparison, 3 of those 12 studies found that the increase in muscle strength following the use of static stimulation was not significant between the experimental and control and within either of the groups[49,51,58]. One study investigated the impact of varying stimulation durations: long (10 mins) and short (5 mins) on different muscle groups. The study found that the group subjected to longer stimulation periods exhibited notably greater increases in muscle strength compared to those with shorter periods of stimulation[49]. Most of the studies (7/12) used a dynamometer to assess muscle strength. Other methods to assess muscle strength included biofeedback, electromyography, 1 repetition maximum (1RM), and 5 times sit to stand. Six studies delivered stimulation within the range of 45-50 Hz[48,50-54]. Another study delivered stimulation at 70 Hz with exercise and saw a significant improvement in strength[55]. Two studies utilized 20 Hz with strength improvements[56,57], and the remaining 2 studies delivered stimulation at 100 Hz[49] and 35 Hz[58]. Six of the studies used the intensity parameters between 40-50 Hz[48,50-54]. All of these studies showed an increase in muscle strength. Three studies used the frequency range >50 Hz, out of which only three studies showed an increase in muscle strength[47,49,55]. Three studies that did not observe significant improvements in muscle strength may be due to the absence of a control group, which limited the ability to compare changes in muscle strength following the intervention. The number of stimulation sessions varied considerably across the studies, ranging from as few as 10 sessions to as many as 24 sessions, reflecting a wide variation in the intervention dosage. Table 3 provides details of the individual studies included (see supplemental materials).

Discussion

This systematic review examined the use of static and dynamic stimulation to strengthen muscles in community-dwelling older adults at risk for or with sarcopenia. Evidence suggests that dynamic stimulation improves muscle strength more than the use of static stimulation. The articles included in this review which investigated static stimulation were performed in populations with chronic illness, with a high prevalence of sarcopenia, such as chronic kidney disease or liver transplantation. Most of the studies performed within the targeted community-dwelling older adult population applied dynamic stimulation. Previous research demonstrated that voluntary resistance exercises were the most effective way to increase skeletal muscle strength and decrease the detrimental effects of sarcopenia[59]. Dynamic stimulation offers a cost-effective approach to optimize outcomes such as to combat decreased activation of the supplementary motor areas of the brain that accompanies decreased muscular strength in individuals with sarcopenia[60]. These forms of ES have been shown to improve cortical reorganization of sensorimotor areas and form new connection in the motor cortex and areas associated with moto control[61]. In addition to improving sensorimotor areas in the motor cortex, Thapa et al also demonstrated enhanced activity in the central, parietal, temporal, and hippocampal regions of the brain[55]. The increased activation of these areas helps to promote increased muscular strength in addition to potentially preventing further cognitive decline. The use of dynamic stimulation likely promotes neuroplastic changes and enhances muscle quality in individuals with sarcopenia, contributing to more sustained improvements in functional activity and a reduction in disability.

Due to the high-intensity nature of the stimulation utilized in static and dynamic stimulation, an intermittent contraction and relaxation of proximal muscle fibers is elicited, recruiting both type I (slow-twitch) and type II (fast-twitch) muscle fibers[62,63]. Type II muscle fibers have a greater responsiveness to repeated muscle contractions occurring through ES, thus being the predominant muscle fiber type strengthened during the intervention[64]. Targeting type II muscle fiber with ES may directly be able to combat the specific type II muscle atrophy occurring with sarcopenia. Voluntary contractions do not typically recruit all available muscle fibers to produce a contraction, however, adding static or dynamic stimulation allows for a central bypass, recruiting all available muscle fibers in the targeted muscle to elicit a stronger contraction[65]. Moreover, there is greater consumption of oxygen and increased blood flow in the muscle during an NMES or FES-induced contraction compared to voluntary muscle contraction[66]. This enhanced circulation supports muscle growth and recovery, contributing to muscle strength gains. Aging leads to a decrease in the number of available motor units to the musculature, as well as compromised vascular

Table 3. Description of the included randomized controlled trials (RCTs).

Study	Population (age), Sample Size	Experimental group (EG)	Control/ comparison group (CG)	Position while receiving stimulation	Target muscle	Stimulation frequency	Duration	Method for assessing muscle strength	Results for Target Muscle Strength
Studies using a stimulation frequency of 20-35 Hz									
Suzuki et al. [2018][57]	Hemodialysis (>65 years) N = 26	Static stimulation	No stimulation	Supine	Quadriceps	20 Hz	3 days x 8 weeks 20 mins/session	Dynamometer	↑ strength in EG compared to CG ($p<0.001$) ↑ strength pre- to post-intervention within EG ($p=0.004$)
Schinner et al. [2023][56] **	Hemodialysis (68±10 years) nN = 32	Static stimulation during virtual reality distraction (EG1) and static stimulation only (EG2)	No intervention	Long-sitting	Quadriceps	20 Hz	3 days x 12 weeks 20 mins/session	Dynamometer	↑ strength in EG2 compared to CG ($p=0.026$) ↑ strength pre- to post-intervention within EG2 ($p=0.021$)
Jang et al. [2021][58] **	Older women residing in the community (~60 years), N = 30	Dynamic stimulation with conventional exercises (EG1) and conventional exercises only (EG2)	No intervention	Sitting and standing	Vastus medialis and vastus lateralis	35 Hz	3 days x 4 weeks 60 mins/session	5 times sit to stand	No difference between groups post intervention, ↑ strength pre- to post-intervention within EG1 ($p=0.004$) and EG2 ($p=0.03$)
Studies using a stimulation frequency of 40-50 Hz									
Esteve V et al. [2017][50]	Hemodialysis (HD) (>65 years), N = 20	Static stimulation during hemodialysis	No intervention	Supine	Quadriceps	50 Hz	3 days x 12 weeks 30-45 mins/session	Dynamometer	↑ strength pre- to post-intervention within EG $p=0.002$)
Bruggeman AK et al. [2017][48] *	Hemodialysis (52-60 years), N = 51	Static stimulation with high frequency (50 Hz)	Static stimulation with low frequency (5 Hz)	Sitting	Quadriceps	5 Hz, 50 Hz	3 days x 4 weeks 60 mins/session	Dynamometer	↑ strength pre- to post-intervention within EG ($p<0.05$)
Hanada et al. [2019][51] *	Liver transplant (52-64 years), N = 45	Static stimulation to quadriceps	Static stimulation to Tibialis anterior	Sitting	Quadriceps	45 Hz	5 days x 4 weeks, 30 mins/session	Dynamometer	No significant ↑ in strength between groups
Sumin et al. [2020][52] *	Post cardiovascular surgery (45-70 years) N = 37	Static stimulation	Standard rehabilitation program	Supine	Quadriceps	45 Hz	Daily, at least 12 sessions , 90 mins/ session	Dynamometer	↑ strength in EG compared to CG post-intervention ($p<0.001$), ↑ strength within EG right ($p=0.004$), left ($p=0.017$)

Table 3. *(Cont. from previous page).*

Study	Population (age), Sample Size	Experimental group (EG)	Control/ comparison group (CG)	Position while receiving stimulation	Target muscle	Stimulation frequency	Duration	Method for assessing muscle strength	Results for Target Muscle Strength
Acheche et al. [2020][53]	COPD (>60 years), N = 42	Static stimulation followed by endurance and lower limb resistance training	Endurance and resistance training, no stimulation	Sitting	Quadriceps and calf muscles	50 Hz	3 days x 4 weeks 90 mins/session	1 repetition maximum (1 RM)	↑ strength in EG compared to CG post-intervention (p=00.5), ↑ strength within EG (p<0.001)
Ramezani et al. [2023][54]	Older adults post COVID-19 (>65 years), N = 40	Dynamic stimulation during voluntary contractions	Sham stimulation during voluntary contractions	Sitting	TA and RF	50 HZ	2 days x 5 weeks 30 mins/session	Biofeedback	↑ RF strength post-intervention and 1 month post p<0.001 and p=0.006) in EG compared with CG ↑ RF strength at post intervention and 1 month post p<0.001 and p=0.002, and ↑ TA strength at post-intervention and 1 month post (p<0.001) within the EG group
Studies using stimulation frequency of >50 Hz									
Acaroz et al. [2019][49]	Older adults in nursing homes (>65 years), N = 53	Static stimulation for short duration (10 mins)	Static stimulation for long duration (5 mins)	Long-sitting	Quadriceps	100 Hz	3 days x 6 weeks 20 mins/session	Dynamometer	No significance in strength between or within groups
Bondi et al. [2022][47]	Healthy elderly (>65 years), N = 11	Static stimulation to quadriceps and lumbar paraspinal muscles	Static stimulation to quadriceps only	Sitting	Quadriceps and lumbar paraspinals	75 Hz	3 days x 8 weeks 18 mins for quadriceps + 15 mins for paraspinal muscles/ session	Maximum voluntary isometric contraction (MVIC)	No significant difference in strength between or within groups
Thapa et al. [2022][55] **	Middle-aged and older women (69.1±5.3) N = 48	Dynamic stimulation with lower limb resistance training (EG1) and Lower limb resistance training without stimulation (EG2)	Seminars on prevention of geriatric diseases	Sitting and prone	Quadriceps	70 Hz	3 days x 4 weeks 50 mins/session	5 times sit to stand	No significant difference in strength between groups, ↑ strength post-intervention within EG1 (p<0.05)

**studies included individuals <55 years of age, Abbreviations: RF = rectus femoris, TA = tibialis anterior, Mins- Minutes, **studies consisting of 2 experimental groups and 1 control or comparison group; Static stimulation = NMES applied while stationary, Dynamic stimulation = NMES or FES applied during single or multi-joint movement.*

responsiveness; static and dynamic stimulation facilitate both an increased neural and vascular response to combat the effects of aging and sarcopenia[67].

The current systematic review demonstrated that frequencies between 35 - 100Hz, when applied during dynamic stimulation, demonstrated an increase in lower extremity strength. This higher frequency produced greater muscle torque and improved type II muscle fiber recruitment while minimizing fatigue during resistance training and functional strengthening. This approach aligns with the theory that the ability to perform functional tasks is more closely linked to an older adult's capacity to generate power than their muscle strength alone[68]. These parameters agree with existing evidence for the use of 50-100Hz to increase muscle strength and function. Other stimulation parameters suggested by a comprehensive review, including orthopedic and neurologic impairments, are a pulse duration of 250-500μs. For the secondary objective of the review, it could be seen that the stimulation parameters varied considerably among the included studies, which leads to a need for further investigation that will focus on establishing improved uniformity among the stimulation parameters to optimally improve muscular strength[69].

For individuals who experience significant functional limitations, even slight improvements in lower limb strength, could hold significance in maintaining autonomy and averting disability. This applies particularly to activities such as sit-to-stand and functional transfers. In the context of the current review, the effectiveness of static and dynamic stimulation on muscular strength could also be affected by the chronicity and characteristics of the subject condition of each study. The spontaneous effect of the stimulation on muscle strength remains unknown.

The included studies all performed supervised ES by a provider. The clinical settings where the provider delivered the intervention varied by study: the acute hospital setting, a nursing home, or an outpatient clinic. None of the studies included in the current review explored the use of ES in the home setting. This could be because there is higher compliance with supervised exercise than unsupervised exercise. To facilitate an individual's ability to perform this intervention at home, unsupervised, training by a rehabilitation professional is recommended, such as a physical or occupational therapist, who has extensive training in modalities to improve muscle strength and function. Once a professional has trained the individual and cleared them for home use, the use of static and dynamic stimulation could improve access to optimize muscle strengthening[70].

The existing barriers for community-dwelling older adults to perform resistance exercises remain a significant limitation to combating sarcopenia. There is a pressing need to formulate strategies to incorporate feasible tools as an adjunct to exercise programs, aiming to amplify their influence on muscle performance. Static or dynamic stimulation have the potential to be an efficient and cost-effective tool to increase muscle strength in community-dwelling older adults. This will likely involve integrating behavior change components into ES-driven interventions, leveraging improvements in muscle strength to promote alterations in physical activity and increase functional independence. Dynamic stimulation could also be considered as a bridging tool to assist community-dwelling older adults who encounter challenges to participating in comprehensive rehabilitation programs. The self-administration of static or dynamic stimulation at home holds great potential to reach a larger patient population who would benefit from this modality. However, ensuring adherence to the program can be difficult because of the lack of validated self-reported adherence measures[70]. Despite the need for improved self-reported adherence measures, the potential use for home-based physical therapy to improve muscle strength will be of large benefit to combat barriers to resistance training for community-dwelling older adults.

Clinical relevance

Dynamic stimulation enhances muscle strength in weak muscles among middle-aged and older adults due to the combination with resistance training and/or functional movements. It is necessary to evaluate objective metrics to gather additional evidence to support the use of static stimulation protocols. Additionally, the ease of use of ES makes it a preferred treatment option for this demographic. The use of dynamic stimulation is a cost-effective method to optimize outcomes and reduce healthcare costs. Further investigation is required to clarify the most effective stimulation parameters for improving muscle strength, and to establish standardized protocols tailored to specific target populations and conditions. In sarcopenic individuals, traditional resistance training exercises may be difficult due to limited strength, mobility, or endurance. ES can be used as a home-based alternative to activate muscle contractions and help maintain or improve muscle mass in this population. This approach can enhance functional capacity, support independence, and reduce the risk of further physical decline.

Limitations

One of the major limitations of this review is most of the studies had small sample sizes. Comparisons between studies were limited by substantial heterogeneity in populations, interventions and assessment and outcome measures. Lack of categorization (very weak, weak, moderately weak) further complicated analysis, as individuals with lower baseline strength may benefit more from static or dynamic stimulation. There is little evidence for the effects of static stimulation for the sarcopenic community-dwelling older adult in the literature at this time, resulting in cohorts with chronic health conditions being included in the current review. While many older adults do have one or more chronic conditions, more research is needed to optimize the interventions provided to this population. A significant factor is the discomfort due to the high intensity of electrically triggered contractions[72]. Adjusting the size of the electrode and distance depending on the skin-fold thickness and surface area can reduce the discomfort of the stimulation by dispersing the current intensity, thus reducing the discomfort[73-75]. There is a lack of self-reported adherence measures - one approach to tracking progress and improving self-reported adherence during unsupervised home-care sessions is to schedule regular follow-up appointments with the clinician, either in-person or virtual[76-78]. Coordinating with an individual's caregiver to assess progress may be another option to improve self-adherence outside the clinical environment[79,80].

Conclusion

The review suggests that static or dynamic stimulation is an effective strategy to increase muscular strength in community-dwelling older adults with chronic conditions. For community-dwelling older adults without chronic conditions, dynamic stimulation is recommended as the effectiveness of static stimulation remains unclear. Hence, future research is required to assess the effectiveness of static stimulation versus dynamic stimulation in this population. Additionally, identifying the optimal parameters of ES that can maximize improvements in muscle strength is essential. This includes exploring variables such as intensity, frequency, duration, and the specific protocols of stimulation, which may vary across individuals and conditions.

Authors' contributions

The manuscript concept was proposed by Dr. Tanvi Bhatt. Swaranka Deshmukh and Gillian McLean conducted the blinded study selection, with final approval from Dr. Tanvi Bhatt. Swaranka Deshmukh, Gillian Mclean and Rudri Purohit conducted the PEDro scoring for the included studies. They also contributed significantly to writing and composition. Rudri Purohit assisted with proofreading, editing, and feedback. Dr. Ross Arena provided valuable insights that enhanced the manuscript. All authors read and approved the final version of the manuscript.

Funding

This study was funded by the Department of Physical Therapy funds and the NIH 1R21HD112862 awarded to Tanvi Bhatt (Corresponding author).

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