The Effects of Neuromuscular Electrical Stimulation (NMES) on Muscle Mass, Muscle Strength, and Functional Ability in The Elderly: A Literature Review

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Abstract.

Sarcopenia is characterized by a loss of muscle in the elderly population with correlative muscle function loss and decreased mobility and independence, and it is associated with increased metabolic and cardiovascular risk. Physical activity is the foundation for prevention and treatment, yet numerous older people are unable to exercise sufficiently due to acute or chronic illnesses, neurological diseases, pain, anxiety, fear of falling, or demotivation. Neuromuscular electrical stimulation (NMES) might be the alternative or add-on treatment as it elicits muscle contractions with very little voluntary demand. This review examined the impact of NMES on muscle mass/size, muscle strength, functional capacity, and plausible mechanisms in elderly subjects. This study used a literature review from PubMed and ScienceDirect, identifying 108 records and including 38 eligible studies on NMES in older adults, with findings synthesized descriptively due to heterogeneity in protocols and outcomes. Overall, NMES was frequently reported to increase or at least maintain muscle mass or size, often in the quadriceps, and to reduce disuse atrophy during immobilization or critical illness, including ICU and acute heart failure settings, particularly when combined with early rehabilitation. Several studies also reported improvements in maximal isometric strength and functional outcomes such as mobility, balance, and gait. Proposed mechanisms include activation of anabolic signaling (IGF-1/PI3K/mTOR), enhanced regeneration markers, and reduced catabolic gene expression (FOXO1A, MSTN, MAFbx, MuRF1), without clear increases in oxidative stress in some studies. NMES appears promising, but standardized dosing and outcomes are needed.

Keywords: *Neuromuscular electrical stimulation; older adults; sarcopenia; muscle mass; muscle strength and functional capacity.*

I. INTRODUCTION

The population in the world is changing, with older adults making up a larger portion and they are experiencing more age-related diseases. Sarcopenia is one of the most recognized, a loss of muscle mass, strength and function with the clinical consequence that it limits older adults in what they can do in daily living activities [1], [2]. As older adults are losing muscle mass and muscle quality, they are also increasingly at risk of having walking problems, becoming easily tired, and losing their independence, a pattern that eventually has them in need of assistance while walking, getting up from a chair, or climbing stairs, among other very basic activities. The impact extends beyond physical function: reduced muscle mass is also linked to metabolic and cardiovascular disturbances, including insulin resistance and hypertension, which ultimately worsen quality of life and increase healthcare utilization [3], [4]. Such this places a burden at many layers, from stress on individual and family caregivers to strain on health systems with greater demand for rehabilitation, long-term care and management of complications associated with immobility. Therefore, the intervention strategies that sustain muscle quality, lower the risk of chronic disease, and retain functional capacity are best candidates in geriatric rehabilitation. In many countries, population aging also drives the need for community-based preventive policies so that muscle-preserving interventions can be accessed before disability becomes established.

Despite the fact that physical activity, especially resistance training, is considered as the main approach to averting muscle mass and function loss, not all elderly individuals are able to engage in it safely and regularly. A range of acute and chronic conditions can limit the ability to exercise at an adequate intensity [5]. During acute heart failure or the acute phase after stroke, hemodynamic and neurological limitations often make sufficiently intense training difficult, even though these periods are also marked by accelerated muscle loss due to bed rest and inflammatory responses. Cognitive decline and dementia add further challenges by undermining understanding of instructions, adherence to programs, and the ability to sustain exercise routines [6], [7]. In addition, chronic pain (for example, in the knee or lower back), a history of falls, fear of falling, and generalized weakness can reduce confidence to move and restrict daily physical activity. Psychological factors such as low motivation, depression, or fatigue also commonly play a role [8]. Beyond patient-related barriers, the evidence base for alternative interventions is not uniform, including for neuromuscular electrical stimulation (NMES), due to differences in protocols (frequency, intensity, duration, on–off ratio, and electrode placement) and variations in population characteristics. This inconsistency makes it difficult for clinicians to determine parameters that are both effective and safe, particularly for vulnerable older adults.

In this context, NMES can be viewed as a relevant option to replace or complement exercise in older adults, especially in those who cannot generate adequate voluntary contractions. NMES delivers electrical current through surface electrodes to evoke involuntary muscle contractions; in other words, the muscles can be activated without requiring substantial conscious effort [9], [10]. This advantage is particularly important in acute conditions or during immobilization, when active exercise is not yet feasible but contractile stimulation is needed to slow the progression of atrophy. In ICU settings, NMES combined with early rehabilitation has been reported to reduce the magnitude of muscle wasting compared with early rehabilitation alone [10]; a similar pattern has been described in acute heart failure patients, with NMES helping to limit declines in lower-limb muscle volume or thickness [11]. With respect to strength, several studies report improvements in maximal isometric strength in the stimulated muscles, both in healthy older adults and in cardiovascular patients following an acute event [12], [13]. NMES may also serve as an adjunct therapy: when combined with active training, it may accelerate strength gains, improve exercise tolerance, and support the transition to more functional resistance-training programs [14].

From a theoretical perspective, the mechanisms of NMES support the plausibility of effects that resemble certain adaptations to exercise. NMES is a form of electrical stimulation delivered above the motor threshold, producing excitomotor stimulation [9]. This differs from sensory electrical stimulation (SES), which is delivered below the motor threshold and primarily stimulates sensory afferents to modulate motor control, balance, and posture through pathways from the spinal cord to cortical regions. In contrast, NMES triggers action potentials in motor nerves, resulting in muscle contractions [15]. Classic evidence shows that when neuromuscular transmission is blocked (for example, by agents acting at the neuromuscular junction), NMES no longer produces contractions, confirming that its primary target is the motor nerve rather than the muscle fibers directly [9]. Repeated NMES-induced contractions may promote peripheral adaptations, including improved motor unit activation, enhanced neuromuscular coordination, and morphological changes such as maintenance or increases in muscle fiber cross-sectional area. At the neural level, repeated exposure may facilitate neuroplastic changes, including axonal sprouting at the neuromuscular junction and more efficient recruitment, which could help sustain benefits even after stimulation stops [16], [17]. Although the sensory effects of NMES are smaller than those of SES, afferent activation during NMES still provides feedback to the central nervous system and may, in theory, support motor learning and movement control, particularly when paired with functional training. This framework helps explain why NMES can improve strength and, under certain conditions, functional abilities such as gait patterns or sit-to-stand performance, while also clarifying why insufficient dosing may yield minimal effects.

Based on this background and the variability of existing findings, the primary aim of this review is to evaluate the scientific evidence on the effectiveness of NMES in older adults for improving or preserving muscle mass or size, muscle strength, and functional capacity, and to describe the physiological and molecular mechanisms underlying these effects. Accordingly, the research question is whether NMES (as a stand-alone therapy or combined with rehabilitation or exercise) can increase or prevent declines in muscle mass or size, enhance muscle strength, and improve functional capacity compared with no NMES, and which mechanisms most plausibly explain these changes. This review offers a twofold contribution. First, scientifically, it helps organize evidence that is scattered and sometimes appears contradictory by interpreting each study's results in the context of protocol characteristics (frequency, duration, intensity, and intervention period) and participant profiles (healthy older adults, sarcopenia, acute heart failure, stroke, ICU, and dementia), enabling readers to better understand why NMES succeeds or fails in specific settings. Second, practically, it can inform preliminary guidance for NMES use in geriatric rehabilitation, including when NMES may serve as a temporary substitute for active exercise, when it is better positioned as an adjunct therapy, and how safety principles and gradual progression of intensity can be applied in frail older adults. In doing so, this review also supports future research aimed at developing more standardized, reproducible NMES protocols that are clinically relevant, so that NMES can function as an effective, safe, and inclusive intervention to help preserve independence in older adults.

II. METHODS

Study type and design

This study is a literature review with a structured search strategy to identify and summarize scientific evidence on the effects of Neuromuscular Electrical Stimulation (NMES) in older adults. Muscle size/mass, strength and functional performance were the dependent variables of interest, compatible with the objectives and scope of the article. The results were descriptively synthesized rather than meta-analyzed since stimulation protocols and outcome measures differed between studies.

Data sources and search strategy

The literature search was conducted in the electronic databases PubMed and ScienceDirect to identify studies relevant to NMES in older adults. Search terms were constructed using Boolean operators (AND/OR) and included the intervention, population and outcomes. Keywords included: "neuromuscular electrical stimulation", "electrical muscle stimulation", "electromyostimulation", "functional electrical stimulation", "older adults", "elderly", "geriatric", "muscle mass", "muscle size", hypertrophy, atrophy, "muscle strength", "functional ability", mobility, balance, and gait. The search prioritized English-language articles and full-text availability when possible, with the publication window focused on the last 10 years used in this article (Table 1).

Study selection process

Study selection was conducted in stages, including identification, title and abstract screening, and full-text review to confirm alignment with the aims of the review. After screening, 38 studies were eligible for inclusion among 108 records identified through the database searching and were included in the synthesis.

Inclusion and exclusion criteria

Inclusion criteria were: (1) participants were older adults (based on the definitions applied in the included studies), (2) the intervention involved NMES or related stimulation modalities within the neuromuscular stimulation spectrum (for example, EMS, FES, or WB-EMS, including protocols such as Russian/Kotz currents when used for muscle stimulation), (3) the study reported at least one primary outcome related to muscle mass/size, muscle strength, or functional ability, and (4) the study used an empirical design such as randomized controlled trials, quasi-experimental studies, clinical studies, pilot studies, or cohort/retrospective designs. Review articles could be included to support background context or provide additional synthesis when relevant to the article's theme.Exclusion criteria were: animal studies, non-older-adult populations, interventions not involving neuromuscular stimulation of muscle, studies that did not report outcomes relevant to the article's focus, and publications available only as abstracts without adequate data.

Data extraction and summary presentation

Data from eligible studies were extracted systematically and summarized in a study characteristics table (Table 1). Extracted variables included: author and year, study design, participant characteristics, electrode placement, stimulation parameters (frequency, pulse width, intensity when available, contraction–rest pattern), session duration, program length, comparator, and key outcomes related to muscle mass/size, muscle strength, functional ability, and molecular or metabolic findings when reported.

Data synthesis

The literature review was conducted by grouping findings according to the structure of the discussion, namely: (1) mechanisms of action of NMES, (2) effects on muscle mass/size and prevention of atrophy, (3) effects on muscle strength, (4) effects on functional capacity, and (5) adaptations in gene expression, metabolism, and muscle anabolism. This approach was chosen to modify for differences in NMES protocol and the heterogeneity of outcome measures used in the studies.

III. RESULT AND DISCUSSION

Mechanism of Action of NMES

Neuromuscular Electrical Stimulation (NMES) is a modality that delivers electrical current through a medium to elicit muscle contractions [18]–[20]. NMES is part of electrical stimulation (E-Stim). Based on the intensity applied and the physiological effects targeted, E-Stim can be classified into NMES and Sensory Electrical Stimulation (SES). SES uses low-intensity current below the motor threshold, thereby influencing sensory nerves without producing muscle contraction. SES stimulates mechanoreceptors and generates neural signals that travel from the periphery to the central nervous system, progressing from the spinal cord to the thalamus, the somatosensory cortex, and ultimately the primary motor cortex. As a result, SES primarily affects sensorimotor activity by providing feedback to peripheral sensory pathways and the central nervous system, which can influence motor abilities related to balance, motor control, and posture [18].

In contrast, NMES delivers higher-intensity current above the motor threshold and induces muscle contraction, referred to as excitomotor stimulation [18], [20]. This stimulation targets the motor system and can lead to changes in muscle mass and muscle strength [18]–[20]. NMES does not stimulate the muscle fibers directly; instead, it triggers action potentials in motor nerves, which subsequently produce muscle contraction. This is supported by studies showing that NMES failed to elicit muscle contraction after intravenous administration of curare, a neuromuscular junction (NMJ) blocker [18], [20]. Repeated NMES influences motor units, promotes neuroplasticity, increases axonal sprouting at the NMJ, and facilitates muscle contraction [20]. In addition to its effects on the motor nervous system, NMES can also activate sensory pathways, although its sensory effects are smaller than those produced by SES. Through activation of sensory afferents, NMES provides feedback to the central nervous system, which may induce central neuroplastic changes after repeated stimulation [18], [20]. NMES-induced neuroplasticity may help explain its longer-term effects, even after stimulation has been discontinued [18], [20].

Effects of NMES on Muscle Mass and Size

Increases in Muscle Mass and Size

Several studies have reported that NMES can increase muscle mass and muscle size. An increase in quadriceps cross-sectional area was observed after NMES was applied three times per week for eight weeks in healthy older adults aged over 65 years [21]. Similarly, an increase in quadriceps muscle mass was reported when NMES was combined with standard rehabilitation in older patients with acute myocardial infarction (AMI) undergoing emergency percutaneous coronary intervention (PCI) [22]. NMES has also been shown to be beneficial in older adults with dementia [23]–[25]. Bilateral lower-limb muscle mass increased after an NMES intervention combined with conventional rehabilitation in older patients with dementia (Nishikawa et al., 2021).

This finding is clinically relevant because older adults with dementia often have difficulty adhering to exercise programs aimed at maintaining muscle mass. Therefore, NMES, which does not rely on an individual’s cognitive status, may serve as an alternative intervention [26]. Increases in rectus femoris and tibialis anterior muscle mass, as well as increases in calf circumference, have also been observed following NMES, whether used as a stand-alone therapy or in combination with exercise [27], [28]. However, some studies have found that NMES did not increase quadriceps femoris muscle mass or thickness [29]. Differences in NMES protocols, including frequency, duration, and intensity, as well as variations in study populations, may help explain these inconsistent findings.

Prevention of Muscle Atrophy

NMES appears to have a protective effect against age-related declines in muscle mass. NMES has been reported to prevent reductions in leg lean mass and mid-thigh lean mass and to slow the progression of atrophy in the knee extensor muscles [30], [31]. Combining NMES with early rehabilitation has also been shown to attenuate lower-limb muscle loss in older ICU patients. In one study, muscle mass decreased by 7.9% in patients who received NMES plus early rehabilitation, compared with 19.8% in those who received early rehabilitation alone [32]. NMES may therefore represent a safe adjunct therapy for ICU patients who are not yet able to engage in optimal physical exercise because of clinical instability. Another study reported benefits of NMES combined with standard rehabilitation in patients with acute heart failure (AHF) in preventing declines in lower-limb muscle volume and thickness, with an 11.6% reduction in the NMES group compared with a 20.4% reduction in the non-NMES group [33]. This benefit is particularly meaningful for older patients with AHF who are not yet able to participate fully in active exercise programs.

Effects of NMES on Muscle Strength

NMES has been shown to improve maximal isometric strength (MIS) in the stimulated muscles [28], [34]–[36]. In healthy older adults, NMES increased MIS of the vastus lateralis and vastus medialis [36]. Similar improvements were reported in older patients with acute heart failure (AHF) who received early rehabilitation plus NMES applied to proximal and distal thigh muscles and ankle muscles in both limbs [37]. This is particularly valuable for AHF patients who are often unable to perform maximal-strength exercise due to their clinical condition [38]–[40]. Comparable findings were also observed in older patients with acute myocardial infarction (AMI) undergoing emergency PCI, where seven days of NMES combined with standard rehabilitation after PCI improved strength of the quadriceps femoris and gastrocnemius muscles [22]. Beyond strength gains, NMES has also been reported to improve muscle endurance and power [41]. In older adults, one contributor to balance impairment and foot pain is flattening of the medial longitudinal arch (MLA), which can result from weakness of the abductor hallucis muscle. NMES combined with short-foot exercise (SFE) may strengthen the abductor hallucis, improve the MLA, and increase navicular height [42], [43]. These effects may help improve balance and reduce foot pain in older adults.

Another study reported that electrical stimulation using EMG-controlled FES applied to the rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius reduced muscular effort, lowered the coactivation index (a measure of simultaneous activation of agonist and antagonist muscles), and improved right–left symmetry of muscle strength. Together, these changes contributed to greater movement efficiency [44].A review article evaluating NMES with different frequencies and durations in stroke patients aged 60–70 years reported a 56.6% increase in dorsiflexor strength, which improved gait patterns in stroke survivors. Reduced spasticity after NMES also facilitated conventional rehabilitation, resulting in better outcomes when NMES was combined with standard rehabilitation [34]. Another review concluded that NMES applied in older adults for six to eight weeks, three times per week, could increase quadriceps femoris strength by 19.5% compared with controls. Strength gains from NMES (9.6%) were comparable to those achieved through resistance training (10%), suggesting that NMES may produce effects similar to resistance exercise in older populations [45].

However, several studies found no clinically meaningful effect of NMES on muscle strength [31], [35], [46]. In a study involving older adults with chronic cerebral ischemia, NMES increased lower-limb strength, but the change was not statistically significant [46]. Other studies reported no improvement in strength of the vastus medialis, rectus femoris, or knee extensor muscles following NMES [31], [35]. Declines in maximal voluntary isometric contraction (MVC) and rate of force development (RFD) were observed in the thigh muscles of both limbs regardless of NMES. This pattern may reflect reduced neural drive due to immobilization and minimal voluntary contraction during the study period, potentially leading to central changes that impair motor drive [31].A study in nursing home residents also did not find increased quadriceps femoris strength after NMES delivered three times per week for six weeks. This may have occurred because stimulation intensity did not reach participants' maximal tolerance due to concerns about rhabdomyolysis in sarcopenic muscle. Nevertheless, the absence of a decline in quadriceps strength suggests that NMES may help maintain muscle strength in inactive older adults with sarcopenia [35].

Effects of NMES on Muscle Strength, Tension, and Cross-Sectional Area

In healthy older adults, NMES has been reported to increase muscle fiber strength by 10% and to improve muscle fiber tension and cross-sectional area (CSA). However, another study found no increase in muscle fiber size or in the number of satellite cells following NMES [36].

Effects of NMES on Functional Capacity

Older adults commonly experience impairments in both static and dynamic balance, often related to declines in core strength and lower-limb muscle strength. One study reported that whole-body electromyostimulation (WB-EMS) applied to the abdominal, lumbar, quadriceps, hamstring, and gluteal muscles improved static balance [47]. NMES applied to lower-limb muscles has also been shown to improve functional performance in older adults, as assessed using the Timed Up and Go test (TUG), Rivermead Mobility Index (RMI), Tinetti Test, Y-Balance Test (YBT), and Functional Reach Test (FRT) [27], [46], [48], [49]. Another study found that NMES applied to the gastrocnemius and tibialis anterior improved ankle balance and reduced internal foot angles, thereby improving gait in older adults [50]. Older adults often show changes in internal foot angle due to weakness of the ankle musculature, which can compromise both static and dynamic balance [51].

Another common problem in older adults, particularly women, is urinary dysfunction. One study reported that NMES reduced the mean myoelectrical potential during relaxation of the bladder musculature. Elevated mean myoelectrical potential, which is often observed in overactive bladder (OAB), increases the likelihood of bladder muscle spasm, a key factor in OAB. NMES was also reported to increase the mean myoelectrical potential of type I pelvic floor muscle fibers (slow-twitch), which can sustain long-duration contractions, thereby helping maintain pelvic strength and reduce the risk of pelvic organ prolapse. In addition, NMES may increase the maximum myoelectric potential of type II pelvic floor muscle fibers (fast-twitch), which are recruited during sudden increases in intra-abdominal pressure, such as coughing or sneezing, thereby reducing urinary incontinence. Overall, NMES may reduce the incidence of OAB, pelvic organ prolapse, and urinary incontinence [52]. Although many studies report benefits of NMES for functional performance, some research has found that WB-EMS does not produce greater functional improvements than resistance training [50].

Effects of NMES on Gene Expression, Metabolism, and Muscle Anabolism

Upregulation of Anabolic Pathways

Several genes involved in muscle growth and satellite cell activation, including insulin-like growth factor 1 (IGF-1), phosphoinositide 3-kinase (PI3K), and mammalian target of rapamycin (mTOR), have been reported to show increased expression after NMES. However, another study found that the NMES-related increase in IGF-1 expression was not statistically significant [30]. Differences in NMES protocols, such as duration, frequency, and intensity, may account for these discrepant results. Study population characteristics may also influence outcomes, with significant findings more commonly reported in healthy older adults, whereas non-significant changes have been observed in hospitalized older patients.NMES may promote muscle repair and regeneration, as reflected by increased expression of apoptosis-related genes such as tumor necrosis factor (TNF) and caspase 6, 7, and 8 (CASP6, CASP7, CASP8) [37], [53], [54].

NMES has also been associated with increased expression of genes involved in muscle regeneration and differentiation, including myogenic differentiation 1 (MYOD1) and paired box 7 (PAX7), alongside TNF, which may accelerate muscle tissue repair. Decreased expression of caspase 9 (CASP9) and B-cell lymphoma 2 (BCL2) following NMES suggests reduced mitochondria-mediated cell death [36].The role of NMES in stimulating muscle protein anabolism is further supported by evidence of increased utilization of branched-chain amino acids (BCAAs) and glycine. This was indicated by lower circulating BCAA and glycine levels after NMES in older ICU patients compared with controls. In addition, lower proline levels after NMES may reflect reduced protein breakdown, as proline can serve as a marker of muscle protein catabolism. NMES has also been reported to increase expression of Ki67+, a marker associated with cell proliferation, supporting faster muscle regeneration [30]. Increased expression of collagen 1 and tenascin C suggests extracellular matrix remodeling that may help maintain muscle tissue structure during recovery following NMES [30].

Downregulation of Catabolic Pathways

NMES may reduce muscle protein catabolism and muscle atrophy, as indicated by decreased expression of genes involved in muscle degradation, including forkhead box O1A (FOXO1A), myostatin (MSTN), muscle atrophy F-box protein (MAFbx), and muscle RING-finger protein 1 (MURF1) [30], [36]

Effects on Oxidative Stress

NMES has not been associated with increased expression of genes involved in oxidative stress regulation, such as glutathione peroxidase 1 (GPX1) and superoxide dismutase 1 and 2 (SOD1 and SOD2). This suggests that NMES may be safe for older adults because it does not appear to induce elevated oxidative stress, including in vulnerable individuals [36].

Enzymatic Activity and Energy Efficiency

One study reported that NMES increased oxidative enzyme activity. These enzymes are central to aerobic metabolism, which produces large amounts of energy. Increased oxidative enzyme activity may therefore indicate more efficient energy production within muscle cells [55].Overall, this review has the advantage of providing a relatively comprehensive overview of NMES in older adults by integrating key clinical outcomes (muscle mass/size, muscle strength, and functional capacity) while also outlining the most plausible mechanisms underlying these changes, from the neuromuscular level (motor nerve activation, motor unit adaptations, and neuroplasticity) to the molecular and metabolic level (evidence of anabolic pathway activation, suppression of catabolic pathways, and improved energy efficiency). It also considers diverse populations, ranging from healthy older adults to clinical groups such as ICU patients, those with acute heart failure or acute myocardial infarction, and older adults with dementia.The practical implication is that NMES may be considered a feasible and relatively safe adjunct intervention to maintain or improve muscle mass and strength and to support function, particularly in older adults who cannot exercise optimally. At the same time, these findings highlight the importance of selecting an appropriate NMES “dose” and protocol design (intensity, frequency, duration, and combination with rehabilitation or exercise) to achieve more consistent clinical benefits and to enable more targeted implementation in geriatric rehabilitation programs.

IV. CONCLUSION

Based on this review, NMES, whether used as a stand-alone therapy or combined with rehabilitation or exercise, can generally increase or preserve muscle mass and size (for example, by increasing cross-sectional area or lean mass) and help prevent atrophy in older adults. These benefits appear particularly relevant to groups difficult to train optimally such as the patients with acute heart failure or acute myocardial infarction or elderly patients with dementia and patients in the ICU. However percent some studies report contrary results which could be attributed to differences in stimulation protocols and/or intensity and/or duration of intervention and/or participants’ characteristics. NMES also tends to improve muscle strength (for example, MIS/MVC in the stimulated muscles) and, in many studies, is accompanied by improvements in functional capacity (such as mobility and balance), although in some contexts the benefits are not superior to resistance training or are not statistically significant. The most plausible mechanisms underlying these effects involve suprathreshold stimulation that triggers action potentials in motor nerves, recruits motor units, and produces repeated contractions, alongside neuromuscular adaptations (including neuroplastic changes and improved transmission at the neuromuscular junction) and sensory feedback to the central nervous system. At the molecular level, NMES may promote anabolic and regenerative pathways (for example, IGF-1/PI3K/mTOR signaling and satellite cell activation) while suppressing catabolic pathways associated with atrophy (for example, FOXO1A, MSTN, MAFbx, and MuRF1).

NMES may also improve metabolic efficiency through increased oxidative enzyme activity. Collectively, these mechanisms might underpin preservation or gains in muscle size, strength and function relative to no NMES The main limitations to this review are that the synthesis was narrative, thus effect sizes could not be quantified or compared. In addition, there was substantial heterogeneity in NMES protocols (frequency, intensity, duration, on–off ratios, and electrode placement), outcome measures, intervention length, and participant characteristics (ranging from healthy older adults to ICU patients and those with acute illness). This heterogeneity is likely responsible for inconsistent results across studies and the conclusions that can be reached. Future research should prioritize controlled clinical trials with standardized interventions and detailed protocol reporting, including dose–response approaches and systematic safety monitoring. Studies should also use consistent clinical outcomes (muscle mass/size, strength, and functional tests), include longer follow-up periods, and conduct subgroup analyses (for example, frail older adults, sarcopenia, dementia, acute heart failure/acute myocardial infarction, and ICU populations) to identify which groups benefit most. In addition, future work should compare NMES as a stand-alone therapy versus NMES combined with exercise or rehabilitation and further investigate biological mechanisms using more consistent and comparable measures.

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