Regence

Medical Policy Manual Durable Medical Equipment, Policy No. 83.04

Functional Neuromuscular Electrical Stimulation

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IMPORTANT REMINDER

Medical Policies are developed to provide guidance for members and providers regarding coverage in accordance with contract terms. Benefit determinations are based in all cases on the applicable contract language. To the extent there may be any conflict between the Medical Policy and contract language, the contract language takes precedence.

PLEASE NOTE: Contracts exclude from coverage, among other things, services or procedures that are considered investigational or cosmetic. Providers may bill members for services or procedures that are considered investigational or cosmetic. Providers are encouraged to inform members before rendering such services that the members are likely to be financially responsible for the cost of these services.

DESCRIPTION

Functional neuromuscular electrical stimulation is a method being developed to restore function to patients with damaged or destroyed nerve pathways through use of an orthotic device with microprocessor controlled electrical neuromuscular stimulation (neuroprosthesis).

MEDICAL POLICY CRITERIA

Functional neuromuscular electrical stimulation (see Policy Guidelines) using any device is considered **investigational** for all indications, including but not limited to the following: as a technique to provide ambulation in patients with spinal cord injury, to restore upper or lower extremity function in patients with nerve damage (e.g., spinal cord injury or post-stroke), to improve ambulation in patients with foot drop caused by congenital disorders or nerve damage (e.g., post-stroke or in those with multiple sclerosis), or as a treatment of pain.

NOTE: A summary of the supporting rationale for the policy criteria is at the end of the policy.

POLICY GUIDELINES

Functional neuromuscular electrical stimulation includes the following types of stimulators:

- Neuromuscular electrical stimulation (NMES)
- Functional neuromuscular stimulation (FNS)
- Functional electrical stimulation (FES)
- Electrical neuromuscular stimulation (ENS)
- Electromyography (EMG) triggered neuromuscular stimulation.

CROSS REFERENCES

1. Interferential Current Stimulation, Durable Medical Equipment, Policy No. 83.07
2. Transcutaneous Electrical Modulation Pain Reprocessing, Medicine, Policy No. 143

BACKGROUND

Functional neuromuscular electrical stimulation is also known as Neuromuscular Electrical Stimulation (NMES), Functional Neuromuscular Stimulation (FNS), Functional Electrical Stimulation (FES), Electrical Neuromuscular Stimulation (ENS), or electromyography (EMG)-triggered neuromuscular stimulation. Neural prosthetic devices consist of an orthotic and a microprocessor-based electronic stimulator with one or more channels for delivery of individual pulses through surface or implanted electrodes connected to the neuromuscular system. Microprocessor programs activate the channels sequentially or in unison to stimulate peripheral nerves and trigger muscle contractions to produce functionally useful movements that allow patients to sit, stand, walk, and grasp. Functional neuromuscular stimulators are closed loop systems, which provide feedback information on muscle force and joint position, thus allowing constant modification of stimulation parameters which are required for complex activities such as walking. These are contrasted with open loop systems, which are used for simple tasks such as muscle strengthening alone, typically in healthy individuals with intact neural control.

REGULATORY STATUS

The following is a list of Functional neuromuscular electrical stimulation devices that have received 510(k) or pre-market approval (PMA) from the U.S. Food and Drug Administration (FDA)*:

Device	Manufacturer	Device Type	510k Clearance	Date	Product Code
NESS H200® (previously Handmaster)	Bioness	Hand stimulator	K022776	2001	GZI
MyndMove System	MyndTec	Hand stimulator	K170564	2017	GZI/IPF
ReGrasp	Rehabtronics	Hand stimulator	K153163	2016	GZI/IPF
WalkAide® System	Innovative Neurotronics (formerly NeuroMotion)	Foot drop stimulator	K052329	2005	GZI
ODFS® (Odstock Dropped Foot Stimulator)	Odstock Medical	Foot drop stimulator	K050991	2005	GZI
ODFS® Pace XL	Odstock Medical	Foot drop stimulator	K171396	2018	GZI/IPF
L300 Go	Bioness	Foot drop stimulator	K190285	2019	GZI/IPF
L100 Go	Bioness	Foot drop stimulator	K200262	2020	GZI/IPF

Foot Drop System	SHENZHEN XFT Medical	Foot drop stimulator	K162718	2017	GZI
Nerve And Muscle Stimulator	SHENZHEN XFT Medical	Foot drop stimulator	K193276	2020	GZI
MyGait® Stimulation System	Otto Bock HealthCare	Foot drop stimulator	K141812	2015	GZI
MStim Drop Model LGT-233	Guangzhou Longest Science & Technology	Foot drop stimulator	K202110	2021	GZI/IPF
ERGYS (TTI Rehabilitation Gym)	Therapeutic Alliances	Leg cycle ergometer	K841112	1984	IPF
RT300	Restorative Therapies, Inc (RTI)	Cycle ergometer	K050036	2005	GZI
Myocycle Home	Myolyn	Cycle ergometer	K170132	2017	GZI
Cionic Neural Sleeve (NS-100)	Cionic	Foot drop stimulator	K221823	2022	GZI/IPF
Reactiv8	Mainstay Medical	Pain Relief – low back muscles - implantable	P190021	2020	QLK

*This list may not be all inclusive and additional devices may be FDA approved.

- Other FDA devices are available that allow patients with impaired function of the extremities to passively and actively exercise using cycle ergometry.
- Cycle ergometers consist of motorized leg ergometer, optional motorized arm crank, and leg and optional arm electrical stimulation. Examples of cycle ergometers that have 510k FDA approval are the RT300 (Restorative Therapies, Inc.) and the Myocycle (Myolyn). Rowing devices have also been devised for exercise.

EVIDENCE SUMMARY

Functional neuromuscular electrical stimulation is also known as Neuromuscular Electrical Stimulation (NMES), Functional Neuromuscular Stimulation (FNS), Functional Electrical Stimulation (FES), Electrical Neuromuscular Stimulation (ENS), or electromyography (EMG)-triggered neuromuscular stimulation. Treatment with NMES devices must be evaluated in general groups of patients against the existing standard of care for the condition being treated. Data from adequately powered, blinded, randomized controlled trials (RCTs) are required to control for the placebo effect, determine its magnitude, and determine whether any treatment effect from a functional neuromuscular stimulation device provides a significant advantage over the placebo.

The principal outcome associated with use of FNS devices includes a clinically significant improvement in functional ability, such that there is an improved ability to complete activities of daily living. As a secondary outcome, positive changes in the patient's quality of life may result from improved functional ability. Physical therapy is an important component of clinical treatment of loss of neuromuscular function. Therefore, comparisons between physical therapy with and without neuromuscular stimulation from adequately powered, blinded, RCTs are required to determine whether any treatment effect from an electrical stimulation device provides a significant advantage over the standard of care.

NMES devices are not designed to be an alternative to a wheelchair and offer, at best, limited, short-term ambulation.[1] Final health outcomes, such as improved functional performance and ability to perform activities of daily living, have not been reported. Without randomized comparisons, it is not known whether similar or improved results could be attained with other training methods.

Concomitant use of NMES with exercise equipment has been proposed to counteract the health consequences of paralyzed limbs, including prevention of muscle atrophy, reduction of muscle spasms, improvement of circulation, improvement in range of motion, improvement in cardiopulmonary function, reduction in pressure sore frequency, and improvements in bowel and bladder function. It is not clear that the health benefits of EMG-triggered NMES exercise cannot be realized through standard passive range of motion exercise.

FUNCTIONAL NEUROMUSCULAR ELECTRICAL STIMULATION OF THE UPPER EXTREMITY

Systematic Reviews

Ou (2023) published a systematic review with meta-analysis to assess the effects of neuromuscular electrical stimulation on the upper limbs of patients with cerebral palsy.[2]

Eight randomized controlled trials (n = 294) were included which, when compared with traditional physical therapy, sensorimotor training and task-oriented training, constraint-induced movement therapy, dynamic bracing, and conventional robot-assisted therapy, neuromuscular electrical stimulation in combination with these therapies resulted in significantly greater functional scale scores (standardized mean difference = 0.80; 95% confidence interval = 0.54 to 1.06), muscle strength of upper limbs (standardized mean difference = 0.57; 95% confidence interval = 0.25 to 0.88), and spasticity of upper limbs (relative risk = 2.53; 95% confidence interval = 1.46 to 4.39; standardized mean difference = -0.18; 95% confidence interval = -0.29 to -0.06) but did not improve the wrist range of motion (standardized mean difference = 0.43; 95% confidence interval = -0.04 to 0.91). In addition, the effect of neuromuscular electrical stimulation on functional scale scores remained after 3-mo follow-up (standardized mean difference = 0.68; 95% confidence interval = 0.16 to 1.2).

Anderson (2022) conducted a multi-center, single-blind, parallel-group, RCT comparing FES delivered by the MyndMove device (n = 27) to conventional therapy (n = 24) in adults with C4 to C7 SCI.[3] The FES therapy consisted of 36 to 40 one-hour sessions within a 14-week period, while conventional therapy consisted of the same time frame, but participants received upper limb conventional therapy instead. The primary outcome was the change in baseline of spinal cord injury independence measure III - self-care (SCIM-SC) scores. Both groups gained a mean of two points in SCIM-SC scores at the end of treatment, which was clinically meaningful, and this impact persisted at the end of the study (24 weeks from the 1st session). However, there was no statistically significant difference between the groups on any outcomes. This trial was limited by the small number of participants (power was not reached) and interruptions of therapy sessions due to the COVID-19 pandemic lockdown in the U.S. and Canada. Additionally, the participants in the FES group were likely more severely impaired than those in the conventional therapy group based on baseline characteristics. Randomization was stratified by site and not on severity of injury.

Loh (2022) published a systematic review (SR) with meta-analysis to evaluate the effect of contralaterally controlled functional electrical stimulation (CCFES) compared to NMES for

upper extremity motor recovery post stroke.[4] Six RCTs were included (n=267). The authors concluded that the CCFES produced greater improvement than NMES. There was significant heterogeneity of methodology for evaluating motor recovery. Only one assessment was consistent in all studies (the Upper Extremity Fugl-Meyer assessment) and no sham group was included.

A SR and meta-analysis published by Monte-Silva (2019) evaluated the effects of electromyogram-triggered neuromuscular electrical stimulation (EMG-NMES) on restoring wrist and hand movement in poststroke hemiplegia.[5] Twenty-six studies (N=782) were included from clinical trials comparing the effect of EMG-NMES versus no treatment or another treatment on stroke upper extremity motor recovery. Fifty percent of the studies were considered to be of high quality. Outcomes were each of the International Classification of Functioning, Disability, and Health (ICF) domains. The meta-analysis showed that EMG-NMES had a robust short-term effect on improving upper limb motor impairment in the Body Structure and Function domain. No evidence was found in favor of EMG-NMES for the Activity and Participation domain. EMG-NMES had a stronger effect for each ICF domain in chronic (greater than or equal to 3 months) compared to acute and subacute phases. This SR included data from a 2017 RCT comparing myoelectric controlled functional electrical stimulation (MeCFES) or task-oriented therapy (TOT) in 68 participants for 25 sessions[6] and a multicenter, single-blind, multi-arm parallel-group study that evaluated participants with upper limb hemiplegia receiving cyclic NMES (n=39), electromyography (EMG) triggered NMES (n=41), or sensory stimulation (n=42) for motor impairment and activity limitations.[7] Additional RCTs are needed to show that EMG-NMES provides additional long-term improvement in upper limb motor impairment in individuals with chronic stroke.

Eraifej (2017) published a SR of RCTs to evaluate the efficacy of FES on upper limb function (activities of daily living and motor function) post-stoke.[8] Twenty studies were included, with a total of 91 patients. The authors stated there is a lack of high-quality evidence to support FES at this time, but when applied within two months after stroke FES may be beneficial.

Lee (2017) published a SR evaluating the efficacy of NMES on shoulder subluxation.[9] Eleven studies with 432 participants were included. The authors concluded NMES may have a positive effect on shoulder subluxation for patients with acute or subacute shoulder subluxation, but all studies were fair to good quality.

Arya (2017) published a SR that included 14 RCTS and eight pre- post-single group studies that evaluated several treatments, one of which was FES/electrical stimulation for shoulder subluxation.[10] The authors stated none of the modalities evaluated improved subluxation and upper limb function effectively.

A SR by Gu (2016) evaluated electrical stimulation for hemiplegic shoulder function.[11] This review included 15 RCTs, and the results of a meta-analysis showed that FES improved shoulder subluxation, but only if it was applied early after stroke. There were no significant effects seen for pain, upper arm motor function, daily function, or quality of life measures.

Randomized Controlled Trials

Karaaslan (2023) published a RCT to evaluate the effectiveness of neuromuscular electrical stimulation in patients with subacromial impingement syndrome.[12] Patients were randomly divided into groups of exercise training (n = 24) and exercise training + neuromuscular electrical stimulation (n = 24). Shoulder function was evaluated with the In both groups,

shoulder function, range of motion, and muscle strength (except flexion muscle strength in the exercise training group) increased, while pain decreased ($p < 0.05$). Compared with the exercise training group, visual analog scale-activity and visual analog scale-night decreased more, and external-rotation range of motion and whole muscle strength increased more in the exercise training + neuromuscular electrical stimulation group ($p < 0.05$). On the other hand, the effect sizes were medium to large for both groups.

Khan (2019) published a RCT to determine the efficacy of theta burst stimulation (TBS) or functional electrical stimulation (FES) when combined with physical therapy (PT) after stroke. Sixty patients were randomized into three groups of 20 each: TBS+PT; FES+PT; and PT alone. The TBS group received intermittent TBS of ipsilesional hemisphere and continuous TBS of contralesional hemisphere while the FES group received FES of paretic limb, both for four weeks. All groups received supervised physical therapy for four weeks followed by home physiotherapy for one year. The primary outcome was the Fugl Meyer Assessment upper limb score (FMA-UL) which was assessed at baseline and at one, three and six months and one year. Compared to the PT group, mean FMA-UL scores were higher in TBS and FESgroups at all follow-ups ($p < 0.001$). From baseline to one year, mean (SD) FMA-UL scores increased from 14.9(2.1) to 55.55(2.46) in the TBS group, 15.5(1.99) to 55.85(2.46) in FES group, and 14.3(2.2) to 43.3(4.22) in the PT group. There was no difference between the FES and TBS groups. The authors conclude that this four-week intervention with TBS or FES combined with PT produces better long-term arm functions as compared to PT alone in patients with acute stroke. However, future RCTs are required due to small sample size and the lack of a sham stimulation in the control groups.

Uswatte (2018) reported a small RCT that compared an expanded form of Constraint-Induced Movement Therapy (eCIMT; n=10) which included electromyography-triggered functional electrical stimulation to a placebo control procedure (n=4) or usual care (n=7) for the treatment of severe hemiparesis.[13] The patients who received usual care were crossed over to eCIMT at four months after enrollment. Both the original and crossover eCIMT groups showed short- and long-term improvements in the Grade-4/5 Motor Activity Log and the Canadian Occupational Performance Measure. This study was limited by extremely small sample sizes.

Harvey (2016) published a RCT to determine the effect of adding a task-specific hand-training program with functional electrical stimulation to a combination of usual care plus three 15-minute sessions per week of one to one hand therapy in patients with sub-acute hand tetraplegia, related to spinal cord injury.[14] Patients in the experimental group (n=37) received intensive training with functional electrical stimulation on one hand for one hour per day, five days a week for eight weeks. The control group (n=33) and the experimental group received 15 minutes of one to one hand therapy three times a week without functional electrical stimulation for eight weeks. Measurement date was evaluated at baseline, 11 weeks and 26 weeks after randomization. The authors concluded adding an intensive task-specific hand training program with functional electrical stimulation does not improve hand function for sub-acute tetraplegia.

Popovic (2011) reported on the use of the Compex Motion electric stimulator device as a supplement to conventional occupational therapy (COT) to improve voluntary grasping among 24 patients with spinal cord injury (SCI).[15] The patients were randomized to either functional electrical stimulation therapy device and COT, or COT alone for 40 hours over the course of 8 weeks. The primary outcome of interest was improvement on the Functional Independence Measure (FIM), a scale of ability to provide self-care in daily living. After 8 weeks, the

functional neuromuscular electrical stimulation group had significantly higher scores on the FIM instrument and several other secondary outcomes (other scales of activities of daily living) after controlling for differences in degree of impairment between the groups. However, durability of treatment effects was not able to be compared as 18 of the original 24 subjects were lost to follow-up at 6 months.

Weber (2010) reported on the use of the Bioness H200 device for use as a supplement to treatment with onabotulinumtoxinA and occupational therapy among 23 stroke patients with spasticity after stroke.[16] The primary outcome was progression in upper limb motor function, as measured by improvement in the Motor Activity Log instrument after 12 weeks of therapy. Although improvements in motor activity were seen among all patients after 6 and 12 weeks, no additional benefit was observed among patients treated with functional neuromuscular electrical stimulation versus the comparison group, potentially due to small sample size.

Some recent RCTs have compared different types of NES. For example, a study published in 2016 compared the effects of contralaterally controlled functional electrical stimulation (CCFES) with cyclic neuromuscular electrical stimulation (cNMES) in 80 stroke patients with chronic upper extremity hemiparesis.[17] Treatment was given over 12 weeks, and consisted of 10 sessions per week of either CCFES- or cNMES-assisted hand opening exercise at home and 20 sessions of functional practice in the laboratory. For the CCRES group, the task practice was stimulation assisted. Outcomes assessed were the change in Box and Block Test, upper extremity Fugl-Meyer and Arm Motor Abilities Test. At six months follow-up, the CCFES group showed greater improvement in the Box and Block test, but there were no significant difference in the other outcomes. There were no non-stimulation control groups in this study, which limits the conclusions that can be drawn.

In addition, a small pilot study evaluated task-oriented electromyography (EMG)-triggered electrical stimulation for shoulder subluxation in participants with subacute hemiparetic stroke.[18] There were 10 patients randomized to the EMG-triggered stimulation group and 10 to the control group that received cyclic FES. The treatments were given five times a week for four weeks, and all patients additionally received four weeks of conventional physical therapy. There were significant improvements in shoulder subluxation, muscle activation, and pain (by Visual Analogue Scale) in the EMG-triggered stimulation group compared to the control FES group, but no differences in the Fugl-Meyer assessment.

Section Summary

Evidence for the use of NMES to restore upper extremity function in conditions including but not limited to stroke and spinal cord injury is limited. The studies reported do not consistently demonstrate significant improvement in function with NMES over control treatments, particularly in the long-term. Additional RCTs with and without NMES are needed to show that NMES provides additional improvement over established treatments as well as demonstration of long-term improvement in upper limb motor impairment.

FUNCTIONAL NEUROMUSCULAR ELECTRICAL STIMULATION OF THE LOWER EXTREMITY

Systematic Reviews and Technology Assessments

Hwang (2024) summarized the rehabilitative effects of electrical stimulation therapy on gait performance in patients recovering from a stroke.[19] A total of 20 articles were included in the

review, quantitative analysis was included for 11 RCTs. Functional electrical stimulation (FES) was the most commonly used electrical stimulation type to improve postural stability and gait performance in stroke patients. The clinical measurement tools commonly used in the three studies to assess the therapeutic effects of FES were Berg balance scale (BBS), 10-meter walk test (10MWT), 6-minute walk test (6mWT), and gait velocity. The BBS score and gait velocity had positive effects in the FES group compared with the control group, but the 10MWT and 6mWT showed the same effects between the two groups. The heterogeneity of BBS scores was also high.

Carvalho (2024) published a SR with meta-analysis examining the effectiveness of neuromuscular electrical stimulation (NMES) added to the exercise or superimposed on voluntary contractions on patient-reported outcomes measures (PROMs) in people with knee osteoarthritis (OA).[20] Six RCTs (n = 367) were included. The systematic literature analysis showed improvement in pain after NMES plus exercise compared with exercise alone in three studies. The other three studies revealed no difference between groups in pain, although similar improvement after treatments. In the meta-analysis, NMES at a specific joint angle combined with exercise was not superior to exercise alone in pain management (standardized mean difference = -0.33, 95% CI = -1.05 to 0.39, p = 0.37). There was no additional effect of NMES on exercise on self-reported functional ability, stiffness, and physical function compared with exercise alone. In only one study, symptoms, activities of daily living, sports function, and quality of life improved after whole-body electrostimulation combined with exercise.

Nakashima (2023) examined the efficacy of NMES on lower limb muscle strength and health related quality of life (HR-QOL) after thoracic and abdominal surgery.[21] A total of 18 randomized control trials involving 915 participants, including 10 on cardiovascular surgery, two on pulmonary surgery, five on digestive system surgery, and one on other surgery, were included. NMES slightly increased lower limb muscle strength and adverse events in cardiovascular surgery. Adverse events (hypotension, pain, and muscle discomfort) occurred in seven patients. HR-QOL was measured in two studies on cardiovascular surgery, but these were not pooled due to concept heterogeneity. Overall, NMES slightly increases lower limb muscle strength after cardiovascular surgery without serious adverse events. The authors concluded that higher-quality randomized control trials in NMES and thoracic and abdominal surgeries are needed.

Two SRs examined the use of electrical stimulation for improving mobility in children with cerebral palsy (CP). Chen (2023) included 14 RCTs (2 crossover studies and 12 parallel studies including 421 patients).[22] Subjects were randomized to NMES to the lower extremity or control (physical therapy). The authors concluded that the NMES group showed greater improvement than the control group in walking speed (standardized mean difference = 0.29; 95% confidence interval = 0.02 to 0.57) and four dimensions (standing, walking, running, and jumping) of the Gross Motor Function Measure (standardized mean difference = 1.24; 95% confidence interval = 0.64-1.83). Zhu (2022) completed a SR to evaluate the effect of FES treatment and gait parameter changes in children with cerebral palsy (CP).[23] Nine studies were included in the review (n= 282; 142 in the FES treatment group and 140 in comfort, general nursing or physical therapy treatment group). The authors conclude that FES could increase walking speed ((SMD = 0.82, P < 0.0001) and step length (SMD = 1.34, 95%CI = 1.07, 1.60, Z = 9.91, P < 0.0001) in children with CP. However, most studies included were single-blind and/or of low quality.

The effectiveness of FES applied to the paretic peroneal nerve to improve post-stroke gait speed was evaluated in a SR published by da Cunha (2020).[24] The search was limited to randomized controlled trials or crossover trials on the effects of FES alone or combined with other therapies in individuals with foot drop after stroke. Fourteen studies (N=1115) participants were included, however only two of the studies used conventional FES on the peroneal nerve. In three studies, FES was paired with conventional physiotherapy and compared with ankle-foot orthotics (AFO) or with other types of stimulation (TENS and NMES). Two studies combined FES with treadmill gait training and compared to sham plus treadmill gait training. The quality of evidence was low for all outcomes and serious risk of bias was noted according to the GRADE system. In the twelve studies (n = 1077) that evaluated gait speed and were included in the meta-analysis, FES was not found to enhance gait speed as compared with conventional treatment [SMD = 0.092 (95% CI: -0.34 to 0.53; I2 89%, p=0.68)]. Data from four studies were included in a sensitivity analysis, which showed that FES combined with physiotherapy could increase gait speed as compared with physiotherapy alone (n=133) [SMD = 0.51 (95% CI: 0.16 to 0.86; I2 0%, p=0.0042)]. A sensitivity analysis in data from four studies that combined FES with unsupervised home exercises (n=355), and three studies that used FES in regular activities at home (n=589). did not reveal a significant difference between groups [SMD = 0.02 (95% CI: -0.23 to 0.19; I2 0%, p=0.849) and SMD=-0.28 (95% CI: -1.53 to 0.96; I2 95%, p=0.653)]. Analysis of data from three studies (n=151) that assessed the effect of FES on active ankle dorsiflexion mobility of the paretic limb found that FES could improve active ankle dorsiflexion as compared with conventional treatment [MD=3.30 (95% CI: 1.48 to 5.12; I2 0%, p=0.0007)]. Data from five studies (n=780) were available for analysis of balance and functional mobility. Across these studies, it was found that FES could improve balance and functional mobility compared with conventional treatments [MD = 2.76 (95% CI: 0.64 to 4.88; I2 90%, p=0.011), MD = -3.19 (95% CI: -5.76 to -0.62; I2 84%, p=0.015), respectively]. Heterogeneity was high for both of these outcomes. Overall, the SR found positive effects of FES on the peroneal nerve for improving gait speed when combined with supervised exercises, but not with unsupervised home exercises. However, the high heterogeneity in the available data preclude determination of the benefits of FES combined with regular activities at home for improving gait speed. There was low quality of evidence for positive effects of FES on active ankle dorsiflexion mobility. The authors conclude that future research with adequate methodological quality is necessary to determine the exact effects of FES on gait speed, ankle dorsiflexion mobility, balance, and functional mobility.

A SR and meta-analyses of RCTs evaluating the efficacy of AFO and FES on walking speed and balance after stroke was published by Nascimento (2020).[25] Eleven parallel, randomized trials (N=1135) of AFO or FES in ambulatory post-stroke patients were included. The methodological quality and reporting assessed by the Physiotherapy Evidence Database (PEDro) score of the trials ranged from 4 to 7, with a mean of 5.8, which is considered fair to good on a scale that ranges from 0 to 10. Significant increases in walking speed compared with no intervention/placebo was found for both AFO (MD 0.24m/s; 95% CI 0.06 to 0.41) and FES (MD 0.09m/s; 95% CI 0.03 to 0.14). AFO and FES were not significantly different for improving walking speed (MD 0.00m/s; 95% CI -0.06 to 0.05) or balance (MD 0.27 points on the Berg Balance Scale; 95% CI -0.85 to 1.39) after stroke.

A SR with meta-analysis by Salazar (2019) evaluated the effectiveness of NMES as an adjuvant therapy to improve gross motor function in children with spastic cerebral palsy.[26] Six RCTs (N=174) were included in the meta-analysis. Medium effect size to improve gross motor function was found with NMES combined with other therapies in children with cerebral palsy in comparison with conventional physical therapy or neurodevelopmental therapy. Gross motor

function was assessed by the Gross Motor Function Measure (GMFM) and its functional dimensions. Sensitivity analysis showed NMES combined with other therapies was effective to improve GMFM-sitting and standing dimensions but not GMFM-walking dimension. The authors conclude that low-quality evidence suggests that NMES may be used as adjuvant therapy to improve sitting and standing dimensions of GMFM in children with spastic cerebral palsy. A previous SR by Moll (2017) that assessed FES of ankle dorsiflexors in young patients with cerebral palsy concluded that there is not enough evidence that FES improves activity function or participation level, but it may play a role as an alternative to orthosis in children with cerebral palsy.[27] Similarly, a meta-analysis conducted by Cauraugh (2010) which evaluated NMES on gait in children with cerebral palsy found moderate effect sizes for impairment (0.616) and activity limitations (0.635).[28] The review is limited by a lack of blinding in the included studies and the heterogeneity of outcome measures.

A SR by Renfrew (2019) evaluated the effect of FES for foot drop on health-related quality of life (HRQOL) in people with multiple sclerosis.[29] Eight studies were eligible for review; seven were of moderate-to-strong methodological quality and one was weak. Seven studies demonstrated significant positive effects of FES on different aspects of HRQOL as measured by the 29-item Multiple Sclerosis Impact Scale, 36-item Short Form Health Status Survey, Canadian Occupational Performance Measure, and Psychosocial Impact of Assistive Devices Scale. While the authors concluded that FES has a positive effect on aspects of HRQOL in people with MS, this is considered preliminary given the limitations of the variety of HRQOL outcomes used.

In 2018, the Canadian Agency for Drugs and Technologies in Health (CADTH) published a Rapid Response report that reviewed the clinical-effectiveness and cost-effectiveness nerve stimulation for foot drop. Four publications met the inclusion criteria and were reviewed. Two publications were systematic reviews and two were RCTs. No differences in functional outcomes were found between FES and ankle foot orthosis. However, FES combined with rehabilitation was more effective than rehabilitation alone for improving walking speed for patients with stroke-related foot drop in one RCT and FES was found to statistically reduce perceived exertion and several related measures in one cross-over RCT.

A SR by Prenton (2018), included in the CADTH review above, reported a meta-analysis of FES or ankle foot orthoses (AFO) for foot drop caused by central nervous system conditions[30]. Eight RCTs met inclusion criteria. One RCT examined patients with cerebral palsy while the rest included stroke patients. The meta-analysis showed equal improvement in walking speed for both devices for stroke patients (p=0.54). A previous SR by the same authors which included many of the same studies reached similar conclusions; comparable improvements for AFO and FES groups was found in 10m walking speed, functional exercise capacity, perceived mobility, and timed up-and-go.[31] This SR included a large multicenter RCT in 495 Medicare-eligible individuals,[32] an industry-sponsored single-blind multicenter trial that randomized 197 patients to 30 weeks,[33] and a small, multicenter within-subject crossover trial.[34] An additional SR evaluating peroneal stimulation for foot drop in stroke patients[35] also concluded that more studies are needed to evaluate the clinical effectiveness of FES on foot drop.

Miller (2017) published a SR to evaluate the efficacy of FES on gait speed for patients with multiple sclerosis.[36] Nineteen studies were evaluated with 490 patients with multiple sclerosis. The studies were rated weak to moderate. The authors stated FES impacts foot drop and gait speed in a positive way, but more RCTs are required comparing FES with other treatment

options. Similar findings are reported in a SR by Springer (2017).[37]

Wonsetler (2017) published a SR (part 1) that evaluated the impact of different therapies on gait by measuring spatiotemporal variables and asymmetry ratios.[38] Two of the 46 studies included were for FES. The authors concluded measuring spatiotemporal variables and asymmetry ratios may provide information on functional improvement, but more studies are needed to evaluate different measures that can determine FES impact on gait.

Yue (2018) performed a SR of RCTs examining the use of NMES, transcutaneous electrical stimulation (TENS), and electroacupuncture (EA) after total knee arthroplasty.[39] High risk of some type of bias was present in over 50% of studies on NMES, mostly in the category of blinding. For TENS and EA, high risk of bias was present in a lower percent of studies, although 75% and 100%, respectively, still had high or unclear risk of bias for blinding of participants and personnel present. Follow-up was through 12 or 13 months in three studies and six months or less in the remainder. Eight studies met the inclusion criteria for NMES, seven for TENS, and two for EA. Six of the studies showed a significant improvement in muscle strength and functional recovery following NMES while two found no significant differences in functional outcomes between the NMES and control groups. In contrast, in a SR evaluating efficacy of different devices after arthroscopic knee surgery, one of which was NMES,[40] the authors stated that NMES is recommended in addition to rehabilitation, however level of evidence was II. Relatedly, Bistolfi (2017) published a SR with meta-analysis that evaluated the effects of NMES following total knee arthroplasty.[41] Six studies with 496 participants were included. The authors concluded that while NMES with a rehabilitation program can slightly improve over a rehabilitation program alone, especially in patients who do not have good muscle activation, these effects were not present in mid and long-term outcomes. Utilization of NMES for osteoarthritis of the knee also was evaluated in a SR by Cherian (2016). The authors noted that while pain improvement from NMES was similar to transcutaneous electrical nerve stimulation, there was heterogeneity amongst NMES studies and long-term follow-up was not evaluated. Additional RCTs are needed to determine the effectiveness of NMES on the functional outcomes.

Langeard (2017) published a SR evaluating how NMES impacts lower limb function in the elderly.[42] Ten studies were retrieved for the review. The authors concluded some of the studies noted that NMES improves function and molecular muscular physiology, but because there is a correlation between gait, balance and risk of falls more research is needed to evaluate if NMES can reduce fall rates in this group.

Randomized Controlled Trials

Moll (2024) evaluated functional electrical stimulation of the peroneal nerve during walking in children with unilateral spastic cerebral palsy (CP).[43] Children (n = 18) with CP participated in two 12-week blocks of treatment with ankle foot orthosis or adapted shoes (conventional treatment) or FES, separated by a six week washout period. The proportion of Goal Attinment Scale (GAS) goals achieved was not significantly higher in the FES versus the conventional treatment phase (goal 1 $p = 0.065$; goal 2 $p = 1.00$). When walking while stimulated with FES, ankle dorsiflexion during mid-swing decreased over time ($p = 0.006$, average decrease of 4.8° with FES), with a preserved increased ankle range of motion compared to conventional treatment ($p < 0.001$, mean range of motion with FES +10.1° compared to AFO). No changes were found in the standard physical examination or regarding satisfaction with orthoses and feelings about the ability to dress yourself. In four patients, FES therapy failed; in 12 patients

FES therapy continued after the trial.

Singh (2024) published a multicenter, randomized, participant-blinded, sham-controlled trial to evaluate the efficacy and safety of tonic motor activation (TOMAC) in patients with restless leg syndrome (RLS).[44] Adults (n = 45) with primary moderate-to-severe RLS who were either medication-naïve (n = 20) or medication-refractory (n = 25) were enrolled. Participants were 1:1 randomized to TOMAC (n = 22) or sham (n = 23) for two weeks and instructed to self-administer 30-min TOMAC sessions when they experienced RLS symptoms. There was a larger reduction in the International RLS Study Group Rating Scale (IRLS) for TOMAC than sham (TOMAC -6.59 vs. sham -2.17; mean difference (MD) = -4.42; 95 % confidence interval [CI] -1.57 to -7.26; p = 0.0040). Subgroup analysis showed similar IRLS mean difference for medication-refractory (MD = -4.50; p = 0.02) and medication-naïve (MD = -4.40; p = 0.08) cohorts, which was significantly different from sham only for the medication-refractory cohort. Meta-analysis of combined data from 33 medication-naïve RLS patients showed a significant reduction in mean IRLS score after two weeks for TOMAC compared to sham (MD = -4.30; 95 % CI -1.36 to -7.24; p = 0.004).

Bogan (2023) published a multi-center, double-blind RCT to evaluate the safety and tolerability of bilateral high-frequency tonic motor activation (TOMAC) for medication-refractory restless legs syndrome (RLS), the RESTFUL study.[45] The TOMAC system evokes tonic motor activation of the tibialis anterior muscle by stimulation of the peroneal nerve. Medication-refractory RLS required a trial of at least one medication used to treat RLS. The study randomized 133 participants to either active TOMAC (n=68) or sham/control (n=65) during the first stage of the study. The primary endpoint was the Clinical Global Impressions-Improvement (CGI-I) response rate at week four. The imputed CGI-I response rate at week four was 45% for the TOMAC arm and 16% for the control group (p=0.00011). During the second stage of the study, 128 participants were assigned to open-label active TOMAC treatment. Both groups showed increased CGI-I response rates during the stage two, with the subjects initially randomized to the sham treatment demonstrating a larger response rate increase at week 8 (TOMAC 45% to 61% response rate increase vs. control 16% to 64% response rate increase). There were no serious device-related adverse events (AEs). The most common device- related AEs were Grade I discomfort, and Grade I site irritation. One case of knee pain and swelling was determined to be possibly device-related and led to treatment discontinuation. The authors concluded that TOMAC use is safe and effective. Limitations of the study include that TOMAC was not compared to other non-pharmacologic interventions for restless legs syndrome. RLS medication use was allowed during the trial which may have interfered with the study results.

Roy (2023) published a follow-up study to RESTFUL in which 103 people who completed the RESTFUL study were assigned (not randomized) to either the control group (n=59) or the treatment group (n=44).[46] The CGI-I response rate from RESTFUL completion to week 24 improved from 63.6% to 72.7% in the treatment group vs. 13.6% to 24.5% in the control group (p<0.0001). Patient-administered stimulation was stable with mean intensity of 29.6mA at week one of the RESTFUL study, 29.5 mA at week eight, and 30.0 mA at week 24 of the extension study. To evaluate response to cessation of TOMAC, the treatment group stopped treatment for eight weeks (weeks 24-32). Both groups demonstrated decreased CGI-I response rates after treatment discontinuation. No serious or severe device-related AEs and no subjects discontinued participation due to an AE. The study found no evidence of tolerance or reduced benefit over time. Limitations include the open-label study design and potential confounding due to participants taking RLS medication if desired. The authors concluded that TOMAC is a

promising treatment for medication-refractory RLS and may serve as an alternative to opioid therapy.

Hachisuka (2021) published the results of a multicenter, prospective, randomized, open-label trial comparing the effectiveness of gait training with or without a peroneal nerve stimulation device on improving gait ability and ankle-specific body functions in stroke patients.[47] In total, 119 stroke patients with foot drop were randomly assigned to the experimental (n=56 gait training + WalkAide device) or control (n=59, gait training only) group. At four weeks, there was no significant difference between groups in the primary endpoint of change from baseline in six-minute walk test (6MWT). In addition, no significant difference between groups was found in several secondary endpoints. In sum, no significant impact of peroneal nerve stimulation on gait or body function in stroke patients were observed.

Prokopiusova (2020) published the results of a randomized trial that compared FES (combined with postural correction) and neuroproprioceptive facilitation and inhibition physiotherapy for two months in patients with multiple sclerosis and foot drop.[48] Primary outcomes were: gait (two-Minute Walk Test; Timed 25-Foot Walk test; Multiple Sclerosis Walking Scale-12) and balance (by e.g. Berg Balance Scale [BBS], the Activities-Specific Balance Confidence Scale [ABC], Timed Up-and-Go Test [TUG]) assessed immediately after and two months after program completion. While the group treated with FES experienced significant improvements immediately after program completion in Activities-Specific Balance Confidence Scale and Berg Balance Scale (all $p<0.05$), none of these outcomes significantly differed between FES and physiotherapy groups at either time point. The study was limited by a lack of blinding of patients and clinicians.

Berenpas (2019) compared the effectiveness of implanted FES versus ankle-foot orthotics (AFO) in helping stroke patients with foot drop avoid obstacles while walking (“gait adaptability”).[49] Two cohorts were studied: the first (n=10) were followed for 26 weeks; the second (n=12) were followed for 52 weeks. All study participants had experienced stroke more than six months prior and regularly used an AFO. A within-subjects repeated measures design was used. Gait adaptability was tested by having participants walk on a treadmill while obstacles were suddenly dropped in front of the paretic leg. Before implantation of the device, participants were tested using only the AFO (at 2 or 3 km/h). Patients were then implanted with a 4-channel peroneal nerve stimulator (ActiGait). Testing was then conducted with FES and with AFO at two weeks postimplantation, then at eight weeks, 26 weeks, and, for the second cohort, 52 weeks. Available response time (ART) was calculated “as the time between obstacle release and the moment the toe would have crossed the front edge of the obstacle in the case of an unaltered step.” ART was stratified into three categories based on at what point in the gait cycle the obstacle was dropped: 450-600 ms (mid stance), 300-450 ms (late stance/early swing), and 150-300 ms (mid swing). Results showed FES success rates were an average of 4.7% higher than with AFO (55.4% vs. 50.7%; $p=0.03$). Significant differences were seen between the three ARTs ($p<0.001$), with higher success rates with longer ARTs. The individual results ranged widely in differences between devices: at 26 weeks they ranged from –29% to 85%. The small sample size and absence of control group limit the study’s generalizability, but larger controlled studies would be difficult given the requirements of the intervention.

A non-blinded randomized trial published by Renfrew (2019) evaluated the effectiveness of FES versus ankle-foot orthoses in 85 treatment-naïve people with multiple sclerosis with persistent (greater than three months) foot drop. Participants were randomized to receive a

custom-made orthotic (n=43) or FES device (n=42) and multi-domain outcomes were assessed at zero, three, six, and 12 months. The authors concluded that ankle-foot orthotic and FES treatment have comparable effects on walking performance and patient-reported outcomes. The high drop-out rate for the study introduced uncertainty in the study findings.

In 2016, a small pilot RCT was published that assessed the effects of NMES in combination with mirror therapy in stroke survivors with hemiplegia.[50] There were 14 patients randomized to NMES plus mirror therapy and physical therapy, and 13 patients randomized to the control treatment of physical therapy alone. Balance, muscle strength and tone, and gait were evaluated at baseline and after four weeks of treatment. The authors reported significant improvements in strength, balance, and walking tests following the intervention.

Another RCT compared locomotor training fast walking plus FES to locomotor training at self-selected or fast speeds without FES in 50 poststroke participants.[51] While fast walking plus FES resulted in larger reductions in energy expenditure with walking than non-FES locomotor training, there were no differences between groups in the six-minute walk test.

Taylor (2013) conducted a small RCT to evaluate FES and physiotherapy exercise for dropped foot and hip instability in 28 patients with secondary progressive multiple sclerosis.[52] Authors reported that both physiotherapy and FES improved mobility; however, these findings should be interpreted with caution due to the small sample size and cross-over study design whereby all patients received FES.

Knutson (2013) conducted a RCT of 26 stroke patients with chronic (greater than six months) foot drop comparing the effects of contralaterally controlled neuromuscular electrical stimulation (CCNMES) to cyclic neuromuscular electrical stimulation (NMES) on lower extremity impairment, functional ambulation, and gait characteristics.[53] The authors reported no significant differences between groups. In addition, the study is limited by a lack of control group with which to compare the NMES treatment group outcomes.

Embrey (2010) conducted a randomized crossover trial on the efficacy of the Gait MyoElectric Stimulator for improvements in gait among 28 post-stroke patients after three months of use.[54] Measures of function, but not activities of daily living, were reported. Patients were a convenience sample and concurrent physical therapy was not applied.

A RCT of functional NMES to improve walking performance in patients with multiple sclerosis (MS) was published by Barrett (2009).[55] Fifty-three patients with secondary progressive MS and unilateral dropped foot were randomized to an 18-week program of either NMES of the common peroneal nerve using a single channel Odstock Dropped Foot Stimulator or a home exercise program, and assessed at six, 12, and 18 weeks. The primary outcome measure was walking speed over a 10-meter distance followed by secondary outcome measures of energy efficiency based on increase in heart rate during walking and walking distance in three minutes. Outcomes related to activities of daily living were not measured. In the NMES group, mean changes between baseline and 18-week measures were non-significant for all three outcome measures, both with and without stimulation. However, within the NMES group, when mean values for walking speed and distance walked were compared with and without stimulation, outcomes were significantly better with stimulation. In the exercise group, increases in walking speed over 10 meters and distance walked in three minutes were also significant ($p=0.001$ and $p=0.005$ respectively). At 18 weeks, the exercise group walked significantly faster than the NMES group ($p=0.028$). The authors note a number of limitations of the study: power calculations were based on the 10-meter walking speed measure only and

indicated that 25 subjects would be required in each group, patients were highly selected, clinical assessors also provided treatment assignments (issues with blinding), and the validity and reliability of the three-minute walk test have not been confirmed (fatigue prevented use of the validated six-minute test). In addition, subjects in the exercise group were told they would receive a stimulator at the end of the trial which may have impacted adherence to the exercise regimen as well as retention in the trial. A second publication on this RCT states that it is not known how much time was spent with the devices each day and that the lack of standardized use of the NMES device is another potential confounder for these findings.[56]

Section Summary

There are numerous studies investigating the use of NMES in improving lower limb function in conditions including restless legs syndrome, cerebral palsy, multiple sclerosis, and in post-stroke recovery. Three RCT's have demonstrated that TOMAC is safe and effective for medication-refractory restless legs syndrome, but the concomitant use of medication and lack of comparison to other non-pharmacologic treatments for RLS limit the ability to draw meaningful conclusions. For other conditions, studies do not demonstrate that use of a neuromuscular stimulator device provides clinically significant improvements for any lower extremity condition. The lack of methodologically sound studies limits comparisons between groups. Duration of treatment effects also is unknown. Additional RCTs comparing outcomes with and without the device are still needed.

FUNCTIONAL NEUROMUSCULAR ELECTRICAL STIMULATION FOR OTHER CONDITIONS

Systematic Reviews

Xu (2024) examined the effect of NMES in mechanically ventilated patients.[57] A total of 23 RCTs comprising 1312 mechanically ventilated adults were included in the SR with meta analysis. The treatments analyzed were NMES, PT, NMES combined with PT (NMES+PT), and usual care (CG). Network meta-analyses revealed that NMES or NMES+PT significantly improved extubation success rate compared to CG, with ORs of 1.85 (95% CI: 1.11, 3.08) and 5.89 (95% CI: 1.77, 19.65), respectively. Additionally, NMES exhibited a slight decrease in extubation success rate compared with NMES+PT, with OR of 0.31 (95% CI: 0.11, 0.93). Nevertheless, neither NMES nor NMES+PT showed any significant improvement in ICU length of stay (LOS), ventilation duration, or mortality when compared with PT or CG. NMES+PT emerged as the most effective strategy for all considered clinical outcomes according to the ranking probabilities. The evidence quality ranged from "low" to "very low" in this network meta-analysis.

Wang (2024) published a SR with meta analysis evaluating the impact of NMES on dysphagia in stroke patients.[58] Nine RCTs and quasi RCTs were included. Differences were found between patients treated with or without NMES in respect of Functional Oral Intake Scale (FOIS) scores (SMD = 0.48; 95% CI 0.26-0.70, P < 0.0001), Penetration-Aspiration Scale (PAS) scores (SMD = - 0.56; 95% CI 1.01-0.10, P = 0.02), and SWAL-QoL scores (SMD = 0.57; 95% CI 0.00-1.14, P = 0.05). No significant difference was manifested in the Water Swallow Test (WST), Repeat Salivary Swallowing Test (RSST), and Dysphagia Outcomes and Severity Scale (DOSS) (SMD: - 0.02; 95% CI 0.38-0.35, P = 0.93).

Zhang (2022) published a SR to investigate the effects of NMES on functional capacity and quality of life (QoL) in patients post cardiac surgery.[59] A total of six studies met the inclusion

criteria (n=400). The NMES treatment had an effect on knee extensor strength (SMD=1.68; p=0.05), but had no effects on six-minute walking distance (MD=44.08; p=0.22), walking speed (MD=0.05; p=0.24), grip strength (MD=3.01; p=0.39), or QoL (SMD=0.53; p=0.19). The authors conclude that NMES use in cardiac surgery patients is limited by low to moderate quality studies. More high-quality research is needed.

A SR was conducted to evaluate the effects of NMES on disabilities and activity limitations in individuals with Chronic Obstructive Pulmonary Disease (COPD).[60] A total of 32 RCT studies (n=1,269) were included in the analysis. The authors reported a small improvement in exercise capacity and muscular strength in the NMES group when compared to the sham group. In addition, combined neuromuscular electrical stimulation and conventional rehabilitation improved exercise capacity (MD 34.28 meters, 95% CI 6.84 to 61.73, n=262) compared to conventional rehabilitation alone. The authors concluded that the improvements were small and some of the studies included were of low quality.

Glattke (2022) published a SR evaluating several rehabilitation modalities after ACL reconstruction including postoperative NMES.[61] Fifty studies met the inclusion criteria (from 824 identified). Although the authors concluded that NMES is effective when used independently and in combination with rehabilitative exercises, they indicated that further evidence with improved study designs are needed to validate rehabilitative modalities including NMES.

The effect of NMES on upper and lower limb strength in patients with chronic kidney failure on hemodialysis was evaluated in a SR with meta-analysis published by Schardong (2020).[62] Ten studies were included, totaling 242 patients. Some concern or high risk of bias was found in RCTs and moderate or critical risk of bias was found in nonrandomized studies. Random-effects meta-analysis showed that NMES increases quadriceps muscle strength (standardized mean difference [MD]=1.46; 95% confidence interval [CI], 0.86-2.07; p<0.0001 moderate quality of evidence), upper limb strength (MD=10.02kgF; 95% CI, 0.78-19.27; p=0.03 low quality of evidence), and functional capacity (MD=30.11m; 95% CI, 15.57-44.65; p<0.0001 moderate quality of evidence). Additional RCTs that address the risks of bias are needed.

Waldauf (2020) published a SR with meta-analysis investigating NMES, cycling exercises or protocolized physical rehabilitation as compared to standard of care in critically ill adults.[63] Forty three RCTs (nine on cycling, 14 on NMES alone and 20 on protocolized physical rehabilitation) including 3,548 patients were reviewed. Reduced duration of mechanical ventilation (MD= -1.7 d [-2.5 to -0.8 d], n = 32 RCTs) and length of stay in ICU (MD= -1.2 d [-2.5 to 0.0 d], n=32 RCTs) were observed for treatment groups, however these effects were only significant for the protocolized physical rehabilitation subgroup. No impact of exercise interventions on mortality (odds ratio 0.94 [0.79-1.12], n=38 RCTs) or days in the hospital (MD=-1.6 [-4.3 to 1.2 d], n=23) was found.

The available data from RCTs evaluating the effect of NMES on swallowing function in dysphagic stroke patients were reviewed Alamer (2020).[64] Eleven RCTs involving 784 patients were included in the analysis and the overall quality of the evidence was moderate to high. The PEDro score of all included studies was ranged from 5 to 9, with the mean score of seven. The treatment duration ranged from 10 to 60 minutes for each session, two to five times per week for a two to six week period. The primary outcome measures of the review were functional dysphagia scale (FDS), video fluoroscopy dysphagia scale (VFDS) and standardized swallowing assessments (SSA). Only two studies blinded the participants and

therapists and four studies blinded the assessor. Of 11 studies, 10 (n=748) found that NMES groups had improved swallowing function in post-stroke dysphagia patients compared to the control, whereas one study (n=36) reported no differences between the experimental and control groups. No meta-analysis was possible due to heterogeneity of the available data.

Sun (2020) published a SR with meta-analysis evaluating the effectiveness of NMES in swallowing disorders across eight RCTs and three quasi-randomized controlled trials (studies in which the method of allocation is not considered strictly random).[65] The quality of evidence was low to very low; all eight studies had small sample sizes, ranging from 18 to 57 contributing to high risk of bias, and only two studies had low risk of bias in allocation concealment. A significant, moderate pooled effect size (MD = 0.62; 95% CI=0.06 to 1.17) was found across all studies for NMES. Analysis of data from studies evaluating stimulation of the suprahyoid muscle groups revealed a negative MD of 0.17 (95% CI=−0.42, 0.08), whereas a large effect size was observed in studies stimulating the infrahyoid muscle groups (MD = 0.89; 95% CI = 0.47 to 1.30) and stimulating the suprahyoid and infrahyoid muscle groups (MD = 1.4; 95% CI = 1.07 to 1.74). Stimulation lasting 45 mins or less showed a large, significant pooled effect size (MD = 0.89; 95% CI = 0.58 to 1.20). Across all studies, no serious adverse events associated with NMES were reported. Larger and well-designed RCTs are needed to reach robust conclusions on the efficacy of NMES on swallowing disorders.

A SR by Novak (2020) provided an evaluation of optimal electrical stimulation parameters for adults with osteoarthritis (OA).[66] The authors found that studies using NMES had a 77% decrease in pain and 72%-218% increase in quadriceps femoris strength. No evaluation of statistical significance in these percentages were reported. The concurrent use of other modalities, such as low-level laser therapy, with NMES in these studies do not permit the conclusion that the effects observed are due to the use of NMES. Heterogeneity in the treatment parameters across studies precluded meta-analysis.

The clinical outcomes of NMES applied during hemodialysis in people with end-stage renal disease was evaluated in a SR published by Valenzuela (2020).[67] The authors included eight studies (N=221) and functional capacity, muscle strength, muscle mass, psychological outcomes, cardiovascular outcomes, biochemical variables and adverse events were the outcomes of interest. Differences between NMES-treated and control groups were analyzed by pooled mean difference between groups with a 95% confidence interval. Improvements were observed in the NMES group in functional capacity as assessed by the 6-minute walk distance test (MD 31 m, 95% CI 13 to 49), peak workload attained in incremental exercise (MD 12.5 W, 95% CI 3.2 to 21.9), knee extensor muscle strength (MD 3.5 kg, 95% CI 2.3 to 4.7) and handgrip strength (MD 2.4 kg, 95% CI 0.4 to 4.4). No clear effects on cardiovascular outcomes or biochemical variables (dialysis efficiency, urea and creatinine) were identified. No major adverse events related to NMES were observed. Although the quality of the included studies was fair to good, two studies followed a quasi-randomized design and the sample size of all included studies was low (consistently < 23 participants in NMES arms). In addition, blinding of participants or investigators was not commonly done, so a placebo effect and potential performance and detection bias cannot be ruled out. Future RCTs, especially long-term trials, are needed to confirm the effectiveness and safety of NMES in dialysis patients.

The effects of electrical stimulation in treating dysphonia were reviewed by Almeida.[68] Eleven publications evaluating the effects of NMES or TENS on dysphonia caused by vocal fold paralysis, spasmodic dysphonia, behavioral dysphonia, or vocal fold nodules were included. The studies were classified as either high quality (three studies) or fair quality (eight studies).

Although the authors found evidence that electrical stimulation may have a therapeutic effect in dysphonia, they conclude that due to the high risk of bias and data heterogeneity, the effectiveness of electrical stimulation in treating dysphonia cannot be established.

A broad SR evaluating interventions aimed at ameliorating reductions in physical performance, muscle strength and muscle quantity in hospitalized adults was published by Welch 2020.[69] Although 44 studies (N=4,522) were included, only three were NMES studies (N=206), all of which combined the intervention with exercise. Findings were inconsistent across studies; a trial in a geriatric medicine population found no change in gait speed, a trial in a respiratory medicine population showed less decline in knee extension strength, and a third trial in a general medicine population found improvements in physical performance with NMES treatment. No meta-analysis was provided. Additional research, particularly regarding adherence, physical activity impact, and treatment protocol is needed before the effectiveness of NMES on preventing or treating sarcopenia in hospitalized adults can be established.

The effects of NMES on exercise capacity, functional performance, symptoms, and health-related quality of life (HRQoL) in patients with chronic obstructive pulmonary disease (COPD) was assessed in a SR with meta-analysis by Wu in 2020.[70] Thirteen RCTs (N=447) were analyzed. Outcome measures included the 6-min walking distance (6MWD), peak rate of oxygen uptake (VO2 peak), St George's Respiratory Questionnaire (SGRQ), and self-reported symptoms of dyspnoea and fatigue. Pooled estimates showed a significant increase in 6MWD the NMES group compared with the control group (mean difference (MD)=27.05, 95% confidence interval (CI): 8.46–45.63, $p<0.001$). No statistically significant difference was observed in VO_2 peak, peak power, or SGRQ. The quality of the evidence was very low, largely limited by poor methodology, which was noted as a primary limitation in the meta-analysis. The authors concluded that NMES is not to be recommended as an effective alternative training modality in the rehabilitation of stable COPD patients.

Zayed (2019) performed a SR and meta-analysis on RCTs comparing NMES plus usual care versus usual care in adult ICU patients on prevention of critical care myopathy.[71] The primary outcome was global muscle strength and secondary outcomes included ICU mortality, duration of mechanical ventilation (MV), and ICU length of stay. Six RCTs were included. There was no significant difference between NMES plus usual care on global muscle strength, ICU mortality, duration of MV, or ICU length of stay in comparison with the usual therapy alone in critically ill patients. The authors conclude that further RCTs are needed to determine patients with maximum benefit and to examine NMES safety and efficacy.

A SR by Burgess (2019) reported the effectiveness of NMES for reducing edema.[72] The seven studies meeting inclusion criteria included three RCTs and four non-randomized clinical trials. Within the studies sourced, there was a wide variation in the parameters utilized, but, in general, NMES was applied for 20–30 min. Stimulation occurred once a day in five studies, five times per week in one study, and reduced from three times to two times, to once per month, in one study. Although all studies reported a reduction in edema with NMES, variance in methodologies prevented the authors from providing a detailed comparison of this primary outcome. This variation in clinical presentations, methodologies, equipment, and rehabilitation settings of the included studies limited the generalizability of the review. Appropriately powered RCTs are required to determine the utility of NMES in the treatment of edema.

Intiso (2017) published a SR evaluating electrical stimulation as an adjunct to botulism toxin type A, for adult spasticity.[73] Nine studies were included, for either neuromuscular stimulation

or functional electrical stimulation. The authors concluded evidence does not support a combined treatment of electrical stimulation and botulism toxin type A, for spasticity. Additional high quality trials are needed.

Chen (2016) published a SR that evaluated the impact on health outcomes for NMES versus rehabilitation for patients with moderate-to severe COPD.[74] Nine RCTs with 276 participants were included. The authors concluded NMES may be effective in improving quadriceps strength and exercise capacity in moderate to severe COPD, but more research is needed to evaluate the effect of NMES on other outcomes including quality of life.

Williams (2016) published a SR that evaluated several non-invasive treatments for peripheral arterial disease (PAD), to improve circulation.[75] Four of the 31 studies included evaluated NMES. The authors concluded there only low-level evidence is available to support the use of electrical stimulation for PAD.

Randomized Controlled Trials

Kurt (2024) completed a small (n = 30) sham controlled randomized study evaluating the effectiveness of external NMES in women with urgency urinary incontinence (UUI).[76] Women aged 18-65 years, who were diagnosed with UUI, were randomly allocated into the NMES (external NMES + lifestyle advice, n = 15) and sham groups (sham NMES + lifestyle advice, n = 15). Both groups performed the application for 30 min, three days a week for eight weeks. The NMES group improved on the urinary symptoms scores (International Incontinence Consultation Questionnaire-Short Form, Modified Oxford Scale, King's Health Questionnaire and Pelvic Organ Prolapse/Urinary Incontinence Sexual Function Questionnaire. Additionally, the perception of subjective improvement and satisfaction compared to the sham group ($p < 0.05$).

Othman (2024) published a single-blinded randomized controlled trail evaluating the effect of NMES and early physical activity on ICU-acquired weakness.[77] Patients (n =124) were randomly assigned to one of four groups: 32 patients in ROM exercises, 30 in NMES, 31 in combined therapy (ROM + NMES), and 31 in the control group. On day seven, ROM + NMES and NMES groups showed higher MRC scores than ROM and control groups (50.37 ± 2.34, 49.77 ± 2.19, 44.97 ± 3.61, and 41.10 ± 3.84, respectively). ICU-AW occurred in 0% of the ROM + NMES group, 60% of the ROM group, 13% of the NMES group, and 100% of the control group ($p < 0.001$). The MV duration (in days) in the ROM + NMES group was shorter (12.80 ± 3.800) than in the ROM, NMES, or control groups (21.80 ± 4.460, 18.73 ± 4.748, and 20.70 ± 3.932, respectively). ICU-LOS was shorter in the ROM + NMES group (17.43 ± 3.17 days) compared with the ROM group (22.53 ± 4.51 days), the NMES group (21.10 ± 5.0 days), and the control group (21.50 ± 4.42 days) with significant differences ($p < 0.001$) between the four groups.

A prospective RCT compared strength gains using NMES versus control (cycle ergometer training) during a pulmonary rehabilitation program, in patients with severe and very severe COPD.[78] A total of 92 patients were evaluated at (n=47 in the NMES group and n= 45 in the control group). The authors reported no significant difference between the two programs on exercise capacity, quadriceps strength and quality of life.

A RCT evaluated the effect of FES as a complement to conventional speech therapy in patients with dysphagia post stroke.[79] Patients (n = 33) were randomized to FES intervention

(n =16) and control (n = 17). The authors concluded that conventional speech therapy improved oral ingestion with or without FES in patients recovering from stroke.

Cerqueira (2022) published a RCT investigating NMES on functional exercise capacity in cardiac surgery patients immediate postoperative, two times daily until postoperative day five.[80] Of 88 patients meeting the inclusion criteria, 45 were included in the analysis. The primary functional outcome was the 6-minute walk test. Secondary outcomes included gate speed, lactate levels, muscle strength, EMG activity of the rectus femoris and the Functional Independence Measure. No significant differences were found between the experimental and control groups. The authors concluded that the NMES carried out in five days had no benefit on functional capacity in the immediate postoperative cardiac surgery.

Yousef (2022) published a RCT to determine the effect of NMES of calf muscles in asthmatic children improved nocturnal symptoms and QOL in asthmatic children.[81] All subjects (n=60) completed 12 weeks of supervised breathing exercises. Subjects were randomized to NMES of the calf muscles, aerobic exercise or control. Both NMES and exercise had improved functional outcomes compared to the control group. However, there were no significant differences between NMES and aerobic exercise.

Hyer (2021) published the results of a RCT evaluating the impact of NMES on calf muscle volume and patient reported outcome measures following Achilles tendon surgery.[82] A total of 40 patients followed a standardized postoperative protocol after surgical repair of the Achilles tendon. Group 1 (n=20) received protocol specific NMES and Group 2 (n=20, "sham device" control group) received subtherapeutic electrical stimulation. Preoperative and postoperative calf circumference (two, six, and 12 weeks) and magnetic resonance imaging (MRI) scans (two and six weeks), and patient-reported functional outcome scores were measured. No statistically significant difference was found between active NMES and sham control group.

The effectiveness of NMES in patients with postoperative complications after cardiovascular surgery was studied in a RCT published by Sumin (2020).[83] In this trial, 18 patients underwent daily NMES starting postoperative day three until discharge in addition to standard rehabilitation program (NMES group), and 19 patients underwent standard rehabilitation program only (control group). Knee extensor strength at discharge, the primary outcome, was significantly higher in the NMES group (28.1 [23.8; 36.2] kg on the right and 27.45 [22.3; 33.1] kg on the left) than in the control group (22.3 [20.1; 27.1] and 22.5 [20.1; 25.9] kg, respectively; $p<0.001$). No significant difference between groups was found in secondary outcomes of handgrip strength, knee flexor strength, quadriceps size, and 6-minute walk distance at discharge. Additional RCT trials are needed to overcome limitations of this study including small sample size and lack of long-term outcome data.

Dos Santos (2019) published the results of an RCT evaluating the effectiveness of NMES, either alone or in combination with exercise on reducing the duration of mechanical ventilation (MV) in critically ill patients.[84] Participants were prospectively recruited within 24 hours following admission to the intensive care unit and randomly assigned to NMES (n=11), exercise (EX, n=13), combined therapy (NMES + EX, n=12), or standard of care (control, n=15). Duration of MV (days) was shorter in the combined therapy (5.7 ± 1.1) and NMES (9.0 ± 7.0) groups in comparison to control (14.8 ± 5.4). The small sample size of this study limits the ability to draw generalizable conclusions regarding NMES in critically ill patients.

Zhang (2019) published the results of a two-arm (RCT) of NMES for chronic urinary retention (CUR) following traumatic brain injury (TBI).[85] Patients were randomly allocated to a treatment

group (n=43) or a sham group (n=43) for an eight-week period treatment and four-week period follow-up. All primary (post-voiding residual urine volume) and secondary outcomes (voided volume, maximum urinary flow rate, and quality of life) were measured at baseline, at the end of eight-week treatment, and four-week follow-up. At the end of eight-week treatment as well as at the end of the four-week follow-up, the patients in the treatment group did not achieve better outcomes in any of the metrics than patients in the control group. The findings of this study showed that NMES therapy does not benefit patients with CUR following TBI.

Feil (2011) published the results of a randomized controlled study of NMES in highly-selected patients from a single clinical rehabilitation site undergoing endoscopically assisted reconstruction of the anterior cruciate ligament (ACL).[86] Participants were randomized to a control group (performed volitional isometric quadriceps muscle contractions but did not use NMES), a group receiving NMES by the Polystim (PS, Biomedical Research Ltd) device, in which electrodes attached to a lead wire are placed on the skin for each treatment, or a group receiving NMES by the Kneehab (KH, Biomedical Research Ltd) device, which integrates the electrodes and wiring into a garment. Although 131 patients were randomized, 35 (26.7%) patients were later excluded from study participation for reasons that included deviation from the course of rehabilitation. An intention-to-treat analysis was performed to compare the estimated treatment effect (pairwise comparison between KH and CO group only), using imputed values for missing data. The data analyzed included observations from 96 subjects as follows: KH group (n = 33 at completion), the PS group (n = 29 at completion), and control group (n = 34 at completion). These sample sizes included in the final dataset did not consistently meet the minimum needed per group (32) to achieve 80% power at a significance level of $p < 0.05$ according to *a priori* power calculations. Outcomes in all groups were improved across the study period and average strength and functional performance measures for the KH group were more improved than PS and control groups. This study is limited by considerable attrition, lack of an active control (sham) group, and lack of longer-term (beyond 24 weeks) follow-up.

Section Summary

The current studies do not demonstrate improved health outcomes from NMES for other conditions, including but not limited to COPD, edema, peripheral artery disease, or spasticity. Based on the available published evidence, additional RCTs comparing this therapy to standard treatment are still required.

NEUROMUSCULAR ELECTRICAL STIMULATION CYCLE ERGOMETERS AND ROWING MACHINES

More recently there has been interest in electromyography (EMG)-triggered functional neuromuscular electrical stimulation with exercise as a therapy for patients with lower extremity paresis. Older studies on this topic include two SRs, one RCT,[87] and several comparative studies.[88-97]

Systematic Reviews

Galvao (2024) evaluated cycling using functional electrical stimulation therapy (FEST) to improve motor function and activity in post-stroke individuals in early subacute phase.[98] Five randomized clinical trials (187 participants) of moderate-quality evidence were included. Cycling using FEST combined with exercise programs promotes relevant benefits in trunk control (MD 9 points, 95% CI 0.36-17.64) and walking distance (MD 94.84 m, 95% CI 39.63-

150.05, I = 0%), the other outcomes had similar benefits. Cycling using FEST alone compared to exercise programs promotes similar benefits in strength, balance, walking speed, walking distance, and activities of daily living.

Mate (2023) published a systematic review evaluating the potential of hybrid functional electrical stimulation (FES) cycling for improving cardiorespiratory fitness for people with a mobility disability related to a central nervous system (CNS) disorder.[99] A total of 13 were studies included. The Downs and Black Checklist was used to assess study quality. During acute bouts of exercise, hybrid FES cycling was moderately more effective than ACE (effect size [ES] of 0.59 (95% CI 0.15-1.02, p = 0.008) in increasing V̇O2peak from rest. There was a large effect on the increase of V̇O2peak from rest for hybrid FES cycling compared with FES cycling (ES of 2.36 [95% CI 0.83-3.40, p = 0.003]). Longitudinal training with hybrid FES cycling showed a significant improvement in V̇O2peak from pre to post intervention with a large, pooled ES of 0.83 (95% CI 0.24-1.41, p = 0.006).

van der Scheer (2021) published the results of a systematic review (SR) of data on the use of functional electrical stimulation (FES) cycling exercise after spinal cord injury (SCI) with a specific focus on health and fitness-related outcomes.[100] Studies were included if they were in populations of participants that were at least 50% adult (≥ 16 years) with traumatic or non-traumatic SCI who were eligible and responsive to FES cycling. Studies in populations with a congenital condition (e.g., spina bifida) or a progressive disease (e.g., multiple sclerosis with spinal cord involvement) were excluded. Ninety-two studies (N=999) adults were included in the review. Study quality was appraised using Cochranes' Risk of Bias or Downs and Black tools; of the 92 studies reviewed, two were classified as Level 1 studies, seven as Level 2 studies, 65 as Level 3 studies, and 18 as Level 4 studies. Several outcome categories were defined, including muscle health, power output, aerobic fitness, fat mass, cardiovascular/ metabolic, bone health, subjective well-being, and functional/neurological outcomes. For muscle health (36 studies), the one Level 1 study reported non-significant findings, while the four Level 2 studies and over 80% of Level 3 or 4 studies reported significant improvements (‘Moderate’ certainty in the evidence for *any* adult with SCI, and ‘High’ certainty in evidence for young to middle-aged adults with SCI). For power output and aerobic fitness, data from Level 1 or 2 studies were not identified, however, Level 3 and 4 studies reported significant improvement in these categories (“Low” certainty in evidence). Limited evidence was available for the other outcomes (‘Very Low’ certainty in evidence due to an absence of Level 1 or 2 studies, effects being inconsistent across the studies, imprecision, and/or indirectness).

A SR with meta-analysis by Fang (2021) was conducted to investigate the effect and dose-response of FES cycling on spasticity in individuals with SCI.[101] The primary outcome measure was spasticity assessed by Modified Ashworth Scale (MAS) or Ashworth Scale for lower limbs. Secondary outcome measures were walking abilities assessed by 6 Min Walk Test (6MWT), Timed Up and Go (TUG), and lower limbs muscle strength (LEMS). Twelve studies (one RCT and 11 nonrandomized or uncontrolled studies) were included in the qualitative assessment and data from eight of these were included in the meta-analysis (N=99). Time since injury ranged from less than four weeks to 17 years and participant age ranged from 20 to 67 years. Spasticity decreased significantly (95% CI=- 1.538 to - 0.182, p = 0.013) in favor of FES-cycling. Subgroup analysis showed that spasticity decreased significantly only in groups with more than 20 training sessions (95% CI=- 1.749 to -0.149, p = 0.020). Inclusion of a single RCT is a limitation of the available data. In addition, MAS of different lower extremities joints were pooled for the analysis, and factors such as level of

injury, time since injury, frequency of FES, treatment duration could not be analyzed by subgroup.

The safety and effectiveness of ergometer training, including the use of FES in ergometer training, in stroke rehabilitation was evaluated in a SR published by Veldema (2020).[102] The review included total of 28 studies (N=1115), however only six trials tested the effects of simple ergometer training in comparison to ergometer training with the assistance of FES in stroke rehabilitation. The meta-analysis found improved balance and postural control (d=1.26; 95% CI, 0.31-2.20; I2=95%) as well as improved motor function and muscle force of lower limbs (d=1.96; 95% CI, 0.92-3.05; I2=100%) in neuromuscular FES-assisted ergometer training over ergometer training alone. No significant effects were detected for cardiorespiratory fitness, walking ability, spasticity and hypertonia, or independence in activities of daily living. There was considerable heterogeneity in study populations, intervention protocols, and outcomes across trials. No adverse events were reported. The authors conclude that current data are too limited to recommend ergometer training in evidence-based rehabilitation. Additional research is needed to overcome the limitations of existing studies.

A SR with meta-analysis published by Ambrosini (2020) evaluated the effects of FES cycling, alone or in addition to usual care on walking, muscle power and tone, balance and activities of daily living in subacute stroke (less than six months) survivors.[103] Seven RCTs (N=273) set in inpatient rehabilitation centers were included. The duration of the intervention ranged from three to eight weeks, and frequency of treatment ranged from three to six sessions per week. Four of the studies had low risk of bias, and the most frequently noted source of bias overall was lack of blinding. One study was adequately blinded with a placebo stimulation. Data from six studies (N=221) were included in the meta-analysis. A significant effect of treatment over placebo was found for walking short distances (SMD [95% CI] = 0.40, [0.13, 0.67]; p=0.004), which was the primary outcome. Secondary outcomes had mixed results, including improvement in the treatment group for capability to maintain a sitting position (MD [95% CI] = 7.92 [1.01, 14.82]; p=0.02; N=118). A moderate quality of evidence supported these findings. No significant differences were found between treatment and control groups for including muscle power functions of the lower limb, capability to maintain a standing position, or to perform activities of daily living. The authors conclude the current evidence of the effect of FES cycling in subacute stroke patients is limited, and that it cannot be recommended over usual care.

A 2019 SR published by Scally examined the outcomes of people with multiples sclerosis (MS) with mobility impairment following FES cycling intervention.[104] Nine studies met the full inclusion criteria including five pre-post studies with no control group, two RCTs, one retrospective study and one case study. Outcome data was available for 76 unique participants, with 82 completing a FES cycling intervention. Two papers reported non-significant improvements in aerobic capacity following a FES cycling intervention. Four papers reported no change in lower limb strength and two papers reported significant reductions in spasticity post training. The authors conclude that the low quality of the literature precludes any definitive conclusions regarding FES cycle training in treating spasticity or reducing cardiovascular disease risk in people with MS.

Shariat (2019) published a meta-analysis evaluating effects of cycling with and without FES on lower limb dysfunction in patients post-stroke.[105] A total of 14 trials satisfied eligibility criteria and were included. Cycling had a positive effect on the six-meter walking test performance (standardized mean difference [SMD], 0.41; 95% confidence interval [CI], 0.11 -0.71; I2=0%)

compared with no or placebo intervention (control). Compared with control, cycling had a positive effect on 10-meter walking speed (SMD, 0.30; 95% CI, 0.05 -0.55; I2=0%), and on balance based on the Berg score (SMD, 0.32; 95% CI, 0.06 -0.57; I2=49%). Cycling with functional electrical stimulation had a positive effect on balance (SMD, 1.48; 95% CI, 0.99 - 1.97; I2=91%) compared with cycling alone. The authors conclude that cycling has a positive effect on walking speed, walking ability and balance. While functional electrical stimulation combined with cycling had positive effects on balance beyond cycling alone, this additional benefit of FES to cycling alone on other outcomes, including walking, was not determined.

Randomized Controlled Trials

Farkas (2021) compared FES leg cycling (ERGYS2) with arm cycling (ACE) in patients with Spinal Cord Injury (SCI).[106] Participants (n=13, 65% male) had motor complete paraplegia (injury at T4-T10) and were previously untrained. Participants were randomized to arm cycling (n=7) or FES leg cycling (n=6) and exercised five times weekly for 16 weeks. Participants in the ACE group had greater energy expenditure and improved cardiometabolic profile compared with FES. ACE and FES showed similar decrease in body fat percentage (6%, p=0.05 and 5%, p=0.008, respectively). The study is limited by a small sample size, limited training duration, and lack of control for diet.

Johnston (2009) reported on an RCT conducted on 30 children with spinal cord injury aged 5 to 13 years.[87] Children were randomly assigned by block randomization to one of three groups: cycling, with or without functional electrical stimulation (FES), or a control group receiving only electrical stimulation therapy at home three times a week for six months. Primary outcomes included improvements in oxygen uptake (VO_2), resting heart rate, forced vital capacity (FVC), and fasting lipid profile. Clinically relevant outcomes, such as those relating to activities of daily living or quality of life, were not investigated.

Neuromuscular Electrical Stimulation Cycling Adherence

Kressler (2019) published an analysis of functional electrical stimulation (FES) cycle usage data from 314 users with spinal cord injury (SCI) who engaged in 20,183 activity sessions.[107] Usage patterns and energy expenditure were compared with authoritative exercise guidelines of 150 minutes of moderate-intensity aerobic activity per week over at least two days per week for a total of 1,000 kcals. Seven percent of participants were classified as high- (greater than or equal to five days per week), 11% as medium- (two to five days per week), and 82% as low-frequency users (less than two days per week). None of the users satisfied authoritative energy expenditure recommendations for disease prevention with FES cycling alone.

Section Summary

It is not clear that the benefits accomplished with EMG-triggered NMES plus cycling cannot be realized through standard passive range of motion exercise. Further, the feasibility and long-term benefits of using NMES cycling is uncertain. Based on the available published evidence, additional RCTs comparing this therapy to standard treatment are still required.

PRACTICE GUIDELINE SUMMARY

DEPARTMENT OF VETERANS AFFAIRS (VA), DEPARTMENT OF DEFENSE (DOD)

The Department of Veterans Affairs (VA) and Department of Defense (DoD) (2024) published an updated Clinical Practice Guideline for the Management of Stroke Rehabilitation.[108] This

guideline suggests neuromuscular electrical stimulation to improve motor outcomes and states the strength of the evidence is weak. The guideline states there is insufficient evidence to recommend for or against the following interventions:

- Contralaterally controlled functional electrical stimulation to improve upper extremity motor outcomes and activities of daily living.
- Neuromuscular electrical stimulation and pharyngeal electrical stimulation for dysphagia.
- Surface electromyography for dysphagia.

THE AMERICAN HEART ASSOCIATION/ AMERICAN STROKE ASSOCIATION

The American Heart Association and American Stroke Association published a guideline for adult stroke rehabilitation in 2016.[109] This guideline comments on the use of electrical stimulation for the treatment of hemiplegic shoulder pain, including NMES, with the conclusion that this modality has not been evaluated sufficiently and its efficacy for pain prevention and treatment remains inconclusive.

AMERICAN ACADEMY OF NEUROLOGY

The American Academy of Neurology published a practice guideline on the treatment of restless legs syndrome in 2016.[110] The guideline does not address the use of tonic motor activation in the treatment of RLS.

SUMMARY

There is not enough research to show that neuromuscular electrical stimulation (NMES) improves health outcomes for people with spinal cord injury, stroke, congenital disorders, nerve damage, pain, or other conditions. Further, the feasibility and long-term health benefits of using NMES cycling is uncertain. Based on the available published evidence, additional randomized controlled trials comparing this combined therapy to standard treatment are needed. Therefore, functional NMES is considered investigational for all indications, including but not limited to treatment of spinal cord injury, stroke, congenital disorders, nerve damage, or pain

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CODES

Codes	Number	Description
CPT	None	
HCPCS	A4544	Electrode for external lower extremity nerve stimulator for restless legs syndrome
	A4560	Neuromuscular electrical stimulator (nmes), disposable, replacement only
	E0490	Power source and control electronics unit for oral device/appliance for neuromuscular electrical stimulation of the tongue muscle, controlled by hardware remote
	E0491	Oral device/appliance for neuromuscular electrical stimulation of the tongue muscle, used in conjunction with the power source and control electronics unit, controlled by hardware remote, 90-day supply
	E0492	Power source and control electronics unit for oral device/appliance for neuromuscular electrical stimulation of the tongue muscle, controlled by phone application
	E0493	Oral device/appliance for neuromuscular electrical stimulation of the tongue muscle, used in conjunction with the power source and control electronics unit, controlled by phone application, 90-day supply
	E0731	Form fitting conductive garment for delivery of TENS or NMES (with conductive fibers separated from the patient's skin by layers of fabric)
	E0743	External lower extremity nerve stimulator for restless legs syndrome, each
	E0744	Neuromuscular stimulator for scoliosis
	E0745	Neuromuscular stimulator, electronic shock unit
	E0764	Functional neuromuscular stimulator, transcutaneous stimulation of muscles of ambulation with computer control, used for walking by spinal cord injured, entire system after completion of training program
	E0770	Functional electrical stimulator, transcutaneous stimulation of nerve and/or muscle groups, any type, complete system, not otherwise specified
	~~K1028~~	~~Power source and control electronics unit for oral device/appliance for neuromuscular electrical stimulation of the tongue muscle, controlled by phone application~~ (Deleted 01/01/2024)
	~~K1029~~	~~Oral device/appliance for neuromuscular electrical stimulation of the tongue muscle, used in conjunction with the power source and control electronics unit, controlled by phone application, 90-day supply~~ (Deleted 01/01/2024)

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