PART III

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Electrical Stimulation for Healthy Muscles

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Electrical Stimulation for Patients With Neurological Problems

FURKAN BILEK • NILUFER CETISLI-KORKMAZ

Introduction

Electrical stimulation (ES) interventions are non-invasive treatments that take into account physiotherapy and rehabilitation interventions with electrical currents. ES is widely preferred in clinical interventions for the symptom management of neurological diseases.[1] Today, ES is used for the management of many neurological symptoms such as reducing pain, regulating spasticity, stimulating muscles with peripheral nerve disorders, preventing muscle or disuse atrophy, during immobility, maintaining joint range of motion (ROM), modulating muscle tone, retraining muscle function, and accelerating bed sore healing.[2,3] In this part, ES approaches are explained within the scope of the rehabilitation of symptoms caused by neurological diseases.

Pain

Recent advances in basic and clinical neuroscience have shown pain as a very common symptom of neurological diseases.[4] The idea that changes in sensory systems are the predominant process in pain has been replaced by the conceptualization of pain as a very complex central nervous system (CNS) condition in which sensory system activation patterns are abnormally integrated with activity in other brain systems. Obvious causes such as pain due to peripheral nerve damage (neuropathic pain) affect several brain regions with a wide variety of other functions, such as the anterior cingulate cortex, insular cortex, ventrolateral orbitofrontal area, amygdala, striatum, thalamus, hypothalamus, rostral ventromedial medulla, periaqueductal grey, pons (locus coeruleus), red nucleus, and medulla oblongata.[5,6] More recently, clinicians and researchers have concluded that in many cases, chronic pain is a direct consequence of neurological disease or can even be considered an integral part of the underlying disease. For example, neurological diseases such as Parkinson's Disease (PD) in which 40-60% of patients report chronic pain, also 57% of Alzheimer's Disease, 8-14% of stroke, 57.8% of traumatic brain injury (TBI), 64.9% of spinal cord injury (SCI), 50-86% of Multiple Sclerosis (MS), 54-80% of back pain, and 89% of Guillain-Barre patients report pain.[6] Pain can cause changes throughout the CNS that have specific effects on emotional processing. The second interaction is complex, for example, pain causes depression and depression causes pain.[7,8] For these reasons, pain management is important in neurological diseases. Non-invasive ES methods are often preferred in pain management in physiotherapy and rehabilitation clinics (Table 18.1). This part describes the ES methods used in the management of pain.

Pain is a common symptom in MS, and recent studies report prevalence rates of up to 73.9%.[9] The hypoalgesic effects of self-administered Transcutaneous Electrical Nerve Stimulation (TENS) on chronic low back pain (LBP) were investigated in the MS population. Low-frequency TENS [4 Hertz

Table 18.1 Electrical stimulation protocols that can be used for pain management in neurological diseases

	Features of the electrotherapy method	Application protocol
High-Frequency Transcutaneous Electrical Nerve Stimulation	Frequency 110 Hz, pulse duration 200 μs, and intensity: The maximum current that can be tolerated without muscle contraction.	Twice a day, for 45 min, 5 days a week for 6 weeks.
Low-Frequency Transcutaneous Electrical Nerve Stimulation	Frequency 4 Hz, pulse duration 200 μs, and intensity: Started from 0 to a muscle contraction threshold of each subject	Twice a day for 45 min, 5 days a week for 6 weeks.
Microcurrent Electrical Stimulation	Frequency 30 Hz, pulse duration 300 μs, and intensity: The maximum current that can be tolerated without muscle contraction.	50 min a day, 5 days a week for 4 weeks.
Diadynamic Currents	Diphase Fixe (DF, full-wave) 2 min, Monophase Fixe (MF, half-wave) 3 min, Long Period (LP, long periods) 3 min, and Court Period (CP, short periods) 2 min.	10 min a day, 10 sessions over 2 weeks.
Interferential Current	Frequency 100 Hz for the first 15 min, 80 Hz for the next 5 min, and intensity: appreciable sensation.	20 min a day, 5 days a week for 4 weeks.

(Hz), 200 microseconds (μs)] and high-frequency TENS (110 Hz, 200 μs) were applied to the participants at least twice a day for 45 minutes (min) for 6 weeks. The findings of this study show that high-frequency TENS is more effective in relieving pain during application, whereas low-frequency TENS has a more permanent hypoalgesic effect in the long term (Figure 18.1).[10]

Figure 18.1 TENS application for low back pain.

The effects of low-frequency TENS and Interferential Current (IFC) methods on pain, functional capacity, and quality of life were compared in individuals with MS. Low-frequency TENS (frequency: 2 Hz, pulse width: 200 μs, intensity: Started from 0 to a muscle contraction threshold of each subject) was applied to the TENS group for 30 min a day, 5 days a week for 4 weeks. The IFC (frequency of 100 Hz for the first 15 min and 80 Hz for the next 5 min, intensity with appreciable sensation) was applied to the IFC group for 20 min a day, 5 days a week for 4 weeks. In this study, it was determined that IFC and TENS applications reduced pain and increased functional capacity.[11]

The effects of TENS therapy on pain intensity and functional capacity were investigated in patients with peripheral or central neuropathic pain. In the pain treatment of individuals with peripheral and central neuropathy, TENS was used to produce symmetrical, biphasic rectangular waves, 80 pulses per second (pps), 350 μs pulse width (duration), and currents up to 60 milliamperes (mA). The sessions lasted 4 weeks (5 days a week, 30 min per session). Throughout the sessions, the intensity of the current was increased until the patients felt "strong but painful and not unpleasant" levels. TENS electrodes were placed diagonally around painful areas. The most important results of this controlled clinical trial were that pain intensities were significantly reduced following TENS treatment in individuals with both peripheral and central neuropathic pain.[12]

In the study planned to investigate the effects of Microcurrent Electrical Stimulation (MES) on pain in diabetic neuropathy patients, MES was applied for 50 min a day, 5 days a week for 4 weeks. The current delivered by the shoes through which the MES was delivered was a pulsed MES of less than 300 microamperes (μA). Based on the results of this study, it was shown that MES to the foot can help

prevent pain and diabetic ulcers by increasing foot blood circulation in Diabetes Mellitus patients.[13]

In the study investigating the effects of TENS on pain in individuals with SCI, TENS treatment was applied for 20 min three times a week for 12 weeks. The treatment parameters of TENS were; pulse frequency with 2 Hz; pulse duration with less than 200 μs; and pulse amplitude with 50 mA. The study finally showed that TENS effectively reduces pain in patients with SCI.[14]

In the study investigating the effect of low-frequency TENS in the treatment of neuropathic pain in patients with SCI, low-frequency TENS was applied 30 min a day for 10 days. Two electrodes were placed proximal to the neuropathic painful area and two distally. The patients were treated with low-frequency TENS (pulse frequency 4 Hz, pulse duration 200 μs, and pulse amplitude 50 mA) daily between 08:00 and 12:00. The results of this study revealed that low-frequency TENS reduced neuropathic pain intensity in the morning, noon, and evening, but not at night in SCI patients.[15]

The medium-term effects of Diadynamic (DD) Currents on relieving symptoms and improving physical functioning in patients with chronic LBP were evaluated. In this study, 8 min of DD Currents treatment (Diphasic Constant for 2 min, the Short Period for 3 min and Long Period for 3 min) was applied. The intensity of the DD Currents varied depending on the tolerance of each patient treated. Physiotherapy programs were applied as 10 sessions over 2 weeks. It was showed that the use of DD Currents in chronic LBP will contribute to the reduction of pain and improvement of physical functions. Therefore, DD Currents have been proposed as adjuvant therapy for the rehabilitation of chronic LBP.[16]

Spasticity

Spasticity has been defined as "irregular sensorimotor control resulting from an CNS lesion manifesting as intermittent or sustained involuntary activation of muscles".[17] Spasticity is a common symptom that affects people with long-term neurological conditions such as stroke, MS, and TBI and SCI. A systematic review of 24 studies on the epidemiology of leg spasticity reported a prevalence of 28-38% in stroke patients, 41-66% in MS patients, and 13% in patients with TBI.[18]

Spasticity ranges from a subtle neurological sign to a massive increase in tone that causes immobility of the joints. The disorder is associated with a variety of complications, including falls, pain, pressure ulcers, infections, and contractures. However, it is unclear whether these complications result from spasticity or co-exist independently.[17,18] Spasticity management requires a balanced approach that weighs the benefits of treatment against the benefits of spasticity. For these reasons, spasticity management is important in neurological diseases. Current interventions to treat spasticity lack a solid evidence base and guidelines often rely on expert advice (Table 18.2). In this part, non-invasive

Table 18.2 Electrical stimulation protocols that can be used for spasticity management in neurological diseases

	Features of the electrotherapy method	Application protocol
High-Frequency Transcutaneous Electrical Nerve Stimulation	Frequency 100 Hz, pulse duration 200 μs, and intensity: 2-3 times the sensory threshold (the minimum threshold for detecting ES for subjects).	30 min a day, 5 days a week for 6 weeks.
Low-Frequency Transcutaneous Electrical Nerve Stimulation	Frequency 1.7 Hz, pulse duration 200 μs, and intensity: The stimulation intensity is increased until a visible muscle contraction (motor threshold) occurs.	60 min a day, 5 days a week for three months.
FES	Frequency 35 Hz, pulse duration 300 μs, and intensity: The stimulation intensity is increased until a visible muscle contraction (motor threshold) occurs.	30 min a day, 3 days a week for 4 weeks.
Faradic Currents	100 Hz pulse (pulse duration = 0.1 ms, pulse interval = 0.9 ms) in surge mode (surge duration = 4 s and rest between surges = 6 s).	20 min a day, 5 days a week for 6 weeks.
Russian Currents	2500-Hz carrier frequency, 50 Hz modulated frequency, and 200 μs phase duration for 10 s "on" period followed by a 50 s "off" period (with a 3-s ramp-up).	10 min a day, 5 days a week for 6 weeks.

electrotherapy approaches for spasticity in neurological disorders are described.

The relative efficacy of baclofen and self-administered TENS in the treatment of lower extremity spasticity in MS was compared. TENS was delivered on the spastic muscle in a rectangular monophasic waveform, with the current frequency set to 100 Hz, the pulse width set to 250 μs. Stimulus strength was set below the motor threshold at an intensity level required to produce a tingling sensation in the stimulated area without muscle twitching or pain. TENS treatment was applied for 20-30 min for 4 weeks. In addition, to overcome accommodation, all participants were instructed to increase the intensity to return it to its original level if the level of sensation decreased. This study showed that both baclofen and TENS can be effective in reducing MS-related spasticity. The mean Modified Ashworth Scale (MAS) score was reported to be significantly lower in the TENS group.[19]

The effects of TENS on spasticity were studied in hospitalized patients with MS with mild to moderate spasticity of the plantar flexor muscles. In patients with bilateral plantar flexor spasticity, the patient was placed in the supine and extension positions. One electrode was placed on the mid-Gastrocnemius and Soleus muscles and the other was placed laterally on the plantar surface of the foot (Figure 18.2). Stimulation frequency of 100 Hz and pulse width of 0.3 millisecond (ms) (high-frequency) TENS was applied for 20 min per day for 4 weeks. TENS was applied optimally. Statistically significant reductions in spasticity of both extremities were demonstrated after 4 weeks.[20]

Figure 18.2 TENS application to the Gastrocnemius and Soleus muscles.

To examine the effect of the Functional Electrical Stimulation (FES) cycle training program on improving leg function in the FES cycle of people with severe MS related weakness or paralysis, 14 participants were included to the study. The FES stimulation parameters for this study were set to a pulse width of 200 μs and a frequency of 50 Hz. Surface electrodes were used to stimulate the participants' Quadriceps Femoris, Hamstrings, and Gluteal muscles (Figure 18.3). The stimulation intensity varied depending on the participant's tolerance and the amount of stimulation required to reach the target cycle speed of 35 to 50 revolutions per min on the ergometer. At the end of the study, people with moderate to severe MS also showed improvements in spasticity and physical symptoms after only 4 weeks of intervention.[21]

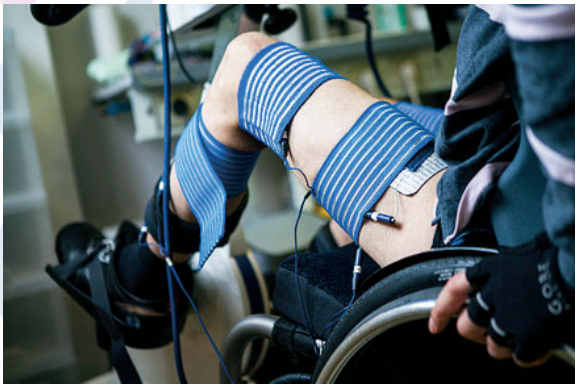

Figure 18.3 FES application with cycle.

Thirty-two individuals with MS were included in the study, both to evaluate the effectiveness of TENS on spasticity in MS and to compare two different application times. Participants were randomized into two groups, and a single blinded crossover design was used to compare 2 weeks of TENS treatments (100 Hz and 0.125 ms pulse width) for 60 min and 8 hours per day. The results of the study showed no statistically significant difference in spasticity after 60 min or 8 hours of TENS per day. The 8-hour administration period resulted in a significant reduction in muscle spasm and pain. Therefore, this study noted that although TENS did not appear to be effective in reducing spasticity, longer-term applications may be beneficial in the treatment of MS patients with pain and muscle spasm.[22]

The effects of single session TENS and FES on lower extremity spasticity were compared in patients with SCI. TENS biphasic square wave pulses with a frequency of 100 Hz and a pulse duration of 300 μs were applied to the spastic muscles for 30 min. Stimulation intensities did not cause muscle contractions and were not increased above 20 mA in persons with sensory impairment. The FES, on the other hand, consists of a 3 seconds (s) ramp-up time, a 5 s hold duration, a 2 s ramp-down time, and a 10 s rest time, providing biphasic rectangular pulses with a pulse rate of 35 Hz and a pulse width of 300 μs. The treatment lasted 30 min. The stimulation intensity is increased until visible muscle contraction (motor threshold) occurs. The intensity was then increased up to 300% of the motor threshold. A single session of ES with FES and TENS has been reported to have similar anti-spasticity effects lasting 4 hours.[23]

The effectiveness of Faradic Currents (FC) and Russian Currents (RC) in reducing ankle plantar-flexor spasticity and improving motor recovery in post-stroke patients was investigated. In this study, FC and RC were applied 5 sessions a week for 6 weeks. Participants performed ES in a sitting position on a chair with their feet on the ground. In the FC, the anode is located on the Common Peroneal Nerve and the cathode is located on the motor point of the Tibialis Anterior muscle (**Figure 18.4**). The FC was delivered according to the following parameters: 100 Hz pulse (pulse duration = 0.1 ms, pulse interval = 0.9 ms) in surge mode (surge duration = 4 s and rest between surges = 6 s). The 2,500 Hz carrier frequency, 50 Hz modulated frequency, and 200 μs phase time for a 10 s "on" period followed by a 50 s "off" period (3 s acceleration) parameters were used to transmit the RC. Both currents were applied for 10 min. The intensity of the current was adjusted to produce the muscle contraction within the participant's tolerance limit. Because voluntary contraction may increase flexor synergy and spastic co-contraction, participants were not asked to voluntarily contract their muscles during the application of ES. The results of the study indicated that both FC and RC may have a minor advantage over exercises alone in improving passive and active ankle ROM and reducing spasticity of the Gastrocnemius and Soleus muscles.[24]

Figure 18.4 Application of electrical stimulation to the Tibialis Anterior muscle.

In the study investigating whether adding TENS to an exercise program in chronic stroke patients reduces spasticity, TENS was applied to the spastic muscle. The same 30 min of TENS was applied 5 days a week for 6 weeks. TENS electrodes were placed on the lateral and medial Quadriceps Femoris and Gastrocnemius muscles of the affected lower extremity. A frequency of 100 Hz and a pulse width of 200 μs were used. The participant pre-stimulation threshold was measured from 0.01 mA and was stimulated at 90% amplitude using the subsensory threshold. In conclusion, it has been shown that a combination of therapeutic exercise and TENS can reduce spasticity and improve balance, gait, and functional activity in patients with chronic paralysis.[25]

The effect of high-frequency (100 Hz) TENS at a specific acupuncture point on spasticity in the paretic leg after stroke was investigated. Electrodes were placed to stimulate the acupuncture point ST 36 and treatment was applied for 30 min a day for 3 months. The intensity of TENS varied from 0 to 60 mA according to the patient. The negative electrode is placed on the acupuncture point ST 36 located on the lower lateral side of the knee joint. The positive electrode was placed dorsally on the lower leg, approximately 10 cm from the knee joint. The electrodes covered a wide area including the Common Peroneal Nerve (L4-S2). The results of this study indicated that stimulation of the acupuncture point ST 36 with high-frequency (100 Hz)

TENS could be an effective clinical method for ES in spasticity.[26]

The effects of low-frequency TENS treatment on motor performance and activities of daily living in the paretic arm were investigated. Starting 6-12 months after stroke, low-frequency (1.7 Hz) TENS was applied to the paretic arm for three months. In conclusion, it was found that low-frequency TENS starting 6-12 months after stroke may lead to the preservation of daily living activities scores at three-year follow-up. However, it has been stated that it may not have a specific effect on motor function in the arm.[27]

The effects of a single trial of TENS on spasticity were investigated in 42 patients with chronic stroke. TENS stimulation was applied to the Gastrocnemius muscle at 100 Hz, 200 μs for 60 min, which was 2 to 3 times the sensory threshold (the minimum threshold for detecting ES for subjects) (Figure 18.5). After one session of TENS, a significant reduction in Gastrocnemius muscle spasticity was detected. However, this effect was observed to return to baseline values within a day.[28]

It was investigated whether transcutaneous ES applied to acupuncture points in patients after acute stroke reduces spasticity and/or increases muscle strength compared to placebo stimulation and standard rehabilitation. The transcutaneous ES group was administered for 60 min with 0.2 ms pulses at 100 Hz in constant mode, within the subject's tolerance level, through electrodes attached to acupuncture points (St 36, Lv 3, GB 34, and Bl 60) on the affected lower extremity. Three weeks of transcutaneous ES to lower leg acupuncture points 5 times a week within 10 days of stroke has been found to significantly reduce ankle plantar flexor spasticity and increase dorsiflexor strength with a reduction in antagonist co-contraction.[29]

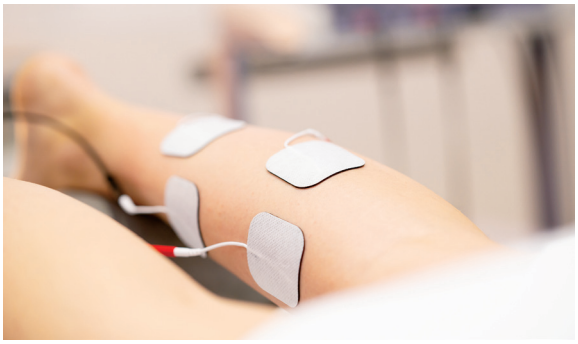

Figure 18.5 Application of electrical stimulation to the Gastrocnemius muscle.

It has been investigated whether TENS can reduce ankle spasticity and improve muscle strength in paralyzed patients. The training lasted 15 min a day and 5 times a week for 6 weeks. The intensity of stimulation delivered by the TENS stimulator was determined to be twice the sensory threshold without muscle contraction. TENS was applied with a pulse width of 200 μs and a frequency of 100 Hz. The results of this study showed that TENS applied to the spastic muscle effectively reduced spasticity and significantly improved muscle strength and balance ability in paralyzed patients after TENS application.[30]

Thirty people were included in the study investigating the sustainability of the effects of TENS applied over the Common Peroneal nerve in post-stroke patients to reduce ankle plantar-flexor spasticity and increase walking speed. One electrode is attached to the head of the fibula over the Common Peroneal nerve and the other to the navel of the Tibialis Anterior (above the motor point) muscle, lateral to the proximal bone of the Tibia. Square pulses of 0.2 ms were transmitted at a frequency of 100 Hz with a short pulse duration of about 50 ms. The current was delivered at an intensity that was 2 to 3 times the sensory threshold level of the participants. The results of the study showed that TENS is effective in reducing spasticity of ankle plantar flexors and improving walking ability. Researchers have recommended a longer application to reduce spasticity.[31]

Paresis and Loss of Strength

Paralysis or paresis is defined as a reduction in voluntary motor unit recruitment, i.e., the inability or difficulty to voluntarily recruit skeletal motor units to generate torque or movement. The injury of higher centers can impair central volitional motor command at various levels, which can be grouped into higher, middle, and lower command levels.[32] Paralysis is an important symptom affecting stroke (33.7%), SCI (27.3%), MS (18.6%) and cerebral palsy (8.3%).[33] In physiotherapy and rehabilitation

programs, different ES methods are used in these paresis and strength losses (Table 18.3).

The synergistic effects of mirror therapy and Neuromuscular Electrical Stimulation (NMES) for hand function in stroke patients were investigated. NMES was applied at 30-70 mA intensity, 250 µs amplitude and 35 Hz frequency in stroke patients. The current lasted for 5 s and then stopped for 5 s. The intensity of the stimulation was determined so that the subjects could feel muscle contraction without feeling tired. In conclusion, it showed that mirror therapy and NMES had a synergistic effect on hand function. Thus, a hand rehabilitation strategy combined with NMES and mirror therapy may be more beneficial than NMES or mirror therapy alone for improving hand function in stroke patients.[34]

The efficacy of inspiratory/expiratory muscle training and NMES to improve dysphagia in stroke has been investigated. Two electrodes were placed on the suprahyoid muscles and 80 Hz transcutaneous ES was applied according to VitalStim® instructions. The patients were instructed to swallow when they felt muscle contraction. Daily sessions of 40 min were applied 5 days a week for 3 weeks. Swallowing safety improved after 3 weeks of NMES intervention. The therapeutic efficacy of NMES and inspiratory and expiratory muscle training in patients with dysphagic subacute stroke has been associated with improved pharyngeal swallow safety signs.[35]

The effectiveness of FES given after acute stroke on motor recovery of the lower extremity was investigated. This study examined whether FES given during acute stroke is more effective than the standard rehabilitation alone in increasing lower extremity motor recovery and walking ability. Surface electrodes were applied to the Quadriceps Femoris, Hamstring, Tibialis Anterior, and medial Gastrocnemius muscles with the patient lying on their side and while supporting the affected lower extremity with a sling (Figure 18.6). FES was delivered in 0.3 ms pulses at 30 Hz, maximum tolerance

Table 18.3 Electrical stimulation protocols that can be used for paresis and loss of strength management in neurological diseases

	Features of the electrotherapy method	Application protocol
Neuromuscular Electrical Stimulation	Frequency 35 Hz, 250 µs amplitude, and the current lasted for 5 s and then stopped for 5 s. Intensity: stimulation was determined so that the subjects could feel the muscle contraction without feeling tired (30-70 mA).	30 min a day, 5 days a week for 3 weeks.
Functional Electrical Stimulation	0.3 ms pulses at 30 Hz and maximum tolerance intensity (20 to 30 mA).	30 min a day, 5 days a week for 3 weeks.
Transcutaneous Electrical Nerve Stimulation	Frequency 100 Hz, pulse duration 200 µs, and intensity with 2-3 times the sensory threshold	30 min a day, 5 days a week for 4 weeks.
High Voltage Pulsed Galvanic Stimulation	Pulse width of 100µs, the pulse frequency 60 pulses/s, and discontinuous form with 5 s of impulse and 5 s of rest	20 min a day, 3 days a week for 6 weeks.
Pulsed Galvanic Current Stimulation	A monophasic waveform with a pulse duration of 100 ms, an interpulse interval of 300 ms, and a pulse rate of 2.5 pulses/s.	30 min a day, 5 days a week for 6 weeks.

Figure 18.6 Functional electrical stimulation applications to lower extremity muscles.

intensity (20 to 30 mA), using an activation sequence mimicking normal gait. NMES was applied for 3 weeks, 30 min a day, 5 days a week. After 3 weeks of treatment, a significant reduction in the percentage of composite spasticity score and a significant improvement in ankle dorsiflexion torque were reported in the FES group, with an increase in the agonist electromyogram and a decrease in the electromyogram co-contraction rate.[36]

The effectiveness of the task-related training program with TENS on the improvement of upper extremity motor function in individuals with chronic paralysis was investigated. ES (2-3 times the sensory threshold, 100 Hz, 200 μs) was applied to the Triceps Brachii muscle belly and wrist extensors using TENS. The applied stimulation intensity is usually adjusted to the intensity that will stimulate the formation of visible muscle contraction. For a period of four weeks, 20 sessions of 30 min were applied in one session, 5 sessions per week. In conclusion, it has been shown that a combined training program with TENS can reduce motor impairment and improve motor activity in stroke patients with chronic upper extremity paresis. Researchers highlighted the benefits of TENS in somatosensory stimulation in this study.[37]

The effect of low-intensity low-frequency TENS (1.7 Hz) initiated 6-12 months after stroke on functional motor capacity of the paretic extremity was investigated. Low-frequency TENS was applied for 60 min, 5 days a week for 3 months. The results showed that motor function was significantly increased. However, Low-frequency TENS has been reported to not reduce pain or spasticity.[38]

The effects of a 6-week intervention with NMES with narrow or wide pulses on walking performance, neuromuscular function, and disability status in patients with relapsing-remitting MS were investigated. NMES was applied to the dorsiflexor and plantar flexor muscles of each leg (10 min, 4 s on and 12 s off). NMES was applied to one leg at a time in a counterbalanced order across sessions. Stimulus frequency was set at 100 Hz with a pulse width of 1 ms for wide-pulse stimulation and at 50 Hz with a pulse of 0.26 ms for narrow-pulse stimulation. To reduce the discomfort associated with NMES, the participant was encouraged to contract the involved muscles while the stimulation was applied.[39]

The changes in motor function and disability status that occur with TENS applied to the extremity muscles of individuals with MS were investigated. While the participants were relaxed and seated in a chair, monophasic rectangular pulses (0.2 ms) were delivered to each limb individually for 10 min. Pulses were used in a continuous mode at 50 Hz frequency for the first 5 min and in a burst mode (5 bursts/s) at ~100 Hz for the second 5 min. The researchers stated that changing the stimulus mode during treatment could minimize the depressive effects of neural cohesion. The current density is adjusted to elicit mild muscle contractions to engage a wide variety of sensory nerve fibers. Nine treatment sessions of TENS of sensory nerves in the limbs of people with MS have been shown to reduce the burden of the disease by improving motor function and reducing patient-reported fatigue levels and walking limitations.[40]

The effects of High Voltage Pulsed Galvanic Stimulation (HVPGS) applied to spasticity-related weaknesses in knee flexors and ankle dorsiflexors in MS patients on strength were investigated. The HVPGS stimulator automatically outputs a pulse width of 100 μs and the pulse frequency was set to 60 Hz. The discontinuous form with 5 s of impulse and 5 s of rest was chosen so as not to cause fatigue. The amplitude was increased until a contraction was observed that did not disturb the patient. A total of 20 min of HVPGS was applied with 3 min rest period. HVPGS was applied for 6 weeks, 3 days a week. According to the results of the study, it was stated that HVPGS was effective in localized muscle strengthening.[41]

In patients with PD and oropharyngeal dysphagia, the effects of NMES application on the quality of life in addition to traditional logopedic dysphagia treatment were investigated. Suprahyoid muscles were stimulated with NMES (frequency 80 Hz, pulse width 700 μs). Participants often reported a "pull" sensation around 7 or 8 mA. The maximum motor level was determined as the highest current level that a participant could tolerate without dis-

comfort during neck stimulation. The electrotherapy device was set to automatically switch from "on" to "off" and back to "on" for 1 s every min. In conclusion, it has been shown that in some patients with dysphagia, such stimulation may interfere with the hyolaryngeal elevation necessary for airway protection during swallowing.[42,43]

The effects of RC stimulation applied to the Tibialis Anterior muscle belly in foot drop associated with lumbar radiculopathy were investigated. A burst frequency of 50 bps with 70 mA constant current with 10/50 s on/off over 12 min and 50% duty cycle was applied to the muscle to achieve tetany with volitional dorsiflexion to the best of the patient's abilities. Physiotherapist assisted foot dorsiflexion during "on" cycle to relieve pain. The study finally shows that RC stimulation can serve as an effective non-surgical option for patients with lumbar radiculopathy causing drop foot.[44]

When ES is added to conventional physiotherapy and rehabilitation program in patients with Bell's Palsy, its effectiveness in terms of clinical and neurophysiological changes has been investigated. A monophasic waveform with a pulse duration of 100 ms, an interpulse interval of 300 ms, and a pulse rate of 2.5 pulses/s was used for 5 times a week for 3 weeks. ES was delivered via carbon-rubber electrodes; a 3 cm^2 anode was placed on each muscle, and a 7 cm^2 cathode was placed on the proximal part of the ipsilateral arm. ES was applied to each of the 11 facial muscles (Frontalis, Corrugator Supercilii, palpebral part of Orbicularis Oculi, Levator Labii Superioris Alaeque Nasi, Levator Labii Superioris, Levator Anguli Oris, Risorius, Orbicularis Oris, Depressor Anguli Oris, Depressor Labii Inferioris, and Levator Menti). ES was performed in three sets of 30 minimum contractions, 5 days a week, over a 3-week period. It has been reported that functional facial movements and electrophysiological outcome measures at 3-month follow-up were improved in patients with Bell's Palsy.[45]

The efficacy of NMES and Shortwave Diathermy therapy for chronic Bell's palsy has been investigated. Two electrodes were placed over 3 muscles: Orbicularis Oris, Zygomaticus, and Frontalis. Besides generating a current, it develops a shortwave diathermy therapy by acting like 2 plates of a capacitor. Therefore, a radio frequency is generated in the area below the line of each electrical waveform to generate a Shortwave Diathermy therapy (8-12 W power and 2.2 MHz frequency). Two different waveforms were used in each session. A triangular and then rectangular monophasic waveform was used to stimulate partially denervated motor units and fully denervated ones, respectively. The ES unit applied 1 channel bipolar ES at a constant 80 Hz pulse rate and a constant biphasic pulse duration of 700 μs. The intensity gradually increased from 0.5 mA until the physiotherapist confirmed visible muscle contraction and the subject felt a gripping sensation in the facial muscles. Electrotherapy applications were made for 30 min/session, 5 sessions/week for 4 weeks. The synergistic use of NMES and Shortwave Diathermy has been reported to provide a significant improvement in voluntary movement symmetry in chronic Bell's Palsy that does not heal spontaneously, by avoiding contractures and synkinesis.[46]

In a study evaluating the effectiveness and safety of a home-based muscle ES system in patients with brachial plexus injury, the Biceps Brachii muscle was stimulated with ES for 15 min. Stimulation parameters included a monophasic triangular waveform, a pulse width of 80 ms, a pulse interval of 1 s, and current intensity (0-100 mA) to the minimum that produced maximum visible Biceps Brachii muscle contraction (Figure 18.7). In this study, ES provided important evidence for the prevention of atrophy as a treatment in patients with peripheral nerve injury.[47]

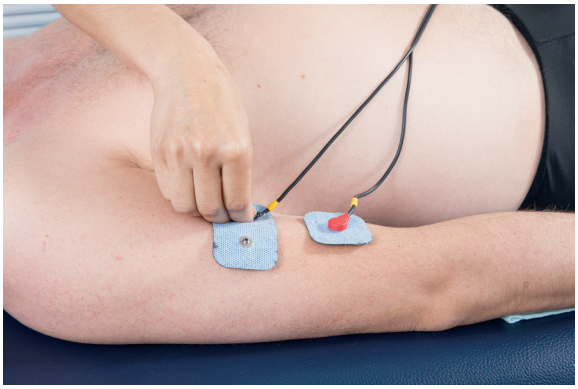

Figure 18.7 Biceps Brachii electrical stimulation application.

Tremor

Tremor is the involuntary, rhythmic oscillation of mutually innervated antagonistic muscle groups that causes a body part to move around a fixed plane in space.[48] Although tremor is frequently seen in PD, its prevalence is estimated to be 0.3%, increasing to 1% in individuals aged 60 years and older.[49] The prevalence of resting tremor (58.2%) is higher than that of action tremor (39.0%).[50] It is difficult to accurately estimate the incidence and prevalence of tremor in MS, but one study found moderate and severe tremor in 32% and 6% of patients, respectively.[51] In this part, non-invasive ES approaches of tremor observed especially in PD are explained (Table 18.4).

ES methods used in tremor can be divided into three main categories: FES, sensory electrical stimulation (SES), and TENS. The three types of peripheral ES approaches have different mechanisms for suppressing the tremor. The FES method induces muscle contraction to modulate its peculiarity to suppress the tremor. On the other hand, SES applies electrical current to the targeted muscle, but the excitation amplitude remains below the motor threshold. The TENS method stimulates the afferent nerve (e.g. Radial and Median nerves) to expose cutaneous afferent fibers and inhibit tremor-related muscles. Stimulation frequency and intensity are two key parameters in the control strategy. The stimulation frequency range used in the studies reviewed is 20 to 250 Hz. The FES method used a relatively lower frequency (ranging from 20 to 40 Hz) compared to SES and TENS.[52-54] The minimum and maximum stimulation frequencies used for SES were 50 Hz and 100 Hz.[55,56] TENS has a higher frequency range of 100–250 Hz.[57,58] The stimulation intensity usually varied in participants with a range of 5–30 mA.[52,55-58]

The effects of ES on tremor were investigated by TENS in PD patients. The electrodes were placed on the dorsal skin of the hand near the metacarpophalangeal joint of the index finger (covering the first interosseous space). A programmable stimulator is used to generate a two-phase, charge-balanced current pulses array with a pulse width of 200 μs at a pulse frequency of 250 Hz. The pulse amplitude of the stimulus was adjusted during the experiment to examine the effect of the stimulation power on the flicker inhibition. It has been reported that the application of TENS for tremor in the upper extremity of PD patients can largely prevent the cutaneous reflexes, evoked by surface stimulation of the dorsal hand skin region innervated by the Superficial Radial nerve.[59]

The effects of TENS (using three different frequencies) were investigated in patients with primary writing tremor (PWT). 5 Hz, 25 Hz, or 50 Hz TENS stimulation was applied. TENS was an asymmetric rectangular biphasic wave (pulse width with 250 μs). Each TENS treatment was administered in 14 sessions of 20 min each (7 days a week for 2 consecutive weeks). At the end of the study, although clinical improvement was observed in handwriting and tremor, no significant change was

Table 18.4 Electrical stimulation protocols that can be used for tremor management in neurological diseases

	Features of the electrotherapy method	Application protocol
Functional Electrical Stimulation	Frequency 30 Hz, 250 μs amplitude and the current lasted for 5 s, and then stopped for 5 s. Intensity: stimulation was determined so that the subjects could feel the muscle contraction without feeling tired (30-70 mA).	30 min a day, 5 days a week for 3 weeks.
Transcutaneous Electrical Nerve Stimulation	Frequency 250 Hz, 200 μs amplitude, and ES should be delivered in 2 s trains separated by 2 s pauses. 2-3 times the sensory threshold (minimum threshold for detecting ES for subjects).	20 min a day, 7 days a week for 2 weeks.
Sensory Electrical Stimulation	Frequency 50 Hz, 250 μs amplitude and the current lasted for 5 s, and then stopped for 5 s. Pulse amplitude with a comfortable level producing motor response of less than 20 mA.	30 min a day, 5 days a week for 4 weeks.

reported between the 2 weeks of 5 and 25 Hz TENS treatment in patients with PWT.[60]

Bladder and Bowel Problems

Neurological diseases that affect the brain structures and spinal tracts that are under the control of the sphincter may cause lower urinary tract symptoms (LUTS). Among LUTS, overactive bladder syndrome may include urgency, frequent urination, nocturnal, and urgency incontinence. Urinary incontinence (UI) has been reported to occur in stroke (29%), PD (58%), peripheral neuropathy (50%), and MS (35%).[61,62] Also, up to 80% of SCI patients, up to 70% of people with MS, and about 10% of people with PD complain of constipation.[63] In this part, the ES methods used for bladder and bowel problems are mentioned (Table 18.5).

In the study investigating the therapeutic effect of TENS on post-stroke urinary incontinence (UI), TENS was applied for 30 min once a day for 60 days. Current parameters were 70 μs pulse duration and unidirectional square wave at 75 Hz frequency, and the maximum therapeutic current was 16 mA (1 kilo ohm). According to the nerve innervation, the electrode pads were placed as follows: the positive electrode (39 cm^2) was on the second lumbar spinous process, and two negative electrodes (30 cm^2) were on the inside of the middle and lower third of the junction between the Posterior Superior Iliac Spine and the Ischia Node. Daily voiding, nocturnal, urgency, and urgency UI were reported to be significantly improved in TENS-treated participants compared to the control group.[64]

The effect of intravaginal NMES and Transcutaneous Tibial Nerve Stimulation (TTNS) on LUTS and health-related quality of life in women with MS was investigated. NMES was used to deliver 200 μs wide electrical pulses to the vaginal wall at the level of the Levator Ani muscle at a frequency of 10 Hz for 30 min at the maximum intensity the participant could tolerate with a vaginal stimulating probe. The stimulation amplitude was reduced to a level just below the motor contraction threshold. Self-adhesive electrodes delivered TTNS, one electrode was applied below the left medial mal-

Table 18.5 Electrical stimulation protocols that can be used for bladder and bowel problems management in neurological diseases

	Indication	Features of the electrotherapy method	Application protocol
Transcutaneous Electrical Nerve Stimulation	**Urinary Incontinence**	Frequency 75 Hz, 70 μs amplitude, and intensity at 16 mA.	30 min a day, 5 days a week for 6 weeks. The positive electrode should be placed on the second lumbar spinous process, and the negative electrode should be placed on the medial side of the middle and lower third of the junction between the Posterior Superior Iliac Spine and the Ischial Node.
Neuromuscular Electrical Stimulation	**Lower Urinary Tract Symptoms**	Frequency 10 Hz, 200 μs amplitude, and the stimulation amplitude should be reduced to a level just below the motor contraction threshold.	30 min a day, 5 days a week for 12 weeks. It should be applied to the vaginal wall at the level of the Levator Ani muscle with a vaginal stimulating probe.
Transcutaneous Tibial Nerve Stimulation	**Lower Urinary Tract Symptoms**	Frequency 10 Hz, 200 μs amplitude, and the stimulation amplitude should be reduced to a level just below the motor contraction threshold.	30 min a day, 5 days a week for 12 weeks. One electrode should be applied below the left medial malleolus and the other should be located 5 cm cephalad to the distal electrode.
Functional Electrical Stimulation	**Constipation**	Frequency 40 Hz, 330 μs amplitude, and intensity: 40 - 50 mA.	15 min twice a day for the first 2 days, then the treatment session is increased to 30 min twice a day. 5 days a week for 6 weeks. Electrodes should be placed on the External Oblique and Transverse Abdominis muscles.

leolus, and the other was located 5 cm cephalad to the distal electrode. It was set at a pulse width of 200 μs at 10 Hz for 30 min, and the stimulation amplitude was reduced to a level just below the motor contraction threshold. The applications lasted for 12 weeks. In this study, it was reported that both NMES and TTNS improved LUTS (including emergency urinary incontinence) in women with MS and caused effective relaxation of pelvic floor muscles.[65]

FES stimulation of the abdominal muscles and its effects on intestinal motility were investigated in the treatment of chronic functional constipation in patients with MS. Participants' External Oblique and Transverse Abdominal muscles were stimulated with FES at 40 Hz, 330 μs pulse width, and 40-50 mA. The treatment was initially 15 min twice a day for the first 2 days and then the treatment session was increased to 30 min twice a day. A total of 30 sessions were applied during the study period of 6 weeks. It has been shown that FES applied to the abdominal muscles improves intestinal motility, which has been reported to decrease colonic transit time as well as whole intestinal transit time.[66]

Pressure Ulcers

Pressure ulcers are defined as an area of localized damage to the skin and underlying tissue caused by sustained mechanical load.[67] Today, pressure sores are an important health problem with serious consequences for the patient, directly affected by the increase in morbidity-mortality and deterioration in the quality of life. Every effort must be oriented in this direction, especially when it is estimated that almost 95% of pressure ulcers are preventable and 60% of occasions are initiated and developed in hospitals. In conclusion, it is stated that ES applications support the treatment of pressure ulcers, especially for a better and faster cleaning, vascularization and subsequent healing of ulcers (Table 18.6).[68]

The effectiveness of HVPGS and ultrasound (US) applications on pressure ulcers developing in individuals hospitalized in the neurology service was investigated. The HVPGS was applied with a device to deliver twin-peaked monophasic pulsed current with 100 pps with a 10-/50-/100-μs pulse width, 2 s ramp-up time, in a continuous mode, and with the intensity set between 50 and 150 V (a point below the level of muscle contraction) and based on intact skin sensory level. The session duration was 60 min 3 times per week for 4 to 12 weeks. The US was administered with a device at a frequency of 3 Mega Hertz (MHz), 20% duty cycle, and 0.3 Watt/cm^2 dose for 1 to 2 min/cm^2 with a pulse pattern in the wound bed and at a frequency of 1 MHz in continuous mode, 1 to 1.5 Watt/cm^2 dose, for 2 to 3 min/cm^2 around the wound. The US was applied 3 times per week for 4 to 12 weeks. In this study, the researchers observed a statistically significant reduction in wound size in both groups. The reduction in the wound area was reported to be improved by 63% in US group and 43% in the HVPGS group.[69]

The effects of 60 min of HVPGS 3-5 times a week on pressure ulcers were investigated in patients with SCI. With an intensity of 100 mA and a frequency of 100 pps (double peak, monophasic, 10 μs pulse width), the polarity was initially negative and changed weekly. At the end of the study, stubborn pressure ulcers, whose duration ranged from 8 to 14 months, were reported to be completely healed by HVPGS.[70]

Table 18.6 Electrical stimulation protocols that can be used for pressure ulcer management in neurological diseases

	Features of the electrotherapy method	Application protocol
High Voltage Pulsed Galvanic Stimulation	The HVPGS should be applied to deliver twin-peaked monophasic pulsed current with 100 pps with a 10-/50-/100-μs pulse width, 2 s ramp-up time, in a continuous mode, and with the intensity set between 50 and 150 V (a point below the level of muscle contraction).	60 min a day, 5 days a week for 12 weeks.

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Electrical Stimulation for Patients With Chronic Obstructive Pulmonary Disease (COPD)

ZELİHA OZLEM YURUK

Introduction

Chronic obstructive pulmonary disease (COPD) is the general name for a group of progressive, partially reversible diseases characterized by airflow limitation. Dyspnea, wheezing, cough, chest tightness, and frequent respiratory infections are the main symptoms of the disease.[1] COPD is a systemic disease with multiple extrapulmonary manifestations, including inhibition of skeletal muscle function, leading to reduced muscle strength and endurance, fatigue, weight loss, and anxiety in individuals.[2] In COPD, limb muscle weakness, atrophy, structural and metabolic changes are observed, and these problems in peripheral muscles have a negative effect on exercise tolerance.[3,4]

Pathophysiological mechanisms underlying peripheral muscle dysfunction in COPD are protein synthesis-degradation imbalance, nutritional abnormalities, muscle disuse, systemic corticosteroids, hypoxia and hypercapnia, changes in muscle remodeling, inflammation, oxidative stress, and mitochondrial abnormalities.[5-8] Changes in the structure of peripheral muscles in individuals with COPD are conversion from type I fibers to type II fibers, reduction in cross-sectional area of type II fibers, and decrease in capillary and mitochondrial density, decrease in the rate of oxidative/glycolytic metabolism. As a result, muscle strength and endurance are decreasing.[9]

The loss of strength and endurance, especially in the lower extremity muscles, causes decreased walking capacity and physical activity. These are associated with exercise intolerance, morbidity, mortality, increased healthcare use, dyspnea, and poor quality of life.[10,11]

The main goals of physiotherapy and rehabilitation are to:[12]

- reduce and control symptoms,
- improve physical capacity,
- ensure independent function,
- reduce the frequency of hospitalizations,
- reverse the effects of the disease on the system,
- increase physical and emotional participation in daily life,
- increase the quality of life,
- reduce the use of health-related care resources.

Patient Evaluation

Before the clinical decision-making for the physiotherapy program and electrical stimulation, detailed patient assessment is necessary. The physiotherapists should interview the patients. Firstly, a review of the medical record can help to identify the patient's medical history and precautions. It is needed to explain the purpose of the electrical stimulation. The physiotherapist should observe for signs of anxiety, dyspnea, confusion, fatigue, abnormal posture, limitations in activities of daily living, and reduced endurance. Also, it is necessary to learn the patient's previous medical condition for contraindications of electrical stimulation.[13]

The aim of the physiotherapy and rehabilitation assessment is to establish the patient's functional ability and limitations. The content of the physio-

therapist's assessment may vary from individual to individual and setting to setting. In individuals with COPD dyspnea, posture, range of motion, anthropometric characteristics, strength (manual muscle test, handheld dynamometer, isokinetic systems), endurance, sensation, fatigue, and quality of life should be assessed.[13]

Electrical Stimulation for Patients with COPD

Exercise training, patient education, pulmonary physiotherapy, and electrical stimulation are used in the physiotherapy and rehabilitation programs of individuals with COPD. Among the electrical stimulation approaches, neuromuscular electrical stimulation (NMES), functional electrical stimulation (FES), magnetic field stimulation, and transcutaneous electrical nerve stimulation (TENS) are the most common interventions for COPD.[13]

Neuromuscular Electrical Stimulation (NMES) in Patients with COPD

The Aim and Effects of NMES in Patients with COPD

An exercise-based pulmonary rehabilitation program is the main approach for COPD. However, some individuals with COPD cannot reach the required level of exercise intensity due to fatigue symptoms and cannot continue the exercise for a sufficient time, even in the first stages of resistance exercise training, since their functional exercise capacity is extremely limited. Also, severe dyspneic individuals with COPD cannot complete the program. NMES is indicated as an alternative to increasing peripheral muscle strength in individuals with COPD who cannot perform the resistive exercise.[14-16]

NMES is generally applied to the thigh and calf muscles of the lower extremity. The upper extremity or diaphragm can also be stimulated.[17,18] Passive training of specific muscle groups with NMES can be tolerated better than active exercises in individuals with COPD, who cannot do active exercise due to severe ventilatory limitation and dyspnea. The metabolic load is lower during NMES than resistance exercises in individuals with COPD. Therefore, it does not increase the load on the ventilatory and cardiac systems.[19-22] Because of the constant metabolic load in combination with stable symptom scores over time, it seems reasonable to hypothesize that the improvements in muscle function are at least partially due to intramuscular changes. Previously, it has been shown that type I and IIa fibers increases following low-frequency (LF) NMES or high-frequency (HF) NMES.[23-25]

NMES can be used in stable and critically ill patients with COPD. NMES can regulate peripheral microcirculation, prevent atrophy by reducing muscle protein breakdown, prevent weakness associated with intensive care, and shorten the weaning time.[26] As a result, NMES is a useful training method to improve lower extremity function, especially in individuals with COPD with activity limitation and intolerance to whole-body training. NMES can be applied in bedridden patients admitted to the intensive care unit for acute COPD exacerbations. NMES can improve muscle function in these environments and facilitate the transition from bed to chair.[27] Latimer et al., compared NMES, and resistive exercises and concluded that resistive exercises have a broader impact on mRNA abundance and, therefore, appear to be a superior intervention for maximizing transcriptional responses in the Quadriceps Femoris muscle of patients with COPD.[28] However, if voluntary resistive exercises are not feasible in a clinical setting, NMES can modify the expression of the genes and improve muscle mass and strength.

The effects of the NMES in patients with COPD are to:[23-28]

- prevent atrophy,
- increase peripheral muscle strength,
- regulate peripheral microcirculation,
- decrease perception of dyspnea,
- strengthen without increasing the metabolic load in the ventilatory and cardiac systems.

NMES Protocol

NMES parameters can be determined according to the specific needs and reactions of each patient, rather than establishing a uniform protocol for all individuals with COPD. However, a general outline of the NMES protocol is shared in the section. The treatment is directed to the Quadriceps Femoris,

Gastrocnemius, Deltoid, Biceps Brachii, abdominal and Diaphragm muscles.[14,15,29]

In NMES, it is recommended to prefer biphasic, symmetrical/asymmetrical currents in the 30 and 80 Hertz (Hz) frequency range, with a stimulation duration between 100 and 400 microseconds (μs). The parameters are well tolerated by the participants.[16,29,30] Oxygen uptake, ventilation, and symptoms does not differ between high frequency (75 Hz) and low frequency (15 Hz) NMES.[31] These specific values provide maximum activation of slow-twitch, fatigue-resistant muscle fibers.[32]

In the NMES application, high repetitive muscle contraction is considered appropriate due to the relaxation of the muscles and considering the rule that the duration of contraction is similar to endurance training. After the contractions, intervals adjusted according to the patient's fatigue level are given. The data obtained emphasize the determination of the most appropriate contraction and relaxation rates for the patient without causing excessive fatigue in the muscles.[14]

It has been stated that the gains in functional exercise capacity achieved with NMES are largely dependent on the patient's ability to tolerate and maintain an increasingly higher current intensity.[32] It is recommended to have a variable amount of visible but clear contraction and to be increased up to the patient's maximum tolerance. The total treatment duration is 4-8 weeks for muscle strengthening. It has been reported that the frequency of treatment can vary between 2-5 per week, and the duration of a treatment session can vary between 15-60 minutes (min).[14,15,29,30]

Electrode placement is decided according to the muscles to be stimulated (Figure 19.1). Electrodes are placed parallel to the fibers of the limb muscles. Stimulation can be performed unilaterally or bilaterally. The therapists use 2 (1 channel) or 4 (2 channels) electrodes. For diaphragmatic NMES, a total of 4 channels and 8 electrodes are used. Two canals are placed upside down on both sides of the xiphoid at the level of the intercostal space of the 7th and 8th ribs with two electrodes.[17] For abdominal stimulation, 4 electrodes are placed approximately 2 cm from the umbilical region bilaterally and symmetrically around the midline.[33]

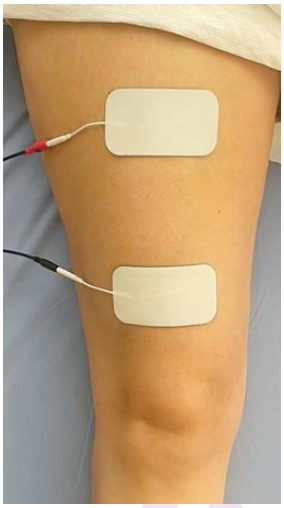

Figure 19.1 Unilaterally Quadriceps Femoris NMES.

Table 19.1 represents the recommended parameters for muscle strengthening in patients with COPD. Table 19.2 shows the recommended parameters for improving muscle endurance in patients with COPD.

Table 19.1 Parameter settings for NMES for muscle strengthening in patients with COPD.[22,31,34]

Current type/waveform	Pulsatile or burst modulated alternating current/symmetrical biphasic or asymmetrical biphasic
Pulse/cycle duration	100-600 μs
Amplitude	Maximum tolerable/ ≥50% maximum voluntary isometric contraction (MVIC) (healthy muscles) ≥10% MVIC (weakened and injured muscles)
Pulse rate (Frequency)	30-80 Hz
Ramp up/ramp down	As tolerated, 1-5 s/1-5 s
On time (Duty cycle)	5-10 s
Off time	15-120 s
Modulation	None
Number of contractions	10-20 repetitions (recommended)
Treatment duration	15-60 min
Frequency of sessions	2-5 times/week, 4-8 weeks
Polarity	None
Electrode placement	2 (1 channel)-small muscles; 4 (2 channels) for larger muscles; parallel to fibers Quadriceps Femoris, Hamstrings, Gastrocnemius Trunk muscles, Deltoideus, Biceps Brachii Bilaterally/unilaterally

Table 19.2 Parameter settings for NMES for muscular endurance training in patients with COPD.[22,31,34]

Current type/waveform	Pulsatile or burst modulated alternating current/symmetrical biphasic or asymmetrical biphasic
Pulse/cycle duration	100-600 µs
Amplitude **Frequency**	Comfortable or maximum tolerable contraction/ 25-50% MVIC 30-80 Hz
Ramp up/ramp down	As tolerated, 1-5 s/1-5 s
On time (Duty cycle)	5-15 s
Off time	5-15 s
Modulation	None
Stimulation duration	15-30 min
Frequency of sessions	3-5 times/week, 6-8 weeks
Polarity	None
Electrode placement	2 (1 channel)-small muscles; 4 (2 channels) for larger muscles; parallel to fibers Quadriceps Femoris, Hamstrings, Gastrocnemius Trunk muscles, Deltoideus, Biceps Brachii Bilaterally/unilaterally

Clinical Evidence of NMES

Studies using NMES to increase peripheral muscle strength in patients with COPD have been increasingly taking place in the literature since the beginning of the 2000s.[14-16,29,30] In studies with NMES has compared alone or combined conventional pulmonary rehabilitation and NMES versus control or sham or pulmonary rehabilitation on disabilities and activity limitation in patients with COPD.[35]

Roig and Reid's systematic review stated that moderate improvement in muscle function and exercise performance gained with the NMES applied to the lower extremities of patients with COPD compared to control, sham therapy, or other treatment groups.[36] In the related review, while NMES is an additional approach to be used in the rehabilitation of patients with the capacity to exercise, it was reported that it can be a primary treatment approach in critically ill patients where long-term immobilization is required. However, it is also noted that NMES has no advantages over voluntary exercise training.

Individuals with COPD have low lower extremity muscle cross-sectional area, lean body mass, fat mass, and fat percentage.[37] A study investigating the effect of NMES on body composition in patients with COPD showed that low and high frequency NMES application for 6-weeks did not create a significant difference in body composition.[38] Vivodtzev et al. compared the effects of 4-weeks of rehabilitation, and NMES added to rehabilitation program of patients with severe COPD with low BMI.[16] They found that BMI increased more in the NMES group.

Skeletal muscle lactate dehydrogenase (LDH) levels are normal or tend to be elevated in individuals with COPD. During exercise, LDH rises more rapidly in these patients than in healthy individuals.[39] Studies have shown that there may be an increase in type II muscle fibers in individuals with COPD, and therefore an increase in LDH levels.[40] In COPD, increased activity of this enzyme is observed in the Quadriceps Femoris muscle of patients with severe airway obstruction and chronic hypoxia.[41] Studies have shown that disease severity as assessed by forced expiratory volume (FEV1) is associated with LDH level.[42,43] LDH may be high when the disease severity is high (FEV1<25%). In a study in the literature, the effect of NMES on LDH was investigated. No significant difference was found in LDH level in the study in which the Quadriceps Femoris muscle was applied NMES at 15 Hz, 3 times a week for 15 min.[44]

The incidence of upper and lower extremity peripheral muscle weakness in individuals with COPD was approximately 30%. The incidence of muscle weakness increases with the severity of the disease.[45] Muscle weakness and/or decreased muscle endurance and muscle atrophy are more prominent, especially in the Quadriceps Femoris muscle.[46] The cross-sectional area of the Quadriceps Femoris muscle is reduced in individuals with COPD.[47] In the study by Zanotti et al., a significant improvement in muscle strength and a decrease in the number of days needed to transfer from bed to chair was achieved with the use of NMES in addition to classical active limb mobilization in bed-bound patients with COPD receiving mechan-

ical ventilation, with marked peripheral muscle hypotonia and atrophy.[29] Bourjeily-Habr et al. reported a significant improvement in isokinetic leg extension peak torque (+39%) in individuals with COPD (FEV1, 38% predicted) after a 6-week NMES training period compared with the sham-treated group.[30] In the study of Dal Corso et al., NMES was applied to the Quadriceps Femoris muscle for 6-weeks in individuals with COPD. Muscle strength was measured with an isokinetic dynamometer, and muscle mass and cross-sections were measured with dual-energy x-ray absorptiometry.[15] In conclusion, it was stated that NMES may cause hypertrophy in type II muscle fibers. However, this was not translated into increased skeletal muscle strength and exercise capacity.

In the literature, the use of NMES in respiratory muscle training is rare. In a study including diaphragmatic NMES, Quadriceps Femoris muscle NMES, and control group, it was reported that maximal inspiratory pressure was higher in both groups than in the control group. In another study conducted in non-intubated patients with COPD, it was stated that NMES application to the diaphragm provided a significant increase in respiratory muscle strength.[17] In a randomized controlled study, in which NMES was applied to the abdominal and chest muscles, there was no change in muscle mass in the stimulated muscle groups. While there was no change in muscle mass in the intervention group, a decrease in muscle mass was found in the control group.[48]

The limitation of exercise capacity in individuals with COPD is due to many factors, such as decreased ventilatory capacity, changes in metabolism and gas exchange, skeletal muscle dysfunction, cardiac failure, and increased symptoms during exertion. These mechanics that occur during exercise lead to a decrease in functional capacity and maximal oxygen consumption.[49] In a Cochrane review, the effects of NMES on general physical condition and health-related quality of life were investigated. Nineteen studies were included in the review, and 267 patients with COPD covered by 16 studies meeting the criteria contributed to the data. NMES increased Quadriceps Femoris muscle strength and endurance, 6-min walking test distance, submaximal symptom-limited exercise test time, and reduced the severity of leg fatigue when the exercise test was completed. At the same time, it was stated that NMES increased the maximum oxygen consumption value insignificantly. It is among the results of the review that NMES, when applied together with traditional exercise training, does not provide additional gain in Quadriceps Femoris muscle strength, but improves the 6-min walking test results. Due to the risk of bias in the studies included in the review, the uncertainty of the estimates, the small number of studies, and the inconsistency between the studies, it was also noted that the level of evidence for the positive effects of NMES on general physical condition and health-related quality of life in patients with COPD is low or very low.[50]

Quality of life in chronic respiratory diseases is affected by age, gender, and severity of disease or airway obstruction level.[51-53] NMES improves the quality of life.[20,44] However, a recent meta-analysis showed that NMES had no clear effect on the quality of life. The meta-analysis also concluded that NMES could improve exercise capacity and reduce the perceived sensation of dyspnea during exercise in patients with COPD, but not to be recommended as an effective alternative training modality in the rehabilitation of stable patients with COPD.[54]

Acheche et al. applied NMES together with endurance training and resistance exercises to a group of patients with COPD in their study.[55] NMES was applied to the Quadriceps Femoris and calf muscles of both legs in three sessions per week for 24 weeks. It has been reported that static and dynamic balance, and exercise tolerance improved in patients who underwent NMES. As the general result of the study it was stated that NMES may also reduce the risk of falls and be a part of pulmonary rehabilitation for individuals with COPD.

Another important aspect of NMES application is compared with traditional exercise training sessions is the reduction of anxiety experienced by patients during and after NMES treatment. Reducing anxiety in advanced COPD cases is important in breaking the emotional barriers of patients and the

vicious circle of emotional barrier-physical activity insufficiency.[15]

Home-Based NMES

A home-based pulmonary rehabilitation program including controlled breathing training, and NMES superimposed onto voluntary muscle contraction can improve cardiorespiratory performance and functionality in stable patients with COPD.[56]

Coquart et al. found that home-based pulmonary rehabilitation, including self-monitored NMES, seems feasible and effective for severely disabled patients with COPD with severe exercise intolerance.[57] In the study, the patients were administered NMES to the bilateral Quadriceps Femoris muscles with surface electrodes with a portable stimulator (a symmetrical biphasic square pulsed current at 50 Hz, 5 s on and 8 s off, 300 μs). The patients increased the intensity up to the maximum tolerated level. NMES was simultaneously applied to both thighs for 30 minutes twice every day. Another study from Bonnevie et al. showed that home-based NMES as an add-on to pulmonary rehabilitation did not result in further improvements in subjects with severe to very severe COPD; moreover, it might have been a burden for some patients.[58]

If NMES is recommended for home-based use, the patients and caregivers should be educated about the application. The physiotherapist should provide information about the risks that may occur during use and monitors the patients regularly.

Functional Electrical Stimulation (FES) in Patients with COPD

FES cycling was developed at the end of the 1980s. Since then, it has been used increasingly in patients with neurological disorders.[59] The principle of FES cycling is to electrically stimulate one or several muscle groups during an active or passive task synchronized by a computer.[60] It has been proposed as an alternative or complement to voluntary exercise for patients with neurological disorders and optimizes training and improve muscle strength and cardiovascular capacity.[61]

FES cycling can effectively increase exercise intensity in patients with COPD in short-term. Further studies should evaluate longer-term FES-cycling rehabilitation programs.[62] In the intervention, electrodes are positioned at each extremity of both Quadriceps Femoris muscles. A rectangular pulsed biphasic current is used and the intensity is modulated to obtain a palpable muscle contraction. The other electrical stimulation parameters can be identical for all patients (phase duration: 300 μs, frequency: 35 Hz). These settings are based on the usual electrostimulation protocols. During cycling, a computer controls the stimulator. The software ensures that muscle contractions are induced at the appropriate pedal angles during knee extension. Following a 2-minute warm-up, the load can be increased to reach the training load determined during the initial exercise test. The patients cycle at a frequency of 50-60 rotations per minute for 30 minutes.[63]

Magnetic Field Therapy in Patients with COPD

Very few investigations have been conducted to explore the effectiveness of magnetic field stimulation in patients with COPD. It seems that there is an increasing space for magnetic field stimulation as a therapeutic option in patients with COPD, mainly to counteract muscular depletion. Most relevant studies have been published in the field of muscular rehabilitation rather than that of the respiratory system. Magnetic field stimulation represents a feasible, well-tolerated, safe therapeutic option, for the treatment of motor-related COPD symptoms. There was no standard treatment protocol. It should be investigated in which groups of patients with COPD (and at which stage) can benefit most from magnetic field stimulation treatment and indicated more precisely the fields and modalities of applications of this therapy.[64]

Bustamante et al. investigated the effects of Quadriceps Femoris muscle magnetic field stimulation in severe patients with COPD.[65] In the study, there were two groups: in the control group the patients with COPD followed clinical monitoring, while in the treatment group, they underwent stimulation of the Quadriceps Femoris of both lower limbs. In the study, magnetic field stimulation was

applied in 15 min sessions, with the intensity and frequency of stimulation adjusted according to the patient's tolerance. In severe patients with COPD, magnetic field stimulation was a well-tolerated therapeutic intervention, which did not enhance muscle oxidative stress while increasing the size of slow-twitch fibers.

Transcutaneous Electrical Stimulation (TENS) in Patients with COPD

TENS is a method of electrical stimulation that primarily aims to provide symptomatic pain relief by exciting sensory nerves and thereby stimulating either the pain gate mechanism and/or the opioid system. The different methods of applying TENS relate to these different physiological mechanisms.[66,67]

As mentioned, dyspnea is the main factor limiting exercise tolerance in individuals with COPD. If dyspnea is reduced, physical activity may increase. It has been shown that a single session of acupuncture-type TENS on acupuncture points (frequency 4 Hz, pulse duration 200 μs, maximum tolerable intensity that does not cause discomfort, 45 minutes) increases the FEV1 level and reduces dyspnea in patients with COPD.[68] In stable patients with COPD, acupuncture-type TENS demonstrated an increase in FEV1 and 6-min walking distance with a significant reduction in desaturation during the 6-Min Walk Test. It has been reported that these changes are accompanied by improvements in psychosocial status and an increase in beta-endorphin levels. It has been hypothesized that acupuncture-type TENS provides bronchodilation by increasing the level of beta-endorphins. Considering these studies, TENS can be used as an adjunctive treatment approach in home-based pulmonary rehabilitation programs and can be applied before outdoor activities or exercise to maximize the educational effect.[69].

Conclusion

In this section, the purpose of electrical stimulation used for patients with COPD, application methods, and literature studies are discussed. NMES, FES, magnetic field therapy, and TENS contribute to other therapeutic interventions within the scope of pulmonary rehabilitation with their beneficial effects such as improving peripheral muscle strength and functional capacity without causing the metabolic load. The electrical stimulation interventions can be used in stable patients with COPD and acute exacerbation stage of COPD. Further studies can be conducted on COPD and other cardiopulmonary system diseases to determine the effect of electrical stimulation.[70,71]

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Electrical Stimulation for Patients With Scoliosis

ZELİHA OZLEM YURUK

Introduction

In a healthy spine, all vertebrae from C1 to L5 align in a neutral position in the frontal plane. Scoliosis is a complex, three-dimensional deformity of the spine that comprises a lateral curvature in the frontal plane, thoracic lordosis in the sagittal plane, and a posterior rib hump, which is produced by rotation of the vertebrae in the transverse plane. These results in posterior elevation of the rib cage on the convex side of the curve and a depression on the concave side. The alignment disorder of the spine was first described by Hippocrates. Galen used the "scoliosis" term for the curvature of the spine.[1]

Scoliosis can be classified according to etiology, localization, curve pattern, angle, functional and structural changes, and age.[2] Scoliosis is usually seen in the thoracic or lumbar region. It is classified as C or S scoliosis according to its pattern. Scoliosis is divided into functional and structural types. Postural, compensatory, nerve root irritation, inflammatory, or hysterical problems may cause functional scoliosis. In functional scoliosis, changes in the spine are reversible. Structural scoliosis is irreversible lateral curvature and rotation of the spine. Structural scoliosis is classified as idiopathic, congenital, neuromuscular, traumatic, or tumor-origin scoliosis. Most cases of scoliosis (80% to 90%) are idiopathic. According to age, it is divided into infantile, juvenile, and adolescent. The most common form of scoliosis is adolescent idiopathic scoliosis, which appears in late childhood or adolescence.[3]

Early diagnosis and treatment are essential for scoliosis.[4] As the condition is most often painless, early diagnosis is difficult, especially in countries where school scoliosis screening is not implemented. External change to the body shape is minimal in the early stages, and most changes in back shape occur predominantly on the back of the trunk, which is difficult for patients to see and can be concealed by clothing.[5]

The consequences of scoliosis are:[6,7]

- Altered spinal mechanics and degenerative changes.
- Pain.
- The loss of spinal mobility.
- The loss of function or disability.
- Cardiac and respiratory dysfunction.
- Psychological problems.

Various treatment methods have been used for the treatment of scoliosis since ancient times. Scoliosis management includes conservative treatment and surgical procedures. The treatment program should be individualized according to the patient assessment and the progression of the curvature.

The main goals of treatment are to:[3,6]

- correct the deformity,
- limit or stop the curvature progression,
- restore trunk symmetry and balance,
- minimize pain,
- avoid cardiopulmonary complications,
- prevent the long-term consequences of the deformity.

The clinician decides the treatment approach by considering the progression, localization, and the pattern of scoliosis. The individual's cosmetic appearance and social factors should also be considered during the decision-making process.[8] Patients with a curvature below 20^0 are re-assessed at 6-12 months intervals. Conservative treatments are prescribed above 20^0 of curvature. If the curvature is above 40^0, surgery is recommended.[9]

Conservative management includes scoliosis-specific exercises, bracing, neuromuscular electrical stimulation (NMES), manual therapy, and activities of daily living modifications.[3] The evidence of these treatments is unclear.[6,10] Scoliosis is a three-dimensional deformity, so treatment should also be considered in three dimensions. Schroth, Lyon, Scientific Exercise Approach to Scoliosis, Dobosiewicz, Side Shift, Barcelona School of Scoliosis, and Functional Individual Therapy of Scoliosis are the most known treatment approaches.[11] A spinal brace may slow the progression rate of the curve but also cause skin irritation, rashes, and decreased physical activity. It also adversely affects self-concepts and body image.[12] NMES is a traditional method used in the treatment of scoliosis. In this chapter, the effects of NMES in the treatment of scoliosis, the NMES protocols used from the past to the present, and the level of evidence are explained.

Patient Evaluation

Before the clinical decision-making for the physiotherapy and rehabilitation program and NMES, a detailed patient assessment is essential. Posture, range of motion, muscle strength, flexibility, pain, and respiratory function should be assessed in patients with scoliosis. Scoliosis-specific evaluations should also be performed with standard physiotherapy and rehabilitation assessment. Radiological evaluation (Cobb angle), Adam's test, Tanner and Risser Sign, and Scoliometer can be used.[13]

Neuromuscular Electrical Stimulation (NMES) in Patients with Scoliosis

The Aim and Effects of NMES in Patients with Scoliosis

The aims of the NMES in patients with scoliosis are to:[14-18]

- limit or stop the curvature progression,
- strengthen paraspinal muscles,
- maintain a balance between muscle groups,
- restore trunk symmetry and balance.

A progress can be observed on patients that are having 20^0-29^0 curves. Patients having curves of 30^0-39^0 at the beginning and skeletally immature individuals (Risser sign 0 or 1) are suitable for NMES. NMES is not used for curvatures above 40^0. In the studies, NMES was used alone for at least 8 hours at night in the long term.[19]

Curtin and Lowery used biomechanical modeling and computational optimization to investigate muscle activation in combination with applied external forces as a treatment of scoliosis.[20] The results indicated that superficial muscle activation on the convex side of the curve provides the best corrective results, supporting previous in vivo stimulation studies for NMES.

Grimby et al. applied 30 Hertz (Hz) frequency long-term NMES at the posterior axillary line on the convex side of the curvature to correct the spinal deformity.[21] The patients were followed up with muscle biopsies taken from the Latissimus Dorsi muscle of the stimulated side before NMES and after 3 and 6 months NMES application. There was a tendency for an increase in the percentage of type I and especially type IIc (undifferentiated) fibers after stimulation. The mean muscle fiber area and fiber areas of the various fiber types did not change significantly. Histopathological findings were generally rare before as well as after 3 months of NMES, the only noticeable finding being a somewhat increased frequency of atrophic fibers in groups after 6 months of stimulation. In all patients, the enzymatic activity of citrate synthase increased after 3 months and further in three pa-

tients after 6 months of NMES. This study provided some evidence of an adaptive process caused by electrical stimulation toward a more fatigue-resistant muscle.

In early studies, it was shown that NMES was effective on scoliosis.[16] However, these studies included immature and a small number of mature patients still under treatment. Recent studies showed that NMES was ineffective in slowing the rate of progression or decreasing the curve.[10] It has been concluded that the effect of NMES is consistent with the natural progression of the disease.[22]

NMES was used for a long duration in early studies. Kowalski et al. investigated the effects of long-term NMES in an animal model.[23] The authors applied NMES to rabbit Supraspinal muscles at 9 hours per day for 3 months. In comparison to the control animals, the muscles of "overstimulated" rabbits exhibited clear signs of microscopically lesions, including depletion and disintegration of myofilaments, proliferation, dilatation, swelling of the sarcoplasmic reticulum, and mitochondria, as well as signs of the destruction of the Z line. The degenerative processes associated with the Z line and the observed microlesions strongly suggest that the failure of the long-term NMES therapy of scoliosis may be attributable to these ultrastructural lesions. In recent years, studies showing the effect of short duration (1 hour) NMES combined with other conservative methods have been published.[18,24]

NMES Protocol

NMES parameters are varied in the literature. However, a general outline of the NMES protocol is shared. After the initial assessment, the family and the patient should be informed about the purpose and process of the treatment. Introducing the electrode and stimulator before administration, may increase the patient's compliance. The stimulator could be given to the parents for home use. Therapists should re-evaluate the patients subsequently at 3-4 months intervals.[19]

NMES parameters could be arranged with a dual channel unit that delivers trains of rectangular, alternating current pulses with a stimulation duration of 150-400 microseconds (μs), a frequency of 25-100 Hz, and 3:3, 6:6, or 5:25 on/off period. The amplitude of the stimulus is slowly increased until the acceptable level [50-70 miliamperes (mA)]. It is recommended to have a variable amount of visible contraction and to be increased up to the patient's maximum tolerance. The duration of the sessions is 1 hour (in recent literature) or above 8 hours at night (in past literature). The total treatment duration varied between the patients. The treatment duration is between 3 months to 2 years.[18,25,26]

NMES can be used paravertebrally with both electrodes on the convexity of the curve. If the curve is an S-pattern, 4 electrodes are used.[25] The electrodes are placed symmetrically to the apex of the curve by avoiding stimulation toward the concavity of the compensatory curves and undesirable stimulation of the shoulder girdle. The distance between the electrodes depends on the curve and trunk size. The electrodes must remain within the boundaries of curvature.

NMES can reduce primer and compensatory spinal curvature in the frontal and sagittal planes. Electrode placement over the lateral trunk muscles rather than on the paraspinal muscles can cause progression of scoliosis. This is called lateral electrical surface stimulation. The amount of curvature is determined by the length of the skeletal lever arms (ribs in the thoracic region, rib cage, and pelvis in the lumbar region). The electrodes can be placed in the lateral trunk muscles for scoliosis, paravertebral muscles for kyphosis, and Rectus Abdominus muscle for lordosis.[16] The physiotherapist should explain and show landmarks (bone prominences etc.) to parents for electrode placement for home use.

Because the treatment duration is so long, skin irritation and contact eczema can be triggered with NMES application. If these side effects occur, the physiotherapist should give a break to the treatment.[27]

Clinical Evidence of NMES

Most studies investigating the effect of NMES in the treatment of scoliosis have been conducted in the past years. The number of recent studies is very few. In a Cochrane review, the authors iden-

Table 20.1 Parameter settings for NMES in patients with scoliosis.[16,18,19,25]

Current type/waveform	Pulsed alternating current / rectangular symmetrical biphasic
Pulse/cycle duration	150-400 μs
Amplitude	Maximum tolerable/50-70 mA
Pulse rate (Frequency)	25-100 Hz
Ramp up/ramp down	As tolerated, 1-5 /1-5 seconds (s)
On time (Duty cycle)	3-6 s
Off time	3-25 s
Modulation	None
Treatment duration	1 hour (in recent literature) At least 8 hours at night during sleeping (in past literature)
Frequency of sessions	7 times/week, 3 months-2 years
Polarity	None
Electrode placement	Convex side of the curve One channel for C scoliosis; 2 channels for S scoliosis Lateral trunk muscles for scoliosis, paravertebral muscles for kyphosis, and Rectus Abdominus muscle for lordosis.

tified no evidence examining the effectiveness of surgical interventions compared with nonsurgical interventions for people with idiopathic scoliosis. As a result, they could not draw any conclusions regarding the benefits or harms of these treatments.[6] Similar to other conservative treatments for scoliosis, there is insufficient evidence for NMES. Early studies from Axelgaard et al. found that NMES had effects on the progression of the curve.[16] After 1980s, studies showed that the effects of NMES was consistent with the natural progression of the disease.[10,22,28]

In a study conducted by the Scoliosis Research Society, 159 girls with a mean age of 13 years (10 to 15 years) who had adolescent idiopathic scoliosis were followed prospectively until skeletal maturity or until the curve had increased to 60^0 or more. All patients had an initial curve of 25^0 to 35^0 and an apical level between the eighth thoracic and first lumbar vertebrae. Of the 159 patients, 120 were observed without treatment and 32 were managed with lateral electrical surface stimulation. The curve progressed at least 6^0 in 80 patients. There was no obvious difference in the outcome between the patients who were managed with observation or NMES.[10]

Scoliosis is a complicated problem for children with severe cerebral palsy (CP). In CP, they do not have many options for treatment and scoliosis is usually refractory. In a recent study by Ko et al. evaluated the effects of lateral electrical surface stimulation on scoliosis and trunk balance in children with severe CP.[18] The 11 children with severe CP and stationary or progressive scoliosis were enrolled. NMES was applied 2 sessions per day, 1 hour/session, for 3 months at home. The parameters were set at 40-80 milliamperes (mA) intensity, 200 μs pulse width, 25 Hz frequency, "on" for 6 s and then "off" for 6 s. Two electrodes were placed on the convex side of the trunk, symmetrically above and below the point directly lateral to the apical vertebra at the mid axillary line on the convex side of the curve, and the other 2 electrodes were placed in the midline between the center of the spine. Radiological assessment, Gross Motor Function Measurement sitting score, and Trunk Control Measurement Scale were evaluated at 4 periods (3 months before, just before, 1 month after, and 3 months after lateral electrical surface stimulation. The median Cobb's angle of 11 children (median age, 9 years) was 25^0, and it showed significant improvements after 1 and 3 months of NMES application. NMES improved trunk balance. The authors concluded that lateral electrical surface stimulation may be an option for managing stationary or progressive scoliosis in children with severe CP who are unable to undergo surgery.

The Cochrane review conducted in 2010 showed that it was not possible to evaluate the efficacy of NMES. Because it is not possible to conduct randomized controlled studies on scoliosis.[9] In past studies, NMES was used as a single treatment method for patients. At present, the results of some studies showed that if NMES is combined with exercise or a brace, it may be more effective.[23,29]

Some researchers compared NMES with different conservative approaches. There are few low-quality studies resulting in a moderate level of evidence supporting that brace treatment is more effective than NMES in preventing the progression of the curve in patients with adolescent idiopathic scoliosis. In addition, there is conflicting evidence that brace treatment negatively affects the quality of life of adolescent idiopathic scoliosis patients compared with NMES.[30]

Some studies claimed that NMES is a viable alternative to bracing and proponents have argued psychological and physical freedom as a major advantage of NMES over brace treatment.[31] Fisher et al. compared 3-years results of NMES with the Milwaukee brace for the treatment of idiopathic scoliosis.[32] Fifty patients in each group were compared retrospectively and matched for age, sex, Risser sign, and curve morphology. Evaluations were performed at 6-month intervals with radiographs and examinations. No significant differences were found in the rates of curve progression or failure. Overall, 70% of the patients in each group were successfully maintained over the course of 3 years. The NMES might be comparable to the Milwaukee brace in managing idiopathic scoliosis. On the controversy, some studies pointed out that conventional rigid orthotic intervention seemed to be more effective than NMES.[12,33]

Conclusion

In this chapter, the purpose of NMES in patients with scoliosis, application methods, and literature studies are discussed. The NMES can be used in progressive idiopathic curves of 20^0-39^0. Although beneficial effects were reported for NMES in primary studies, the clinical evidence of NMES in scoliosis is inconclusive. In past studies, NMES was used for a long time, and it seems impractical. In light of current knowledge, it may be possible to use it combined with other conservative treatment methods for a short period. Further studies should be planned on scoliosis to determine the effects of NMES.

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Electrical Stimulation for Patients With Disuse Atrophy

ZELİHA OZLEM YURUK

Introduction

Skeletal muscle is a crucial tissue for movement, metabolic homeostasis, and thermogenesis. It makes up approximately 40% of the total body weight and 50% of the total protein. Muscle atrophy is characterized by weakening, shrinking, and decreasing muscle mass and fiber cross-sectional area at the histological level because of immobility, aging, malnutrition, medications, or a wide range of injuries or diseases. Muscle atrophy results from an imbalance between protein synthesis and protein degradation, although the mechanisms are incompletely understood and vary depending on the cause. It manifests as a reduction in force production, easy fatigue, and decreased exercise capability, along with a lower quality of life.[1]

Disuse atrophy is a common cause of muscle atrophy and can be local (due to injury or bracing) or general (bed rest). The rate of muscle atrophy from disuse (10-42 days) is approximately 0.5–0.6% of total muscle mass per day, although there is considerable variation between people. Prolonged disuse (>10 days), in which the muscle is compromised primarily by declines in muscle protein synthesis rates rather than changes in muscle protein breakdown, was investigated in most research. Evidences suggest that more active protein breakdown occurs during short-term immobility (<10 days). The duration of immobilization, age, and general health state of the individual are also important factors for the loss of muscle mass.[2]

Bed rest is frequently prescribed for critically ill patients because it is assumed to be beneficial for preventing complications, conserving metabolic resources, and providing patient comfort. Furthermore, higher levels of physical activity in critically ill patients are assumed to be impractical or not feasible. Bed rest is prescribed for several clinical conditions, including after surgery, acute flares of rheumatoid arthritis, tuberculosis, acute myocardial infarction, and acute low back pain. Bed rest can cause several complications, including disuse atrophy, joint contractures, thromboembolic disease, insulin resistance, microvascular dysfunction, systemic inflammation, atelectasis, and pressure ulcers.[3]

Local immobilization is generally induced by casting or bracing, which isolates muscle disuse in a single muscle or muscle group. Bed rest causes a greater decrement in muscle mass than local immobilization due to systemic factors. This demonstrates that interventional strategies should not only focus on preventing muscle loss during a period of disuse but also aim to attenuate the decline in metabolic health that occurs during disuse in a bed rest model.[4]

The two key anabolic stimuli for skeletal muscle tissue are muscle contraction and food intake.[4] Muscle atrophy can be delayed, prevented, and sometimes reversed with treatment. Physical ac-

tivity, exercise, and electrical stimulation (ES) are used in physiotherapy and rehabilitation programs for patients with disuse atrophy. The physical activity can already preserve skeletal muscle mass and strength during a period of disuse. However, an increase in voluntary physical activity is not realistic due to limb immobilization or general weakness. ES is an optimal safe approach instead of physical activity.[4,5]

Patient Evaluation

Before clinical decision-making for the physiotherapy and rehabilitation program and ES physical examination is essential. The content of the physiotherapist's assessment may vary from individual to individual and setting to setting. Firstly, a review of the medical record can help to identify the patient's medical history and precautions. Physiotherapists evaluate muscle strength, range of motion, anthropometric properties, endurance, posture, fatigue, and pain in patients with disuse atrophy. Functional tests (balance, gait, etc.) are also performed for recovery. Also, it is necessary to learn the patient's previous medical condition for contraindications of ES.[6]

Electrical Stimulation for Patients with Disuse Atrophy

Aim and Effects of ES in Patients with Disuse Atrophy

ES has effects on tissue level and clinical function level in disuse atrophy.[4] Neuromuscular Electrical Stimulation (NMES), Functional Electrical Stimulation (FES), and Magnetic Field Stimulation can be used for patients with disuse atrophy.

Effects of ES at the Tissue Level

Muscle contraction is one of the more potential stimuli that can increase muscle protein synthesis.[7] Although performing voluntary physical activity is undoubtedly the most effective intervention to preserve muscle mass, it is often impossible to maintain a certain level of voluntary physical activity during periods of forced bed rest or limb immobilization.[8] In such clinical conditions, NMES could be applied to induce contractions and stimulate muscle anabolism.[4] A single session of high-frequency and high-intensity acute application of NMES has been demonstrated to increase muscle protein synthesis by 27%.[9] This positive effect of NMES on muscle protein synthesis rates translated to preservation of muscle mass during 5 days of leg immobilization in healthy, young individuals.[4] However, this was not accompanied by any beneficial effects on muscle strength. This result is in line with other studies that demonstrated the efficacy of NMES in preventing muscle loss in various clinical conditions.[10-13] Importantly, these findings also support the use of NMES in intensive care unit (ICU) patients.[14] NMES can increase muscle protein synthesis rates in the elderly and basal phosphorylation in ICU patients.[4,9] It was shown that NMES could also suppress muscle protein breakdown.[15,16] These data underline the effectiveness of NMES in disuse settings.

Although NMES is clearly an effective tool for attenuating disuse atrophy, little information is available on how it can be effectively applied.[4] To specify its impact on skeletal muscle tissue, the long-term effect of high-frequency (>50 Hertz-Hz) NMES has been investigated in a fiber type-specific manner.[17] Increases in both type I and II muscle fiber size have been observed in healthy individuals and patients following multiple sessions of NMES training.[18,19]

Although it is clear that high-frequency NMES exerts its greatest effect on type II fibers, there is a discrepancy as to whether this is located predominantly in type IIa or type IIb fibers.[20,21] In situations of muscle disuse and critical illness, it has been shown that NMES leads to a relatively greater impact upon type II muscle fiber size compared with type I muscle fiber size.[14] The specific effect of NMES on type II fibers may be due at least partly to their more superficial location than type I fibers, making them more sensitive to the stimulus from surface electrodes.[22] This makes NMES a highly relevant interventional strategy in various situations where individuals suffer from predominant type

II muscle fiber atrophy, such as following injury and during immobilization, critical illness, or aging.[14,23-25]

Many researchers have examined the efficacy of NMES on one specific muscle. An important next step would be to target multiple muscle groups to maximize the relevance of applying NMES in clinical practice. Although the Quadriceps Femoris muscle is one of the most susceptible muscles to atrophy, large muscle groups such as the Hamstring, Gastrocnemius, and back muscles would likely benefit from treatment with NMES.[26]

Electromagnetic field stimulation produces the stimulus at a deep level, avoiding skin sensation. Therefore, the use of repetitive magnetic stimulation of muscle is increasing. An experimental study showed that magnetic field stimulation prevented atrophy resulting from 6 weeks of immobility in rats.[27]

Effects of ES at the Functional Level

Although NMES has short-term effects at the tissue level, it also impacts metabolic health and functional capacity in the long term. NMES was applied intermittently to the knee extensor muscles of 7 patients with congestive heart failure (mean ejection fraction of 20%) for 8 weeks. The peak torque of the knee extensor muscles increased significantly by 13%, and maximal isometric force increased significantly by 20%.[28] Similar effects on Quadriceps Femoris muscle function were obtained in patients with severe chronic obstructive pulmonary disease. There were also improvements in exercise capacity.[29] NMES can regulate peripheral circulation, prevent atrophy by reducing muscle protein breakdown, and prevent weakness associated with ICU.[30] As a result, NMES is a useful training method for patients with disuse atrophy due to limb or bed rest immobilization.

Magnetic field stimulation also has clinical effects on critically ill patients. The magnetic stimulation of the Quadriceps Femoris was found to be a feasible training method for the lower limbs, with positive effects on muscle function and effort capacity.[31] FES cycling in bed is an option for bed rest patients. However, the potential effects of FES have not been shown.[32]

ES Protocol for Disuse Atrophy

NMES for Bed Rest Immobilization (General Immobilization)

NMES parameters can be determined according to the specific needs and reactions of each patient rather than establishing a uniform protocol.[33] However, a general outline of the NMES protocol is shared. The treatment is directed to lower extremity muscles during bed rest.

In NMES, Russian current, High Voltage Pulsed Galvanic Stimulation (HVPGS), or Faradic current can be preferred. It is recommended to prefer biphasic, symmetrical/asymmetrical, or twin peak waveforms in 30 and 80 Hz frequency ranges, with a stimulation duration between 100 and 600 microseconds (μs). In the NMES application, high repetitive muscle contraction is considered. After contractions, intervals are adjusted according to the patient's fatigue level. The obtained data emphasize the determination of the most appropriate contraction and relaxation rates for the patient without causing excessive fatigue in the muscles.[21]

It is recommended to have a variable amount of visible but clear contraction and to be increased up to the patient's maximum tolerance.[33] The total treatment duration varied due to the immobilization period. However, 4-8 weeks are required for muscle strengthening. It has been reported that the frequency of treatment can vary between 3 and 5 per week, and the duration of a treatment session can vary between 15 and 60 minutes (min).[6]

Electrode placement is decided according to the muscles to be stimulated. Electrodes are placed parallel to the fibers of the limb muscles. Stimulation can be performed unilaterally or bilaterally. The therapists use 2 (1 channel) or 4 (2 channels) electrodes (Figure 21.1 and Figure 21.2).[33]

Table 21.1 represents the recommended parameters for muscle strengthening and improving circulation in patients with disuse atrophy. Table 21.2 shows the recommended parameters for improving muscle endurance in patients with disuse atrophy.

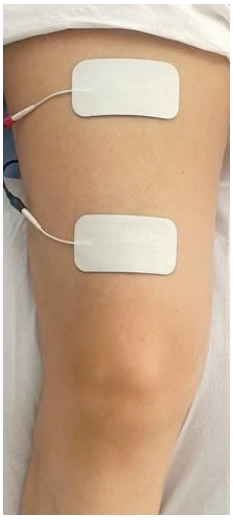

Figure 21.1 Quadriceps Femoris NMES.

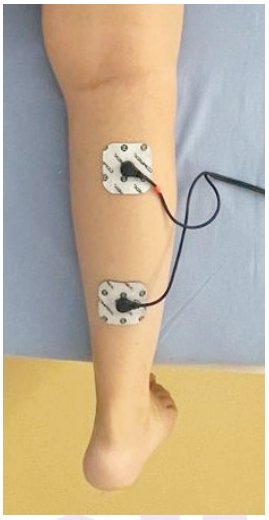

Figure 21.2 Gastrocnemius NMES.

Table 21.1 Parameter settings of NMES for muscle strengthening and improving circulation in patients with disuse atrophy. [6,33]

Current type/ waveform	Pulsatile or burst modulated alternating current/symmetrical biphasic or asymmetrical biphasic Twin peak monophasic
Pulse/cycle duration	100-600 μs
Amplitude	Maximum tolerable/ ≥50% maximum voluntary isometric contraction (MVIC) (healthy muscles) ≥10% MVIC (weakened muscles)
Pulse rate (Frequency)	30-80 Hz
Ramp up/ramp down	As tolerated, 1-5 /1-5 seconds (s)
On time (Duty cycle)	2-10 s
Off time	5-60 s
Modulation	None
Treatment duration	15-60 min
Frequency of sessions	3-5 times/week, 4-8 weeks
Polarity	None
Electrode placement	2 (1 channel)-small muscles; 4 (2 channels) for larger muscles; parallel to fibers Lower extremity muscles Bilaterally/unilaterally

Table 21.2 Parameter settings of NMES for muscular endurance training in patients with COPD. [6,19]

Current type/ waveform	Pulsatile or burst modulated alternating current/symmetrical biphasic or asymmetrical biphasic Twin peak monophasic
Pulse/cycle duration	100-600 μs
Amplitude	Comfortable or maximum tolerable contraction/ 25-50% MVIC
Frequency	30-80 Hz
Ramp up/ramp down	As tolerated, 1-5 s/1-5 s
On time (Duty cycle)	5-15 s
Off time	5-15 s
Modulation	None
Stimulation duration	15-30 min
Frequency of sessions	3-5 times/week, 6-8 weeks
Polarity	None
Electrode placement	2 (1 channel)-small muscles; 4 (2 channels) for larger muscles; parallel to fibers Lower extremity muscles Bilaterally/unilaterally

NMES for Limb Immobilization (Local Immobilization)

NMES can prevent bone and cartilage deterioration in short-term brace-immobilized limbs of rabbits.[34] NMES also prevents muscle atrophy during the bracing period in humans. The stimulation protocol is the same for bed-rest patients. However, it is necessary to open windows over the appropriate areas of the brace to assess electrode placement. A pen electrode should be used as an active electrode. A larger passive electrode should be placed near the cast or brace. NMES can be performed 2-5 days a week during the immobilization period. Since pressure over bony prominences will occur during the NMES, care must be taken with casting techniques before combining NMES and casting.[35]

FES for Disuse Atrophy

FES cycling in bed is used as an alternative stimulation technique combined with exercise. In the intervention, 4 electrodes are positioned at each extremity of both Quadriceps Femoris muscles. A rectangular pulsed biphasic current is used, and the intensity is modulated to obtain a palpable muscle contraction. The other ES parameters can be identical for all patients (phase duration: 300 µs, frequency: 35 Hz). These settings are based on the usual ES protocols. During cycling, a computer controls the stimulator. The software ensures that muscle contractions are induced at the appropriate pedal angles during the knee extension. Following a 2 min warm-up, the load can be increased according to the patient's tolerance. The patients cycled at a frequency of 50-60 rotations per minute for 20 min. FES cycling can be performed 7 days a week.[32] Table 21.3 shows the recommended FES parameters.

Magnetic Field Stimulation for Disuse Atrophy

There are a few studies on magnetic field stimulation for disuse atrophy. Therefore, generalizability of the protocol is not possible. In the stimulation, the coils are applied at the point between the upper third and the lower two-thirds of the Vastus Lateralis, the optimum location for eliciting a contraction response. The intensity and frequency of stimulation are adjusted according to the patient's tolerance and the performance of the equipment. Stimulation follows a cyclical pattern of 2 s on, with contraction elicited by a burst of twitches, and 4 s off, repeat over a period of 15 min on each thigh. Stimulation can be performed at 1.5-2 millitesla (mT) capacity and 15-40 Hz frequency. [27,31]

Table 21.3 Parameter settings of FES for patients with COPD.[32,33]

Current type/ waveform	Pulsatile or burst modulated alternating current/symmetrical biphasic or asymmetrical biphasic
Pulse/cycle duration	100-600 µs (50% duty cycle)
Amplitude	Comfortable or maximum palpable contraction/ 25-50% MVIC
Frequency	30-50 Hz
Ramp up/ramp down	1 s
On time (Duty cycle)	Activity specific
Off time	Activity specific
Modulation	None
Stimulation duration	20-30 min
Frequency of sessions	3-7 times/week, 6-8 weeks
Polarity	None
Electrode placement	4 electrodes (2 channels) on Quadriceps Femoris muscle, bilaterally

Clinical Evidence of ES

ES to prevent or reverse disuse atrophy has been assessed in several clinical studies. The results are variable because of variability in the progression of the disease, differences in techniques for applying ES, and differences in how the effects of ES were assessed.[4]

NMES in Patients with Disuse Atrophy

NMES After Knee Surgery

Following the anterior cruciate ligament (ACL) reconstruction, restricted weight-bearing and immobilization result in thigh and calf muscle atrophy

and weakness. Hasegawa et al. assessed the effect of NMES on the prevention of muscle atrophy in patients during the early rehabilitation stage after ACL reconstruction.[36] Twenty patients with acute ACL tears were randomly divided into two groups. The control group participated in only the usual physiotherapy and rehabilitation program. In addition to this protocol, the NMES group received a 20 Hz exponential pulse from the 2nd post-operative day to 4 weeks after the surgery. The results showed that NMES implemented during the early rehabilitation stage is effective in maintaining and increasing muscle thickness and strength in the operated limb.[36]

The recovery of Quadriceps Femoris muscle strength and function after total knee arthroplasty (TKA) is suboptimal, which predisposes patients to disability with increasing age. Stevens-Lapsley et al. evaluated the efficacy of NMES initiated 48 hours after TKA as an adjunct to standard physiotherapy and rehabilitation program.[37] The NMES was applied twice per day at the maximum tolerable intensity for 15 contractions. The early addition of NMES effectively attenuated the loss of Quadriceps Femoris muscle strength and improved functional performance following TKA. The effects were most pronounced and clinically meaningful within the first month after surgery but persisted through 1 year after surgery.[37]

NMES in Advanced Diseases

Patients with advanced progressive disease often experience muscle weakness, which can adversely impact their ability to be independent and their quality of life. In those patients who are unable or unwilling to undertake whole-body exercise, NMES is acceptable to patients and has led to improvements in muscle function, exercise capacity, and quality of life.[6]

It has been shown that NMES improves endurance, muscle strength, and cross-sectional area of thigh muscles in patients with chronic heart failure. Therefore, NMES is an effective option for "passive" exercise.[38] In people admitted to either an ICU or a respiratory high-dependency unit, NMES combined with conventional exercise may accelerate the attainment of a functional milestone. Therefore, it is likely that the addition of NMES strength protocol to a program of exercise will be of most benefit to people who are experiencing or recovering from an exacerbation. Regardless of whether it was applied alone or together with conventional exercise training, NMES appears not to increase the risk of adverse events.[39] A Cochrane review showed that NMES is a promising method for advanced disease. However, the authors concluded that the effectiveness of NMES based on individual studies lacks power and precision.[6]

NMES for Prevention of Venous Thromboembolism

The formation of unwanted blood clots in the deep veins of the legs is a serious and potentially fatal health problem because blood clots in the legs can travel to the lungs and cause death. Unwanted blood clots in the legs can occur as the result of reduced mobility, increased tendency for blood clotting, and other factors. NMES is thought to be effective as a mechanical method of preventing blood clots in the legs. A Cochrane review aimed to identify available evidence on the effectiveness of NMES compared with other methods in preventing the formation of unwanted blood clots. Evidence shows no clear difference in the risk of deep vein thrombosis (DVT) between NMES and alternative methods of prophylaxis but suggests that NMES may be associated with a lower risk of DVT compared with no prophylaxis and a higher risk of DVT compared with low-dose heparin.[40]

NMES in Geriatrics

Reidy et al. studied the effect of NMES and protein supplementation in elderly individuals who were taken to full bed rest for 5 days.[41] In the study, NMES was applied bilaterally to the Quadriceps Femoris muscle 3 times a day for 40 min. The authors found that NMES could prevent muscle mass but could not prevent function loss. Although NMES and protein supplementation are effective in preserving muscle mass in elderly individuals receiving inpatient care, physical activity is required for the continuation of function.

FES in Patients with Disuse Atrophy

FES cycling was developed at the end of the 1980s. Since then, it has been used increasingly in patients with neurological disorders.[42] The principle of FES cycling is to electrically stimulate one or several muscle groups during an active or passive task synchronized by a computer.[43] It has been proposed as an alternative or complement to voluntary exercise for patients with neurological disorders and optimizes training and improves muscle strength and cardiovascular capacity.[44]

In a randomized controlled trial, the effects of FES-assisted cycle therapy for mechanically ventilated adults in the ICU were investigated. A hundred and fifty patients received FES-assisted cycle or standard therapies. The authors reported that FES-assisted cycle therapy did not improve physical disability 6 months after surviving critical illness in mechanically ventilated patients with anticipated long ICU stays. They noted that, at ICU discharge, there were no differences in the ICU length of stay or functional performance.[45] Fossat et al. investigated FES cycling added to standardized early rehabilitation would result in greater muscle strength at discharge from the ICU in a single center-blinded randomized controlled trial enrolling 314 critically ill adult patients.[32] Patients were randomized to early in-bed leg cycling plus ES of the Quadriceps Femoris muscles added to standardized early rehabilitation or standardized early rehabilitation alone. There were no significant differences between the groups at 6 months. The authors concluded that the early FES cycling program did not improve global muscle strength at discharge from the ICU.[32]

Magnetic Field Therapy in Patients with Disuse Atrophy

Magnetic field stimulation represents a feasible, well-tolerated, safe therapeutic option for different pathologies.[27] However, very few studies have investigated the effectiveness of magnetic field stimulation in patients with disuse atrophy. Bustamante et al. investigated the effects of Quadriceps Femoris muscle magnetic field stimulation in critically ill patients.[31] In the study, magnetic field stimulation was applied in 15 min sessions, with the intensity and frequency of stimulation adjusted according to the patient's tolerance. The authors found that magnetic field stimulation was a well-tolerated therapeutic intervention that did not enhance muscle oxidative stress, while increasing the size of slow-twitch fibers.

Conclusion

In this section, the purpose of ES for patients with disuse atrophy, application methods, and literature studies are discussed. NMES, FES, and magnetic field stimulation can be used for patients with disuse atrophy. NMES has beneficial effects on improving peripheral muscle strength and functional capacity without causing the metabolic load in individuals with disuse atrophy due to bed rest. However, the use of NMES for local limb immobilization is limited and has only been mentioned in early studies. The effects of FES and magnetic field stimulation are not clear for disuse atrophy. Because the number of studies is limited. Further studies can be conducted on disuse atrophy to determine the effects of ES.

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Strengthening of Healthy Muscles

DOVYDAS GEDRIMAS • VAIDA ALEKNAVIČIŪTĖ-ABLONSKĖ

Strengthening of Healthy Muscles

Neuromuscular electrical stimulation (NMES) involves the application of a series of intermittent stimuli to superficial skeletal muscles with the main objective to trigger visible muscle contractions due to the activation of intramuscular nerve branches. Electrical stimulation (ES) is generally delivered using one or more active electrodes positioned in proximity to the muscle motor points, and pre-programmed stimulation units. An intact motor nerve is a prerequisite for eliciting muscle contractions with NMES.[1]

Depending on the status of the muscle being stimulated, NMES can be used for the preservation of muscle mass and function during prolonged periods of disuse or immobilization, for the recovery of muscle mass and function following prolonged periods of disuse or immobilization, for the improvement of muscle function in different healthy populations: elderly subjects, adult subjects, recreational and competitive athletes, and also as a pre-operative strengthening modality, i.e. "pre-rehabilitation".[2]

Strengthening of Healthy Muscles in Adults

Usually, healthy muscle stimulation is performed in athletes or in rehabilitation settings to prevent disuse muscle atrophy or to supplement exercise programs for faster muscle mass and strength gains. It has been largely acknowledged that NMES is a relevant tool resulting in increased maximal isometric voluntary strength.[3]

In healthy subjects, adaptation of muscle physiology is observed when repeated ES is used, such as during muscle training. An increase occurs in the cross-sectional area of type I muscle fibers of the overall muscle group that was trained. This is associated with an increase in the amount of the IIa isoform of heavy chains of myosin and increases when voluntary contraction is combined with the stimulation. These alterations depend on the type of stimulation used and could be paralleled with improved maximal strength of the trained muscle and higher muscle electrical activity.[4]

Strengthening of Healthy Muscles in Athletes

There is a lot of evidence that electromyostimulation (ES of the muscle) has an impact on strength gains. In rugby players, for example, isolated stimulation of the Quadriceps Femoris, Gluteus Maximus and Triceps Surae muscles during a 12-week period led to a marked increase in the strength and power of these muscles.[5] In another study, the combination of ES and plyometric training improved the maximal strength of the Quadriceps Femoris, as well as vertical jump and sprint.[6] Because these gains are likely due to the intensity of the stimulation, it is extremely important to use comfortable currents. ES in healthy subjects and athletes looks more like a complement to classical strengthening

programs, particularly in combination with the simultaneous voluntary contraction. Its main advantages are increase in the muscle workload, as a complement to classical training, and inducement in a contraction pattern different from the pattern during voluntary contraction.[7]

Russian current can be used for muscle strengthening in athletes. The frequency used is 2.5 Hertz (Hz). Each burst of ES lasts for a short duration, usually 10-50 milliseconds (ms). The bursts are delivered in trains, with a frequency of around 50 bursts per second. The Russian current is usually applied with a duty cycle of 1:5 or 1:10, which means the stimulation is on for 5 seconds (s) and off for 25 s or on for 10 s and off for 50 s in each cycle. The amplitude or intensity of the ES should be set to a level that induces visible muscle contractions, but it should be comfortable and tolerable for the athlete.[8]

Strengthening of Healthy Muscles During the Limb Immobilization Period

Knees are usually immobilized after surgery or severe traumatic lesions, such as anterior cruciate ligament ruptures. In this situation, amyotrophy and strength loss appear rapidly in the Quadriceps Femoris muscle. Numerous clinicians use direct muscle stimulation to limit the appearance of these muscle changes and accelerate their return to normal functional levels. This technique is believed to help fight post-traumatic or post-surgery muscle sideration. ES is used during and/or after the immobilization period alone or is associated with voluntary muscle contraction.[9] The main result of stimulation is less reduction in muscle strength in patients receiving ES treatment during the disuse period.

Faradic current can be used during this period. Typically, low-frequency ES is used during limb immobilization. Frequencies in the range of 1 to 50 Hz are commonly employed. The pulse duration is usually set between 0,1-1 ms. The intensity of the ES should be adjusted to a level that induces muscle contractions. It should be strong enough to elicit muscle responses without causing discomfort or pain to the individual. Common duty cycles include 1:1 (equal on-off time) or 1:2 (stimulation on for 1 s, followed by 2 s off). The duration of each ES session can vary based on the specific treatment plan and individual needs. Sessions typically range from 15 to 60 minutes (min).[10]

Findings on the post-immobilization period show the positive effect of the stimulation for Quadriceps Femoris with a faster return to normal walking pattern after surgery. Moreover, ES combined with voluntary contractions (either at different times or simultaneously) seems more efficient than when used in isolation.[11] Thus, for traumatic and orthopedic problems of the lower limbs, ES seems to be useful in the first phase of treatment. This treatment helps to limit the amyotrophy and strength loss associated with the traumatism, surgery, and the following transitory segment immobilization.[4]

Strengthening of Healthy Muscles During Affections Leading to Cachexia and Extended Bed-Rest

Research shows the benefits of direct muscle ES during medical conditions [particularly cardiac insufficiency and chronic obstructive pulmonary disease (COPD)] associated with cachexia in its severe form. Cachexia is characterized in particular by diffuse amyotrophy and a major decrease in muscle force. Vivodtzev et al. emphasized the interest of associating muscle ES (Quadriceps Femoris muscle) with usual rehabilitation (slow gait training on treadmill and active limb mobilization) in COPD and malnourished patients.[11] In this randomized controlled study, patients who participated in such a program showed significant improvement in the strength of their Quadriceps Femoris muscle, walking distance, and body mass index. Moreover, a significant reduction in dyspnea was observed during daily living activities.[12]

In addition to the strength gain, ES has a positive effect on dyspnea, gait abilities, and exercise tolerance. Zanotti et al. also indicated a positive effect of muscle ES associated with active exercises on the duration of bed-rest time in patients with chronic respiratory insufficiency who needed mechanical ventilation.[12] In addition to the strength

gain measured in the stimulated muscles, aerobic capacity as well as quality of life improved, particularly in patients waiting for a heart transplant.[13]

Apart from pathologies, ES is also one of the tools commonly used by astronauts during microgravity flights to fight amyotrophy and loss of muscle strength.[4] In athletic training or pathology treatments, the programs that associate ES with voluntary muscle contractions (superimposed or combined ES) seem to have more effect than ES alone. Apart from its application in exercise traumatology or orthopedics, direct muscle ES could be an efficient tool to fight the reduction in muscle mass and function observed in numerous affections leading to long bed rest, including those in the context of intensive care.[14]

The basic stimulation protocol for healthy muscles consists of a warm-up phase [5 minutes (min), 5 Hz, 250 microseconds (μs)], a stimulation period [30 min, 100 Hz, 400 μs, 5 s on (0.75 s ramp-up, 3.5 s contraction, 0.75 s ramp down), and 10 s off], and a cooling-down phase (5 min, 5 Hz, 250 μs). Physiotherapists should set the intensity of the stimulation to a level at which the full contraction of muscle is visible and slight movement of a limb is present.[10]

Strengthening of Healthy Muscles in Children

Strengthening of Healthy Muscles in Children with Neurological Conditions

Children differ from adults in many muscular performance attributes, such as size-normalized strength and power, endurance, fatigability, and recovery from exhaustive exercise.[15] ES for children is usually performed when there are neurological conditions, such as cerebral palsy (CP), where muscle control is impaired due to central nervous system disorders. The vast majority of CP children have trouble walking. For children with CP, enhancing walking or other functional abilities is frequently the main therapy objective. Also, upper extremity control is often affected by these central nervous system disorders. This is where ES comes to help besides physical exercises.[16]

Studies have shown that Functional Electrical Stimulation (FES) therapy can lead to the recovery of upper limb function, specifically improvements in dexterity, range of motion, and activities of daily life. Benefits of increased limb awareness and improved sensory function have been reported as well in children with CP.[17] Electrode placement is usually the same for muscle stimulation in children as recommended for FES electrode placement in adults. One electrode is placed on the origin of the muscle, and the other electrode is placed on the motor point of the muscle. The intensity of stimulation should reach a motor threshold when muscle contraction starts. It must be mentioned that not all children tolerate ES and its effect, sometimes electrical-induced feeling of tingling is too irritating. When it is absolutely necessary to perform ES, lower intensity may be a possible option, but it may not be sufficient to cause the muscle contraction. Another option may be to use an anesthetic cream on the skin before the ES. In a study of Quadriceps Femoris and Triceps Surae muscle stimulation for children with CP, Stackhouse et al. used an anesthetic cream (EMLA; 2.5% prilocaine, 2.5% lidocaine) to the area of stimulation and covered it with a self-adhesive occlusive dressing for 2 hours (h) before stimulation.[18] This anesthetic cream was used to reduce discomfort during ES and reduce the possibility of reflex responses.

FES may be used to achieve a direct "orthotic" effect during gait, for example, by triggering the ankle dorsiflexors to lift the foot in swing or to trigger the Quadriceps Femoris muscle to extend the knee in stance. Possible long-term "therapeutic" effects of FES include a reduction in the tendency for muscle atrophy and improved motor control by improving the effectiveness of neural pathways.[19]

Ankle dorsiflexion may be achieved by placing one electrode over the fibular head to stimulate the Peroneal nerve and the other electrode on the motor end point of the Tibialis Anterior muscle. Pulse width should be set to a maximum of 300 μs and frequency set to 33 Hz. This type of stimulation can be used every day during walking activities. The same parameters can be used for Quadriceps Femoris stimulation during standing phase if necessary.[20]

Upper limb stimulation is usually performed for wrist, hand, and finger control. NMES should be applied with a tolerable and comfortable density (10-25 mA) and a pulse width of 300 μs, frequency of 30 Hz, and an on-time of 12 s (includes a ramp up of 1 s and a ramp down of 1 s/ an off-time of 5 s). In order to achieve maximum contraction of the wrist and fingers when applying NMES, the child should be in a sitting position with the elbow, forearm and hand in 90° of flexion, pronation and neutral position, respectively.[21]

Garzon et al. suggested intensity values according to the electrode size used for FES.[17] The bigger the electrode, the higher current intensity. When using 1 cm x 3 cm electrodes, current intensity may be 2.7 milliamperes (mA). For 2.5 cm (circular) electrode intensity increases to 3.5 mA. 5 cm x 5 cm electrode – 7.9 mA intensity, 9 cm x 5 cm electrode – 10.6 mA intensity.

Strengthening of Healthy Muscles in Children with Orthopedic Conditions

Another quite common musculoskeletal condition in children is flat foot deformation, which usually occurs because of weakness of foot supporting muscles. Abd-Elmonem et al. suggested the use of NMES on plantar intrinsic foot muscles. In their study, the authors placed one electrode on the muscle motor point (Abductor Hallucis muscle; largest cross-sectional area of the intrinsic foot muscles), while the other electrode was placed behind the head of the first metatarsal bone.[22] The suggested current parameters are: frequency – 85 Hz with 5 s contraction time and 12 s rest time, while the ramp-up and ramp-down times are – 0.3 and 0.7, respectively. The current intensity should be adjusted based on individual tolerance without reporting pain or discomfort while standing on both feet.[22]

Strengthening of Healthy Muscles in Elders

Skeletal muscle atrophy undoubtedly occurs with advancing age. According to longitudinal studies in people aged 75 years or over, muscle mass is lost at a rate of 0.64 – 0.70% per year in women and 0.80 – 0.98% per year in men. However, during periods of physical inactivity, skeletal muscle atrophy is substantially accelerated. For instance, data from immobilization and bed rest studies show a substantial 1 kg loss of muscle mass in 10 days.[23]

While there are several contributors to physical limitations with advancing age, one of the most prominent contributors are undoubtedly a reduction in skeletal muscle performance. One of the hallmark changes of aging linked to reductions in muscle performance is the loss of skeletal muscle mass, which is commonly referred to as sarcopenia.[23] The muscle atrophy starts with the lower limbs and is a principal risk factor for falls and impaired gait, which affect activities of daily living.[24]

NMES is a fine tool to counteract the onset or aggravation of the sarcopenia process activating the plasticity of muscular tissue.[25] It is commonly accepted that NMES can offer advantages over voluntary training for people who have limited ability or are noncompliant for volitional exercise because of its promotion of specific motor unit recruitment.[24] There is also evidence that NMES increases muscle strength, especially in periods with reduced mobilization.[25] Many studies have shown that NMES improves the regenerative capacity of skeletal muscle in elderly subjects. Accordingly, the skeletal muscle strength and mobility of NMES-stimulated elderly subjects significantly improved during the period of regular stimulation.[26]

In order to prevent muscle atrophy in the elderly, NMES may be performed 3-4 times a week. Usually, the muscle stimulation of the lower limbs is necessary to ensure good locomotion and balance skills. However, upper limb or trunk muscles may also be stimulated with respect to muscle weakness and symptoms felt. The main stimulated muscle groups usually are Quadriceps Femoris muscle, especially Vastus Lateralis and Vastus Medialis and calf muscles, because their activity is necessary not only for walking but also for balance control.[27]

In studies that evaluated the effect of ES for the elderly, the main current parameters are: pulsed 75 Hz rectangular-wave current, 400 μs pulse width, delivered with a ramp-up time of 1.5 s, a steady

tetanic stimulation time of 4 s, and a ramp-down time of 0.75 s (total duration of contraction, 6.25 s). A longer rest phase is necessary in order to delay the onset of fatigue. Thus, a rest interval of 20 s may be set between duty cycles. It is recommended to gradually increase intensity to an individual maximally tolerable sensation in order to obtain the maximum result of stimulation. A person should be motivated to adjust intensity during the stimulation session to maintain the highest tolerable intensity throughout the session, as inevitably some adaptations occurs.[26]

Several other studies used 60-85 Hz frequency for stimulating muscles of elderly people for atrophy prevention. Pulse width in this age group usually around 350 - 600 μs. This parameter may also be adjusted if stimulation sensation is too irritating, and pulse width may be shortened for each individual separately. Stimulation time should not be shorter than 20 min in order to get an optimal effect. Stimulation on and off cycle should be chosen using 1:2 ratio, for example 3 s on and 6 s off.[28-30]

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Electrical Stimulation for Patients With Orthopedic Problems

DOVYDAS GEDRIMAS • VAIDA ALEKNAVIČIŪTĖ-ABLONSKĖ

Epicondylitis

Lateral epicondylitis is common as it affects 1%-3% of the population. Non-operative treatment represents first-line therapy and may include no active treatment, strengthening, Extracorporeal Shock-Wave Therapy, Transcutaneous Electrical Nerve Stimulation (TENS), and injections of corticosteroid, platelet-rich plasma, and autologous blood. Surgery may be considered when non-operative treatment fails.[1]

Pain from lateral epicondylitis usually initiates after repetitive or excessive extension of the wrists during supination. Lateral epicondylitis is characterized by continuous slight traumatic symptoms at the humeroradial joint and a gradual increase in such symptoms. Missing early treatment leads to a decrease in muscular strength. Pain is one of the problems experienced by patients and can be potentially accompanied by physical, physiological, or psychological disability.[2]

For strengthening a Faradic current can be used with these parameters: A frequency in the range of 30 to 50 Hz is commonly employed to induce muscle contractions. The pulse duration is usually set between 0.1 to 1 millisecond (ms). The intensity of stimulation should be set to a level that effectively contracts the targeted muscles without causing discomfort or pain. It should be strong enough to generate visible muscle contractions. Common duty cycles include 1:2 [stimulation on for 1 second (s), followed by 2 s off] or 1:5 (stimulation on for 1 s, followed by 5 s off). treatment time varies between 15 and 30 minutes (min).[2]

Weng et. al. compared the efficacy of low-frequency TENS, high-frequency TENS, and sham TENS, all focused on acupuncture points.[3] Significant differences were found at 2 weeks' follow-up on a change in pain scores between low-frequency TENS versus sham TENS and between high-frequency TENS and sham TENS versus high-frequency TENS. Authors suggested that ES for pain control is always a good choice for pain reduction in epicondylitis cases. No significant difference was found in pain between high-frequency and low-frequency TENS. Electrode placement example is shown in Figure 23.1.

There is also evidence of Microcurrent therapy in reducing pain intensity and improving the function and strength of the elbow. A few trials evaluated its effect. In the first trial there were two groups of patients and used a monophasic current of 50 and 500 microamperes (μA) for 3 weeks, once a day for 99 min for 21 days. The second trial was also divid-

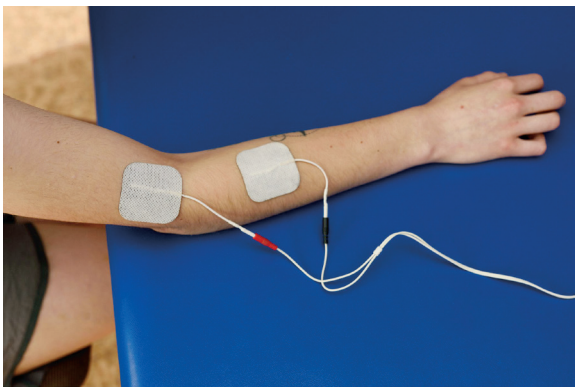

Figure 23.1 TENS electrode placement for lateral epicondylitis.

ed into two groups, for the first one, a monophasic current of 40 μA once a day for 6 hours (h) and for 3 weeks was applied, which gave the total duration of treatments 189 h. Moreover, in the second group, a regulated current of 40-500 μA was applied for 3 weeks, except that in the first week, it was applied 3 times a day for 30 min for 5 days; in the second week, twice a day for 30 min for 5 days; and in the third week, once a day for 30 min for 5 days (15h in total). The authors performed assessments after 3, 6, and 15 weeks of treatment. The best results were obtained in the first trial for the first group, where a monophasic current and a constant intensity of 50 μA were used (93% of patients felt much better and were healed). These results were maintained 15 weeks after the end of treatment.[4] Thus, a few electrotherapy modalities can be used for epicondylitis induced pain.

Joint Pain (Arthritis)

Electrotherapy is commonly used in the physiotherapy and rehabilitation programs of patients with Romatoid Arthritis (RA) to relieve pain and improve function. TENS is a widely used form of electroanalgesia, with the existence of many clinical reports and studies concerning its use. TENS is thought to produce analgesia according to the gate control theory. The electrical stimuli delivered by TENS units can be varied to suit a patient's tolerance as well as to produce the best efficacy. Current amplitude, for example, can be set at low, medium, or high intensity (for comfort); pulse width or duration from 10 to 1000 ms; and frequency from 0.5-10 Hz for high intensity, and 80-100 impulses per second for lower intensity. The positioning of electrodes may also be important in eliciting analgesia. The placement of electrodes is dependent upon getting optimal stimulation from the mode of TENS being used. According to the gate control theory approach, the stimulus from TENS must be transmitted into the central nervous system. This transfer is enhanced by electrode placement on optimal sites. They may, for example, be placed directly over the painful area, over cutaneous nerves, acupuncture points, or other trigger points. Another electrode placement site is over the dermatome zone, which is most closely related to the area of pain. If two or more of these entities are stimulated simultaneously (due to specific placement of electrodes) then greater specificity of the application will be achieved.[5]

TENS may be effective for relieving musculoskeletal pain (such as joint pain from RA) in people with RA. TENS can be applied by people themselves as needed, conveniently in their own home. Despite the widespread and ongoing use of TENS by physiotherapists and people with several conditions including RA for the control of pain, the application of this treatment modality in the clinic is largely based on empiric evidence. TENS is suggested as a potential therapy for the treatment of musculoskeletal conditions in American Physical Therapy Association guidelines. The Arthritis Society also recommends the use of TENS for pain and joint swelling in people with RA.[6]

TENS has been demonstrated to be effective for chronic pain lasting over 3 months. Various modes of TENS device settings have different stimulation parameters and are thought to have certain biological mechanisms for their analgesic effects. In systematic reviews, it was suggested that when strong burst mode TENS was used for 6 weeks, pain relief improved considerably compared to placebo TENS. Also, it was found that acupuncture-like TENS had more rapid effects, as pain was reduced at the end of the 2-week treatment period. However, if the treatment duration was less than 2 weeks, TENS did not demonstrate a significant difference in pain relief compared to placebo, which may suggest that the effects of TENS applied in any mode are cumulative and require at least 2-6 weeks of use for a significant clinical reduction in pain to be experienced.[7]

Evidence suggests that the pain-relieving effects of TENS are more effective with higher intensity pulses, as in acupuncture-like TENS, which may act in the same manner as traditional acupuncture. However, classical acupuncture-like TENS requires a higher intensity current, which causes muscle twitching and may be uncomfortable or painful for the patient, in which case conventional TENS may be more appropriate.[8]

In Cheing et al's study, 40 min was found to produce a 60.31% reduction in Visual Analog Scale scores and was deemed the ideal duration time for TENS application.[9] This produced a longer half duration of pain relief 2 h post-stimulation and 2 weeks after the treatment period compared to placebo, 20 and 60 min of TENS. It is possible that by not using long enough stimulation periods, the body's endogenous opioids will not be released and consequently there will be no analgesic effect.[9]

Numerous potentially beneficial indications exist for the use of TENS for patients with RA: neurogenic pain, musculoskeletal pain (such as joint pain from RA), visceral pain, post-stroke therapy, and other medical and surgical indications. TENS can be conveniently applied by the patients themselves as needed, in their own homes. Despite the widespread, ongoing use of TENS for the control of pain by physiotherapists and patients with several conditions including RA, the application of this treatment modality in the clinic is largely based on empiric clinical evidence.[10] Electrode placement for knee pain and shoulder pain are shown in Figure 23.2 and Figure 23.3.

Not only TENS but also Neuromuscular Electrical Stimulation (NMES) can be used in cases of RA. NMES has been shown to be safe and effective

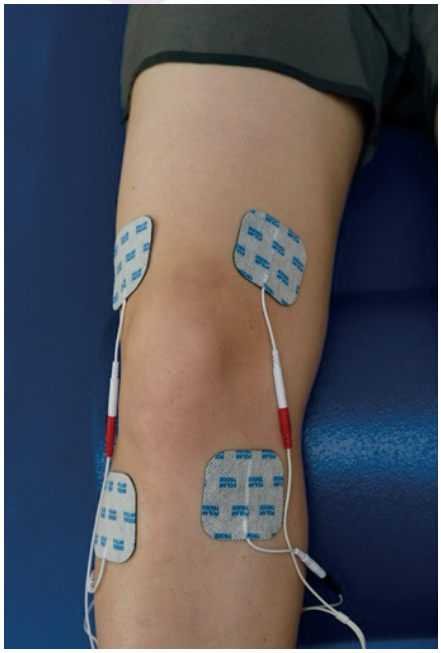

Figure 23.2 TENS electrode placement for knee pain.

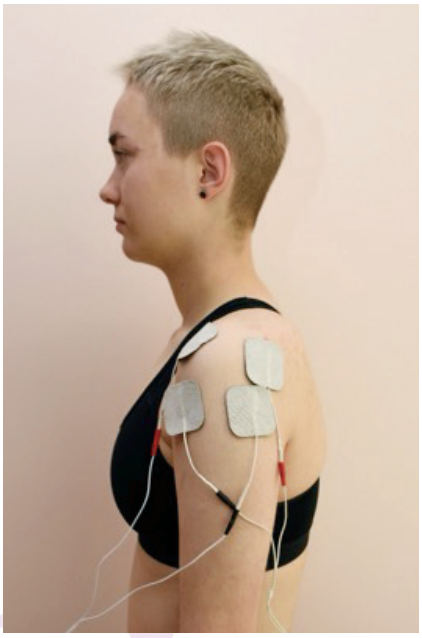

Figure 23.3 TENS electrode placement for shoulder pain.

in improving Quadriceps Femoris muscle mass in different populations, including those with RA. The effectiveness of NMES seems to be intensity dependent (i.e., higher intensities result in larger muscle improvements). The intensity of NMES training is defined as the magnitude of torque produced by the NMES-elicited muscle contraction. NMES training intensity is generally expressed as a percentage of the torque produced compared with a patient's maximum voluntary isometric contraction. One drawback of NMES is that electrical stimuli produced during application can be uncomfortable. Hence, clinicians usually increase the current intensity based on a patient's tolerance, which might not always reflect the necessary training intensity required to improve muscle mass or strength. Currently, information on the NMES current intensity necessary to effectively produce changes in muscle mass or strength is scarce, and studies investigating the effect of NMES on muscle quality (i.e., amount of fat accumulated within the muscle) are lacking.[11]

Most research on the effectiveness of NMES has been conducted in populations without RA (e.g., adults who are healthy, people who have had anterior cruciate ligament reconstruction, and people with chronic obstructive pulmonary disease. The

studies showed a positive relationship between NMES training intensity and improvements in muscle strength and physical function.[12]

In RA cases NMES with alternating symmetrical square waves can be used at 40-100 Hz frequency, 300 μs pulse duration, and 20 min application in order to strengthen muscles. On and off ratio can be adjusted 7 s on and 23 s off.[13]

Low back pain

Chronic low back pain (CLBP) is a major common public health condition with a 12-month prevalence of 66% in women and 58% in men, and a lifetime prevalence of 84%. This condition is also a leading cause of disability worldwide. It has been reported that various factors account for the development and/or maintenance of CLBP. Additionally, patients with such conditions are often accompanied by high treatment costs, sick leave, and low quality of life.[14]

CLBP is a symptom with an unknown etiology. Patients with CLBP are commonly prescribed stabilization exercises. Prescribing stabilization exercises is based on the rationale that CLBP is associated with motor control impairments and atrophy of the paraspinal muscles. These impairments presumably render the spinal muscles unable to produce sufficient activation to maintain spinal stability. However, stabilization exercises have only a small treatment effect in the short term, and their effectiveness has not been shown in the long term. Additionally, NMES can be used to obtain better results. The NMES electrodes can be applied bilaterally to the lumbar paraspinal muscles. A pillow should be placed under the abdomen of the prone-lying patient. Two large (12 cm × 6 cm) self-adhesive electrodes should be applied to the paraspinal muscles, one electrode on each side. The High Voltage Pulsed Galvanic Stimulation parameters are set to produce a pulse frequency of 75 Hz, a pulse duration of 250 μs, with a 4 s ramp up and ramp down time, and a 6 s stimulation period at the maximum amplitude, followed by a 50 s rest period to minimize fatigue. Patients should be instructed to perform active trunk extension as soon as they felt the electrical current ramp up and to return to the resting prone position when the current ramped down. This method combines active movement with NMES.[15]

Other parameters may be used for paraspinal muscle stimulation: Surged Faradic current with frequency of 50 Hz, pulse duration of 250 ms, and 10 s on and 30 s off phase. The current intensity can be gradually increased to the maximum tolerance of the individual. Each painful area should be treated for a total of 30 min each session, once daily for a total of 4 weeks.[14]

TENS is also used for patients suffering from CLBP without radicular pain. Four electrodes should be placed on the the painful area (Figure 23.4). For those experiencing CLBP associated with radicular pain, 2 electrodes should be placed spanning the painful area of the back and 2 electrodes on the trajectory of the spreading pain area involved in the radiculopathy. Stimulation may be continued for 1 h a day. It is recommended for patients to complete 1 h treatment sessions per day for a total of 3 months.[16]

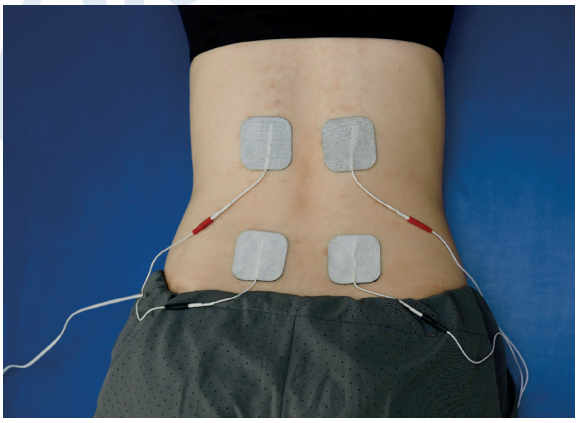

Figure 23.4 TENS electrode placement for low back pain.

Chronic Neck Pain

Chronic neck pain is a highly prevalent condition, affecting 10% to 24% of the general population. It can also limit the daily activities of 11% to 14% of all workers annually, leading to work absenteeism and economic implications.[17] Neck pain is defined as any specific pain located below the superior nuchal line and above the spine of the scapula line from the back, as well as above the superior border of the clavicle and the suprasternal notch.[18]

In order to treat neck pain, TENS electrodes should be placed symmetrically in the upper cervical spine area on both sides symmetrically, frequency of 100 Hz, pulse width of 250 μs, 20 min each time during the course of treatment (Figure 23.5). If pain is in Trapezius muscle, electrodes should be placed along the muscle fibers (Figure 23.6). At least 10 sessions should be completed to obtain accumulative results.[19] If using conventional TENS, parameters should be 60-100 Hz, at sensory threshold for 20 min. If using burst TENS, the recommended parameters are 2-4 Hz for 30 min. If using modulation TENS, parameters may be 100 Hz, at motor threshold for 20 min.[20]

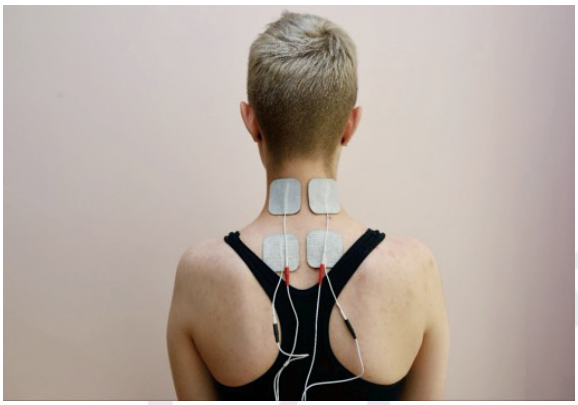

Figure 23.5 TENS electrode placement for neck pain.

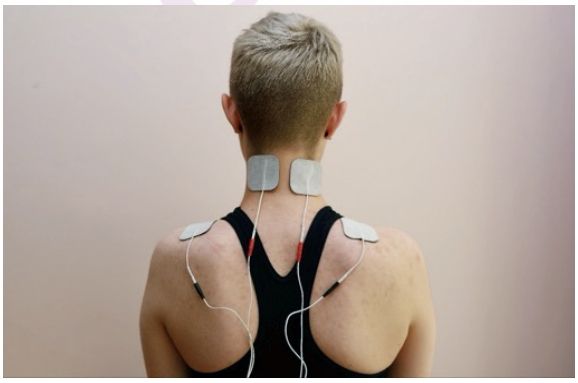

Figure 23.6 TENS electrode placement for Trapezius muscle pain.

Usually patients' pain reduces when applying high frequency or low frequency TENS, so the clinician should use parameters that are more suitable for each patient. Sometimes, when performing electrical stimulation, patients may feel discomfort despite the fact that the chosen frequency is correct and meets the recommendations. In that case, a physiotherapist may adjust the pulse width. The longer the pulse width may cause more irritation. This should especially be considered in acute phases of pain. So, if 250 μs pulse duration causes discomfort or irritation, pulse width may be reduced to 50 - 150 μs. This adjustment should let the patient feel more gentle stimulation even if intensity is higher than before, when pulse width was e.g. 250 μs.[20]

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Electrical Stimulation for Patients With Sports Injuries

DOVYDAS GEDRIMAS • VAIDA ALEKNAVIČIŪTĖ-ABLONSKĖ

Electrical Stimulation for Patients with Sports Injuries

Following injuries to joints and muscles, the injured parts of the body are often immobilized for some time to allow the damaged joints, bones, and muscles to heal. While immobilization is usually necessary, it has harmful consequences on the function of muscles, and recovery is often slow because muscles have deteriorated during the period of immobilization. In these cases, electrical stimulation (ES) of muscles during the period of immobilization and afterwards is beneficial and speeds up recovery.[1]

The most thoroughly explored condition is that after knee injury, particularly after the rupture of the anterior cruciate ligament (ACL). This injury affects young and active people and is usually a result of sport injury. Traditionally, the leg is immobilized and often surgery must be carried out to re-suture the ACL. Interestingly, even months after surgery, the thigh muscles, particularly the Quadriceps Femoris muscle, do not regain their normal strength, which for active individuals is a disadvantage.[1] Studies showed that healthy inactive muscle tissue generally atrophies at approximately 0.5% per day. Of particular relevance is the time-course of muscle atrophy, with the first 1-2 weeks showing the greatest relative loss of muscle mass. During this period, 150-400 g of muscle tissue can be lost from a single, immobilized leg. In line with this, the loss of muscle strength and decline in (local) insulin sensitivity occur rapidly within the first 1-2 weeks after the onset of immobilization.[2]

Inactivity of other joints of both upper and lower limbs is likely to have similar effects on the muscles involved in movement of these joints as that described for Quadriceps Femoris muscles, they become atrophic, produce less force, and are fatigable. Their recovery is likely to be more complete and faster if neuromuscular electrical stimulation (NMES) is used both during and after immobilization. There is much evidence that when the Quadriceps Femoris muscles are electrically stimulated during the period of immobilization and subsequent recuperation, the recovery of force of the muscle is more complete and the period of restricted movement is shorter than without this intervention.[2]

When specific parts of the body needs to be immobilized for long periods of time in a cast or brace due to a fracture of bone, tears of ligaments or tendons, in order to allow healing of the damaged area to take place, stimulation of the muscles by placing self-adhesive electrodes under the cast or brace or into the opening of the cast will prevent development of the detrimental changes and help to follow a more intensive rehabilitation regime later on.[3]

Of interest to the injured athlete, Dirks et al. developed a strategy for applying NMES during the first few days of fully casted limb immobilization.[4] The authors used 100 Hertz (Hz) frequency and 400 microseconds (μs) pulse width current.

They demonstrated that substantial muscle atrophy observed in the initial 5 days of immobilization can be entirely prevented by 30 minutes

(min) of NMES performed twice daily in healthy and young men.[4,5]

Knee Injuries and Electrical Stimulation

Knee injuries affect 80% of sports people, particularly those engaged in rugby or football, and it follows that even in cases where surgery is not necessary. A period of enforced rest will quickly lead to muscle deterioration. A program of physiotherapy and rehabilitation using NMES to strengthen the Quadriceps Femoris muscle can vastly accelerate the rate of recovery of the lower extremity and its use.[6]

Reduced ability to make voluntary contractions of the Quadriceps Femoris muscle is a common problem after knee injury, even though there is no damage to the muscle or innervating nerve. This condition is often referred to as arthrogenic muscle inhibition. Muscle weakness after surgery or injury can be partly explained by atrophy of the muscle, but also by this decreased ability to activate the muscle fibers available. The latter is suggested to be a protective, reflexive response to alter neural drive to the surrounding musculature after joint injury, hence precluding voluntary muscle work and normal function.[6]

In most cases of knee immobilization, NMES is effective in preventing the decrease in muscle strength, muscle mass, and the oxidative capacity of thigh muscles. Most studies indicate that NMES is more effective in preventing muscle atrophy when compared to no exercise, isometric exercise of the Quadriceps Femoris muscle group, isometric co-contractions of both Hamstrings and Quadriceps Femoris muscle groups, and combined isometric exercise.[3] NMES has been attempted in cases where voluntary muscle contractions are inhibited after injury or surgery because of its ability to induce action potentials in the motor nerves and over-rule inhibition, thus making strength exercise possible. For clinicians working with knee injury patients, NMES is a useful tool in rehabilitation when traditional exercises are limited by inhibition.[6]

NMES has been proven to be effective for preventing the reduction of muscle protein synthesis, muscle mass, and strength after knee injury. NMES also attenuates loss of oxidative enzymatic activity and leg muscle mass/strength in subjects submitted to 30 days of bed rest. Dirks et al. found that NMES increased muscle protein synthesis and inhibited the activation of protein degradation pathways in subjects with knee immobilization for 5 days, thereby preventing muscle mass loss.[4] In addition, NMES increases muscular and functional resistance, especially in clinical patients, as well as muscle oxidative capacity and maximal oxygen consumption. In addition, similar to endurance training, NMES increases antioxidant capacity, therefore proving useful in reducing the redox imbalance elicited by disuse periods.[7]

The recommended NMES parameters for Quadriceps Femoris muscle stimulation: High Voltage Pulsed Galvanic Current, frequency of 50-70 Hz and pulse width of 200-400 μs. The duty cycle should be appointed to 1:3 ratio, for example 5 seconds (s) of on and 15 s off, or 10 s of on and 30 s off. Current intensity should be set to maximum tolerable intensity. Usually, it is followed by visible muscle contraction. NMES can be used for 30-50 min a day.[6]

The recommended NMES parameters for lower limb atrophy prevention are frequency of 100 Hz and pulse width of 400 μs. This stimulation should be used for 30 min twice a day.[5]

Electrode placement example for Quadriceps Femoris muscle stimulation is shown in Figure 24.1. Transcutaneous Electrical Nerve Stimulation (TENS) can be also used for relieving pain in knee pain.[3] TENS electrode placement for knee pain is shown in Figure 24.2.

Anterior Cruciate Ligament Injuries and Electrical Stimulation

Quadriceps Femoris muscle weakness is common following the ACL reconstruction. Despite aggressive physiotherapy and rehabilitation programs directed at improving Quadriceps Femoris

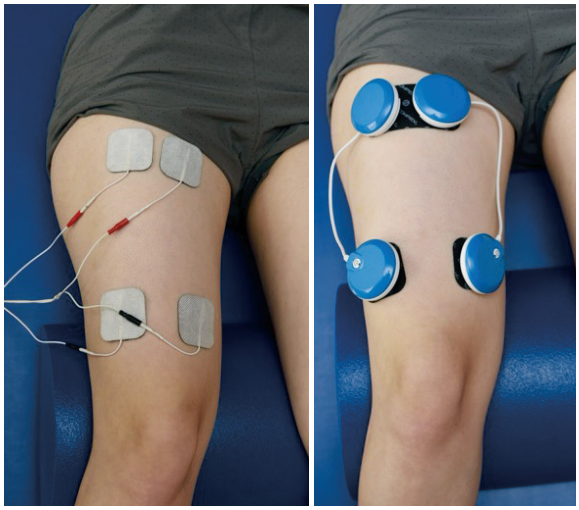

Figure 24.1 Electrode placement for Quadriceps Femoris muscle strengthening (left side - self-adhesive cord electrode, right side - self-adhesive wireless electrodes).

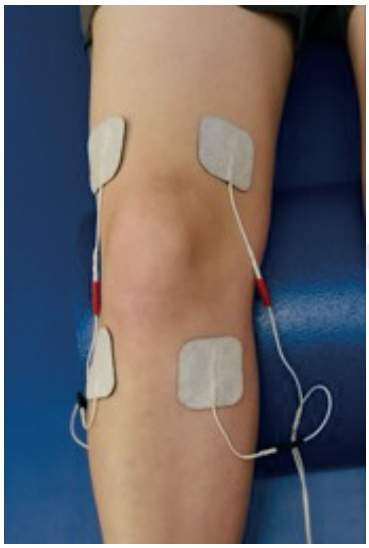

Figure 24.2 TENS electrode placement for knee pain.

muscle function, a universally effective treatment approach to reverse this muscle weakness has yet to be identified. Quadriceps Femoris muscle weakness that accompanies ACL injury is related to reduced functional performance, the potential for re-injury, and the development of post-traumatic osteoarthritis.[8]

NMES is a clinical modality that has the potential to treat Quadriceps Femoris muscle activation failure by initiating action potentials in intramuscular nerve branches, resulting in an involuntary contraction of the muscle. Because NMES exogenously stimulates the muscle, large diameter Type II muscle fibers are thought to be selectively recruited, resulting in a greater potential for muscle force production. Importantly, in ACL reconstructed individuals, alternating current of 2500 Hz has been found to be more effective than exercise alone in improving Quadriceps Femoris muscle activation.[8]

Achilles Tendinopathy and Electrical Stimulation

Achilles tendinopathy is one of the more common overuse injuries sustained by runners, with a reported approximate 52% lifetime incidence in recreational runners.[3] Pain is localized to the mid-portion (2-6 cm proximal to the insertion) or insertion of the Achilles tendon. Symptoms are often provoked during tendon loading activities, which include running, jumping, walking uphill, or ascending and descending stairs.[9]

Galvanic ES can affect nociception through segmental inhibition, descending central inhibition, and several other neuromodulatory mechanisms. It uses direct current to facilitate ion movement in the tissues, promoting blood flow and potentially aiding in the healing process.[10]

TENS is a common modality used by rehabilitation clinicians and has been studied employing a variety of pulse frequencies, intensity levels, and durations, making it difficult to determine its effectiveness. The intensity level of TENS appears to mediate the analgesic response, with higher intensities resulting in greater hypoalgesia in humans.[11] ES that is delivered at high intensities (just below motor threshold through pain threshold level stimulation) can reduce central sensitization. TENS can restore central inhibition and increase pressure pain thresholds at the local treatment site and sites beyond, and may thus be useful in reversing some of the adaptations that the nervous system makes when confronted with chronic pain (Figure 24.3).[12]

The effects of burst TENS on Achilles tendon healing has been investigated in various research. Two studies investigated TENS in 20 patients who acquired sports-related Achilles tendon injuries.

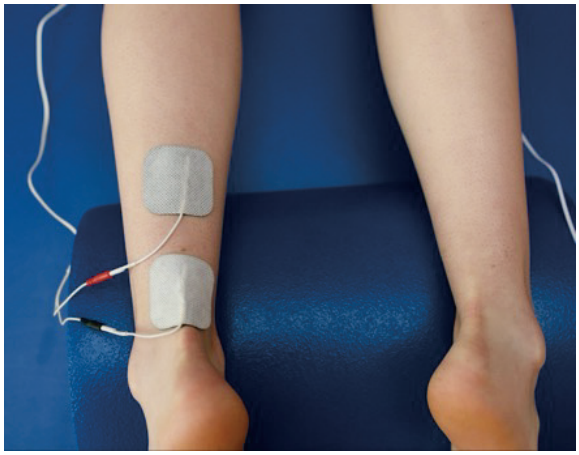

Figure 24.3 TENS electrode placement for Achilles tendon pain.

Treatment with burst TENS was performed 5 days per week during the 2nd and 3rd weeks of post-operative care. The following parameters were used: burst TENS with a pulse train duration of 300 μs, internal frequency of 100 Hz, burst frequency of 2 Hz, and variable amplitude according to the patient's tolerance.[13,14]

Burssens et al. investigated the effects of burst TENS on collagen formation after Achilles tendon suture in man.[14] Among the 20 patients, 18 completed the study, 9 underwent TENS and 9 received simulated treatment. It was found that the group who received burst TENS treatment experienced effective proliferation of fibroblasts, and production, maturation, and organization of collagen fibers. Therefore, evidence suggested that TENS could have a positive influence on the Achilles tendon healing in males.[14] Achilles tendon rupture has been described for many years as a serious injury and one of the most common among the musculo-tendinous lesions. However, it is interesting to note that these findings are restricted only to healing in the Achilles tendon because of its superficial location and by the fact that it can be easily stimulated by the current.[15]

Ankle Injuries and Electrical Stimulation

Ankle injuries are very common between professional athletes and recreational sports, with an incidence in the general population of the United States of 2.15 per 1000 persons each year. The most common injury mechanism is a combination of inversion and adduction of the foot in plantar flexion (supination). This injury mechanism can cause damage to the lateral ankle ligaments; most of these lesions—in particular, incomplete tearing of ligaments, can be treated conservatively.[16]

Standard of care for lateral ankle sprains includes protection, rest, ice, compression, and elevation. However, sports medicine clinicians continue to incorporate ES during the acute and subacute phases of healing in an attempt to expedite the process and allow for an earlier return to participation. Pain and edema, as a result of structural damage, often result in functional limitations. Preventing edema formation or enhancing resolution of edema and continuously modulating pain during rehabilitation may allow for the quickest functional progression and subsequently may decrease the time lost to injury following lateral ankle sprains.[17]

The 25 min application of a non-tetanic (5 Hz) NMES was suggested to generate a hyperperfusion of the vascular walls surrounding the skeletal muscle, thereby decreasing the inflammatory response as measured by a reduction in creatine kinase.[18] The TENS device unit, which was adjusted to deliver a biphasic current with a symmetrical waveform at 50 Hz for 15 s, tuned for a 3 s ramp up time, and a 30 s rest time with a 250 μs pulse duration can be used.[19] TENS Electrode placement for ankle sprain is shown in Figure 24.4.

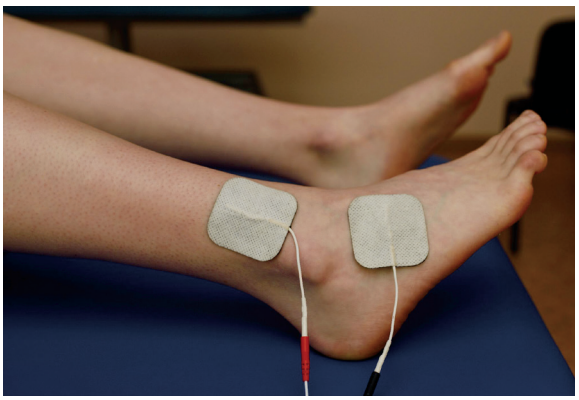

Figure 24.4 TENS electrode placement for ankle sprain.

Shoulder Injuries and Electrical Stimulation

The shoulder is the most mobile joint in the human body. It allows the upper extremity to rotate up to 180 degrees in three different planes, enabling the arm to perform a versatile range of activities. This mobility comes at a cost which leaves the shoulder prone to injury.[20] The highest risk for these injuries is for overhead athletes in sports where throwing motion is essential. Also, contact sports such as rugby tend to have an increased risk for shoulder injuries. While a single traumatic event may cause injury, more commonly, it is repetitive overuse that leads to the failure of one or more of these structures.[21]

Usually, anterior shoulder dislocation or subluxation are the main injuries that require rest and rehabilitation before returning to sport. Restoration of dynamic joint stability is initiated in the acute and subacute phases after the splint is removed. NMES of rotator cuff structures, particularly the posterior rotator cuff, may also be helpful adjunct for muscular recruitment during the acute process (Figure 24.5).[22] A systematic review by Lee et al. recommends using 10-36 Hz frequency to manage shoulder recovery after subluxation.[23]

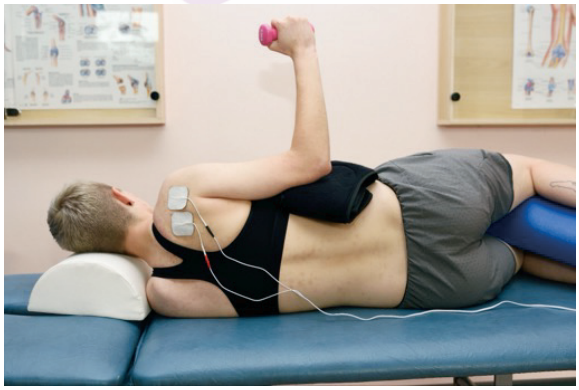

Figure 24.5 Electrode placement for infraspinatus muscle strengthening with active muscle contraction.

Pain management in the shoulder should be accomplished using TENS following instructions for acute pain management parameters of ES (Figure 24.6).[23]

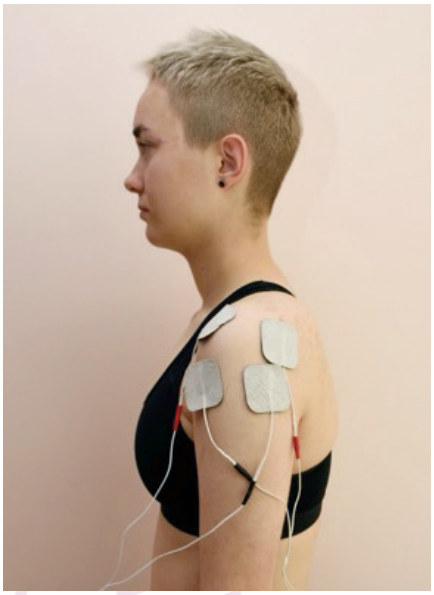

Figure 24.6 TENS electrode placement for shoulder joint pain.

Wrist and Elbow Injuries and Electrical Stimulation

Approximately 25% of all sports-related injuries involve the hand or wrist. Common injuries generally fall into two different categories: traumatic (acute) or overuse (chronic). Sports such as hockey, football, or wrestling tend to result in more traumatic injuries than others. The main traumatic injuries in this region are muscle strains, joint dislocation, ligament tears, inflammation, and fracture injuries in the fingers. Chronic injuries are more common in sports that require repetitive motions. The main overuse injuries are tendonitis, tendon dislocation, nerve injuries, and stress fractures.[24]

ES can be used as an additional measure in acute injury treatment protocols. Usually, ES is used for pain control in acute stages of trauma. TENS can be used on a site of pain if there are no contraindications, such as open wounds or fractures that need immobilization. Parameters for this stimulation are the same as those for acute pain management. High-frequency TENS is recommended in this phase. Stimulation at 110 Hz can help to reduce pain (impulse duration:200 μs). TENS is used 20 min duration for single session in a day. If an athlete's condition becomes chronic,

the physiotherapist may choose low-frequency TENS. Procedure parameters are 20 min at 4-10 Hz (impulse duration:200 μs). Electrodes are placed on a site or around the area of pain.[25]

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