Clinical Practice Guideline: **Electric Stimulation for Pain, Swelling and Function in the Clinic Setting**

Date of Implementation: **June 16, 2016**

Product: **Specialty**

Related Policies:
CPG 121: Passive Physiotherapy Modalities
CPG 135: Physical Therapy Medical Policy/Guideline
CPG 155: Occupational Therapy Medical Policy/Guideline
CPG 269: H Wave Electrical Stimulation

GUIDELINES

I. Use of electric stimulation (e.g., TENS, EMS) is considered medically necessary in a clinic setting and under the direct supervision of a physical therapist or similar professional for an individual when prescribed as part of a comprehensive treatment program for pain and swelling, and only used short term (e.g., up to 2 weeks).

Note: The medical records must document the response to the use of electrical stimulation, including specific parameters related to the type of electric stimulation (e.g., low or high frequency TENS, electrode placement).

II. Neuromuscular Electrical Stimulation (NMES) is considered medically necessary for disuse atrophy where the nerve to the muscle is intact, and the individual has any of the following non-neurological reasons for the disuse atrophy and only in conjunction with active exercise:
- Major hip or knee surgery where there is failure to respond to basic therapeutic exercises as initiated in physical therapy/rehabilitation; or
- Previous immobilization (e.g., casting or splinting) of an extremity (arm or leg).

III. Microcurrent electrical nerve stimulation (MENS) therapy is considered unproven for the treatment of chronic back pain and all other indications.

IV. Microcurrent point stimulation is considered unproven for the treatment of chronic pain and any other indications.

V. H-WAVE® stimulation is considered unproven for diabetic peripheral neuropathy and for all other indications including:
- To accelerate healing
- To reduce edema

- To reduce pain from causes other than chronic diabetic peripheral neuropathy
- To treat chronic pain due to ischemia

VI. Threshold Electrical Stimulation is considered not medically necessary for any condition.

VII. Pelvic floor stimulation (electric and magnetic stimulation is considered unproven for the treatment of urinary or fecal incontinence except for the following condition):

- Pelvic floor electrical stimulation with a non-implantable stimulator may be covered as medically necessary for the treatment of stress and/or urge urinary incontinence in cognitively intact patients who are a Medicare beneficiary and who have failed a documented trial of pelvic muscle exercise (PME) training.
  - A failed trial of PME training is defined as no clinically significant improvement in urinary continence after completing 4 weeks of an ordered plan of pelvic muscle exercises designed to increase periurethral muscle strength.
  - The patient's medical record must indicate that the patient receiving a non-implantable pelvic floor electrical stimulator was cognitively intact, motivated, and had failed a documented trial of pelvic muscle exercise (PME) training.
  - Stimulation delivered by vaginal or anal probes connected to an external pulse generator may be billed as 97032. Stimulation delivered via electrodes should be billed as G0283.
  - Utilization of electrical stimulation may be necessary during the initial phase of treatment, but there must be an improvement in function. These modalities should be utilized with appropriate therapeutic procedures to effect continued improvement.
  - Medicare beneficiary has an intact nerve supply to the muscle, including brain, spinal cord, and peripheral nerves, and other non-neurological reasons for disuse are causing the atrophy (e.g., post-casting or splinting of a limb, and contracture due to soft tissue scarring).
  - Documentation must clearly support the medical necessity of electrical stimulation if used more than 12 visits as an adjunctive therapy or for muscle retraining.

VIII. Percutaneous Electrical Nerve Stimulation (PENS) and Percutaneous Neuromodulation Therapy (PNT) are considered unproven for any indication.

IX. NMES/Electrical Stimulation (e.g., Guardian dysphagia dual chamber unit, VitalStim Therapy device) is considered unproven for the treatment of dysphagia.

X. Deep Pharyngeal Neuromuscular Stimulation (DPNS) is considered unproven.

XI. RST-SANEXAS neoGEN® Electric cell-Signaling Treatments (EcST) is considered unproven for any indication (e.g. peripheral neuropathy).

XII. Hako-Med treatments are considered unproven for any indication (e.g. peripheral neuropathy).

Note: Use should be to support an active care approach (i.e., therapeutic exercise, active self-care). Its use in the treatment of sub-acute or chronic conditions beyond the acute inflammatory response time frame requires demonstration of clinically meaningful and lasting improvements in function and pain, documentation of the anticipated benefit, as well as condition-specific rationale in order to be considered medically necessary.

Electrical stimulation (except NMES) is contraindicated in areas of sensory deficits. A patient's sensory deficits (decrease or loss) do not allow them to provide the correct feedback necessary for the safe and effective application to the affected area. Electrical stimulation in other related areas without sensory deficits may be appropriate.

Home Electrical Stimulation Devices (Electrical Stimulators)

If coverage for an in-home electrical stimulation device is available, the following conditions apply. In-home electrical stimulation units are considered medically necessary for the following scenarios:

- Neuromuscular electrical stimulation (NMES) (HCPCS Code E0745) and related supplies (HCPCS Code A4595) are considered medically necessary when used as a component of a comprehensive rehabilitation program for the treatment of disuse atrophy when the nerve supply to the atrophied muscle is intact.
- A transcutaneous electrical nerve stimulator (TENS) (HCPCS Code E0720, E0730) and related supplies (HCPCS Code A4595) are considered medically necessary for supervised or unsupervised, in-home use as an adjunct to conventional post-operative pain management within 30 days of surgery.
- Conductive Garment: A conductive garment (HCPCS Code E0731) is considered medically necessary when used in conjunction with a medically necessary in-home NMES or TENS device for ANY of the following clinical situations:
    - The use of conventional electrodes, tapes or lead wires is not feasible either because the individual has a large area requiring treatment or a large number of sites requiring stimulation.
    - The site(s) requiring stimulation (i.e., back) is/are difficult to reach with conventional electrodes, tapes or lead wires.
    - A co-existing medical condition (e.g., skin problems) precludes the use of conventional electrodes, tapes, or lead wires.

In-home electrical stimulation units for all other scenarios are considered unproven.

CPT/HCPCS Codes and Descriptions

CPT®/HCPCS Codes	CPT®/HCPCS Codes Description
97014	Application of a modality to 1 or more areas; electrical stimulation (unattended)
97032	Application of a modality to one or more areas; electrical stimulation (manual) each 15 minutes
G0283	Electrical stimulation (unattended), to one or more areas for indication(s) other than wound care, as part of a therapy plan of care
64555	Percutaneous implantation of neurostimulator electrode array; peripheral nerve (excludes sacral nerve)

BACKGROUND AND DESCRIPTION

Electrical stimulation (ES) therapy involves the application of electrodes to the affected area of the body for the purpose of delivering electrical current. There are several forms of electrical current used in rehabilitation settings. Electrical stimulation is used for muscle re-education (disuse atrophy), pain relief, reduction of swelling, and healing enhancement. This CPG will focus on the use of electric stimulation for pain, swelling and function (muscle re-education/disuse atrophy) when used in the outpatient clinic setting.

A TENS unit must be distinguished from other electrical stimulators (e.g., neuromuscular stimulators) which are used to directly stimulate muscles and/or motor nerves. Transcutaneous electrical nerve stimulation (TENS) is characterized by biphasic current and selectable parameters such as pulse rate and pulse width. TENS uses a battery-operated device that applies electrical stimulation via transmission of pulses of various configurations at the site of pain by wired electrodes that are taped to the surface of the skin. For example, conventional TENS or high frequency TENS delivers 40–150 hertz (Hz) compared to acupuncture-like TENS that delivers a low frequency at 1–10 Hz. Pulsed TENS uses low-intensity firing in high-frequency bursts at 100 HZ. Units often have preset programs with variations and modulations of frequencies and durations of pulses. TENS has been used for a number of applications. In theory, TENS stimulates sensory nerves to block pain signals; it also stimulates endorphin production to help normalize sympathetic

function. TENS has been used to relieve acute or chronic pain related to musculoskeletal conditions, pain associated with active or post-trauma injury, obstetrical pain, or postoperative pain. TENS for pain control occurs via the gate theory or the endogenous opiate theory. Conventional transcutaneous electrical stimulation (TENS) is an example of the use of the gate theory to control or block pain. Low-rate TENS is an example of the use of the endogenous opiate theory of pain control. TENS can also be delivered through the use of a form-fitting conductive garment (for example, a garment with conductive fibers that are separated from the individual's skin by layers of fabric). This garment is applied when a condition exists that precludes conventional TENS electrode placement.

In an editorial by Johnson and Jones (2016), the contradictory nature of TENS research evidence was noted, creating uncertainty for practitioners. For example, it is recommended in NICE guidelines that TENS should be offered for short-term relief of osteoarthritis, rheumatoid arthritis and musculoskeletal pain secondary to multiple sclerosis, but not for nonspecific low back pain. Authors recommend that practitioners be mindful that recommendations not to offer TENS are based on a paucity of evidence on which to make a judgment rather than evidence of inferiority or equivalence to placebo. Trying to interpret research on TENS is challenging because summarizing research findings is hindered by inconsistent terminology, variability in clinical technique and poor study design. Current research evidence suggests that it is reasonable to offer TENS as an adjunct to core treatment for most painful conditions, especially because it is inexpensive and has a favorable safety profile compared with long-term medication. However, it must be kept in mind that it should be combined with an active exercise program.

Microcurrent Electrical Nerve Stimulation (MENS) involves the use of a device that delivers small amounts of electrical current (millionths of an amp) to help relieve pain and heal soft tissues of the body. The application of microcurrent stimulation to an injured area is proposed to realign the body’s electrical current and increase the production of adenosine triphosphate, resulting in increased healing and recovery and blocking of perceived pain. The electrical current is subsensory and usually not felt. MENS differs from TENS in that it uses a significantly reduced electrical stimulation (i.e., 1,000 times less current than TENS). The goal of TENS is to block pain, while MENS acts on naturally occurring electrical impulses to decrease pain by stimulating the healing process (Frequency Specific Microcurrent, 2014). Frequency specific microcurrent (FSM) is a type of microcurrent therapy. The microcurrent device has two separate channels that allow both the frequency and current to be set independently for each channel. FSM is proposed as a treatment option for nerve and muscle pain, shingles, and herpes (Frequency Specific Microcurrent, 2011).

The H-WAVE® electrical stimulation device generates a biphasic, exponentially decaying waveform with pulse-wide widths. Its waveform distinguishes it from TENS and other forms of electrical stimulators. H-WAVE® is classified as a powered muscle stimulator. The hypothesis that the H-WAVE® device (Electronic Waveform Lab, Inc., Huntington

Beach, CA), a small-diameter fiber stimulator, is a paradigm shift of electrotherapeutic treatment of pain associated with human neuropathies and sports injuries is based on a number of its properties. The primary effect of H-WAVE® device stimulation (HWDS) is the stimulation of "red-slow-twitch" skeletal muscle fibers. The authors propose, based on the unique waveform, that the H-WAVE® device specifically and directly stimulates the small smooth muscle fibers within the lymphatic vessels ultimately leading to fluid shifts and reduced edema. The H-WAVE® device was designed to stimulate an ultra-low frequency (1-2 Hz), low tension, non-tetanizing, and non-fatiguing contraction, which closely mimics voluntary or natural muscle contractions. The H-WAVE® device can stimulate small fibers due in part to its exponentially decaying waveform and constant current generator activity. The main advantage of these technologies over currently applied electrical stimulators (e.g., TENS, interferential, NMES high-volt galvanic, etc.) is that H-WAVE® small fiber contraction does not trigger an activation of the motor nerves of the large white muscle fibers or the sensory delta and C pain nerve fibers, thus eliminating the negative and painful effects of tetanizing fatigue, which reduces transcapillary fluid shifts. Another proposed function of the H-WAVE® device is an anesthetic effect on pain conditions, unlike a TENS unit which in the short term activates a hypersensory overload effect (gate theory) to stop pain signals from reaching the thalamic region of the brain. When the H-WAVE® device is used at high frequency (60 Hz), it supposedly acts intrinsically on the nerve to deactivate the sodium pump within the nerve fiber, leading to a long-lasting anesthetic/analgesic effect due to an accumulative postsynaptic depression. The large pulse width theoretically enables contraction in the muscle for extended periods of time at a low fatigue rate and increases circulation, muscle relaxation, pain relief and wound healing. H-WAVE® stimulation has been used in the treatment of pain related to a variety of etiologies, such as diabetic neuropathy, muscle sprains, temporomandibular joint dysfunctions, or reflex sympathetic dystrophy. H-WAVE® electrical stimulation must be distinguished from the H-waves that are a component of electromyography.

Other waveforms are used for pain modulation as well, including interferential current (IFC), which is produced by two interfering alternating currents. Interferential stimulation (IFS) is characterized by 2 alternating-current sine waves of differing medium frequencies that combine together to produce an interferential current that is also known as a beat pulse or alternating modulation frequency. One of the 2 currents is held at 4,000 Hz, and the other can be held constant or varied over a range of 4,001 to 4,100 Hz. Interferential therapy (IFT) delivers a crisscross current at 4000–4150 pulses per second, resulting in deeper muscle penetration. It is theorized that IFT prompts the body to secrete endorphins and other natural painkillers and stimulates parasympathetic nerve fibers to increase blood flow and reduce edema. Interferential currents reportedly can stimulate sensory, motor, and pain fibers. Because of the frequency, the interferential wave meets low impedance when crossing the skin to enter the underlying tissue. This deep tissue penetration can be adjusted to stimulate parasympathetic nerve fibers for increased blood flow. According to

proponents, interferential stimulation differs from TENS because it allows a deeper penetration of the tissue with more comfort (compliance) and increased circulation.

High Voltage Galvanic Stimulation (HVGS) or high volt pulsed current (HVPC) is characterized by high voltage pulsed stimulation and is proposed primarily for local edema reduction through muscle pumping and polarity effect. High volt pulsed current (HVPC) is used for tissue healing and edema control based on polarity principles. Edema is comprised of negatively charged plasma proteins, which leak into the interstitial space. The theory of HVPC is that the high voltage stimulus applies an electrical potential which disperses the negatively charged proteins away from the edematous site, thereby helping to reduce edema (Cameron, 2017).

Neuromuscular electric stimulation (NMES) is the application of electrical current through electrodes on the skin to targeted muscles to elicit muscle contraction. NMES is proposed to promote neuromuscular re-education, improve motor unit recruitment, and thus to prevent or diminish muscle atrophy and is an established treatment modality for disuse atrophy when the nerve supply to the muscle is intact. NMES is typically used as a component of a comprehensive rehabilitation program. Compared to TENS, NMES delivers a stronger current with a wider pulse width. Neuromuscular electrical stimulation can be grouped into 2 categories: (i) stimulation of muscles to treat muscle atrophy due to disuse (e.g., post-surgical, immobilization), and (ii) enhancement of functional activity in neurologically impaired individuals. These devices within the second category use electrical impulses to activate paralyzed or weak muscles in precise sequence and have been utilized to provide SCI patients with the ability to walk (e.g., The Parastep I System). Neuromuscular electrical stimulation used in this manner is commonly known as functional electrical stimulation (FES).

Electric stimulated muscle contraction/neuromuscular electric stimulation (NMES) has been found to enhance muscle function gains post-surgically. Patients who have received an anterior cruciate ligament (ACL) reconstruction have demonstrated accelerated recovery and greater muscle function when NMES is used in combination with exercise; however, the impact on functional outcomes is inconsistent (Cameron, 2017). Similar results were noted with knee OA patients and for other inflammatory conditions of the knee. Most research studied the use of NMES on the quadriceps muscle, however clinically NMES may be used for other joints and muscle groups (Cameron, 2017). Functional electric stimulation (FES) is proposed for use in certain neurologic populations. As an example, FES can be applied to the anterior tibialis muscle to assist in dorsiflexion during gait for patients with foot drop. Several studies support the integration of FES for patients with spinal cord injury or who have sustained a stroke for various activities. As long at the peripheral nervous system is intact, any patients with central nervous system dysfunction may benefit from FES use. In these situations, effectiveness of FES is thought to be most likely due to the direct effect of muscle strengthening in addition to increased excitability

of the motor neuron pool produced by the motor level electrical stimulation (Cameron, 2017).

PENS and PNT combine the theories of electroacupuncture, and TENS and the terms are often used interchangeably. PENS involves the delivery of an electrical current through the insertion of a needle below the skin at the site of pain compared to acupuncture that places needles based on energy flow. It is not the same as acupuncture. PENS is similar to TENS except that the needles are inserted one to four centimeters around or adjacent to the applicable nerve. Up to ten needles with five electrical channels may be used. PENS is generally reserved for patients who fail to obtain pain relief from TENS. PENS may also involve the application of electric stimulation to needles placed at the dermatomal levels corresponding to the painful area. PNT is a variation of PENS which was developed as a treatment for neck and back pain. This treatment involves insertion of very fine needle-like electrodes into the skin of the neck or back to stimulate nerve fibers in the deep tissues. The treatment regimen suggested by manufacturers typically consists of two to three, 30-minute sessions per week, for two to six weeks.

VitalStim® Therapy is a type of NMES that uses a mild electrical current that is intended to treat dysphagia by re-educating the muscles and improving swallowing. Guardian dysphagia dual chamber unit is proposed for use for muscle re-education by application of external stimulation for pharyngeal contraction. VitalStim® therapy was approved by the US Food and Drug Administration in 2001 for the treatment of dysphagia through the application of neuromuscular electrical stimulation to cervical swallowing muscles. To date, however, aside from the developer's own studies, there are no peer-reviewed publications supporting these claims. Deep pharyngeal neuromuscular stimulation (DPNS) is an electrical stimulation therapy for people with dysphagia. DPNS stimulates the cranial nerves by directly touching specific areas within the mouth and throat. This causes the pharyngeal and lingual muscles to contract. Over time, this is postulated to strengthen the patient’s gag reflex and help to improve long-term swallowing functionality.

Contraindications and Precautions

Contraindications for use of Electrical Currents include:

- Demand pacemakers, implantable defibrillator, or unstable arrhythmia
- Placement of electrodes over carotid sinus
- Areas where venous or arterial thrombosis or thrombophlebitis is present
- Pregnancy – over or around the abdomen or low back

Precautions for Electrical Current use include:

- Cardiac disease
- Impaired mentation
- Impaired sensation

- Malignant tumors
- Areas of skin irritation or open wounds

EVIDENCE AND RESEARCH

TENS

There are many published reports regarding the use of TENS for various types of conditions such as low back pain (LBP), myofascial and arthritic pain, sympathetically mediated pain, neurogenic pain, visceral pain, diabetic neuropathy and postsurgical pain. While randomized controlled trials (RCTs) have focused on both high and low frequency TENS, all of the currently available studies have methodological flaws that limit interpretation, including inadequate blinding, lack of reporting of dropouts, lack of reporting of stimulation variables, and lack of proper outcome measures (Johnson et al., 2015). However, it is recognized that TENS is widely accepted in the physician and therapy community as a treatment of a variety of etiologies of pain in combination with comprehensive treatment program.

According to the Philadelphia Panel Evidence-Based Clinical Practice Guidelines on Selected Rehabilitation Interventions for Low Back Pain publication (2001), TENS demonstrated no effectiveness for improvements in pain or function in subjects with chronic low back pain (LBP). Evidence was stated as good (level I). The Panel recommends that there is poor evidence to include or exclude TENS alone as an intervention for chronic LBP. According to The Cochrane Collaboration systematic review on TENS for chronic LBP (Khadilkar et al., 2005) there is limited and inconsistent evidence to support the use of TENS as an isolated intervention for chronic LBP. In 2010, the Therapeutic and Technology Assessment Subcommittee of the American Academy of Neurology (AAN) published a report finding TENS ineffective for chronic low back pain (Dubinsky and Miyasaki, 2010). The results indicated that there are conflicting reports of TENS compared to sham TENS in the treatment of chronic low back pain, with two Class II studies showing benefit, but two Class I studies and another Class II study not showing benefit. Because the Class I studies are stronger evidence, TENS is established as ineffective for the treatment of chronic low back pain. Their recommendations were that TENS is not recommended for the treatment of chronic low back pain (Level A) and further research into the mechanism of action of TENS is needed, as well as more rigorous studies for determination of effectiveness. Per ACOEM guidelines, TENS for acute or sub-acute LBP or acute radicular pain syndromes is not recommended given insufficient evidence (ACOEM, 2007). In a review by Poitras and Brosseau (2008), it was determined that globally, high- and low-frequency TENS appears to have an immediate impact on pain levels in subjects with non-specific chronic LBP, with high-frequency TENS achieving better results. Studies included were of relatively poor quality and the lack of consistent parameters from study to study makes comparisons difficult. Based on this review, TENS appears to be of no benefit for long term pain or perceived disability (Poitras and Brosseau, 2008). Khadilkar et al. (2008) updated the 2005 Cochrane Review to determine whether

TENS is more effective than placebo for the management of chronic LBP. Only randomized controlled clinical trials (RCTs) comparing TENS to placebo in patients with chronic LBP were included. Four high-quality RCTs (585 patients) met the selection criteria. Clinical heterogeneity prevented the use of meta-analysis. There was conflicting evidence about whether TENS was beneficial in reducing back pain intensity and consistent evidence in two trials (410 patients) that it did not improve back-specific functional status. There was moderate evidence that work status and the use of medical services did not change with treatment. In general, patients treated with acupuncture-like TENS responded similarly to those treated with conventional TENS. However, in two of the trials, inadequate stimulation intensity was used for acupuncture-like TENS, given that muscle twitching was not induced. Adverse effects included minor skin irritation at the site of electrode placement. Authors concluded that the evidence from the small number of placebo-controlled trials does not support the use of TENS in the routine management of chronic LBP. Further research was encouraged.

The American Society of Anesthesiologists (ASA) and American Society of Regional Anesthesia and Pain Medicine (ASRA) support the use of TENS in their revised guideline recommending that "TENS should be used as a multimodal approach to pain management for patients with chronic back pain and may be used for other pain conditions (e.g., neck and phantom limb pain)" (ASA/ASRA, 2010). A Cochrane review that identified 25 eligible RCTs was not favorable in their analysis of the literature support of TENS for various chronic pain conditions, primarily due to the quality of the available literature (Nnoaham and Kumbang, 2008). These authors found positive results for pain relief in 13 out of 22 studies that compared TENS to a placebo or other inactive control group. In studies that compared different TENS modes, seven of nine studies found no difference in pain relief between high vs. low frequency TENS. Overall, the low methodological quality and low power of the available literature did not allow the authors to make firm conclusions regarding the effectiveness of TENS for chronic pain.

In 2013, Pivec et al. studied the clinical and economic impact of TENS in patients with chronic LBP through analysis of a national database. This study evaluated patients who were given TENS compared with a matched group without TENS prior to intervention and at one-year follow-up. Patients who were treated with TENS had significantly fewer hospital and clinic visits, used less diagnostic imaging, had fewer physical therapy visits, and required less back surgery than patients receiving other treatment modalities. Jaurequi et al. (2016) conducted a systematic review and meta-analysis of the efficacy of TENS for the treatment of chronic, musculoskeletal low back pain. Thirteen studies, which included randomized controlled trials, cohort studies, and randomized crossover studies (*n*=267), met inclusion criteria. Follow-ups ranged from 2–24 weeks with a mean follow-up of seven week. The duration of treatment ranged from 2–24 weeks (mean 6 weeks). The overall standardized mean difference in pain from pre- to post-treatment with TENS showed a significant improvement of TENS on pain reduction. When subdivided into treatment

duration, patients that were treated for less than five weeks (*n*=8 studies) had significant effects on pain, while those treated for more than five weeks did not. The heterogeneity among studies was substantially significant among the TENS groups. Limitations of the studies included: small patient populations; variations in treatment times, TENS frequency and length of follow-up; and conflicting outcomes. The authors noted that despite the positive results, large multi-center prospective randomized trials are needed to develop the appropriate treatment protocols for this patient population. According to the AHRQ Comparative Effectiveness publication on Non-Invasive Treatments for Low Back Pain (2016), additional evidence demonstrates that TENS is not effective versus sham TENS. Effectiveness of TENS was previously classified as insufficient, and the strength of evidence remains low because of methodological limitations in the trials and imprecision. Evidence on harms associated with TENS was limited but suggests an increased risk of skin site irritation without an increased risk of serious adverse events (AHRQ, 2016). According to the American College of Physician's Noninvasive Treatments for Acute, Subacute, and Chronic Low Back Pain clinical practice guideline (2017), evidence was insufficient to determine the effectiveness of transcutaneous electrical nerve stimulation (TENS).

Two practice guidelines support the use of TENS, one for rheumatoid arthritis based on positive results in one (1) RCT (Ottawa Panel Evidence-Based Clinical Practice Guidelines, 2004), and one for the treatment of knee osteoarthritis based on meta-analysis of five (5) RCTs included in the analysis (Philadelphia Panel Practice Guidelines, 2001). Johnson et al. (2015) assessed the analgesic effectiveness of TENS, as a sole treatment, for acute pain in adults. Only RCTs of adults with acute pain (< 12 weeks) were examined with TENS given as a sole treatment and assessed pain was with subjective pain scales. The types of acute pain included in this Cochrane Review were procedural pain, e.g., cervical laser treatment, venipuncture, screening flexible sigmoidoscopy and non-procedural pain, e.g., postpartum uterine contractions and rib fractures. There was a high risk of bias associated with inadequate sample sizes in treatment arms and unsuccessful blinding of treatment interventions. Seven trials reported minor adverse effects, such as mild erythema and itching underneath the electrodes and participants disliking TENS sensation. Authors concluded that this review offers tentative evidence that TENS reduces pain intensity over and above that seen with placebo (no current) TENS when administered as a stand-alone treatment for acute pain in adults. The high risk of bias associated with inadequate sample sizes in treatment arms and unsuccessful blinding of treatment interventions makes definitive conclusions impossible.

Jin et al. (2010) conducted a systematic review to evaluate the effectiveness of TENS on diabetic peripheral neuropathy. Three randomized controlled trials (*n*=78) met inclusion criteria. TENS was reported more effective than placebo in the reduction of mean pain score at 4 and 6 weeks follow-up but not at 12 weeks. Pieber et al. (2010) conducted a systematic review of the literature to evaluate electrotherapy, including TENS, for the

treatment of peripheral neuropathy in patients with diabetes. Three randomized controlled trials (*n*=76) and one retrospective review (*n*=54) evaluating TENS met inclusion criteria. The studies included short-term follow-ups and conflicting results. One study reported significant improvement in pain and another study reporting recurrence of pain after cessation of TENS. Due to the small patient populations, short-term treatment duration, short-term follow-up and poor study methodology, large multi-center randomized controlled trials are needed to further evaluate the long-term effect of TENS on diabetic neuropathy. Hurlow et al. (2012) conducted an update review of the 2009 review by Robb et al. One new study met inclusion criteria (*n*=24). There were significant differences in participants, treatments, procedures and symptom measurement tools used in the studies. The clinical utility of TENS for the treatment of cancer pain has not been established. Robb et al. (2009) conducted a systematic review of the literature to evaluate TENS for the treatment of cancer-related pain. Two randomized controlled trials (*n*=64) met inclusion criteria. Meta-analysis was not conducted due to the disparities between patient population, mode of TENS, treatment duration, and outcome measures prevented meta-analysis. There is insufficient evidence to support TENS for the treatment of cancer-related pain.

Mulvey et al. (2010) conducted a systematic review of randomized controlled trials to assess the effectiveness of TENS for the treatment of phantom pain and stump pain following amputation in adults. No studies were identified. Johnson et al. (2015b) conducted an update of this Cochrane review and found no new randomized controlled trials evaluating TENS for the treatment of phantom pain and stump pain. Rheumatoid Arthritis: In a systematic review of the literature, Brosseau et al. (2003) evaluated the effectiveness of TENS for the treatment of rheumatoid arthritis of the hand. Three randomized controlled trials (*n*=78) met inclusion criteria. Conventional TENS (C-TENS) and acupuncture-TENS (acu-TENS) were compared to either placebo or each other. Pain outcomes on the effect of TENS were conflicting. Acu-TENS was beneficial for reducing pain intensity and improving muscle power scores compared to placebo. No clinical benefit on pain was reported with C-TENS compared to placebo. C-TENS resulted in a clinical benefit on the patients' assessment of change compared to acu-TENS. The authors concluded that more well-designed studies with a standardized protocol and adequate numbers of subjects were needed to fully identify the effect of TENS for the treatment of RA of the hand.

Dissanayaka et al. (2016) compared the effectiveness of transcutaneous electrical nerve stimulation and interferential therapy (IFT) both in combination with hot pack, myofascial release, active range of motion exercise, and a home exercise program on myofascial pain syndrome patients with upper trapezius myofascial trigger point. Following randomization of patients into three groups (hot pack, active range of motion exercises, myofascial release, and a home exercise program with postural advice), transcutaneous electrical nerve stimulation-standard care and IFT-standard care-were administered eight times during 4 weeks at regular intervals. Pain intensity and cervical range of motions (cervical

extension, lateral flexion to the contralateral side, and rotation to the ipsilateral side) were measured at baseline, immediately after the first treatment, before the eighth treatment, and 1 week after the eighth treatment. Immediate and short-term improvements were marked in the transcutaneous electrical nerve stimulation group (n = 35) compared with the IFT group (n = 35) and the control group (n = 35) with respect to pain intensity and cervical range of motions ($P < 0.05$). The IFT group showed significant improvement on these outcome measurements than the control group did ($P < 0.05$). Authors concluded that TENS with standard care facilitates recovery better than IFT does in the same combination.

Page et al. (2016) completed a Cochrane Database Systematic Review on electrotherapy modalities for rotator cuff disease. Examples included therapeutic ultrasound, low-level laser therapy (LLLT), transcutaneous electrical nerve stimulation (TENS), and pulsed electromagnetic field therapy (PEMF). These modalities are usually delivered as components of a physical therapy intervention. Authors synthesized the available evidence regarding the benefits and harms of electrotherapy modalities for the treatment of people with rotator cuff disease. Randomized controlled trials (RCTs) and quasi-randomized trials, including adults with rotator cuff disease (e.g., subacromial impingement syndrome, rotator cuff tendinitis, calcific tendinitis), and comparing any electrotherapy modality with placebo, no intervention, a different electrotherapy modality or any other intervention (e.g., glucocorticoid injection) were included. Trials investigating whether electrotherapy modalities were more effective than placebo or no treatment or were an effective addition to another physical therapy intervention (e.g., manual therapy or exercise) were the main comparisons of interest. Main outcomes of interest were overall pain, function, pain on motion, patient-reported global assessment of treatment success, quality of life and the number of participants experiencing adverse events. Most trials (n = 43) included participants with rotator cuff disease without calcification (four trials included people with calcific tendinitis). Sixteen (34%) trials investigated the effect of an electrotherapy modality delivered in isolation. Only 23% were rated at low risk of allocation bias, and 49% were rated at low risk of both performance and detection bias (for self-reported outcomes). The trials were heterogeneous in terms of population, intervention and comparator, so none of the data could be combined in a meta-analysis. Authors were uncertain whether transcutaneous electrical nerve stimulation (TENS) was more or less effective than glucocorticoid injection with respect to pain, function, global treatment success and active range of motion because of the very low-quality evidence from a single trial. Authors concluded that uncertainty exists as to whether TENS is superior to placebo, and whether any electrotherapy modality provides benefits over other active interventions (e.g., glucocorticoid injection) because of the very low quality of the evidence. Further trials of electrotherapy modalities for rotator cuff disease should be based upon a strong rationale and consideration of whether or not they would alter the conclusions of this review.

In an article by Vance et al. (2014) titled "Using TENS for pain control: the state of the evidence," transcutaneous electrical nerve stimulation (TENS) is described as a nonpharmacological intervention that activates a complex neuronal network to reduce pain by activating descending inhibitory systems in the central nervous system to reduce hyperalgesia. Within the article, authors describe the current mechanisms of TENS reduction on analgesia, which is thought to be more complex than previously described. More specifically, TENS activates a complex neuronal network to result in a reduction in pain. At frequencies and intensities used clinically, TENS activates large diameter afferent fibers. This afferent input is sent to the central nervous system to activate descending inhibitory systems to reduce hyperalgesia. Specifically, blockade of neuronal activity in the periaqueductal gray (PAG), rostral ventromedial medulla (RVM) and spinal cord inhibit the analgesic effects of TENS showing that TENS analgesia is maintained through these pathways. In parallel, studies in people with fibromyalgia show that TENS can restore central pain modulation, a measure of central inhibition. Therefore, TENS appears to reduce hyperalgesia through both peripheral and central mechanisms. Authors do report that the evidence for TENS efficacy is conflicting. Sluka et al. (2013) suggests that certain factors should be considered when evaluating the research. These include dosing of TENS, negative interactions with long-term opioid use, the population and outcome assessed, timing of outcome measurement, and comparison groups. Population-specific systemic reviews and meta-analyses are emerging, indicating both high frequency (HF) and low frequency (LF) TENS being shown to provide analgesia, specifically when applied at a strong, non-painful intensity. They conclude that additional research is necessary to determine if TENS has effects specific to mechanical stimuli and/or beyond reduction of pain and will improve activity levels, function and quality of life. These authors are considered experts in the area of TENS research, and they offer these interesting practice points:

- High frequency (HF) and low frequency (LF) transcutaneous electrical nerve stimulation (TENS) activate different opioid receptors. Both applications have been shown to provide analgesia specifically when applied at a strong, non-painful intensity. HF TENS may be more effective for people taking opioids.
- Effective analgesia for chronic pain conditions may be limited by the development of tolerance to TENS if repeated application of either LF or HF TENS at the same frequency and intensity is used daily (i.e., same dose). Strategies to prolong analgesia may include varying these parameters.
- Targeting the use of TENS during movement or activity may be most beneficial.
- TENS may be effective in restoration of central pain modulation, a measure of central inhibition.
- A clearer picture of TENS effectiveness will emerge as trials with attention to optimal dosing and appropriate outcome measures increase in numbers.

Gibson et al. (2019) provided an overview of evidence from Cochrane Reviews of the effectiveness of TENS to reduce pain in adults with chronic pain (excluding headache or

migraine). They included nine reviews investigating TENS use in people with defined chronic pain or in people with chronic conditions associated with ongoing pain. The evidence reported within each review was consistently rated as very low quality. The authors considered the approach of combining sham and no intervention data to be problematic since these different comparisons may be estimating different true effects. Authors found the methodological quality of the reviews was good, but quality of the evidence within them was very low. They were therefore unable to conclude with any confidence that, in people with chronic pain, TENS is harmful, or beneficial for pain control, disability, health-related quality of life, use of pain-relieving medicines, or global impression of change. Pietrosimone et al. (2020) aimed to determine the effect of TENS + therapeutic exercise (TE) on patient-reported function, quadriceps strength, and voluntary activation, as well as physical performance compared with sham TENS + TE (Sham) and TE alone in individuals with symptomatic knee OA and quadriceps voluntary activation failure (QVAF). Ninety individuals participated in a double-blinded randomized controlled trial. Everyone received 10 standardized TE sessions of physical therapy. TENS + TE and Sham groups applied the respective devices during all TE sessions and throughout activities of daily living over 4 wk. Improvements in WOMAC subscales, quadriceps strength, and voluntary activation, 20-m walk times, chair-stand repetitions, and stair-climb time were found at post 1 and post 2 compared with baseline for all groups ($P < 0.05$). WOMAC Pain and Stiffness improved in the TENS + TE group compared with TE alone at post 1 ($P < 0.05$); yet no other between-group differences were found. Authors concluded that TE effectively improved patient-reported function, quadriceps strength, and voluntary activation, as well as physical performance in individuals with symptomatic KOA and QVAF but augmenting TE with TENS did not improve the benefits of TE.

A Best Practices for Chiropractic Management of Patients with Chronic Musculoskeletal Pain: A Clinical Practice Guideline authored by Hawk et al. (2020), stated that for chronic low back pain, TENS or interferential current may be beneficial as part of a multimodal approach, at the beginning of treatment to assist the patient in becoming or remaining active. For chronic neck pain, they recommend TENS and interferential current in the same manner as for chronic low back pain.

Rapazo et al. (2021) investigated the effectiveness of electrical stimulation (ES) for neck pain (NP). Main results showed evidence of moderate quality that ES combined with other intervention significantly decreases the pain intensity compared to other intervention immediately post-treatment and at short-term follow-up; evidence of low quality showed significant effects of ES combined with other intervention in decreasing neck disability compared to other intervention immediately post-treatment; evidence of very-low quality that ES increased the pressure pain threshold compared to placebo immediately post-treatment and that ES + other intervention also increased the pressure pain threshold compared to other intervention at short-term follow-up. Authors concluded that ES

combined with other intervention seems to be useful to relieve pain and to improve disability in people with NP, however, more studies are needed.

Dias et al. (2021) compared the immediate analgesic effect of transcutaneous nerve stimulation (TENS) and interferential current (IFC), with different combinations of parameters, in individuals with chronic low back pain (CLBP). 280 individuals with CLBP were included in the study, both genders, randomized in 8 groups, all individuals underwent a single application of TENS or IFC for 30min. The assessments were carried out prior to the intervention, as well as immediately after, with the following outcomes: pain intensity (Numeric Pain Rating Scale-NPRS), qualitative pain characteristics (McGill Pain Questionnaire-MPQ), and pressure pain threshold (PPT) by pressure algometry (PA) in 4 points of the low back region. Authors concluded that both TENS and IFC presented immediate analgesic effect in CLBP, with emphasis on the interferential current of 4 KHz modulated at 100Hz.

According to the National Institute for Health and Care Excellence (NICE) review (2021), they report the following for TENS:

- TENS versus sham TENS and usual care
    - Quality of life
        - Moderate quality evidence from 1 study with 202 participants showed no clinically important difference between TENS and sham TENS at ≤3 months.
        - Quality of life Moderate to low quality evidence from 1 study with 202 participants showed no clinically important difference between TENS and usual care at ≤3 months.
    - Pain reduction
        - Very low-quality evidence from 2 studies with 242 participants showed a clinically important difference for TENS compared to sham TENS at ≤3 months.
        - Moderate quality evidence from 1 study with 40 participants showed a clinically important difference for TENS at >3 months compared to sham TENS.
        - Low quality evidence from 1 study with 202 participants showed no clinically important difference between TENS and usual care at ≤3 months.
    - Physical function
        - High quality evidence from 1 study with 202 participants showed no clinically important difference between TENS and sham TENS at ≤3 months.
        - High quality evidence from 1 study with 202 participants showed no clinically important difference between TENS and usual care at ≤3 months.

- Psychological distress
  - Moderate to low quality evidence from 1 study with 202 participants showed no clinically important difference between TENS and sham TENS at ≤3 months.
  - Moderate to low quality evidence from 1 study with 202 participants showed no clinically important difference between TENS and usual care at ≤3 months.
- Pain interference
  - Low quality evidence from 1 study with 202 participants showed no clinically important difference between TENS and sham TENS at ≤3 months.
  - Low quality evidence from 1 study with 202 participants showed no clinically important difference between TENS and usual care at ≤3 months.
- Pain self-efficacy
  - High quality evidence from 1 study with 202 participants showed no clinically important difference between TENS and sham TENS at ≤3 months.
  - High quality evidence from 1 study with 202 participants showed no clinically important difference between TENS and usual care at ≤3 months.

Reichenbach et al. (2022) sought to determine the effectiveness of TENS at relieving pain and improving physical function as compared to placebo TENS, and to determine its safety, in patients with knee osteoarthritis. 220 participants with knee osteoarthritis were recruited between October 15, 2012, and October 15, 2014. Patients were randomized to 3 weeks of treatment with TENS (n = 108) or placebo TENS (n = 112). The primary endpoint was knee pain at the end of 3-weeks treatment assessed with the WOMAC pain subscale. Secondary outcome measures included WOMAC physical function subscale and safety outcomes. There was no difference between TENS and placebo TENS in WOMAC pain at the end of treatment, nor throughout the trial duration. Subgroup analyses did not indicate an interaction between patient/treatment characteristics and treatment effect on WOMAC pain at the end of treatment (P-interaction ≥0.22). The occurrence of adverse events was similar across groups, with 10.4% and 10.6% of patients reporting events in the TENS and placebo TENS groups, respectively (P = 0.95). No relevant differences were observed in secondary outcomes. Authors concluded that TENS does not improve knee osteoarthritis pain when compared to placebo TENS. Therapists should consider other potentially more effective treatment modalities to decrease knee osteoarthritis pain and facilitate strengthening and aerobic exercise.

Johnson et al. (2022) investigated the efficacy and safety of transcutaneous electrical nerve stimulation (TENS) for relief of pain in adults in a systematic review and meta-analysis.

The review included 381 RCTs (24, 532 participants). Pain intensity was lower during or immediately after TENS compared with placebo (moderate-certainty evidence). Methodological (e.g., sample size) and pain characteristics (e.g., acute vs chronic, diagnosis) did not modify the effect. Pain intensity was lower during or immediately after TENS compared with pharmacological and non-pharmacological treatments used as part of standard of care (low-certainty evidence). Levels of evidence were downgraded because of small-sized trials contributing to imprecision in magnitude estimates. Data were limited for other outcomes including adverse events which were poorly reported, generally mild and not different to comparators. Authors concluded that there was moderate-certainty evidence that pain intensity is lower during or immediately after TENS compared with placebo and without serious adverse events.

Wu et al. (2022) evaluated the effects of Transcutaneous Electric Nerve Stimulation (TENS) on pain, function, walking ability and stiffness in people with Knee osteoarthritis (KOA). Twenty-nine studies were found (1398 people, age range 54-85, 74% are female) and fourteen were included in this review. Intervention duration was divided as short term (immediately after intervention), medium term (<four weeks) and long term (≥ four weeks). Active TENS showed greater improvement in Visual Analogue Scale (VAS) than sham TENS. Combining TENS with other interventions produced superior outcomes compared with other interventions for VAS in all the terms. In the meanwhile, TENS combined with other interventions was superior to other interventions for the pain subgroup of Western Ontario and McMaster Universities Arthritis Index in the medium term and long term. TENS combined with other interventions was superior to other interventions for function in the medium term and long term. Authors concluded that TENS could significantly relieve pain, decrease dysfunction and improve walking ability in people with KOA, but it is not effective for stiffness.

Beltran-Alacreu et al. (2022) determined if the use of PENS is more effective and should be recommended when compared to TENS for the reduction of musculoskeletal pain intensity. Nine RCTs were included in the qualitative analysis, with seven of them in the quantitative analysis (n = 527). The overall effect of PENS on pain was statistically but not clinically superior to TENS with a high level of heterogeneity. When only studies with a lower risk of bias (n = 3) were analyzed, the heterogeneity decreased, and no difference was observed between TENS and PENS with a moderate recommendation level according to GRADE. There were no data concerning adverse effects. There is low-quality of evidence for more pain intensity reduction with PENS, but the difference was not clinically significant. However, when only studies with low risk of bias are meta-analyzed, there is a moderate quality of evidence that there is no difference when TENS or PENS is applied for pain intensity.

Evans et al. (2022) summarized the reported efficacy of transcutaneous single nerve stimulators in management of migraine frequency and severity. Fourteen studies, which

treated 995 patients, met inclusion criteria, including 7 randomized controlled trials and 7 uncontrolled clinical trials. Transcutaneous nerve stimulators reduced headache frequency in episodic migraines (2.81 fewer headache days per month, 95% CI 2.18-3.43, I2 = 21%) and chronic migraines (2.97 fewer headache days per month). Transcutaneous nerve stimulators reduced headache severity in episodic headaches (2.23 fewer pain scale points). Authors concluded that preventive use of transcutaneous nerve stimulators provided clinically significant reductions in headache frequency in individuals with chronic or episodic migraines. Individuals with episodic migraines also experienced a reduction in headache pain severity following preventive transcutaneous nerve stimulation.

Fertout et al. (2022) assessed the efficacy of transcutaneous electrical nerve stimulation (TENS) for the management of temporomandibular disorders (TMD) and to determine the indications and most appropriate application modalities in a systematic review. Fourteen articles were retained, corresponding to a total of 532 patients, among which, 285 had a TMD. Immediately after a TENS session, significant relief of pain (19.2% to 77%), significant functional improvement (mouth opening amplitude increased by between 8.7% and 19.46%), and reduced electromyographic activity of the anterior temporalis and masseter muscles were observed. However, studies comparing TENS to other physical medicine modalities (ultrasound and laser) reported equivalent results. Authors concluded that further randomized comparative clinical trials will be necessary to optimize the use of TENS (program, duration of sessions, duration of treatment) for different types of TMD.

Vance et al. (2022) addressed the continued uncertainty about the clinical efficacy of TENS to alleviate pain, despite years of research and note that this uncertainty is related to the quality of the clinical trials included in systematic reviews. This summary of the evidence includes only trials with pain as the primary outcome. In comparison with their 2014 review, there appears to be improvement in adverse events and parameter reporting. Importantly, stimulation intensity has been documented as critical to therapeutic success. Examinations of the outcomes beyond resting pain, analgesic tolerance, and identification of TENS responders remain less studied areas of research. This literature review supports the conclusion that TENS may have efficacy for a variety of acute and chronic pain conditions, although the magnitude of the effect remains uncertain due to the low quality of existing literature. In order to provide information to individuals with pain and to clinicians treating those with pain, authors suggest that resources for research should target larger, high-quality clinical trials including an adequate TENS dose and adequate timing of the outcome and should monitor risks of bias. Systematic reviews and meta-analyses should focus only on areas with sufficiently strong clinical trials that will result in adequate sample size.

Davison et al. (2022) systematically reviewed and evaluated available literature examining the effectiveness of using electrical stimulation to promote clinical outcomes after hip fractures. Initial screening indicated 24 articles were appropriate for full-text review, and

four articles met the inclusion criteria. In included studies, electrical stimulation (i.e., TENS) reduced pain (mean difference (MD) = 3.3 points on 10-point Visual Analogue Scale, $p < .001$), improved range of motion (ROM) (MD: 25.7°, $p < .001$), and accelerated functional recovery immediately after hip fracture ($p < .001$). Conflicting evidence existed when using neuromuscular electrical stimulation to improve muscle strength and other functional outcomes (e.g., mobility); however, nine experts advised that longer-term interventions might be necessary to achieve significant improvement in muscle strength. Authors concluded that the available evidence, albeit limited, supports the early application of noninvasive electrical stimulation (e.g., TENS) for improving clinical outcomes (i.e., reducing pain, improving ROM, and accelerating functional recovery after hip fractures). They could not find conclusive evidence on the effectiveness of using electrical stimulation to improve muscle strength. This review establishes the need for future additional high-quality trials in this field.

Leemans et al. (2022) estimated the effects of musculoskeletal rehabilitation interventions on movement-evoked pain and to explore the assessment methods/protocols used to evaluate movement-evoked pain in adults with musculoskeletal pain. Meta-analysis was conducted for outcomes with homogeneous data from at least 2 trials. The mean change in movement-evoked pain was the primary outcome measure. Thirty-eight trials were included, and 60 different interventions were assessed. There was moderate-certainty evidence of a beneficial effect of exercise therapy compared to no treatment on movement-evoked pain in adults with musculoskeletal pain. There was low-certainty evidence of a beneficial effect of transcutaneous electrical nerve stimulation compared to no treatment. There was no benefit of transcutaneous electrical nerve stimulation when compared to sham transcutaneous electrical nerve stimulation.

Microcurrent Electrical Nerve Stimulation

There is insufficient evidence in the published peer-reviewed scientific literature to support the safety and effectiveness of MENS including frequency specific microcurrent (FSM). Studies include small patient populations and short-term follow-ups with conflicting outcomes and in some cases reported outcomes were no better than placebo (Rajpurohit et al., 2010; Zuim et al., 2006). More recently, microcurrent, using very small electrical devices contained within wound dressings, has been evaluated as a therapy to speed the closure of chronic wounds. However, research published to date has not produced findings that suggest this form of ES can accelerate wound closure (Houghton, 2014). Nair (2018) did not some positive findings for wound healing, however more research is needed to confirm results. Iijima and Takahashi (2021) summarized the level of knowledge regarding the effects of microcurrent therapy (MCT) on musculoskeletal pain in adults. Randomized controlled trials (RCTs) investigating the effects of MCT on musculoskeletal pain were included. Additionally, non-RCTs were included to assess the adverse events. The primary outcomes were pain and adverse events related to MCT. A comprehensive assessment of 4 RCTs and 5 non-RCTs that met the inclusion criteria revealed that MCT significantly

improved shoulder pain (1 study, 40 patients) and knee pain (1 study, 52 patients) compared with sham MCT without any severe adverse events. MCT has clinically significant benefits for knee pain. This study also revealed a clinically significant placebo response in treating knee pain. This evidence highlights the substantial effect of placebo response in clinical care. Authors concluded that the findings of this meta-analysis highlight the effect of placebo response in treating knee pain. MCT is a potential, core nonpharmacologic treatment option in clinical care with minimal adverse events and should be further investigated.

H-WAVE®

There is insufficient evidence in the published peer reviewed scientific literature to support the safety and effectiveness of the H-WAVE® electrical stimulators. Blum et al. (2008) conducted a systematic review and meta-analysis of randomized and nonrandomized controlled trials to evaluate the safety and efficacy of H-WAVE® therapy. Five studies (*n*=6535) met inclusion criteria. H-WAVE® was shown to decrease pain across various chronic soft tissue inflammation and neuropathic pain conditions, decrease pain medication intake (*n*=2 studies) and increase functionality (*n*=2 studies). However, author-noted limitations of the studies included the heterogeneity of the studies, inconsistency of the effects (e.g., reduction in pain medication, functionality), data were obtained from cross-sectional studies, data were subjective in nature (i.e., there were no formal examination findings, test results and/or laboratory values), various outcome measures, potential selection bias of publications for this review, and due to a lack of reported data it was not possible to statistically evaluate the safety of the therapy. Williamson et al. (2021) systematically searched human clinical studies on H-Wave® device stimulation (HWDS) was conducted as well as a comprehensive review of articles articulating possible HWDS mechanisms of action. Studies unrelated to H-Wave® were excluded. Multiple clinical studies have reported significant benefits for diabetic and non-specific neuropathic pain, where function also improved, and pain medication usage substantially dropped. Authors concluded that low- to moderate-quality HWDS studies have reported reduced pain, restored functionality, and lower medication use in a variety of disorders, although higher-quality research is needed to verify condition-specific applicability. HWDS has enough reasonable evidence to be considered as an adjunctive component of non-opioid multi-modal pain management, given its excellent safety profile and relative low cost. It is important to consider that two authors have a conflict of interest as they are consultants for Electronic Waveform Lab Inc. and have an interest in a positive outcome.

Interferential Current (IFC)

Studies for IFC are primarily in the form of case reports, case series and some randomized controlled trials with small patient populations, short-term treatment sessions and short-term follow-ups. Randomized controlled trials with large patient populations and long-term follow-ups comparing IFT to established treatment options are lacking. The California Technology Assessment Forum (2005) evaluated the literature on IFT for the treatment of

musculoskeletal pain and concluded that this treatment modality has not been shown to be as beneficial as alternative treatments such as nonsteroidal anti-inflammatory drugs and exercise therapy. Although IFT was found to be a generally safe technique, it did not meet the CTAF technology assessment criteria for the treatment of musculoskeletal pain. Fuentes et al. (2010) conducted a systematic review and meta-analysis of randomized controlled trials (*n*=20) to evaluate the pain-reducing effectiveness of IFC in the management of musculoskeletal pain. Twenty studies met inclusion criteria. Seven studies assessed IFC for joint pain (e.g., osteoarthritis), nine for muscle pain (e.g., low back pain, neck pain), three for soft tissue shoulder pain (e.g., tendinitis) and one for postoperative pain. Three studies were considered to be of poor methodological quality, 14 of moderate quality and three of high quality. Methodological issues included small sample sizes, heterogeneity of patient population, inappropriate handling of withdrawals and dropouts, and lack of appropriate randomization, concealment of allocation and blinding of patients and assessors. Fourteen studies (*n*=1114) were used for meta-analysis. Only three studies reported adverse events (e.g., blisters, burns, bruising, swelling). The authors concluded that the analgesic effect that IFC is superior to that of the concomitant interventions was unknown; IFC alone was not significantly better than placebo or other therapy at discharge or follow-up; the heterogeneity across studies and methodological limitations prevented conclusive statements regarding analgesic efficacy; and the results should be viewed with caution due to the limited number of studies that used IFC as a monotherapy. The American College of Physicians and the American Pain Society Joint Clinical Practice Guideline for the Diagnosis and Treatment of LBP (Chou and Huffman 2007) concluded that there was not enough evidence to support the use of interferential therapy, TENS, traction, ultrasound, or short-wave diathermy for acute or chronic LBP. These results were based on systematic reviews and randomized trials of one or more of the aforementioned therapies for treatment of acute or chronic LBP that reported pain outcomes, back specific function, general health status, work disability or patient satisfaction. In a review by Poitras and Brosseau (2008), they determined that due to limited studies of sufficient quality, no recommendations could be made for the use of ultrasound, interferential current, or electrical muscle stimulation for the treatment of chronic LBP.

Facci et al. (2011) compared the effects of TENS and interferential current among patients with nonspecific chronic low back pain. One hundred and fifty patients were randomly divided into three groups: TENS (group 1), interferential current (group 2) and controls (group 3). The patients designated for electrotherapy received ten 30-minute sessions, while the control group remained untreated. All patients and controls were evaluated before and after treatment using a visual analog scale and the McGill Pain and Roland Morris questionnaires, and regarding their use of additional medications. Results showed no statistically significant difference between the TENS and interferential current groups. The only difference was found between these groups and the controls, with noted improvement in outcome measures for the treatment groups.

According to the AHRQ publication on Non-Invasive Treatments for Low Back Pain (2016), insufficient evidence from four trials exists regarding the effectiveness of interferential therapy versus other interventions, or interferential therapy plus another intervention versus the other interventions alone for low back pain, due to methodological limitations and imprecision. According to the American College of Physician's Noninvasive Treatments for Acute, Subacute, and Chronic Low Back Pain clinical practice guideline (2017), evidence was insufficient to determine the effectiveness of electrical muscle stimulation and inferential therapy.

Rutjes et al. (2009) conducted a systematic review of randomized or quasi-randomized controlled trials of electrical stimulation, including IFT (*n*=4 studies), for the treatment of osteoarthritis of the knee. Due to the poor methodological and reporting quality of the studies, the effectiveness of IFT could not be confirmed.

Zeng et al. (2015) investigated the efficacy of different electrical stimulation (ES) therapies in pain relief of patients with knee osteoarthritis (OA). 27 trials and six kinds of ES therapies, including high-frequency transcutaneous electrical nerve stimulation (h-TENS), low-frequency transcutaneous electrical nerve stimulation (l-TENS), neuromuscular electrical stimulation (NMES), interferential current (IFC), pulsed electrical stimulation (PES), and noninvasive interactive neurostimulation (NIN), were included. IFC was the only significantly effective treatment in terms of both pain intensity and change pain score at last follow-up time point when compared with the control group. Meanwhile, IFC showed the greatest probability of being the best option among the six treatment methods in pain relief. However, the evidence of heterogeneity and the limitation in sample size of some studies could be a potential threat to the validity of results. Authors also state that although the recommendation level of the other ES therapies is either uncertain (h-TENS) or not appropriate (l-TENS, NMES, PES and NIN) for pain relief, it is likely that none of the interventions is dangerous.

Almeida et al. (2018) investigated the effects of transcutaneous electrical nerve stimulation and interferential current on acute and chronic pain. Eight studies with a pooled sample of 825 patients were included. In general, both transcutaneous electrical nerve stimulation and interferential current improved pain and functional outcomes without a statistical difference between them. Authors concluded that transcutaneous electrical nerve stimulation and interferential current have similar effects on pain outcome The low number of studies included in this meta-analysis indicates that new clinical trials are needed.

In 2019, Kadi et al. (2019) evaluated IFS for treating pain after total knee arthroplasty surgery. A total of 113 individuals were randomized to IFS (*n*=57) or sham treatment (*n*=56). There were 98 individuals (87%) who completed the study. After 30 days, there was no significant difference between groups in pain assessed by a VAS, 0.278. Pain medication use (paracetamol) also did not differ significantly between groups after

treatment and neither did outcome measures assessing range of motion or edema. In this study, IFS was not beneficial at improving outcomes after total knee arthroplasty.

Hussein et al. (2022) aimed to analyze the recently available information regarding the efficacy of IFC in alleviating the pain of musculoskeletal origin. This review included 35 trials of variable methodological quality from which 19 trials were selected for the meta-analysis. In general, IFC alone versus placebo demonstrated a significant pain-relieving effect. On the other hand, IFC showed no significant difference when added to standard treatment compared to placebo plus standard treatment or standard treatment alone. Similarly, IFC showed no significant difference when compared to other single interventions (laser, TENS, cryotherapy). Authors concluded that IFC alone is better than placebo at discharge. However, the low number of studies raises suspicions about this conclusion. IFC alone or added to other interventions is not more effective than comparative treatments in relieving musculoskeletal pain.

Chen et al. (2022) conducted a systematic review and meta-analysis to assess the effectiveness of interferential current therapy (IFC) in patients with knee osteoarthritis. Ten RCTs with 493 patients met the inclusion criteria. Nine RCTs were included in the meta-analysis. The IFC groups exhibited significant improvements relative to the control groups for short-term pain scores, long-term pain scores, and short-term Western Ontario and McMaster Universities Osteoarthritis Index scores. All included studies did not observe any obvious adverse effects of IFC. IFC can be recommended as a treatment for knee osteoarthritis because it improves short- and long-term pain and short-term function. However, large-scale and high-quality RCTs with longer follow-up are required to establish an appropriate standardized treatment.

High Volt Galvanic Stimulation (HVGS)

The few studies identified in the literature addressing HVGS were mostly randomized clinical trials and case studies published before 1997 with small patient populations and short-term follow-up. Patient selection criteria were lacking. More recently, Snyder et al. (2010) systematically reviewed the basic-science literature regarding the effects of high-voltage pulsed stimulation (HVPS) for edema control. Included studies investigated HVPS and its effect on acute edema formation and included outcome measures specific to edema. Eleven studies met the inclusion criteria. Studies were critiqued by electrical stimulation treatment parameters: mode of stimulation, polarity, frequency, duration of treatment, voltage, intensity, number of treatments, and overall time of treatments. According to Snyder et al., (2010), the available evidence indicates that HVPS administered using negative polarity, pulse frequency of 120 pulses/s, and intensity of 90% visual motor contraction may be effective at curbing edema formation. In addition, according to authors, evidence suggests that treatment should be administered in either four 30-min treatment sessions (30-min treatment, 30-min rest cycle for 4 h) or a single, continuous 180-min session to achieve the edema-suppressing effects. Often such treatment occurs in an athletic

training room for college athletes and may not be feasible in an outpatient clinical setting. Authors suggest that findings supported by the basic science research provides a general list of treatment parameters that may successfully manage the formation of edema after acute injury in animal subjects They believe this should facilitate further research related to HVPS and the effects on edema in humans. At this time, there is insufficient evidence in the published peer reviewed scientific literature to support the safety and efficacy of HVG/HVPS stimulation.

PENS and PNT

There is insufficient evidence in the published peer-reviewed literature to support the safety and effectiveness of PENS or PNT as a treatment option for chronic pain. Overall, studies have included small patient populations and short-term follow-ups. For low back pain, most of the literature is of poor quality with all trials evaluating chronic low back pain. In a technology brief, Hayes (2017) investigated the effectiveness of PENS for the treatment of low back pain (LBP). Three randomized controlled trials (*n*=34 to 200) evaluated the efficacy and safety of PENS for chronic LBP (CLBP) in adults and one study evaluated PNT for subacute radiating LBP. Hayes rated the studies as very low-quality of evidence. There was no clinically significant improvement with the use of PENS. When compared with other therapies, PENS monotherapy was favored over treatment with PENS followed by TENS or TENS alone at one month; however, the difference was not maintained at two months. Another study reported no difference in outcomes with PENS vs. sham. There is insufficient evidence to support PENS for the treatment of LBP. Weiner et al. (2008) conducted a randomized controlled trial (*n*=200) to evaluate the efficacy of PENS in adults with chronic low back pain. Patients were randomized to either 1) PENS, 2) brief electrical stimulation to control for treatment expectance (control-PENS), 3) PENS plus general conditioning and aerobic exercise (GCAE) or to 4) control-PENS plus GCAE. Treatment was delivered twice a week for six weeks to the 50 participants in each group. All groups reported significantly reduced pain (McGill Pain Questionnaire short form) and disability and improved gait velocity, which was sustained at six months. Significantly fewer fear avoidance beliefs were reported in the CGAE group compared to the non-CGAE group. Comparable reduced pain and function were reported by the PENS and control-PENS group, whether delivered for five minutes or 30 minutes. Thus, the exact dose of electrical stimulation needed for analgesia could not be determined. PENS and GCAE were more effective than PENS alone in reducing fear avoidance beliefs, but not in reducing pain or in improving physical function. There was a statistically significant improvement in chair rise time in the control-PENS plus CGAE compared to control-PENS alone. The overall drop-out rate was 8%. In the Agency for Healthcare Research and Quality (AHRQ) publication "Noninvasive Treatments for Low Back Pain" by Chou et al. (2016), the two studies on PENS that were of fair quality contradicted one another, as one found that PENS plus exercise was superior to sham plus exercise, while the other did not. Some studies looked at LBP with radicular signs while others did not or were unclear. Overall, the literature doesn't support PENS for treatment of chronic low back pain without radicular

symptoms. There was insufficient evidence to determine effects of PENS versus sham, PENS plus exercise versus exercise alone, or PENS versus other interventions (TENS), due to methodological limitations and imprecision. Harms were poorly reported in trials of PENS.

Kang et al. (2007) conducted a single-blinded, randomized study of 63 patients with knee pain secondary to osteoarthritis. Twenty-eight patients were randomly assigned to the sham group and 35 to the live treatment group. The study investigated the efficacy of PNT in reducing knee pain and medication consumption during the first week following treatment. Pain levels were rated on a 100-mm visual analog pain scale. The live group had greater efficacy than the sham group in all time periods; however, only in the immediate post-treatment period did it reach statistical significance (p=0.0361). The overall median pain intensity difference over all periods was 14.5 for the live group and 6.5 for the sham group and reached statistical significance. At one week follow-up, the live group reported significantly less medication use than the sham group. Plaza-Manzano et al. (2020) evaluated the effects of percutaneous electrical stimulation (PENS) alone or as an adjunct with other interventions on pain and related disability in musculoskeletal pain conditions. Sixteen studies were included and included heterogeneous musculoskeletal conditions with short- or midterm follow-ups. The risk of bias was generally low; but the heterogenicity of the results downgraded the level of evidence. Authors concluded that there is low level of evidence suggesting the effects of PENS alone or in combination for pain, but not related disability, in musculoskeletal pain.

Beltran-Alacreu et al. (2022) aimed to determine if the use of PENS was more effective and should be recommended when compared to TENS for the reduction of musculoskeletal pain intensity. Studies published until 31/12/2020, comparing the effectiveness of PENS and TENS, were considered. The main outcome was pain assessed with a visual analog scale or numerical pain rating scale. Nine RCTs were included in the qualitative analysis, with seven of them in the quantitative analysis (n = 527). The overall effect of PENS on pain was statistically but not clinically superior to TENS with a high level of heterogeneity. When only studies with a lower risk of bias (n = 3) were analyzed, no difference was observed between TENS and PENS with a moderate recommendation level according to GRADE. There were no data concerning adverse effects. There was low-quality of evidence for more pain intensity reduction with PENS, but the difference was not clinically significant. However, when only studies with low risk of bias are meta-analyzed, there was a moderate quality of evidence that there is no difference when TENS or PENS is applied for pain intensity.

According to National Institute for Health and Care Excellence (NICE), regarding PENS:

- PENS versus sham PENS
  - Quality of life
    - Low quality evidence from 1 study with 89 participants showed a clinically important benefit of PENS compared to sham PENS at ≤3 months.
    - Very low to low quality evidence from 1 study with 24 participants showed a clinically important benefit of PENS compared to usual care at ≤3 months.
  - Pain reduction
    - Low quality evidence from 1 study with 89 participants showed a clinically important benefit of PENS compared to sham PENS at ≤3 months.
    - Low quality evidence from 1 study with 24 participants showed a clinically important benefit of PENS compared to usual care at ≤3 months.

NMES and FES

Electric stimulated muscle contraction/neuromuscular electric stimulation (NMES) has been found to enhance muscle function post surgically. Patients who have received an ACL reconstruction have demonstrated accelerated recovery and greater muscle function when NMES is used in combination with exercise; however, the impact on functional outcomes is inconsistent (Cameron, 2017). Similar results were noted with knee OA patients and for other inflammatory conditions of the knee. Most research studied the use of NMES on the quadriceps muscle, however clinically NMES may be used for other joints and muscle groups (Cameron, 2017). NMES has been shown to be part of an effective rehabilitative regimen for patients following ligament/knee surgery. It may help prevent muscle atrophy associated with knee immobilization, may enable patients to ambulate sooner, and may reduce the use of pain medication as well as length of hospital stay (Arvidsson, 1986; Lake, 1992; Gotlin et al, 1994; Snyder-Mackler et al, 1991 and 1995). Bax et al (2005) systematically reviewed the available evidence for the use of NMES in increasing strength of the quadriceps femoris. The authors concluded that limited evidence suggests that NMES can improve strength in comparison with no exercise, but volitional exercises appear more effective in most situations. The authors' cautious conclusions reflect the general poor quality of the included studies. It is also important to understand that at the time NMES is used, it is to re-education the neuromuscular system and engage more motor units with muscle contraction. Given this, the mechanism of strength increase is likely due to improved neuromuscular action vs. a true strength increase of the muscle.

Monaghan et al. (2010) completed a Cochrane review regarding the effectiveness of NMES as a means of increasing quadriceps strength in patients before and after total knee replacement. Only two studies were identified for inclusion in the review. No significant

differences were reported in either study for maximum voluntary isometric torque or endurance between the NMES group and the control group, but significantly better quadriceps muscle activation was reported in the exercise and neuromuscular stimulation group compared with the exercise group alone in the second study. This difference was significant at the mid training (six week) time point but not at the twelfth week post training time point. Both studies carried a high risk of bias. Mean values were not given for strength, endurance, cross sectional area or quality of life. Pain outcomes, patient satisfaction or adverse effects were not reported in either study. The results were presented as percentage improvements from baseline and the number of subjects in each group was unclear. Authors concluded that the studies found in this review do not permit any conclusions to be made about the application of neuromuscular stimulation for the purposes of quadriceps strengthening before or after total knee replacement. At that time the evidence for the use of neuromuscular stimulation for the purposes of quadriceps strengthening in this patient group is unclear.

Kim et al. (2010) performed a systematic review of RCTs assessing the effects of NMES on quadriceps strength, functional performance, and self-reported function after ACL reconstruction. Eight randomized controlled trials were included. Authors concluded that NMES combined with exercise may be more effective in improving quadriceps strength than exercise alone, whereas its effect on functional performance and patient-oriented outcomes is inconclusive. Inconsistencies were noted in the NMES parameters and application of NMES. Imoto et al. (2011) systematically evaluated the effectiveness of electrical stimulation on rehabilitation after ligament and meniscal injuries. Seventeen studies evaluating ES after anterior cruciate ligament reconstruction and two studies evaluating ES after meniscectomy were included. There was a statistically significant improvement in quadriceps strength through ES and in functional outcomes six to eight weeks after surgical reconstruction of the anterior cruciate ligament. Authors concluded that there is evidence that ES coupled with conventional rehabilitation exercises may be effective in improving muscle strength and function two months after surgery. Maddocks et al. (2013) evaluated the effectiveness of NMES for improving muscle strength in adults with advanced disease and to examine the acceptability and safety of NMES, and changes in muscle function (strength or endurance), muscle mass, exercise capacity, breathlessness and health-related quality of life. They included randomized controlled trials (RCTs) in adults with advanced chronic obstructive pulmonary disease (COPD), chronic heart failure, cancer or human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS) comparing a program of NMES as a sole or adjunct intervention to no treatment, placebo NMES or an active control. Eleven studies involving a total of 218 participants met the inclusion criteria across COPD, chronic heart failure and thoracic cancer. Authors concluded NMES appears an effective means of improving muscle weakness in adults with progressive diseases such as COPD, chronic heart failure and cancer. Further research is needed to confirm findings and determine most effective parameters.

Bemner et al. (2016) completed a critically appraised topic on the effectiveness of neuromuscular electrical stimulation in improving voluntary activation of the quadriceps. Four randomized controlled trials (RCTs) met the inclusion criteria and were included. Of the included studies, one reported statistically significant improvements in quadriceps voluntary activation in the intervention group relative to a comparison group, but the statistical significance was not true for another study consisting of the same sample of participants with a different follow-up period. One study reported a trend in the NMES group, but the between group differences were not statistically significant in three of the four RCTs. Current evidence does not support the use of NMES for the purpose of enhancing quadriceps voluntary activation in patients with orthopedic knee conditions. There is level B evidence that the use of NMES alone, or in conjunction with therapeutic exercise, does not enhance quadriceps voluntary activation in patients with orthopedic knee conditions (e.g., anterior cruciate ligament injuries, osteoarthritis, total knee arthroplasty).

Jones et al. (2016) updated a Cochrane Database review on the effectiveness of neuromuscular electrical stimulation for quadriceps muscle weakness in adults with advanced disease. Programs of NMES appear to be acceptable to patients and have led to improvements in muscle function, exercise capacity, and quality of life. However, estimates regarding the effectiveness of NMES based on individual studies lack power and precision. Randomized controlled trials in adults with advanced chronic respiratory disease, chronic heart failure, cancer, or HIV/AIDS comparing a program of NMES as a sole or adjunct intervention to no treatment placebo NMES, or an active control were included. Eighteen studies (20 reports) involving a total of 933 participants with COPD, chronic respiratory disease, chronic heart failure, and/or thoracic cancer met the inclusion criteria for this update, an additional seven studies since the previous version of this review. All but one study that compared NMES to resistance training compared a program of NMES to no treatment or placebo NMES. Most studies were conducted in a single center and had a risk of bias arising from a lack of participant or assessor blinding and small study size. The quality of the evidence using GRADE comparing NMES to control was low for quadriceps muscle strength, moderate for occurrence of adverse events, and very low to low for all other secondary outcomes. The included studies reported no serious adverse events and a low incidence of muscle soreness following NMES. NMES led to a statistically significant improvement in quadriceps muscle strength. An increase in muscle mass was also observed following NMES, though the observable effect appeared dependent on the assessment modality used. Across tests of exercise performance, mean differences compared to control were statistically significant for the 6-minute walk, but not for the incremental shuttle walk, endurance shuttle walk, or for cardiopulmonary exercise testing with cycle ergometry. Authors concluded that NMES may be an effective treatment for muscle weakness in adults with advanced progressive disease and could be considered as an exercise treatment for use within rehabilitation programs. Further research is very likely to have an important impact on the confidence in the estimate of effect and may

change the estimate. Further research to understand the role of NMES as a component of, and in relation to, existing rehabilitation approaches is needed.

Gatewood et al. (2017) aimed to investigate the efficacy of device modalities used following arthroscopic knee surgery. Outcome measures included: muscle strength, range of motion, swelling, blood loss, pain relief, narcotic use, knee function evaluation and scores, patient satisfaction and length of hospital stay. Twenty-five studies were included in this systematic review, nineteen of which found a significant difference in outcomes. Authors concluded that NMES improve quadriceps strength and overall knee functional outcomes following knee surgery. Yue et al. (2018) assessed the evidence relative to the comparative effectiveness of neuromuscular electrical stimulation (NMES), transcutaneous electrical nerve stimulation (TENS), and electroacupuncture (EA) for improving patient rehabilitation following total knee arthroplasty (TKA). Data were analyzed from 17 randomized controlled trials involving 1285 procedures: 8 NMES studies (608 procedures), 7 TENS studies (560 procedures), and 2 EA studies (117 procedures). Qualitative analysis suggested that NMES was associated with higher quadriceps strength and functional recovery after TKA. Recovery benefits were maximal when the stimulation was performed once or twice a day for 4-6 weeks at an intensity of 100-120 mA and frequency of 30-100 Hz. The electrode should be sufficiently large (100-200 cm2) to reduce discomfort. TENS at an intensity of 15-40 mA and frequency of 70-150 Hz provided effective analgesia after TKA. EA at an intensity of 2 mA and frequency of 2 Hz may also provide postoperative analgesia of TKA. Authors concluded that as adjunct modalities, NMES and TENS can effectively improve rehabilitation after TKA without triggering significant intolerance, and maximal benefits depend on optimized parameters and intervention protocols. EA may be an effective adjunct modality for analgesia after TKA.

Novak et al. (2020) sought to provide guidelines for treatment parameters regarding electrical stimulation by investigating its efficacy in improving muscle strength and decreasing pain in patients with knee osteoarthritis. Nine randomized control trials were included in the review. First, the review confirmed that neuromuscular electrical stimulation is the most effective electrical stimulation treatment in the management of knee OA, and its efficiency is higher when combined with a strengthening program. Second, frequency of at least 50 Hz and no more than 75 Hz with a pulse duration between 200 and 400 μs and a treatment duration of 20 mins is necessary for successful treatment. Peng et al. (2021) evaluated the effect of neuromuscular electrical stimulation (NMES) on quadriceps muscle strength, pain, and function outcomes following total knee arthroplasty (TKA). Nine RCTs that involved 691 patients were included in the meta-analysis. Pooled analysis showed that NMES improved quadriceps muscle strength after TKA within 1 month, 1-2 months, 3-4 months, and 12-13 months; pain between 1 and 2 months and between 3 and 6 months, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) between 3 and 4 months, timed up and go test (TUG) within 1 month, 3 minute walk test between 3 and 6 months, and SF-36 MCS between 3 and 6 months after TKA.

Authors concluded that as a supplementary treatment after TKA, postoperative NMES could improve the short-term to long-term quadriceps muscle strength, mid-term pain, and mid-term function following TKA. However, many outcomes failed to achieve statistically meaningful changes and minimal clinically important difference (MCID), thus the clinical benefits remained to be confirmed.

Labanca et al. (2022) investigated whether adding NMES to TKA rehabilitation leads to a better quadriceps strength recovery in comparison with standardized rehabilitation. A second aim was to investigate which are the most commonly used NMES pulse settings and their effectiveness. Intervention studies evaluating the effects of a rehabilitation intervention based on quadriceps NMES in patients undergoing TKA were retrieved. Four studies met the inclusion criteria. Due to the limited number and the heterogeneity of the selected studies, it was not appropriate to carry out a meta-analysis. All the studies reported higher quadriceps strength in patients undergoing quadriceps NMES, particularly early after TKA. The addition of NMES or traditional strength training shows similar long-term effects. Short duration and low-intensity NMES have limited effects on quadriceps strength. Heterogeneity was found on NMES methodologies and pulse settings. In conclusion, NMES is effective for quadriceps strength recovery following TKA. NMES intensity and duration are essential for good NMES outcomes on quadriceps strength. Further studies on NMES methodologies, pulse features and settings are required to address the gaps in knowledge on NMES following TKA.

Culvenor et al. (2022) synthesized the evidence for effectiveness of rehabilitation interventions following ACL and/or meniscal tear on symptomatic, functional, clinical, psychosocial, quality of life and reinjury outcomes. Authors included 22 systematic reviews (142 trials of mostly men) evaluating ACL-injured individuals and none evaluating isolated meniscal injuries. Authors synthesized data from 16 reviews evaluating 12 different interventions. Moderate-certainty evidence was observed for: (1) neuromuscular electrical stimulation to improve quadriceps strength; (2) open versus closed kinetic chain exercises to be similarly effective for quadriceps strength and self-reported function; (3) structured home-based versus structured in-person rehabilitation to be similarly effective for quadriceps and hamstring strength and self-reported function; and (4) postoperative knee bracing being ineffective for physical function and laxity. There was low-certainty evidence that: (1) preoperative exercise therapy improves self-reported and physical function postoperatively; (2) cryotherapy reduces pain and analgesic use; (3) psychological interventions improve anxiety/fear; and (4) whole body vibration improves quadriceps strength. There was very low-certainty evidence that: (1) protein-based supplements improve quadriceps size; (2) blood flow restriction training improves quadriceps size; (3) neuromuscular control exercises improve quadriceps and hamstring strength and self-reported function; and (4) continuous passive motion has no effect on range of motion. Authors concluded that the general level of evidence for rehabilitation after ACL or meniscal tear was low. Moderate-certainty evidence indicates that several rehabilitation

types can improve quadriceps strength, while brace use has no effect on knee function/laxity.

The main goal of stroke rehabilitation is to improve function to allow patients greater independence in their activities of daily living, resulting in an improvement in quality of life. Typical treatment techniques of stroke rehabilitation comprise various combination of range of motion (ROM) and muscle strengthening exercises, mobilization activities, and compensatory techniques. Other key therapies include neurophysiological and/or developmental based methods in which the treatment program incorporates neuromuscular re-education techniques. It is in these situations that FES is used for stroke rehabilitation. It has been utilized to manage contracture of joints, maintain ROM, facilitate voluntary motor control, and reduce spasticity. However, there is insufficient evidence that FES is effective as a rehabilitative tool for patients who suffered strokes. In particular, there are little data supporting the long-term effectiveness of this modality for stroke rehabilitation and other neurologic conditions. In a Cochrane review, Price and Pandyan (2000) ascertained the effectiveness of any form of surface electric stimulation in the prevention and/or treatment of pain around the shoulder at any time after stroke. These investigators concluded that the evidence from randomized controlled studies so far does not confirm or refute that ES around the shoulder after stroke influences reports of pain, but there do appear to be benefits for passive humeral lateral rotation. A possible mechanism is through the reduction of glenohumeral subluxation. The authors stated that further studies are needed. Van Peppen et al (2004) determined the evidence for physical therapy interventions aimed at improving functional outcome after stroke. 151 studies were included in this systematic review; 123 were randomized controlled trials (RCTs) and 28 controlled clinical trials (CCTs). Researchers reported that while strong evidence was found regarding use of NMES for glenohumeral subluxation, no or insufficient evidence in terms of functional outcome was found for FES and NMES aimed at improving dexterity or gait performance. Furthermore, in a review on therapeutic orthosis and electric stimulation for upper extremity hemiplegia after stroke, Aoyagi and Tsubahara (2004) stated that despite a number of studies suggesting the effectiveness of electrical stimulation for reducing shoulder subluxation or improving the function of wrist and finger extensors in the short term, the long-term effectiveness after discontinuation as well as the motor recovery mechanism remains unclear. More research is needed to determine the evidence-based effectiveness of electrical stimulation for stroke survivors. Koyuncu et al. (2010) conducted a randomized controlled trial to evaluate FES for the treatment of 50 hemiplegic patients with shoulder subluxation and pain secondary to stroke. All patients received conventional rehabilitation and the study group also received FES stimulation to the supraspinatus and posterior deltoid muscles on the hemiplegic side, five times a day, one hour each for four weeks. Comparison of the resting AROM vs. PROM VAS value changes showed no significant difference between the groups. There was a significant difference between the two groups for the amount of change in shoulder subluxation in favor of the study group, indicating increased stability of the shoulder. Authors suggest that that

applying FES treatment to the supraspinatus and posterior deltoid muscles in addition to conventional treatment when treating the subluxation in hemiplegic patients is more beneficial than conventional treatment by itself. Gu and Ran (2016) reviewed the evidence for the effect of functional electrical stimulation (FES) on shoulder subluxation, pain, upper arm motor function, daily function, and quality of life in patients with stroke when added to conventional therapy. The results of this meta-analysis showed a significant difference in shoulder subluxation between the FES group and the placebo group, only if FES was applied early after stroke. And a significant difference was observed posttreatment in the Fugl-Meyer Motor Assessment between the FES group and the placebo group. No effects were found on pain, upper arm motor function, daily function, and quality of life outcomes. Authors concluded that FES can be used to prevent or reduce shoulder subluxation early after stroke. However, findings did not support the efficacy of use of FES for pain reduction, improvement in arm strength, movement, functional use, daily function, or quality of life after stroke.

FES has been proposed for improving ambulation in patients with gait disorders such as drop foot, hemiplegia due to stroke, cerebral injury, or incomplete spinal cord injury. As an example, FES can be applied to the anterior tibialis muscle to assist in dorsiflexion during gait for patients with foot drop. Several small studies support the integration of FES for patients with spinal cord injury or who have sustained a stroke for various activities. As long at the peripheral nervous system is intact, any patients with central nervous system dysfunction may benefit from FES use. Effectiveness of FES may be likely due to the direct effect of muscle strengthening in addition to increased excitability of the motor neuron pool produced by the motor level electrical stimulation (Cameron, 2017). Yan and colleagues (2005) evaluated whether FES was more effective in promoting motor recovery of the lower extremity and walking ability than standard rehabilitation alone. A total of 46 patients were assigned randomly to one of three groups receiving standard rehabilitation with FES or placebo stimulation or alone (control). They received treatment for 3 weeks, starting shortly after having the stroke. Outcome measurements included composite spasticity score, maximum isometric voluntary contraction of ankle dorsi-flexors and planter-flexors, and walking ability. After 3 weeks of treatment, those receiving FES plus standard rehabilitation did better on several measures of lower limb functioning compared to the other 2 groups. All patients in the FES group were able to walk after treatment, and 84.6 % of them returned home, in comparison with the placebo (53.3 %) and control (46.2 %) groups. However, these authors stated that generalization of the results from this study should be performed with caution because of subject selection criteria, which did not cover all stroke categories or subjects aged younger than 45 or older than 85 years. Randomized controlled trials and case series have primarily included small patient populations (*n*=14-64) with short-term follow-ups and heterogeneous treatment regimens and outcome measures (Esnour, et al., 2010; Nooijen, et al., 2009; Everaert, et al., 2010; Stein, et al., 2010; Barrett, et al., 2010; Postans, et al., 2004).

In a Cochrane review on electrostimulation for promoting recovery of movement or functional ability after stroke, Pomeroy et al (2006) sought to find out whether electrostimulation improved functional motor ability to do activities of daily living. Twenty-four trials were included in the review. Authors reported that electrostimulation improved some aspects of functional motor ability and some aspects of motor impairment and normality of movement over no treatment. For electrostimulation compared with placebo, this review found that electrostimulation improved an aspect of functional motor ability. For electrostimulation compared with conventional physical therapy, they found that electrostimulation improved an aspect of motor impairment. There were no statistically significant differences between electrostimulation and control treatment for all other outcomes. Authors caution that these results need to be interpreted with reference to the following: (1) the majority of analyses only contained one trial; (2) variation was found between included trials in time after stroke, level of functional deficit, and dose of electrostimulation; and (3) the possibility of selection and detection bias in the majority of included trials. Researchers conclude that data were insufficient to inform clinical use of electrostimulation for neuromuscular re-training. Research is needed to address specific questions about the type of electrostimulation that might be most effective, in what dose and at what time after stroke. Pereira et al. (2012) conducted a systematic review of randomized controlled trials to evaluate the effectiveness of FES in improving lower limb function in chronic stroke patients (mean time since stroke ≥ 6 mos.). Seven RCTs including a pooled sample size of 231participants met inclusion criteria. Analysis revealed a small but significant treatment effect in favor of FES on the 6-minute walk test. Authors conclude that FES may be an effective intervention in the chronic phase post stroke. However, its therapeutic value in improving lower extremity function and advantage over other gait training approaches remains uncertain.

More recently, Howlett et al. (2015) conducted a systematic review and meta-analysis to investigate the effectiveness of FES in improving activity following a stroke and to determine if FES is more effective than training alone. Eighteen randomized and non-randomized comparisons studies (*n*=485) met inclusion criteria. One study had three arms which was counted as a separate comparison group (*n*=19 comparisons). Because of incomplete data, all trials were not included in the meta-analysis. Only measures that reflected the International Classification of Function domain of activity performance were used in analyses. In some trials only one measure was available and in trials with more than one measure the reviewers chose the measure that most closely reflected the task being trained. Various outcome measures were used for lower-limb and upper-limb activity assessments. FES had a small to moderate effect on activity compared to no FES or placebo and had a moderate effect on activity compared to training alone. However, due to the lack of available data, the authors were unable determine if FES improved subject participation or if the benefits of FES are long-term. Author-noted limitations of the studies included: the lack of blinding of therapist and participants; the potential of small trial bias with 25 being the average number of participants per trial; and combining data for the meta-analysis

that was collected using different outcome measures. There was also heterogeneity of subject characteristics including time after stroke, the limb that was trained, and the severity of stroke. In a randomized controlled study, Bethoux et al. (2015) compared changes in gait quality and function between FES and ankle-foot orthoses (AFOs) in individuals with foot drop post-stroke over a 12-month period. They completed a follow-up analysis on a multi-center unblinded RCT that had been conducted at 30 rehabilitation centers. Subjects continued to wear their randomized device for all home and community ambulation for another 6 months to final 12-month assessments. Primary outcomes were the 10 Meter Walk Test (10MWT) and device-related serious adverse event rate. Secondary outcome measures were the 6-Minute Walk Test (6MWT), GaitRite Functional Ambulation Profile, and the Modified Emory Functional Ambulation Profile (mEFAP). A total of 495 subjects were randomized, and 384 completed the 12-month follow-up. Both FES and AFO groups showed statistically and clinically significant improvement for 10MWT. No significant between group differences were found. At 12 months, both FES and AFOs continue to demonstrate equivalent gains in gait speed. Results suggest that long-term FES use may lead to additional improvements in walking endurance and functional ambulation; further research is needed to confirm these findings.

Prenton et al. (2016) conducted a systematic review and meta-analysis of randomized controlled trials to compare the effects of FES and ankle foot orthoses (AFO) for foot drop of central neurological origin. Five synthesized randomized controlled trials (*n*=815) were included. Orthotics included customized and off the shelf AFOs. Meta-analysis of the outcomes of the 10-meter (m) walking speed (5 trials) (*n*=789) and functional exercise capacity (3 trials) (*n*=761) showed between group comparable improvements which were not significant (p=0.79; p=0.31, respectively). There were no significant differences in meta-analysis for the 10-meter (m) walk test using data at short- (4 trials; *n*=771) and longer-term (3 trials; *n*=713) time-points for FES vs. AFO. There was a significant difference (p=0.04) in favor of the AFO for the medium-term 10-m test. Analyses revealed between group comparable improvements in functional exercise capacity. The timed up-and-go test was reported in two studies, and both reported between-group comparable improvements (p=0.812 and p=0.539). The mobility domain of the Stroke Impact Scale (SIS) was reported by three trials (*n*=701) and showed comparable between-group improvements (p=0.80). This meta-analysis indicates that AFOs have positive combined-orthotic effects on walking that are equivalent to FES for foot-drop caused by stroke regardless of length of use. The fact that the reviewed trials only included subjects age 18 years and older who had experienced a stroke prevents the results from being generalized to other populations. Other limitations of the analysis included the risk of bias in the studies and the heterogeneity of the AFO and FES devices used.

Stein et al. (2015) conducted a systematic review (*n*=29 studies; 940 subjects) and meta-analysis (*n*=14 studies; 383 subjects) of randomized controlled trials to evaluate the effect of NMES on spastic muscles after stroke. The primary outcome was spasticity, assessed

by the Modified Ashworth Scale. The secondary outcome was range of motion (*n*=13 studies), assessed by a goniometer. Outcomes were conflicting. Some studies reported an improvement in spasticity (*n*=12 studies) and range of motion (*n*=13 studies) with NMES when used as an adjunctive therapy and some studies did not. Based on sensitivity analysis, no effects on spasticity and range of motion were seen on wrists and no effect on spasticity of elbows. The degree of spasticity and the criteria for spasticity assessment varied. Most studies showed evidence of bias. Other study limitations included: heterogeneity of outcome measures; time of treatment following stroke (1.5 months to more than 12 months); various degrees of chronic tissue changes; heterogeneity of conventional therapies used (e.g., active leg cycling, occupational therapy, stretching, Botulinum Toxin A), missing data; and heterogeneity of stimulation frequency and pulse duration. Large scale and high-quality randomized controlled trials are needed to establish the true efficacy NMES in this patient population. Sharififar et al. (2018) aimed to determine the effect on motor function of extremities of adding an electrical sensory modality without motor recruitment before or with routine rehabilitation for hemiparesis after stroke by a comprehensive systematic review and meta-analysis. Authors concluded that electrical sensory input could contribute to routine rehabilitation to improve early post-stroke lower-extremity impairment and late motor function, with no change in spasticity. Prolonged periods of sensory stimulation such as TENS combined with activity can have beneficial effects on impairment and function after stroke.

Kristensen et al. (2021) sought to determine the effectiveness of neuromuscular electrical stimulation (NMES) toward improving activities of daily living (ADL) and functional motor ability post stroke and to investigate the influence of paresis severity and the timing of treatment initiation for the effectiveness of NMES. The inclusion criteria were randomized controlled trials exploring the effect of NMES toward improving ADL or functional motor ability in survivors of stroke. The search identified 6064 potential articles with 20 being included. Data from 428 and 659 participants (mean age, 62.4 years; 54% male) for outcomes of ADL and functional motor ability, respectively, were pooled in a random-effect meta-analysis. The analysis revealed a significant positive effect of NMES toward ADL, whereas no effect on functional motor ability was evident. Subgroup analyses showed that application of NMES in the subacute stage and in the upper extremity improved ADL, whereas a beneficial effect was observed for functional motor abilities in patients with severe paresis. Authors concluded that the results of the present meta-analysis are indicative of potential beneficial effects of NMES toward improving ADL post stroke, whereas the potential for improving functional motor ability appears less clear. Furthermore, subgroup analyses indicated that NMES application in the subacute stage and targeted at the upper extremity is efficacious for ADL rehabilitation and that functional motor abilities can be positively affected in patients with severe paresis.

Johnston et al. (2021) provided evidence to guide clinical decision-making for the use of either ankle-foot orthosis (AFO) or functional electrical stimulation (FES) as an

intervention to improve body function and structure, activity, and participation as defined by the International Classification of Functioning, Disability and Health (ICF) for individuals with poststroke hemiplegia with decreased lower extremity motor control within this clinical practice guideline. A review of literature published through November 2019 was performed across 7 databases for all studies involving stroke and AFO or FES. Data extracted included time post-stroke, participant characteristics, device types, outcomes assessed, and intervention parameters. Outcomes were examined upon initial application and after training. Recommendations were determined on the basis of the strength of the evidence and the potential benefits, harm, risks, or costs of providing AFO or FES. One-hundred twenty-two meta-analyses, systematic reviews, randomized controlled trials, and cohort studies were included. Strong evidence exists that AFO and FES can each increase gait speed, mobility, and dynamic balance. Moderate evidence exists that AFO and FES increase quality of life, walking endurance, and muscle activation, and weak evidence exists for improving gait kinematics. AFO or FES should not be used to decrease plantarflexor spasticity. Studies that directly compare AFO and FES do not indicate overall superiority of one over the other. But evidence suggests that AFO may lead to more compensatory effects while FES may lead to more therapeutic effects. Due to the potential for gains at any phase post-stroke, the most appropriate device for an individual may change, and reassessments should be completed to ensure the device is meeting the individual's needs. It is important to note that this CPG cannot address the effects of one type of AFO over another for the majority of outcomes, as studies used a variety of AFO types and rarely differentiated effects. The recommendations also do not address the severity of hemiparesis, and most studies included participants with varied baseline ambulation ability. Authors summarize that this CPG suggests that AFO and FES both lead to improvements post-stroke. Future studies should examine timing of provision, device types, intervention duration and delivery, longer term follow-up, responders versus nonresponders, and individuals with greater impairments.

van der Scheer et al. (2021) summarized and appraise evidence on functional electrical stimulation (FES) cycling exercise after spinal cord injury (SCI), in order to inform the development of evidence-based clinical practice guidelines. Ninety-two studies met the eligibility criteria, comprising 999 adults with SCI representing all age, sex, time since injury, lesion level and lesion completeness strata. For muscle health (e.g., muscle mass, fiber type composition), significant improvements were found in 3 out of 4 Level 1-2 studies, and 27 out of 32 Level 3-4 studies (GRADE rating: 'High'). Although lacking Level 1-2 studies, significant improvements were also found in nearly all of 35 Level 3-4 studies on power output and aerobic fitness (e.g., peak power and oxygen uptake during an FES cycling test) (GRADE ratings: 'Low'). Authors concluded that the evidence indicates that FES cycling exercise improves lower-body muscle health of adults with SCI and may increase power output and aerobic fitness. Mahmoudi et al. (2021) systematically reviewed the effect of functional electrical stimulation (FES) on balance as compared to conventional therapy alone in post-stroke. Nine papers were included in this review. The total number

of participants in this review study was 255. The age of participants ranged from 20 to 80 years. Stroke patients were in chronic phase (*n* = 5) and in subacute phase (*n* = 4). Various parameters, including the target muscles, the treatment time per session (20 min-2 h), number of treatment sessions (12-48) and FES frequency (25-40 Hz), were assessed. Among the studies, significant between-group improvement favoring FES in combination with conventional therapy was found on the Berg Balance Scale (*n* = 7) and Timed Up and Go Scale (*n* = 4) when compared to conventional therapy alone. There was no adverse effect reported by any studies. Authors concluded that FES was reported to be more beneficial in balance improvement among stroke patients when combined with conventional balance therapy. The studies were limited by low-powered, small sample sizes ranging from 9 to 48, and lack of blinding, and reporting of missing data.

Ye et al. (2021) comprehensively and critically appraised the clinical benefits and engineering designs of functional electrical stimulation (FES)-rowing for management of individuals with spinal cord injury (SCI). Comparison of peak oxygen consumption (V̇o2peak) rates showed that V̇o2peak during FES-rowing was significantly higher than arm-only exercise; FES-rowing training improved V̇o2peak by 11.2% on average, with a 4.1% increase in V̇o2peak per month of training. FES-rowing training reduced bone density loss with increased time postinjury. The rowing ergometer used in 2 studies provided motor assistance during rowing. Studies preferred manual stimulation control (*n*=20) over automatic (*n*=4). Authors concluded that results suggest FES-rowing is a viable exercise for individuals with SCI that can improve cardiovascular performance and reduce bone density loss. Further randomized controlled trials are needed to better understand the optimal set-up for FES-rowing that maximizes the rehabilitation outcomes. Karamian et al. (2022) summarized the various forms of electrical stimulation technology that exist and their applications for SCI. With regards to FES and NMES, authors report positive findings for improvement in muscle function and functional activities.

Chiu et al. (2014) conducted a systematic review to determine the effectiveness of FES vs. activity training alone in children with cerebral palsy. Five randomized controlled trials met inclusion criteria. The experimental group had to receive FES while performing an activity such as walking. The studies used outcome measures of activity that best reflected the activity used in the study. When continuous data (e.g., walking speed) were not available, ordinal data (e.g., Gross Motor Function Measurement) were used. A statistically significant between-group difference in activity in the FES groups was reported for the three studies that compared FES with no FES. Improvements were seen immediately after the intervention period, but long-term follow-up was not reported. The two studies investigating the effects of FES vs. activity training reported no significant differences between the groups. The results reported that FES is better than no FES, but that FES is not more effective than activity training. Outcomes could not be pooled for meta-analysis due to incomplete data and the large difference in baseline scores. Due to the inability to conduct a meta-analysis, the authors stated that firm conclusions could not be made.

Limitations of the studies included the heterogeneous patient populations and the variations in the frequency, intensity and duration of the interventions. Bosques et al. (2016) discussed the potential clinical applicability, while clarifying the differences in electrical stimulation (ES) treatments and the theory behind potential benefits to remediate functional impairments in youth in a comprehensive review. The synthesis of the literature suggests that improvements in various impairments may be possible with the integration of ES. Most studies were completed on children with cerebral palsy (CP). Electrical stimulation may improve muscle mass and strength, spasticity, passive range of motion (PROM), upper extremity function, walking speed, and positioning of the foot and ankle kinematics during walking. Sitting posture and static/dynamic sitting balance may be improved with ES to trunk musculature. Bone mineral density may be positively affected with the use of Functional Electrical Stimulation (FES) ergometry. ES may also be useful in the management of urinary tract dysfunction and chronic constipation. Among all reviewed studies, reports of direct adverse reactions to electrical stimulation were rare. In conclusion, NMES and FES appear to be safe and well tolerated in children with various disabilities. Authors suggested that physiatrists and other healthcare providers better understand the indications and parameters in order to utilize these tools effectively in the pediatric population.

Springer and Khamis (2017) completed a systematic review on the orthotic and therapeutic effects of functional electrical stimulation on gait in people with multiple sclerosis (MS). Twelve relevant studies were reviewed. Eleven studies reported the effects of peroneal stimulation. Most found a significant orthotic effect (measured during stimulation), mainly on walking speed. Only three assessed the therapeutic effect (carry-over), which was not significant. Authors concluded that the evidence suggests that FES has a positive orthotic effect on walking in patients with MS. Yet, more robust trials are needed to substantiate this finding. Therapeutic efficacy of FES was not demonstrated.

Ou et al. (2022) assessed the effects of neuromuscular electrical stimulation on the upper limbs of patients with cerebral palsy. Eight randomized controlled trials (N = 294) were included in the meta-analysis. Compared with traditional physical therapy, sensorimotor training and task-oriented training, constraint-induced movement therapy, dynamic bracing, and conventional robot-assisted therapy, neuromuscular electrical stimulation in combination with these therapies resulted in significantly greater functional scale scores, muscle strength of upper limbs, and spasticity of upper limbs but did not improve the wrist range of motion. In addition, the effect of neuromuscular electrical stimulation on functional scale scores remained after 3-mo follow-up. Authors concluded that neuromuscular electrical stimulation effectively improved hand function, muscle strength, and spasticity in patients with cerebral palsy.

Chen et al. (2023) investigated whether neuromuscular electrical stimulation improves mobility in children with spastic cerebral palsy. A total of 14 randomized controlled trials

(2 crossover studies and 12 parallel studies including 421 patients) were included in this meta-analysis. Compared with the control group (conventional physical therapy), the treatment group exhibited greater improvement in walking speed and the standing, walking, running, and jumping dimension of the Gross Motor Function Measure. Authors concluded that neuromuscular electrical stimulation improved mobility in children with spastic cerebral palsy, particularly in standing, running, and jumping function, and it is safe for children with spastic cerebral palsy.

Zhu et al. (2022) summarized and analyzed the relationship between functional electrical stimulation treatment and gait parameter changes in children with cerebral palsy. Nine papers were included in the analysis, with a total of 282 children with cerebral palsy, including 142 patients in the functional electrical stimulation treatment group and 140 patients in the comfort treatment, general nursing, or other physical therapy. The results showed that functional electrical stimulation could increase the walking speed of children with cerebral palsy and increase the walking step length of children with cerebral palsy. Authors concluded that functional nerve stimulation treatment could increase the gait speed and step length of children with cerebral palsy, which could improve the walking of children with cerebral palsy. Furthermore, this study needs more research data to support the authors' findings.

Ignácio et al. (2022) sought to determine what the effect is of an intravaginal electrical stimulation regimen on their ability to contract the pelvic floor muscles and on self-reported urinary incontinence in women who are unable to contract their pelvic floor muscles voluntarily. Sixty-four women with pelvic floor muscle function assessed by bi-digital palpation to be grade 0 or 1 on the Modified Oxford Scale. For 8 weeks, participants randomised to the experimental group received weekly 20-minute sessions of intravaginal electrical stimulation with instructions to attempt pelvic floor muscle contractions during the bursts of electrical stimulation in the final 10 minutes of each session. The control group received no intervention. The primary outcome was ability to voluntarily contract the pelvic floor muscles, evaluated through vaginal palpation using the Modified Oxford Scale. Secondary outcomes were prevalence and severity of urinary incontinence symptoms assessed by the International Consultation on Incontinence Questionnaire on Urinary Incontinence-Short Form (ICIQ-UI-SF) score from 0 to 21. Sixty-one participants provided outcome data. After the intervention, the ability to contract the pelvic floor muscles was acquired by 36% of the experimental group and 12% of the control. The experimental group also improved by a mean of 2 points more than the control group on the ICIQ-UI-SF score. Authors concluded that in women who are unable to contract their pelvic floor muscles voluntarily, 8 weeks of intravaginal electrical stimulation with voluntary contraction attempts improved their ability to contract their pelvic floor muscles and reduced the overall severity and impact of urinary incontinence on quality of life. Although the main estimates of these effects indicate that the effects are large enough to be

worthwhile, the precision of these estimates was low, so it is not possible to confirm whether the effects are trivial or worthwhile.

Zhu et al. (2022) evaluated the efficacy and safety of pelvic floor muscle training (PFMT) combined with biofeedback (BF), electrical stimulation (ES) therapy, or both for postpartum lower urinary tract symptoms (LUTS). Seventeen studies were included. The results of the meta-analysis showed that PFMT plus ES with or without BF was more effective than PFMT alone. Patients receiving PFMT plus ES and BF achieved greater improvement than controls receiving PFMT alone in incontinence quality of life scores, pelvic floor muscle strength, and urodynamic parameters (maximum urethral closure pressure, abdominal leak point pressure, and maximum urinary flow rate), and 1-h urine leakage also decreased. Authors concluded that PFMT plus ES with or without BF exhibited better efficacy and safety for early postpartum LUTS than PFMT alone.

Ali et al. (2022) sought to determine the effects of nonsurgical, minimally or noninvasive therapies on urge urinary incontinence (UUI) symptoms and quality of life (QoL) in individuals with neurogenic bladder (NGB). Randomized controlled trials that compared therapies such as intravaginal electrical stimulation (IVES), transcutaneous electrical nerve stimulation (TENS), neuromuscular electrical stimulation (NMES), transcutaneous tibial nerve stimulation (TTNS), pelvic floor muscle training (PFMT), and behavioural therapy (BT) to control were included. Meta-analyses revealed a significant effect of electrical stimulation on UUI due to multiple sclerosis and stroke. The pooled analyses of TTNS and revealed significant effects of these interventions on QoL in people with Parkinson's disease. However, meta-analyses revealed nonsignificant effects for PFMT and BT on UUI due to Parkinson's disease. Authors concluded that their meta-analyses found electrical stimulation to be beneficial for improving the symptoms of UUI among people with multiple sclerosis and those with stroke. The review also revealed that TTNS and BT might improve QoL for people with NGB due to Parkinson's disease, although the effects of PFMT and BT on UUI warrant further investigation.

Sarmento et al. (2022) perform an updated and comprehensive literature review focused on the effects of pelvic floor electrical stimulation. Regarding the studied populations, the results demonstrated heterogeneity between human and animal populations. Articles comprised studies that investigated the therapeutic effects of electrical stimulation on pelvic floor dysfunctions in humans, totaling 1303 participants. From these, only the research performed by 25 included men in the study population, which investigated 96 patients with urinary incontinence post-radical prostatectomy. Authors concluded that non-invasive electrical stimulation has shown promise in the clinical improvement of disorders associated with pelvic floor fragility. The vast majority of studies addressed in this review showed that electrostimulation improves urination control and sexual quality, in addition to providing greater collagen production and maintaining the effectiveness of sphincter contraction.

Learnardo et al. (2022) compared biofeedback-assisted pelvic muscle floor training (PFMT) and pelvic electrical stimulation (ES) as an intervention group, with PFMT or bladder training (BT) as the control group, in women with an overactive bladder (OAB) in a meta-analysis. Eight studies involving 562 patients (comprising 204 patients with biofeedback-assisted PFMT, 108 patients with pelvic ES, and 250 patients who received PFMT alone or BT and lifestyle recommendations only, as the control group) were included. The ES group showed significant differences in terms of changes to QoL, episodes of incontinence, and the number of participants cured or improved, while the biofeedback group resulted in nonsignificant changes in QoL, episodes of incontinence, and the number of participants cured or improved, both compared to the control group respectively. Authors concluded that this meta-analysis shows that low-frequency pelvic ES appears to be sufficient and effective as an additional intervention for women with OAB in clinical practice according to improvements in the subjects' QoL and reduction of symptoms. Meanwhile, biofeedback-assisted PFMT does not appear to be a significant adjuvant for conservative OAB therapy.

Todhunter-Brown et al. (2022) summarized Cochrane Reviews that assessed the effects of conservative interventions for treating urinary incontinence (UI) in women. The common types of UI are stress (SUI), urgency (UUI) and mixed (MUI). A wide range of interventions can be delivered to reduce the symptoms of UI in women. Conservative interventions are generally recommended as the first line of treatment. Authors included reviews that compared a conservative intervention with 'control' (which included placebo, no treatment or usual care), another conservative intervention or another active, but non-conservative, intervention. They included 29 relevant Cochrane Reviews. Seven focused on physical therapies; five on education, behavioural and lifestyle advice; one on mechanical devices; one on acupuncture and one on yoga. Fourteen focused on non-conservative interventions but had a comparison with a conservative intervention. There were 112 unique trials (including 8975 women) that had primary outcome data included in at least one analysis. For UUI, (five reviews): Conservative intervention versus control: there was moderate to high-certainty evidence demonstrating that PFMT plus feedback, PFMT plus biofeedback, electrical stimulation and bladder training were more beneficial than control for curing or improving UI. Women using electrical stimulation plus PFMT had higher quality of life than women in the control group. One conservative intervention versus another conservative intervention: for cure or improvement, there was moderate certainty evidence that electrical stimulation was more effective than laseropuncture. There was high or moderate certainty evidence that PFMT resulted in higher quality of life than electrical stimulation and electrical stimulation plus PFMT resulted in better cure or improvement and higher quality of life than PFMT alone. For all types of urinary incontinence (13 reviews): Conservative intervention versus control: there was moderate to high certainty evidence of better cure or improvement with PFMT, electrical stimulation, weight loss and cones compared to control. Specific to electrical stimulation and exercise, authors concluded that there is high certainty that PFMT is more beneficial than control for

all types of UI for outcomes of cure or improvement and quality of life and electrical stimulation is beneficial for women with UUI. Most evidence within the included Cochrane Reviews is of low certainty.

Stania et al. (2022) sought to determine the therapeutic efficacy of intravaginal electrical stimulation (ES) in women with SUI. Of the 686 records identified, a total of 10 articles met the inclusion criteria. A meta-analysis revealed significant differences between the ES and no active treatment groups in the pooled objective cure rates and subjective cure or improvement rates. No significant differences were found in the pooled number of incontinence episodes per 24 h, the pooled Incontinence Quality of Life Questionnaire scores or the pooled number of adverse effects between the ES and other conservative treatment groups. Authors concluded that there was insufficient evidence for or against the use of intravaginal ES therapy for women with SUI, partly due to the variability in the interventions of the included trials and the small number of trials included.

Electrical stimulation (ES) has been examined for the treatment of dysphagia. However, there is currently insufficient evidence to support the effectiveness of ES in treating this condition. No peer-reviewed literature was found for DPNS specifically, but rather is limited to electrical stimulation, FES, or NMES. In a non-concurrent cohort study, Blumenfeld et al. (2006) assessed the effectiveness of ES in treating persons with dysphagia and aspiration. The charts of 40 consecutive subjects undergoing ES and 40 consecutive persons undergoing traditional dysphagia therapy (TDT) were reviewed. The swallow severity scale improved from 0.50 to 1.48 in the TDT group ($p < 0.05$) and from 0.28 to 3.23 in the ES group ($p < 0.001$). After adjusting for potential confounding factors, persons receiving ES did significantly better in regard to improvement in their swallowing function than persons receiving TDT ($p = 0.003$). The authors concluded that the findings suggested that dysphagia therapy with transcutaneous ES is superior to traditional dysphagia therapy alone in individuals in a long-term acute care facility. They also stated that confirmation of these findings with a prospective, placebo-controlled, randomized clinical trial is needed before a definitive determination regarding the effectiveness of ES dysphagia therapy can be made. Kiger et al. (2006) compared the outcomes using transcutaneous neuromuscular electrical stimulation (VitalStim® therapy) to outcomes using traditional swallowing therapy for deglutition disorders. A total of 22 patients had an initial and a follow-up video-fluoroscopic swallowing study or fiberoptic endoscopic evaluation of swallowing and were divided into an experimental group that received VitalStim® treatments and a control group that received traditional swallowing therapy. Outcomes were analyzed for changes in oral and pharyngeal phase dysphagia severity, dietary consistency restrictions, and progression from non-oral to oral intake. Results of chi-square analysis showed no statistically significant difference in outcomes between the experimental and control groups.

Huckabee and Doeltgen (2007) reviewed NMES as an emerging modality in an attempt to advise the New Zealand medical community about the application of it as a treatment for pharyngeal swallowing impairment (dysphagia). Authors conclude that there are potential benefits of the use of this treatment but key concerns for patient safety and long-term outcomes exist. Shaw et al. (2007) sought to evaluate the effectiveness of VitalStim® therapy in a heterogeneous group of dysphagic patients. They performed a retrospective analysis of 18 patients who received this therapy at an urban tertiary referral center. All patients underwent pre-therapy evaluation by speech-language pathologists, including modified barium swallow and/or functional endoscopic evaluation of swallowing and clinical evaluation of swallowing that included assessment of laryngeal elevation, diet tolerance, and swallowing delay, and were then assigned an overall dysphagia severity score. After therapy, all patients underwent the same assessments. Twelve of the 18 also underwent a functional swallowing telephone survey months (range, 1 to 21 months) after their therapy to assess whether the improvement was worthwhile and sustained. Eleven of the 18 patients (61%) demonstrated some improvement in their swallowing. Six of the 18 patients (33%) were improved enough to no longer require a feeding tube. However, of the 5 patients categorized as having "severe dysphagia" before therapy, only 2 showed any improvement, and these patients still required a feeding tube for adequate nutrition. Telephone surveys did confirm that those who improved with their therapy seemed to maintain their progress and that most patients were satisfied with their therapy. Authors concluded that VitalStim therapy seems to help those with mild to moderate dysphagia. However, the patients with the most severe dysphagia in the study did not gain independence from their feeding tubes but could potential help those with mild to moderate dysphagia. Carnaby-Mann and Crary (2007) examined the evidence on neuromuscular electrical stimulation for swallowing rehabilitation. A total of 81 studies were reviewed. Seven were accepted for analysis. A significant summary effect size was identified for the application of NMES for swallowing. Best-evidence synthesis showed indicative findings in favor of NMES for swallowing. The analysis revealed a small but significant summary effect size for NMES for swallowing. Because of the small number of studies and low methodological grading for these studies, caution should be taken in interpreting this finding. These results support the need for more rigorous research in this area. This is in agreement with the observation of Steele et al (2007) who noted that although ES approaches to the restoration and rehabilitation of swallowing is an exciting area of research which holds promise for future clinically relevant technology and/or therapy, implementation of ES in clinical swallowing rehabilitation settings still remains pre-mature.

Clark et al. (2009) systematically reviewed the literature examining the effects of NMES on swallowing and neural activation. The review was conducted as part of a series examining the effects of oral motor exercises (OMEs) on speech, swallowing, and neural activation. Out of 899 citations initially identified for the broad review of OMEs, 14 articles relating to NMES qualified for inclusion. Most of the studies (10/14) were considered

exploratory research, and many had significant methodological limitations. Authors concluded that the review revealed that surface NMES to the neck has been most extensively studied with promising findings, yet high-quality controlled trials are needed to provide evidence of efficacy. Surface NMES to the palate, faucial pillars, and pharynx has been explored in Phase I research, but no evidence of efficacy is currently available. Intramuscular NMES has been investigated in a single Phase I exploratory study. Additional research is needed to document the effects of such protocols on swallowing performance. Christiaanse et al. (2011) compared the change in swallowing function in pediatric patients with dysphagia who received neuromuscular electrical stimulation (NMES) to a control group who received usual oral motor training and dietary manipulations without NMES. Children were classified into two groups based on the etiology of their dysphagia (primary vs. acquired). Only the treatment group who had acquired dysphagia improved more than the similar subgroup of control children. Authors concluded that NMES treatment of anterior neck muscles in a heterogeneous group of pediatric patients with dysphagia did not improve the swallow function more than that seen in patients who did not receive NMES treatment. However, there may be subgroups of children that will improve with NMES treatment. Geeganage et al. (2012) assessed the effectiveness of interventions for the treatment of dysphagia and nutritional and fluid supplementation in patients with acute and subacute stroke. Authors included 33 studies involving 6779 participants. Swallowing therapies included the following: acupuncture, drug therapy, neuromuscular electrical stimulation, pharyngeal electrical stimulation, physical stimulation (thermal, tactile), transcranial direct current stimulation, and transcranial magnetic stimulation. Authors conclude that there remains insufficient data on the effect of swallowing therapy, feeding, and nutritional and fluid supplementation on functional outcome and death in dysphagic patients with acute or subacute stroke. Behavioural interventions and acupuncture reduced dysphagia, and pharyngeal electrical stimulation reduced pharyngeal transit time.

Tan et al. (2013) assessed the overall efficacy by comparing the two treatment protocols in a meta-analysis. Studies that compared the efficacy of treatment and clinical outcomes of NMES versus traditional treatment (TT) in dysphagia rehabilitation were assessed. Seven studies were eligible for inclusion, including 291 patients, 175 of whom received NMES and 116 of whom received TT. Of the seven studies, there were two randomized controlled trials, one multicentre randomized controlled trial and four clinical controlled trials. The change scores on the Swallowing Function Scale of patients with dysphagia treated with NMES were significantly higher compared with patients treated with TT. However, subgroup analysis according to etiology showed that there were no differences between NMES and TT in dysphagia post-stroke. No studies reported complications of NMES. Authors concluded that NMES is more effective for treatment of adult dysphagia patients of variable etiologies than TT. However, in patients with dysphagia post-stroke, the effectiveness was comparable. Miller et al (2014) performed a systematic review of the literature on the use of neuromuscular electrostimulation (NMES) in otorhinolaryngology

that have been published in German or English. The search identified 180 studies. These were evaluated and relevant studies were included in the further evaluation. The authors concluded that the evidence collected to date is encouraging; particularly for the treatment of certain forms of dysphagia and laryngeal paresis. Terré and Mearin (2015) evaluated the effectiveness of neuromuscular electrical stimulation (NMES) treatment in patients with oropharyngeal dysphagia secondary to acquired brain injury. Twenty patients with neurological oropharyngeal dysphagia (14 stroke and six severe traumatic brain injury) were enrolled in a prospective randomized study, with patients and assessors blinded (to group allocation): 10 patients underwent NMES, and conventional swallowing therapy and 10 patients underwent sham electrical stimulation (SES) and conventional swallowing therapy. Both groups completed 20 sessions. Feeding swallowing capacity was evaluated using the functional oral intake scale (FOIS). After treatment, the NMES group increased by 2.6 points (4.5 points) compared with only 1 point (3.1 points) for the SES group. At 3 months of follow-up, mean scores were 5.3 and 4.6 respectively; thus, both groups improved similarly. At that time point (3 months), tracheal aspiration persisted in six patients in each group. However, a significant improvement in relation to the bolus viscosity at which aspiration appeared was found in the NMES group versus the SES group. Also, a significant increase in pharyngeal amplitude contraction was observed at the end of treatment (1 month) in the NMES group compared with the SES group. Authors concluded that NMES significantly accelerated swallowing function improvement in patients with oropharyngeal dysphagia secondary to acquired brain injury.

Chen et al. (2016) evaluated whether swallow treatment with neuromuscular electrical stimulation is superior to that without neuromuscular electrical stimulation, and whether neuromuscular electrical stimulation alone is superior to swallow therapy. Eight studies were identified. Authors concluded that swallow treatment with neuromuscular electrical stimulation seems to be more effective than that without neuromuscular electrical stimulation for post-stroke dysphagia in the short-term considering the limited number of studies available. Evidence was insufficient to indicate that neuromuscular electrical stimulation alone was superior to swallow therapy. Alamer et al. (2020) summarized the latest best scientific evidence on the efficacy of neuromuscular electrical stimulation on swallowing function in dysphagic stroke patients. Evidence of overall quality was graded from moderate to high. Eleven RCTs involving 784 patients were analyzed. The primary outcome measures of this review were functional dysphagia scale (FDS) and standard swallowing assessment. This review found neuromuscular electrical stimulation (NMES) coupled with traditional swallowing therapy could be an optional intervention to improve swallowing function after stroke in rehabilitation department.

Liang et al. (2021) explored the clinical efficacy of VitalStim electrical stimulation combined with swallowing function training for patients with dysphagia following an acute stroke. Seventy-two patients with dysphagia following an acute stroke were admitted to the hospital and were further divided into two groups using prospective research methods.

There were 36 cases in each group according to the random number table method. The control group received conventional medical treatment and swallowing function training while the experimental group received conventional medical treatment and VitalStim electrical stimulation combined with swallowing function training. The overall response rate of the experimental group (94.44%) was higher than that of the control group (77.78%), and the difference was statistically significant. Compared with before treatment, the upward and forward movement speeds of the hyoid bone, anterior movement speed, the grading score of the Kubota drinking water test, Caiteng's grading score, serum superoxide dismutase, 5-hydroxytryptamine, and norepinephrine levels, Fugl-Meyer Assessment score, and multiple quality of life scores of the two groups showed improvement after treatment. While the standard swallowing assessment score, serum malondialdehyde level, and National Institutes of Health Stroke Scale score decreased, the aforementioned indices showed a significant improvement in the experimental group. Authors concluded that the results of this study indicate that VitalStim electrical stimulation combined with swallowing function is effective for treating dysphagia following an acute stroke. It can effectively improve swallowing, neurological, and limb motor functions, reduce complications, promote physical recovery, and improve overall quality of life of patients.

Miller et al. (2022) evaluated recent studies regarding a potential effectiveness of transcutaneous NMES applied to the anterior neck as a treatment for dysphagia. Eighteen studies were identified with varying patient groups, stimulation protocols, electrode placement and therapy settings. However, 16 studies have reported of beneficial outcomes in relation with NMES. It could generally be concluded that there is a considerable amount of level 2 studies which suggest that NMES is an effective treatment option, especially when combined with traditional dysphagia therapy for patients with dysphagia after stroke and patients with Parkinson's disease, or with different kinds of brain injuries. Further research is still necessary in order to clarify which stimulation protocols, parameters and therapy settings are most beneficial for certain patient groups and degrees of impairment.

Literature does not support the use of NMES for the treatment of heart failure (Arena et al., 2010) conducted a systematic review of the literature to evaluate the evidence supporting NMES and inspiratory muscle training (IMT) for the treatment of systolic heart failure. Thirteen NMES studies met inclusion criteria, ten were randomized controlled trials. Although the studies reported improvement in aerobic capacity, peak oxygen uptake and strength and endurance of muscle groups, the studies were limited by patient population (i.e., mostly males), diverse NMES training protocols, variation in the type of muscle contraction elicited (i.e., titanic vs. twitch), the use of different muscle groups and different comparators. The percent improvement in peak oxygen uptake was consistently greater with conventional therapy (i.e., bicycle/treadmill). Sillen et al. (2009) conducted a systematic review of randomized controlled trials to analyze the role of NMES in strength, exercise capacity, and disease-specific health status in patients with congestive heart failure

(*n*=9 studies) and chronic obstructive pulmonary disease (*n*=5 studies) with disabling dyspnea, fatigue, and exercise intolerance. The limited number of studies, heterogeneous patient populations and variability in NMES methodology prohibited the use of meta-analysis. Although some of the studies reported significant improvements with NMES compared to no exercise or usual care, outcomes, including adverse events, were conflicting. Additional studies are indicated to provide sufficient evidence to establish the clinical utility of NMES in this patient population.

PRACTITIONER SCOPE AND TRAINING

Practitioners should practice only in the areas in which they are competent based on their education, training and experience. Levels of education, experience, and proficiency may vary among individual practitioners. It is ethically and legally incumbent on a practitioner to determine where they have the knowledge and skills necessary to perform such services and whether the services are within their scope of practice.

It is best practice for the practitioner to appropriately render services to a member only if they are trained, equally skilled, and adequately competent to deliver a service compared to others trained to perform the same procedure. If the service would be most competently delivered by another health care practitioner who has more skill and training, it would be best practice to refer the member to the more expert practitioner.

Best practice can be defined as a clinical, scientific, or professional technique, method, or process that is typically evidence-based and consensus driven and is recognized by a majority of professionals in a particular field as more effective at delivering a particular outcome than any other practice (Joint Commission International Accreditation Standards for Hospitals, 2013).

Depending on the practitioner's scope of practice, training, and experience, a member's condition and/or symptoms during examination or the course of treatment may indicate the need for referral to another practitioner or even emergency care. In such cases it is prudent for the practitioner to refer the member for appropriate co-management (e.g., to their primary care physician) or if immediate emergency care is warranted, to contact 911 as appropriate. See policy *Managing Medical Emergencies (CPG 159 – S)* for information.

References

Ali MU, Fong KN, Kannan P, Bello UM, Kranz G. Effects of nonsurgical, minimally or noninvasive therapies for urinary incontinence due to neurogenic bladder: a systematic review and meta-analysis. Ther Adv Chronic Dis. 2022;13:20406223211063059. Published 2022 Mar 18

Alamer A, Melese H, Nigussie F. Effectiveness of Neuromuscular Electrical Stimulation on Post-Stroke Dysphagia: A Systematic Review of Randomized Controlled Trials. Clin Interv Aging. 2020 Sep 3;15:1521-1531. Doi: 10.2147/CIA.S262596

Almeida CC, Silva VZMD, Júnior GC, Liebano RE, Durigan JLQ. Transcutaneous electrical nerve stimulation and interferential current demonstrate similar effects in relieving acute and chronic pain: a systematic review with meta-analysis. Braz J Phys Ther. 2018 Sep — Oct;22(5):347-354

American College of Occupational and Environmental Medicine (ACOEM); 2nd ed. Elk Grove Village (IL); 2007. Low back disorders. Occupational medicine practice guidelines: evaluation and management of common health problems and functional recovery in workers. 366 [1310 references]

American Society of Anesthesiologists Task Force on Chronic Pain Management; American Society of Regional Anesthesia and Pain Medicine. Practice Guidelines for Chronic Pain Management: An Updated Report by the American Society of Anesthesiologists Task Force on Chronic Pain Management and the American Society of Regional Anesthesia and Pain Medicine. Anesthesiology 2010; 112(4):810-833

Aoyagi Y, Tsubahara A. Therapeutic orthosis and electrical stimulation for upper extremity hemiplegia after stroke: a review of effectiveness based on evidence. Top Stroke Rehabil. 2004 Summer;11(3):9-15

Arena R, Pinkstaff S, Wheeler E, Peberdy MA, Guazzi M, Myers J. Neuromuscular electrical stimulation and inspiratory muscle training as potential adjunctive rehabilitation options for patients with heart failure. J Cardiopulm Rehabil Prev. 2010 Jul-Aug;30(4):209-23

Arvidsson I, Arvidsson H, Eriksson E, Jansson E. Prevention of quadriceps wasting after immobilization: An evaluation of the effect of electrical stimulation. Orthopedics. 1986;9(11):1519-1528

Barrett C, Taylor P. The effects of the odstock drop foot stimulator on perceived quality of life for people with stroke and multiple sclerosis. Neuromodulation. 2010 Jan;13(1):58-64

Bax L, Staes F, Verhagen A. Does neuromuscular electrical stimulation strengthen the quadriceps femoris: A systematic review of 49 randomized controlled trials. Sports Med. 2005;35(3):191-212

Beltran-Alacreu H, Serrano-Muñoz D, Martín-Caro Álvarez D, Fernández-Pérez JJ, Gómez-Soriano J, Avendaño-Coy J. Percutaneous Versus Transcutaneous Electrical Nerve Stimulation for the Treatment of Musculoskeletal Pain. A Systematic Review and Meta-Analysis. Pain Med. 2022;23(8):1387-1400. doi:10.1093/pm/pnac027

Bergman S. Management of musculoskeletal pain. Best Pract Res Clin Rheumatol. 2007;21:153-166

Bethoux F, Rogers HL, Nolan KJ, Abrams GM, Annaswamy T, Brandstater M, Browne B, Burnfield JM, Feng W, Freed MJ, Geis C, Greenberg J, Gudesblatt M, Ikramuddin F, Jayaraman A, Kautz SA, Lutsep HL, Madhavan S, Meilahn J, Pease WS, Rao N, Seetharama S, Sethi P, Turk MA, Wallis RA, Kufta C. Long-Term Follow-up to a Randomized Controlled Trial Comparing Peroneal Nerve Functional Electrical Stimulation to an Ankle Foot Orthosis for Patients With Chronic Stroke. Neurorehabil Neural Repair. 2015 Nov-Dec;29(10):911-22

Blum K, Chen AL, Chen TJ, Prihoda TJ, Schoolfield J, DiNubile N, Waite RL, Arcuri V, Kerner M, Braverman ER, Rhoades P, Tung H. The H-Wave device is an effective and safe non-pharmacological analgesic for chronic pain: a meta-analysis. Adv Ther. 2008 Jul;25(7):644-57

Blum K, Ho CK, Chen AL, Fulton M, Fulton B, Westcott WL, Reinl G, Braverman ER, DiNubile N, Chen TJ. The H-Wave(I) Device Induces NODependent Augmented Microcirculation and Angiogenesis, Providing Both Analgesia and Tissue Healing in Sports Injuries. Phys Sportsmed. 2008 Dec;36(1):103-14

Blumenfeld L, Hahn Y, Lepage A, Leonard R, Belafsky PC. Transcutaneous electrical stimulation versus traditional dysphagia therapy: a nonconcurrent cohort study. *Otolaryngol Head Neck Surg*. 2006;135(5):754-757. doi:10.1016/j.otohns.2006.04.016

Bogduk N. Management of chronic low back pain Med J Aust 2004; 180 (10): 542-544

Bosques G, Martin R, McGee L, Sadowsky C. Does therapeutic electrical stimulation improve function in children with disabilities? A comprehensive literature review. J Pediatr Rehabil Med. 2016 May 31;9(2):83-99

Bremner CB, Holcomb WR, Brown CD, Perreault ME. The Effectiveness of Neuromuscular Electrical Stimulation in Improving Voluntary Activation of the Quadriceps: A Critically Appraised Topic. J Sport Rehabil. 2016 Nov 11:1-21

California Technology Assessment Forum. Interferential Stimulation For The Treatment Of Musculoskeletal Pain. 2005. Retrieved on March 11, 2023 from

https://www.scribd.com/document/15028105/Interferential-Stimulation-for-the-Treatment-of-Musculoskeletal-Pain

Cameron, M. Physical Agents in Rehabilitation: An Evidence-Based Approach to Practice. 5th edition. Saunders; 2018

Carnaby-Mann GD, Crary MA. Examining the evidence on neuromuscular electrical stimulation for swallowing: a meta-analysis. Arch Otolaryngol Head Neck Surg. 2007 Jun;133(6):564-71

Castel LD, Freburger JK, Holmes GM, Scheinman RP, Jackman AM, Carey TS. Spine and pain clinics serving North Carolina patients with back and neck pain: what do they do, and are they multidisciplinary? Spine 2009;34:615-622

Centers for Medicare and Medicaid Services. National Coverage Determination (NCD): Electrotherapy for Treatment of Facial Nerve Paralysis (Bell's Palsy) (160.15). Retrieved on March 11, 2023 from https://www.cms.gov/medicare-coverage-database/details/ncd-details.aspx?NCDId=94&ncdver=1&bc=AAAAgAAAAAAA&

Centers for Medicare and Medicaid Services. Local Coverage Determination (LCD): Outpatient Physical and Occupational Therapy Services (L33631). Retrieved on March 11, 2023 from https://www.cms.gov/medicare-coverage-database/details/lcd-details.aspx?LCDId=33631&ver=51&NCDId=72&ncdver=1&SearchType=Advanced&CoverageSelection=Both&NCSelection=NCD%7cTA&ArticleType=Ed%7cKey%7cSAD%7cFAQ&PolicyType=Final&s=---%7c5%7c6%7c66%7c67%7c9%7c38%7c63%7c41%7c64%7c65%7c44&KeyWord=laser+procedures&KeyWordLookUp=Doc&KeyWordSearchType=And&kq=true&bc=IAAAABAAAAAA&

Centers for Medicare and Medicaid Services. National Coverage Determination (NCD): Transcutaneous Electrical Nerve Stimulation (TENS) for Acute Post-Operative Pain (10.2). Retrieved on March 11, 2023 from https://www.cms.gov/medicare-coverage-database/details/ncd-details.aspx?NCDId=145&ncdver=2&bc=AAAAgAAAAAAA&

Centers for Medicare and Medicaid Services. National Coverage Determination (NCD): Transcutaneous Electrical Nerve Stimulation (TENS) for Chronic Low Back Pain (CLBP) (160.27). Retrieved on March 11, 2023 from https://www.cms.gov/medicare-coverage-database/details/ncd-details.aspx?NCDId=354&ncdver=1&bc=AAAAgAAAAAAA&

Centers for Medicare and Medicaid Services. National Coverage Determination (NCD) for Treatment of Motor Function Disorders with Electric Nerve Stimulation (160.2). Retrieved on March 11, 2023 from https://www.cms.gov/medicare-coverage-database/details/ncd-details.aspx?ncdid=22

Centers for Medicare and Medicaid Services. National Coverage Determination (NCD) for Non-Implantable Pelvic Floor Electrical Stimulator (230.8) Retrieved on March 11, 2023 from https://www.cms.gov/medicare-coverage-database/view/ncd.aspx?NCDId=231

Cetin N, Aytar A, Atalay A, Akman MN. Comparing hot pack, short-wave diathermy, ultrasound, and TENS on isokinetic strength, pain, and functional status of women with osteoarthritic knees: A single-blind, randomized, controlled trial. Am J Phys Med Rehabil. 2008;87:443-451

Chen HL, Yang FA, Lee TH, Liou TH, Escorpizo R, Chen HC. Effectiveness of interferential current therapy in patients with knee osteoarthritis: a systematic review and meta-analysis of randomized controlled trials. Sci Rep. 2022;12(1):9694. Published 2022 Jun 11. doi:10.1038/s41598-022-13478-6

Chen YH, Wang HY, Liao CD, Liou TH, Escorpizo R, Chen HC. Effectiveness of neuromuscular electrical stimulation in improving mobility in children with cerebral palsy: A systematic review and meta-analysis of randomized controlled trials. Clin Rehabil. 2023;37(1):3-16. doi:10.1177/02692155221109661

Chen YW, Chang KH, Chen HC, Liang WM, Wang YH, Lin YN. The effects of surface neuromuscular electrical stimulation on post-stroke dysphagia: a systemic review and meta-analysis. Clin Rehabil. 2016 Jan;30(1):24-35

Chiu HC, Ada L. Effect of functional electrical stimulation on activity in children with cerebral palsy: a systematic review. Pediatr Phys Ther. 2014 Fall;26(3):283-8.

Chou R, Deyo R, Friedly J, Skelly A, Hashimoto R, Weimer M, Fu R, Dana T, Kraegel P, Griffin J, Grusing S, Brodt E. Noninvasive Treatments for Low Back Pain. Comparative Effectiveness Review No. 169. (Prepared by the Pacific Northwest Evidence-based Practice Center under Contract No. 290-2012-00014-I.) AHRQ Publication No. 16-EHC004-EF. Rockville, MD: Agency for Healthcare Research and Quality; February 2016

Chou R and Hoyt Huffman LH. Nonpharmacologic therapies for acute and chronic low back pain: A review of the evidence for an American Pain Society/American College

of Physicians Clinical Practice Guideline. Annals of Internal Medicine. 2007;147(7):492-504

Chou R, Qaseem A, Snow V, Casey D, Cross Jr T, Shekelle P, Owens DK. Diagnosis and treatment of low back pain: A joint clinical practice guideline from the American College of Physicians and the American Pain Society. Annals of Internal Medicine. 2007;147(7):478-490

Christiaanse ME, Mabe B, Russell G, Simeone TL, Fortunato J, Rubin B. Neuromuscular electrical stimulation is no more effective than usual care for the treatment of primary dysphagia in children. Pediatr Pulmonol. 2011 Jun;46(6):559-65

Clark H, Lazarus C, Arvedson J, Schooling T, Frymark T. Evidence-based systematic review: effects of neuromuscular electrical stimulation on swallowing and neural activation. Am J Speech Lang Pathol. 2009 Nov;18(4):361-75

Culvenor AG, Girdwood MA, Juhl CB, et al. Rehabilitation after anterior cruciate ligament and meniscal injuries: a best-evidence synthesis of systematic reviews for the OPTIKNEE consensus. Br J Sports Med. 2022;56(24):1445-1453. doi:10.1136/bjsports-2022-105495

Davison P, Wilkinson R, Miller J, Auais M. A systematic review of using electrical stimulation to improve clinical outcomes after hip fractures. Physiother Theory Pract. 2022;38(12):1857-1875. doi:10.1080/09593985.2021.1894620

Dias LV, Cordeiro MA, Schmidt de Sales R, et al. Immediate analgesic effect of transcutaneous electrical nerve stimulation (TENS) and interferential current (IFC) on chronic low back pain: Randomised placebo-controlled trial. J Bodyw Mov Ther. 2021;27:181-190

Dissanayaka TD, Pallegama RW, Suraweera HJ, Johnson MI, Kariyawasam AP. Comparison of the Effectiveness of Transcutaneous Electrical Nerve Stimulation and Interferential Therapy on the Upper Trapezius in Myofascial Pain Syndrome: A Randomized Controlled Study. Am J Phys Med Rehabil. 2016 Sep;95(9):663-72

Dubinsky RM, Miyasaki J, American Academy of Neurology, Efficacy of transcutaneous electrical nerve stimulation in the treatment of pain in neurologic disorders (an evidence-based review), Neurology® 2010; 74: 173-176

ELECTROPHYSICAL AGENTS - Contraindications And Precautions: An Evidence-Based Approach To Clinical Decision Making In Physical Therapy. Physiother Can. 2010;62(5):1-80. Doi:10.3138/ptc.62.5

Esnouf JE, Taylor PN, Mann GE, Barrett CL. Impact on activities of daily living using a functional electrical stimulation device to improve dropped foot in people with multiple sclerosis, measured by the Canadian Occupational Performance Measure. Mult Scler. 2010 Sep;16(9):1141-7

Evans AG, Horrar AN, Ibrahim MM, et al. Outcomes of transcutaneous nerve stimulation for migraine headaches: a systematic review and meta-analysis. J Neurol. 2022;269(8):4021-4029. doi:10.1007/s00415-022-11059-1

Everaert DG, Stein RB, Abrams GM, Dromerick AW, Francisco GE, Hafner BJ, Huskey TN, Munin MC, Nolan KJ, Kufta CV. Effect of a foot-drop stimulator and ankle-foot orthosis on walking performance after stroke: a multicenter randomized controlled trial. Neurorehabil Neural Repair. 2013 Sep;27(7):579-91

Facci LM, Nowotny JP, Tormem F, Trevisani VF. Effects of transcutaneous electrical nerve stimulation (TENS) and interferential currents (IFC) in patients with nonspecific chronic low back pain: randomized clinical trial. Sao Paulo Med J. 2011;129(4):206-16

Fertout A, Manière-Ezvan A, Lupi L, Ehrmann E. Management of temporomandibular disorders with transcutaneous electrical nerve stimulation: A systematic review. Cranio. 2022;40(3):217-228. doi:10.1080/08869634.2019.1687986

Frequency Specific Microcurrent. Retrieved on March 11, 2023 from http://frequencyspecific.com/microcurrent-experimental-results-5407/about/

Fuentes JP, Armijo Olivo S, Magee DJ, Gross DP. Effectiveness of interferential current therapy in the management of musculoskeletal pain: a systematic review and meta-analysis. Phys Ther. 2010 Sep;90(9):1219-38

Gatewood CT, Tran AA, Dragoo JL. The efficacy of post-operative devices following knee arthroscopic surgery: a systematic review. Knee Surg Sports Traumatol Arthrosc. 2017 Feb;25(2):501-516

Geeganage C, Beavan J, Ellender S, Bath PM. Interventions for dysphagia and nutritional support in acute and subacute stroke. Cochrane Database Syst Rev. 2012 Oct 17;10:CD000323

Gibson W, Wand BM, Meads C, Catley MJ' O'Connell NE. Transcutaneous electrical nerve stimulation (TENS) for chronic pa—n – an overview of Cochrane Reviews. Cochrane Database Syst Rev. 2019 Apr 3;4(4):CD011890. Doi: 10.1002/14651858.CD011890.pub3

Gotlin RS, Hershkowitz S, Juris PM, et al. Electrical stimulation effect on extensor lag and length of hospital stay after total knee arthroplasty. Arch Phys Med Rehabil. 1994;75(9):957-959

Graham N, Gross AR, Carlesso LC, Santaguida PL, Macdermid JC, Walton D, Ho E; ICON. An ICON Overview on Physical Modalities for Neck Pain and Associated Disorders. Open Orthop J. 2013 Sep 20;7:440-60

Gross AR, Goldsmith C, Hoving JL, Haines T, Peloso P, Aker P, et al. Conservative management of mechanical neck disorders: a systematic review. J Rheumatol 2007; 34:1083-1102

Gu P, Ran JJ. Electrical Stimulation for Hemiplegic Shoulder Function: A Systematic Review and Meta-Analysis of 15 Randomized Controlled Trials. Arch Phys Med Rehabil. 2016 Sep;97(9):1588-94

Guzman J, Haldeman S, Carroll LJ, Carragee EJ, Hurwitz EL, Peloso P, et al. Clinical practice implications of the Bone and Joint Decade 2000-2010 Task Force on Neck Pain and Its Associated Disorders: from concepts and findings to recommendations. Spine 2008;33:S199-S213

Haldeman S, Dagenais S. What have we learned about the evidence-informed management of chronic low back pain? Spine J. 2008 Jan-Feb;8(1):266-77

Hawk C, Whalen W, Farabaugh RJ, Daniels CJ, Minkalis AL, Taylor DN, Anderson D, Anderson K, Crivelli LS, Cark M, Barlow E, Paris D, Sarnat R, Weeks J. Best Practices for Chiropractic Management of Patients with Chronic Musculoskeletal Pain: A Clinical Practice Guideline. J Altern Complement Med. 2020 Oct;26(10):884-901. Doi: 10.1089/acm.2020.0181

Hayes Inc. Hayes Brief. Percutaneous electrical nerve stimulation for treatment of low back pain. Lansdale, PA: Hayes, Inc. Feb 9, 2017

Houghton PE. Clinical Trials Involving Biphasic Pulsed Current, MicroCurrent, and/or Low-Intensity Direct Current. Adv Wound Care (New Rochelle). 2014 Feb1;3(2):166-183

Howlett OA, Lannin NA, Ada L, McKinstry C. Functional electrical stimulation improves activity after stroke: a systematic review with meta-analysis. Arch Phys Med Rehabil. 2015 May;96(5):934-43

Hsueh TC, Cheng PT, Kuan TS, Hong CZ. The immediate effectiveness of electrical nerve stimulation and electrical muscle stimulation on myofascial trigger points. Am J Phys Med Rehabil 1997;76:471-476

Huckabee ML, Doeltgen S. Emerging modalities in dysphagia rehabilitation: neuromuscular electrical stimulation. N Z Med J. 2007 Oct 12;120(1263):U2744

Hurlow A, Bennett MI, Robb KA, Johnson MI, Simpson KH, Oxberry SG. Transcutaneous electric nerve stimulation (TENS) for cancer pain in adults. Cochrane Database of Systematic Reviews 2012, Issue 3. Art. No.: CD006276

Hurwitz EL, Carragee EJ, van d, V, Carroll LJ, Nordin M, Guzman J, et al. Treatment of neck pain: noninvasive interventions: results of the Bone and Joint Decade 2000-2010 Task Force on Neck Pain and Its Associated Disorders. J Manipulative Physiol Ther 2009;32:S141-S175

Hussein HM, Alshammari RS, Al-Barak SS, Alshammari ND, Alajlan SN, Althomali OW. A Systematic Review and Meta-analysis Investigating the Pain-Relieving Effect of Interferential Current on Musculoskeletal Pain. Am J Phys Med Rehabil. 2022;101(7):624-633. doi:10.1097/PHM.0000000000001870

Ignácio Antônio F, Bø K, Pena CC, et al. Intravaginal electrical stimulation increases voluntarily pelvic floor muscle contractions in women who are unable to voluntarily contract their pelvic floor muscles: a randomised trial. J Physiother. 2022;68(1):37-42

Iijima H, Takahashi M. Microcurrent Therapy as a Therapeutic Modality for Musculoskeletal Pain: A Systematic Review Accelerating the Translation From Clinical Trials to Patient Care. Arch Rehabil Res Clin Transl. 2021;3(3):100145. Published 2021 Jul 21

Imoto AM, Peccin S, Almeida GJ, Saconato H, Atallah ÁN. Effectiveness of electrical stimulation on rehabilitation after ligament and meniscal injuries: a systematic review. Sao Paulo Med J. 2011 Dec;129(6):414-23

Jamtvedt G, Dahm KT, Christie A, et al. Physical therapy interventions for patients with osteoarthritis of the knee: An overview of systematic reviews. Phys Ther. 2008;88:123-136

Jauregui JJ, Cherian JJ, Gwam CU, Chughtai M, Mistry JB, Elmallah RK, Harwin SF, Bhave A, Mont MA. A Meta-Analysis of Transcutaneous Electrical Nerve Stimulation for Chronic Low Back Pain. Surg Technol Int. 2016 Apr;28:296-30

Jin DM, Xu Y, Geng DF, Yan TB. Effect of transcutaneous electrical nerve stimulation on symptomatic diabetic peripheral neuropathy: a meta-analysis of randomized controlled trials. Diabetes Res Clin Pract. 2010 Jul;89(1):10-5

Johnson M, Martinson M. Efficacy of electrical nerve stimulation for chronic musculoskeletal pain: A meta-analysis of randomized controlled trials. Pain. 2007;130:157-165

Johnson MI, Jones G. Transcutaneous electrical nerve stimulation: current status of evidence. Pain Manag. 2017 Jan;7(1):1-4

Johnson MI, Paley CA, Howe TE, Sluka KA. Transcutaneous electrical nerve stimulation for acute pain. Cochrane Database Syst Rev. 2015 Jun 15;6:CD006142

Johnson MI, Paley CA, Jones G, Mulvey MR, Wittkopf PG. Efficacy and safety of transcutaneous electrical nerve stimulation (TENS) for acute and chronic pain in adults: a systematic review and meta-analysis of 381 studies (the meta-TENS study). BMJ Open. 2022;12(2):e051073. Published 2022 Feb 10

Johnston TE, Keller S, Denzer-Weiler C, Brown L. A Clinical Practice Guideline for the Use of Ankle-Foot Orthoses and Functional Electrical Stimulation Post-Stroke. J Neurol Phys Ther. 2021;45(2):112-196

Jones S, Man WD, Gao W, Higginson IJ, Wilcock A, Maddocks M. Neuromuscular electrical stimulation for muscle weakness in adults with advanced disease. Cochrane Database Syst Rev. 2016 Oct 17;10:CD009419

Kadı MR, Hepgüler S, Atamaz FC, et al. Is interferential current effective in the management of pain, range of motion, and edema following total knee arthroplasty surgery? A randomized double-blind controlled trial. Clin Rehabil. 2019; 33(6):1027-1034

Kang RW, Lewis PB, Kramer A, Hayden JK, Cole BJ. Prospective randomized single-blinded controlled clinical trial of percutaneous neuromodulation pain therapy device versus sham for the osteoarthritic knee: a pilot study. Orthopedics. 2007 Jun;30(6):439-45

Karamian BA, Siegel N, Nourie B, et al. The role of electrical stimulation for rehabilitation and regeneration after spinal cord injury. J Orthop Traumatol. 2022;23(1):2. Published 2022 Jan 6

Khadilkar A, Milne S, Brosseau L, Robinson V, Saginur M, Shea B, Tugwell P, Wells G. Transcutaneous electrical nerve stimulation (TENS) for chronic low-back pain. Cochrane Database Syst Rev. 2005 Jul 20;(3):CD003008. Review. Update in: Cochrane Database Syst Rev. 2008;(4):CD003008

Khadilkar A, Odebiyi DO, Brosseau L, Wells GA. Transcutaneous electrical nerve stimulation (TENS) versus placebo for chronic low-back pain. Cochrane Database Syst Rev. 2008 Oct 8;(4):CD003008

Kiger M, Brown CS, Watkins L. Dysphagia management: an analysis of patient outcomes using VitalStim therapy compared to traditional swallow therapy. Dysphagia. 2006 Oct;21(4):243-53

Kim KM, Croy T, Hertel J, Saliba S. Effects of neuromuscular electrical stimulation after anterior cruciate ligament reconstruction on quadriceps strength, function, and patient-oriented outcomes: a systematic review. J Orthop Sports Phys Ther. 2010 Jul;40(7):383-91

Koyuncu E, Nakipoğlu-Yüzer GF, Doğan A, Ozgirgin N. The effectiveness of functional electrical stimulation for the treatment of shoulder subluxation and shoulder pain in hemiplegic patients: A randomized controlled trial. Disabil Rehabil. 2010;32(7):560-6

Kristensen MGH, Busk H, Wienecke T. Neuromuscular Electrical Stimulation Improves Activities of Daily Living Post Stroke: A Systematic Review and Meta-analysis. Arch Rehabil Res Clin Transl. 2021;4(1):100167. Published 2021 Nov 12

Labanca L, Bonsanto F, Raffa D, Orlandi Magli A, Benedetti MG. Does adding neuromuscular electrical stimulation to rehabilitation following total knee arthroplasty lead to a better quadriceps muscle strength recovery? A systematic review. Int J Rehabil Res. 2022;45(2):118-125. doi:10.1097/MRR.0000000000000525

Leonardo K, Seno DH, Mirza H, Afriansyah A. Biofeedback-assisted pelvic floor muscle training and pelvic electrical stimulation in women with overactive bladder: A systematic review and meta-analysis of randomized controlled trials. Neurourol Urodyn. 2022;41(6):1258-1269. doi:10.1002/nau.24984

Leemans L, Polli A, Nijs J, Wideman T, den Bandt H, Beckwée D. It Hurts to Move! Intervention Effects and Assessment Methods for Movement-Evoked Pain in Patients With Musculoskeletal Pain: A Systematic Review with Meta-analysis. J Orthop Sports Phys Ther. 2022;52(6):345-374. doi:10.2519/jospt.2022.10527

Liang Y, Lin J, Wang H, et al. Evaluating the Efficacy of VitalStim Electrical Stimulation Combined with Swallowing Function Training for Treating Dysphagia following an Acute Stroke. Clinics (Sao Paulo). 2021;76:e3069. Published 2021 Nov 8. doi:10.6061/clinics/2021/e3069

Maddocks M, Gao W, Higginson IJ, Wilcock A. Neuromuscular electrical stimulation for muscle weakness in adults with advanced disease. Cochrane Database Syst Rev. 2013 Jan 31;1:CD009419

Mahmoudi Z, Mohammadi R, Sadeghi T, Kalbasi G. The Effects of Electrical Stimulation of Lower Extremity Muscles on Balance in Stroke Patients: A Systematic Review of Literatures. J Stroke Cerebrovasc Dis. 2021;30(8):105793

Miller S, Kühn D, Jungheim M, Schwemmle C, Ptok M. Neuromuskuläre Elektrostimulationsverfahren in der HNO-Heilkunde [Neuromuscular electric stimulation therapy in otorhinolaryngology]. *HNO*. 2014;62(2):131-140. doi:10.1007/s00106-013-2810-4

Miller S, Peters K, Ptok M. Review of the effectiveness of neuromuscular electrical stimulation in the treatment of dysphagia - an update. Ger Med Sci. 2022;20:Doc08. Published 2022 Jun 14. doi:10.3205/000310

Monaghan B, Caulfield B' O'Mathúna DP. Surface neuromuscular electrical stimulation for quadriceps strengthening pre and post total knee replacement. Cochrane Database Syst Rev. 2010 Jan 20;(1):CD007177

Mulvey MR, Bagnall AM, Johnson MI, Marchant PR. Transcutaneous electrical nerve stimulation (TENS) for phantom pain and stump pain following amputation in adults. Cochrane Database of Systematic Reviews 2010, Issue 5. Art. No.: CD007264

Nair HKR. Microcurrent as an adjunct therapy to accelerate chronic wound healing and reduce patient pain. J Wound Care. 2018 May 2;27(5):296-306

National Guideline Centre (UK). Evidence review for electrical physical modalities for chronic primary pain: Chronic pain (primary and secondary) in over 16s: assessment of all chronic pain and management of chronic primary pain. London: National Institute for Health and Care Excellence (NICE); April 2021

Nnoaham KE, Kumbang J. Transcutaneous electrical nerve stimulation (TENS) for chronic pain. Cochrane Database Syst Rev. 2008:CD003222

Nooijen CF, Ter Hoeve N, Field-Fote EC. Gait quality is improved by locomotor training in individuals with SCI regardless of training approach. J Neuroeng Rehabil

Novak S, Guerron G, Zou Z, Cheung G, Berteau JP. New Guidelines for Electrical Stimulation Parameters in Adult Patients With Knee Osteoarthritis Based on a Systematic Review of the Current Literature. Am J Phys Med Rehabil. 2020 Aug;99(8):682-68.

Ottawa panel evidence-based clinical practice guidelines for electrotherapy and thermotherapy interventions in the management of rheumatoid arthritis in adults. Phys Ther. 2004;84:1016-1043

Ou CH, Shiue CC, Kuan YC, Liou TH, Chen HC, Kuo TJ. Neuromuscular Electrical Stimulation of Upper Limbs in Patients With Cerebral Palsy: A Systematic Review and Meta-analysis of Randomized Controlled Trials. Am J Phys Med Rehabil. 2023;102(2):151-158. doi:10.1097/PHM.0000000000002058

Page MJ, Green S, Mrocki MA, Surace SJ, Deitch J, McBain B, Lyttle N, Buchbinder R. Electrotherapy modalities for rotator cuff disease. Cochrane Database Syst Rev. 2016 Jun 10;(6):CD012225

Peng L, Wang K, Zeng Y, Wu Y, Si H, Shen B. Effect of Neuromuscular Electrical Stimulation After Total Knee Arthroplasty: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. Front Med (Lausanne). 2021;8:779019. Published 2021 Dec 3

Pereira S, Mehta S, McIntyre A, Lobo L, Teasell RW. Functional electrical stimulation for improving gait in persons with chronic stroke. Top Stroke Rehabil. 2012 Nov-Dec;19(6):491-8

Philadelphia panel evidence-based clinical practice guidelines on selected rehabilitation interventions for knee pain. Phys Ther. 2001;81:1675-1700

Philadelphia panel evidence-based clinical practice guidelines on selected rehabilitation interventions for shoulder pain. Phys Ther. 2001;81:1719-1730

Philadelphia Panel. Philadelphia Panel evidence-based clinical practice guidelines on selected rehabilitation interventions for low back pain. Phys Ther. 2001;81(10):1641-74

Pieber K, Herceg M, Paternostro-Sluga T. Electrotherapy for the treatment of painful diabetic peripheral neuropathy: a review. J Rehabil Med. 2010 Apr;42(4):289-95

Pietrosimone B, Luc-Harkey BA, Harkey MS, Davis-Wilson HC, Pfeiffer SJ, Schwartz TA, Nissman D, Padua DA, Blackburn JT, Spang JT. Using TENS to Enhance Therapeutic Exercise in Individuals with Knee Osteoarthritis. Med Sci Sports Exerc. 2020 Oct;52(10):2086-2095

Pivec R, Stokes M, Chitnis AS, Paulino CB, Harwin SF, Mont MA. Clinical and economic impact of TENS in patients with chronic low back pain: analysis of a nationwide database. Orthopedics. 2013 Dec;36(12):922-8

Plaza-Manzano G, Gómez-Chiguano GF, Cleland JA, Arías-Buría JL, Fernández-de-Las-Peñas C, Navarro-Santana MJ. Effectiveness of percutaneous electrical nerve stimulation for musculoskeletal pain: A systematic review and meta-analysis. Eur J Pain. 2020 Jul;24(6):1023-1044

Poitras S, Brosseau L. Evidence-informed management of chronic low back pain with transcutaneous electrical nerve stimulation, interferential current, electrical muscle stimulation, ultrasound, and thermotherapy. Spine J. 2008 Jan-Feb;8(1):226-33

Pomeroy VM, King L, Pollock A, Baily-Hallam A, Langhorne P. Electrostimulation for promoting recovery of movement or functional ability after stroke. Cochrane Database Syst Rev. 2006 Apr 19;(2):CD003241

Postans NJ, Hasler JP, Granat MH, Maxwell DJ. Functional electric stimulation to augment partial weight-bearing supported treadmill training for patients with acute incomplete spinal cord injury: A pilot study. Arch Phys Med Rehabil. 2004 Apr;85(4):604-10

Prenton S, Hollands KL, Kenney LP. Functional electrical stimulation versus ankle foot orthoses for foot-drop: A meta-analysis of orthotic effects. J Rehabil Med. 2016 Oct 5;48(8):646-656

Price CI, Pandyan AD. Electrical stimulation for preventing and treating post-stroke shoulder pain. Cochrane Database Syst Rev. 2000;(4):CD001698

Qaseem A, Wilt TJ, McLean RM, Forciea MA; Clinical Guidelines Committee of the American College of Physicians. Noninvasive Treatments for Acute, Subacute, and Chronic Low Back Pain: A Clinical Practice Guideline From the American College of Physicians. Ann Intern Med. 2017 Apr 4;166(7):514-530

Rajpurohit B, Khatri SM, Metgud D, Bagewadi A. Effectiveness of transcutaneous electrical nerve stimulation and microcurrent electrical nerve stimulation in bruxism associated with masticatory muscle p—n--a comparative study. Indian J Dent Res. 2010 Jan-Mar;21(1):104-6

Rampazo ÉP, Martignago CCS, de Noronha M, Liebano RE. Transcutaneous electrical stimulation in neck pain: A systematic review and meta-analysis. Eur J Pain. 2022;26(1):18-42

Reichenbach S, Jüni P, Hincapié CA, et al. Effect of transcutaneous electrical nerve stimulation (TENS) on knee pain and physical function in patients with symptomatic knee osteoarthritis: the ETRELKA randomized clinical trial. Osteoarthritis Cartilage. 2022;30(3):426-435

Robb K, Oxberry SG, Bennett MI, Johnson MI, Simpson KH, Searle RD. A cochrane systematic review of transcutaneous electrical nerve stimulation for cancer pain. J Pain Symptom Manage. 2009 Apr;37(4):746-53

Rutjes AW, Nüesch E, Sterchi R, Kalichman L, Hendriks E, Osiri M, Brosseau L, Reichenbach S, Jüni P. Transcutaneous electrostimulation for osteoarthritis of the knee. Cochrane Database Syst Rev. 2009 Oct 7;(4):CD002823

Shaw GY, Sechtem PR, Searl J, Keller K, Rawi TA, Dowdy E. Transcutaneous neuromuscular electrical stimulation (VitalStim) curative therapy for severe dysphagia: myth or reality? Ann Otol Rhinol Laryngol. 2007 Jan;116(1):36-44

Sillen MJ, Speksnijder CM, Eterman RM, Janssen PP, Wagers SS, Wouters EF, Uszko-Lencer NH, Spruit MA. Effects of neuromuscular electrical stimulation of muscles of ambulation in patients with chronic heart failure or COPD: a systematic review of the English-language literature. Chest. 2009 Jul;136(1):44-61

Sluka KA, Bjordal JM, Marchand S, Rakel BA. What makes transcutaneous electrical nerve stimulation work? Making sense of the mixed results in the clinical literature. Phys. Ther. 2013;93(10):1397–1402

Sluka KA, Walsh D. Transcutaneous electrical nerve stimulation: Basic science mechanisms and clinical effectiveness. J Pain. 2003;4:109-121

Snyder-Mackler L, Delitto A, Bailey SL, Stralka SW. Strength of the quadriceps femoris muscle and functional recovery after reconstruction of the anterior cruciate ligament. A prospective, randomized clinical trial of electrical stimulation. J Bone Joint Surg Am. 1995;77(8):1166-1173

Snyder-Mackler L, Ladin Z, Schepsis AA, Young JC. Electrical stimulation of the thigh muscles after reconstruction of the anterior cruciate ligament. J Bone Joint Surg. 1991;73(7):1025-1036

Springer S, Khamis S. Effects of functional electrical stimulation on gait in people with multiple sclerosis - A systematic review. Mult Scler Relat Disord. 2017 Apr;13:4-12

Stania M, Niemiec B, Kamieniarz A, Chmielewska D. Intravaginal electrical stimulation as a monotherapy for female stress urinary incontinence: A systematic review and meta-analysis. Complement Ther Clin Pract. 2022;49:101624. doi:10.1016/j.ctcp.2022.101624

Stein C, Fritsch CG, Robinson C, Sbruzzi G, Plentz RD. Effects of electrical stimulation in spastic muscles after stroke: systematic review and meta-analysis of randomized controlled trials. . Stroke. 2015 Aug;46(8):2197-205

Steele CM, Thrasher AT, Popovic MR. Electric stimulation approaches to the restoration and rehabilitation of swallowing: a review. *Neurological Research*. 2007;29(1):9–15

Stein RB, Everaert DG, Thompson AK, Chong SL, Whittaker M, Robertson J, Kuether G. Long-term therapeutic and orthotic effects of a foot drop stimulator on walking performance in progressive and nonprogressive neurological disorders. Neurorehabil Neural Repair. 2010 Feb;24(2):152-67

Tan C, Liu Y, Li W, Liu J, Chen L. Transcutaneous neuromuscular electrical stimulation can improve swallowing function in patients with dysphagia caused by non-stroke diseases: a meta-analysis. J Oral Rehabil. 2013 Jun;40(6):472-80

Teoli D, An J. Transcutaneous Electrical Nerve Stimulation. In: StatPearls. Treasure Island (FL): StatPearls Publishing; November 4, 2021

Terré R, Mearin F. A randomized controlled study of neuromuscular electrical stimulation in oropharyngeal dysphagia secondary to acquired brain injury. Eur J Neurol. 2015 Apr;22(4):687-e44

Todhunter-Brown A, Hazelton C, Campbell P, Elders A, Hagen S, McClurg D. Conservative interventions for treating urinary incontinence in women: an Overview of Cochrane systematic reviews. Cochrane Database Syst Rev. 2022;9(9):CD012337. Published 2022 Sep 2. doi:10.1002/14651858.CD012337.pub2

van der Scheer JW, Goosey-Tolfrey VL, Valentino SE, Davis GM, Ho CH. Functional electrical stimulation cycling exercise after spinal cord injury: a systematic review of health and fitness-related outcomes. J Neuroeng Rehabil. 2021;18(1):99. Published 2021 Jun 12

Van Peppen RP, Kwakkel G, Wood-Dauphinee S, Hendriks HJ, Van der Wees PJ, Dekker J. The impact of physical therapy on functional outcomes after stroke: what's the evidence? Clin Rehabil. 2004 Dec;18(8):833-62

Vance CG, Dailey DL, Rakel BA, Sluka KA. Using TENS for pain control: the state of the evidence. Pain Manag. 2014 May;4(3):197-209

Vance CGT, Dailey DL, Chimenti RL, Van Gorp BJ, Crofford LJ, Sluka KA. Using TENS for Pain Control: Update on the State of the Evidence. Medicina (Kaunas). 2022;58(10):1332. Published 2022 Sep 22. doi:10.3390/medicina58101332

Walsh DM. TENS: Clinical Applications and Related Theory. In. New York: Churchill Livingston; 1997

Walsh NE, Brooks P, Hazes JM, et al. Standards of care for acute and chronic musculoskeletal pain: The bone and joint decade (2000-2010). Arch Phys Med Rehabil. 2008;89:1830-1845

Weiner DK, Perera S, Rudy TE, Glick RM, Shenoy S, Delitto A. Efficacy of percutaneous electrical nerve stimulation and therapeutic exercise for older adults with chronic low back pain: a randomized controlled trial. Pain. 2008 Nov 30;140(2):344-57

Welch V., Brosseau L, Saginur M, Shea B, Tugwell P, Wells G. Transcutaneous electrical nerve stimulation (TENS) for chronic low back pain. Cochrane Database Syst Rev. 2001;(2):CD003008

Williamson TK, Rodriguez HC, Gonzaba A, Poddar N, Norwood SM, Gupta A. H-Wave® Device Stimulation: A Critical Review. J Pers Med. 2021;11(11):1134. Published 2021 Nov 2

Wu Y, Zhu F, Chen W, Zhang M. Effects of transcutaneous electrical nerve stimulation (TENS) in people with knee osteoarthritis: A systematic review and meta-analysis. Clin Rehabil. 2022;36(4):472-485. doi:10.1177/02692155211065636

Yan T, Hui-Chan CW, Li LS. Functional electrical stimulation improves motor recovery of the lower extremity and walking ability of subjects with first acute stroke: a randomized placebo-controlled trial. Stroke. 2005 Jan;36(1):80-5

Yan D, Vassar R. Neuromuscular electrical stimulation for motor recovery in pediatric neurological conditions: a scoping review. Dev Med Child Neurol. 2021;63(12):1394-1401

Ye G, Grabke EP, Pakosh M, Furlan JC, Masani K. Clinical Benefits and System Design of FES-Rowing Exercise for Rehabilitation of Individuals with Spinal Cord Injury: A Systematic Review. Arch Phys Med Rehabil. 2021;102(8):1595-1605

Yue C, Zhang X, Zhu Y, Jia Y, Wang H, Liu Y. Systematic Review of Three Electrical Stimulation Techniques for Rehabilitation After Total Knee Arthroplasty. J Arthroplasty. 2018 Jul;33(7):2330-2337

Zeng C, Li H, Yang T, Deng ZH, Yang Y, Zhang Y, Lei GH. Electrical stimulation for pain relief in knee osteoarthritis: systematic review and network meta-analysis. Osteoarthritis Cartilage. 2015 Feb;23(2):189-202

Zhu D, Xia Z, Yang Z. Effectiveness of physiotherapy for lower urinary tract symptoms in postpartum women: systematic review and meta-analysis. Int Urogynecol J. 2022;33(3):507-521

Zhu Q, Gao G, Wang K, Lin J. Effect of Functional Electrical Stimulation on Gait Parameters in Children with Cerebral Palsy: A Meta-Analysis. Comput Math Methods Med. 2022;2022:3972958. Published 2022 Sep 22. doi:10.1155/2022/3972958

Zuim PR, Garcia AR, Turcio KH, Hamata MM. Evaluation of microcurrent electrical nerve stimulation (MENS) effectiveness on muscle pain in temporomandibular disorders patients. J Appl Oral Sci. 2006 Jan;14(1):61-6