REVIEW ARTICLE

Clinical applications and consideration of interventions of electrotherapy for orthopedic and neurological rehabilitation

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Abstract: Electrotherapy or electrical stimulation (ES) is a part of clinical intervention in the rehabilitation field. With rehabilitation intervention, electrotherapy may be provided as a treatment for pain relief, strengthening, muscle education, wound recovery, or functional training. Although these interventions may not be considered as the primary therapy for patients, the advantages of the ease of operation, lower costs, and lower risks render ES to be applied frequently in clinics. There have also been emerging ES tools for brain modulation in the past decade. ES interventions are not only considered analgesics but also as an important assistive therapy for motor improvement in orthopedic and neurological rehabilitation. In addition, during the coronavirus disease pandemic, lockdowns and self-quarantine policies have led to the discontinuation of orthopedic and neurological rehabilitation interventions. Therefore, the feasibility and effectiveness of home-based electrotherapy may provide opportunities for the prevention of deterioration or extension of the original therapy. The most common at-home applications in previous studies showed positive effects on pain relief, functional ES, muscle establishment, and motor training. Currently, there is a lack of certain products for at-home brain modulation; however, transcranial direct current stimulation has shown the potential of future home-based rehabilitation due to its relatively small and simple design. We have organized the features and applications of ES tools and expect the future potential of remote therapy during the viral pandemic.

Keywords: Electrotherapy; Interferential therapy; Neuromuscular stimulation; Transcranial direct current stimulation; Transcutaneous electrical nerve stimulation; Transcranial magnetic stimulation

1. INTRODUCTION

Electrotherapy or electrical stimulation (ES) interventions are noninvasive treatments accounting for physical therapy (PT) interventions with electric currents. ES is commonly used in clinical interventions for pain relief and neuromuscular applications.[1] For pain relief, electric currents have been applied to treat arthritis, local swelling, and pain in ancient Greece. Currently, transcutaneous electrical nerve stimulation (TENS) and interferential therapy (IFT) are widely used in the analgesic area.[2,3] Meanwhile, due to muscle contraction induced by ES, some types of ES have been used to stimulate muscles with peripheral nerve impairment, such as in cases of paralysis, in the past. In modern times of electrotherapy, ES for neuromuscular stimulation (NMES) is used to prevent muscle contracture or disuse during long-term bedridden states or immobilization. NMES is also applied to maintain or improve the range of motion, reduce muscle tone, and re-educate muscle function. Clinically, therapists have expanded the use of NMES as an alternative to neural activation of the muscles of patients' limbs, also called functional ES (FES). FES takes advantage of ES for muscle movement and activates specific muscles during daily activities. In addition, ES is classified into three categories: low, medium, and high frequency.[4]

Low frequency: 1 Hz to 1000 Hz (1 kHz) or pulses emitted per second—Medium frequency: 1 kHz to 10 kHz—High frequency: >10 KHz.[5]

In general, low-frequency ES might induce less discomfort. As for the depth of stimulation, a higher frequency may theoretically arrive at deeper tissue. However, if the frequency is higher, ES will be delivered in the nonresponse period of the nerve. Therefore, ES pulses must be adjusted for nerve tissue. For example, IFT provides a synthetic wave of medium frequency to provoke muscle reactions.

Recently, some novel ES methods have been applied in clinical studies, such as transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS). By generating fast changes in the magnetic field, TMS delivers ES through the brain, allowing for specific modulation of cortical excitability

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through action potentials.[6] The tDCS technique, which is garnering a growing interest in the neuroscience field, is also a noninvasive method for brain modulation using direct currents. With the anodal or cathodal nature of the electrode,[7] tDCS alters neuronal excitability, resulting in the modification of brain activity.[8]

Given the coronavirus disease (COVID-19) pandemic since 2020, manpower shortage is also a growing issue in clinical practice. Noninvasive ES is a user-friendly, economical treatment conferring fewer side effects, which may assist in remote rehabilitation. In this review, we discuss the basic mechanisms and implications of electrotherapy. This may help clinical staff rearrange their rehabilitation interventions.

2. TENS

TENS is a low-frequency ES primarily used in clinical rehabilitation owing to its advantages of the ease of use, lower costs, and lower risks. TENS is generally applied to the surface of a patient's body for acute conditions (Fig. 1). TENS is also popular for clinical and home use by placing two of the four electrodes on patients' skin for analgesia. There are two primary mechanisms underlying the effect of pain relief associated with TENS.[9] One is the pain gate mechanism, wherein nonpainful input such as ES closes the nerve "gates" of painful inputs and prevents the transmission of pain signals to the central nervous system. This gating mechanism occurs in the dorsal horn of the spinal cord. The second is the endogenous opioid system, which occurs at the spinal cord level and in peripheral sensory neurons.[10] TENS activates pain inhibition, stimulating the release of endogenous opioids.[11]

2.1. Clinical application of TENS

By activating the large diameter of the non-noxious afferent to elicit pain relief, TENS produces a strong but comfortable sensation. Systematic reviews of ES have suggested that TENS with adequate intensities is effective for pain control associated with surgery, osteoarthritis, neuropathy related to diabetes, fibromyalgia and spinal cord injury, and some acute conditions.

A recent review also suggested that TENS could be used for the treatment of primary dysmenorrhea.[11] In general, the electrodes are applied to pain sites, peripheral nerves, nerve roots, and contralateral/unilateral dermatomes or myotomes.

3. IFT

Compared to TENS, IFT provides noninvasive medium-frequency ES, which has lower impedance in human soft tissue with minimal side effects. Therefore, the higher-frequency ES crosses the skin barrier easier to travel to deeper layers of pain without an increase in discomfort. In addition, the frequency of the IFT that delivers muscle beats can be controlled by different channels of the ES input. Although a higher-frequency ES may penetrate deep areas, the frequency may not easily induce muscle beats. Therefore, by combining two different frequencies from each channel, IFT generates lower-frequency waves to stimulate nerves. For example, one current is at 4100 Hz with its companion current at 4000 Hz; thus, the resultant beat frequency would be 100 Hz.[2] The mechanism for pain relief is similar to the concept underlying TENS.[12] The electrode positioning must cover the area of the treatment by crossing placement with four electrodes (two bipolar channels) to generate the "interferential current."

3.1. Clinical application of IFT

IFT has been popular for PT for a long time. The suction electrode application method has been used for several years and makes it easier to apply IFT on segments requiring extensive coverage, such as the trunk, hip joints, knee joints, and shoulder joints (Fig. 2).

In clinical practice, IFT is used for pain relief, muscle stimulation, increased local blood flow, tissue healing, and swelling reduction, although the most common use is to provide pain relief.[13] Previous systematic reviews have suggested that IFT is effective for reducing pain in some clinical cases, such as knee osteoarthritis or pain relief interventions included in a multimodal treatment plan.[14,15]

4. NMES AND FES

NMES and FES are often used for neuromuscular rehabilitation after nerve injury. The forms of NMES or FES that are implemented by therapists involve applying ES to muscles and nerves to produce muscle contraction via depolarization of the motor nerves. Electrode types are divided into monopolar and bipolar electrodes. For monopolar electrodes (cathodal and anodal), the cathode should be placed on the motor point of the target muscle. In contrast, bipolar electrodes should be placed on the muscle belly or at the proximal and distal ends of the muscle. With repeated ES on a muscle, the muscle may exhibit enhanced strength, retrained contraction control, or maintenance of the muscle size and range of motion. A previous study suggested that NMES induces plasticity of the motor cortex.[16]

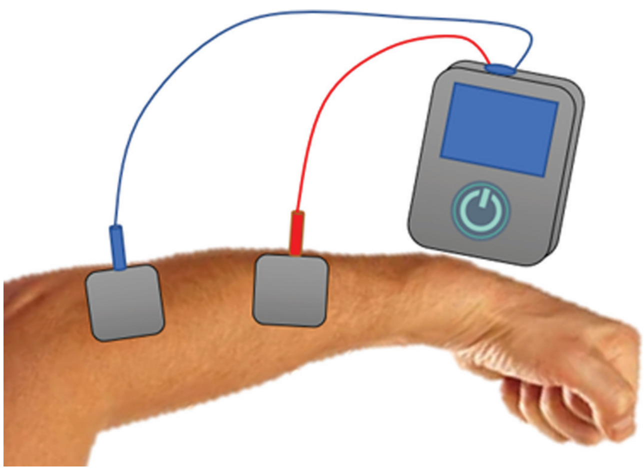

Fig. 1 Transcutaneous electrical nerve stimulation (TENS) over the arm.

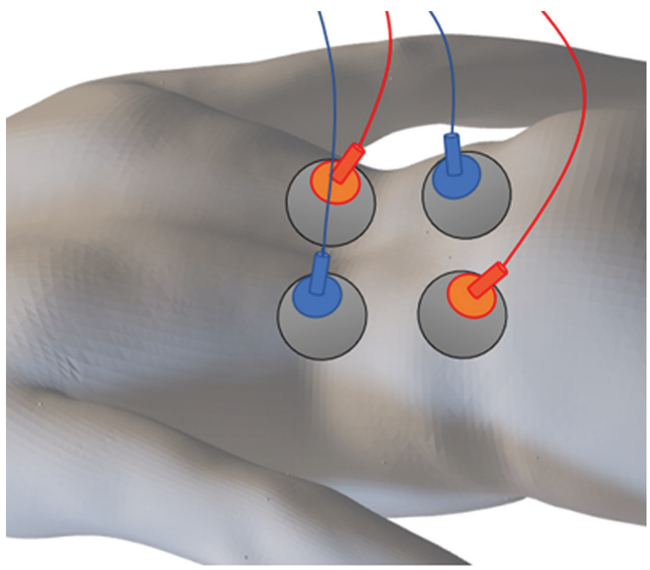

Fig. 2 Interferential therapy (IFT) over the lower back.

4.1. Clinical application of NMES

NMES is often delivered for muscle strengthening (Fig. 3), and FES is used for the timely activation of specific muscles during "tasks" within a typical PT session (Fig. 4). For musculoskeletal conditions, NMES is applied for muscle strengthening during postoperative management[17,18] or chronic diseases, such as knee pain.[19]

For neurological conditions, NMES plays the role of FES in stroke rehabilitation for reducing shoulder subluxation, enhancing the function of open hands, or increasing foot dorsiflexion during walking. In this decade, a growing number of studies are focusing on the combination of FES and powered exoskeleton systems for walking assistance in individuals with spinal cord injury.[20–23]

5. TMS AND TDCS

Unlike the aforementioned ES forms, TMS and tDCS directly deliver currents for the modulation of electrical processes in the brain. Both TMS and tDCS are noninvasive methods that provide ES through the skin and skull with electrodes on a patient's head. Compared to that of tDCS, the implementation of TMS is different from the aforementioned ES methods. Via an electromagnetic coil (Fig. 5), TMS generates a deep electric current by changing the magnetic field. This technique provides relatively precise stimulation to the brain; however, conventional TMS requires a relatively large device and space. In addition, it requires the full participation of patients during stimulation. Therefore, TMS is difficult to conduct with the activities of patients. tDCS is a brain stimulation tool with a battery and smaller device connected to the anode and cathode (Fig. 6). The electrodes of tDCS should be placed directly over a subject's scalp. In tDCS, the current changes neuronal excitability, resulting in the modification of brain activity.[8]

5.1. Clinical application of TMS and tDCS

Noninvasive brain ES provides a potential intervention for Parkinson's disease,[24] psychiatric diseases,[25] schizophrenia,[26] and depression.[27] Furthermore, some studies have shown that tDCS promotes neuroplasticity processes.[28–30] tDCS has gradually increased applicability in the neurorehabilitation field.[31–34]

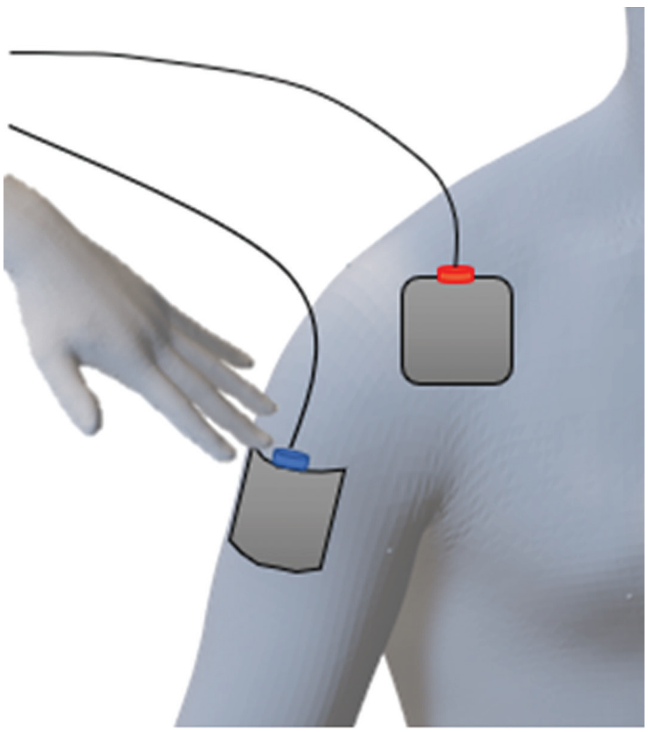

Fig. 3 Neuromuscular stimulation (NMES) for the shoulder subluxation.

Fig. 4 Functional electrical stimulation (FES) for the drop foot.

6. SAFETY CONCERNS

In general, cardiac pacemakers, pregnancy, and epilepsy are considered contraindications of ES.[35] Regarding the positions of the electrodes' placement, the electrodes should not be placed on the site of lack of sensation, head, neck, chest, abdomen, or sites of active tumors. Skin irritation may be caused by allergic factors (electrode and tape) or skin abrasion. Skin burns may be induced by a chemical burn with direct currents or an electrical burn with high-current amplitudes.[36] The ES process must be carefully monitored.

7. TELEREHABILITATION DURING THE COVID-19 PANDEMIC

During the COVID-19 pandemic, lockdowns and self-quarantine policies increased the difficulties of implementing face-to-face treatment for medical staff and patients.[37] This limitation has undoubtedly had a severe impact on healthcare systems that provide rehabilitation.[38] Therefore, the feasibility and effectiveness are important issues of telerehabilitation. Regarding the application of telerehabilitation, TENS devices are currently the most common. TENS devices are small, easy to operate, and have well-developed processes. Many TENS products have passed the U.S. Food and Drug Administration (FDA), E.U. Medical Device Regulation (MDR), and Taiwan FDA certifications; thus, there is a verified feasibility for pain relief and muscle relaxation at home. Regarding the application of FES in patients, several studies have demonstrated the feasibility of in-home rehabilitation with FES or NMES to improve upper- and lower-extremity function and muscle mass in patients with neurological disorders, such as spinal cord injury.[39–41] Although the setup and adjustment of devices are relatively time-consuming and challenging, their therapeutic effect is promising after the adjustment is completed. In addition, motor training for patients with stroke[42] and those undergoing bladder and urinary function training[43,44] have shown positive results in at-home rehabilitation. Notably, it has beneficial effects on pulmonary rehabilitation in patients

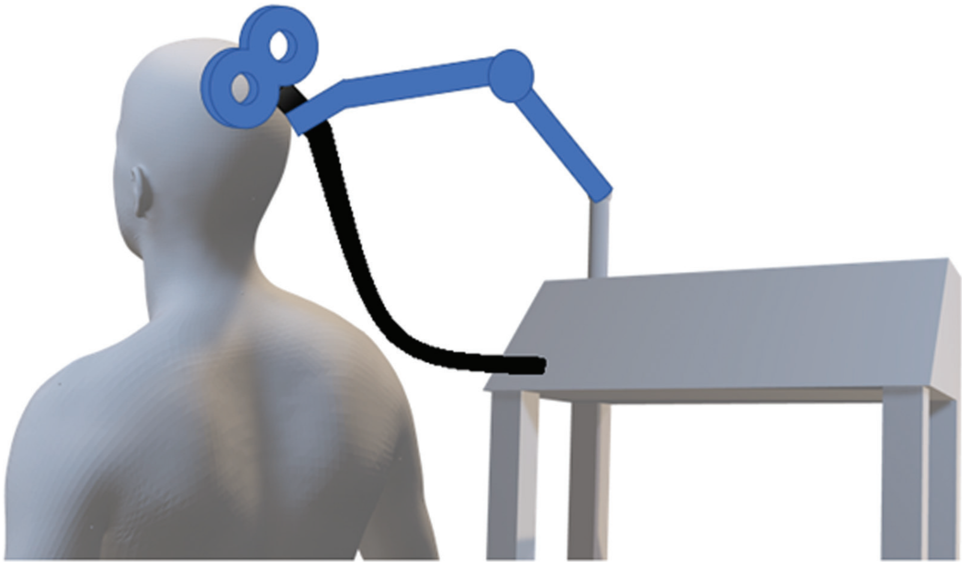

Fig. 5 Transcranial magnetic stimulation (TMS) with the electromagnetic coil.

with chronic obstructive pulmonary disease,[45] and the method of pulmonary rehabilitation may be a useful aid to current rehabilitation in patients during COVID-19 recovery. As for the use of tDCS, many do-it-yourself applications have been revealed in previous studies.[46,47] Some home-based products have been commercialized; however, they are currently mainly used for the treatment of cognitive and depressive disorders.[48] ES for telerehabilitation seems to be promising based on previous studies; however, in-home rehabilitation still encounters many challenges that require overcoming in clinical practice, such as ensuring safety during at-home therapy, evaluating and modifying prescriptions, and charging for medical services. The implementation of remote applications requires the assistance of government authorities and healthcare systems.

In conclusion, in clinical practice, electrotherapy often does not play the role of the main intervention. Combined with other therapies, ES is provided for specific conditions. For instance, TENS and IFT provide pain relief and reduce edema for further movement training. NMES delivers currents to maintain muscle strengthening and range of motion for functional activity training. tDCS and TMS change neuroplasticity to enhance neurorehabilitation in psychiatric, physical, and occupational therapy. Nevertheless, electrotherapy has the advantages of the ease of use, lower costs, and lower risks, which is beneficial for

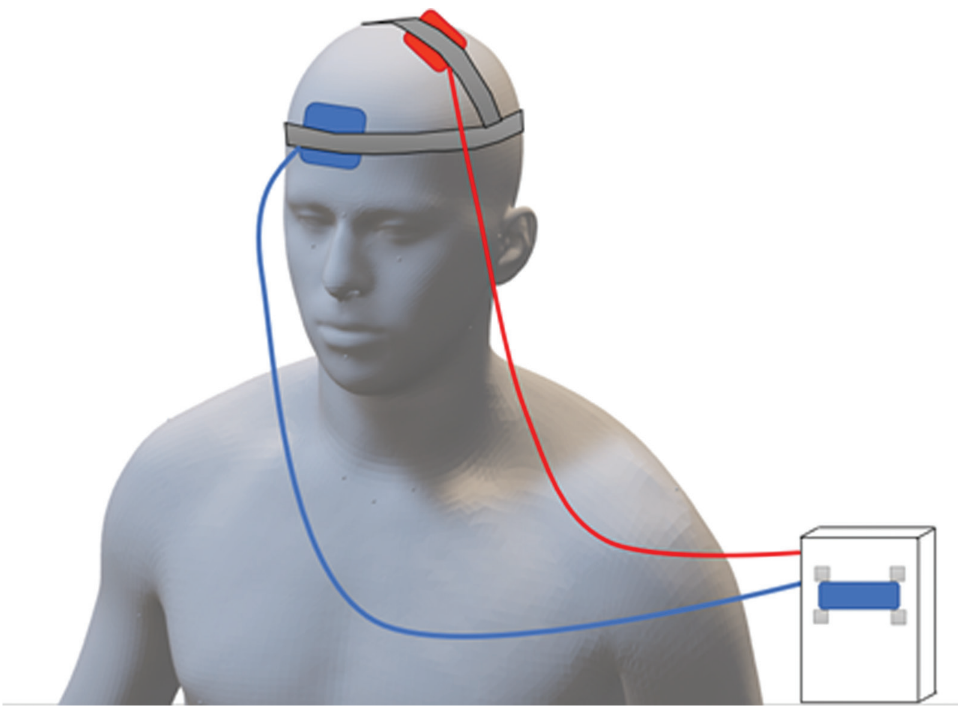

Fig. 6 Transcranial direct current stimulation (tDCS) setting over forehead.

economizing manpower. Furthermore, it may provide remote therapy within the field of rehabilitation during the COVID-19 pandemic. Further research on the safety of its use by patients and their families at home is warranted.

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