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Currents Used for Electrical Stimulation

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Galvanic Current

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Introduction

Current refers to the movement or flow of electric charge, typically carried by free electrons, within a material or through a circuit. It is measured in units of amperes (A), which represent the amount of charge passing through a specific point in a circuit per unit of time. The movement of charge can involve various particles, including free electrons, positive ions, and negative ions. This flow of charge is not purely linear but rather exhibits some degree of randomness as these charged particles move. It is recommended that therapeutic intensities should generally not exceed 80 to 100 milliamperes (mA). Exceeding these levels can pose a risk of adverse effects or potential harm to the individual undergoing therapy. It is important to adhere to safe and appropriate intensity levels to ensure the well-being and safety of the patient during treatment. In order to depolarize a nerve cell membrane, a sufficient number of electrons need to be compelled to move through conductive tissues. This movement occurs due to the principle that like charges repel each other, while opposite charges attract. Consequently, a region with a high concentration of electrons will experience a flow toward an area with a lower concentration. The larger the disparity in electron concentration between the two regions, the greater the potential for electron flow to occur. This process is essential for the depolarization of the nerve cell membrane and the transmission of electrical signals within the nervous system. The therapeutic application of a is called "Galvanization (Galvanism)". The generation of DC can be achieved through chemical, mechanical, and thermoelectric methods.[1]

Galvanic Current

"Galvanism" refers to the application of low-voltage and low-amperage DC. It is one of the oldest forms of therapeutic electricity (Figure 9.1). The waveform of the Galvanic Current can be continuous or pulsed, according to the representation of the flow of electrons. When electrons flow toward the negative pole, electrochemical effects occur at the circuit's poles. These electrochemical effects lead to specific physiological changes in tissues at

Figure 9.1 Galvanic equipment.

the site of application. The use of current to elicit physiological changes in tissues is known as "Medical Galvanism". This effect is employed, for example, in "Iontophoresis", where the ionic medication is driven into tissues. While the local electrochemical and physiological effects are important, physiotherapists should also consider the general effects of Galvanization. These effects include stimulation of the vasomotor system, influencing the distribution of blood and lymph. The use of Galvanism and its effects should be approached with proper knowledge, training, and caution. It is important to consult with a qualified healthcare professional before attempting any therapeutic interventions involving Galvanic Current.[2]

Equipment

The devices used in electrotherapy that specifically provided only DC were called Galvanostats or Pantostats. The discovery and use of semiconductors in current regulation systems enabled the production of well-filtered and constant DC, with the ability to modulate the offered current waveforms. The current trend is to design and utilize complex devices that can deliver various types and forms of currents.[3]

The equipment used for DC (Galvanic Current) applications may vary depending on the specific therapy or treatment being administered. Here are some common types of equipment used for delivering a DC:[3]

1. Galvanic Stimulator: This is a specialized device designed to deliver the Galvanic Current. It typically consists of a power source, controls to adjust intensity and duration, and electrodes for application to the body.
2. Electrodes: Electrodes are used to apply the Galvanic Current to the body. They come in various sizes and shapes, such as pads, sponges, or specialized applicators, and are typically made of conductive materials like metal or carbon.
3. Conductive Gel or Electrode Solution: A conductive gel or electrode solution is often applied to the skin before placing the electrodes. This helps improve conductivity and ensures good contact between the electrodes and skin.
4. Cables and Connectors: These are used to connect the electrodes to the Galvanic Stimulator. They transmit the electrical current from the device to the electrodes.
5. Safety Features: Galvanic stimulators may include safety features such as current limiting circuits, adjustable intensity controls, and built-in timers to ensure safe and controlled application of the current.

It is important to note that the specific equipment used may vary depending on the intended application and the physiotherapist preferences. Always follow the manufacturer's instructions and consult with a qualified physiotherapist for proper usage and safety guidelines.[3]

The Mechanism of Action and Physiological Effects:

The Galvanic Current generates consistent electrochemical and physiological effects at the location of application (Table 9.1).[4]

Table 9.1 Predictable electrochemical and physiological effects produced by the Galvanic Current

	Electrochemical Effects	Physiological Effects
Positive pole (anode)	Attracts acids	Stops hemorrhage
	Attracts oxygen	Relieves acute inflammation
		Dehydrates/hardens tissue
		Constricts arterioles
		Decreases nerve irritability
Negative pole (cathode)	Attracts bases (alkaloids)	Increases hemorrhage
	Attracts hydrogen	Congests/irritates tissue
		Relieves chronic inflammation
		Dilates arterioles
		Increases nerve irritability

The physiological effects of the positive pole of the Galvanic Current are similar to the effects of cold applications, while the negative pole is analogous to hot applications. To achieve the polar effect of the Galvanic Current, two electrodes of unequal size are required, with the smaller electrode serving as the active pad and typically being no more than half the size of the larger dispersive electrode. The milliamp rule limits the amperage density to 1 mA/inch^2 of the active electrode.[4]

The smaller active pad exhibits stronger polar effects compared to the larger dispersive pad because the smaller electrode size increases the current density. One method to determine the negative lead is to immerse the leads in salted water and gradually increase the amperage until bubbles form at the leads. The negative pole attracts positively charged hydrogen ions, resulting in the accumulation of more, and smaller bubbles compared to the positive lead.[4]

The Galvanic Current can be used to drive charged ions and ionic medication into the tissues. Positively charged medications are delivered by the positive pole, while negatively charged medications are delivered by the negative pole. The Galvanic Current primarily penetrates into the dermis's corium layer, reaching a depth of approximately 1 mm. From there, the medication is dispersed through capillary circulation to a larger area of tissue. Although the depth of current penetration and ionic dispersal are relatively shallow, some believe that the field effect generated may impact ionic molecules at greater depths.[5]

The consequences of the physiochemical tissue changes generated by the passage of DC and include:[5]

- Bio electrolysis: The movement of ions in the electric field.
- Iontophoresis: The transportation of ions through tissues.
- Electrolysis: The decomposition of compounds into ions due to the electric current.
- Electroosmosis: The movement of fluid within tissues due to the electric field.
- Changes in membrane potential: The alteration in the electrical potential across cell membranes.
- Modulation of neuromuscular excitability: The effect on the excitability of nerves and muscles.
- Thermal effects: The heat generated by the current flow (with higher current amplitude).
- Electromagnetic induction: The induction of electrical currents in tissues due to the changing magnetic field.
- Changes in the tissue composition: The alteration in the chemical composition of tissues.

Specialized studies have shown that the passage of the Galvanic Current through tissues occurs primarily through electrolysis, and to a lesser extent through the other mentioned phenomena. Electrolysis refers to the movement of anions and cations in the electric field.

The Galvanic Current produces physiological effects on the body, particularly on easily excitable tissues such as nerves. In therapy, the Galvanic Current is applied smoothly and has specific effects on sensory nerve fibers, motor fibers, the central nervous system, and the circulatory system:[3]

1. Sensory nerve fibers: Galvanic Current causes tingling sensations that increase with current intensity. Prolonged exposure can lead to an analgesic effect, reducing sensitivity to touch and pain.
2. Motor fibers: Galvanic Current reduces the threshold for motor fiber excitation, increasing their excitability. Sudden changes in current intensity can cause immediate muscle contractions, which are useful for preparing denervated muscles before other treatments.
3. Central nervous system: Galvanic Current decreases reflex activity in descending applications and increases excitability in ascending applications.
4. Circulatory system: Galvanic Current can influence blood circulation.

Overall, the Galvanic Current has specific effects on nerve fibers, the central nervous system, and blood circulation. These effects are used in various therapeutic applications in electrotherapy.[3]

Cordingley (1937) described two techniques known as general and central Galvanization. In "General Galvanization", one electrode is applied to the sacrum (the triangular bone at the base of the spine), while the other electrode is moved slowly along the spine and extremities. This technique enhances the lymphatic circulation throughout the body. "Central Galvanization" follows a similar approach, but the stationary electrode is placed over the solar plexus, which is a complex network of nerves located in the upper abdomen. The purpose of Central Galvanization is also to enhance the lymphatic circulation. Both General and Central Galvanization techniques are used to stimulate lymphatic flow, which plays a crucial role in the immune system and the removal of waste products and toxins from the body. These techniques are considered as part of the broader application of the Galvanic Current in naturopathic medicine to support overall health and well-being.[6]

The Purpose of the Galvanic Current

Medical Galvanism, or the use of Galvanic Current modalities, employs the DC to achieve specific therapeutic effects. Using current provides targeted and controlled therapeutic effects to enhance patient outcomes. This modality offers several applications, including:[7]

1. Muscle Rehabilitation: Galvanic Stimulation can be used to aid in the rehabilitation of muscles affected by nerve injuries or weakness. By delivering a controlled current, it helps activate motor nerves and promote muscle contractions, facilitating muscle re-education and strengthening.
2. Tissue Healing and Edema Reduction: The Galvanic Current can promote tissue healing by improving local blood circulation and oxygenation. It also aids in reducing edema by facilitating the movement of fluids through the tissues and promoting lymphatic drainage.
3. Iontophoresis: Medical galvanism is used in iontophoresis, a technique used to deliver medications or therapeutic substances through the skin into the underlying tissues. The Galvanic Current enhances the transport of charged particles allowing for targeted and controlled delivery of medications for localized therapeutic effects.
4. Pain Management: Galvanic stimulation has been used to manage pain by modulating the nerve activity and reducing pain signals. It can help relieve various types of pain, including acute and chronic pain, by promoting the release of endorphins and influencing the nerve transmission.[7]

Muscle Rehabilitation

The stimulating action of the Galvanic Current on the motor nerve fibers is used in practice, as preparation of the denervated muscles for the excitatory currents. At the negative (-) pole, when it is used as an active electrode, the excitability threshold for the motor fibers decreases, so their excitability increases: It will therefore be possible to stimulate the motor fibers and cause contraction. Studies have proven that the sudden decrease or increase in current intensity represents a sufficiently important stimulus, triggering a prompt muscle contraction. Because of the physiological changes of denervated muscles, only modified Galvanic current can elicit a contraction response. The pulse duration should be above 100 milliseconds (ms) (300-600 ms) and the pulse interval should be two times of pulse duration (200-1000 ms).[5]

Naturopathic Indications and Applications

Naturopathic practitioners have historically used Galvanism and Iontophoresis for various indications. Some of these applications include:[6]

Hepatic drainage: The Galvanic Current is used to support liver function and promote detoxification.

Hemorrhoids: The Galvanic Current may be used in the management of hemorrhoids, a condition characterized by swollen blood vessels in the rectal area.

Wart and tinea infections: Positive iontophoresis with magnesium sulfate has been used for the removal of warts and treatment of fungal infections like tinea.

Corn removal: Sodium chloride Iontophoresis has been employed for the removal of corns, which are thickened areas of skin on the feet.

Indolent ulcers: Zinc ionization has been applied in the treatment of indolent ulcers, which are chronic non-healing wounds.

Cervicitis: Copper ionization has been used in cases of cervicitis, which is inflammation of the cervix.

Rhinitis, hay fever, and otitis media: Positive galvanism has been employed for the management of rhinitis (nasal inflammation), hay fever (allergic rhinitis), and otitis media (middle ear inflammation).[3]

These applications of Galvanism and Iontophoresis have been described within the field of naturopathic medicine, providing a range of potential therapeutic options for various conditions.[6]

In addition to the previously mentioned applications, adjunctive Galvanic treatment has been recommended for various conditions in naturopathic medicine. Some of these conditions include:[6]

Dysmenorrhea: Galvanic treatment may be used as an adjunct therapy for menstrual pain.

Abscesses: Galvanism can be applied in the treatment of abscesses, which are localized collections of pus.

Amenorrhea: Galvanic current may be used to support the restoration of menstrual flow in cases of amenorrhea, the absence of menstrual periods.

Adhesion resorption: Galvanic treatment is recommended to aid in the resorption of adhesions, which are fibrous bands that can form between tissues.

Bronchitis: Galvanism may be used as an adjunctive therapy for bronchitis, an inflammation of the bronchial tubes.

Colitis: Galvanic treatment is recommended for colitis, which is inflammation of the colon.

Emphysema: Galvanism can be applied in cases of emphysema, a chronic lung condition characterized by damaged air sacs.

Endometritis: Galvanic Current may be used to support the treatment of endometritis, which is inflammation of the endometrium (inner lining of the uterus).

Tonsillar swelling: Galvanism is recommended to help reduce the swelling of the tonsils.

Uterine and intestinal hemorrhage: Galvanic treatment may be employed in cases of uterine and intestinal bleeding.

Incontinence: Galvanism is recommended as an adjunct therapy for urinary incontinence.

Inflammation in its second stage: Galvanic treatment may be used in the second stage of inflammation to support the healing process.

Pelvic inflammation: Galvanism is recommended for the treatment of pelvic inflammation.

Hepatitis and meningitis: Galvanic treatment may be considered as an adjunctive therapy for hepatitis (liver inflammation) and meningitis (inflammation of the meninges).

Menorrhagia and metrorrhagia: Galvanism is recommended to help manage excessive menstrual bleeding (menorrhagia) and irregular uterine bleeding (metrorrhagia).

Migraine and neuralgia: Galvanic treatment may be used as an adjunct therapy for migraine headaches and neuralgia (nerve pain).

Orchitis: Galvanism is recommended in cases of orchitis, which is inflammation of the testicles.

Cardiac palpitation: Galvanic treatment may be employed as an adjunct therapy for cardiac palpitations, irregular or rapid heartbeats.

Chronic peritonitis: Galvanism is recommended for the treatment of chronic peritonitis, which is inflammation of the peritoneum (abdominal lining).

Salpingitis: Galvanic treatment may be used in cases of salpingitis and inflammation of the fallopian tubes.

Impotence: Galvanism is recommended as an adjunct therapy for impotence, the inability to achieve or maintain an erection.

Urethral stricture and trachoma: Galvanic treatment is recommended for urethral strictures (narrowing of the urethra) and trachoma (a bacterial eye infection).

Toothache pain: Galvanism may be used to help alleviate toothache pain.

These applications highlight the potential use of Galvanic treatment as an adjunct therapy in naturopathic medicine for a wide range of conditions.[5]

Application Methods

The application methods of Galvanic Current can include:

Plate Electrodes: This involves placing flat electrode pads directly on the skin at the desired treatment area. The positive and negative electrodes are positioned accordingly based on the intended therapeutic effect.

Electrolytic or Galvanic Bath: This method utilizes a bath or pool filled with an electrolyte solution through which the body part or the entire body is immersed. Electrodes are submerged in the electrolyte solution, and the Galvanic Current is applied to the body through the conductive medium.

Partial or Four-Cell Galvanic Bath: In this technique, specific body parts are immersed in separate compartments within a multi-cell bath. Each compartment contains an electrode and an electrolyte solution, allowing for the targeted application of the galvanic current to different areas simultaneously (Figure 9.2).[7]

Figure 9.2 Partial or Four-Cell Galvanic Bath

Iontophoresis: This method involves the transcutaneous delivery of medicinal substances using the Galvanic Current. Electrodes are attached to the skin, and a specific medication or solution is applied to the treatment area. The Galvanic Current facilitates the transportation of the medication into the underlying tissues (Figure 9.3).

Figure 9.3 Iontophoresis

These various application methods of Galvanic Current provide flexibility in targeting specific areas, delivering therapeutic substances, and promoting desired physiological effects for the intended therapeutic purposes.[3]

Safety and Contraindications

While Galvanic Current is generally considered safe, certain precautions and contraindications should be considered. These include:

1. Milliamp rule: Adhering to the milliamp rule is crucial to prevent burns or discomfort caused by excessive current intensity. Following this rule ensures that the amperage is within a safe range for the patient.
2. Allergic sensitivity: Some individuals may have allergic reactions or sensitivities to the ions applied during Galvanic Current therapy. It is important to consider the patient's medical history and assess for any known allergies before initiating treatment.
3. Broken skin: Electrode pads should not be placed over the broken or damaged skin, as it may cause further irritation or infection. The skin should be intact and clean before applying electrodes.
4. Electronic implants: Patients with electronic implants, such as pacemakers or neurostimulators, should not undergo Galvanic stimulation. The electrical currents may interfere with the

proper functioning of these devices, posing potential risks to the patient's health.

5. Impaired pain sensation: Tissues with impaired pain sensation, such as in neuropathy or nerve damage, should be treated with caution. The patient may not be able to provide accurate feedback on discomfort or burning sensations, increasing the risk of injury.

It is important to assess each patient individually, consider their medical history, and ensure proper application techniques to maintain safety during Galvanic Current therapy. Consulting with a physician and physiotherapist can help determine the suitability and safety of Galvanic Stimulation for specific individuals.[8]

References

1. Placzek JD, Boyce DA. (2016), Orthopaedic physical therapy secrets-E-book. 3rd ed. Elsevier Health Sciences. ISBN:978-0323286879.
2. Blake E. (2012), Electrotherapy and hydrotherapy in chronic pelvic pain. Chaitow L, Jones R, (eds). In: Chronic pelvic pain and dysfunction: Practical physical medicine. China: Elsevier Churchill Livingstone. (p.377). ISBN:9780702050435.
3. SCRI Group. Curentul galvanic, galvanoionizarea: proprietati fizice, aparatura utilizata, actiunile biologice, efectele fiziologice, modalitati de aplicare, indicatii si contraindicatii. Accessed: https://www.scrigroup.com/sanatate/Curentul-galvanic-galvanoioniz64871.php. Accessed Date:12.08.2023.
4. Slovenko R. Malpractice in psychiatry and related fields. The Journal of Psychiatry & Law. 1981;9(1):5-63. doi:10.1177/009318538100900103.
5. Blake E, McMakin C, Lewis DC, Buratovich N, Neary Jr DE. (2008), Electrotherapy modalities. Chaitow L, Ed. In: Naturopathic physical medicine: Theory and practice for manual therapists and naturopaths. 1st ed. UK: Churchill Livingstone. (pp. 539-562). ISBN:0443103909.
6. Blake E, Chaitow L. (2008), History of Naturopathic physical medicine. Chaitow L, Ed. In: Naturopathic physical medicine: Theory and practice for manual therapists and naturopaths. 1st ed. UK: Churchill Livingstone. (p. 54). ISBN:0443103909.
7. Sands WA, McNeal JR, Murray SR, Stone MH. Dynamic compression enhances pressure-to-pain threshold in elite athlete recovery: Exploratory study. J Strength Cond Res. 2015;29(5):1263-72. doi:10.1519/JSC.0000000000000412.
8. Busse JW, Bhandari M. Therapeutic ultrasound and fracture healing: A survey of beliefs and practices. Arch Phys Med Rehabil. 2004;85(10):1653-56. doi:10.1016/j.apmr.2003.12.040.

Co-funded by the
Erasmus+ Programme
of the European Union

Low-Voltage and Medium-Frequency Currents

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Definition and History of Low-Voltage Current in Medicine

Low-voltage current therapy from electrotherapy currents is used therapeutically to stimulate muscles, nerves, and soft tissues. Low-voltage currents were discovered while investigating whether electricity has other effects besides its thermal effect. The Italian physician Luigi Aloisio Galvani recognized the effect of electricity on animals and introduced the use of electric currents. In the late 1780s, Aloisio Galvani observed that when a scalpel touched the nerves of a dead frog, muscle contraction and an electrical potential difference were created. After his observations, he concluded that electricity can be produced by animals and that the electrical activity transmitted by the nerves moves toward the muscles.[1] While the use of Direct currents for muscle contraction continued to become widespread in the process, weaker muscles contracted more weakly than strong ones, necessitating the search for new currents.[2,3] With the 20th century, it was found that denervated muscles could also be stimulated with electrical currents. Electrical stimulation (ES) is used today in innervated or denervated muscles, pain control, muscle spasm, spasticity, protection of the joint range of motion, and fracture treatment. The basic physical property of low-voltage currents is that they are constantly displaced in the body and are of low or medium-frequency. These currents cause sudden ion exchanges in the tissue and release excitation on the nerves.[4]

Low-Voltage Current Types and Characteristics

Electrons do not move unless there is an electrical potential difference between the two points with respect to the charged particles. The electrical potential difference that must be applied to create a flow of electrons is called volt. Voltage, on the other hand, is the force released during the electron flow occurring between two points with volt difference. The electric currents we use at home in our daily lives produce a force of 115 or 220 Volts (V). Currents used in therapy are classified as low or high voltage currents.[5] Currents below 150 V are considered low-voltage currents. 5000 Hertz (Hz) is the cut-off value for the frequency, and the use of low-voltage currents in the clinic differs according to their frequencies and waveforms. The most commonly used low-voltage currents in clinical rehabilitation are Faradic, Russian, Sinusoidal, and Diadynamic currents.[6,7]

Faradic Current

Parameters of the Faradic Current

Low-voltage and low-frequency currents are basically divided into two types as Intermittent Galvanic current and Faradic current. Faradic currents were in the form of an asymmetrical, biphasic waveform consisting of a 1 millisecond (ms) sharp and sudden negative increase followed by a smooth positive curve of 4-19 ms at first use. The first Faradic currents used were alternating currents due to the constant reversal of the current direction. The amplitude of the negative portion of the wave was not large enough to produce any physiological response. Since these wave characteristics are difficult to tolerate in rehabilitation, it was started to be used by keeping the frequency constant and changing the pulse durations. The new form, resembling a monophasic sawtooth, rises gradually and falls abruptly. This waveform can stimulate denervated muscle without affecting the innervated muscle. Because the gradual increase in current intensity allows the accommodation of the normal muscle, it provides contraction in the denervated muscle. Faradic current, which is frequently preferred in rehabilitation, resembles a very short-term monophasic intermittent Galvanic current with a frequency between 50 and 100 Hz and a stimulation duration of 0.01 to 1 ms.[6]

To provide better results in therapy, the Faradic current used is differentiated to provide near-normal tetanic contraction and muscle relaxation. The machines and apparatus used must have sufficient control, to control muscle contraction and relaxation and to gradually increase the impulses. Today, the production of the Faradic current by electrotherapy devices is also differentiated. In the old devices, the direction of the current was produced by diversifying the coil structure. Asymmetrical, biphasic currents that travel in both directions between the electrodes were produced by these coils. In new devices, the Faradic currents can be diversified with the help of electronic cards without requiring mechanical arrangement. By varying the waveform, current types can be provided in various durations, frequencies, and waveforms. This diversity allows the selection of the most suitable one for the patient (Figure 10.1).[6,7]

Effect Mechanisms of Faradic Current

Electrical impulses with the appropriate pulse duration, strength, and shape provide an action potential in the nerve. As a result of depolarization in the motor nerve, the action potential moves along the nerve membrane and the potential reaching the muscle spreads to the muscle fibers, causing muscle contraction. In normal muscle contraction physiology, depolarization of sensory nerves creates activation in the sensory cortex area, triggering impulses from the central nervous system to the muscles. Stimulation to the muscle first elicits contraction in Type I slow oxidative small-sized muscle fibers and then on fast glycolytic Type II fibers. In applications made directly on motor nerves and muscles, such as Faradic currents, this sequence is reversed.[8]

Usage Fields of Faradic Current

ES can be used to induce contraction in muscles that cannot be actively contracted due to pain, weakness or constraints such as a cast. The Faradic current, one of the currents used for this purpose, provides significant increases in muscle mass and strength. The Faradic current also increases glycogen content, adenosine triphosphate synthesis capacity, and metabolism.[9] The pumping action released by contractions helps to accelerate blood flow and discharge metabolic wastes from the muscles. Faradism under pressure, which is one of the special techniques of the application of the Faradic current, is used for edema control by increasing venous and lymphatic drainage.[6]

Another field of the use of the Faradic current is examination and treatment in the muscle denervation process. A denervated muscle will fail to

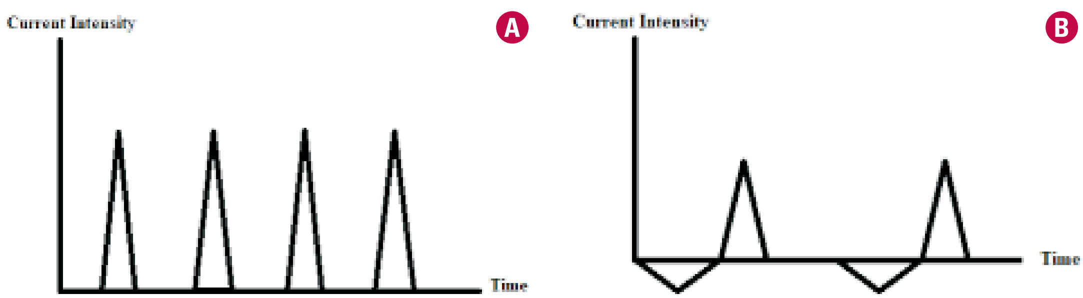

Figure 10.1 A. Ancient Faradic form (Created by the author), B. New Faradic Form

respond to the Faradic stimulation if left untreated for approximately two weeks or more. This is due to the fact that the Faradic current cannot stimulate the denervated muscles because of its 0.1-1 ms duration. In addition, since the muscle tissue starts to break down after the 10th day, it loses its excitability. The contractibility of the denervated muscle cannot be achieved with low-frequency currents such as the Faradic currents.[9,10] However, prolonged Faradic stimulation of denervated muscles provides a beneficial effect on excitability.[11] If there is no electrophysiological evidence of denervation in the muscle and neuropraxia causes muscle weakness, the Faradic currents ranging in duration from 0.1 ms to 1 ms may be preferable.[12] Novak stated that the effect of ES to prevent muscle degeneration has not yet been determined. If ES is used, the stimulation parameters must match the normal muscle firing pattern. In order to achieve this equality, it is necessary to be able to contract while the patient feels the flow.[13]

The Faradic current accelerates regeneration after neuropraxia in the motor nerve. The stimuli below the lesion level easily penetrate the muscle and cause contraction.[6] Low-intensity currents applied to the proximal parts of the motor nerves can provide nerve regeneration and proliferation of Schwann cells. The Faradic current can be used together with steroids, surgical techniques, and exercise to accelerate nerve regeneration.[14] It has been reported that low-intensity 20 Hz or less frequency) stimulation between 30 minutes (min) and 1 hour increases the regenerative efficiency.[15] However, it should be noted that in the complete incision of the nerve, there is a response to the Faradic current until the degeneration process ends, but after the degeneration is completed, the nerve only responds to the Direct current.[6,10]

The Faradic current is also used for retraining the muscle and learning the new work of the muscle in cases where there is no voluntary control of the muscle, such as tendon transplantation, reconstructive operations, and deformities.[6,16,17] For example, in diseases such as pes planus and hallux valgus, the foot intrinsic muscles are not used for a long time because cannot voluntarily produce muscle contraction. In such cases where muscle movement patterns are disrupted, correct movement can be taught with the Faradic stimulation and active contractions can be achieved.[6] In clinical practice, the treatment usually starts with the Galvanic current and then the Faradic current is preferred in muscle retraining and denervated muscle rehabilitation.[16]

Effusions present in the tissues after surgery cause adhesions. The Faradic current may be preferred if sufficient active exercise cannot be performed to prevent adhesions. The resulting muscle contraction, stretches and loosens the adhesions.[6,17] In muscle transplantation from the Gracilis muscle in facial paralysis, daily Faradic flow for 5-10 min is recommended until voluntary contraction is obtained from the muscle. It is a generally accepted approach to start treatment at 6 weeks after transplantation.[12] It has been reported that low-frequency ES should be used until electromyographic reinnervation is observed in muscle transfer after brachial plexus injury.[18]

The stimulation of the antagonist muscle with the Faradic current is preferred to stretch the soft tissue, that cause contracture and limitation of joint movement, and to increase the range of motion. For example, in scoliosis, the trunk muscles on the convex side can be stimulated to stretch the muscles that shorten in the concave part of the curve and cause movement limitation. Ad et al. stated that motor stimulation with 40-80 milliamperes (mA) intensity, 0.2 ms duration, and 25 Hz frequency is effective in scoliosis and improves trunk balance.[19] In the treatment of scoliosis, just not applied to the convex area. Karabay et al. applied the Faradic current with 20-30 mA intensity, 0.25 ms duration, and 25 Hz frequency to the abdominal and back muscles of children with cerebral palsy in sessions of 30 min, 5 days a week for 4 weeks. Treatment resulted in improvement in Cobb's angle and kyphotic angle.[20]

As it is used to strengthen healthy muscles, the Faradic current is preferred for muscle strengthening after different ailments. In patients with chronic heart failure, it has been reported that the Faradic current with a pulse duration of 200 ms and a frequency of 10 Hz, 1 hour a day, 5 days a week for 5 weeks, maintains cardiac output and causes an increase in exercise capacity. This effect occurs as a result of the increase in oxidative capacity in the muscles.[21] It has also been reported that the same protocol provides functional independence by increasing knee extensor strength in patients with hip replacement.[22] In order to increase the torque power in the muscles, the use of low-frequency (20 Hz) currents instead of high frequency (60 Hz) currents provides more benefits.[23]

Faradic Current Treatment Protocol and Practical Information

The Faradic current provides impulses with duration of 0.1-1 ms and frequency of 50-100 Hz. These parameters cause tetanic contraction of the innervated muscles. However, due to the short duration of stimulation, it is difficult to obtain a response from the denervated muscle. The new devices provide more channel output and produce more tolerable current form. Response can also be obtained from denervated muscles with interrupted currents with a pulse duration of 100 ms, repeated 20 times per minute. This parameter allows the innervated muscle fibers to contract rapidly and the denervated muscles to contract slowly. If the room temperature is below normal, denervated muscle contraction may be lost. In such cases, it should be considered that finding the motor point of the muscles during the application will increase the contraction power.[11]

An appropriate treatment protocol for the Faradic current should be shaped according to muscle size and energy metabolism of the muscle. While lower pulse duration and current intensity are preferred in small sized muscles, the number of treatment sessions should be higher. To tolerate muscle fatigue, the treatment session should usually be divided into 2 or 3. Treatment should be applied for 10-15 sessions or 2-3 weeks for optimal gain in contraction speed, 20-25 sessions or 4-5 weeks for muscle strength gains. It is recommended to perform 35 sessions or 7 weeks of application to increase muscle endurance.[11]

We mentioned that the Faradic current is often preferred to provide contraction in the muscle tissue after nerve injuries in the clinic. In applications, the patient, device, and necessary equipment should be prepared in advance and necessary safety precautions should be taken. The pads used during application should be made of lint-free fabric. Excessive fabric thickness prevents the risk of chemical accumulation and thus the risk of burns. A pencil electrode wrapped in cotton should be used if a specific muscle is desired to be stimulated. If a plate electrode is used, the edges of the electrode should be blunt. A positively charged (passive) electrode could be placed on the proximal part of the application area, and a negatively charged (active) electrode could be placed on the distal part. The active electrode is the electrode where electrons enter the tissue and is smaller than the passive electrode. The active electrode should be placed on the motor point. Pads should be soaked with salt water or tap water but not dry or dripping wet.[11]

Russian Current

History and Parameters of the Russian Current

Medium-frequency currents are currents with frequencies between 1000 and 10000 Hz. These currents provide deeper penetration and higher tolerance than low-frequency currents. Russian currents, which are a medium-frequency current and used for muscle strengthening, were first called "interventional currents" in the 1950s.[24] In 1977, Yakov Kots claimed that the Russian current increased the muscle strength of elite athletes to 40%. Although he did not give details and references in his study, the movement easily took its place in the literature as the Russian or the Kots current.[25]

The Russian current is a medium-frequency alternating current with a frequency of 2500 Hz. The current consists of successive bursts with polyphasic waveforms. Each period of the current consisting of 50 periods per second (s) consists of a burst of 10 ms and a rest interval of 10 ms. Each 10 ms burst contains 25 current loops. The most common sine wave and square wave applications are preferred (Figure 2). These bursts reduce the total

Figure 10.2 Russian Current Wave Form (Created by the author).

amount of current delivered to the patient, by this patient's tolerance increases.[6,24]

The frequently preferred parameters of the Russian movement are;

- Pulse duration: 50- 400 ms
- Frequency: 1000 Hz to 2500 Hz
- Beat cycle: reported 5-15 s.[26]

Effect Mechanism of the Russian Current

Normal motor ES acts by activating motor units. Motor units consisting of a motor neuron and its innervated muscle fibers are regularly activated starting from the smallest motor units during voluntary muscle contractions to larger motor units as the force requirement increases. During ES, including the Russian current, the motor units contract non-selectively. The largest motor units contract first. More muscle fibers are activated than during voluntary contractions. This causes a greater force to emerge. However, since the activation of motor units is not selective and the activation of muscle fibers is asynchronous, a contraction force as sharp as voluntary contractions is not obtained. Therefore, voluntary muscle contraction is desired along with ES in Russian currents. This dual contraction mechanism enables more muscle fibers to work and hypertrophy.[25,27] The combination of the Russian current with exercise, provides coordination and trains fast-twitch and quickly fatigued motor units, provides athletic skills and coordination in parallel with the increase in muscle strength.[28]

Usage Fields of the Russian Current

Since the skin impedance is inversely proportional to the frequency of the applied current, the Russian currents penetrate more deeply than low-frequency currents. The contraction produced by the Russian current is physiologically as close to normal contraction as possible. In this way, patient discomfort and fatigue are low, and the current tolerance level is high.[29] The Russian currents are generally preferred to increase muscle strength. Muscle strength increases by approximately 30-40% in athletes who receive medium-frequency stimulation.[30] In a study using 50 Hz bursts in Russian current, the maximum torque occurred at a frequency of 1 (kilo hertz) kHz. For the optimum effect, it is recommended to use a frequency of 2.5 kHz in applications with direct muscle stimulation and 1 kHz in applications on the nerve trunk. For maximum muscle torque generation, a burst time of 2 ms and frequency of 1-2.5 kHz can be used. Because the feeling of discomfort is quite high for the Russian currents, it can be applied with a burst time of 4 ms and a frequency of 4 kHz to minimize the feeling of discomfort. However, it should be noted that in this case less force will released.[24]

The application of the Russian current to the hip muscles of elderly neurological patients has positive effects on the motor mobility of the patients.[29] The use of the Russian current to strengthen the Quadriceps Femoris muscle group after the anterior cruciate ligament reconstruction, facilitates healing and increases the intensity of contraction.[31] Russian currents increase the extremity muscle strength as well as respiratory. It is used to increase expiratory muscle strength. It has been reported that a 25-minute application with a frequency of 2.5kHz, by adjusting the pulse and resting time according to the inspiratory and expiratory frequencies, increases expiratory muscle strength.[32]

Treatment Protocol of the Russian Current and Practical Information

After daily trainings patients, who are applied Russian current, can tolerate progressively higher intensities. Due to this gain, the current intensity should be increased from the first sessions, considering the patient's tolerance. If the force production is to be increased, stimulation must have a tiring effect. For this, the dose needs to be adjusted in the best way. The Russian current is used in a treatment cycle known as the Russian technique. This technique is also called the 10/50/10 technique. After a 10 s "on" period, a 50 s "off" period is applied and this technique is continued for 10 min. In this technique, it is recommended to support voluntary muscle contractions with exercise after ES.[25]

The perception of discomfort due to stimulation may limit the effectiveness of the Russian current. If there is a feeling of discomfort, re-detection of the motor point can be performed with changes in electrode size and positioning to minimize impedance effects. Electrode sizes are generally preferred as 5cmx5cm. While smaller electrodes increase current density, they can cause pain. Large electrodes can cause antagonist muscle activation and decrease the desired force. It should not be forgotten that the device-patient preparation process and safety measures, which are prerequisites in clinical applications, are valid for the Russian currents.[26]

Sinusoidal Current

Parameters of the Sinusoidal Current

Sinusoidal currents are symmetrical sine wave currents with a frequency of 50 Hz. These currents contain 100 Hz of 10 ms each (Figure 10.3). Currents produced by reducing the voltage to 60-80 V with intermediate transformers are generally used to provide rhythmic muscle contractions. Other effects of current are analgesic and edema reducing effects. Sinusoidal currents with pronounced sensory stimulation are usually applied over large areas. They are rarely used to provide local muscle stimulation.[6] The sinus waveform is recommended when it is desired to create isometric contractions that cause the least tissue trauma on the skin by emphasizing the comfort of the patients.[33]

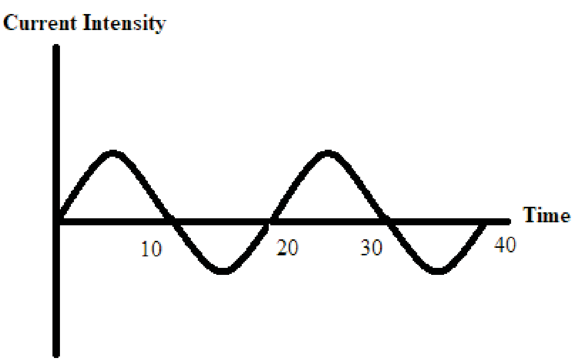

Figure 10.3 Sinusoidal current (Created by author).

Effect Mechanism of the Sinusoidal Current

The action potential that occurs in the sinusoidal current applications, specifically stimulates the sensory and motor nerves.[34] These currents are not used for the chemical and thermal effects of other electrical currents. The Sinusoidal currents produce a pricking sensation on the skin. This feeling is more than the feeling that occurred by the Faradic current. With this application, erythema may occur by increasing the blood flow in the subcutaneous tissues. However, motor nerves can be stimulated by increasing the current intensity.[10] Activation of potassium channels rather than inactivation of sodium channels by high-frequency biphasic currents causes nerve conduction block and exerts analgesic effect.[34]

Usage Fields of the Sinusoidal Current

The biphasic Sinusoidal current is used in various applications such as pain management, muscle stimulation, electrical nerve blocking and wound healing. Because of the nerve blocking effect, the Sinusoidal currents can be used in the treatment of pain. In vivo experiments have shown that the Sinusoidal frequencies greater than 10 kHz will cause a localized block in rats. The Sinusoidal frequencies below 5 kHz, on the other hand, may lead to a decrease in muscle strength as they reduce the release of neurochemicals at the muscle-nerve junction. If higher frequencies are used to block nerve conduction, the stimulation intensity should also be increased.[34]

If the number of stimuli is increased in Sinusoidal currents, tetanic contraction occurs in the muscle. The Sinusoidal currents can stimulate denervated muscles, but the patient cannot tolerate this current because high current intensity is needed. Therefore, the Faradaic current is preferred over sinusoidal flow.[10] The Sinusoidal currents can also be preferred to increase muscle strength in the innervated muscle. High current intensity at low-frequency is required for contraction. However, since the sinusoidal current of this intensity and frequency will encounter skin resistance, the feeling of needling increases and it may become difficult to tolerate the current for the patient.[35-37]

Due to the sinusoidal rhythm of the central system, the Sinusoidal currents also have a central effect. Leung and Yu found that the Sinusoidal currents induced a maximal response in mildly depolarized hippocampal CA1 neurons in vitro.[38]

In the literature, the sinusoidal currents have been preferred to accelerate wound healing. In particular, the stimulation effect of the biphasic current contributes to faster healing of chronic wounds.[39] With sinus waveform stimulation at 30 Hz, 250 microseconds (μs) pulse width and 20 mA current parameters to heal diabetic foot wounds.[40]

In addition to its therapeutic effects, sinusoidal currents at different frequencies can be used for the sensory evaluation. Measurement of the pain threshold value can be achieved using different sinusoidal stimulus frequencies (5-2000 Hz).[41]

Treatment Protocol of the Sinusoidal Current and Practical Information

Before starting treatment, the patient should be explained why the treatment is necessary and how he or she will feel during treatment. The sensation to be felt can be described as a slight pulling and tingling sensation in the skin. If the upper extremity is to be treated, the patient should be seated in a chair and a wooden treatment bed should be placed in front of him. If the lower extremity is to be treated, the patient should be placed in the supine or side position. If the patient's skin is dry, the patient will feel more discomfort. To reduce this feeling of discomfort, moisturizing creams or a saline solution should be applied to the application area at least one hour before treatment. In this way, the resistance on the skin can be reduced from 5000 to 1000 Ohms. If there is a wound or skin fold on the skin, this part should be covered with sterile vaseline to prevent the electric charge from concentrating on this point.[7]

Diadynamic Currents

History and Parameters of the Diadynamic Currents

The Diadynamic currents were developed by the dentist Pierre Bernard in France in the early 1950s. Pierre Bernard reported that these currents have a broad analgesic effect on soft tissue injuries and systemic disorders. The Diadynamic currents are obtained by combining the Galvanic and Faradic currents. The Diadynamic currents include five different types with different physiological and therapeutic effects.[42]

Alternating type sinusoidal single-pulse monophase fixed (MF) and double-pulse diphase fixed (DF) are low-frequency currents obtained from unidirectional or bidirectional regulation of the current. By combining these two currents, curt period (CP), long period (LP), and rhythm syncope (RS) types are obtained. The risk that occurs during treatment in the Diadynamic current is same as in the Galvanic current. The main effect occurs under the negative electrode (cathode). An irritating and burning effect may occur under this electrode in long-term use. Types of the Diadynamic currents are listed below.[43]

Monophase Fixed (MF)

The MF is a unidirectional current with a frequency of 50 Hz and a sinusoidal waveform. The current fluctuates in 10 ms intervals. The analgesic effect of the MF, which has a strong dynamogenic effect, is low but long-lasting. During the MF, patients experience a very strong vibration and a deep sense of compression. The MF is used in painful conditions due to spasm and when the stimulation of sympathetic ganglia is desired.[6,44]

Diphase Fixed (DF)

The DF is a bidirectional current with a frequency of 50 Hz, just like the MF. The current, which has an analgesic effect, reduces the sympathetic tone. While the patient feels trembling and tingling during the DF, there may be short-term loss of light touch sensation. The DF is administered at intervals of 10-15 s for pain modulation. Due to the rapid adaptation of the tissues, the optimal administration time is 1-2 min and is used before the administration of other types of the Diadynamic currents.[5,6,43]

Curt Period (CP)

The CP modulated in short periods is created by the rhythmic alternation of a one-second single and double pulse current at regular intervals. The CP has vasodilation, hyperemia, and analgesia effects. Used for ischemic disease of the lower extremities, muscle atony, joint stiffness, facial ophthalmic neuralgia, subacute post-traumatic pain, and muscle spasm. The application time for one area is about 3-5 min. The total application time should not exceed 12 min. However, for the treatment of ischemic disease of the lower extremities, the time can be increased but should not exceed 25 min. The duration of the application varies according to the depth of the targeted area and tissue. The CP can be applied twice a day in acute situations, once a day in other situations, and once a week during the continuation of treatment.[5,6,43]

Long Period (LP)

While obtaining the LP, the current is changed to the DF after 6 seconds (s) of the MF flow. The DF is achieved by a second half-wave (again lasting 6 s) with gradually increasing amplitude and lasting 6 s. At the end of 6 s, it is switched to the MF again. The LP has inhibitory and analgesic effects. It also has a stimulating effect on smooth muscle at appropriate intensity. It is preferred in diseases such as neuralgia, myalgia, lumbago, functional disorders of the locomotor system in general, and gastric and intestinal hypotonia.[5,43]

Rhythm Syncope (RS)

The RS, a modulation of the MF, has a 1 s transition and 1 s rest time. It has equal pulse and rest periods within 1 s transition time. The frequency of the RS, which is a unidirectional current, is 0.5 Hz. It has a contractile effect on the muscles but can be irritating. Since pain occurs during contraction and its tolerance is low, care should be taken when using it for muscle strengthening.[5,6,43]

Effect Mechanism of the Diadynamic Current

The effects that occur during the application of the current last for several hours after the treatment is terminated. They exhibit the stimulating effect of low-voltage currents on sensory and motor nerves. One of the theories explaining the analgesic effect of the Diadynamic currents is the gate control theory of Wall and Melzack. Recently, opiate system activation for pain inhibition has become more popular in pain modulation. The release of polypeptides called endorphins with the application of the Diadynamic current is used to explain the analgesic effect. Pain inhibition and current tolerance can be achieved by keeping the pulse and resting times of the current short. In this way, the continuation of the dynamogenic effect is ensured. Alternatively, the dynamogenic effect of the Diadynamic currents has been used to treat different ailments.[45]

The Usage Fields of the Diadynamic Current

The Diadynamic currents increase the blood flow to the area by expanding the capillaries as they pass through the body. Increased blood flow locally relaxes the muscles, reduces edema and pain. Therefore, the Diadynamic currents are used in chronic traumas, sprains, degenerative joint diseases, circulatory disorders and pain management. When Demidaś and Zarzycki investigated the effect of electrotherapy on the sense of touch and pain in musculoskeletal disorders, they found that the Diadynamic currents were effective in increasing the sense of touch and inhibiting pain at a level similar to the Transcutaneous Electrical Nerve Stimulation (TENS). Therefore, they emphasized that the Diadynamic currents should be put on the agenda in pain management as an alternative current to the TENS.

The Diadynamic currents, which have a very common usage area, are used for temporomandibular joint pain management, dysmenorrhea, vertebral column pain, osteoarthritis, joint sprains, subluxations, muscle injuries, epicondylitis, sudeck atrophy, myalgia, torticollis, muscle atrophy, and circulatory disorders such as Raynaud's syndrome and Burger's disease. It is also used in the treatment of neuralgia and neuralgia.[45-48] It has been reported that it is more effective than the Direct current, Microcurrent, and TENS in reducing pain, especially when used as a single agent.[47]

Treatment Protocol of the Diadynamic Current and Practical Information

The Diadynamic currents are low-frequency currents with a Galvanic current component. It is necessary to take into account the degenerative effect that will occur on the skin with the effect of the Galvanic current during applications. Therefore, the safe application time of each application was determined to be 6 min. If an application is made longer than 6 min, the current should be stopped and the electrodes should be changed. If electrode replacement is contraindicated due to the anode-cathode effect or if the application time is longer than 12 min, protective solutions should be preferred. The combination of the Diadynamic current variants is frequently used in practice. It is recommended to use the CP before the LP for analgesic effect. If this situation is not taken into account, the analgesic effect of the LP is destroyed by the stimulating effect of the CP. Currents are usually used in the order as the DF, CP, and LP. Depending on the application time and current density, the Diadynamic current types with the Galvanic component of more than 50% reach a maximum depth of 4 or 5 cm, while the DF and LP with a modulated the Galvanic component of 66% reach deeper.[44]

Application time depends on various factors such as the disease, the stage of the disease, the purpose of the treatment, the personality structure and attitude of the patient, and the level of muscle tone. Depending on the severity of the disease, the preferred parameter should be applied for 3-5 min. If the application will be made on a large area or deeper structures, the application period should be extended. It should be applied 5 times a week in acute cases and once a week in chronic conditions.[47]

The correct adjustment of electrode size and current intensity increases the treatment efficiency. Before using the Diadynamic current, a Galvanic current of 1-3 mA is given to the tissue. The Diadynamic current intensity is then increased up to the tolerance level. Although the tolerance level varies from patient to patient, it is usually between 3 and 12 mA. For the DF and LP types, it is necessary to slightly exceed the threshold level a little.[44,47]

The Diadynamic currents, which differ in their application, can be preferred two days after acute joint injuries. In areas where the direct application is contraindicated, paravertebral application can be made to the nerve roots. In applications with two electrodes in internal organ disorders, one electrode can be placed on the paravertebral segment and the other on the main area. For example, in the treatment of ischemic problems of the lower extremities, the anode is placed paravertebral to the L3 – S1 region and the cathode is placed on the anterior upper part of the calf. To increase sympathetic activity, the DF can be applied for 10-12 min. In the treatment of regional muscle spasms, the anode is placed on the trigger point and the cathode is placed on the origin of the muscle. For painful spasm of the muscles, both electrodes are placed on the muscle body using the CP-LP combination.[44,47]

Hazards and Contraindications of Low-Voltage and Medium-Frequency Current

The Direct current and low-frequency currents encounter high electrical resistance in the outer layers of the skin. In order for a current of sufficient intensity to reach the deep tissues, a high current must pass through the skin. Therefore, such currents cause pain in the treatment of deep tissues.[49] No risk has been reported for low-voltage currents. However, in some cases, such as high fever, hypertension, anemia, severe kidney and heart failure, history of cobalt therapy, and mental disability, physiotherapists should be skeptical of practice. The contraindications for TENS applications, which is a low-voltage current model, should also be considered for other low-voltage currents. Contraindications can be listed as;

- Some electrolytic reactions of the skin depending on the duration and frequency of treatment.
- The presence of pacemaker or implanted electronic devices.
- During the first trimester of pregnancy.
- Hemorrhagic conditions.
- Open wounds, carotid sinus, and over eye applications.
- Uncontrolled epilepsy.
- Electrophobia.[6,50]

References

1. Beretta D, Neophytou N, Hodges JM, Kanatzidis MG, Narducci D, Martin- Gonzalez M, et al. Thermoelectrics: From history, a window to the future. Mater Sci Eng R Rep. 2019;138:210-55. doi:10.1016/j.mser.2018.09.001.
2. Macdonald AJR. A Brief review of the history of electrotherapy and its union with acupuncture. Acupunct Med. 1993;11(2):66-75. doi:10.1136/aim.11.2.66.
3. Tiktinsky R, Chen L, Narayan P. Electrotherapy: Yesterday, today and tomorrow. Haemophilia. 2010;16:126-31. doi:10.1111/j.1365-2516.2010.02310.x.
4. Erbahceci F. (2019), Temel fizyoterapi rehabilitasyon. 1. Baskı. Ankara: Hipokrat Kitabevi. ISBN:978-605-7874-31-3
5. Quillen WS, Underwood FB. (2002), Therapeutic modalities for physical therapists. 2. ed. McGraw-Hill/Appleton & Lange. p. 51-112. ISBN:0-07-137692-5
6. Jagmohan S. (2011), Manual of practical electrotherapy. 1. ed. Jaypee Brothers Publisher. p. 8-88 ISBN:9-35-025059-4
7. Vaz MA, Frasson VB. Low-frequency pulsed current versus kilohertz-frequency alternating current: A scoping literature review. Arch Phys Med Rehabil. 2018;99(4):792-805. doi:10.1016/j.apmr.2017.12.001.
8. Mitra PK. (2006), Handbook of practical electrotherapy. 1. ed. Kolkata: Jaypee. p. 15-57. ISBN:8180616207
9. Fischer E. The effect of faradic and galvanic stimulation upon the course of atrophy in denervated skeletal muscles. 1939;127(4):605-19. doi:10.1152/ajplegacy.1939.127.4.605.
10. Karaduman AA, Yılmaz ÖT, Akel BS. (2019), Fizyoterapi ve rehabilitasyon. 1. ed. Hipokrat Yayınevi. p. 135-159. ISBN:978-605-9160-23-0
11. Kramer JF, Mendryk SW. Electrical stimulation as a strength improvement technique: A review. J Orthop Sports Phys Ther. 1982;4(2):91-8. doi:10.2519/jospt.1982.4.2.91.
12. Schuhfried O. (2021), Pre- and post-op rehabilitation in facial palsy patients. In: Tzou C-HJ, Rodríguez-Lorenzo A, editors. Facial palsy: Techniques for reanimation of the paralyzed face. 1st ed. Cham: Springer International Publishing. p. 39-45. ISBN:978-3030507831.
13. Novak CB. Rehabilitation following motor nerve transfers. Hand Clin. 2008;24(4):417-23. doi:10.1016/j.hcl.2008.06.001.
14. Lopes B, Sousa P, Alvites R, Branquinho M, Sousa AC, Mendonça C, et al. Peripheral nerve injury treatments and advances: One health perspective. Int J Mol Sci. 2022;23(2):918-45. doi:10.3390/ijms23020918.
15. Alvites R, Rita Caseiro A, Santos Pedrosa S, Vieira Branquinho M, Ronchi G, Geuna S, et al. Peripheral nerve injury and axonotmesis: State of the art and recent advances. Cogent Medicine. 2018;5(1):1466404. doi:10.1080/2331205X.2018.1466404.
16. Phansopkar P, Athawale V, Birelliwar A, Naqvi W, Kamble S. Post-operative rehabilitation in a traumatic rare radial nerve palsy managed with tendon transfers: A case report. Pan Afr Med J. 2020;36(1):1-7. doi:10.11604/pamj.2020.36.141.23994.
17. Chen PY, Cheen JR, Jheng YC, Wu HK, Huang SE, Kao CL. Clinical applications and consideration of interventions of electrotherapy for orthopedic and neurological rehabilitation. J Chin Med Assoc. 2022;85(1):24-9. doi:10.1097/jcma.0000000000000634.
18. Doi K. Management of total paralysis of the brachial plexus by the double free-muscle transfer technique. J Hand Surg Eur. 2008;33(3):240-51. doi:10.1177/1753193408090140.
19. Ko EJ, Sung IY, Yun GJ, Kang J-A, Kim J, Kim GE. Effects of lateral electrical surface stimulation on scoliosis in children with severe cerebral palsy: A pilot study. Disabil Rehabil. 2018;40(2):192-8. doi:10.1080/09638288.2016.1250120.
20. Karabay İ, Dogan A, Arslan MD, Dost G, Ozgirgin N. Effects of functional electrical stimulation on trunk control in children with diplegic cerebral palsy. Disabil Rehabil. 2012;34(11):965-70. doi:10.3109/09638288.2011.628741.
21. Maillefert JF, Eicher JC, Walker P, Dulieu V, Rouhier-Marcer I, Branly F, et al. Effects of low-frequency electrical stimulation of quadriceps and calf muscles in patients with chronic heart failure. J Cardiopulm Rehabil. 1998;18(4):277-82. doi:10.1097/00008483-199807000-00004.
22. Gremeaux V, Renault J, Pardon L, Deley G, Lepers R, Casillas JM. Low-frequency electric muscle stimulation combined with physical therapy after total hip arthroplasty for hip osteoarthritis in elderly patients: A randomized controlled trial. Arch Phys Med Rehabil. 2008;89(12):2265-73. doi:10.1016/j.apmr.2008.05.024.
23. Mettler JA, Magee DM, Doucet BM. Low-frequency electrical stimulation with variable intensity preserves torque. Journal of electromyography and kinesiology. J Electromyogr Kinesiol. 2018;42:49-56. doi:10.1016/j.jelekin.2018.06.007.
24. Ward AR. Electrical stimulation using kilohertz-frequency alternating current. Phys Ther. 2009;89(2):181-90. doi:10.2522/ptj.20080060.
25. Ward AR, Shkuratova N. Russian electrical stimulation: the early experiments. Phys Ther. 2002;82(10):1019-30. doi:10.1093/ptj/82.10.1019.
26. da Silva VZM, Durigan JLQ, Arena R, de Noronha M, Gurney B, Cipriano G. Current evidence demonstrates similar effects of kilohertz-frequency and low-frequency current on quadriceps evoked torque and discomfort in healthy individuals: A systematic review with meta-analysis. Physiother Theory Pract. 2015;31(8):533-9. doi:10.3109/09593985.2015.1064191.
27. Bickel CS, Gregory CM, Dean JC. Motor unit recruitment during neuromuscular electrical stimulation: A critical appraisal. Eur J Appl Physiol. 2011;111(10):2399-407. doi:10.1007/s00421-011-2128-4.
28. Nelson RM, Currier DP. (1991), Clinical electrotherapy. 2nd ed. USA: Appleton&Lange. ISBN:0-8385-1334-1334.
29. Amirova L, Avdeeva M, Shishkin N, Gudkova A, Guekht A, Tomilovskaya E. Effect of modulated electromyostimulation on the motor system of elderly neurological patients. Pilot study of Russian currents also known as kotz currents. Front Physiol. 2022;13:1-8. doi:10.3389/fphys.2022.921434.
30. Delitto A, Brown M, Strube M, Rose S, Lehman R. Electrical stimulation of quadriceps femoris in an elite weightlifter: A single subject experiment. Int J Sports Med. 1989;10(3):187-91. doi:10.1055/s-2007-1024898.

31. Snyder-Mackler L, Delitto A, Stralka SW, Bailey SL. Use of electrical stimulation to enhance recovery of quadriceps femoris muscle force production in patients following anterior cruciate ligament reconstruction. Phys Ther. 1994;74(10):901-7. doi:10.1093/ptj/74.10.901.
32. Acqua AMD, Döhnert MB, Dos Santos LJ. Neuromuscular electrical stimulation with russian current for expiratory muscle training in patients with chronic obstructive pulmonary disease. J Phys Ther Sci. 2012;24(10):955-9. doi:10.1589/jpts.24.955.
33. Bennie SD, Petrofsky JS, Nisperos J, Tsurudome M, Laymon M. Toward the optimal waveform for electrical stimulation of human muscle. Eur J Appl Physiol. 2002;88(1):13-9. doi:10.1007/s00421-002-0711-4.
34. Changfeng T, Groat WCD, Roppolo JR. Simulation of nerve block by high-frequency sinusoidal electrical current based on the Hodgkin-Huxley model. IEEE Trans Neural Syst Rehabil Eng. 2005;13(3):415-22. doi:10.1109/TNSRE.2005.847356.
35. Williamson RP, Andrews BJ. Localized electrical nerve blocking. IEEE Trans Biomed Eng. 2005;52(3):362-70. doi:10.1109/TBME.2004.842790.
36. Selkowitz DM. Improvement in isometric strength of the quadriceps femoris muscle after training with electrical stimulation. Phys Ther. 1985;65(2):186-96. doi:10.1093/ptj/65.2.186.
37. Soo CL, Currier DP, Threlkeld AJ. Augmenting voluntary torque of healthy muscle by optimization of electrical stimulation. Phys Ther. 1988;68(3):333-7. doi:10.1093/ptj/68.3.333.
38. Leung LS, Yu H-W. Theta-frequency resonance in hippocampal CA1 neurons in vitro demonstrated by sinusoidal current injection. J Neurophysiol. 1998;79(3):1592-6. doi:10.1152/jn.1998.79.3.1592.
39. Cukjati D, Robnik-Šikonja M, Reberšek S, Kononenko I, Miklavčič D. Prognostic factors in the prediction of chronic wound healing by electrical stimulation. Med Biol Eng Comput. 2001;39(5):542-50. doi:10.1007/BF02345144.
40. Petrofsky JS, Lawson D, Berk L, Suh H. Enhanced healing of diabetic foot ulcers using local heat and electrical stimulation for 30 min three times per week. J Diabetes. 2010;2(1):41-6. doi:10.1111/j.1753-0407.2009.00058.x.
41. New PZ, Jackson CE, Rinaldi D, Burris H, Barohn RJ. Peripheral neuropathy secondary to docetaxel (Taxotere). Neurology. 1996;46(1):108-11. doi:10.1212/WNL.46.1.108.
42. Camargo BF, Santos MMd, Liebano RE. Hypoalgesic effect of Bernard's diadynamic currents on healthy individuals. Rev Dor. 2012;13:327-31. doi: 10.1590/S1806-00132012000400004.
43. Kipenskyi AV, Korol II, Prodchenko NS. Formation of diadynamic currents with a universal low-frequency signal generator for electrotherapy. In 2020 IEEE KhPI Week on Advanced Technology (KhPIWeek);2020:299-304. doi:10.1109/KhPIWeek51551.2020.9250168.
44. de la Barra Ortiz HA, Cofré C, López C, Montecinos I. Efficacy of diadynamic currents in the treatment of musculoskeletal pain: A systematic review. Physiother Quart. 2021;31(3):1-25. doi:10.5114/pq.2023.117021.
45. Ratajczak B, Hawrylak A, Demidaś A, Kuciel-Lewandowska J, Boerner E. Effectiveness of diadynamic currents and transcutaneous electrical nerve stimulation in disc disease lumbar part of spine. J Back Musculoskelet Rehabil. 2011;24:155-9. doi:10.3233/BMR-2011-0289.
46. Demidaś A, Zarzycki M. Touch and pain sensations in diadynamic current (DD) and transcutaneous electrical nerve stimulation (TENS): A randomized study. Biomed Res Int. 2019;2019:1-7. doi:10.1155/2019/9073073.
47. Pelikán M. (2010), Přístroj pro elektroléčbu. 1 ed. Vysoké učení technické, Brně. p. 23-60
48. Kırdı N. (2016), Elektroterapide temel prensipler ve klinik uygulamalar. 2nd ed. Ankara: Hipokrat Kitabevi. ISBN:978-605-9160-03-2.
49. Goats GC. Interferential current therapy. Br J Sports Med. 1990;24(2):87-92. doi:10.1136/bjsm.24.2.87.
50. Coutaux A. Non-pharmacological treatments for pain relief: TENS and acupuncture. Jt Bone Spine. 2017;84(6):657-61. doi:10.1016/j.jbspin.2017.02.005.

Co-funded by the
Erasmus+ Programme
of the European Union

Ultra-Reiz (Trabert) Currents

MEHMET DURAY

The History of Ultra-Reiz Current

Trabert currents, known today as Ultra-Reiz currents, was described by Dr. Trabert in 1957. With Ultra-Reiz currents, which aim to create a massage effect in areas where electric current passes, it is aimed to emphasize the effect of analgesia and hyperemia in the treatment. Ultra-Reiz currents, which are designed to create a fluctuating and kneading effect in the applied area, were called "stimulation current massages" in the first years due to the massage effect it created.[1,2]

Characteristics of Ultra-Reiz Current

The Ultra-Reiz current, with a frequency of 143 Hertz (Hz) and a total period of 7 milliseconds (ms), has a 5 ms rest period after monophasic square wave pulses with a 2 ms transition time (Figure 11.1). Ultra-Reiz current applied over the skin combines the Galvanic current effect and the sensory stimulus effect. The Galvanic component of the Ultra-Reiz current is around 28.5%.[2-5] Although the strength of the Trabert current varies, it has a fixed pole and current direction.[3]

Ultra-Reiz current is used for symptom modulation after degenerative lesion.[6] When the current is applied, the patient feels a state of relaxation and well-being with the massage effect on the muscles, followed by a non-irritating bursting sensation.[2]

The Effect Mechanism of Ultra-Reiz Current

The main effects and aims of Ultra-Reiz current are;

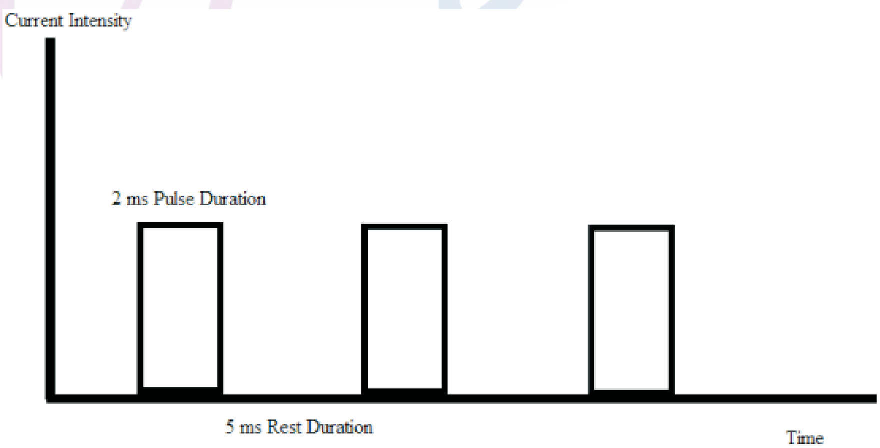

Figure 11.1 Ultra-Reiz Current. (Created by author).

- to reduce the activation of the sympathetic system and increase the activation of the parasympathetic system,
- to provide analgesia,
- to relax muscle spasms,
- to increase blood circulation,
- reflected effect,
- to create muscle contraction.[2,5-7]

Reducing the Activation of the Sympathetic System and Increasing the Activation of the Parasympathetic System

Ultra-Reiz current not only stimulates motor and sensory nerves but also provides regulatory stimulation of the autonomic nervous system. By providing tetanic contraction with Ultra-Reiz current, muscle tension can be reduced and the sympathetic activation response can be broken. However, the stimulation of the parasympathetic part of the autonomic nervous system by the Ultra-Reiz current causes vasodilation as a reflex. In cases where autonomic stimulation with Ultra-Reiz current is desired, electrodes should be placed in accordance with the passage route of the autonomic nerves.[8] The parasympathetic and sympathetic system functions were shown in Figure 11.2.

Providing Analgesia

The most common aim of using Ultra-Reiz current is to reduce pain. There are many publications stating that pain is reduced after Ultra-Reiz cur-

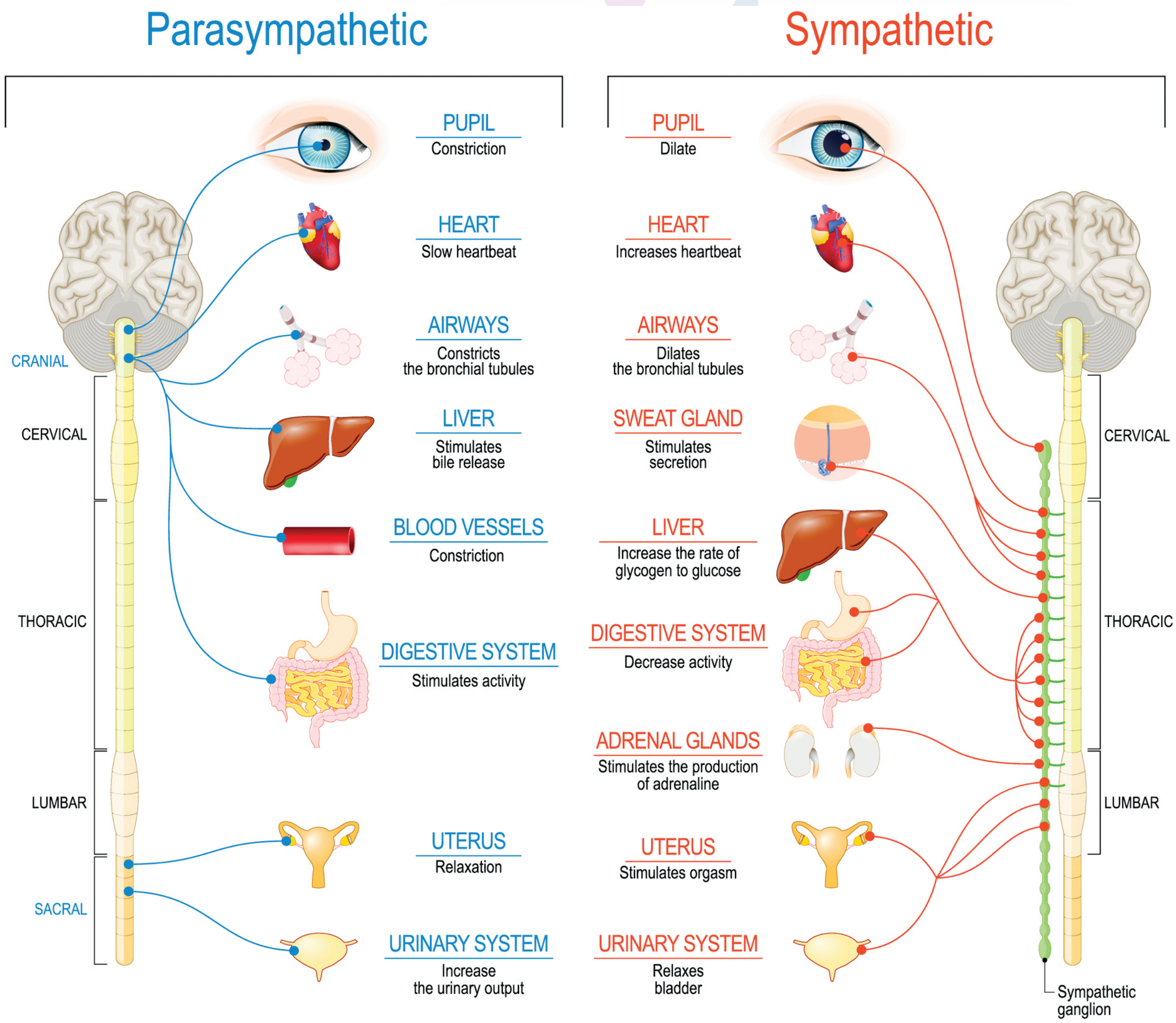

Figure 11.2 Parasympathetic and Sympathetic System Functions

rent applications.[8-10] Pain can be blocked from any point of the transit route, whether it is a pain with a high conduction velocity transmitted by A-delta fibers after a trauma or a deep pain sensation with a low conduction velocity with unmyelinated C fibers. The method for inhibiting the transmission carried by the pain fibers by stimulating other afferent nerves is known as the "masking effect". This effect comes to the fore especially in applications with electrical stimulation. Since the frequency (143 Hz) of the Ultra-Reiz current is higher than the frequency of pain fibers with slow conduction velocity, the masking effect becomes more prominent.[2]

One of the main effects of the Ultra-Reiz current is the sensory stimulus. Rapid exteroceptive nerve fiber stimulation blocks the pain at the level of the medulla spinalis.[3,6] However, Ultra-Reiz current, which stimulate opioid peptide release, allow stronger modulation of pain.[6]

Especially in the rehabilitation of spinal pain, Ultra-Reiz current can provide pain modulation by stimulating thick myelinated afferent fibers in accordance with the gate control theory. Combining the treatment with vacuum application increases the analgesic effect and reduces lumbosacral movement limitation due to pain.[11] Ultra-Reiz currents, which are used especially in the rehabilitation of spinal pain, are widely used in the rehabilitation of athletes.[1] The electrode placement is adjusted by the physiotherapist according to the characteristics of the painful area.[12]

Relaxing Muscle Spasms

Ultra-Reiz current has a massage effect. Both an increase in blood flow and a mechanical stimulus on the muscle reduce muscle spasms.[2] Ultra-Reiz current produces tetanic muscle contractions that reduce sympathetic system activity and thus muscle tension. In addition to the massage effect, the autonomic effect also relaxes muscle spasms by proving vasodilation.[6]

Increasing the Blood Circulation

Pulse and resting duration of the Ultra-Reiz current (2-5 ms) are quite suitable for therapeutic purposes in increasing blood flow. First of all, it should be indicated that the stimulation of muscle activity during the flow increases the pumping effect of the muscles. The metabolic activity induced as a result of increased muscle function increases arteriovenous and lymphatic circulation. However, the prerequisite for the increase in circulation by this mechanism is that the muscle, which electric current is applied, does not exhibit a paretic picture and is completely healthy in terms of excitability.[2]

Another circulation-enhancing effect of the Ultra-Reiz current is hyperemia. Hyperemia after Ultra-Reiz flow does not only occur on the skin surface but also in the deep layers of the muscles. This situation describes an agonistic reaction between skin and muscles.[2]

The fact that the application causes parasympathetic stimulation, it also creates reflex vasodilatation.[5,6]

Reflected Effect

Ultra-Reiz current also stimulates cutaneous reflexes and increases circulation in internal organs. By stimulating the autonomic fibers acting on the cutaneous nerves or the vessels of the internal organs, the smooth muscles innervated by these nerves are stimulated. The release of vasoactive substances such as histamine and acetylcholine in the regions affected by Ultra-Reiz current also supports the increase in blood circulation. Because of this reflex connection between the skin and the organs, blood supply to the internal organs is ensured. This is also the case in different physiotherapy and rehabilitation applications such as massage. Interventions on the skin can produce reflex therapeutic effects on different body parts and segments.[2,3]

Creating Muscle Contractions

Ultra-Reiz current is also used to create muscle contractions and prevent atrophy.[5,13] These muscle contractions are difficult to see with the naked eye. Accommodation developed against the current decreases the amount of contraction detected by palpation or observation after a while.[13]

Ultra-Reiz Current Application

Ultra-Reiz current is applied with medium-sized electrodes (8x10 or 9x12).[3,13,14] Electrodes used especially in spinal applications are placed paravertebral or longitudinally.[2,14] The distance between the electrodes should be 3-4 cm. The current intensity is increased in a controlled manner. After the patient feels a tingling that does not cause discomfort, the optimum current intensity suitable for the patient is determined and the application is made at this current intensity. The patient will not feel the current delivered within a few minutes. Upon notification of the patient, the current intensity is increased again until the patient feels it.[14]

In the applications for contraction, the observation of the physiotherapist comes to the fore. It should be noted that 143 Hz is a frequency that produces tetanic contractions. Therefore, all the applied muscle fibers are activated and contracted. For this reason, the current intensity should be adjusted very well and carefully by the physiotherapist. The current is gradually increased so that the tolerable motor threshold is not exceeded. The physiotherapist should have the ability to fine tune the flow. In interventions performed on movable joints, such as the upper and lower extremities, the application should not be made directly on the target area (joint) in order not to give a stimulation to the bone.[2]

It is difficult for a physiotherapist determine whether the muscles in the spine are working at an optimal level. Therefore, the current intensity can be decreased and increased again in order to be aware of muscle contractions and relaxations.[2]

Whether it is the tingling sensation felt or the amount of contraction achieved, as the desired effect decreases, the current intensity is increased and the tolerance limit is reached in the patient within 5 to 7 minutes. Although it varies according to the patient, the current intensity that can be increased up to 70-80 milliamperes (mA) should be used with thick moist viscose sponge or electrode pads that absorb a lot of water.[3,13,14]

Since the current causes a strong metabolic change, it may need to be used with at least one-day interval between each session. In daily use, thermal reactions, tactile sensitivity, and the development of a different type of pain may occur. To avoid these effects, Ultra-Reiz current can be used with other currents with the same purpose.[3]

Although it is recommended to use 6-8 sessions of Ultra-Reiz current, the number of sessions can be shortened according to our level of reaching the target. If Ultra-Reiz current can be applied effectively, successful results are obtained in the first 2-3 sessions.[3,13] At the end of a single treatment session, positive effects are reported, especially for the inhibition of pain.[4,13]

Indications of Ultra-Reiz Current

- Radiculopathy, cervical, thoracic, and lumbar region osteochondrosis, and spondyloarthroses[2]
- Other spinal degenerations[1,2]
- Other osteochondrosis and arthrosis[2,13]
- Sudeck Atrophy[5]
- Neuralgia[13]
- Hyperalgesia [5]
- Post-traumatic situations[13]
- Osteoarthritis [15]
- Myalgia [2]
- Spinal pain [11,16]
- Hemiplegic shoulder pain [12]

Contraindications

Application of Ultra-Reiz current to paretic muscles is contraindicated. The muscle may either be unable to respond to 143 Hz stimulation or may respond for a very short time. Forcing the muscle to stimulate may increase the existing muscle denervation.[2]

Ultra-Reiz current should not be applied on or near metal implants. If applied, electrochemical burns may occur with an electrophoretic effect. For this reason, electrode placement should be done at least 15-20 cm away from the metal implant.[3] Ultra-Reiz current is also not used in patients with

- fever,
- malignancy,
- the presence of tuberculosis,

- pregnancy (especially on the lumbar region),
- a pacemaker or implant stimulators,
- cooperation problems (who cannot give feedback on the given current intensity).[13]

References

1. Wenk W. Einführung in die elektrotherapie. medizintechnik: Verfahren-systeme-informationsverarbeitung. 2007;603-14. doi:10.1007/978-3-540-34103-1_34.
2. Nausester V. Ultra-Reizstrom: Nach Träbert. Zeitschrift des Schweizerischen. 1978;1-4. doi:10.5169/seals-930605.
3. Rodrigues Martín JM. (2004), Electroterapia en fisioterapia. 2nd ed. Madrid: Médica Panamericana. ISBN:978-84-7903-753-6.
4. Efisioterapia. Tratamiento de las AAF: Corrientes Trabert. Accessed: https://www.efisioterapia.net/articulos/tratamien-to-las-aaf-corrientes-trabert. Date:17.06.2023.
5. Laskowska J, Hadław-Klimaszewska O, Jankowska A, Zdziechowski A, Woldańska-Okońska M. Overview of wellness methods for people practicing sports. Wiadomości Lekarskie. 2021;74(2):355-61. doi:10.36740/WLek202102133.
6. Dakowicz A, Milewska AJ, Gradkowska A, Matys A, Tarkowska K, Białowieżec M. Efficiency of selected physiotherapeutic treatments for low back pain. Prog Health Sci. 2016;6(2):70-6. doi:10.5604/01.3001.0009.5051
7. Jagielski J. Próba Zastosowania Lasera Jako Jednej Z. Metod leczenia fizjoterapeutycznego w bólowych zespołach kręgosłupa lędźwiowo-krzyżowego. Balneol Pol. 1994;35:11-13. doi:10.21164/pomjlifesci.460.
8. Kuciel-Lewandowska J, Olejniczak V, Paprocka-Borowicz M, Berner E, Ratajczak B, Hawrylak A. The efficiency evaluation of the Träbert and Kotz currents therapy in patients with lumbar pain. Acta Bio-Opt Inform Med. 2010;3(16):215-8.
9. Kuciel-Lewandowska J, Jarosz N. The efficiency evaluation of the tens and Träbert currents therapy in patients with lower spine pain. Acta Balneolog. 2010;52(1):16-23.
10. Szczepanowska-Wołowiec B, Dudek J. the estimation of the effectiveness of Träbert's current treatment for pain ailments in the lumbar spine section. Med Stud. 2008;9:41-50.
11. Charłusz M, Gasztych J, Irzmański R, Kujawa J. Comparative analysis of analgesic efficacy of selected physiotherapy methods in low back pain patients. Ortop Traumatol Rehabil. 2010;12(3):225-36. PMID:20675864.
12. Amin LML. (2020), Rehabilitation plan and process in patients after stroke. Bachelor's Thesis. Masaryk University Faculty of Medicine. Accessed: https://is.muni.cz/th/loj2d/Final_Thesis.pdf. Date:17.06.2023.
13. Kırdı N. (2016), Elektroterapide temel prensipler ve klinik uygulamalar. 2nd ed. Ankara: Hipokrat Kitabevi. ISBN:978-605-9160-03-2.
14. Chwieśko-Minarowska S, Kuryliszyn-Moskal A, Olędzka A, Moskal-Jasińska D. The effectiveness of short-term massage versus Träbert current therapy in patients with low back pain. Acta Balneologica. 2019;61(4):247-51. doi:10.36740/ABal201904104.
15. Decintan WN, Pristianto A, Santosa TB. (2022), Efek electro therapy Trabert current and pulse burst knee osteoarthritis pain grade II. Academic Physiotherapy Conference Proceeding. ISSN: 2809-7475. Accessed: https://proceedings.ums.ac.id/index.php/apc/issue/view/3. Date:17.06.2023.
16. Jaber NA, Noori AS, Hussien EA, Jaber MA. A review of treatment methods using electrical stimulation. J Pharm Sci. 2022;6(6):1-16. doi:10.26389/AJSRP.B040922.

Co-funded by the Erasmus+ Programme of the European Union

Microcurrent Electrical Neuromuscular Stimulation

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Microcurrent Electrical Neuromuscular Stimulation

Microcurrent Electrical Neuromuscular Stimulation (MENS) was developed as a physical therapy modality delivering current in the microampere range. It has been reported that MENS has several physiological effects such as pain relief and facilitation of tissue repair including tendon injuries, skin ulcers, wounds, bedsores, and ligament injuries.[1-8]

MENS current intensities vary between 1 and 999 microamperes (μA). It has been successfully used to enhance soft tissue healing and to treat fracture non-unions. The efficacy of MENS in the treatment of these conditions has led some clinicians to suggest that it might also be valuable in the treatment of musculoskeletal injury.[9]

MENS is a physical modality delivering sub-sensory, low-amperage current and thus mimics the electrical intensity found in living tissue. If microcurrents of a physiological amperage were delivered into damaged muscle tissues, it could control the altered membrane function by various mechanisms, such as the maintenance of intracellular Ca^{2+} homeostasis and the upregulation of adenosine triphosphate (ATP) production. Studies revealed that treatment of muscle damage with MENS therapy with low-amperage <500μA can reduce the severity of muscle symptoms.[10]

With MENS the patient cannot feel the current since there is not enough current to stimulate sensory nerve fibers. Traditionally, MENS therapy has been used to increase the rate of healing in injured athletes, to treat and manage muscle pain and dysfunction and to increase the rate of fracture repair.[11]

Nowadays, interest in the use of low-intensity current such as MENS is increasing, as its effects take place at the cell level (protein synthesizing activity, increased ATP generation), with sub-sensory application (i.e., painless), besides the absence of collateral effect, low cost, and easy utilization.[12]

Physiological Effects of the MENS

Pain Control

MENS therapy remains a relatively obscure modality and is unfamiliar to many clinicians. This may in part be due to the mixed evidence of its effectiveness, with studies using some forms of MENS therapy failing to find evidence of its use for pain relief. The mechanism of pain control using a MENS therapy device, also called Micro-Tens device, differs from traditional Transcutaneous Electrical Nerve Stimulation (TENS) using nerve excitation by sensory stimulation. One theory of the MENS for pain control is, it can create or change the constant Direct Current (DC) flow of the neural tissues, which may have some way of biasing the transmission of the painful stimulus. MENS may also make the nerve cell membrane more receptive to neurotransmitters that will block transmission. The mechanism for pain control using MENS is still under investigation. MENS has demonstrated trends for decreasing pain and increasing function with acute knee pain over 4-weeks. Also during this intervention natural tissue healing occurs.[13]

Current in the range of 10 up to 500 μA was observed to increase ATP production, amino acid transportation, protein synthesis, and waste product removal in tissues whereas ATP production leveled off between 500 and 1000 μA and decreased when the current was above 1000 μA.[14] TENS devices provide up to 60 times higher current levels than that seen to decrease ATP production, which may explain why TENS units have not been found to be effective in treatment of delayed onset muscle soreness (DOMS). Typical Microcurrent applications use only low and simple one channel frequencies such as 0.3 Hertz (Hz), 3 Hz, 10 Hz, 30 Hz, and 300 Hz.[9]

One of the methods of using MENS is through special "transducer gloves" that allow managing microcurrent signals through manipulation techniques. It is a key component for many medical and sport applications, and it is largely used for rehabilitation, training, and recovery purposes.[15] The utilization of electric field and currents comparable to different cells results in the stimulation of growth and tissue restoration and diminution of edema. The consequences on ATP production are described by proton actions, whereas the amino acids transport through the cell are facilitated by the alterations of the electrical gradients across the membranes. Throughout stimulation of damaged muscles, MENS manages the modified membrane function by various processes, such as the preservation of intracellular Ca^{2+} homeostasis and with the augmented production of ATP levels.[12]

There is evidence that in infants with congenital muscular torticollis, MENS therapy improves the range of motion of the neck since the therapeutic effect of MENS therapy is likely related to increase in the numbers of sarcomeres and ATP production, thereby improving contractility as keeping a muscle in a shortened position is a disadvantage because of the decrease in the number of sarcomeres in the muscle cells. When using MENS therapy device, intensity should be 25 μA and frequency 8 Hz. Therapy time is recommended 60 minutes (min) daily for 4 weeks. This level of current intensity is significantly below each child's threshold of sensation. Current should be characterized by a monophasic rectangular pulse format with polarity reversal every 2 seconds (s).[16]

Tissue Healing

MENS is now being successfully applied to promote healing in a number of situations including soft tissue healing and the treatment of nonunion fracture, among others. MENS has been shown to delay the onset of myalgia, improve sympathetic nerve tone, promote wound healing, increase beta-endorphin and pain threshold levels, repress bacterial growth, reduce foot muscular fatigue and pain, and increase the blood flow rate. Pain alleviation and tissue changes induced by MENS therapy have been observed during treatment of myofascial pain syndrome patients with chronic back pain.[17]

Microcurrent stimulation between 200-800 μA is a way of supercharging the tissue with ATP, which will reside there until needed. By this means, much of the research shows that a 200% increase in healing rate can be explained as it applies to hundreds of conditions. In a clinical sense, any healing process takes a great deal of ATP and may be accelerated through a means of increasing ATP in the tissue. MENS accomplishes this by increasing ATP in the tissue by up to 400%. The body does have a vast capacity to store ATP. One can build ATP reserves. This is one reason that, unlike other forms of electric therapy such as interferential, or higher amperage TENS and Galvanic; MENS stands unique in that it has a cumulative effect, rather than a diminishing effect. Other electric stimulation approaches decrease ATP levels. MENS therapy, which is used from one to usually 600 μA clinically, is the modality of choice for increased tissue healing. Research and clinical trials have shown that with MENS, there is a 40-50% reduction in healing time of ulcers and sprain/strains, fractures heal faster and stronger, and that even bad scarring (keloid scars) remodel to become a healthier and stronger scar. Other ATP related MENS effects include decreased inflammation, edema and swelling, and increased physical endurance in sports.[18]

MENS has the advantage of rarely causing muscle contractions and uncomfortable sensations to the skin, and has only a few electrical side effects; hence, this stimulation is suitable for patients who have limited mobility after surgery. The basis of the stimulation is the ion channel and cellular communication that stimulate cell activity by normalizing the cell's electrical environment.[18] Furthermore, it activates the differentiation, proliferation, and migration of cells by facilitating the tissue healing and recovery process.[17] Schmidt-Malan et al. reported that MENS stimulates receptor proteins by opening Na^{+} and Ca^{2+} pathways in the cell membranes to stimulate the proliferation of cells such as chondrocytes, bone cells, fibroblasts, and vascular endothelial cells. The differentiation and migration of the cell process enhances functional improvement.[19] Also MENS promotes higher fibroblast and new capillary formation in the early phase of tendon healing.[20]

MENS plays a role in restoring cells or facilitating healing by increasing the creation of ATP and proteins, and curing wounds through the supply of electric energy at the cell level, which restores the potential of the cell membrane to normal potential. It was shown that MENS have been beneficial for a wide range of conditions such as fracture and fatigue recovery, and various diseases involving cancers and diabetic nerve damage. In particular, MENS is known to be effective for cumulative fatigue recovery as it reduces creatine kinase in the blood of patients with DOMS. MENS can induce cell responses in damaged tissues through bioelectricity thereby assisting with the healing of tissues. It can also facilitate endogenous bioelectric current, which would reduce resistance in the damaged portion, and promote conduction of bioelectric current assisting with the recovery of homeostasis of the human body. That is, MENS enhances electrical and chemical processes, which assist the healing process, returning damaged muscle tissues to a normal state. MENS is more effective for the recovery of muscle fatigue and muscle tone than only taking a rest. The MENS therapy increases collagen formation speed in the recovery of damaged cells more than in the TENS therapy, which is why the MENS had a more positive effect on muscle fatigue and muscle tone.[21,22]

MENS is also beneficial for preventing muscle atrophy. Moon et al. demonstrated that MENS might prevent progression of Gastrocnemius muscle atrophy and facilitate the regeneration of muscle cells.[23] Fujiya et al. also confirmed that the MENS facilitated regrowth of atrophied soleus muscle.[8] These effects could increase protein synthesis and stimulate satellite cell proliferation. Therefore, MENS has the potential to become an effective therapeutic intervention to recover muscle atrophy induced by chronic immobilization. The intensity of electric current also plays an important role in the effective treatment of muscle damage. According to the previous studies, when an electric current with an intensity of 100–500 μA was applied to treat muscle damage, the healing process, including amino acid transport, triphosphate generation, and protein synthesis, could be achieved. Then the healing effect increased by 30%–40% above the control level along with the activation of myogenic precursor cells (satellite cells). On the contrary, when the intensity exceeded 1000 μA, these biostimulatory effects were reversed.[24]

When the effectiveness of MENS with two different electric current intensities (50 μA vs. 500 μA) compared, it was concluded that current intensity of 50 μA was more effective than 500 μA in alleviating symptoms and promoting tendon normalization. Also it was confirmed that the regrowth of unloading-associated atrophied mouse Soleus muscle is stimulated by MENS.[24]

Application Types

Probe Electrodes

Usually probes are used by healthcare specialists to alleviate pain and increase function. These work better than self-adhesive electrodes, because it is possible to place them directly and around the painful area. When using probes, saturate them with an appropriate electromedical conducting solution. Saline solution may be used if a conducting solution is not available. Apply firm pressure to help minimize skin resistance.[25]

While manufacturer's recommendations vary, probes are typically applied for approximately 10 s per placement. Usually one treatment set is a group of 12-20 of these for 10 s probe placements, each at a different angle of approach.

Probes placement should be applied using these recommendations:

1. First treat over a wide area well beyond the problem area. An example of this strategy for knee pain would be to treat from the medial, superior thigh to the lateral foot, then the lateral hip to the medial foot. At 10 s per location this is completed in 20 s.
2. Treat closer in directly around the involved area (e.g., two oblique angles, one or two medial-lateral, one or two anterior-posterior probe placements) for a total of 1 minute.
3. Treat around the contralateral side, directly opposite the problem site (e.g., opposite knee) for at least 20 s, even if it is asymptomatic.
4. Connect the two contralateral sides by placing a probe on each side simultaneously at four or more locations distal to the area being treated.

The same principle can be used in other joints or body parts too.

Plaque and Self-Adhesive Electrodes

Self-adhesive electrodes are placed within the same guidelines as the probes, except for a longer period of time. For optimum results, electrodes may also need to be moved around the problem area. Whereas the probes are used for 10 s a site, electrodes should be left at each location for at least 5 to 10 min. Accordingly, electrodes are best used for home care.

It is recommended to use low resistance electrodes. Standard TENS electrodes have a resistance of about 200 Ohms, while some silver electrodes have a resistance of only 20 Ohms. Only low resistance electrodes will work effectively with MENS devices.[25] Electrode placement examples are shown below (Figure 12.1-3).

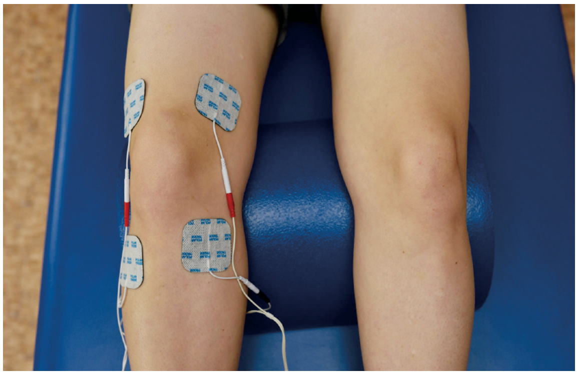

Figure 12.1 MENS electrode placement for local knee pain.

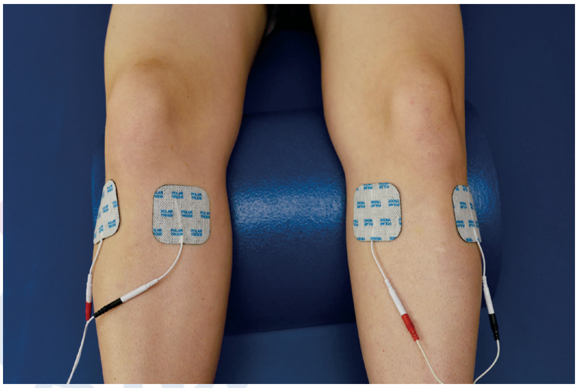

Figure 12.2 MENS electrode placements for contralateral treatment of right knee pain.

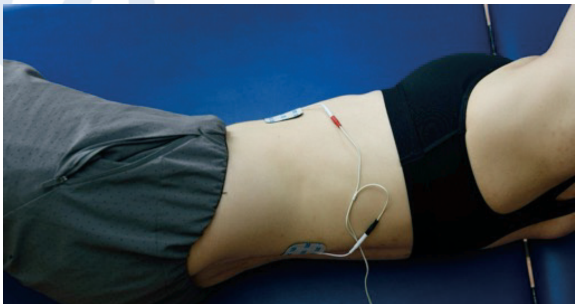

Figure 12.3 MENS electrode placement for back pain. One electrode is placed next to the spine at the level where the problem is, and the other on the contralateral side, antero-laterally (front and opposite side).

Transducer Gloves

Usually microcurrent instruments are supplied with graphite/vinyl gloves. The lightweight gloves have electric micro jacks cemented to the dorsal surface, and are designed to conduct current and provide sensitive tactile perception. Therapist that uses gloves directly on the skin can conduct massage, manipulation, mobilization techniques to reduce pain, increase blood flow, and tissue elasticity (Figure 12.4). This method combines two treatment methods: soft tissue mobilization and MENS procedure, which complement each other.[26]

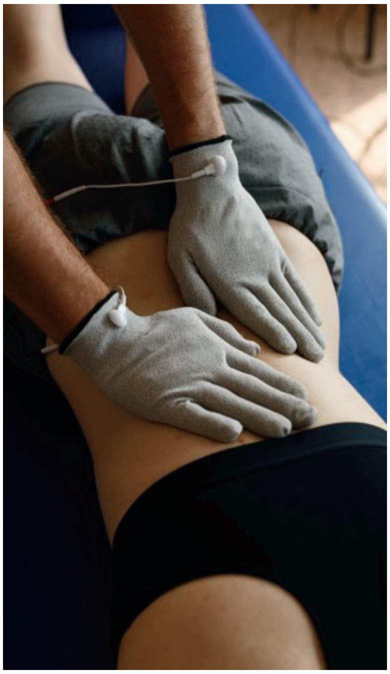

Figure 12.4 MENS transducer gloves application for low back pain.

Wireless MENS

Electric stimulation is traditionally performed by applying on the tissue pin or dressing electrodes connected by cables to a current-generating device. In contrast, Wireless Microcurrent Stimulation (WMCS) technology is an innovative, simple, non-invasive, and pain-free method to transfer current wirelessly to the wound by using oxygen and nitrogen ability to donate electrons. The charged particles create a DC of very low intensity. With no physical contact to the wound thanks to its spray effect, it offers a radical advantage compared with other currently used electrical stimulation techniques.

The WMCS devices work by transferring distantly low intensity electric current to the patients. The patient has to be part of an electrical circuit and, for this reason, has to be connected with the device through a wrist strap wire (usually placed on the patient's intact skin, far away from the wound, e.g. in case of leg ulcers it is normally placed at the wrist joint). A control box permits the adjustment of the current (15-40μA) and treatment duration. Distance from the head of the device to any wound should be 12-15 cm. The treatment surface covered is about 400cm^2, which can be increased by moving away the head of the device from the wound. The charged particles create a DC of very low intensity. With no physical contact to the wound thanks to its spray effect, it offers a radical advantage compared with other currently used ES techniques. Recommended treatment time is 45 min, so it is important that the patient lays or sits comfortably because the wound position relative to the WMCS device should remain steady throughout the treatment.[27]

Indication and Contraindications

Indications for MENS

In addition to the problems mentioned above, there were some more indication for the usage of MENS.[28]

- Joint pain,
- Soft tissue pain,
- Neuralgia,
- Tendinitis,
- Bursitis,
- Phantom pain syndrome,
- Rheumatoid arthritis,
- Migraine,
- Torticollis,
- Epicondylitis,
- Frozen shoulder,
- Low back pain,
- Intervertebral disc syndrome.

Contraindications for MENS

- Conditions with unknown etiology,
- Conditions which demand cardiac pacemakers,
- Areas over cancer lesions or the carotid sinus and the transcerebral area,
- Pregnancy,
- Seizures,
- Pain of central origin,
- Epilepsy,
- Areas over skin and vascular disorder.[29]

References

1. Nessler JP, Mas DP. Direct-current electrical stimulation of tendon healing in vitro. Clin Orthop Relat Res. 1987;(217):303-12. PMID:3493869.
2. Owoeye I, Spielholtz NI, Fetto J, Nelson AJ. Low- intensity pulsed galvanic current and the healing of tenotomized rat achilles tendons: Preliminary report using load-to-breaking measurements. Arch Phys Med Rehabil. 1987;68(7):415-8. PMID:3496866.
3. Gault WR, Gatens PF. Use of low intensity direct in management of ischemic skin ulcer. Phys Ther. 1976;56:265-9. doi:10.1093/ptj/56.3.265.
4. Wolcott LE, Wheeler P, Hardwicke HM, Rowley BA. Accelerated healing of skin ulcer by electrotherapy: Preliminary clinical results. South Med J. 1969;62(7):795-801. doi:10.1097/00007611-196907000-00008.
5. Byl NN, McKenzie AL, West JM, Whitney JD, Hunt TK, Hopf HW, et al. Pulsed microamperage stimulation: A controlled study of healing of surgically induced wounds in Yucatan pigs. Phys Ther. 1994;74:201-13. doi:10.1093/ptj/74.3.201.
6. Huckfeldt R, Flick AB, Mikkelson D, Lowe C, Finley PJ. Wound closure after split-thickness with the use of continuous direct anodal microcurrent applied to silver nylon wound contact dressing. J Burn Care Res. 2007;28(5):703-7. doi:10.1097/BCR.0B013E318148C945.
7. Carley PJ, Wainpel SF. Electrotherapy for acceleration of wound healing: Low intensity direct current. Arch Phys Med Rehabil. 1985;66(7):443-6. PMID:3893385.
8. Fujiya H, Ogura Y, Ohno Y, Goto A, Nakamura A, Ohashi K, et al. Microcurrent electrical neuromuscular stimulation facilitates regeneration of injured skeletal muscle in mice. J Sport Sci Med. 2015;14(2):297. doi:10.7600/jpfsm.5.69.
9. Allen JD, Mattacola CG, Perrin DH. Effect of microcurrent stimulation on delayed-onset muscle soreness: A double-blind comparison. J Athl Train. 1999;34(4):334-7. PMID:16558582.
10. Kwon DR, Kim J, Kim Y, An S, Kwak J, Lee S, et al. Short-term microcurrent electrical neuromuscular stimulation to improve muscle function in the elderly: A randomized, double-blinded, sham-controlled clinical trial. Medicine (Baltimore). 2017;96(26):e7407. doi:10.1097/MD.0000000000007407.
11. Curtis D, Fallows S, Morris M, McMakin C. The efficacy of frequency specific microcurrent therapy on delayed onset muscle soreness. J Bodyw Mov Ther. 2010;14(3):272-9. doi:10.1016/j.jbmt.2010.01.009.
12. Piras A, Zini L, Trofè A, Campa F, Raffi M. Effects of acute microcurrent electrical stimulation on muscle function and subsequent recovery strategy. Int J Environ Res Public Health. 2021;18(9):4597. doi:10.3390/ijerph18094597.
13. Lawson D, Lee KH, Kang HB, Yang N, Llewellyn T, Takamatsu S. Efficacy of microcurrent therapy for treatment of acute knee pain: A randomized double-blinded controlled clinical trial. Clin Rehabil. 2021;35(3):390-8. doi:10.1177/0269215520965320
14. Cheng N, Van Hoof H, Bockx E, Hoogmartens MJ, Mulier JC, De Dijcker FJ, et al. The effects of electric currents on ATP generation, protein synthesis, and membrane transport of rat skin. Clin Orthop Relat Res. 1982;(171):264-72. PMID: 7140077.
15. Babault N, Cometti C, Maffiuletti NA, Deley G. Does electrical stimulation enhance post-exercise performance recovery? Eur J Appl Physiol. 2011;111(10):2501-7. doi:10.1007/s00421-011-2117-7.
16. Ahn JK, Kwon DR, Park GY, Lee KH, Rim JH, Jung WB, et al. Therapeutic effect of microcurrent therapy in children with in-toeing gait caused by increased femoral anteversion: A pilot study. Ann Rehabil Med. 2017;41(1):104-12. doi:10.5535/arm.2017.41.1.104.
17. Park RJ, Son H, Kim K, Kim S, Oh T. The effect of microcurrent electrical stimulation on the foot blood circulation and pain of diabetic neuropathy. J Phys Ther Sci. 2011;23(3):515-8. doi:10.1589/jpts.23.515.
18. Yi D, Lim H, Yim J. Effect of microcurrent stimulation on pain, shoulder function, and grip strength in early post-operative phase after rotator cuff repair. Medicina. 2021;57(5):491. doi:10.3390/medicina57050491.
19. Schmidt-Malan SM, Brinkman CL, Karau MJ, Brown RA, Waletzki BE, Berglund LJ, et al. Effect of direct electrical current on bones infected with staphylococcus epidermidis. JBMR Plus. 2019;3(5):e10119. doi:10.1002/jbm4.10119.
20. Ayub DM, Kusumawardani MK, Masduchi RH, Hernugrahanto KD, Sulistyowati NN. Microcurrent neuromuscular electrical stimulation helps to promote fibroblast and capillary formation in the early healing phase of achilles tendon rupture: An experimental study on animal model. Mal J Med Health Sci. 2021;17(supp6):5-10. eISSN:2636-9346.
21. Bailey S. How microcurrent stimulation produces ATP-one mechanism. Dynamic Chiropractic. 1999;17(18):6.
22. Kang DH, Jeon JK, Lee JH. Effects of low-frequency electrical stimulation on cumulative fatigue and muscle tone of the erector spinae. J Phys Ther Sci. 2015;27(1):105-8. doi:10.1589/jpts.27.105.
23. Moon YS, Kwon DR, Lee YJ. Therapeutic effect of microcurrent on calf muscle atrophy in immobilised rabbit. Muscle Nerve. 2018,58(2):270-6. doi:10.1002/mus.26110.
24. Park GY, Kwon DR, Moon YS. Low-intensity microcurrent therapy promotes regeneration of atrophied calf muscles in immobilized rabbits. J Biomed Res. 2019;33(1):30. doi:10.7555/JBR.32.20180056.
25. Chevalier A, Armstrong K, Gokal R. Microcurrent point stimulation applied to acupuncture points for the treatment of non-specific lower back pain. J Altern Complement Integr Med. 2016;2(2):16. doi:10.24966/ACIM-7562/100016.
26. McMakin CR. Microcurrent therapy: A novel treatment method for chronic low back myofascial pain. J Bodyw Mov Ther. 2004;8(2):143-53. doi:10.1016/j.jbmt.2003.12.006.
27. Wirsing PG, Habrom AD, Zehnder TM, Friedli S, Blatti M. Wireless micro current stimulation–An innovative electrical stimulation method for the treatment of patients with leg and diabetic foot ulcers. Int Wound J. 2015;12(6):693-8. doi:10.1111/iwj.12204.
28. Cameron MH. (2012), Physical agents in rehabilitation: From research to practice. 4th ed. Philadelphia, USA: WB Saunders Company. ISBN:978-1455728480.
29. Zuim PRJ, Garcia AR, Turcio KHL, Hamata MM. Evaluation of microcurrent electrical nerve stimulation (MENS) effectiveness on muscle pain in temporomandibular disorders patients. J Appl Oral Sci. 2006;14(1):61-6. doi:10.1590/s1678-77572006000100012.

Co-funded by the Erasmus+ Programme of the European Union

Transcutaneous Electrical Nerve Stimulation

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Transcutaneous Electrical Nerve Stimulation

Transcutaneous electrical stimulation (TES) is a technique to artificially activate motor nerves and muscles. It can be used for rehabilitation or the restoration of lost motor functions, e.g., in subjects with brain or spinal cord lesions. Apart from selectively activating motor nerves and muscles, TES activates sensory fibers and pain receptors, producing discomfort and sometimes pain.[1] It is used in various clinical settings to treat diverse acute and chronic pain conditions, and although clinical studies of its long-term efficacy have yielded variable results, it has become popular with both patients and health professionals of different disciplines, including physiotherapists, midwives, nurses and doctors.[2]

TES definition can be divided to:

a) Transcutaneous electrical nerve stimulation (TENS),
b) Transcutaneous electrical neuromuscular stimulation (TENMS) or transcutaneous electrical muscle stimulation (TEMS).

The difference and similarity between TENS and TES, TENMS (or TEMS) is that TENMS (or TEMS) is characterized by effective muscle contraction without creating pain, which can often give superior beneficial effects in improvement of micro-circulation, muscle function and subsequent relief of pain and other symptoms compared with TENS that creates stimulation of large diameter sensory nerve fibers without creating significant muscle contraction.[3]

In TES, surface electrodes are placed on the skin in order to stimulate motor nerves. Clinically, TES is applied for the rehabilitation of stroke subjects or spinal cord injured subjects, or for supporting tasks of daily living using so called neuroprostheses. In these applications, two main aspects are important 1) the selective activation of specific muscles to generate the intended motor function and 2) a comfortable stimulation to increase patient acceptance of TES. Usually, clinicians try to minimize discomfort caused by electric current by optimizing stimulation parameters, electrode location, and electrode size.[1]

Main TENS Parameters

In TENS application, there are several varying frequencies, intensities, and pulse durations to the skin for pain relief. Different TENS modalities use varying combinations of frequency and intensity settings on the device to elicit pain relief. This peripheral stimulation induces electrical activity, which inhibits the brain's perception of pain.[4]

TENS devices are designed so that users can adjust the electrical characteristics of the currents including: pulse frequency [usually less than 200 Hertz (Hz)], pulse amplitude [usually less than 70 milliamperes (mA)], pulse duration [usually 50 microseconds (μs) to 250 μs], and pulse pattern (sometimes termed "mode" and including continuous, burst, and modulated). Modulated pulse patterns may help to reduce tolerance to TENS caused by repeated use and include modulated frequency, modulated amplitude, and modulated duration.[4]

TENS propagates along smaller afferent sensory fibers specifically to override pain impulses. "Low-frequency TENS" is consistently defined as the delivery of a pulsed current of 10 Hz or less or low-frequency trains (bursts) of high-frequency pulsed current (i.e. burst mode TENS). When very low frequencies are used, TENS specifically targets sensory nerve fibers and does not activate motor fibers; therefore, no discernible muscle con-traction is produced.[5]

"Acupuncture-like TENS" is also attributed to low-frequency TENS. It is described as low frequency (~2–4 Hz) and high-intensity TENS, evoking tolerable but painful sensations. Acupuncture-like TENS is more related to the diffuse noxious inhibitory control phenomenon: a strong noxious input causes the release of endogenous opioids in the periaqueductal gray and rostral ventral medulla, which in turn results in a diffuse descending inhibition of nociception.[6] In essence, Acupuncture-like TENS is thought to help close the gateway of pain transmission and hence result in a reduction in pain.[7]

"High-frequency TENS" is defined as a pulsed current with the delivery of high-frequency (~50–100 Hz) and low-intensity current, evoking a comfortable, nonpainful tingling sensations.[8] High-frequency TENS is usually related to the Gate Control Theory that high-frequency and low-intensity stimulation of large-diameter A-beta afferents results in a segmental inhibition of the transmission of nociceptive information at the dorsal horn level.[6]

High-frequency TENS is not always applied at a low-intensity and low-frequency TENS is not always applied at a high-intensity. Low-frequency TENS applied 10% below the motor threshold generates analgesia in humans and reduces primary and secondary joint inflammation in animal models of nociception.[9-11] The critical factor for response to TENS is the perceptual experience of the intensity of currents during stimulation, regardless of frequency. Evidence suggests that optimal hypoalgesia is achieved using pulse amplitudes (mA) that generate a strong, non-painful TENS sensation and therefore, pulse amplitude should be titrated during treatment to maintain this intensity level.[12] To summarize, treatment parameters can be divided into two main groups (Table 13.1).

Electrode Placement and Size

Response to TENS is also influenced by the site of stimulation according to the placement of electrodes. Best practice guidelines suggest that electrodes should be placed on healthy sensate skin so that the TENS sensation covers (permeates) the painful area. This is achieved by placing electrodes directly over or "bracketing" the painful site (Figure 13.1). This may not always be possible because, for example, skin sensation is altered, there is a skin lesion, or a body part is absent. In these circumstances, electrodes are placed over the

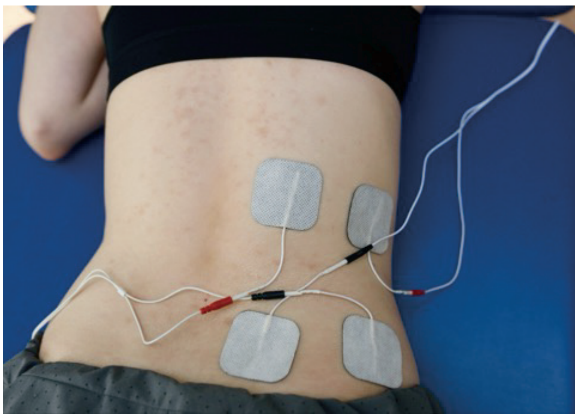

Figure 13.1 TENS electrode placement around the painful area ("Bracketing" technique).

Table 13.1 Recommended parameters for transcutaneous electrical nerve stimulation for pain control

Parameter setting	Frequency (Hz)	Pulse duration (µs)	Intensity (mA)	Treatment time
High-rate TENS	>100 Hz	50 – 80 µs	Till tingling sensation	May be used as long as needed
Low-rate TENS	2-10 Hz	150 – 300 µs	Till visible contraction	20-30 minutes (min)

main nerves proximal to the site of pain, close to the vertebrae of the spinal segments, over contralateral dermatomes, over acupuncture points, or over myofascial trigger points. Research findings on the effect of the site of stimulation on treatment outcome are ambiguous. Consideration also needs to be given to the duration and regularity of treatment and the timing of outcome measurements. In particular, evidence suggests that the effects of TENS are maximal during stimulation or immediately after stimulation.[11,13]

The TENS procedure can be performed on a painful area on the skin or can be applied over acupuncture sites. Clinically, application of TENS at these acupoints reduces pain and may be more effective than when applied over non-acupoint sites when measuring pain and pain thresholds to heat and pressure in normal subjects, as well as in patient populations compared with sham TENS. In postoperative hysterectomy subjects, TENS at the acupoint sites reduced opioid intake, nausea, and dizziness compared with TENS at non-acupoint sites.[14]

In a study investigating the comfort of two electrode sizes (4.5 x 4.5 cm and 6 x 6 cm) on the Quadriceps Femoris and Hamstrings muscles, a difference in stimulation sensation was found. To generate the same muscle force output, the human volunteers preferred the larger electrodes. Usually bigger electrodes are used on larger muscles or larger pain areas, while smaller electrodes can be used on smaller pain areas or muscles.[15] Small electrodes are used, for example, in array electrodes that were proposed to improve the efficacy of TENS systems. Such array electrodes are composed of multiple electrode elements, which can be individually activated to move the electrode location. Elements that are too small might not be effective on persons with thick fat layers because the large current spread within the fat layer prevents the current to reach the motor nerves laying deeper.[16]

Another effect of small electrodes is the generation of high current densities, which may be uncomfortable, indeed painful, and can limit the effectiveness of TENS. However, not only the current density influences the perceived comfort during TENS but also the electrode size and stimulation parameters (at constant current density). In the upper extremities, specifically for hand functions, the electrode size influences selective activation of the multiple muscles bundled closely together. More selective activation of the different muscles can be achieved using smaller electrodes.[17]

Also, it is concluded that when evaluating various parameters of pain, maximal tolerable sensory or motor threshold, larger electrodes were significantly more comfortable and produced the highest force, when compared with the smaller electrodes. For example, when stimulating the Tibial nerve, larger electrodes (3.6 x 3.6 cm) could deliver current with comfortable sensation, while smaller electrodes (0.6 x 0.6 cm) generated much more pain and gave the same stimulation effect.[18]

Electrode placement examples for low back pain (Figure 13.2), neck pain (Figure 13.3), knee pain (Figure 13.4) are shown below.

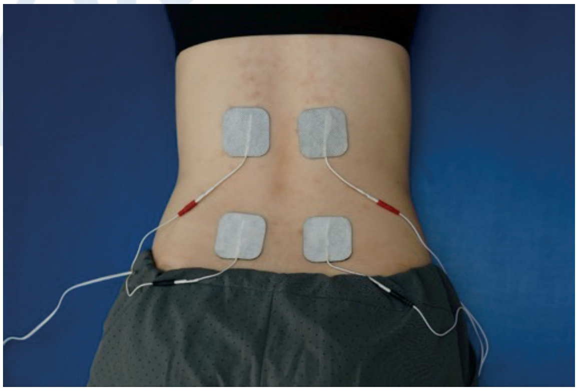

Figure 13.2 TENS electrode placement for low back pain.

Figure 13.2 TENS electrode placement for neck pain.

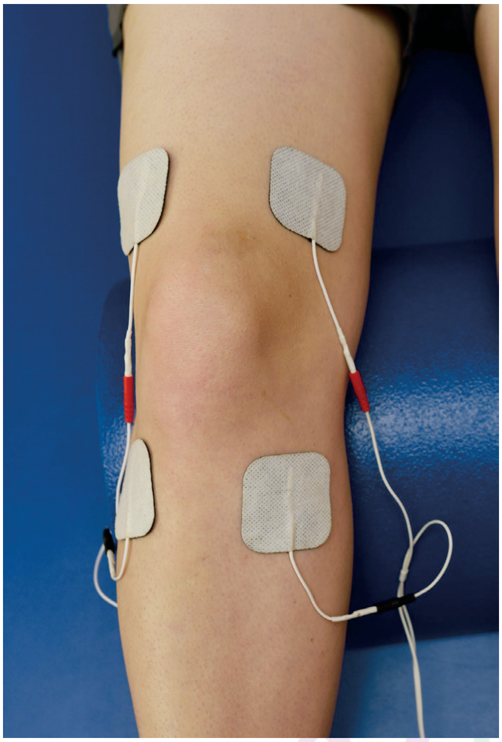

Figure 13.4 TENS electrode placement for knee pain.

Analgesic Mechanisms of TENS

TENS activates a complex neuronal network to reduce pain. The frequencies and intensities used clinically in TENS activates large diameter afferent fibers. This afferent input is sent to the central nervous system to activate the descending inhibitory systems to reduce hyperalgesia. Specifically, the blockade of neuronal activity in the periaqueductal gray, rostral ventromedial medulla and spinal cord inhibits the analgesic effects of TENS shows that TENS analgesia is maintained through these pathways. In parallel, studies in people with fibromyalgia showed that TENS can restore central pain modulation, which is a measure of central inhibition. Therefore, TENS reduces hyperalgesia through both **peripheral** and **central** mechanisms.[19]

Central Mechanisms of TENS

Both low-frequency and high-frequency TENS reduce dorsal horn neuron activity. In animals with peripheral inflammation or neuropathic pain, enhanced activity of dorsal horn neurons (i.e., central sensitization) to both noxious and innocuous stimuli is reduced by both low and high-frequency TENS. In parallel, there is a reduction in both primary and secondary hyperalgesia by both low and high-frequency TENS. Furthermore, in people with fibromyalgia and osteoarthritis, there is a reduction in pressure pain thresholds not only at the site of stimulation, but also at sites outside the area of application, implicating a reduction in central excitability.[20]

High-frequency TENS also reduces central neuron sensitization, and release of the excitatory neurotransmitters glutamate and substance P in the spinal cord dorsal horn in animals with inflammation. The reduction in glutamate is prevented by blockade of δ-opioid receptors. Thus, one consequence of the activation of inhibitory pathways by TENS is to reduce excitation and consequent neuron sensitization in the spinal cord.[14]

Peripheral Mechanisms of TENS

Both low- and high-frequency TENS have effects at the site of stimulation. High-frequency TENS reduces substance P, which is increased in dorsal root ganglia neurons in animals after tissue injury. Blockade of peripheral opioid receptors prevents analgesia produced by low-frequency, but not high-frequency TENS. Thus, TENS may also alter the excitability of peripheral nociceptors to reduce afferent input to the central nervous system.[21]

Underlying Mechanisms of TENS for Pain Control

Gate Control Theory

The theoretical underpinning for pain relief by electrical stimulation of the skin was established through the publication of the Gate Control Theory of Pain by Melzack and Wall (Melzack, Wall, 1965).[22] They proposed that neural activity in low-threshold cutaneous afferents (e.g. A-beta axons) would inhibit onward transmission of nociceptive (pain-related) information in the spinal cord and brainstem. Normally, activity in low-threshold cutaneous afferents is generated by low-intensity mechanical stimuli such as "rubbing the skin". They suggested that electrical currents could be used to stimulate the low-threshold cutaneous afferents to reduce pain. The physiological intention of using conventional TENS is to generate a strong but non-painful TENS sensation as this is indicative of selective activation of low-threshold cutaneous afferents (A-beta axons). Evidence suggests that this inhibits onward transmission of nociceptive information at the first synapse in the spinal cord or brain stem (i.e. segmental modulation).[12]

The larger-diameter axons are activated at a lower electrical threshold than smaller-diameter axons, the Gate Control Theory predicts that electrical stimulation of a mixed nerve at an intensity high enough to produce sensory paresthesia should also produce relief of pain.[23] The Gate Control Theory of pain proposes that the transmission of nerve impulses from afferent fibers to spinal cord transmission (T) cells is modulated by a gating mechanism in the spinal dorsal horn. This gating mechanism is influenced by the relative amount of activity in large-diameter and small-diameter fibers, so that large fibers tend to inhibit transmission (close the gate), while small fibers tend to facilitate transmission (open the gate).[24]

The analgesic action of TENS is mediated by peripheral and central nervous system mechanisms, both spinal and supra spinal. The stimulation of large diameter (A-beta) afferent fibers is thought to "close the gate" and reduce the perception of pain. Acupuncture-like TENS stimulates A-delta and C fibers and is therefore thought to achieve pain control mostly through the descending pain suppression system.[7]

Opioid Release Theory

Electrical stimulation may also control pain by stimulating the production and release of endorphins and enkephalins. These substances, also known as endogenous opioids, act similarly to morphine and modulate pain perception by binding to opiate receptors in the brain and other areas, where they act as neurotransmitters and neuromodulators. Opioids also activate descending inhibitory pathways that involve nonopioid (serotonin) systems.[25]

Low-frequency pulses, at 2 to 10 Hz, at an intensity high enough to produce motor contraction, known as "low-frequency TENS", use repetitive stimulation of motor nerves to produce brief, repetitive muscle contractions or twitches to stimulate endogenous opioid production and release and increase opioid receptor binding potential. Further increasing the intensity to produce a painful noxious stimulus through stimulation of nociceptive A-delta nerves, known as "acupuncture-like TENS", likely also works by this mechanism. A pulse frequency range of 2 to 10 Hz is usually used for low-frequency TENS to minimize the risk of muscle soreness and because frequencies of less than 10 Hz are the most effective for increasing endorphin and enkephalin levels.[25]

Earlier studies have suggested that only low-frequency TENS stimulated the production of endogenous opioids. However, more recent studies indicate that both high- and low-frequency TENS activate opioid receptors, although possibly different opioid receptors. For example, although low doses of naloxone, a mu-opioid receptor blocker, block the analgesia produced by low-frequency TENS (4 Hz) and not the analgesia produced by conventional high-frequency TENS (100 Hz), high doses of naloxone will block the effects of high-frequency TENS, suggesting that high-frequency TENS also stimulates some opioid production.[12] Furthermore, naltrindole, a delta opioid receptor blocker, only blocks the analgesia produced by high-frequency TENS and not the analgesia |produced by low-frequency TENS. Notably, high-frequency TENS appears to be more effective than low-frequency TENS in patients taking opioids.[25]

Low-frequency TENS will usually control pain for 4 to 5 hours after a 20 min to 30 min treatment. It is effective for this length of time because the half-life of the endogenous opioids released is approximately 4.5 hours. Low-frequency TENS should not be applied for longer than 45 min at time because prolonging the repetitive muscle contraction produced by the stimulus can result in delayed-onset muscle soreness.[25]

Because TENS, particularly low-frequency TENS, exerts its effect by increasing opioid levels, patients may develop tolerance to the stimulation that is similar to opioid tolerance. Tolerance causes higher doses of the intervention to be needed to produce an effect. Patients may develop tolerance to TENS by the fourth of the fifth day of stimulation. Frequency modulations, similar to those used to prevent accommodation, delay tolerance to TENS-induced analgesia.[25]

Indications, Contraindications, and Precautions

Indications for TENS

- Acute and chronic pain,
- Arthritis,
- Post-surgery pain,
- Neuralgia,
- Sports trauma caused pain,
- Phantom limb pain,
- Rheumatoid and osteoarthritis,
- Degenerative bone and muscle diseases,
- Lumbago,
- Migraine.[25]

Contraindications for TENS

- Demand cardiac pacemaker, implantable defibrillator, or unstable arrhythmia,
- Placement of electrodes over the carotid sinus,
- Areas where venous and arterial thrombosis or thrombophlebitis is present,
- Pregnancy – over or around the abdomen or low back (exception when electrical stimulation may be used for pain control during labor),
- Do not use stimulated muscle contractions for pain control, as with low-frequency TENS, when muscle contractions may disrupt healing (e.g., muscle or tendon tear, overuse, or acute injury).[25]

Precautions for TENS

- Cardiac disease,
- Impaired mentation,
- Impaired sensation,
- Malignant tumors,
- Areas of skin irritation or open wounds,
- Because of the muscle contractions, low-frequency TENS may cause delayed-onset muscle soreness,
- Because TENS can effectively reduce pain, patients may need to be instructed to avoid potentially symptom-aggravating activities.[25]

References

1. Kuhn A, Keller T, Lawrence M, Morari M. The influence of electrode size on selectivity and comfort in transcutaneous electrical stimulation of the forearm. IEEE Trans Neural Syst Rehabil Eng. 2010;18(3):255-62. doi:10.1109/TNSRE.2009.2039807.
2. Gibson W, Wand BM, Meads C, Catley M, O'Connell NE. Transcutaneous electrical nerve stimulation (TENS) for chronic pain-an overview of Cochrane Reviews. Cochrane Database Syst Rev. 2019;4(4):CD011890. doi:10.1002/14651858.CD011890.pub3.
3. Francis RP, Johnson MI. The characteristics of acupuncture-like transcutaneous electrical nerve stimulation (acupuncture-like TENS): A literature review. Acupunct Electrother Res. 2011;36(3-4):231-58. doi:10.3727/036012911803634139.
4. Facci LM, Nowotny JP, Tormem F, Trevisani VFM. 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. doi:10.1590/s1516-31802011000400003.
5. Doucet BM, Lam A, Griffin L. Neuromuscular electrical stimulation for skeletal muscle function. Yale J Biol Med. 2012;85(2):201-15. PMID:22737049.
6. Peng WW, Tang ZY, Zhang FR, Li H, Kong YZ, Iannetti GD, et al. Neurobiological mechanisms of TENS-induced analgesia. Neuroimage. 2019;195:396-408. doi:10.1016/j.neuroimage.2019.03.077.
7. Hurlow A, Bennett MI, Robb KA, Johnson MI, Simpson KH, Oxberry SG. Transcutaneous electric nerve stimulation (TENS) for cancer pain in adults. Cochrane Database Syst Rev. 2012;2012(3):CD006276. doi:10.1002/14651858.CD006276.pub3.
8. Leonard G, Goffaux P, Marchand S. Deciphering the role of endogenous opioids in high-frequency TENS using low and high doses of naloxone. Pain. 2010;151(1):215-9. doi:10.1016/j.pain.2010.07.012.
9. Chen CC, Tabasam G, Johnson MI. Does the pulse frequency of transcutaneous electrical nerve stimulation (TENS) influence hypoalgesia? A systematic review of studies using experimental pain and healthy human participants. Physiother. 2008;94(1):11-20. doi:10.1016/j.physio.2006.12.011.
10. King EW, Sluka KA. The effect of varying frequency and intensity of transcutaneous electrical nerve stimulation on secondary mechanical hyperalgesia in an animal model of inflammation. J Pain. 2001;2(2):128-33. doi:10.1054/jpai.2001.19963.
11. 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):1397-402. doi:10.2522/ptj.20120281.

12. Arienti C. Is transcutaneous electrical nerve stimulation (TENS) effective in adults with fibromyalgia? A Cochrane Review summary with commentary. J Musculoskelet Neuronal Interact. 2019;19(3):250-2. PMID:31475930.
13. Johnson MI. (2014), Transcutaneous electrical nerve stimulation (TENS): Research to support clinical practice. Oxford University Press. ISBN:9780199673278.
14. Vance CG, Dailey DL, Rakel BA, Sluka KA. Using TENS for pain control: The state of the evidence. Pain Manag. 2014;4(3):197-209. doi:10.2217/pmt.14.13.
15. McNeal DR, Baker LL. Effects of joint angle, electrodes and waveform on electrical stimulation of the quadriceps and hamstrings. Ann Biomed Eng. 1988;16(3):299-310. doi:10.1007/BF02368005.
16. Kuhn A, Keller T, Micera S, Morari M. Array electrode design for transcutaneous electrical stimulation: A simulation study. Med Eng Phys. 2009;31(8):945-51. doi:10.1016/j.medengphy.2009.05.006.
17. Lyon GM, Leane GE, Clarke-Moloney M, O'Brien JV, Grace PA. An investigation of the effect of electrode size and electrode location on comfort during stimulation of the gastrocnemius muscle. Med Eng Phys. 2004;26(10):873-8. doi:10.1016/j.medengphy.2004.08.003.
18. Verhoeven K, van Dijk JG. Decreasing pain in electrical nerve stimulation. Clin Neurophysiol. 2006;117(5):972-8. doi:10.1016/j.clinph.2006.01.006.
19. Dailey DL, Rakel BA, Vance CG, Liebano RE, Amrit AS, Bush HM, et al. Transcutaneous electrical nerve stimulation reduces pain, fatigue and hyperalgesia while restoring central inhibition in primary fibromyalgia. Pain. 2013;154(11):2554-62. doi:10.1016/j.pain.2013.07.043.
20. Mello LF, Nóbrega LF, Lemos A. Transcutaneous electrical stimulation for pain relief during labor: A systematic review and meta-analysis. Rev Bras Fisioter. 2011;15(3):175-84. PMID:21829980.
21. Santos CM, Francischi JN, Lima-Paiva P, Sluka KA, Resende MA. Effect of transcutaneous electrical stimulation on nociception and edema induced by peripheral serotonin. International Int J Neurosci. 2013;123(7):507-15. doi:10.3109/00207454.2013.768244.
22. Melzack R, Wall PD. Pain Mechanisms: A New Theory: A gate control system modulates sensory input from the skin before it evokes pain perception and response. Science. 1965;150(3699):971-9. doi:10.1126/science.150.3699.971.
23. Henderson JM. Peripheral nerve stimulation for chronic pain. Curr Pain Headache Rep. 2008;12(1):28-31. doi:10.1007/s11916-008-0006-5.
24. Hadjistavropoulos T, Craig KD. (2004), Pain: Psychological perspectives. 1st ed. New York: Psychology Press. doi:10.4324/9781410609861.
25. Cameron MH. (2017), Physical agents in rehabilitation: An evidence-based approach to practice. 6th ed. Elsevier. ISN:978-0323761949.

Co-funded by the Erasmus+ Programme of the European Union

Medium-Frequency Current

EVA ILIE

Introduction

Medium-Frequency Alternating Currents (MFACs) are widely used in physiotherapy and rehabilitation and are characterized by frequencies ranging from 1 to 10 kilohertz (kHz). These currents find extensive application in therapeutic settings.[1]

The two most commonly used frequencies in the medium-frequency range are 4 kHz, known as "Interferential Currents (IFCs)", and 2.5 kHz, known as "Russian Currents". These frequencies are preferred because the skin acts as a capacitive barrier to the flow of current, and as the frequency increases, the skin impedance decreases. This allows better penetration of the current and more effective therapeutic outcomes.[1]

At kilohertz levels, the impedance of the skin is significantly reduced, resulting in less electrical energy being dissipated in the superficial epidermis. As a result, a higher proportion of the electrical energy is available to stimulate the underlying tissue. This becomes particularly important when the goal is to stimulate motor nerves, which are typically located deeper within the body. The reduced impedance allows for more efficient transmission of the electrical current to the targeted tissues, enhancing the effectiveness of the stimulation.[2]

MFAC is often modulated to produce bursts of sinusoidal current, with the frequency of these bursts typically ranging from 1 to 150 Hz. It is believed that the nerve fiber response to successive kilohertz frequency pulses, generated by each cycle of the alternating current stimulus, will sum up to produce a single-action potential in response to each burst of MFAC. The expected nerve firing at the modulation frequency suggests that the physiological and therapeutic effects would be similar to those observed with low-frequency pulsed currents.

Based on this assumption, it is predicted that the response to MFAC would be primarily influenced by changes in skin impedance rather than the carrier frequency itself. In other words, higher carrier frequencies are expected to provide more efficient stimulation of deeply located nerves.

The relationship between stimulus intensity (voltage) and different physiological responses using MFAC frequencies ranging from 1 to 35 kHz has been investigated.[3] Sensory, motor, and pain thresholds were specifically measured using 10 milliseconds (ms) bursts delivered at a burst frequency of 50 Hz. The results showed that all thresholds decreased to their lowest point at approximately 10kHz and then sharply increased beyond that frequency. However, as the frequency increased beyond 10 kHz, the downward trend predicted by the decreasing skin impedance was not consistently observed. Additionally, the study revealed that the ratio between pain and motor thresholds, which indicates the separation between the two thresholds, was highest at around 10 kHz. On the other hand, it is believed that the ratio between motor and sensory thresholds, which indicates the separation between the two thresholds, was at its lowest point around 10 kHz. Based on these findings, it can be concluded that for the most comfortable stimulation, the optimal frequency is near 10 kHz.[3]

The optimal frequency for minimum threshold voltage varies depending on the size of the electrodes used. This is because the thresholds are influenced by a balance between the decreasing skin impedance at higher MFAC frequencies and the decreasing sensitivity of nerve fibers. Both skin and nerve fiber membranes act as capacitive barriers, contributing to this phenomenon.

When a stimulus is applied to a nerve fiber, it takes time for the membrane to charge and reach the threshold for generating an action potential. If the stimulus duration is short, a higher intensity is required to reach the nerve-firing threshold. This includes to both rectangular pulsed current stimulation and single-cycle MFAC stimulation.

As the frequency of MFAC increases, the duration of the sinusoidal pulses becomes shorter. This means that a higher stimulus intensity is needed to reach the threshold. The nerve fiber becomes less sensitive at higher MFAC frequencies, requiring a higher stimulus intensity to depolarize the membrane.[4]

The frequency at which the threshold is at a minimum depends on the balance between decreasing skin impedance and decreasing nerve fiber sensitivity. At lower frequencies, the threshold decreases primarily due to the decrease in skin impedance. However, at higher frequencies, the threshold increases because of the decreasing sensitivity of the nerve fiber membrane.

The optimal frequency for transcutaneous stimulation depends on the specific outcome measure. For pain-free, low-force muscle contractions, the optimal frequency is around 9 kHz, regardless of electrode size or delivery mode. On the other hand, the frequency at which the absolute threshold is lowest varies based on electrode size. It was found that for the maximum torque production using a 10 ms burst mode, a frequency of 1 kHz or less was optimal.[5]

This suggests that clinical MFAC stimulators, whether providing Russian or Interferential currents, should offer a range of carrier frequencies to accommodate different desired outcomes.

Interferential Current

Physiotherapists commonly use transcutaneous electrical stimulation for therapeutic purposes. They have the option to choose between different frequencies and modes of application for the alternating current. The current can be applied directly or continuously, or it can be delivered as a series of pulses. Each type of current has its own advantages and disadvantages when used in therapy. Evidence-based electrotherapy promotes faster patient recovery by utilizing applied energy as a trigger to stimulate physiological events, leading to therapeutic benefits and pain relief.[6]

Interferential Therapy uses "medium-frequency" alternating currents to mimic the effects of low-frequency currents in the tissues (Figure 14.1). By applying two MFAC, a low-frequency Interference current is generated, providing the benefits of low-frequency stimulation without the unpleasant side effects such as pain, discomfort, or skin irritation.[7]

Interferential current was pioneered by the Austrian physicist Nemec in 1950s.[8] IFCs therapy is a type of transcutaneous electrical stimulation that utilizes medium-frequency current, typically around 4 kHz.[9] The interaction of two slightly different medium-frequency currents in IFCs therapy results in the generation of an amplitude-modulated low-frequency current ranging from 0 to 250 Hz.[10]

One of the claimed advantages of IFCs over low-frequency currents is its ability to reduce the impedance presented by the skin.[11] Another po-

Figure 14.1 Interferential Current.

tential benefit of IFCs is their ability to generate an amplitude-modulated frequency parameter, resulting in the production of a low-frequency current that can penetrate deep into the treatment area.[8] Various theoretical physiological mechanisms have been proposed in the literature to support the analgesic effects of IFCs. These include the Gate Control Theory, increased circulation, descending pain suppression, block of nerve conduction, and placebo effects.[12]

Two types of IFCs are available: IFCs and premodulated IFCs. “True” IFCs involves the use of four electrodes, with two MFACs applied through two isolated circuits. The currents are intended to interfere inside the tissue, producing the desired therapeutic effect. In “premodulated” IFCs, the interference of the two medium-frequency currents occurs within the machine itself. The resulting wave, which is an amplitude-modulated current, is then transmitted to the tissue using a single pair of electrodes.[13]

Since its inception, IFCs have been employed in clinical settings to alleviate pain and address various symptoms associated with musculoskeletal injuries.[14]

Principles of IFCs

The principle of IFCs therapy is based on the relationship between skin impedance and the frequency of stimulation. Skin impedance decreases as the frequency increases, and this can be expressed using the formula $Z = 1/2FC$, where Z represents impedance in ohms, F represents frequency in Hz, and C represents the capacity of the skin in microfarads.

By using MFACs, the impedance of the skin is significantly reduced compared to lower frequencies. For instance, at 50 Hz, the skin impedance is approximately 3200 Ohms, whereas at 4000 Hz, it decreases to 40 Ohms. This reduction in impedance enables the interference current, which is a low-frequency current, to effectively stimulate biological tissues.

The advantage of applying MFACs is that they can penetrate the skin more easily, requiring less electrical energy input to reach deeper tissues. This not only facilitates a more efficient and effective stimulation but also minimizes discomfort experienced by the individual undergoing the therapy.

IFCs are generated by combining two medium-frequency currents that are slightly out of phase. This can be achieved by either applying the currents to interfere within the tissues or mixing them within the stimulator before application. One of the currents is typically set at a fixed frequency, such as 4000 Hz, while the other current is adjustable within a range, such as between 4000 and 4250 Hz. IFCs therapy utilizes the principle of interference to optimize the penetration of current into the tissues while minimizing the unwanted stimulation of cutaneous nerves.

The Use of IFCs

IFCs have shown potential benefits in five key clinical applications:

1. Providing relief and managing acute and chronic pain.
2. Stimulating muscle activity and promoting the muscle rehabilitation.
3. Enhancing the blood circulation and improving tissue oxygenation.
4. Reducing edema and promoting the resolution of swelling.
5. Facilitating the healing and repair process of soft tissues.[15]

Management of Pain

The analgesic effect of IFCs therapy may be attributed, in part, to Wedensky inhibition of type C nociceptive fibers, although there are likely other involved mechanisms. The Gate Control Theory, initially proposed by Melzack and Wall, and subsequently modified, remains a central explanation for this effect.

The Gate Control Theory suggests that action potentials from large-diameter myelinated afferent nerves in the skin compete with small-diameter unmyelinated fibers carrying pain information to access the central ascending sensory tracts in the spinal cord’s dorsal horn. The theory proposes that activity in the large fibers takes precedence, “closing the gate” to pain information and preventing it from reaching conscious awareness. This mechanism leads to pain reduction.

The "descending pain suppression mechanism" involves the release of endogenous opiates in response to nociceptive information. When pain signals reach the thalamus, they interact with various structures in the midbrain, including the raphe nuclei. The increased activity in fibers descending from the raphe nuclei to the spinal segment where the pain information entered leads to the release of inhibitory neurotransmitters. These neurotransmitters block further conduction of pain signals.[16]

IF current is used in the management of acute and chronic pain arising from various sources, including:

- Post-traumatic pain, which may result from injuries or accidents.
- Sympathetically maintained pain, such as in conditions like shoulder-hand syndrome, reflex sympathetic dystrophy, and Reynaud's disease.

IFCs can be beneficial in these cases to alleviate pain and promote healing.

Applying higher frequencies, typically around 100 Hz, at a sensory level of stimulation can activate pain gate mechanisms, effectively masking pain symptoms and providing relief. On the other hand, using lower frequencies, up to 10 Hz, at motor level intensities can activate opioid mechanisms, offering a degree of pain relief through the release of endogenous opioids.

In cases of sympathetically maintained pain, IFCs can help decrease the activity of the sympathetic ganglion and sympathetic nerves, helping to alleviate pain associated with these conditions.[15]

Muscle Management

Neurons experiencing Wedensky inhibition show reduced sensitivity and exhibit a firing rate independent of the frequency of the applied stimulus. This phenomenon, known as the "Gildemeister Effect", can be observed when rapidly stimulating a motor nerve with comfortable IFCs. It leads to an asynchronous depolarization of individual motor units, resembling the pattern observed during a normal voluntary contraction. In contrast, traditional low-frequency neuromuscular stimulation mainly recruits large axon motor neurons with lower thresholds, which innervate muscle fibers that easily fatigue. This recruitment pattern is synchronous and differs from a normal contraction.[16]

The muscle contraction can be achieved by stimulating the motor nerves using a various frequency, typically ranging from 10 to 50 Hz. Lower frequencies, such as 1-10 Hz, will elicit a series of twitches, while higher frequencies, such as 50 Hz, will result in a sustained tetanic contraction. The selection of treatment parameters depends on the specific desired effect and therapeutic goal.

IFCs therapy can be used as a neuromuscular stimulation technique with several potential applications, including:

1. Relaxation of muscle spasms: IFCs helps reduce muscle spasms and promotes muscle relaxation, providing relief from pain and stiffness associated with spasms.
2. Prevention and retardation of disuse atrophy: By stimulating the motor nerves and promoting muscle contraction, IFCs can help prevent or slow down muscle wasting (atrophy) that may occur due to disuse or immobilization.
3. Muscle re-education: IFCs can be used to facilitate the re-education of muscles after injury or surgery. It can assist in improving muscle coordination, strength, and control.
4. Maintenance of range of motion: By promoting muscle activation and movement, IFCs can help maintain or improve the range of motion in joints, preventing or reducing stiffness and joint contractures.

These applications highlight the potential benefits of IFCs therapy in various aspects of neuromuscular rehabilitation and support the recovery and functional restoration of muscles.[15]

Promoting Circulation and Reducing Edema

IFCs therapy at a frequency of 100 Hz is suggested to be effective in reducing acute edema. This frequency stimulates the musculoskeletal pump and inhibits sympathetic activity, aiding in the drainage of fluid from the affected area. Additionally, IFCs have been found to directly influence the cell membrane, reducing the leakage of intracellular fluid.[16]

For the optimal treatment of chronic edema, a two-stage application is recommended. The initial stage involves applying a current at 100 Hz to promote vasodilation, allowing improved blood flow. In the second stage, the frequency is adjusted to 10 Hz, activating the musculoskeletal pump to facilitate the removal of fluid that has returned to the venous and lymph channels. This two-stage approach helps address both the underlying vascular issues and fluid drainage for effective management of chronic edema.[17]

A commonly used beat frequency for IFCs therapy is around 15 Hz or a sweep range of 10-25 Hz. This frequency range is effective in providing therapeutic benefits and promoting pain relief. By using the beat frequency or a sweep of frequencies within this range, IFCs therapy can target specific physiological responses and stimulate the desired therapeutic effects in the tissues.[16]

IFCs therapy leads to increased vasodilation through two main mechanisms:

1. Stimulation of parasympathetic nerve fibers: IFCs have the ability to activate parasympathetic nerve fibers, which promote vasodilation and increased blood flow. This can be beneficial in the treatment of circulatory disorders where improved blood circulation is desired.
2. Inhibition of sympathetic activity: IFCs can help to depress the activity of certain cervical and lumbo-sacral sympathetic ganglia. By reducing the constrictor tone of arteries, it contributes to increased circulation, particularly in conditions like Reynaud's disease where there is heightened arterial constriction.[15]

By targeting these mechanisms, IFCs therapy enhances blood flow and improves the circulation in affected areas, providing potential benefits for various circulatory disorders and conditions.[17]

Effects on Tissue Healing

IFCs therapy has been shown to induce changes in the intracellular concentration of various enzymes and molecules, leading to a range of therapeutic effects. These effects include:

1. Modulation of cyclic adenosine monophosphate (cAMP) levels: IFCs treatment has been reported to affect the levels of cAMP, an important signaling molecule involved in many cellular processes. These changes in cAMP levels may contribute to the observed therapeutic effects of IFC, although the exact mechanisms are not fully understood.
2. The alteration of acetylcholine esterase: IFCs therapy has been associated with changes in acetylcholine esterase, an enzyme involved in the breakdown of acetylcholine. These changes may influence neural signaling and contribute to the effects of IFCs on nerve repair and regeneration.
3. Modification of alkaline phosphatase and lysosomal enzymes: IFCs treatment has been found to impact the levels of alkaline phosphatase and lysosomal enzymes. These enzymes play crucial roles in cellular metabolism and tissue repair processes. The modulation of their concentrations may facilitate bone healing, tissue regeneration, and other repair processes. [16]

These observed changes in enzyme and molecule concentrations provide insights into the mechanisms underlying the therapeutic effects of IFCs. However, further research is needed to fully understand the specific pathways and interactions involved.

IFCs therapy is not widely used for tissue healing purpose, despite reported positive outcomes in the management of acute fractures of the tibia and fibula. Treatment involving IFCs at a frequency of 20 Hz for 20 minutes (min), 5 days per week, has been associated with promising results. However, the adoption of IFCs in fracture treatment remains limited.[18]

Treatment with IFCs using a frequency of 20 Hz for 20 min has been shown to enhance the healing process of mandibular fractures. Additionally, applying IFCs at a frequency of 100 Hz for 20 min has been found to expedite the resolution of Sudeck's atrophy and pseudarthrosis. These findings suggest that IFCs can be beneficial in promoting healing and recovery in these specific conditions.[16].

Management of Urinary Incontinence

IFCs have shown benefits for patients with both stress and urge incontinence, despite their different causes. Stress incontinence occurs due to an incompetent urethral sphincter mechanism, whereas urge incontinence is caused by disinhibition of the detrusor muscle. Patients experiencing either type of incontinence or a combination of both have reported a decreased frequency of micturition after being treated with IFCs therapy at a frequency range of 0-10 Hz for 15 min, 3 days per week. This suggests that IFCs can be effective in managing symptoms and improving bladder control in patients with various forms of incontinence.

IFCs at 5-10 Hz for 30 min effectively treats urge incontinence by targeting small afferent fibers in the pudendal nerve. This stimulates reflex inhibition of the detrusor muscle and contraction of the pelvic floor muscles. The clinical evaluation is lacking, and IFCs therapy is not effective for anorectal incontinence.[16]

Techniques of Application

In the "quadripolar technique", four electrodes are placed in a coplanar arrangement to treat a flat surface. Each electrode is positioned around the target area, and the channels run perpendicular to each other, intersecting at a midpoint. The interference effect of the currents branches off at 45° angles from the center of the treated area. This configuration ensures that tissues within this area receive the maximum treatment effect.

In the "bipolar technique", the mixing of the two channels occurs within the generator instead of within the tissue. This technique does not penetrate the tissues as deeply as the quadripolar application, resulting in more sensory sensation. In certain situations, where the stimulation of a longitudinal zone is required, the bipolar technique may be preferred. Bipolar electrode placements are commonly used when the goal of the treatment is muscle contraction. [15].

Treatment Parameters

Treatment parameters refer to the specific settings and variables used during the application of IFCs therapy. These parameters can be adjusted to customize the treatment based on the individual's condition and desired outcome. Some common treatment parameters include:

1. Frequency: The frequency of the IFCs, typically ranging from 1 Hz to 10,000 Hz. The choice of frequency depends on the intended effect, such as pain relief or muscle stimulation.
2. Amplitude: The intensity or strength of the current, usually measured in milliamperes (mA). The amplitude should be set at a comfortable level for the individual, taking into consideration their sensitivity and tolerance.
3. Treatment Duration: The duration of each treatment session, typically measured in min. The length of the session may vary depending on the condition being treated and the response of the individual.
4. Electrode Placement: The specific positioning of the electrodes on the body. The placement may vary depending on the target area, the desired effect, and the treatment technique (e.g., quadripolar or bipolar).
5. Treatment Frequency: The frequency of treatment sessions per week or per day. The frequency may be determined based on the individual's condition and treatment goals, ranging from multiple sessions per day to a few sessions per week.

It is important to note that the selection of treatment parameters should be guided by professional expertise and tailored to the individual's needs.

Meanwhile, frequency plays a crucial role in IFCs therapy as it determines the physiological response and target tissues. Here are alternative frequency ranges for different tissues:

1. Sympathetic Nerve: 1-5 Hz
   - Stimulation of sympathetic nerves is optimal in this frequency range.
2. Parasympathetic Nerve: 10-150 Hz
   - The parasympathetic nerves respond well to frequencies within this range.

3. Motor Nerve: 10-50 Hz
    - To induce muscle contractions and stimulate motor nerves, frequencies in this range are effective.
4. Sensory Nerve: 90-100 Hz
    - Sensory nerves are typically stimulated within the frequency range of 90-100 Hz.
5. Nociceptive Fibers: 90-150 Hz
    - Nociceptive fibers, which transmit pain signals, respond well to frequencies within this range.
6. Smooth Muscle: 0-10 Hz
    - Frequencies between 0 and 10 Hz are suitable for stimulating smooth muscle tissues.

It is important to note that these frequency ranges are general guidelines and may vary depending on the individual, their condition, and treatment goals. The specific frequency used should be determined by a healthcare professional based on a thorough assessment of the patient.[15]

References

1. Hanke TA, Nelson RM, Hayes KW, Currier DP. (1999), Therapeutic uses of biofeedback. Nelson RM, Currier DP, eds. In: Clinical electrotherapy. 3rd Ed. USA: Appleton&Lange. ISBN:083851491X.
2. Reilly JP, Antoni H, Chilbert MA, Skuggevig W, Sweeney JD. (1992), Electrical stimulation and electropathology. 1st ed. Cambridge University Press. ISBN:0521417910.
3. Ward AR, Robertson VJ. Sensory, motor, and pain thresholds for stimulation with medium frequency alternating current. Arch Phys Med Rehabil. 1998;79(3):273-8. doi:10.1016/s0003-9993(98)90006-5.
4. Reilly JP. Electrical models for neural excitation studies. Johns Hopkins APL Technical Digest. 1988;9(1):44-59.
5. Ward AR, Robertson VJ. Variation in motor threshold with frequency using kHz frequency alternating current. Muscle Nerve. 2001;24(10):1303-11. doi:10.1002/mus.1148.
6. Tiktinsky R, Chen L, Narayan P. Electrotherapy: Yesterday, today and tomorrow. Haemophilia. 2010;16:126-31. doi:10.1111/j.1365-2516.2010.02310.x
7. Kroeling P, Gross A, Graham N, Burnie SJ, Szeto G, Goldsmith, et.al. Electrotherapy for neck pain. Cochrane Database Syst Rev. 2013;(8):CD004251. doi:10.1002/14651858.CD004251.pub5.
8. Baetti A, Rayner A, Chipchase L, Souvlis T. Penetration and spread od interferential current in cutaneous, subcutaneous and muscle tissue. Physiotherapy. 2011; 97(4):319-26. doi:10.1016/j.physio.2011.01.008.
9. Fuentes J, Armijo-Olivo S, Magee DJ, Gross D. Does amplitude-modulated frequency have a role in the hypoalgesic response of interferential current on pressure pain sensitivity in healthy subjects? A randomised crossover study. Physiotherapy. 2010;96(1):22-9 doi:10.1016/j.physio.2009.06.009.
10. Fuentes J, Armijo-Olivo S, Magee DJ, Gross DP. A preliminary investigation into the effects of active interferential current therapy and placebo on pressure pain sensitivity: A random crossover placebo-controlled study. Physiotherapy. 2011;97(4):291-301. doi:10.1016/j.physio.2011.01.001.
11. Robertson V, Ward A, Low J, Reed A. (2006), Electrotherapy explained: Principles and practice. 4th ed. London: Heidi Harrison. ISBN:0750688437.
12. Palmer S, Martin D. (2002), Interferential current for pain control. In Kitchen S. (Ed.). Electrotherapy: Evidence-based practice. 11th edition. Churchill Livingstone. pp.287-300. ISBN:0443072167.
13. Ozcan J, Ward AR, Robertson VJ. A comparison of true and premodulated interferential currents. Arch Phys Med Rehabil. 2004;85(3):409-15. doi:10.1016/s0003-9993(03)00478-7.
14. Wright A, Sluka KA. Nonpharmacological treatments for musculoskeletal pain. The Clin J Pain. 2001;17(1):33-46. doi:10.1097/00002508-200103000-00006.
15. Cairo University. Medium frequency currents. Accessed: http://www.lib.pt.cu.edu.eg/Medium%20Frequency%20Current.pdf
16. Goats GC. Interferential current therapy. Br J Sports Med. 1990;24(2):87-92. doi:10.1136/bjsm.24.2.87.
17. Wadsworth H, Chanmugam AP. (1983), Electrophysical agents in physiotherapy: Therapeutic & diagnostic use. Science press. ISBN:0855831162.
18. Ganne JM, Speculand B, Mayne LH, Goss AN. Inferential therapy to promote union of mandibular fractures. Aust N Z J Surg. 1979;49(1):81-3. doi:10.1111/j.1445-2197.1979.tb06442.x.

Co-funded by the
Erasmus+ Programme
of the European Union

High-Voltage Pulsed Galvanic Stimulation

MEHMET DURAY

History of High-Voltage Pulsed Galvanic Stimulation

Electrophysical agents have been used for pain, edema, and muscle strengthening for many years in the field of physiotherapy.[1,2] In experimental studies, the effectiveness of high-voltage currents began for the control of pain and edema of electrotherapy to be studied towards the middle of the 1900s. Haslip, an American researcher, developed High-Voltage Interrupt Galvanic Stimulation (HVPGS), which he called the Dyna wave, in 1945. After nearly 20 years of work, Young published the first study on the edema control of HVPGS in 1966, and the current began to be popularly used in the 1970s.[3,4]

Differences Between High and Low-Voltage Current

Low-voltage stimulators produce power below 150 Volts, while high-voltage stimulators produce power in the 150-500 V range. Compared to low-voltage currents, HVPGS can easily pass into deep tissues without causing discomfort to the patient, as it encounters less resistance by the skin. Moderate muscle contractions occur in patients due to the short duration of the phase with the minimized the feeling of discomfort and easy passage to the deep tissues. While the therapeutic effects trigger each other, the improvement at the physiological level leads to functional results.[4-6] In order to obtain these effects with less painful sensation, applying the voltage with a low current intensity during the pulse period constitutes the basic application principle of HVPGS. Long pulse duration currents are needed to provide stimulation with low-voltage stimulators. Therefore, pulses with an excitation time of about 300 microseconds (µs) and a frequency of 35 Hertz (Hz) are used in low-voltage current applications.[7]

The peripheral circulation in the skin and contractile structures increases with low-voltage electrical stimulation. HVPGS increases the circulation in the skin and contractile structures to a lesser extent compared to low-voltage. However, by providing autonomous activation, circulation could be increased by the direct effect, by the effect of acid and base reaction under the electrodes, and by the indirect effect that occurs after the stimulation of somatic sympathetic reflexes. Another important mechanism that provides increased blood circulation and should be considered is the pumping effect on blood vessels due to muscle contraction. Thus, venous return will increase secondary to muscle contraction.[7]

High-Voltage Current Characteristics

HVPGS applied at 300-500 V, has twin peak pulses with a very short duration of 7-200 µs.[6] The current, which has an average of 100 µs stimulation time (duration), has a resting time (interval) of 9900 µs (pulse/rest time is 1/99) (Figure 15.1). The current with a short pulse and long rest period is applied for a fixed time and monophasic twin peak pulse is formed in the form of a pointed spike. In the very

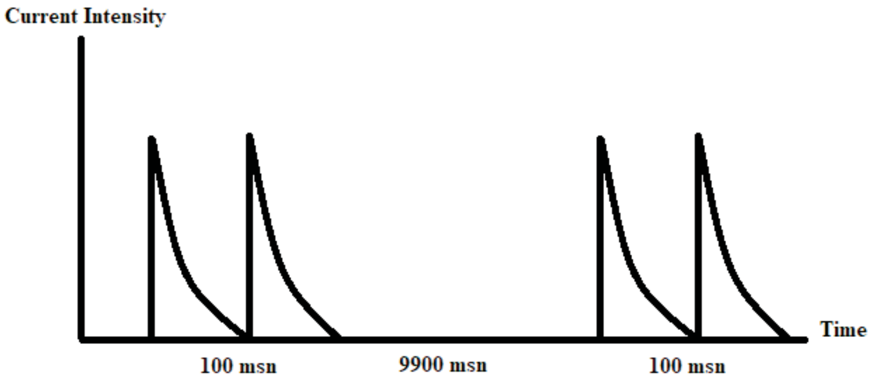

Figure 15.1 High-Voltage Pulsed Galvanic Stimulation Wave Form (Created by author).

characteristic waveform, the current intensity rises rapidly and falls rapidly. The second beat after the first beat prevents the irritation of the first spike. With a frequency of 1-200 beats/second, HVPGS crosses the skin very quickly, encountering lower skin resistance due to its high-frequency.[6,8,9] This makes HVPGS an easily tolerable and highly effective agent.[10] The current to the continuous modulation is often pulsed 80-100 times and could be surged according to preference. HVPGS could be used in many situations, disease-specific treatment time, voltage requirement, and other treatment parameters vary.[6] HVPGS characteristics are shown in Table 15.1.

Table 15.1 Characteristics of the current parameters

Current characteristics	Twin peak monophasic beat Short stimulation-long rest time High-voltage
Stimulated tissues	Motor and sensory nerves Deep tissues
Frequency	Preferably could be increased or decreased
Polarity	Positive or negative pole excitation could be preferred
Application	Monopolar/Bipolar
Treatment time	30-60 minutes (min)
Treatment frequency	3-7 days/week

The Effect Mechanisms of High-Voltage Pulsed Galvanic Stimulation

HVPGS is an electrotherapy agent designed to stimulate deep tissues. It contributes to the modulation of pain and healing of wounds depends to damage or functional insufficiency of deep tissues.[6] HVPGS is a current that provides motor stimulation, which allows selective stimulation of muscle fibers. The fact that HVPGS contains high-intensity short pulses that stimulate the motor nerves before the sensory nerves makes the flow more preferable.[11] HVPGS provides neuromuscular stimulation by reversing the atrophy mechanism, increasing enzymatic activity, providing isolated muscle contraction, and preventing muscle atrophy.[5]

The short pulse duration of the HVPGS results in selective sensory and motor stimulation, but a few nociceptor stimulations. This feature makes HVPGS tolerable in terms of application.[7] Since it has a short stimulation time and rapidly increasing current intensity and voltage, it is also effective in strengthening the muscles by causing effective nerve stimulation, preventing the atrophy of innervated muscles and accelerating wound healing.[9,11,12] The current easily and quickly passes through the skin and reaches to the deep nerve and muscle tissues, ensuring the continuity of tissue regeneration. The current, which is especially preferred in the treatment of pressure sores, prevents the proliferation of microorganisms with cathode stimulation, and accelerates the regeneration of the wound by creating a galvanotaxic effect with anode stimulation. With its effect mechanism in deep tissues, HVPGS provides healing not only in dermal but also in subdermal tissue.[9,12] HVPGS stimulates DNA and protein synthesis in fibroblasts when applied at an effective intensity. The largest scale

DNA and protein synthesis is achieved at a rate of 100 beats per second with negative pole stimulation. Meanwhile, increasing the voltage above 250 Volts inhibits DNA and protein synthesis.[1,13]

Pulse duration cannot be shortened in HVPGS. Therefore, the frequency must be increased to increase the current density. Increasing the amplitude of the current facilitates the passage of the current to the deeper tissues, and this results with the stimulation of the nerves and muscles located deeper. Since this situation increases the effectiveness of muscle contraction, the muscle contraction could be achieved with stimulation even if the electrodes are not placed exactly where the nerve is superficial or where the motor point of the muscle is. The passage of the stimulus to the deep tissues not only stimulates the sensory and motor structures, but also stimulates the autonomic nerves and smooth muscles of the vasomotor structures.[7]

Since the current can easily depolarize the nerve, a tingling sensation and paresthesia sensation is perceived by the patient. HVPGS is also effective in relieving neurogenic pain with a combined effect of blocking pain pathways after nerve stimulation, relieving deep muscle spasm by stimulating trigger points, and increasing post-feeding wound healing.[6,14] These effects not only reduce symptoms but also improve functional abilities and confidence in movement.[14]

HVPGS provides pain management through several different mechanisms. The main mechanism is based on the stimulation of opiate substance, enkephalin, and beta-endorphin synthesis in the central nervous system. The increase in the release of these morphine-like substances from the pituitary, together with HVPGS, creates an analgesic effect and improves the quality of movement.[14] Centrally blockage of the pain is achieved in 2 ways.[7] The first way is to create a more intense stimulus than pain at the motor point of the muscle or at the acupuncture point with HVPGS. This method has been used for many years. The other way is the diffusion of non-painful stimuli to areas of painful sensory fiber activation. With HVPGS, over-pain stimulus spreads to areas where painful sensory fiber activation is seen. By increasing the electrode size, painless sensory fiber stimulation could be achieved more effectively.[7]

Special Uses of High-Voltage Pulsed Galvanic Stimulation

Main purposes of use of HVPGS are:

- Achieving effective muscle contraction,
- Increasing muscle strength up to the functional level,
- Increasing and regulation of circulation,
- Reducing pain and edema,
- Acceleration of wound healing,
- Preventing secondary complications.[15]

Muscular Dystrophies

The discussions about whether electrotherapy could be used or not in patients with muscular dystrophy is still continuing. The fact that HVPGS is an easily tolerated agent at low current intensity raised the question of whether it would be appropriate to use HVPGS in patients with muscular dystrophies. It has been reported that HVPGS applied to proximal muscles, such as the Deltoid and Quadriceps Femoris, not only increases the strength of the muscle, but also increases participation to the daily living activities. Considering the need for patients with muscular dystrophies, who were a special group that not to be overtired, HVPGS could increase muscle strength without causing pain and fatigue. However again, note that the use of electrotherapy in patients with muscular dystrophies will be a controversial issue for a long time. Professionals who prefer to use it, should apply the specific electrotherapy applications planned specifically for these patients in the most meticulous way.[15]

Use in Athletes

HVPGS exhibits neuromuscular effects similar to the Russian Current, which is one of the most commonly used electrotherapy agents in athletes. HVPGS is recommended to be used in combination with exercise, as it has greater effectiveness on muscle strength and endurance by this approach.[16]

Use in the Treatment of Immobile Patients

It is used for the prevention of pressure sores, especially in patients with stroke and spinal cord injury. It plays a protective role in patients by increasing blood supply, collagen synthesis, and fibroblast activation, thus facilitating wound healing. It is an effective agent also in the management of pain in these patient groups, who are very sensitive to pain.[6,13]

Constipation

HVPGS has also been used in the treatment of constipation in recent years. It is well-known that HVPGS reduces pain and muscle spasms, and also effective in muscle strengthening. HVPGS leads to stimulation of neuroendocrine nerves and induces impulses that increase intestinal motility. An increase in intra-abdominal pressure, increase in painless bowel movements, decrease in rectal bleeding, edema, and burning symptoms with the application of HVPGS to the abdominal muscles increases the functionality of the intestine. While pelvic floor dyssynergia decreases, pelvic floor muscle strength and functions increase.[17]

Muscle Retraining After Orthopedic Pathologies

Muscle retraining, in which the bipolar technique is preferred, can be applied by making the current surge or intermittent.[4]

Muscle Retraining After Neurological Pathologies

HVPGS can also be used for muscle retraining after neurological diseases. As in orthopedic problems, the current can be applied by making it surge or intermittent.[4] HVPGS is preferred because it produces more power with less discomfort in neurological disorders.[18] In patients with diplegic cerebral palsy, it has been reported that HVPGS improves head control.[19] It was concluded that HVPGS increased the strength of lower extremity muscles, decreased fatigue and increased the effects of neurorehabilitation techniques in patients with MS.[20]

High-Voltage Pulsed Galvanic Stimulation Application

The accepted electrode placement and treatment protocol for the relief of muscle spasm and trigger point pain is the same as for low-frequency applications.[4,6] Standard rubber electrodes are used for wound healing. The wound area should be cleaned. The wound should be debrided and covered with sterile gauze.[4,11]

In applications, the electrode size is generally preferred as 4x4 or 5x5.[4,11] Preferably, the passive electrode used should have 3 times the surface area of the active electrode and the passive electrode should be placed more proximal. The current intensity should be increased to a tolerable limit gradually where the patient will not feel discomfort. The intensity of stimulation should be increased to result in a painless sensation or a strong contraction, depending on the treatment goal. The duration of treatment is 30-60 min.[6]

HVPGS could be applied with monopolar or bipolar techniques. If the monopolar technique is to be applied, the electrode connected to the "–" or "+" pole is placed on the treatment area. The use of polarity depends on the treatment purpose. The other electrode is placed further away from the treatment area, preferably to the proximal of the active electrode. If the bipolar technique is to be applied, the electrodes connected to the opposite poles are placed close to each other, with the area to be treated between.[7] The passive electrode should be larger than the active electrode and placed more proximal.[6] The effect on the tissues differs depending on the current intensity. The current intensity should be gradually increased or decreased.[6,7]

HVPGS specifically stimulates the sensorial and motor nerve fibers. The pulsing process allows rapid muscle re-education and atrophy rehabilitation. It should be kept in mind that high-frequency applications may cause early fatigue in cases of muscle weakness and atrophy. Additionally, the pumping activity that occurs as a result of muscle contraction reduces swelling by providing the mobility of the edema fluid.[9,12] HVPGS is not generally used as a stand-alone treatment modality.

While the muscle contraction created by HVPGS contributes significant reduction of pain, it is also mentioned that it can be used together with other methods such as taping.[11]

While HVPGS is preferred to be applied at least 5 days a week for wound healing, it could be applied at least 3 days a week in the treatment of muscle spasm and strengthening.[4,21]

Advantages of High-Voltage Pulsed Galvanic Stimulation

- Allows for painless selective sensory fiber stimulation.
- Since the skin resistance is low, deep tissues and nerves are easily stimulated.
- It can be used for different purposes from wound healing to muscle contraction.
- HVPGS increases joint mobility by reducing pain and edema, increasing microcirculation and mechanical stretching.[7]

Disadvantages of High-Voltage Pulsed Galvanic Stimulation

- Most of the HVPGS devices are not portable. Therefore, the patient must come to the clinic.[7]

Side Effect Profile of High-Voltage Pulsed Galvanic Stimulation

Compared to low voltage and long pulse duration agents, the tolerable short pulse duration reduces chemical and heat related side effects. Therefore, HVPGS is a suitable agent for long-term use without any noticeable side-effect profile.[7]

Contraindications of High-Voltage Pulsed Galvanic Stimulation

HVPGS is contraindicated for the patients with

- Osteomyelitis,
- Cancer,
- Pacemaker use,
- Pregnancy,
- Those who use topical substances that can cause wound irritation, tissue toxicity, or an allergic reaction.[21]

Considerations

- Care should be taken not place electrodes on or around the heart, phrenic nerve, carotid sinus, or larynx muscles.[21]
- Attention should be paid to areas with sensory disorders, tissue that have lost their skin integrity, and hemorrhagic tissues. If so risky, no application should be made on these areas.
- Patients with epilepsy should be monitored during the application.[5]

References

1. Ahmad ET. High-voltage pulsed galvanic stimulation: Effect of treatment duration on healing of chronic pressure ulcers. Ann Burns Fire Disasters. 2008:21(3):124-8. PMID:21991123.
2. Singh J. (2011), Manual of practical electrotherapy. 1st ed. Jaypee Brothers Publishers. ISBN:9350250594.
3. Nelson RM, Currier DP. (1991), Clinical electrotherapy. 2nd ed. USA: Appleton&Lange. ISBN: 0-8385-1334-1334.
4. Kırdı N. (2016), Elektroterapide temel prensipler ve klinik uygulamalar. 2nd ed. Ankara: Hipokrat Kitabevi. ISBN:978-605-9160-03-2.
5. Ewidea M. High-volt pulsed stimulation. Accessed:https://kfs.edu.eg/pt/pdf/18420218463748.pdf.
6. Mitra PK. (2006), Handbook of practical electrotherapy. 1st ed. Jaypee. ISBN:8180616207.
7. Wells LM. (1986), A comparative study of positive versus negative polarity in the treatment of acute ankle sprains utilizing high-voltage electrogalvanic stimulation. University of the Pacific, Thesis.Accessed: https://scholarlycommons.pacific.edu/cgi/viewcontent.cgi?article=3121&context=uop_etds.
8. Belanger AY. (2002), Evidence-based guide to therapeutic physical agents. 1st ed. Lippincott Williams & Wilkins. ISBN:0781721083.
9. Mohr T, Carlson B, Sulentic C, Landry R. Comparison of isometric exercise and high volt galvanic stimulation on quadriceps femoris muscle strength. Phys Ther. 1985;65(5):606-12 doi:10.1093/ptj/65.5.606.
10. Junquiera CL. (1992), Basic histology. 7th ed. Appleton Lange. ISBN:0838505767.
11. Kaya D, Yüksel İ, Callaghan MJ, Güney H, Atay ÖA, Citaker S, et al. High voltage pulsed galvanic stimulation adjunct to rehabilitation program for patellofemoral pain syndrome: A prospective randomized controlled trial. Turk J Physiother Rehabil. 2013:24(1):1-8. doi:10.21653/tfrd.156477.
12. Brukner P, Khan K. (1995), Clinical Sports medicine. 2nd ed. Sydney: McGraw-Hill Book Company. ISBN:9780074711088.
13. Mawson AR, Siddiqui FH, Connolly BJ, Sharp CJ, Stewart GW, Summer WR, et al. Effect of high voltage pulsed galvanic stimulation on sacral transcutaneous oxygen tension levels in the spinal cord injured. Spinal Cord. 1993;31(5):311-9. doi:10.1038/sc.1993.55.

14. Potturi G, Agarwal A, Vajrala KR. Effect of high voltage pulsed galvanic stimulation (HVPGS) on neurogenic pains-A simple randomized clinical controlled trail. IJSER. 2018;9(12):255-9.
15. Kılınc M, Yıldırım S. The effects of electrical stimulation and exercise therapy in patients with limb girdle muscular dystrophy a controlled clinical trial. Neurosciences. 2015;20(3):259-66. doi:10.17712/nsj.2015.3.201501097.
16. Akınoglu B, Kocahan T. Russian current versus high voltage current with isokinetic training on the quadriceps muscle strength and endurance. JER. 2020;16(3):272-8. doi:10.12965/jer.2040260.130.
17. Pooja M, Jeba C. Effect of high voltage pulsed galvanic stimulation for constipation in acute stroke -A randomized clinical trial. Turk J Physiother Rehabil, 2021;32(3): 2553-8 (https://www.researchgate.net/publication/352478689_EFFECT_OF_HIGH_VOLTAGE_PULSED_GALVANIC_STIMULATION_FOR_CONSTIPATION_IN_ACUTE_STROKE_-A_RANDOMIZED_CLINICAL_TRIAL?_iepl%5BgeneralViewId%5D=penYnh5AykLJ8M2TzCbVhfaWBnsyo5dXrV1m&_iepl%5Bcontexts%5D%5B0%5D=searchReact&_iepl%5BviewId%5D=awlXuc7tpz4Cih1w8qUZFB1XWGG7KeysyxUf&_iepl%5BsearchType%5D=publication&_iepl%5Bdata%5D%5BcountLessEqual20%5D=1&_iepl%5Bdata%5D%5BinteractedWithPosition1%5D=1&_iepl%5Bdata%5D%5BwithEnrichment%5D=1&_iepl%5Bposition%5D=1&_iepl%5BrgKey%5D=PB%3A352478689&_iepl%5BtargetEntityId%5D=PB%3A352478689&_iepl%5BinteractionType%5D=publicationTitle).
18. Wong RA. High voltage versus low voltage electrical stimulation. Force of induced muscle contraction and perceived discomfort in healthy subjects. Phys Ther 1986;66(8):1209-14. doi:10.1093/ptj/66.8.1209.
19. Sherief AAA, Hamed SA. Effect of high voltage pulsed galvanic stimulation on head control in spastic diplegic cerebral palsy. J Am Sci 2013; 9(3):185-8. doi:10.5505/vtd.2016.60320.
20. Çetişli Korkmaz N, Kırdı N, Temuçin CM, Armutlu K, Yakut Y, Karabudak R. Improvement of muscle strength and fatigue with high voltage pulsed galvanic stimulation in multiple sclerosis patients-A non-randomized controlled trial. J Pak Med Assoc. 2011;61(8):736-43. PMID:22355992.
21. Lampe KE. Electrotherapy in tissue repair. Hand Ther. 1998:11(2):131-9. doi:10.1016/s0894-1130(98)80011-2.

Co-funded by the
Erasmus+ Programme
of the European Union

Functional Electrical Stimulation

DOVYDAS GEDRIMAS • VAIDA ALEKNAVIČIŪTĖ-ABLONSKĖ

Functional Electrical Stimulation

Functional Electrical Stimulation (FES) has long been used in orthopedic and neurological rehabilitation. Its efficacy and application are well documented in diagnoses from knee osteoarthritis to stroke.[1] The acronym FES is probably the most commonly used in the literature; however, a distinction should be made that this method of electrical stimulation (ES) usually refers to the process of pairing the stimulation simultaneously or intermittently with a functional task.[2]

FES has also been described as the stimulation of impaired muscles to augment task-specific movement to improve motor control with time. By achieving a muscle contraction during functional activities, it is believed that the muscle may "learn" how to contract actively over time and that strength gains may allow the weaning off machine use with time.[3]

There are a wide variety of therapeutic applications of FES. FES has been used to maintain or increase range of motion, reduce edema, promote healing of fracture or tissue, reduce muscle spasm and the effects of spasticity, improve circulation, prevent or reverse disuse atrophy, and facilitate movement. It has also been used for neuromuscular re-education and orthotic substitution.

In order for ES to be classified as FES, muscle contraction needs to occur during a meaningful functional activity. This stimulation may be timed specifically to contract when that particular muscle is meant to contract during a task, but not necessarily so.[3] The FES system generates a train of electrical stimuli that trigger action potentials in intact peripheral nerves, which further activate muscle contractions. The magnitude of the stimulus intensity determines the number of nerve fibers activated and in turn the force of muscle contraction.[4]

Recruitment of motor units by ES progresses from large to small, the reverse order of voluntary contractions, because axons of the largest diameter are the easiest to activate. Voluntary contractions preferentially recruit force-producing, slow-contracting, fatigue-resistant (type I) fibers before more forceful, faster, fatigable (type II) units. This allows for asynchronous activation of varied motor units, which enables smooth switching between active and inactive motor units to maintain muscle activity, while allowing recovery time for individual motor units and for smooth and graded movement. Electrically elicited contractions lack smooth, gradual onset, reflecting biased and synchronous motor unit recruitment.[1] FES not only stimulates motor nerve fibers but also afferent sensory nerve fibers.[5] The contractions recruit motor units based on size and proximity to the stimulation electrode. This produces multiple combinations of motor units that are activated, preventing graded and isolated movement. This all or nothing recruitment is also a factor in fatigue. Fatigue occurs more rapidly in an electrically generated contraction because a greater portion of fatigable motor units is necessary for a given contraction. Combining voluntary contractions with ES produces the best and strongest contraction, as ES recruits different motor units that are not activated at a given moment by voluntary contraction.[1]

The primary goal of neuromuscular FES is to supplement lost functions. In FES, muscles are stimulated in a coordinated manner with the objective of providing function. One of the best known applications is the Peroneal nerve stimulator in patients with a drop foot. Thus, FES systems are used to assist patients either by substituting or supporting movements. FES is often applied in patients whose functional recovery has already plateaued. However, it has been shown that repeated muscle activation within the framework of FES might also lead to improvement of voluntary motor control, which exceeded the time of stimulation.[6]

FES may also provide therapeutic physiological benefits to the users through the activation of paralyzed muscles for exercise as well as the performance of activities of daily living. In FES, restoration of voluntary movement is elicited by electrical activation of lower motor neurons through the stimulation of axons along peripheral nerves or within the spinal cord itself.[7]

Parameters of Electrical Stimulation

Frequency

"Frequency" refers to the pulses produced per second during stimulation and is stated in units of Hertz (Hz, e.g., 40 Hz = 40 pulses per second). The frequencies of ES used can vary widely depending on the goals of the task or intervention, but most clinical regimens use 20-50 Hz patterns for optimal results. In order to avoid fatigue or discomfort, constant low frequency stimulation is typically used, which produces smooth contraction at low force levels. Higher frequencies are generally reported to be more comfortable because the force response is smoothed and has a tingling effect, whereas lower frequencies elicit a tapping effect where individual pulses can be distinguished.[8]

Ramping of Stimulation Frequency

Frequently, a gradation of stimulation up to the desired frequency and intensity is used for patient comfort. "Ramp time" refers to the period of time from when the stimulation is turned on until the actual onset of the desired frequency. Ramp time is used in clinical applications when a patient may have an increased tone that creates resistance against the stimulated movement. For instance, a person with flexor hypertonicity at the elbow would benefit from a gradual ramping up of stimulation frequency to allow more time to activate elbow extensors moving in opposition to tightened flexors to successfully complete the movement.[9]

Pulse Width/Duration

ES devices deliver "pulses" in waveform patterns that are often represented by geometric shapes such as square, peaked, or sine waves. These shapes characterize electrical current that rises above a zero baseline for the extent of the stimulation paradigm (uniphasic; e.g., direct current) or current that alternates above and below the baseline (biphasic or alternating current). The time span of a single pulse is known as the "pulse width" or "pulse duration". In biphasic (a positive phase combined with a negative) pulses, the pulse duration considers both phases. Typically, dynamic Quadriceps Femoris muscle extensions similar to those used in FES cycling tests exhibit pulse widths between 300-600 microseconds (μs). Some investigators have suggested that low-frequency stimulation with short pulse durations (500-1000 μs) will exhibit a lower fatigue index. However, even shorter pulse widths (10-50 μs) have been shown to affect the recruitment of muscle fibers and can generate a larger maximum torque in a smaller number of fibers before causing a contraction in another muscle fascicle. This is important because a greater recruitment ratio within muscle fascicles can possibly increase performance time. Therefore, pulse width can be increased to potentially recruit more fibers in the surrounding area as fatigue ensues.[10]

A study comparing 50, 200, 500, and 1000 μs pulse widths when 20 Hz stimulation was delivered to the Soleus muscle found that wider pulse widths produced stronger contractions of plantar flexion and additionally augmented overall contractile properties. In addition, longer pulse durations will typically penetrate more deeply into subcutaneous tissues, so these widths should be used when trying to impact secondary tissue layers.[10]

Duty Cycle

“Duty cycle” describes the actual on and off time of a neuromuscular ES (NMES) program and is usually stated in ratio form, such as 1:2 [10 seconds (s) on, 20 s off] or percentages such as 70%, indicating time on percentage when compared to total on and off time combined. Common clinical applications use a 1:3 duty cycle as standard, but this ratio can be modified to accommodate the needs of the patient as well as the goals of the treatment.[9]

Amplitude/Intensity

Another parameter that will contribute to fatigue is the strength of the current being administered or the “intensity” / “amplitude” (usually reported in milliamperes, mA) with which the stimulation is delivered. The higher the intensity, the stronger the depolarizing effect in the structures underlying the electrodes. Higher intensities can foster increases in strength, strength gains are consistently found following training with ES programs. Lower intensities can induce more central nervous system input than higher intensities. Intensity will also factor into patient comfort, with higher intensities are typically less tolerated. However, frequency and intensity inevitably will determine the quality of muscle contraction produced.[10]

Variations of Electrical Stimulation Delivery

Another type of “transcutaneous stimulation” is electromyography (EMG) triggered ES. This type of stimulation assists patients who are relearning specific muscle movements for function. Muscle activity is monitored by means of EMG recording electrodes such that when the EMG signal reaches a specific threshold (usually set by the physiotherapist) the stimulation will activate, thus assisting the patient to complete a movement. This intervention has been described as being even more reinforcing than cyclic stimulation due to the proprioceptive feedback and voluntary component involved.[11]

“Percutaneous stimulation” uses electrodes that are inserted through the skin into the muscle of choice and is thought to be a superior choice to transcutaneous surface electrodes when specificity of stimulation is paramount. The leads of the electrodes exit the skin and connect to an external stimulator, bypassing sensory and therefore minimizing discomfort. These hair-thin electrodes can usually target specific deeper muscle locations without the consequence of unintentionally activating surrounding tissues, as often happens in transcutaneous applications. The electrodes can be left in place on average for about 3 months, but skin irritation and breaking or dislodging of the electrode can occur. Percutaneous FES implants are effective for significantly reducing shoulder pain associated with post-stroke glenohumeral subluxation.[2]

Electrode Placement and Size

The success of the FES current to reach the underlying tissue is highly related to “electrode size” and “electrode placement” as well as conductivity of the skin-electrode interface. Larger surface electrodes will activate more muscle tissue but will disperse the current over a wider surface area, decreasing current density. Smaller electrodes will concentrate current densities, allowing for focal concentration of current with less chance of stimulation crossover into nearby muscles, but dense current increases the chance for discomfort or pain.[12]

The placement of electrodes will also markedly influence the muscle response and should be carefully considered. Contention regarding optimal placement of electrodes is prevalent throughout the literature, with much of the debate centering on whether the “muscle belly” or the “motor point” is the preferential location. Physiotherapists frequently place electrodes directly over the muscle belly or in ineffective locations. Manufacturers also provide suggested electrode placement charts or guides that are usually included with the device purchase, also a source for clinicians using NMES in practice. Studies show that physiotherapists around the globe are using electrode placement methods which are suggested by stimulator manuals without completely analyzing their hypothetical reasons.[13]

A study investigating the effect of NMES delivered to the Tibialis Anterior and Vastus Lateralis muscles of the lower extremity compared electrode placement using the motor point of the muscle (accurately located through stimulation) with placement using the recommended sites of several manufacturer's suggestions. This resulted in significant differences in muscle performance outcome; motor point placement not only produces higher torques but also increased blood flow and oxygen use was greater using the motor point positions.[2]

The motor point is usually located at the center of the muscle mass where the motor nerve enters the muscle. To find the best position, the physiotherapist may slightly move the negative electrode around. The main objective is to find the spot where the minimum amount of ES will easily excite the greatest muscular contraction without causing pain.[13] Some devices have a motor point pen electrode, which can be used to find the best position for electrode placement. In this case, the physiotherapist uses a pen electrode at various locations of the muscle belly to identify the most comfortable and efficient location for stimulation. Therefore, the knowledge of anatomy is essential for physiotherapists to perform ES because electrodes should be placed directly on the muscle.[14]

Usually, a positive red-pin electrode (anode) is placed near the upper insertion or top of the muscle. Negative black-pin electrode (cathode) must be placed at the motor point of the muscle, because it elicits stronger and easier contraction.[13] However, according to Shanmugam, a cathode pole may be placed over the insertion points and an anode pole may be placed distally to obtain stronger muscle contraction.[13]

The effectiveness of FES also depends on electrode size. The optimal electrode size depends on the target muscle. For example, small electrodes are more precise than larger ones for selective activation of forearm muscles. However, accurate positioning of a small electrode may require more time than a larger electrode to test over the skin surface of the target muscle. The location of the stimulating electrode is critical for eliciting the desired muscle contractile response. Positioning the electrode close to the sensory nerve may lead to the activation of skin surface receptors and cause discomfort. Consequently, patients may refuse such treatment. Therefore, electrode location is an urgent issue in clinical applications of body surface ES.[15]

Electrode placement for Quadriceps Femoris muscle stimulation (Figure 16.1) and for Infraspinatus muscle (Figure 16.2) are shown below. The same principle can be applied to other muscles.

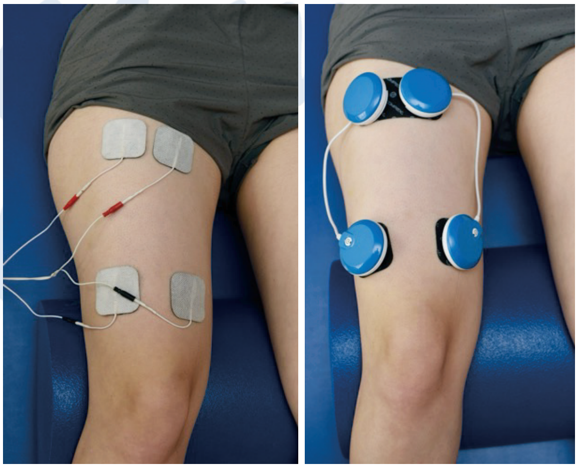

Figure 16.1 Electrode placement for Quadriceps Femoris muscle strengthening (left side - self-adhesive cord electrode, right side - self-adhesive wireless electrodes).

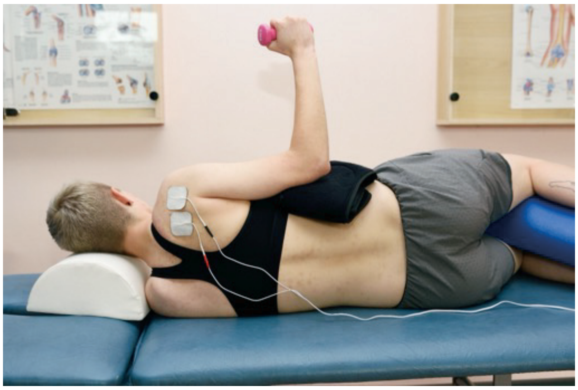

Figure 16.2 Electrode placement for Infraspinatus muscle strengthening with active muscle contraction.

Indications and Contraindications

Indications

- To improve muscle strength and prevent muscle atrophy.
- To improve and maintain the range of motion around a joint.
- To reduce muscle spasticity and spasms.
- To increase cardiovascular function through the activity of large muscle groups.[16]

Contraindications

- Demand cardiac pacemaker, implantable defibrillator, or unstable arrhythmia,
- Placement of electrodes over the carotid sinus,
- Areas where venous or arterial thrombosis or thrombophlebitis is present,
- Pregnancy – over or around the abdomen or low back (exception when ES may be used for pain control during labor),
- When contraction of the muscle may disrupt healing (e.g., muscle or tendon tear, overuse, or acute injury).[17]

Precautions for FES

- Cardiac disease,
- Impaired mentation,
- Impaired sensation,
- Malignant tumors,
- Areas of skin irritation or open wounds,
- May cause delayed-onset muscle soreness.[17]

References

1. Martin R, Sadowsky C, Obst K, Meyer B, McDonald J. Functional electrical stimulation in spinal cord injury: From theory to practice. Top Spinal Cord Inj Rehabil. 2012;18(1):28-33. doi:10.1310/sci1801-28.
2. Doucet BM, Lam A, Griffin L. Neuromuscular electrical stimulation for skeletal muscle function. Yale J Biol Med. 2012;85(2):201-15. PMID:22737049.
3. Joffe JR. (2014). The effect of functional electrical stimulation on abdominal muscle strength and gross motor function in children with cerebral palsy. A randomized control trial (Master's thesis, University of Cape Town). Accessed: https://open.uct.ac.za/bitstream/handle/11427/5940/thesis_hsf_2014_joffe_jr.pdf?sequence=1
4. Sivaramakrishnan A, Solomon JM, Manikandan N. Comparison of transcutaneous electrical nerve stimulation (TENS) and functional electrical stimulation (FES) for spasticity in spinal cord injury-A pilot randomized cross-over trial. J Spinal Cord Med. 2018;41(4):397-406. doi:10.1080/10790268.2017.1390930.
5. Quandt F, Hummel FC. The influence of functional electrical stimulation on hand motor recovery in stroke patients: A review. Exp Trans Stroke Med. 2014;6(1):1-7. doi:10.1186/2040-7378-6-9.
6. da Cunha MJ, Rech KD, Salazar AP, Pagnussat AS. Functional electrical stimulation of the peroneal nerve improves post-stroke gait speed when combined with physiotherapy. A systematic review and meta-analysis. Ann Phys Rehabil Med. 2021;64(1):101388. doi:10.1016/j.rehab.2020.03.012.
7. Mushahwar VK, Jacobs PL, Normann RA, Triolo RJ, Kleitman N. New functional electrical stimulation approaches to standing and walking. J Neural Eng. 2007;4(3):S181-97. doi:10.1088/1741-2560/4/3/S05.
8. De Kroon JR, IJzerman MJ, Chae J, Lankhorst GJ, Zilvold G. Relation between stimulation characteristics and clinical out- come in studies using electrical stimulation to improve motor control of the upper extremity in stroke. J Rehabil Med. 2005;37(2):65-74 doi:10.1080/16501970410024190.
9. Bijak M, Rakos M, Hofer C, Mayr W, Strohhofer M, Raschka D, et al. Stimulation parameter optimization for FES supported standing up and walking in SCI patients. Artif Organs. 2005;29(3):220-3. doi:10.1111/j.1525-1594.2005.29039.x
10. Mesin L, Merlo E, Merletti R, Orizio C. Investigation of motor unit recruitment during stimulated contractions of tibialis anterior muscle. J Electromyogr Kinesiol. 2010;20(4):580-9. doi:10.1016/j.jelekin.2009.11.008.
11. Barth E, Herrman V, Levine P, Dunning K, Page SJ. Low-dose, EMG-triggered electrical stimulation for balance and gait in chronic stroke. Top Stroke Rehabil. 2008;15(5):451-5. doi:10.1310/tsr1505-451.
12. Sluka KA, Walsh D. Transcutaneous electrical nerve stimulation: Basic science mechanisms and clinical effectiveness. J Pain. 2003;4(3):109-21. doi:10.1054/jpai.2003.434.
13. Shanmugam S. Inverse electrode placement may help to improve electrotherapeutic effects in the field of chronic pain management. Korean J Pain. 2016;29(3):202-4. doi:10.3344/kjp.2016.29.3.202.
14. Botter A, Oprandi G, Lanfranco F, Allasia S, Maffiuletti NA, Minetto MA. Atlas of the muscle motor points for the lower limb: Implications for electrical stimulation procedures and electrode positioning. Eur J Appl Physiol. 2011;111:2461-71. doi:10.1007/s00421-011-2093-y.
15. Bao X, Zhou Y, Wang Y, Zhang J, Lu X, Wang Z. Electrode placement on the forearm for selective stimulation of finger extension/flexion. PloS One. 2018;13(1):e0190936. doi:10.1371/journal.pone.0190936.
16. Nussbaum EL, Houghton P, Anthony J, Rennie S, Shay BL, Hoens AM. Neuromuscular electrical stimulation for treatment of muscle impairment: Critical review and recommendations for clinical practice. Physiother Can. 2017;69(5):1-76. doi:10.3138/ptc.2015-88.
17. Cameron MH. (2012). Physical agents in rehabilitation: From research to practice. 4th ed. Elsevier Health Sciences. ISBN:1455728489.

Co-funded by the
Erasmus+ Programme
of the European Union

Magnetic Field Stimulation

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Introduction

A magnetic field is produced by an electric current or electric field. The magnetic field produced by an electric current presents the same physical parameters characteristic of the generating electric current.[1] Magnetic field therapy is a method of treating inflammatory conditions and reducing the associated pain, through the action of a pulsating or static magnetic field on different parts of the body. Electromagnetic fields are generated by low-frequency currents (50 or 100 Hz).[1]

Treatment with magnetic fields has been used since the XVIs:

- Paracelsus - used magnets to stimulate callus in fractures.
- 1845 - Faraday discovers magnetism and the law of electromagnetic induction.
- 1902 - the first studies on the biological effects of magnetic fields are published.

Magnetic fields are produced in coils through which electric current flows. The magnetic field can be continuous or pulsating (as the current that produces it). The intensity of the magnetic field - the density of the lines of magnetic force - is measured in Tesla (T), in subunits millitesla (mT). The terrestrial magnetic field varies from the value of approximately 60 mT at the poles to the value of 30 mT at the equator.[1]

Recent studies have demonstrated the biological effects produced by pulsating (interrupted) magnetic fields in particular. The continuous magnetic field does not produce adverse effects on the human body. The World Health Organization allows the application of the continuous magnetic field of 2-3 T on the human body. A bracelet with magnets has 20-130 mT.[1]

Various in vitro and animal model studies have demonstrated the ability of non-ionizing magnetic fields to play an important role in various forms of cancer. In addition, these studies have also shown that magnetotherapy is a relatively safe form of treatment, with magnetic fields acting selectively on diseased tissues.[1] Clinical tests have shown that magnetotherapy does indeed have the effect of reducing pain. Magnets penetrate deep into tissues and create a magnetic field that energizes, alkalizes, and oxygenates, improving the immune system function and the body's healing capabilities. Positive and negative magnetic polarities have different effects on biological systems. Magnets can be used in antitumor therapy due to their ability to stop the development of cancer cells. Studies have also shown that the therapy can also be used in the treatment of arthritis, glaucoma, infertility, and diseases related to aging. It appears that negative magnetic fields have beneficial effects on living organisms, while positive magnetic fields have harmful effects.[1] The biological value of oxygen is increased under the influence of negative electromagnetic field, which causes oxygen to be drawn from the blood into the cell under the influence of negatively charged DNA. The negative electromagnetic field does not affect the pH balance in any way, maintaining the alkaline balance, which in turn stimulates the presence of a greater amount of oxygen in the body.[1]

Theoretically, static magnetic fields (SMF) can alter ion flux, membrane potential, membrane configuration, ion pump activity, or neurotransmitter release. Most of the biological phenomena associated with SMF can be caused by changes in cellular calcium. It is observed that a SMF of 1,000-4,000 Gauss (G) changes the structure of proteins and enzymes and the kinetics of reactions involving free radicals. After the application of SMF, the reduction of the action potential of the neurons in the experimental studies and the permeability changes in the synthetic liposome vesicles were observed.[1]

Mechanism of Magnetic Field Stimulation

The action mechanism of magnetic fields on the body is not fully known. It is considered to be similar to that of electromagnetic radiation (short waves):[1]

- the production of energetic changes at the level of cell membranes with increased membrane diffusion and increased cellular metabolism
- stimulation of vascular neoformation
- stimulating the growth of reparative granulation tissue in wounds
- stimulation of collagen production at the cartilage level
- stimulation of cellular oxidative enzyme activity (cytocymoxidase, peroxidase) with better use of oxygen.

The magnetic fields penetrate deep into the tissues, creating a magnetic field stimulation that improves the function of the immune system and the body's healing capabilities. Magnetotherapy can be applied continuously (having a sedative effect), intermittently, rhythmically, or without any rhythm (having a general stimulating effect).[2]

Beneficial effects of the magnetic field stimulation have been demonstrated on:[2]

- central and vegetative nervous system
  - continuous magnetic field stimulation – sedative and parasympathetic effect
  - interrupted magnetic field stimulation – excitatory and sympathetic effect
  - frequencies below 10 Hz – vagotonic
  - 50 Hz frequencies – sympathetic
- blood and lymphatic circulation
  - the interrupted magnetic field stimulates the development of neoformation vessels and the kinetics of lymphatic vessels
- cellular metabolic processes
  - continuous magnetic fields stimulate anabolism
  - interrupted magnetic fields stimulate catabolism
- the neuromuscular system – especially the phasic muscles
  - the continuous magnetic field stimulation increases the rhythmicity of discharges in the motor neurons with the increase of the recruitment phenomenon
  - the interrupted magnetic field stimulation increases the contraction force of the muscle fibers

Effects of Therapy with Low-Frequency Magnetic Field Stimulation

A. Unmodulated continuous forms:
   - sedative effect,
   - sympatholytic effect,
   - trophotropic effect.

B. Interrupted forms:
   - excitatory effect,
   - sympathetic effect,
   - ergotropic effect.

The choice of forms of application (continuous or interrupted), depends on the basic condition, constitutional type, individual neuro-vegetative reactivity, and the biorhythm of the subject. The effects of magnetic fields are:

- acceleration of fracture callus
- stimulation of wound healing
- sedation and analgesia
- microcirculation stimulation

Rules of the Application of Treatment with Low-Frequency Magnetic Field Stimulation

- The treatment sofa should be made of insulating material (Figure 17.1).
- It is recommended that the patient remove metal objects from the body.
- Avoid placing the coils in the vicinity of the patient's possible metal implants.
- The application of treatment to patients with pacemakers strictly prohibited.
- The patient sits in supine position, dressed loosely.
- Cephalic extremity oriented to the north.
- The arrows on the cervical and lumbar coil is oriented towards the cephalic extremity.
- The locating coils are positioned according to the poles marked with the respective symbols North - South, on the treated region.

Application Technique

- Magnetic field stimulation devices have applicators that sit on treatment areas or coils (cervical and lumbar) that are attached to a treatment bed (Figure 17.1).
- applicators or coils are applied over the patient's clothing
- modern devices can also be applied to areas with metal implants (interrupted magnetic fields)
- distance of at least 1 m is indicated between magnetotherapy devices and other electrical devices (see the manufacturer's instructions)

Figure 17.1 Magnetic field stimulation devices.

Indications of Low-Frequency Magnetic Field Therapy

Magnetic field stimulation could be used in wide range of diseases or problems such as:[3,4]

A. Rheumatic diseases
   - Chronic degenerative rheumatism
   - abarticular rheumatism (tendonitis, myalgia, myogelosis),
   - inflammatory rheumatism (rheumatoid polyarthritis stage I and II, spondylitis ankylosing spondylitis, psoriatic arthritis)

B. Post-traumatic sequelae
   - Wounds
   - Contusions
   - Muscle Hematomas
   - Sprains
   - Musculotendinous ruptures
   - Post-fractures, fracture consolidation

C. Neuropsychiatric disorders
   - Neuroses
   - Neurovegetative Dystonia
   - Hemiplegia
   - Paraplegia
   - Parkinson's Disease

D. Cardiovascular diseases
   - functional peripheral vascular diseases
     - Raynaud's Disease
     - Raynaud's Syndrome
     - Acrocyanosis
   - organic peripheral vascular diseases:
     - Thromboangiitis obliterans
     - Atherosclerosis obliterans of the limb
     - Diabetic arteriopathy
     - Cerebral atherosclerosis
     - Arterial hypertension (mild and moderate form)
   - stage I and II lymphedema

E. Respiratory diseases
   - Bronchial asthma
   - Chronic bronchitis

F. Digestive disorders
   - Chronic gastritis
   - Chronic gastroduodenal ulcers
   - Biliary motility disorders

G. Endocrine disorders
- Type II Diabetes Mellitus
- Hyperthyroidism

H. Gynecological conditions
- Dysmenorrhoea
- Non-specific chronic metro-adnexitis
- Non-specific chronic cervicitis
- Climax and preclimax disorders

I. Neurological conditions:
- Spasticity after vascular accidents

Contraindications of Low-Frequency Magnetic Field Stimulation

- Pacemaker wearers
- Hypotensive syndromes
- Advanced cerebral atherosclerosis
- Hemorrhagic conditions, severe hematological diseases
- Anemias
- Malignant tumors
- Active pulmonary/extrapulmonary tuberculosis
- Infectious diseases, febrile conditions
- Insufficiency: renal, hepatic, cardiac, pulmonary
- Psychoses, epilepsy
- Pregnancy

Principles of the Application of Therapy Through Low-Frequency Magnetic Field Stimulation

- Depending on the condition and the objectives pursued, both the form of application and the frequency of work are chosen,
- The duration of the session varies depending on the disease and objectives (20 - 30 - 45 minutes),
- Number of sessions is large (12 - 18 – 22 sessions)
- Rate of application is daily.[5]

Transcranial Magnetic Stimulation

Transcranial magnetic stimulation (TMS) is a non-invasive form of brain stimulation in which a continuously changing magnetic field is used to induce electrical current in a specific area of the brain through electromagnetic induction. An electric pulse generator, or stimulator, is connected to a magnetic coil, which in turn is connected to the scalp (Figure 17.2). The stimulator generates a changing electric current inside the coil that induces a magnetic field. This field then causes a second inductance of inverted electrical charge within the brain itself.[4] Anthony Barker invented a device in 1985 that could alter the activity of neurons by applying a magnetic field to the scalp. This procedure is called "Transcranial Magnetic Stimulation".[6]

During TMS therapy, a magnetic pulse is applied to the scalp and travels through the skull to the brain. Reaching the brain, it induces an electric current in the neurons. The term "transcranial" refers to the passage of the magnetic field through the skull, and "magnetic stimulation" refers to the use of a magnetic field to stimulate the neurons under the skull.[6]

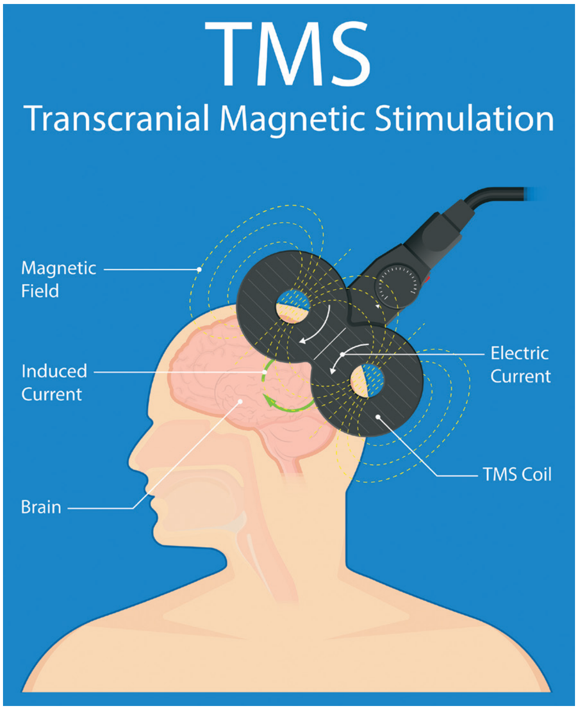

Figure 17.2 Transcranial magnetic stimulation.

When TMS was invented, researchers used it to determine which parts of the brain were connected to different parts of the body. For example, scientists found that applying TMS to a certain part of the scalp caused the hand of a participant in the experiment to tremble. In this way, the part of the brain responsible for controlling hand muscle movements was discovered.[7] In the 1990s, the first research studies using brain scanning to see images of the brain deepened the state of the brains of depressed people. These studies showed that the left side of the prefrontal cortex, a brain region, was underactive in depression, leading the researchers to wonder if they could use TMS to increase the activity of neurons in this brain region.[5] Initial findings of TMS applied to the left prefrontal cortex for depression showed that symptoms of depression improved. This discovery opened the horizon to new treatment possibilities for neuropsychiatric diseases.

Transcranial and Peripheral Magnetic Field Stimulation Procedures in Chronic Pain

According to the International Association for the Study of Pain definition, pain is "an unpleasant sensory and emotional experience associated or similar to that associated with real or potential tissue damage". The mechanisms of activation and regulation of pain perception are extremely complex and include bidirectional communications between peripheral receptors, the immune system (responsible for inflammatory processes), the endocrine system, and the nervous system.[8]

In the case of chronic pain, adaptation mechanisms appear both at the level of the peripheral nervous system (sensory and motor peripheral nerves) and central (cerebral circuits) that end up maintaining several vicious circles.[9] The brain circuits involved in the perception of pain are closely interconnected with those responsible for the affective (emotions) and cognitive components (e.g., in the case of a painful episode, all attention is channeled towards the pain). That is why chronic pain is difficult to treat and most of the time it is complicated with emotional changes, sleep disturbance, difficulty concentrating, etc.[10]

Magnetic stimulation therapy is addressed to patients with lumbago, cervical pain, headache, migraine, facial pain, neuropathic pain, chronic pelvic pain syndrome, etc. Some approach through magnetic stimulation sessions consists in combining TMS procedures with those of tcMS-PNS, in a manner customized to the characteristics of each individual patient.[8]

The applied therapeutic strategy is established by the coordinating physician after a specific functional evaluation of both neuromuscular imbalances and secondary complications of chronic pain that participate in maintaining the vicious circle.

Advantages of Magnetic Field Stimulation as a Treatment Method for Patients with Chronic Pain

- It provides direct access to the peripheral nervous system. By activating the motor nerves, the contraction of different muscle groups is obtained, and by using several frequencies, a different recruitment of muscle fibers is obtained.
- It provides direct access to the central nervous system, having the effect of modulating brain circuits both those involved in pain processing and those involved in emotional and cognitive functions.
- It significantly increases the chances of getting out of the previously created vicious circles, by combining the effects of peripheral and central nervous system modulation.
- Acts directly on the neurophysiological mechanisms responsible (at least partially) for the pain syndrome (acts directly on the cause).
- It does not create addiction.
- It can be associated with other interventional or pharmacological methods (there are no contraindications in this sense).
- It is painless.
- Adverse effects are negligible and/or very rare.

References

1. Ciobanu DI. (2014), Electroterapia pentru kinetoterapeuți: Principii și practică. Editura Universității din Oradea. ISBN:6061012675.
2. Singh J. (2011), Manual of practical electrotherapy. New Delhi: Jaypee Brothers Medical Publishers Ltd. ISBN:9789350250594.
3. Scribd. Curs de Electroterapie. Accessed: http://www.scribd.com/doc/190069286/184117022-
4. Howson DC. Peripheral neural excitability. Implications for transcutaneous electrical nerve stimulation. Phys Ther. 1978;58(12):1467-73. doi:10.1093/ptj/58.12.1467.
5. Waller-Wise R. Transcutaneous electrical nerve stimulation: An Overview. J Perinat Educ. 2022;31(1):49-57. doi:10.1891/J-PE-D-20-00035.
6. Den ARV, Luykx RHJI. (2005), Low and medium frequency electrotherapy. Rotterdam: Enraf-Nonius B.V. ISBN:NA
7. Sanservino E. (1980), Membrane phenomena and cellular processes under action of pulsating magnetic fields. Lecture at the 2nd International Congress Magneto Medicine. Rome.
8. Lefaucheur JP, Aleman A, Baeken C, Benninger MDH, Brunelin J, Di Lazzaro V, et al. Evidence-based guidelines on the therapeutic use of repetitive transcranial magnetic stimulation (rTMS): An update (2014-2018). Clin Neurophysiol. 2020;131(2):474-528. doi:10.1016/j.clinph.2019.11.002.
9. Edu.Reginamaria.Ro. Procedurile de stimulare magnetica transcraninana si periferica in durerea cronica. Accessed: https://www.reginamaria.ro/articole-medicale/procedurile-de-stimulare-magnetica-transcraninana-si-periferica-durerea-cronica.
10. Supermagneti.ro. Stimulare magnetica transcraniana (TMS): Solutia afectiunilor neuropsihice. Accessed:https://supermagneti.ro/blog/stimulare-magnetica-transcraniana-tms-solutia-afectiunilor-neuropsihice/.