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С КУРСОМ ПОВЫШЕНИЯ КВАЛИФИКАЦИИ И ПЕРЕПОДГОТОВКИ

О. В. Воротницкая, Л. А. Малькевич, О. О. Чешик

ИМПУЛЬСНАЯ ЭЛЕКТРОТЕРАПИЯ

IMPULSE ELECTROTHERAPY

Учебно-методическое пособие

Минск БГМУ 2026

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Представляет собой структурированное введение в электротерапию, раскрывая ее терапевтические возможности в области обезболивания, нейромышечной активации и стимуляции тканевой репарации. Изложена классификация методов электротерапии, характеристики различных видов электрических токов, используемых в клинической практике.

Предназначено для студентов лечебного, военно-медицинского и педиатрического факультетов, а также медицинского факультета иностранных учащихся в рамках учебной дисциплины «Физиотерапия и медицинская реабилитация».

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Воротницкая Ольга Викторовна
Малькевич Людмила Антоновна
Чешик Ольга Олеговна

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LIST OF ABBREVIATIONS

AC — alternating current
DC — direct current
PC — pulsed current
TENS — transcutaneous electrical nerve stimulation
DDC — diadynamic current
SMC — sinusoidally modulated currents
TECAR — transfer of energy capacitive and resistive
IFC — interferential current
TW — type of work

MOTIVATIONAL CHARACTERISTICS OF THE TOPIC

Total lesson time: 6 hours.

Electrotherapy is an essential component of modern rehabilitation practice. Although students are familiar with the general means and methods of physiotherapy, their effective and justified. A clear understanding of the physiological mechanisms, the classification of electrotherapy modalities, and the characteristics of different electrical currents is essential for future clinicians.

These concepts form the basis for selecting appropriate treatment methods, ensuring patient safety, and achieving effective therapeutic outcomes. When students master these fundamentals, they are better prepared to apply electrotherapy confidently and responsibly in clinical practice.

This educational manual introduces the core principles, mechanisms, and clinical applications of electrotherapy, with particular attention to impulse electrotherapy.

The material is designed to support students as they build a solid theoretical foundation and develop the practical reasoning skills needed to use electrotherapy as a meaningful and effective therapeutic tool.

The topic is studied by 5thyear students of the medical, militarymedical, pediatric faculties, and the medical faculty for foreign students within the academic discipline «Medical Rehabilitation and Physiotherapy».

Purpose of the lesson: to familiarize students with the theoretical foundations and practical possibilities of electrotherapy, with emphasis on the principles and clinical use of impulse electrotherapy.

Lesson objectives:

– study the classification of electrotherapy modalities and understand their therapeutic potential;

– learn the characteristics of various types of electrical currents used in physiotherapy;

– understand the physiological mechanisms underlying impulse electrotherapy;

– learn to determine indications and contraindications for different electrotherapy methods;

– be able to select appropriate parameters of pulsed currents for specific clinical tasks;

– learn to integrate electrotherapy into comprehensive rehabilitation programs;

– develop skills in safe and evidencebased application of electrotherapy techniques.

Requirements for the initial level of knowledge. To fully master the topic, the student should repeat:

– from the course of normal physiology: physiology of excitable tissues membrane potentials and action potentials, conduction of nerve impulses and neuromuscular transmission, physiology of skeletal muscle contraction, general and specific physiology of the central and peripheral nervous systems, autonomic regulation and reflex mechanisms;

– from the course of biophysics: electrical properties of biological tissues, interaction of electric fields with cells and membranes;

– from the course of neurology: disorders of peripheral and central motor pathways, sensory systems and pain pathways;

– from internal diseases: cardiovascular diseases relevant to electrotherapy safety, pathophysiological mechanisms influencing tissue perfusion and healing.

Test questions from related disciplines:

1. Physiology of excitable tissues and mechanisms of action potential generation.
2. Electrical properties of biological membranes.
3. Mechanisms of muscle contraction and neuromuscular transmission.
4. Pain pathways and mechanisms of pain modulation.
5. Contraindications to physiotherapeutic treatment.
6. Basic principles of therapeutic use of physical factors.
7. Anatomy and physiology of the peripheral nervous system.
8. General principles of patient safety in physiotherapy.

Test questions on the topic of the lesson:

1. Electrotherapy: definition, goals, and its place in medical rehabilitation.
2. Classification of electrotherapy modalities.
3. Types of electrical currents used in physiotherapy: direct, alternating, and pulsed currents.

4. Impulse electrotherapy: characteristics of pulse shape, duration, frequency, and amplitude.

5. Physiological mechanisms of action of pulsed currents.

6. Indications and contraindications for impulse electrotherapy.

7. TENS, diadynamic currents, sinusoidally modulated currents, interferential therapy: principles and clinical use.

8. Safety rules and patient preparation for electrotherapy procedures.

9. Selection of electrotherapy parameters for pain modulation, muscle stimulation, and trophic effects.

10. Integration of electrotherapy into comprehensive treatment and rehabilitation programs.

INTRODUCTION

Electrotherapy is one of the major branches of physiotherapy, based on the use of electrical energy for prophylactic, therapeutic, and rehabilitative purposes.

Electricity is a set of physical phenomena determined by the existence, interaction, and movement of electric charges.

Electric charge is a physical quantity that determines the ability of a body to generate an electromagnetic field and to participate in electromagnetic interactions. The carriers of electric charge are negatively and positively charged particles — the structural components of the atom.

Depending on the mobility of electric charges, materials are classified into:

1) conductors (charges move easily):

– type I: metals;

– type II: solutions of salts, alkalis, acids; biological fluids of the human body.

2) semiconductors (possess charge carriers under certain conditions);

3) nervous system tissues;

4) dielectrics (do not contain free charge carriers): gases, rubber, amber, ligaments, tendons, epidermis, bone without periosteum, stroma of internal organs

Electric current is defined as the ordered flow of electrically charged particles (electrons/ions) moving through a conductor or space.

The SI unit of electric current is the **ampere (A)**, which represents one coulomb of charge passing a point per second. The conventional symbol for current is «**I**».

$$I = q / t.$$

Current density (i) is a vector physical quantity whose magnitude is defined as the ratio of the electric current (I) flowing through a conductor to the crosssectional area (S) of that conductor.

In the SI system, the unit of current density is the **ampere per square meter (A/m²)**.

$$i = I / S.$$

An electric field is a form of matter through which interaction and communication between electric charges are carried out. The direction of electric current is conventionally taken as the direction of movement of positively charged particles.

For the quantitative description of an electric field, the concept of **electric field intensity (E)** is used. The number of field lines passing through a surface of 1 cm², oriented perpendicular to them, corresponds to the magnitude of the field intensity.

Electric field intensity is a vector quantity. The direction of the intensity vector coincides with the direction of the force acting on a positive charge.

Depending on the type of electrical energy, the type of electric current and its parameters, various modalities of electrotherapy are distinguished.

TYPES OF ELECTROTHERAPEUTIC CURRENTS

Electrotherapy uses three fundamental types of electric current. They differ in the direction of electron flow and in whether the flow is continuous or interrupted:

1. Direct Current (DC).
2. Alternating Current (AC).
3. Pulsed Current (PC) (fig. 1).

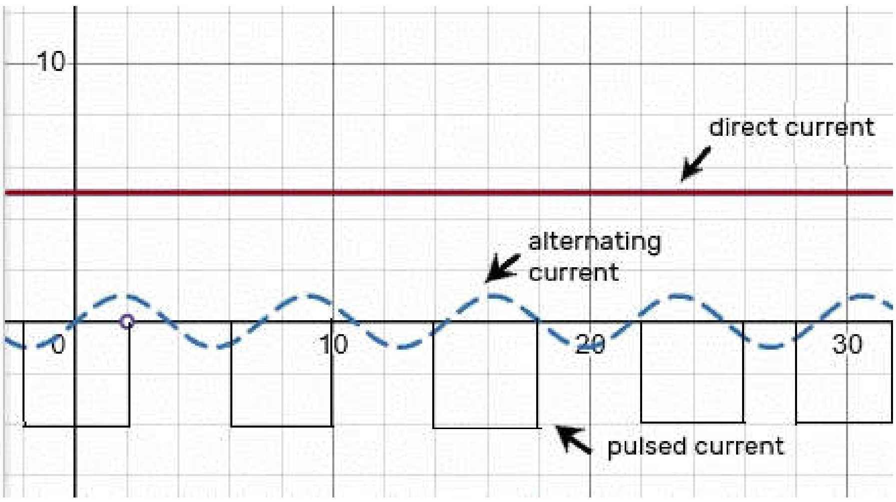

Fig. 1. Types of electric current

Direct current is a continuous, uninterrupted, unidirectional flow of charged particles.

In therapeutic practice, it is traditionally known as galvanic current.

Key features:

1. The flow of charged particles moves in one direction only.
2. There are no pauses and no changes in polarity.
3. Produces distinct polar effects (ion migration, pH changes under electrodes).
4. Commonly used in galvanization and medicated iontophoresis.

Alternating current is a continuous, uninterrupted, bidirectional flow of charged particles. The direction of flow reverses periodically, causing the polarity to alternate.

Key features:

1. Polarity changes cyclically.
2. The flow is continuous, without pauses.
3. Physiological effects depend on frequency, waveform, and amplitude.
4. Used in many mediummodalities (e. g., interferential therapy, sinusoidally modulated currents).

Pulsed Current is a unidirectional or bidirectional flow of charged particles that periodically stops for a measurable interval. The current is delivered in discrete pulses separated by rest periods.

Key features:

1. The flow is intermittent, consisting of pulses and pauses.
2. Can be monophasic (unidirectional) or biphasic (bidirectional).
3. Pulse parameters (duration, frequency, shape) determine the therapeutic effect.
4. Widely used in neuromuscular stimulation, pain modulation, and electrical muscle stimulation (table).

Classification of electrotherapy modalities

Type of electricity	**Current Type**		**Frequency characteristic of the current**	**Electrotherapy modalities, names of currents**
Electrical current	Direct	Continuous	–	Galvanic current, electrophoresis
		Pulsed	Low-frequency (from 1 to 100 Hz)	Impulse galvanization, faradic current, electrostimulation

End of the table

Type of electricity	Current Type		Frequency characteristic of the current	Electrotherapy modalities, names of currents
	Rectified alternating	Continuous with rhythmically modulated amlitude — «pulsed»	50 or 100 Hz	DDC
	Alternating	Pulsed	Low-frequency (from 2 to 500 Hz)	TENS
		Continuous AC → lowfrequency modulation → «pulsed currents» in tissue	Medium frequency — carrier frequency (2000 4000 Hz); Low frequency — modulated frequency (1–250 Hz)	Interferential currents
		Carrier current itself is continuous AC, but amplitudemodulated by lowfrequency → «pulsed currents»	Medium frequency -carrier frequency (2000 4000 Hz); Low frequency — modulated frequency (1–250 Hz)	Sinusoidally modulated currents (Amplipulse therapy)
		Pulsed	High frequency 110 kHz	Local darsonvalization
		Continued	High frequency 480–520 kHz	TECAR
Electric field	–	Continued or pulsed	Very High Frequency 30–300 MHz 27.12 MHz	Short wave diathermy
Electric field	–	Continued	Ultra-high frequency 3000–30000 MHz 2450MHz	Microwave diathermy

CHARACTERISTIC FEATURES OF ELECTROTHERAPEUTIC CURRENTS

The **waveform** is the shape of a single pulse or cycle as it appears on a graph of current (or voltage) versus time. To describe pulsed and alternating current waveforms, two groups of characteristics are used: descriptive (qualitative) characteristics and quantitative characteristics.

1. Descriptive (Qualitative) Characteristics:

a) number of phases;

b) symmetry of phases;

c) waveform shape.

Number of phases. A phase is a unidirectional flow of current on a currentintensity–time graph. Waveforms may contain one or more phases within a single pulse.

Monophasic — each pulse has one phase, deviating from the baseline in one direction only.

Biphasic — each pulse contains two phases, deviating in opposite directions from the baseline.

Symmetry of Phases. Symmetry refers to whether the two phases of a biphasic pulse are identical in size and shape, as if one phase were a mirror image of the other.

Symmetrical biphasic waveform: both phases are equal in amplitude and duration.

Asymmetrical biphasic waveform: the phases differ in amplitude, duration, or shape.

Symmetry affects patient comfort and the distribution of electrical charge in tissues.

Waveform Shape. Waveform shape refers to how the current pulse or cycle looks when plotted on a graph of intensity versus time.

Different electrical stimulators can generate a variety of waveform shapes (fig. 2).

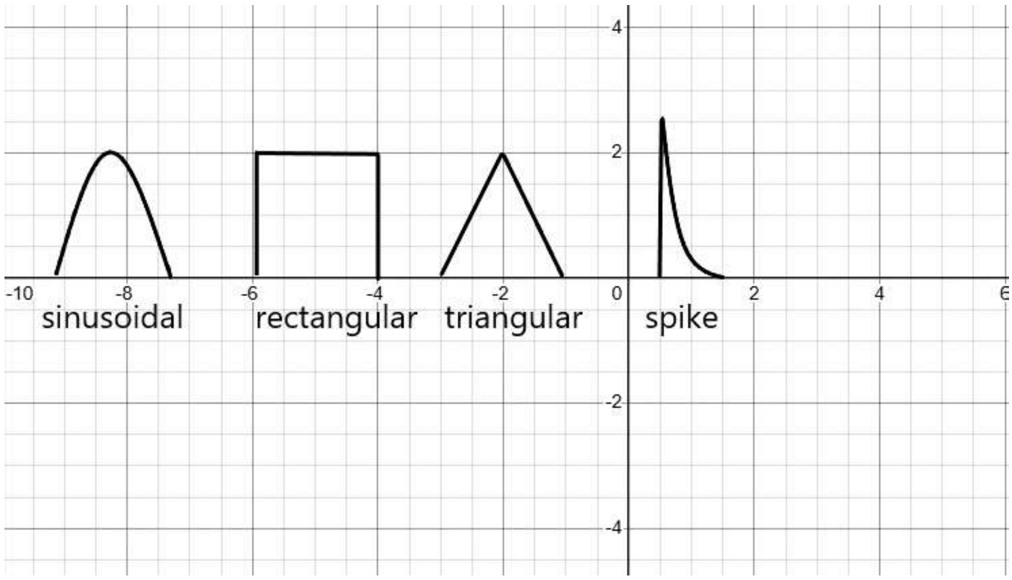

Fig. 2. Waveform shapes

The choice of waveform is important because it influences patient comfort, tissue response, and the ease with which current penetrates the tissues.

Common waveform shapes used in electrotherapy include:

– **Sinusoidal wave** — smooth, continuous rise and fall; typical of alternating current.

– **Rectangular (square) wave** — rapid rise and fall; commonly used in neuromuscular stimulation because it efficiently depolarizes nerves.

– **Exponential wave** — gradual rise or fall; sometimes used for denervated muscle stimulation.

– **Triangular wave** — linear rise and fall; less abrupt and often more comfortable for sensitive patients.

– **Spike wave** — very sharp, brief peaks.

Each waveform shape has a characteristic pattern of current delivery, which affects:

– how quickly nerves depolarize;

– how comfortable the stimulation feels;

– how deep the current penetrates;

– what clinical goals can be achieved (e. g., pain modulation, muscle strengthening, edema reduction).

2. Quantitative Characteristics. Quantitative characteristics describe the measurable properties of a current waveform. One of the most important of these is amplitude, which reflects the strength of the electrical stimulation.

a) Amplitude represents the magnitude of current flow at any point on a currentversustime graph. In clinical practice, amplitude is commonly referred to as the intensity of stimulation. It is measured in milliamperes (mA).

b) TimeDependent Parameters describe how long different parts of a pulse or cycle last. These characteristics help determine how nerves and muscles respond to electrical stimulation.

b1. Phase Duration

The time from the start to the end of one phase. (Used for monophasic and biphasic pulses.)

b2. Pulse Duration (Pulse Width)

The time from the start to the end of all phases within a single pulse.

For monophasic pulses, phase duration = pulse duration.

For biphasic pulses, pulse duration includes both phases.

b3. Period

The time from one point on a pulse or AC cycle to the same point on the next cycle. It is the reciprocal of frequency:

Period = 1 / Frequency

For pulsed current: Period = Pulse Duration + Interpulse Interval

b4. Rise Time

The time it takes for the current to increase from zero to its peak amplitude at the beginning of a phase.

b5. Decay Time

The time it takes for the current to decrease from peak amplitude back to zero at the end of a phase.

b6. Interpulse Interval

The time between two successive pulses. Measured in milliseconds (ms) or microseconds (μs). This is the «rest time» between pulses.

b7. Frequency (f)

The number of pulses delivered per second. For pulsed current: measured in pulses per second (PPS). For alternating current: measured in cycles per second (Hz).

Current Modulations.

Modulation refers to any planned change in the characteristics of an electrical current during treatment. These changes may be gradual, rhythmic or intermittent.

Amplitude Modulation.

A variation in the peak amplitude (intensity) of a series of pulses. Example: rhythmic increase and decrease in intensity.

Modulation depth.

Modulation depth is the relative amplitude of the variation of a carrier amplitude caused by a modulating signal; it quantifies how strongly the carrier is modulated and is expressed as a percentage.

PhaseDuration Modulation.

Regular changes in the length of each phase within a series of pulses.

Frequency Modulation.

Cyclic changes in the number of pulses delivered per second.

Ramp Modulation.

A gradual increase (rampup) or decrease (rampdown) in: pulse amplitude, pulse duration, or both.

Used to make muscle contractions smoother and more comfortable.

Timing Modulations.

Timing modulation refers to how pulses or bursts are arranged over time.

Burst mode.

A burst is a short group of pulses (in pulsed current) or a short group of AC cycles (in ACbased currents) delivered together, followed by a pause between bursts, not inside the waveform itself.

Continuous Mode.

A steady, uninterrupted flow of pulses, AC cycles, or bursts throughout the treatment.

On Time and Off Time.

Used when stimulation is delivered in repeating work–rest cycles. On Time — the period when pulses, AC, or bursts are being delivered. Off Time — the period when no stimulation is delivered.

Duty Cycle.

The proportion of time the current is ON during one full cycle.

Duty Cycle = On Time + Off Time / On Time × 100 %

Example: 10 seconds ON and 20 seconds OFF → Duty cycle = 33%.

ELECTRODES AND ELECTRODE APPLICATION TECHNIQUES IN ELECTHROTHERAPY

An electrode is a conductive material that serves as the interface between an electrical stimulator and body tissues. Conductive electrodes are connected to the stimulator by insulated wires, commonly referred to as electrode leads, cables, or cords.

Types of Electrodes.

Electrodes used in electrotherapy include:

1. Surface electrodes — attached to the skin.
2. Invasive (indwelling) electrodes — implanted near tissues such as peripheral nerves or bone.
3. Internal electrodes — used within body cavities.
4. Special bath electrodes — used in waterbased applications.

Surface electrodes.

Surface electrodes may be made of: polymer materials, carbonimpregnated silicone rubber, metals such as stainless steel, lead, or aluminum.

A moist pad (cloth pads soaked in warm water) is required to reduce skin resistance and provide a lowresistance pathway for current flow from the stimulator to the tissues. These features help protect the skin from electrolysis products, reduce initial skin resistance and improve contact between the skin and the electrode.

Requirements for cloth pads:

– made of light flannel, gauze, or calico;
– approximately 1 cm thick;
– must extend 1–2 cm beyond the edges of the electrode on all sides.

Polarity.

Polarity is relevant for direct current and some pulsed currents.

Negative Electrode (Cathode, –).

Stimulates nerve fibers more readily during rising current. The outer surface of the nerve membrane is positively charged at rest, making it more easily depolarized by increasing negativity.

Positive Electrode (Anode, +).

Can also provoke a nerve impulse as current rises, but requires higher amplitude, because it influences the nerve surface from a greater distance.

In clinical electrotherapy, the negative electrode (cathode) is usually connected to a black lead wire, while the positive electrode (anode) is connected to a red lead wire.

Electrode Size.

Electrode size is inversely proportional to current density:

Current Density = Current (mA) / Electrode Area (cm^2).

Key principles: Larger electrodes → lower current density. More comfortable, but less specific stimulation. Smaller electrodes → higher current density. Require less current to stimulate tissues, but may cause discomfort.

As electrode size increases, skin impedance decreases, allowing greater current flow at a given voltage.

Electrode size should match the size of the treatment area.

Electrode Placement.

Electrode placement depends on: size of the treatment area, desired current density, type of excitable tissue (nerve or muscle), anatomical location of motor points and other highly conductive skin areas.

Electrode Application Techniques:

1. Monopolar (Unipolar) Technique. This method uses two types of electrodes: Active electrode — placed over the target tissue; smaller in size. Dispersive electrode — completes the circuit; significantly larger (at least 2.5 times the area of the active electrode).

Characteristics: high current density under the active electrode — focused therapeutic effect; low current density under the dispersive electrode — minimal or no sensation.

2. Bipolar Technique. Two electrodes of equal or nearly equal size are placed within the target treatment area.

Example: stimulation of weak peroneal muscles — both electrodes placed over the muscle belly.

This arrangement produces equal current density under both electrodes.

Common placements:

1. Longitudinal — electrodes are placed on the same surface; this arrangement is used when it is necessary to affect an extended structure, for example a nerve, a neurovascular bundle, or muscles.

a) ascending — cathode placed superiorly, anode placed inferiorly. This electrode arrangement produces an excitatory effect (stimulation of muscle contractility, general stimulation, increase in arterial blood pressure);

b) descending — anode placed superiorly, cathode placed inferiorly. This electrode arrangement produces an inhibitory effect (muscle relaxation, sedative effect).

2. Transverse — electrodes are placed on opposite surfaces. The effect is exerted on all tissues located between the electrodes. Used to target internal organs and deeply located structures.

3. Tangential — obliquetransverse placement of electrodes; used when it is necessary to bypass an organ or a protruding body part, for example to reach the left lung while avoiding the heart or to stimulate the bridge of the nose.

3. Quadripolar Technique. This technique uses four electrodes connected to two separate channels. The currents from the two channels may intersect within the tissues. Primarily used in interferential therapy.

Also used in some TENS applications.

4. Water Bath Method. The Water Bath Method is a technique of electrode application in which the treated body part is immersed in water, and the electrodes are placed in the same water to allow the electrical current to pass evenly through the fluid medium to the tissues. Water serves as a conductive interface, ensuring uniform contact and reducing skin resistance, especially in areas where direct electrode placement is difficult.

DOSING OF PULSED CURRENTS AND ALTERNATING CURRENTS

Dosing for pulsed and alternating currents is determined by intensity, frequency, session duration, course length, and patient sensations.

Unlike galvanic current, dosing is not based on current density, because pulsed and AC waveforms do not produce electrochemical reactions and distribute current differently.

Each current type (TENS, IFC, DDC, SMC, Kots) has specific adjustable characteristics — such as pulse duration, frequency, burst mode, ramp time, and waveform shape — that are selected according to the therapeutic goal.

1. Intensity (Amplitude).

The maximum current density (i) for currents must not exceed 0.1 mA/cm², and the total current intensity (J) must not exceed 50 mA.

Intensity is set according to the desired physiological effect:

a) sensory-level stimulation (TENS, IFC): comfortable tingling without muscle contraction;

b) motor-level stimulation (Kots, DDC, SMC): visible, smooth, painless muscle contraction;

c) patient Sensations.

Acceptable: light tingling, buzzing, tapping, smooth, painless contraction (if required).

Unacceptable: sharp pain, burning or stinging, discomfort under electrodes.

These indicate excessive intensity or poor electrode contact.

2. Frequency.

Frequency determines the type of physiological response:

– 1–10 Hz: rhythmic muscle twitches, endorphin release;
– 20–50 Hz: smooth tetanic contraction;
– 50–80 Hz: enhance microcirculation and provide analgesia;
– 80–150 Hz: sensory analgesia.

Units: PPS (pulses per second) for pulsed currents. Hz (cycles per second) for alternating currents.

3. Duration of Each Session.

Session duration depends on the technique and treatment goal.

Typical session duration: 10–30 minutes.

Stimulation of the muscles is performed with work–rest cycles. This is especially important for denervated muscle. In this case, each muscle or treatment field is stimulated for 3–5 minutes, followed by a rest period of 3–5 minutes, and this cycle is repeated three times. During one procedure, stimulation can be applied to up to three muscles or treatment fields.

4. Course of Treatment.

Standard therapeutic course: 10–12 procedures May be extended to up to 20 procedures depending on clinical need.

The course may be repeated after 4–6 months This interval prevents overstimulation and allows tissues to recover.

CONTRAINDICATIONS FOR ELECTROTHERAPY

General contraindications:

– malignant neoplasms;
– systemic blood disorders;
– severe cachexia;
– circulatory decompensation;
– active haemorrhage or suspicion of haemorrhage;
– severe psychosis;
– fever (body temperature above 37.5 °C);
– active tuberculosis;
– pregnancy;
– decompensated disorders of the respiratory system, kidneys, or liver.

Specific contraindications for electrotherapy:

– metallic implants in the treatment area;
– skin lesions or dermatological diseases with lesions in the treatment area;
– acute purulent inflammatory processes;
– individual intolerance to electrotherapy;
– electronic devices in the treatment area (e. g., pacemakers, insulin pumps).

DIADYNAMIC CURRENTS

Diadynamic currents (DDC) (Bernard's current) — is a method of impulse therapy, by which patients get a low frequency half-sinusoidal form of impulse current, of 50–100 Hz, during the period of 0,01 sec (fig. 3). DD currents were discovered in 1929 by the French dentist Pierre Bernard, who was looking for the most suitable way to relieve pain.

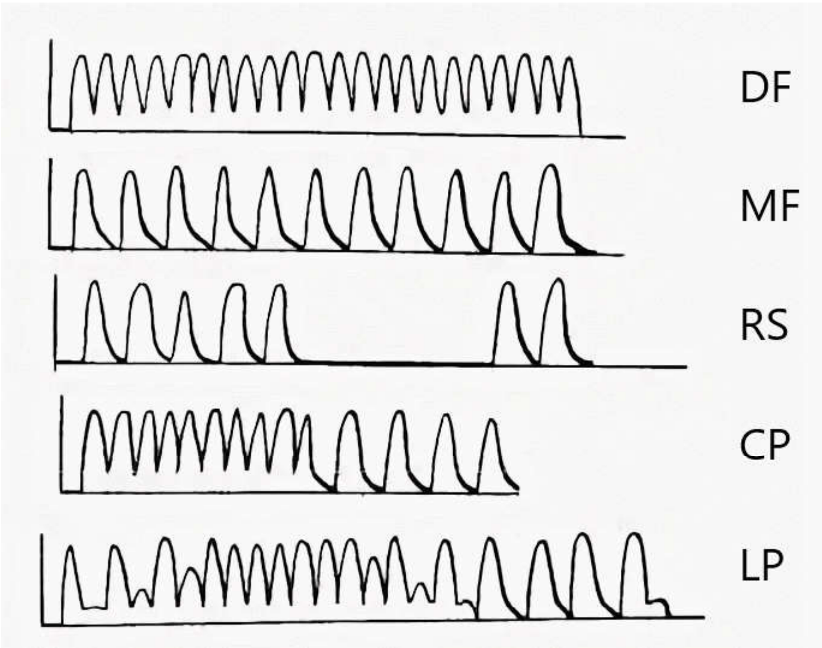

Fig. 3. Types of DDC

Types:

– **MF** (from French monophasé fixe) — one-way rectified network frequency 50 Hz the rectifier passes only one half-wave of the input voltage;

– **DF** (from French diphasé fixe) — two-way rectified network frequency 100 Hz the rectifier passes both half-waves of the input voltage;

– **CP** (from French courant modulé en courtes périodes) — alternating MF and DF in a short period rhythmic alternation of MF and DF at regular second intervals;

– **LP** (from French courant modulé en longues périodes) — alternating MF and DF in a long period slow rhythmic alternation of MF and DF with a slow gradual rise of one wave and its subsequent retreat;

– **RS** (syncopal rhythm) — MF during 1.5 (1) sec alternate with pause during 1.5 (1) sec.

Physiological effects:

– diadynamic currents are used to relieve pain, increase blood circulation and relax muscles;

– stimulation of sensory nerve by DDC cause depolarization of sensory nerves produce masking effect/analgesic effect;

– stimulation of motor nerve by DDC cause excitatory effect on motor nerves produce muscle contraction;

– DDC provides vasodilation and hyperarmia that increase local circulation and promotes tissue healing;

– alters cell membrane permeability facilitates tissue healing;

– stimulation of vibration sense cause control masking pain (gate-control pain mechanism).

Therapeutic effects:

– pain relief;

– increase local microcirculation;

– muscle re-education;

– facilitates tissue healing, by increasing cell activity.

This method is therefore often used in the treatment of acute and chronic pain syndrome, post-traumatic conditions, disorders of the locomotor system, swelling, sprains, degenerative joint diseases, impaired blood supply to the limbs.

Dosing of Procedures (DDC). Several types of diadynamic currents (DDC) are typically applied within a single procedure. The most commonly used protocol for pain management includes the following sequence: DF — 2–5 min, CP — 3–5 min, LP — 3–5 min

DF (100 Hz) is the most comfortable current for the patient. It increases tissue electrical conductivity and potentiates the effects of subsequent currents, which is why it is used as the introductory phase. CP provides a pronounced analgesic effect, therefore it is applied after DF. LP is a more irritating current, so it is added after the severe pain has been reduced.

Additional notes: RS current, due to its intermittent (pulsed) pattern, is most often used for muscle stimulation. DF can also be used for diadynamophoresis.

Intensity. Current intensity (J, mA) is increased until a painless vibration is felt under the electrodes.

Duration. Time per field/zone: 10–12 minutes. Total duration per day: approximately 30 minutes, meaning that 2–3 fields (zones) can be treated in one procedure.

Course. From single sessions to 8–12 procedures, performed daily or every other day.

Example of a DDC prescription (fig. 4).

Diagnosis: Arthritis of the left shoulder joint.

Pain syndrome.

DDC to the left shoulder.

DF — 4 min, CP — 4 min, LP — 2 min.
J: up to painless vibration.
Course: 8–10 procedures, performed daily.

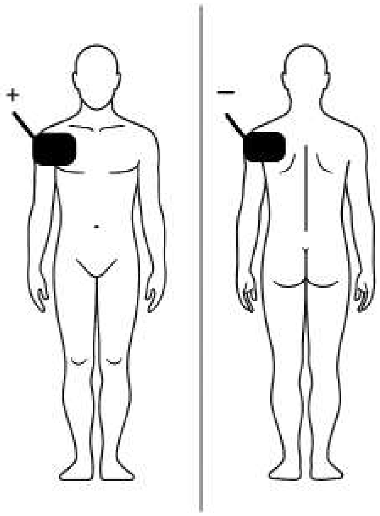

Fig. 4. Example of a DDC prescription

SINUSOIDALLY MODULATED CURRENTS

Sinusoidally modulated currents (SMC) are alternating currents with a carrier frequency from 2000 to 5000 Hz, modulated by a low frequency from 10 to 150 Hz and in amplitude.

High frequency allows current to easily penetrate the skin and provide a therapeutic effect deep in the tissue.

Modes:

– alternating(1);

– rectified (2).

Types of work (TW):

– **I TW** — (constant modulation) — it is a continuous sinusoidal current with a carrier frequency of 5000 Hz, which can be modulated by a low fixed frequency in the range from 10 to 150 Hz and by amplitude (modulation depth);

– **II TW** — (action pause) — it is a continuous sinusoidal current with a carrier frequency of 5000 Hz, which can be modulated by a low fixed frequency in the range from 10 to 150 Hz and by amplitude (modulation depth) alternating with pauses (1 type of work with pauses);

– **III TW** — (modulated current — carrier frequency) — it is a continuous sinusoidal current with a carrier frequency of 5000 Hz, which can be modulated by a low fixed frequency in the range from 10 to 150 Hz and by amplitude (modulation depth) alternating with current with frequency of 5000 and not modulated;

– **IV TW** — (modulated current (constant frequency, that programmed by device) — modulated current (we can choose frequency)) — TW in which current modulated by two different frequencies alternates. 1 part has a constant frequency, the second changes;

– **V TW** — (modulated current — carrier frequency — pause) — it is IV TW with pauses.

Modes and types of work are shown in fig. 5.

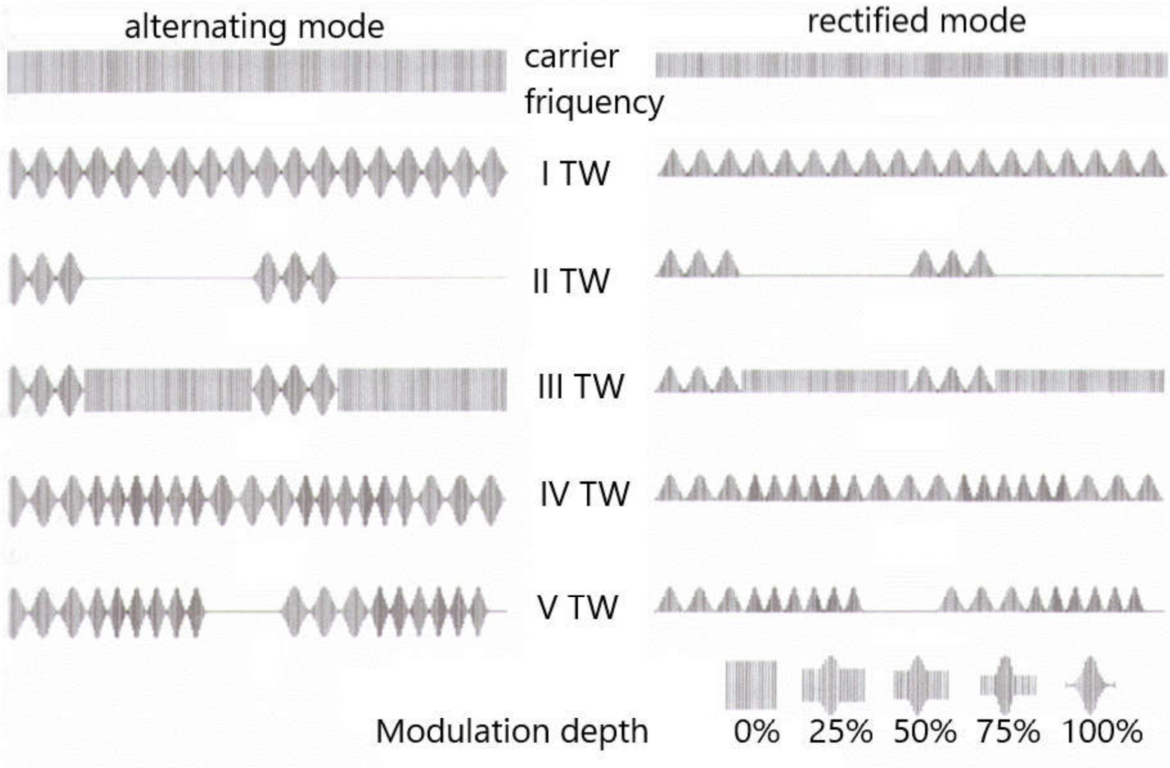

Fig. 5. Modes and types of work of of sinusoidally modulated currents

Therapeutic effects and indications:

– relief of pain;
– improving muscle strength;
– re-education/retraining of muscle control;
– maintain and improvement of range of motion;
– acceleration of wound healing;
– improving local blood circulation;
– reducing oedema;
– temporary reduction of spasticity.

Dosing the procedures. ***Mode and current characteristics.***

Alternating (1) mode is used most frequently. Rectified (2) mode is selected when a stronger therapeutic effect is required, for example, if the neuromuscular system does not respond to stimulation delivered in the more comfortable alternating (1) mode, or when performing electrophoresis.

Several types of sinusoidally modulated currents are commonly applied within a single treatment session.

Type I TW may be used as an introductory current or for electrophoresis.

Type II and Type V TW are currents with pauses and are used for muscle stimulation.

Type III and Type IV TW provide a pronounced analgesic and trophostimulating effect.

The carrier frequency, depending on the device, may vary from 2000 to 5000 Hz. A higher carrier frequency produces a less irritating and less intense sensation. The choice of therapeutic frequency depends on the treatment goal and is described above.

The modulation depth can be adjusted from 0 to 100% or more. A higher modulation depth produces a more intense and more irritating effect.

The duration of the current phase and the pause phase (for Type II and Type V TW), as well as the duration of the programmed current phase — that is, the duration of the phase of the current delivered at the carrier frequency (for Type III TW) or at the constant therapeutic frequency set by the device (for Type IV TW) — may vary from 1 s : 1.5 s, 2 s : 3 s, up to 4 s : 6 s. Longer phases produce a less irritating effect.

Intensity (J, mA) — increased until an unpainful vibration is felt under the electrodes.

Duration of procedure. 10–12 minutes per field/area.

Total duration per day: up to 30 minutes, meaning 2–3 fields can be treated in one session.

For electrical muscle stimulation — up to 60 minutes, up to 6 fields.

Course: from single procedures to 8–12 sessions, performed daily or every other day.

Example of a prescription for SMC (fig. 6).

Diagnosis: Vertebrogenic lumbosacral radiculopathy.

Pain syndrome.

Sinusoidally modulated currents to the lumbar region.

Alternating mode.

Type III and Type IV TW — 5 minutes each.

Therapeutic frequency: 100 Hz.

Modulation depth: 75 %.

Phase duration: 2 s : 3 s.

Intensity: up to painless vibration.

Course: 8–10 procedures, performed daily.

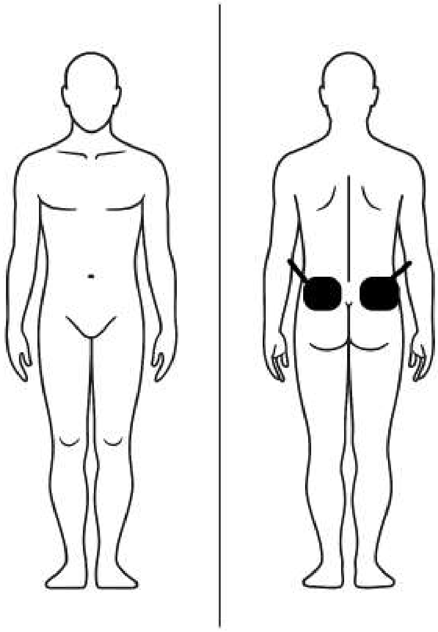

Fig. 6. Example of a prescription for SMC

TRANSCUTANEOUS ELECTRICAL NERVE STIMULATION

Transcutaneous electrical nerve stimulation (TENS) is a low frequency modality, which is a non-invasive analgesic technique, which is used to relieve nociceptive, neuropathic and musculoskeletal pain.

Transcutaneous Electrical Nerve Stimulation is the application of electricalstimulation to the skin via surface electrodes to stimulate nerve fibers, primarily used for relieve of pain.

TENS provides afferent stimulation for pain management. It is a technique of neuro-modulation that affects the sensory pathways by modifying the impulse.

TENS is often generated by a battery operated small machines.

Modes of TENS:

1. Conventional TENS/High TENS.
2. Acupuncture like TENS/Low TENS.
3. Burst TENS.
4. Modulated TENS.

Modes of TENS are shown in fig. 7.

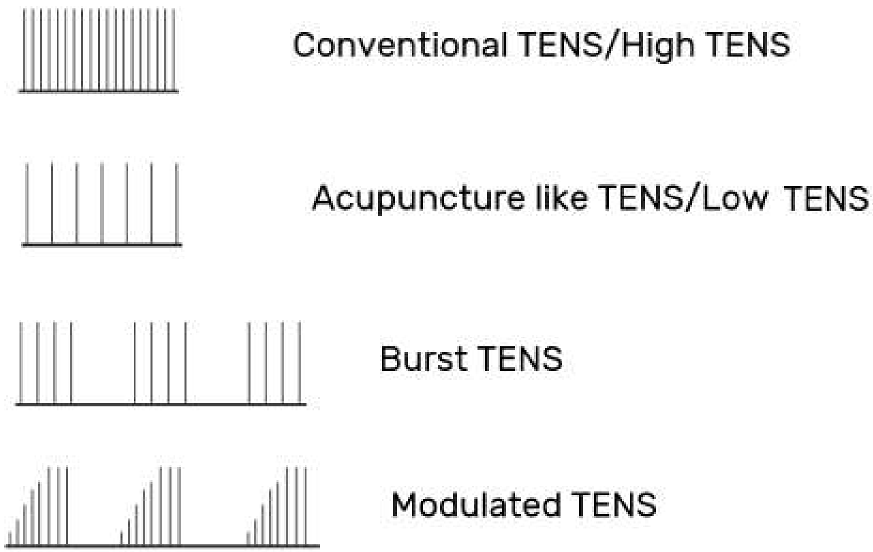

Fig. 7. Modes of TENS

1. Conventional TENS/High TENS.

This mode of TENS is the most commonly used technique and it is selected as the first line of option for most of the patients.

High Frequency: 90–130 Hz.

Low Intensity: it produce sensory stimulation (up to 30 mA).

Short Palse Duralive: 100–150 ms.

Treatment time: 40–60 minutes.

Uses: acute pain relief, post-surgical pain relief.

Electrode placement: over dermatome.

Mechanism of Pain Relief: High TENS primarily activates large diameter, low threshold, non-noxious afferents AB fibers and pre synoptically suppresses the Aq fibers at the substantia gelatinosa of dorsal gray horns cells of the spensal-cord (pain gate mechanism). Thus, there Is rapid onset of pain relief but temporary analgesia.

High TENS also work by elevating the release of inhibitory neurotransmitters such as gamma amino butyric acid and serotonin and reducing the release of excitatory neurotransmitters such as glutamate and aspartate.

2. Low TENS.

It can be used in case of chronic pain syndrome or if patients do not respond to the High TENS.

Low frequency: 2–4 Hz.

High intensity: it will produce noxious sensation and muscle twitch (approximately more than 30 mA).

Longer pulse duration: 200 ms.

Treatment time: 30–40 minutes.

Electrode placement: over the muscles, acupuncture points, trigger points.

Uses: chronic musculoskeletal pain relief.

Mechanism of pain relief: primarily stimulates small diameter, high threshold Aβ fibers, C fibers and small motor fibers, furthermore it activates extra segmental descending pain inhibitory pathways. This mode of TENS is believed to operate primarily through descending pain suppression system endogenous opiate mechanism.

Thus there is slow onset of pain relief but relatively longer analgesia, usually lasts longer than conventional TENS.

3. Burst TENS.

Burst mode has high frequency series of pulses delivered at a low frequency. Burst mode comprises a base line low frequency current together with high frequency trains.

The frequency of series of pulse is 1–5 Hz with the internal frequency of trains around 100Hz.

Intensity: high.

Mechanism of pain relief: burst TENS stimulates both the small diameter (Aδ fibres) and large diameter (Aβ fibres) at the same time.

Mechanism of pain relief: Simulates small diameter, high threshold cutaneous afferents Aδ fibres blockade and elicits peripheral nerve activate extra segmental analgesic mechanism.

4. Modulated TENS.

Modulation means, there is variation in frequency, amplitude and pulse duration in a cyclical fashion. Sometimes some units have modulation in two or all three of these parameters.

If the output is set for amplitude modulation, a cyclical modulation in amplitude is produced which increases from zero to preset level then back to zero again. With this, we can overcome the nerve accommodation and provides more comfort to the patient.

Mechanism of pain relief: pain gate control and opiate mechanism.

Indications:

– acute pain;
– post operative incision pain;
– labour pain;
– primary dysmenorrhea;
– myofascial pain dysfunction;
– chronic pain;
– pain of arthritis (osteo arthritis, rheumatoid arthritis);
– chronic musculoskeletal pain (chronic low back pain, neck pain);
– stump pain and phantom limb pain;
– radiculopathies with pain syndrome.

Dosing of Procedures. The choice of adjustable parameters depends on the device being used. Portable batterypowered devices most often offer preset programs such as highfrequency TENS, lowfrequency TENS, or burst mode, and the clinician only needs to select the appropriate mode and adjust the intensity according to the patient's sensations.

Example of a TENS Prescription (fig. 8).

Diagnosis: Postoperative pain syndrome.

Highfrequency TENS applied to the area of the postoperative wound.

Frequency: 100 Hz.

Pulse duration: 100 ms.

Intensity: up to a painless, vibration under the electrodes.

Duration: 40 minutes, three times per day until pain relief is achieved.

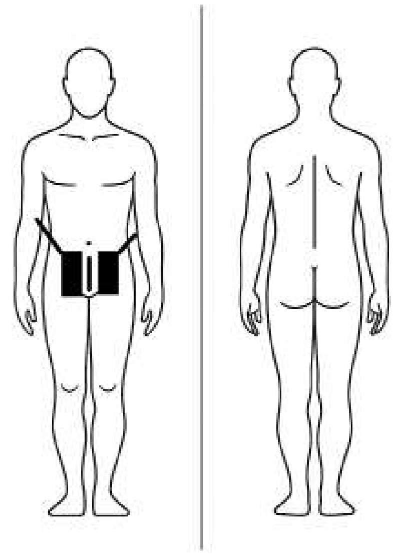

Fig. 8. Example of a TENS prescription

INTERFERENTIAL CURRENTS

Interferential therapy was introduced by Dr. Nemec in Vienna, Austria in the early 1950s. This method was developed to reduce the discomfort typically associated with lowfrequency electrical stimulation while preserving its therapeutic benefits. Interferential current represents a form of electrotherapy in which kilohertzrange carrierfrequency sinusoidal or pulsed currents are used to penetrate deep tissues by overcoming the natural impedance of the skin.

Two mediumfrequency currents are applied so that they are slightly out of phase with each other. As these currents intersect within the tissues, they interfere, and the point of intersection produces a lowfrequency physiological effect. The superimposition or interference of two mediumfrequency alternating currents with slightly different frequencies generates a lowfrequency «beat» effect. The resulting amplitudemodulated interference wave has beat frequencies ranging from 1 to 250 Hz, which have been reported to produce analgesic and trophic effects in humans.

The beat frequency — also referred to as the amplitudemodulated frequency or treatment frequency — is equal to the numerical difference between the two mediumfrequency currents.

Example:

Channel 1: 5000 Hz (carrier frequency).

Channel 2: 5100 Hz (carrier frequency).

Beat frequency = 100 Hz (fig. 9).

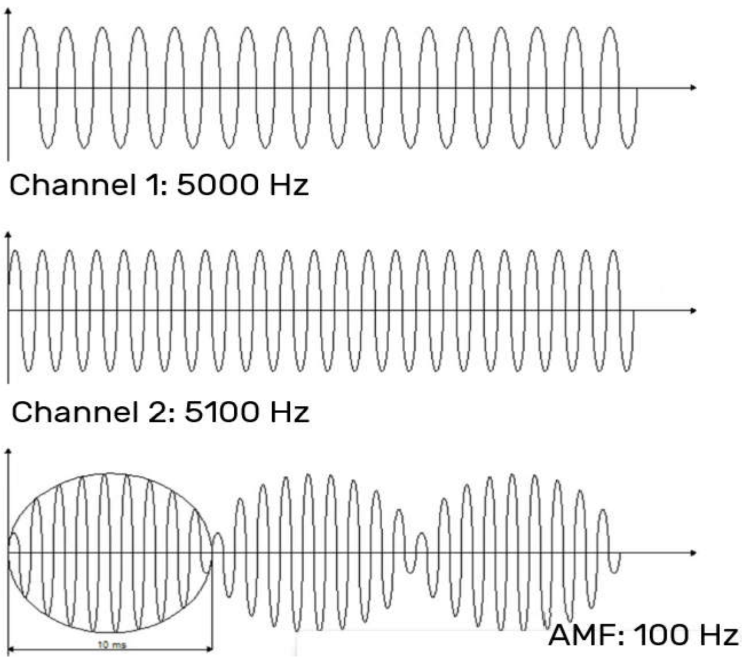

Fig. 9. Interferential current

This beat frequency behaves like a lowfrequency current and stimulates nerves and muscles, producing both analgesic and trophic effects.

Types of Beat Frequency:

– constant beat frequency;

– variable beat frequency.

Constant Beat Frequency. A constant beat frequency occurs when the difference between the two mediumfrequency currents remains fixed. The resulting beat frequency is simply the numerical difference between the two applied frequencies. For example, if the two circuits differ by 60 Hz, the beat frequency will consistently remain at 60 Hz.

Variable Beat Frequency. A variable beat frequency is produced when one carrier frequency stays constant while the second one changes within a programmed range, creating a variable or sweep frequency. The device typically sets the time required to cycle through the selected frequency range, which is usually around 15 seconds. Examples of sweep ranges include 1–10 Hz, 1–120 Hz, and 90–120 Hz.

Advantages of variable beat frequency:

– more comfortable for the patient;

– reduces the likelihood of nerve accommodation or adaptation;

– delays the onset of fatigue.

Static Interference. In static interference, the current lines intersect along vector directions that bisect the angles formed between the electrodes. Through vector addition, the currents combine to create a characteristic cloverleaf–shaped stimulation pattern. The strongest interference effect appears at approximately 45° relative to the perpendicular lines. Both current intensity and beat frequency gradually decrease from the diagonal 45° regions toward the perpendicular axes.

Uses: applied to localized tender points, such as those seen in tendonitis, capsulitis, bursitis, and similar conditions.

Dynamic Interference. Dynamic interference is produced by rotating the static interference field. The interferential currents (IFC) field is rhythmically scanned through an arc of about 45°, which creates what known as dynamic interference. This shifting pattern results in maximal interference over a broader circular area, allowing the current to penetrate a larger volume of tissue. The rhythmic movement causes continuous changes in the location of peak current intensity and in the amplitudemodulated frequency.

Uses: indicated for treating larger regions, especially when the exact focal point of pathology is unclear. This increases the likelihood that the affected tissues will be adequately stimulated.

Dosing and methodology of interferential therapy. During interferential therapy, the electrodes are positioned so that the two current circuits intersect within the area requiring treatment. The type of interferential therapy and the treatment frequency are selected according to the therapeutic goals and the patient's diagnosis.

Current intensity. The intensity should be adjusted to produce a strong but comfortable prickling sensation without muscle contraction, or a painless vibration without contractions.

Treatment duration. Treatment duration is 10–15 minutes. A single area should not be treated at normal intensity for more than 20 minutes. If more than one area is treated, the total treatment time should not exceed 30 minutes. Excessive dosing of IFC may cause the patient to feel excessively fatigued later in the day.

Frequency of treatment:

In most cases, treatment is administered daily or every other day, with a course of 12 sessions.

Example of an IFC prescription (fig. 10).
Diagnosis: rotator cuff syndrome.
Beat frequency: variable, 80–120 Hz.
Intensity: up to a painless vibration.
Duration: 20 minutes, each day, course of 10 procedures.

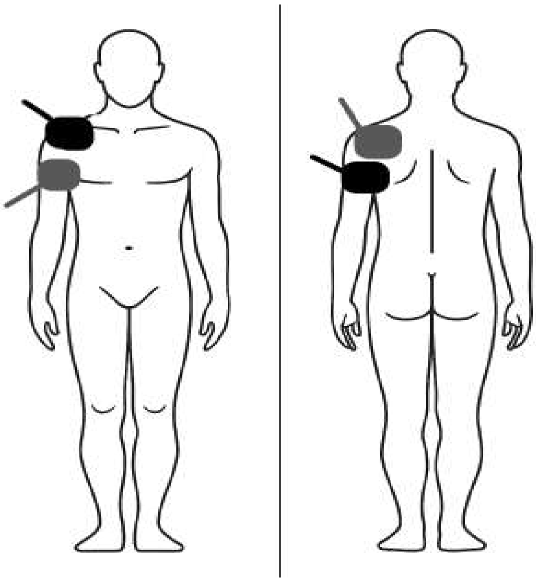

Fig. 10. Example of an IFC prescription

SELF-CONTROL OF TOPIC COMPREHENSION

To self-monitor the mastery of the lesson topic, students are recommended to answer test questions and situational tasks.

Situational tasks

Task 1

Patient A., 29 years old. Diagnosis: acute low back pain after prolonged sitting; marked nociceptive pain without neurological deficit.

Determine the optimal TENS parameters (mode, frequency, pulse duration, intensity, electrode placement, treatment duration) to achieve rapid pain relief.

Task 2

Patient D., 63 years old. Diagnosis: chronic cervical myofascial pain with moderate muscle hypertonicity.

Determine the appropriate type of work of SMC, mode, modulation frequency, modulation depth, phase/pause ratio, intensity, and electrode placement.

Task 3

Patient: B., 34 years old. Diagnosis: acute posttraumatic softtissue pain of the shoulder girdle.

Determine the appropriate type of DDC current, sequence of modes, modulation (if applicable), intensity, electrode placement, and total treatment duration to achieve rapid analgesia in the acute phase.

Task 4

Patient: C., 58 years old. Diagnosis: chronic knee pain due to osteoarthritis (stage II).

Determine the appropriate IFC parameters, carrier frequencies, beat frequency, modulation depth, intensity, and electrode placement to reduce chronic joint pain.

Task 5

Patient: D., 33 years old. Diagnosis: partial axonal neuropathy of the peroneal nerve with partial denervation of the tibialis anterior.

Determine the appropriate type of work of SMC, mode, modulation frequency, modulation depth, phase/pause ratio, intensity, electrode placement, and treatment duration for effective stimulation of a denervated muscle.

Correct solutions

Task 1

Mode: highfrequency TENS.

Frequency: 90–130 Hz.

Pulse duration: 100 µs.

Intensity: sensory level — strong but comfortable tingling, no muscle contraction.

Electrode placement: over the painful dermatome or paravertebral L4–S1 region.

Duration: 40–60 minutes, each day or two — three times per day until pain relief is achieved.

Reasoning: Highfrequency TENS activates Aβ fibers and provides rapid analgesia via the paingate mechanism.

Task 2

Type of Work: III TW.

Mode: alternating (1).

Therapeutic frequency: 80 Hz.

Modulation depth: 75 %.

Phase/pause ratio: 2 s : 3 s.

Intensity: until painless vibration.

Time: 10–15 min, each day, course of 10 procedures.

Electrode placement: paravertebral cervical region or over trigger points

Reasoning: Type of work III provides strong analgesic and trophic effects for chronic myofascial pain.

Task 3

Type of current: DF 4 min – CP 6 min.

Modulation frequency: not applicable for DDC.

Intensity: sensory level — strong but comfortable tingling, no muscle contraction.

Electrode placement: surrounding the painful area.

Duration: 10–12 minutes, each day, course of 6 procedures or until pain relief is achieved.

Reasoning: DDC provides rapid analgesia by blocking nociceptive transmission and reduce protective muscle spasm.

Task 4

Carrier frequencies: 3000 Hz.

Beat frequency: 80 Hz for analgesia.

Intensity: sensory level — strong but comfortable tingling.

Electrode placement: crossed pattern around the knee joint.

Duration: 20–30 minutes, each day, course of 10 procedures.

Reasoning: mediumfrequency carriers penetrate deep tissues; beat frequency 80 Hz provides analgesia via Aβfiber activation with good tolerance in chronic pain.

Task 5

Type of work: II TW.

Mode: rectified (2).

Therapeutic frequency: 30 Hz.

Modulation depth: 100 %.

Phase/pause ratio: 4 s : 6 s.

Intensity: until painless, visible muscle contraction.

Electrode placement: — (cathode): over the motor point of tibialis anterior; + (anode): on the belly of the muscle.

Duration: 3 repetitions × 5 minutes, with 3minute breaks; daily; course of 12 procedures.

Reasoning: type II TW provides muscle contraction.

Tests

1. Which statements correctly describe direct current (DC) in electrotherapy:

a) it is a continuous, unidirectional flow of charged particles;
b) it produces distinct polar effects under electrodes;
c) it periodically reverses polarity;
d) it is commonly used in galvanization and iontophoresis;
e) it contains pulses separated by rest intervals?

2. Which characteristics apply to pulsed current (PC):

a) the current flow is intermittent, consisting of pulses and pauses;
b) it can be monophasic or biphasic;
c) it is always continuous and bidirectional;
d) pulse duration and frequency determine the therapeutic effect;
e) it produces no interpulse interval?

3. Which materials are classified as dielectrics according to the text:

a) rubber;
b) metals;
c) tendons;
d) biological fluids;
e) bone without periosteum?

4. Which parameters are considered timedependent characteristics of electrical pulses:

a) amplitude;
b) phase duration;
c) pulse duration;
d) frequency;
e) rise time;
f) electrode size?

5. Which statements about electrode placement techniques are correct:

a) in monopolar technique, the active electrode is smaller than the dispersive electrode;
b) bipolar technique uses two electrodes of equal or nearly equal size;
c) quadripolar technique uses four electrodes connected to two channels;
d) transverse placement affects only superficial tissues;
e) longitudinal placement can be ascending or descending depending on polarity?

6. Which statements correctly describe the nature of diadynamic currents (DDC):

a) they are lowfrequency halfsinusoidal impulse currents;
b) their frequency is typically 50–100 Hz;

c) they were developed to stimulate denervated muscle exclusively;
d) they were introduced by Pierre Bernard in 1929;
e) they are a form of highfrequency continuous AC?

7. Which descriptions correctly match the types of DDC:
a) MF — oneway rectified 50 Hz current;
b) DF — twoway rectified 100 Hz current;
c) CP — alternating MF and DF in short rhythmic periods;
d) LP — alternating MF and DF with slow rhythmic transitions;
e) RS — continuous DF without pauses?

8. Which physiological effects are produced by diadynamic currents:
a) analgesia through sensory nerve depolarization;
b) vasodilation and hyperemia improving local circulation;
c) increased membrane permeability supporting tissue healing;
d) selective inhibition of motor nerves only;
e) muscle contraction through motor nerve stimulation?

9. Which therapeutic indications are appropriate for DDC:
a) acute and chronic pain syndromes;
b) posttraumatic conditions;
c) degenerative joint diseases;
d) impaired blood supply to limbs;
e) acute purulent infections?

10. Which statements about dosing of DDC procedures are correct:
a) a typical analgesic sequence is DF → CP → LP;
b) DF is used first because it increases tissue conductivity;
c) RS is mainly used for muscle stimulation;
d) total daily treatment time is about 30 minutes;
e) the course usually consists of 1–3 procedures only?

11. Which statements correctly describe sinusoidally modulated currents:
a) they use a mediumfrequency carrier current between 2000–5000 Hz;
b) they are modulated by a low frequency between 10–150 Hz;
c) they cannot penetrate deep tissues due to high skin impedance;
d) their amplitude can be modulated (modulation depth);
e) they are a form of direct current?

12. Which descriptions correctly match the Types of Work (TW):
a) I TW — continuous sinusoidal current with constant modulation;
b) II TW — modulated current alternating with pauses;
c) III TW — alternation of modulated current and unmodulated carrier frequency;

d) IV TW — alternation of two modulated currents with different frequencies;
e) V TW — IV TW with pauses?

13. Which therapeutic effects are associated with sinusoidally modulated currents:
a) pain relief;
b) improvement of muscle strength and control;
c) reduction of spasticity;
d) destruction of scar tissue;
e) reduction of oedema and improvement of local circulation?

14. Which statements about dosing and parameter selection are correct:
a) alternating mode (1) is the most commonly used;
b) rectified mode (2) is used when a stronger therapeutic effect is needed;
c) Type II and V TW are used for muscle stimulation because they include pauses;
d) Type III and IV TW provide strong analgesic and trophic effects;
e) higher carrier frequency produces a more irritating sensation?

15. Which statements correctly describe the dosing of SMC procedures:
a) intensity is increased until a painless vibration is felt;
b) duration per field is typically 10–12 minutes;
c) total daily duration is up to 30 minutes (2–3 fields);
d) for muscle stimulation, total duration may reach 60 minutes;
e) standard course consists of 1–3 procedures only?

16. Which statements correctly describe TENS as a modality:
a) it is a lowfrequency, noninvasive analgesic technique;
b) it is primarily used to stimulate motor fibers for strengthening;
c) it provides afferent sensory stimulation for pain modulation;
d) it is typically delivered through small batterypowered devices;
e) it is an invasive method requiring needle electrodes?

17. Which parameter set correctly corresponds to Conventional (High) TENS:
a) frequency 90–130 Hz;
b) pulse duration 100–150 ms;
c) high intensity producing muscle twitch;
d) sensorylevel stimulation up to ~30 mA;
e) treatment time 40–60 minutes?

18. Which characteristics correctly describe Lowfrequency (Acupuncturelike) TENS:
a) frequency 2–4 Hz;
b) produces noxious sensation and muscle twitch;

c) short pulse duration of 50–80 ms;
d) activates descending pain inhibitory pathways;
e) provides slow onset but longlasting analgesia?

19. Which statements about Burst TENS are correct:
a) it delivers highfrequency trains of pulses at a low overall frequency;
b) train frequency is typically 1–5 Hz with internal frequency around 100 Hz;
c) it stimulates both largediameter Aβ fibers and smalldiameter Aδ fibers;
d) it is used only for acute pain;
e) it activates extrasegmental analgesic mechanisms?

20. Which clinical indications are appropriate for TENS:
a) acute postoperative pain;
b) labour pain and primary dysmenorrhea;
c) chronic musculoskeletal pain (e. g., low back pain);
d) phantom limb pain and stump pain;
e) acute purulent infections?

21. Which statements correctly describe the physical basis of interferential therapy:
a) it uses two mediumfrequency currents;
b) the interference of the two currents produces a lowfrequency beat effect;
c) the carrier frequency typically ranges from 1 to 250 Hz;
d) the beat frequency equals the numerical difference between the two currents;
e) IFT cannot penetrate deep tissues due to high skin impedance?

22. Which statements correctly describe constant and variable beat frequencies:
a) constant beat frequency occurs when the frequency difference remains fixed;
b) variable beat frequency is produced when one carrier frequency changes within a programmed range;
c) constant beat frequency is typically used to avoid nerve accommodation;
d) variable beat frequency cycles through a range in about 15 seconds;
e) variable beat frequency is less comfortable for patients?

23. Which characteristics correctly describe static and dynamic interference:
a) static interference produces a cloverleaf–shaped stimulation pattern;
b) maximum static interference occurs at approximately 45° to perpendicular lines;
c) dynamic interference scans the IFC field through an arc of about 45°;

d) dynamic interference stimulates a smaller tissue volume than static interference;

e) static interference is used for localized tender points?

24. Which statements about dosing and methodology of IFT are correct:

a) electrodes must be positioned so that the two current circuits intersect in the treatment area;

b) intensity should produce a strong but comfortable prickling without muscle contraction;

c) a single area should not be treated for more than 20 minutes;

d) total daily treatment time should not exceed 30 minutes;

e) excessive dosing may cause increased energy and alertness?

25. Which statements correctly describe clinical use and treatment parameters of IFT:

a) treatment is usually performed daily or every other day;

b) a typical course consists of around 12 procedures;

c) variable beat frequencies (e. g., 80–120 Hz) are used for analgesia;

d) IFT is contraindicated for musculoskeletal pain;

e) stable IFC mode is appropriate for focal conditions such as rotator cuff syndrome?

Answers to tests: **1** — a, b, d; **2** — a, b, d; **3** — a, c, e; **4** — b, c, d, e; **5** — a, b, c, e; **6** — a, b, d; **7** — a, b, c, d; **8** — a, b, c, e; **9** — a, b, c, d; **10** — a, b, c, d; **11** — a, b, d; **12** — a, b, c, d, e; **13** — a, b, c, e; **14** — a, b, c, d; **15** — a, b, c, d; **16** — a, c, d; **17** — a, b, d, e; **18** — a, b, d, e; **19** — a, b, c, e; **20** — a, b, c, d; **21** — a, b, d; **22** — a, b, d; **23** — a, b, c, e; **24** — a, b, c, d; **25** — a, b, c, e.

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