Basic principle of electricity and electrical stimulation current
Learning Outcomes

Understand the basic concepts, terminology, and physiology of electrical stimulation and be able to differentiate among them.

Guide the selection of optimal current parameters for effective and safe delivery of electrical stimulation to accomplish therapeutic treatment goals.

Understand adjustment of treatment parameters to meet the needs and responses of individual patients to the application of electrical stimulation to accomplish therapeutic treatment goals.

Describe the principles behind the application of electrodes for electrical stimulation to elicit a comfortable level of stimulation and discuss what can be done to improve patient comfort.

Be able to create a safe environment when using electrical equipment.
Outline

Introduction and History

Electrical Current Parameters
- Current types
- Waveforms
- Time-Dependent Parameters
- Other Electrical Current Parameters

Effects of Electrical Currents
- Stimulation of Action Potentials in Nerves/Muscles
- Wound healing/inflammatory
- Pain

Indications for the Use of E-Stim

Contraindications and Precautions for the Use of E-Stim

Currents Application Technique
- Patient Positioning
- Electrode Type
- Electrode Placement
- General Instructions for Electrical Stimulation
- Documentation
Electrotherapy
- Application of electrical energy for therapeutic purposes

Electrical current is a flow of charged particles

Electrical stimulation
- Application of therapeutic electrical current devices to stimulate excitable tissues, with the aim of producing physiological reaction for therapeutic benefits.

<table>
<thead>
<tr>
<th>ACRONYM</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMS</td>
<td>Electrical muscle stimulation</td>
</tr>
<tr>
<td>ESTR</td>
<td>Electrical stimulation for tissue repair</td>
</tr>
<tr>
<td>NMES</td>
<td>Neuromuscular electrical stimulation</td>
</tr>
<tr>
<td>TENS</td>
<td>Transcutaneous electrical nerve stimulation</td>
</tr>
<tr>
<td>FES</td>
<td>Functional electrical stimulation</td>
</tr>
</tbody>
</table>
Electrical Current Parameters

- Current types
- Waveforms
- Time-Dependent Parameters
- Other Electrical Current Parameters
  - Current density
  - Tissue impedance
# Current Types

<table>
<thead>
<tr>
<th></th>
<th>Direct current (DC)</th>
<th>Alternating Current (AC)</th>
<th>Pulsed current (PC)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Def.</strong></td>
<td>is continuous unidirectional flow of e-’s toward (+) pole</td>
<td>The e-flow in alternating directions in both sides of isoelectric line from (−) and (+) pole.</td>
<td><strong>pulsatile current</strong>&lt;br&gt;An interrupted current, whereby the current flows in a series of pulses separated by periods when no current flows. Can take on the directionality characteristics of AC or DC current.</td>
</tr>
<tr>
<td><strong>Shape</strong></td>
<td><strong>Monophasic</strong></td>
<td><strong>Biphasic</strong></td>
<td><strong>Monophasic or biphasic</strong></td>
</tr>
<tr>
<td><strong>Types</strong></td>
<td>“Galvanic current”&lt;br&gt;Interrupted direct current or “interrupted galvanic”</td>
<td>Current can be symmetrical, asymmetrical e.g. TENS,</td>
<td>Groups of pulses are interrupted for short periods of time (inter-pulse intervals) &amp; repeat. Russian current Interferential current</td>
</tr>
<tr>
<td><strong>Uses</strong></td>
<td>Iontophoresis&lt;br&gt;Stimulate of denervated muscle;</td>
<td>Pain relief&lt;br&gt;Neuromuscular stimulation.</td>
<td>Pain relief&lt;br&gt;Neuromuscular stimulation&lt;br&gt;Wound healing</td>
</tr>
</tbody>
</table>
Current types

Direct current (DC)

Alternating Current (AC)

Pulsatile current
1-Alternating vs. Direct Current

Direct current

- Chemical reaction
- Chemical burn

Alternating current

- Pulsed current
- No chemical reaction

- Very short pulse duration
- Reversing polarity

- No Chemical burn
Waveforms

Waveform is a graphic representation of “shape, direction, amplitude, duration and frequency” of the electrical current.

1-Waveforms Shape:
Waveforms Classification

Waveform

- Monophasic
- Biphasic
- Polyphasic

Symmetrical

Asymmetrical

Balanced

Unbalanced
Waveforms Classification

**Monophasic**
One phase only (+ or -)
Current flows in one direction only.

**Biphasic**
Two phases (+ and -)
Current flows in both directions.

**Polyphasic (pulsatile)**
Many phases
Waveforms Classification

(a) Balanced and symmetrical biphasic pulse
(b) Unbalanced and asymmetrical biphasic pulse

Symmetrical, balanced

Asymmetrical, unbalanced

Asymmetrical, balanced
<table>
<thead>
<tr>
<th>Time-Dependent Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pulse duration</strong> + <strong>Interpulse interval</strong></td>
</tr>
<tr>
<td><strong>Phase duration</strong> + <strong>Interphase interval</strong></td>
</tr>
<tr>
<td><strong>Burst duration</strong> + <strong>Inter-burst interval</strong></td>
</tr>
<tr>
<td>Frequency</td>
</tr>
</tbody>
</table>
**Frequency**

The number of cycles or pulses per second. Frequency is measured in Hertz (Hz) for cycles or pulses.

- **Low Frequency**
  - < 1000Hz
  - Direct current (DC)/ Galvanic
  - Interrupted direct current/faradic current
  - Transcutaneous electrical nerve stimulation (TENS)
  - High Voltage Pulsed Current (HVPC)
  - Didynamic Current

- **Medium Frequency**
  - 10000-10000
  - Interferential current
  - Russian current

- **Medium Frequency**
  - >10000
  - Ultrasound
  - Shortwave diathermy

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Frequency

- High frequency (> 60-120Hz)
  - Acute pain
  - Spinal pain modulation

- Lower frequency (≤ 20Hz)
  - Chronic pain
  - Supra-spinal pain modulation

### Sensory level

- High frequency (> 60-120Hz)
  - Acute pain
  - Spinal pain modulation

- Lower frequency (≤ 20Hz)
  - Chronic pain
  - Supra-spinal pain modulation

### Motor level

- < 20Hz
  - Individual twitch

- 20-35Hz
  - Individual twitches become less distinguishable summation

- ≥35Hz
  - Tetany muscle contraction

### Degree of mechanical adaptation

- Fatigue

### Amount of tissue impedance

Types of muscles contraction and

- Acute pain
- Spinal pain modulation

- Chronic pain
- Supra-spinal pain modulation
**Pulse Attributes**

**Pulse**: An individual waveform is referred to a pulse. It contains one, or more phases. It is measured in microseconds or milliseconds.

**Pulse duration (PD) = pulse width**: is the time from beginning of first phase of pulse to the end of last phase of a pulse “On Time”

**Interpulse interval**
- is the time between individual pulses “OFF Time”

**Phase duration**
- is a duration of one phase of pulse “on time”

**Interphase interval**
- The time between phases of a pulse “OFF time”

(F) Phase duration.
(G) Pulse duration.
Pulse Attributes

- Shorter phase durations (150 sec) requires greater intensity (amplitude) to evoke an action potential.
- Longer phase durations (200 sec) requires less intensity (amplitude) to evoke an action potential.
- Muscle contraction: Optimum duration – 100-500 sec
- Stimulation of denervated muscle: Optimum duration > 10msec
4-Pulse attributes

Burst

A finite series of pulses flowing for a limited time, followed by no current flow.

\textbf{Burst period} = \text{burst interval (BI)} + \text{inter-burst interval (IBI)}.

1-\text{Burst interval (BI)}

is the length of the time during which burst occurs.
Phase charge is the amount of electrical energy delivered to the tissue with each phase of each pulse which can be measured in micro coulombs per second (μC/sec).

Phase charge relates to:
- Strength of the stimulus or intensity
- The potential for issue damage

[Diagram showing comparison between Monophasic and Biphasic pulses with Amplitude and Duration axes.]
**Ramp up/ramp down time**

**Ramp up**

The ramp up time is the time it takes for the current amplitude to increase from zero, at the end of the off time, to its maximum amplitude during the on time.

Raneged 1-8 seconds (2-second)

**Plateau**

Time during which pulses remain at maximum preset intensity

**Ramp down**

is the time it takes for the current amplitude to decrease from its maximum amplitude during on time back to zero
Concept check
Concept check

Give the name of each letter and define it, than explain it role in clinical application of electricity for electrotherapy.
Give the name of each letter and define it, than explain it role in clinical application of electricity for electrotherapy.
OTHER ELECTRICAL CURRENT PARAMETERS

- Current amplitude
- Current density
- Tissue impedance
  - Polarity
Current Amplitude

Intensity (I)=Amplitude
Is the rate of an (e⁻) flow through a conductor from cathode (-) to anode (+), per second.
Measured in (mA= 1/1,000 ampere) or
1 amp = 6.25 x 10^{18} e^- / sec

Peak current amplitude :
is the maximum (highest) amplitude form zero value of the phase of pulse

Peak to peak amplitude
is the amplitude measured from the peak (maximum) of one phase to the peak (maximum) of next phase only for biphasic current
Current Amplitude

- Increase intensity
- Increase strength of stimulation muscles contraction/
- Increase strength of sensory perception
- Increase depth of penetration to deeper tissue (nerve & muscles)
- Increase number of motor unit recruited

Cross-sectional diameter: Large-diameter nerves depolarize first

Location of the nerve: Superficial nerves depolarize first

- Nonnoxious paresthesias, Tingling, prickling, pins and needles
- Strong uncomfortable paresthesias, strong muscle contraction
Current Density (CD)

The amount of current per unit area

Electrode distance Determines the Current Density

A placed closely electrodes, high CD in superficial tissues.

A spaced apart electrodes, high CD in the deeper tissue (nerve & muscle).

Electrode Size Determines the Current Density
**Tissue impedance**

- **Ohm’s law** showing a comparison of constant current and constant voltage stimulators: \( I = \frac{V}{R} \)

  **Volt (V)** a unit of force required to move a current of 1 amp in 1 sec against a resistance of 1 (110 V or 220 V)
  Higher voltages (> 150 V), deeper penetration e.g. HVPC

**Resistance (R)**
Is a quantitative degree of opposition to the flow of electron.
It is directly proportional to length and inversely proportional to cross section area of a conductor.
Tissue impedance

Check the concept

• (a) If you had a 100 V electrical stimulator applied to a muscle that was providing 20,000 Ω resistance, how much current would flow through the muscle?

• (b) What would the current how be if you decreased skin/muscle resistance to 10,000 Ω?

• Ohm’s law tells us there are two ways of increasing current in a circuit. What are they?
Impedance is the resistance of the tissue to the passage of electrical current.

\[ Z = \frac{1}{2\pi FC} \]

- High – impedance tissue: skin & fat
- Dray skin resistance: (100,000-600,000 Ω)
- Moist skin resistance: (1000-20,000 Ω)

How to overcome resistance to passage of current?

Check your answer in slide ???????????????????????????????????????
Clinical Pearl

Practical tips to decrease skin Resistance

1. **Decrease** distance between electrodes (length)
2. **Increase** the size of electrodes (cross section area)
3. **Minimize** air-electrode interface
4. Use electrodes jelly or moisten the electrodes
5. Pre-warming the skin by moisten heat (i.e. hot packs)
**Polarity**

The charge of an electrode

Positive (anode) or negative (cathode) with a direct or monophasic pulsed current

Constantly changing with an alternating or biphasic pulsed current.

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**Anode**

- Lowest Concentration of Electrons
- Connected to the positive terminal
- **Color code is red**
- Attracts (-) Ions
- Acidic Reaction
- Hardening of Tissues
- Decreased Nerve irritability
- Used in later stage of tissue healing to enhance epithelial migration across the wound bed

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**Cathode**

- Greatest Concentration of Electrons
- Connected to the negative terminal
- **Color code is black**
- Attracts (+) Ions
- Alkaline Reaction
- Softening of Tissues
- Increased Nerve Irritability
- Used in the early inflammatory stage (3-7 days)
- Used in infected wound
- Facilitates Membrane Depolarization
- Usually Considered More Comfortable

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Physiologic Response to electrical stimulation

Effects of Electrical Currents

- Stimulation of Action Potentials in Nerves/Muscles
- Wound healing/inflammatory
- Pain
Physiologic Response to electrical stimulation

- Excitation of nerve cells
- Changes in cell membrane permeability
- Protein synthesis
- Stimulation of fibroblast, osteoblast
- Modification of microcirculation

- Skeletal muscle contraction
- Smooth muscle contraction
- Tissue regeneration

- Modification of joint mobility
- Change circulation & lymphatic activity

- Analgesic effects secondary
Stimulation of Action Potentials In Nerves

Muscle and Nerve Excitation: Concepts to Review

- Resting membrane potential
- Action potential generation and propagation
- Nerve and muscle structure
- Classification of peripheral nerves
- Muscle fiber type and recruitment pattern
- Structure of the motor unit
- Motor unit recruitment

Changing intensity and types of contraction influenced by:

- Frequency
- Intensity
- Pulse duration
- Number of motor unit recruited
## Nerve & Muscles Response to E-Stim

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Slow-Twitch (ST)</th>
<th>Fast-Twitch A (FT-A)</th>
<th>Fast-Twitch B (FT-B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contraction time</td>
<td>Slow</td>
<td>Fast</td>
<td>Very Fast</td>
</tr>
<tr>
<td>Size of motor neuron</td>
<td>Small</td>
<td>Large</td>
<td>Very Large</td>
</tr>
<tr>
<td>Resistance to fatigue</td>
<td>High</td>
<td>Intermediate</td>
<td>Low</td>
</tr>
<tr>
<td>Activity used for</td>
<td>Aerobic</td>
<td>Long-term Anaerobic</td>
<td>Short-term Anaerobic</td>
</tr>
<tr>
<td>Force production</td>
<td>Low</td>
<td>High</td>
<td>Very High</td>
</tr>
<tr>
<td>Mitochondrial density</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Capillary density</td>
<td>High</td>
<td>Intermediate</td>
<td>Low</td>
</tr>
<tr>
<td>Oxidative capacity</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Glycolytic capacity</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Major storage fuel</td>
<td>Triglycerides</td>
<td>CP, Glycogen</td>
<td>CP, Glycogen</td>
</tr>
</tbody>
</table>
Nerve & Muscles Response to E-Stim

1. Facilitate or initiate muscle contraction.
2. Re-educate transplanted muscle contraction.
3. Maintain viability of denervated muscles
4. Increase muscle strength and endurance
5. Retard and prevent disuse atrophy
6. Reduce abnormal muscle tone (e.g. spasticity)
7. Improve postural alignment
8. Maintain and/or increase range of motion
9. To improve circulation and lymphatic drainage
10. To reduce edema
Effect of E-Stim on Tissue Repair

1. Increase capillary permeability and blood flow
2. Increase macrophage, leucocytes and activities.
3. Increase fibroblast & osteoblast activity.
4. Induce bactericidal effects.
5. Improve circulation and lymphatic drainage
6. Reduce edema
Effect of E-Stim on pain modulation

- Modulation of pain perception through central and peripheral mechanisms

1. Blocking ascending pathways Gate control theory
2. Blocking descending pathway
3. Opiate-mediated pain control
4. Local vasodilatation of blood vessels in ischemic tissues
E-stimulation

- Indications
- Precautions
- Contraindications
E-Stim Indications

- Modulate acute, chronic and postoperative pain
- Stimulate contraction of denervated muscles
- Muscle strength and reeducations
- Decrease muscles spasm and control spasticity
- Decreased traumatic edema
- Wound healing and tissue repair (tendon, ligament)
- Diabetic wound, decubitus ulcer, venous and atrial insufficiency ulcer
- Stimulate nerve regeneration
- Increase range of motion
- Increase circulation through pumping action of contracted muscles
E-Stim Contraindications

- Demand cardiac pacemaker or unstable arrhythmias
- Over area of venous or arterial thrombosis or thrombophlebitis
- Over Recent fracture, external fixation
- Near the operating diathermy devices.
- Over anterior neck (e.g. carotid sinus, vagus and phrenic nerve).
- Over bony prominence
- Over or around Malignancy region
- Over /around hemorrhage area.
- Pregnancy—over or around the abdomen
Precautions E-Stim

- Hypertension patients (monitor blood pressure)
- Impaired sensation (e.g. Spinal cord injury, neuropathy)
- Deep internal fixators/open wound
- Cardiac patients (monitor for signs of dizziness, shortness of breath & syncope)
- Recent surgery (muscles, tendon, ligament),
- Allergic reaction to gels, tapes, or electrodes
- On patients who are unable to provide clear feedback (infant, Old, head injury patients, impaired cognition),
Currents Application Technique

- Patient Positioning
- Electrode Type
- Electrode Placement
- General Instructions for Electrical Stimulation
**Patient Positioning**

<table>
<thead>
<tr>
<th>Patient positioning is dictated by the</th>
<th>Patient comfort and modesty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area to be treated,</td>
<td>Goal(s) of treatment, and</td>
</tr>
<tr>
<td>Device used.</td>
<td>Device used.</td>
</tr>
</tbody>
</table>
Electrodes are devices attached to the terminals of electrical stimulator through which current enters and leaves the body. Electrodes come in a variety of sizes, shapes, and materials, and are named according to their function. The three most popular electrode systems over the years have been:

- **Metal-sponge electrodes**: durable, reusable, inexpensive, inflexible
- **Carbone electrodes**: Relatively inexpensive, fairly durable, gel or water required, may cause skin irritation
- **Self adhesive electrodes**: expensive, less durable, flexible, skin irritation, Contamination
Electrodes

II-Locations/orientation

1. On/or around the painful area.
2. Over specific dermatome corresponding to the painful area.
3. Over specific myotomes corresponding to the painful area.
4. Spinal cord segment.
5. Course of peripheral nerve.
7. Over trigger point.
8. Acupuncture point.

Muscle fibers are 4 times more conductive when the current flows with the direction of the fibers than when it flows across them.
**Electrodes Configuration**

**Bipolar Configuration**
- Equal electrodes size
- Equal Current density under each electrode

**Monopolar,**

1. **Active electrode (s) [smaller]** is stimulating electrode and placed on the target muscle, greatest current density – treatment effect.
2. **Dispersive electrode [larger]** – required to complete the circuit, low current density – little or no sensation is felt from this electrode

**Quadripolar Configuration**
- Quadripolar: four electrodes are placed on the target tissue Interferential.
Check the Concept
E-stim Clinical Decision Making

Examination/Evaluation of Patient
- pathology
- impairment
- functional limitation
- disability

Is Electrical Stimulation indicated?
- yes
- no

Can electrical stimulation be used with this patient?
- yes
- no

Contraindications
- EMS
- ESTR
- NMES
- FES
- TENS

Therapeutic Goal
- subsensory
- sensory
- motor
- noxious

Clinical Stimulation Level
- monophasic
- biphasic
- polyphasic

Waveform
- continuous
- interrupted

Delivery

Current Characteristics
- phase duration
- frequency
- ramp
- on/off time

Electrode Placement
- 1 channel
- dual channel
- quadrapolar

Choose commercial unit

Simultaneous, reciprocal

Treatment Time/ Start

Is treatment tolerated?
- yes
- no

Continue
- Adjust parameters
- Terminate
Safety Considerations

**Basic Safety**: Protection against direct physical hazards when medical electrical equipment is used under normal or other conditions.

**Equipment**

- Inspection of equipment before use is an important safety measure that should be implemented as routine.

**Patients**

- Examination and questioned the patient relative to the indications and contraindications of E-stim of the modality being used
- E.g. Skin Condition and Sensation