Basic principle of electricity and electrical stimulation current

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Objectives

- Define the most common terminology related to electricity.
- Differentiated between different current types
- Categorize various waveforms and pulse characteristics
- Discuss the various treatment parameters that must be considered with electrical stimulation
- Explain current flow through various types of biological tissue.
- Explain muscle and nerve response to electrical stimulation.
- Enumerate the indications & contraindication of electrical stimulation.
- Be able to create a safe environment when using electrical equipment.
Outline

Basic terminology

Part I
- Basic current types
- Frequency
- Current amplitude
- Current density and electrodes sizes
- Polarity reaction
- Types of electrodes and configurations used with electrical stimulation application.

Part II
- Physiologic Response to electrical stimulation
  - Response of Non-Excitable Tissues
  - Effect of ES on Musculoskeletal System
  - Effect of ES on Wound Healing
  - Effect on Pain Perception
- Therapeutic & Clinical Use of ES (Indications) and Contraindications to ES
- Safety in Clinical Environment
Electrical Stimulation Related Terms

**Basic terminology**

- **Electricity**
  - A form of energy that exhibits magnetic, chemical, mechanical, and thermal effects; formed from the interaction of positive (+) & negative (−) charges.

- **Electrical Current**
  - A flow of charged particles electron (e−)/ions from higher to lower concentration.

- **Electrotherapy**
  - Application of electrical energy for therapeutic purposes

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

1. **Voltage (electrical potential difference):**
   - The differences of electrical energy between two points that produce electrical force capable of moving charged particles through conductors.

**Volt (V)**
- A unit of force required to move a current of 1 amp in 1 sec against a resistance of 1 Ω (110 V or 220 V).

- Higher voltages result in deeper penetration.
  - **High Volt:** ≥150 V
  - **Low Volt:** ≤150 V
**Electrical Stimulation Related Terms**

### Intensity (Magnitude) of Current
- It is the rate of an \(e^-\) flow through a conductor from cathode (-) to anode (+), per second.
- Measured in Ampere or (mA = 1/1,000 ampere) or (μA; 1/1,000,000 ampere)

\[
1 \text{ amp} = 6.25 \times 10^{18} e^- / \text{sec}
\]

### Resistance:
- 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.

### Ohm: \((Ω)\) unit to measure resistance to current flow;
- \(1 \text{ ohm}\) = the amount of resistance needed to develop \(0.24 \text{ calories}\) of heat when \(1 \text{ Am}\) of current is applied for \(1 \text{ second}\)
**Electrical Stimulation Related Terms**

**Ohm's law** current is directly proportion to voltage & inversely proportional to resistance

\[ I = \frac{V}{R} \]

I=current flow, V=Potential differences, R=Resistance

**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 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?
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)

N.B. Preheating the treatment area may increase the comfort of the patient but also increases resistance and need for higher output intensities
Electrical Stimulation Related Terms

**Conductor** is a substance that can transport electrical charge (or current) from one point to another. It must have free \{e^-\} in their outer orbit that can be pushed along metals.

**Higher** conductance materials:
- free flow of e^-
  - Silver, Copper,
  - Electrolyte solutions
  - Blood cell: highest ionic & H\textsubscript{2}O
  - Inner layer of the skin
  - Nerves
  - Muscle fibers
  - Cell membranes

**Low** conductance materials:
- few free e^-s
  - Air, Wood, Glass, Rubber
  - Bone
  - Cartilage
  - Tendons
  - Ligaments
  - Outer layer of Skin has keratinized epithelium (little H\textsubscript{2}O) acts as insulator

*Human body:* The greater is the percentage of H\textsubscript{2}O in the tissues, the better is the conductance of electricity.
Electric Circuits

**Series Circuit**

- Only one pathway for current flow
- $R_{\text{total}} = R_1 + R_2 + R_3$
- Voltage will decrease at each resistance component
- Higher resistance and lower current flow

![Series Circuit Diagram]

**Parallel Circuit**

- More than one pathway for flow of electrons
- $1/R_{\text{total}} = 1/R_1 + 1/R_2 + 1/R_3$
- Voltage will not decrease at each resistance component
- Lower resistance and higher current flow

![Parallel Circuit Diagram]
Current enters the body through a **SERIES** circuit (skin & fat). Once the current enters the tissues, it takes many different **PARALLEL** paths in Human body; the greater is the percentage of $\text{H}_2\text{O}$ in the tissues, the better is the conductance of electricity & lower resistance.
Waveforms related parameters

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

1-Waveforms Shape:

- Sine wave
- Rectangular wave
- Square wave
- Triangular wave
- Saw tooth wave
- Trapezoid wave

All types of current may take on any of the waveform
Waveforms related parameters

- **Symmetrical waveforms**
  Each phase
  - Equal in amplitude,
  - Equal in shape & size
  - Net charge is zero

- **Asymmetrical waveforms**
  Each phase
  - Not equal in amplitude,
  - Not equal in shape & size
  - Net charge > than zero.
Parameters of electrical Current stimulation

1) **Types of currents:** Alternating vs. direct current
2) **Frequency**
3) **Intensity of current**
4) **Time dependent parameter (Pulse attributes)**
5) **Tissue impedance**
6) **Current density**
7) **Electrodes considerations**
   7-A- **Polarity**
   7-B- **Types and size**
   7-C- **Placement**
   7-D- **Configurations**
   7-F- **Orientation**
## 1-Basic Current types

<table>
<thead>
<tr>
<th>Direct current (DC)</th>
<th>Alternating Current (AC)</th>
<th>Pulsed current (PC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Def.</td>
<td>The e-flow in alternating directions in both sides of isoelectric line from (−) pole to (+)pole.</td>
<td>Interrupted electron flow. The simplest form of interruption is to turn the switch on and off.</td>
</tr>
<tr>
<td>is continuous unidirectional flow of e−s toward (+) pole</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shape</th>
<th>Monophasic</th>
<th>Biphasic</th>
<th>Monophasic or biphasic</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Types</th>
<th>Traditional “galvanic current”</th>
<th>Current can be symmetrical, asymmetrical e.g. TENS,</th>
<th>Groups of pulses are interrupted for short periods of time (inter-pulse intervals) &amp; repeat. Russian current Interferential current</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Modulated Interrupted direct current or “interrupted galvanic”</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Uses</th>
<th>Iontophoresis Stimulate contraction of denervated muscle;</th>
<th>Pain relief Neuromuscular stimulation.</th>
<th>Pain relief Neuromuscular stimulation Wound healing</th>
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</thead>
</table>

![Current Types Diagram](image-url)
1-Alternating vs. Direct Current

Nerve doesn’t know the difference between different current types (e.g. AC and DC, PC)

The biggest difference between direct current and alternating current is the ability of direct current (e.g. continuous unidirectional, long pulse duration current) to produce chemical reaction.

- Direct current
  - Chemical burn
  - chemical reaction
- Low voltage pulsed current
- High voltage pulsed current
- Alternating current
  - No chemical reaction
  - lower voltages (20–35 V)
  - Very short pulse duration
  - Reversing polarity
  - No Chemical burn
2-Frequency

Frequency is a cycles/sec (cps): the number of cycles completed each second

Low
<1000Hz

Medium
1000-10000Hz

High
> 10000Hz

Direct current (DC)/ Galvanic
Interrupted direct current/faradic current
Transcutaneous electrical nerve stimulation (TENS)
High Voltage Pulsed Current (HVPC)
Didynamic Current

Interferential current
Russian current

Short wave diathermy(SWD)
Ultrasound (US)
2-Frequency (CPS, PPS, Hz)

Frequency determines types of muscles contraction and degree of mechanical adaption

<table>
<thead>
<tr>
<th>Frequency range</th>
<th>Muscle contraction types</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 20Hz</td>
<td>Individual twitch</td>
</tr>
<tr>
<td>20-35Hz</td>
<td>Individual twitches become less distinguishable summation</td>
</tr>
<tr>
<td>≥50</td>
<td>Tetanic muscle contraction</td>
</tr>
</tbody>
</table>

**Mechanical adaption**
Increase amount between pulse (inter-pulse duration allows muscles fibers to recovery from fatigue

**Effects of frequency on the pain modulation (sensory level)**
1. Spinal pain modulation > 60-120Hz
2. Supra-spinal pain modulation ≤20Hz
**3-Current Intensity=Amplitude**

**Peak current amplitude**: is the maximum (highest) amplitude from zero value of the phase.

**Peak to peak amplitude** is the amplitude measured from the peak (maximum) of one phase to the peak (maximum) of next phase.
3-Current Intensity=Amplitude

Increase intensity will increase
- Strength of stimulus sensory and motor (e.g. contraction).
- Depth of penetration of current to deeper tissue (nerve & muscles)
- Number of motor unit recruited

Nerves always depolarize in the following orders
- Sensory nerves
- Motor nerves
- Pain nerves
- Muscle fiber

Based on the
Cross-sectional diameter: Large-diameter nerves depolarize first
Location of the nerve: Superficial nerves depolarize first
**Pulse:** An individual waveform is referred to a pulse
   It contains one, or more phases.
   It is measured in microseconds or milliseconds.

Pulse named by number of phases

- **Monophasic**
  - One phase
  - Current flows in one direction only.

- **Biphasic**
  - Two phases
  - Current flows in both directions.

- **Polyphasic (pulsatile)**
  - Many phases
4-Time dependent parameters

**Pulse Period**

= pulse duration (PD) + the inter-pulse interval (IPI). (msec., μsec)

1-Pulse duration (PD) = pulse width: is the length of time electrical flow is “on”, the time form beginning of first phase of pulse to the end of last phase of a pulse

2-Interpulse interval (IPI); is the time where electrical flow is “off”

Phase duration is a duration of one phase of pulse, and it is length of time current flow in one direction before return to zero line
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-Time dependent parameters**

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

**Burst period** = burst interval (BI) + inter-burst interval (IBI).

1- **Burst interval (BI)** is the length of the time during which burst occurs.

2- **Interburst interval (IBI)** is length of the time between two successive bursts, and current flow is “off”
4-Pulse Attributes

Pulse Train: individual patterns of waveforms, durations &/or frequencies that are linked together (repeat @ regular intervals)

Amplitude Ramp: gradual rise &/or fall in amplitude of a pulse train (causes a gradual ↑ in the force of MS. contractions by progressive recruitment of motor units)

Ramp up
Time during which the intensity increases

Plateau
Time during which pulses remain at maximum preset intensity

Ramp down
Time during which the intensity decreases
Concept check
Concept check

Give the name of each letter and define it, than explain it role in clinical application of electricity for electrotherapy.
Charge is equal to the current intensity ($I$) x time $Q = IT$, and is measured by coulombs.

**Pulse charge** Electrical charge of a single pulse or Sum of phase charges

**Phase charge**: Electrical charge of a single phase, expressed as coulombs. Time integral; result of both amplitude and width.
Impedance is the resistance of the tissue to the passage of electrical current.

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

- High – impedance tissue: skin, bone & fat
- Dray skin resistance: (100.000-600,000Ω)
- Moist skin resistance: (1000-20,000 Ω)

How to overcome resistance to passage of current?

1. Decrease distance between electrodes
2. Increase the size of electrodes
3. Minimize air-electrode interface
4. Use electrodes jelly or moisten the electrodes
5. Pre-warming the skin by moisten heat modalities (e.g. hot packs)
6-Current Density (CD)

The amount of current per unit area.

CD is highest where electrodes contact the skin and decreased as the electricity penetrates into deeper tissues.

Increases CD will increase perception of stimulus

CD is equal under same sized and proper (at least 2 inches) distance of electrodes.
6-Current Density (CD)

Electrode Size/distance Determines the Current Density E

A placed closely electrodes produces high CD in superficial tissues.

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

Large electrode (dispersive electrode) CD is less

Small electrode (active electrode) closed relatively to treatment area (nerve and muscle), CD is greater
7-A-Polarity

Positive Pole (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

Negative Pole (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 of tissue (3-7 days)
- Used in infected wound

With AC Current and Interrupted DC Current Polarity Is Not Critical

- Select Negative Polarity For Muscle Contraction
  - Facilitates Membrane Depolarization
  - Usually Considered More Comfortable

- Negative Electrode Is Usually Positioned Distally
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
7-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.
7-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.
Physiologic Response to electrical stimulation

- Analgesic effects secondary to endogenous pain suppressors released.
- Analgesic effects from the stimulation of certain neurotransmitters to control neural activity in the presence of pain stimuli.
  - Modification of joint mobility
  - Change circulation & lymphatic activity
  - Skeletal muscle contraction
  - Smooth muscle contraction
  - Tissue regeneration
- Excitation of nerve cells
- Changes in cell membrane permeability
- Protein synthesis
- Stimulation of fibroblasts, osteoblasts
- Modification of microcirculation
Nerve & Muscles Response to ES

Resting potential
Action potential
Depolarization
Propagation of action potential
Absolute Refractory period
Re-polarization
All-or-none Principle

Changing intensity and types of contraction influenced by:

- Frequency
- Intensity
- Pulse duration
- Number of motor unit recruited
Nerve & Muscles Response to ES

1. Resting potential: all voltage-gated channels closed.
2. At threshold, Na⁺ activation gate opens and $P_{Na⁺}$ rises.
3. Na⁺ enters cell, causing explosive depolarization to +30 mV, which generates rising phase of action potential.
4. At peak of action potential, Na⁺ inactivation gate closes and $P_{Na⁺}$ falls, ending net movement of Na⁺ into cell. At the same time, K⁺ activation gate opens and $P_{K⁺}$ rises.
5. K⁺ leaves cell, causing its repolarization to resting potential, which generates falling phase of action potential.
6. On return to resting potential, Na⁺ activation gate closes and inactivation gate opens, resetting channel to respond to another depolarizing triggering event.
7. Further outward movement of K⁺ through still-open K⁺ channel briefly hyperpolarizes membrane, which generates after hyperpolarization.
8. K⁺ activation gate closes, and membrane returns to resting potential.
## Types of muscles fibers

<table>
<thead>
<tr>
<th>Property</th>
<th>Slow</th>
<th>Intermediate</th>
<th>Fast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross-sectional diameter</td>
<td>Small</td>
<td>Intermediate</td>
<td>Large</td>
</tr>
<tr>
<td>Tension</td>
<td>Low</td>
<td>Intermediate</td>
<td>High</td>
</tr>
<tr>
<td>Contraction speed</td>
<td>Slow</td>
<td>Fast</td>
<td>Fast</td>
</tr>
<tr>
<td>Fatigue resistance</td>
<td>High</td>
<td>Intermediate</td>
<td>Low</td>
</tr>
<tr>
<td>Color</td>
<td>Red</td>
<td>Pink</td>
<td>White</td>
</tr>
<tr>
<td>Myoglobin content</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Capillary supply</td>
<td>Dense</td>
<td>Intermediate</td>
<td>Scarcie</td>
</tr>
<tr>
<td>Mitochondria</td>
<td>Many</td>
<td>Intermediate</td>
<td>Few</td>
</tr>
<tr>
<td>Glycolytic enzyme concentration in sarcoplasm</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Substrates used for ATP generation during contraction</td>
<td>Lipids, carbohydrates, amino acids (aerobic)</td>
<td>Primarily carbohydrates (anaerobic)</td>
<td>Carbohydrates (anaerobic)</td>
</tr>
<tr>
<td>Alternative names</td>
<td>Type I, S (slow), red, SO (slow oxidizing), slow-twitch oxidative</td>
<td>Type II-A, FR (fast resistant), fast-twitch oxidative</td>
<td>Type II-B, FF (fast fatigue), white, fast-twitch glycolytic</td>
</tr>
</tbody>
</table>
Effect of Electrical stimulation

Musculoskeletal System

Muscle excitation results in contraction, so increase muscles strength/endurance. Increase muscle blood flow.

Increased Muscle fiber hypertrophy (both type I and type II fibers)

Increased proportion of type I muscle fibers.

Attenuation of the decrease in ATPase, e.g., immobilization.

Wound Healing

Increase capillary permeability and blood flow

Increase macrophage, leucocytes and activities.

Increase fibroblast & osteoblast activity.

Induce bactericidal effects.

Reduction of edema.

Pain Perception

Modulation of pain perception through central and peripheral mechanisms.
Therapeutic & Clinical Use of ES (Indications)

A-Electrical stimulation of neuromuscular system

1. To Facilitate or initiate muscle contraction.
2. To re-educate transplanted muscle contraction.
3. To stimulate dennervated muscles
4. To increase muscle strength and endurance
5. To retard and prevent disuse atrophy
6. To reduce abnormal muscle tone (e.g. spasticity)
7. To improve postural alignment
8. To maintain and increase range of motion
9. To improve circulation and lymphatic drainage
10. To reduce edema
Therapeutic & Clinical Use of ES (Indications)

B-Pain modulation
To relive pain (acute, chronic & postoperative)

C-To stimulate biological tissue for promotion of healing
To stimulate bone growth?
To promote wound healing (e.g. Diabetic foot ulcer, Bed, sores & Incisional wound)
To facilitate edema reduction

D-To facilitated transmission of drugs across the skin (Iontophoresis)
Contraindications to ES

- Over thoracic area (e.g. Pacemakers)
- In region with venous or arterial thrombosis or thrombophlebitis
- Recent fracture, external fixation (metal implant)
- Near the operating diathermy devices.
- Over anterior neck (avoid stimulation of the vagus or phrenic nerve).
- Over the lumber, lower abdomen or perineal area of pregnant woman.
- Over the eye.
- Over bony prominence
- Malignancy (in, or over region of neoplasm).
- Over /around hemorrhage area.
Precautions ES

- Hypertension patients (monitor blood pressure)
- Third trimester (N.B TENS can be used to relieve pain)
- Impaired sensation (e.g. Spinal cord injury, neuropathy)
- Deep internal fixators/open wound
- Cardiac patients (monitor for signs of dizziness, shortness of breath and syncope)
- Recent surgery (muscles, tendon, ligament), contraction will affect surgical repair
- Allergic reaction to gels, tapes, or electrodes
- On patients who are unable to provide clear feedback (infant, Old, head injury patients, impaired cognition), frequent monitor
Safety in Clinical Environment

- **Safety**: freedom from unacceptable risk of harm.

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

- **Risk**: The probable rate of occurrence of a hazard causing harm and the degree of severity of the harm.

**Electrical hazards**

- Electrical shocks (micro and macro) due to equipment failure, failure of power delivery systems, ground failures, burns, fire, etc.

  - **Microshock** is imperceptible electrical shock because of leakage of current less than 1mA.

  - **Macroshock** is perceptible electrical shock because of leakage of current greater than 1mA.
Safety tips

<table>
<thead>
<tr>
<th>Current (mA)</th>
<th>Sensation Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5mA</td>
<td>Tingling sensation</td>
</tr>
<tr>
<td>5-8mA</td>
<td>Intense or painful sensation</td>
</tr>
<tr>
<td>8-20mA</td>
<td>Threshold of involuntary muscle contraction</td>
</tr>
</tbody>
</table>
Safety Tips in Use of Electricity

• The therapist should be very familiar with the equipment being used & any potential problems that may developed.

• It should not be assumed that all three–pronged wall outlets are automatically grounded to the earth, the ground must be checked.

• Any defective equipment should be removed from the clinic immediately.

• The plug should not be jerked out of wall by pulling on the cable

• Extension cords or multiple adaptors should be never used.

• When applying electrodes, take care to avoid overlapping negative and positive electrodes, and avoid having conductive materials

• Equipment should be reevaluated on a yearly basis.

• Do not let electrical current flow across a pregnant uterus or a cardiac pacemaker.

• Avoid electrical burn, over-fatigue of stimulated muscles
Compression Wrap

2 Electrodes on triceps surae

Edema

Elevation

2 Electrodes on hamstrings