Introduction to electrical current in physical therapy

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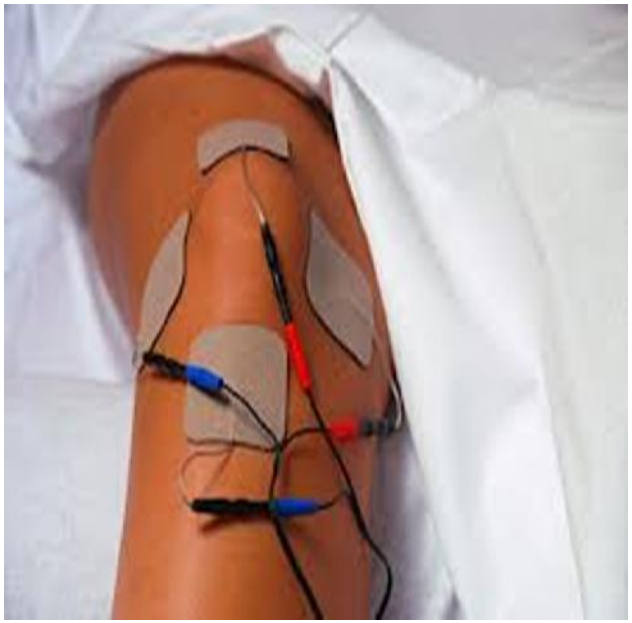


Objectives

- Establish the various clinical parameters that must be considered with electrical stimulation
  - Basic current types
  - Frequency
  - Current amplitude
  - Current density and electrodes sizes
  - Polarity reaction
  - Types of electrodes and configurations used with electrical stimulation application.
- 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

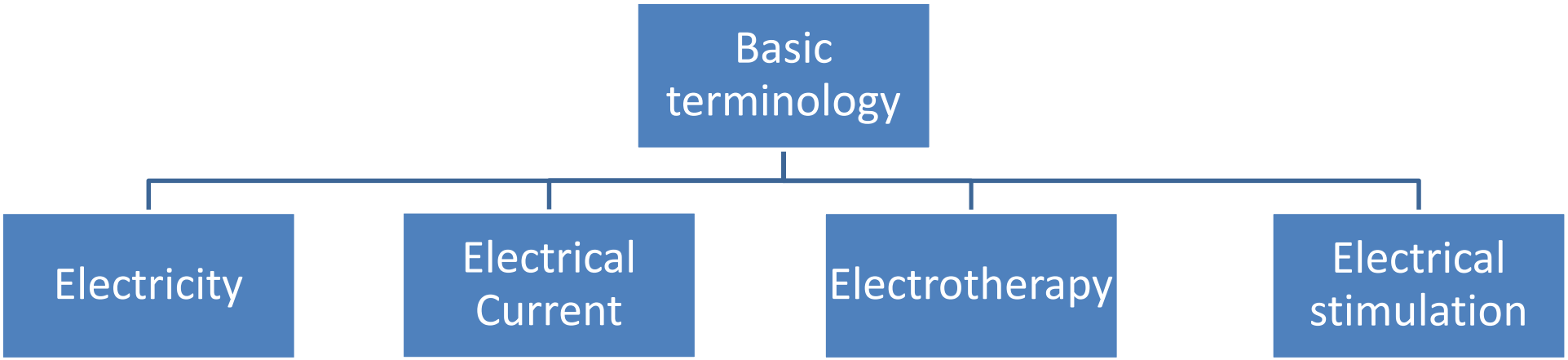
Part I

- 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



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

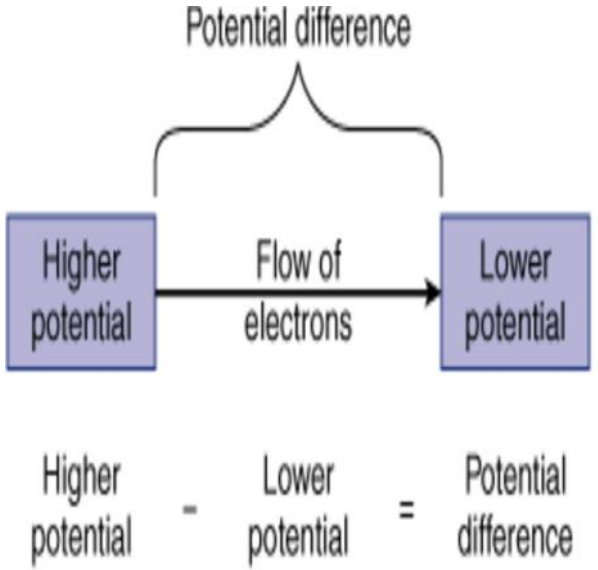
A flow of charged particles electron (e^-)/ions from higher to lower concentration.

Application of electrical energy for therapeutic purposes

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

Electrical Stimulation Related Terms

- **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 0r 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) $1 \text{ amp} = 6.25 \times 10^{18} \text{ e}^- / \text{sec}$

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 ohm = the amount of resistance needed to develop **0.24 calories** of heat when **1 Am** of current is applied for **1 second**

Electrical Stimulation Related Terms

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

$$I = V/R$$

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 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?

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^-_s

- Silver, Copper,
- Electrolyte solutions
- Blood cell: highest ionic & H_20
- Inner layer of the skin
- Nerves
- Muscle fibers
- Cell membranes

Low conductance materials:

few free e^-s

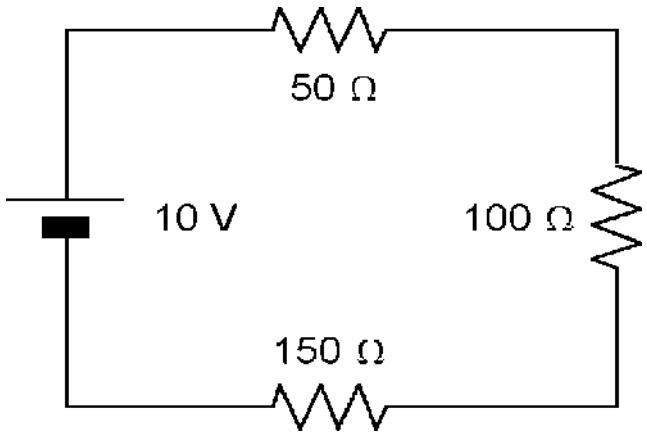
- Air, Wood, Glass, Rubber
- Bone
- Cartilage
- Tendons
- Ligaments
- Outer layer of Skin has keratinized epithelium (little H_20) acts as insulator

Human body: The greater is the percentage of H_2O in the tissues, the better is the conductance of electricity.

Electric Circuits

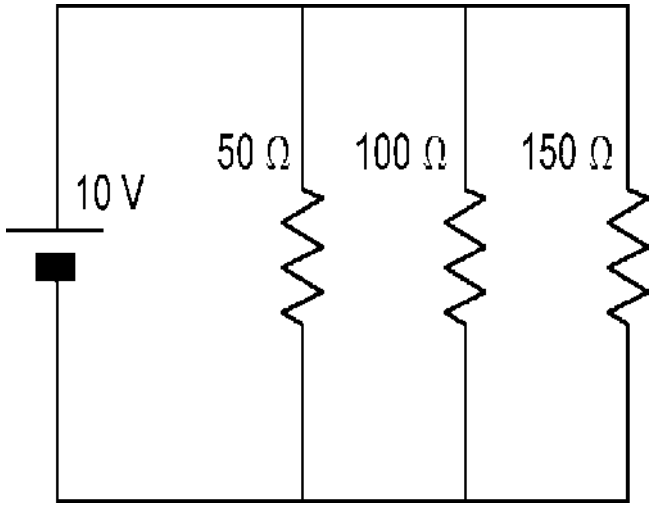
Series Circuit

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

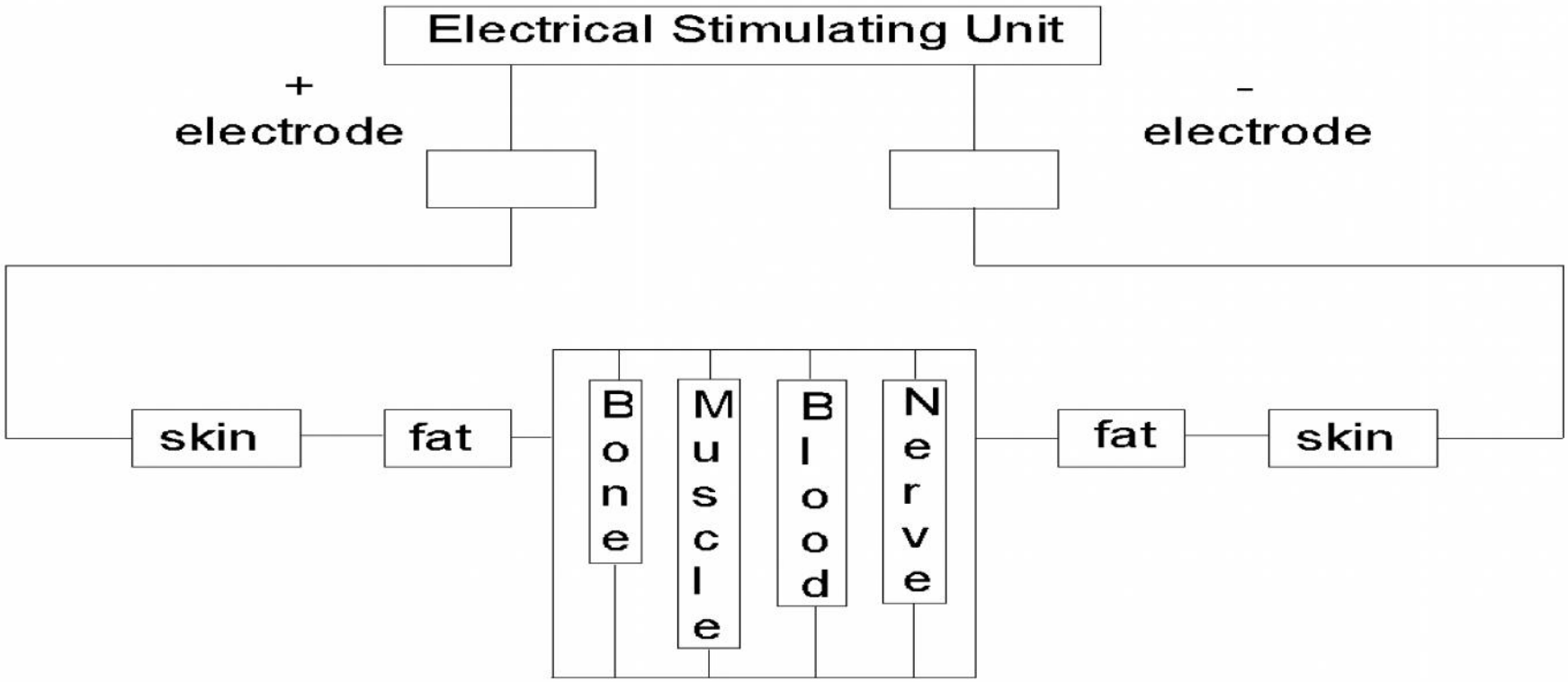


Parallel Circuit

- More than one pathway for flow of electrons
- $1/R_{total} = 1/R1 + 1/R2 + 1/R3$
- Voltage will not decrease at each resistance component
- Lower resistance and higher current flow



Electrical Circuits in the Human Body



Current enters the body through a SERIES circuit (skin &fat).
Once the current enters the tissues, it takes many different PARALLEL paths

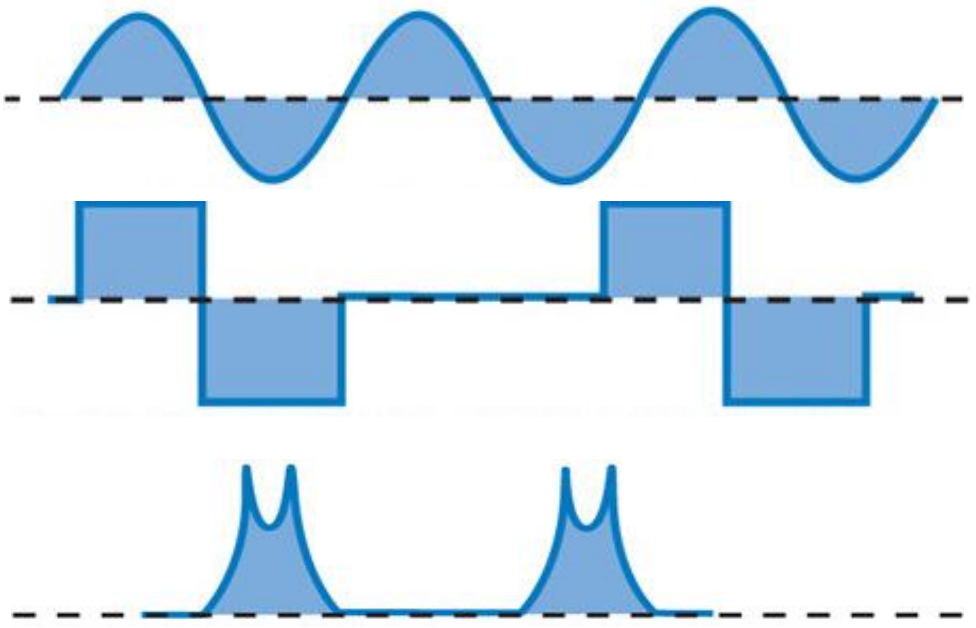
in Human body; the greater is the percentage of H_2O in the tissues, the better is the conductance of electricity & lower resistance.

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

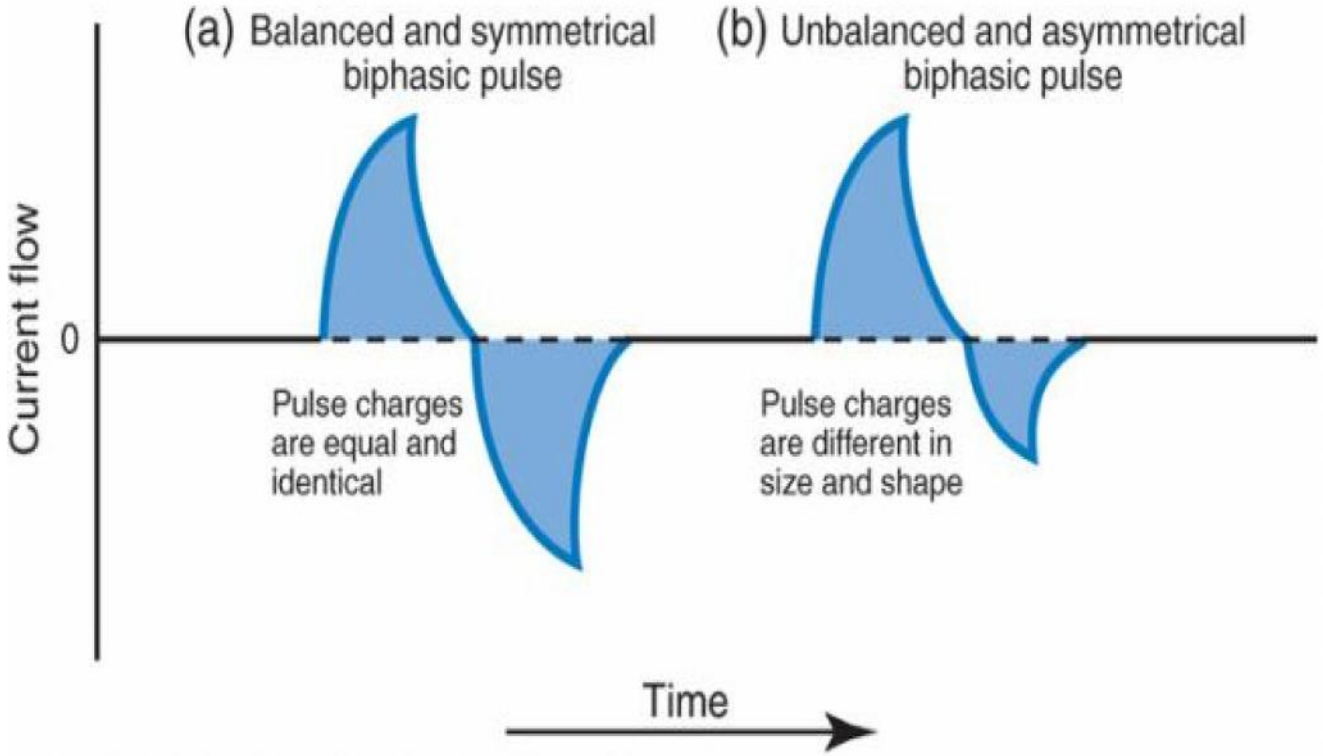
Asymmetrical waveforms :

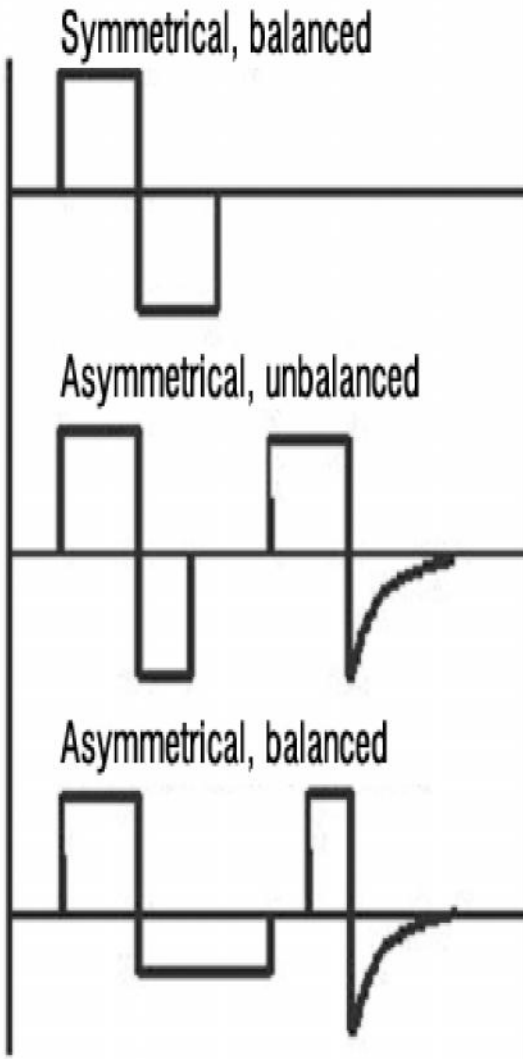
Each phase

Not equal in amplitude,

Not equal in shape &size

Net charge > than zero.





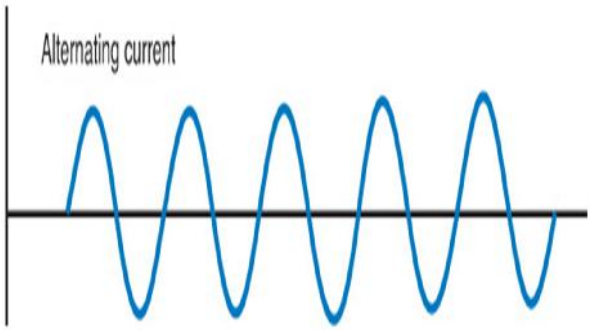
Parameters of electrical Current stimulation

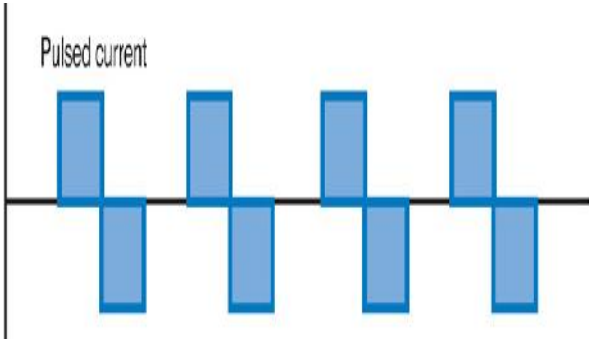
1) *Types of currents: Alternating vs. direct current*
2) *Frequency*
3) *Intensity of current*
4) *Time dependent parameter (Pulse attributes)*
5) *Tissue impedance*
6) *Current density*
7) *Electrodes considerations*

   7-A-Polarity
   7-B-Types and size
   7-C-placement
   7-D-Configurations
   7-F-Orintation

1-Basic Current types

	Direct current (DC)	Alternating Current (AC)	Pulsed current () PC
Def.	is continuous unidirectional flow of e-'s toward (+) pole	The e- flow in alternating directions in both sides of isoelectric line from (–) pole to (+)pole.	Interrupted electron flow The simplest form of interruption is to turn the switch on and off
Shape	Monophasic	Biphasic	Monophasic or biphasic
Types	Traditional "galvanic current" Modulated Interrupted direct current or " interrupted galvanic"	Current can be symmetrical, asymmetrical e.g. TENS, Russian current Interferential current	Groups of pulses are interrupted for short periods of time (inter-pulse intervals) & repeat.
Uses	Iontophoresis Stimulate contraction of denervated muscle;	Pain relief Neuromuscular stimulation.	Pain relief Neuromuscular stimulation Wound healing

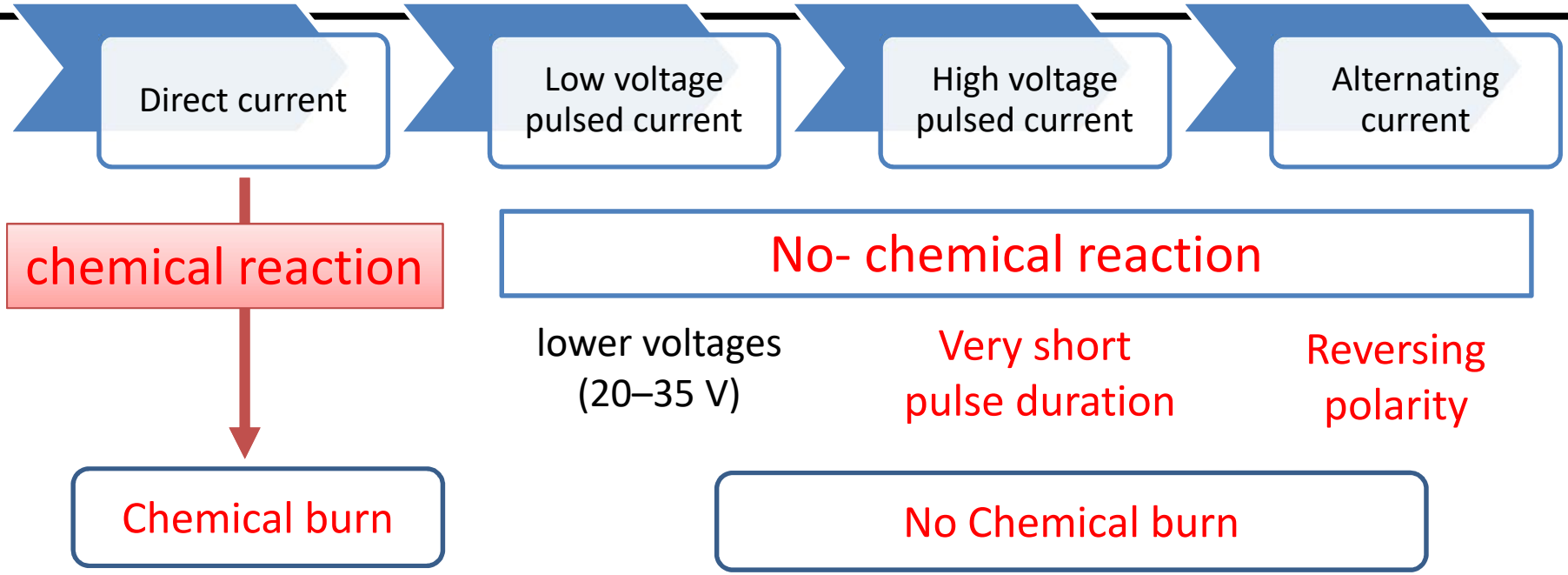




1-Alternating vs. Direct Current

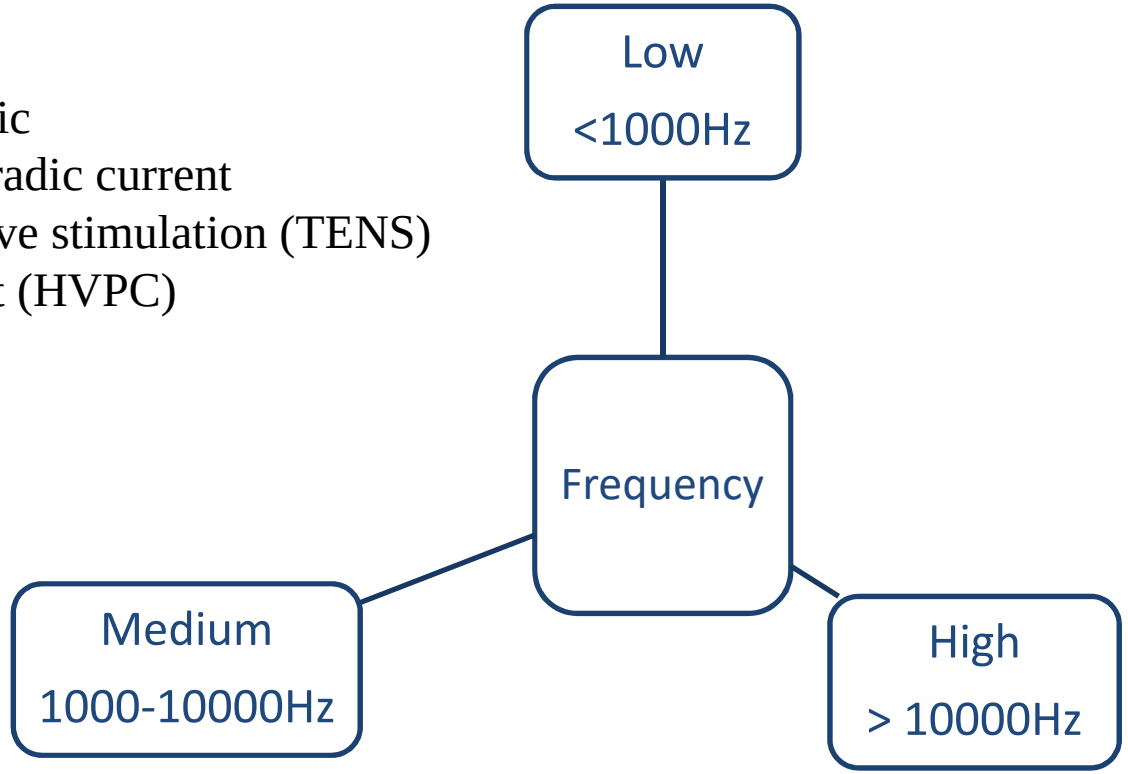
Nerve doesn't know the difference between different current types (e.g. AC and DC, PC)

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**.



2-Frequency

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



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

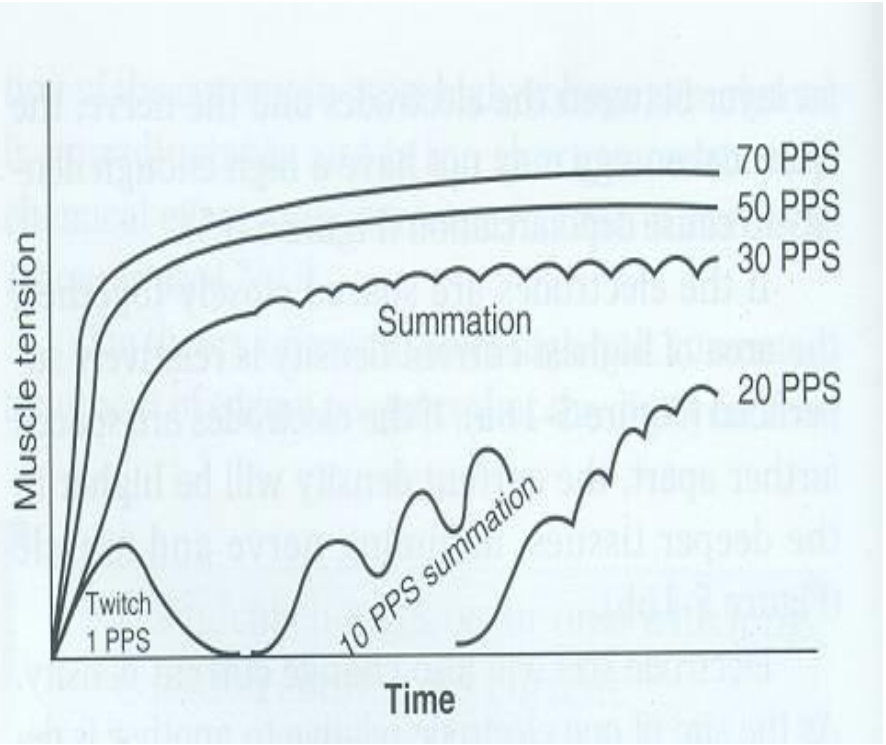
Interferential current
Russian current

Short wave diathermy(SWD)
Ultrasound (US)

2-Frequency (CPS, PPS, Hz)

Frequency determines types of muscles contraction and degree of mechanical adaption

Frequency range	Muscle contraction types
< 20Hz	Individual twitch
20-35Hz	Individual twitches become less distinguishable summation
≥50	Tetanic muscle contraction
Mechanical adaption	
Increase amount between pulse (inter-pulse duration allows muscles fibers to recovery form fatigue	



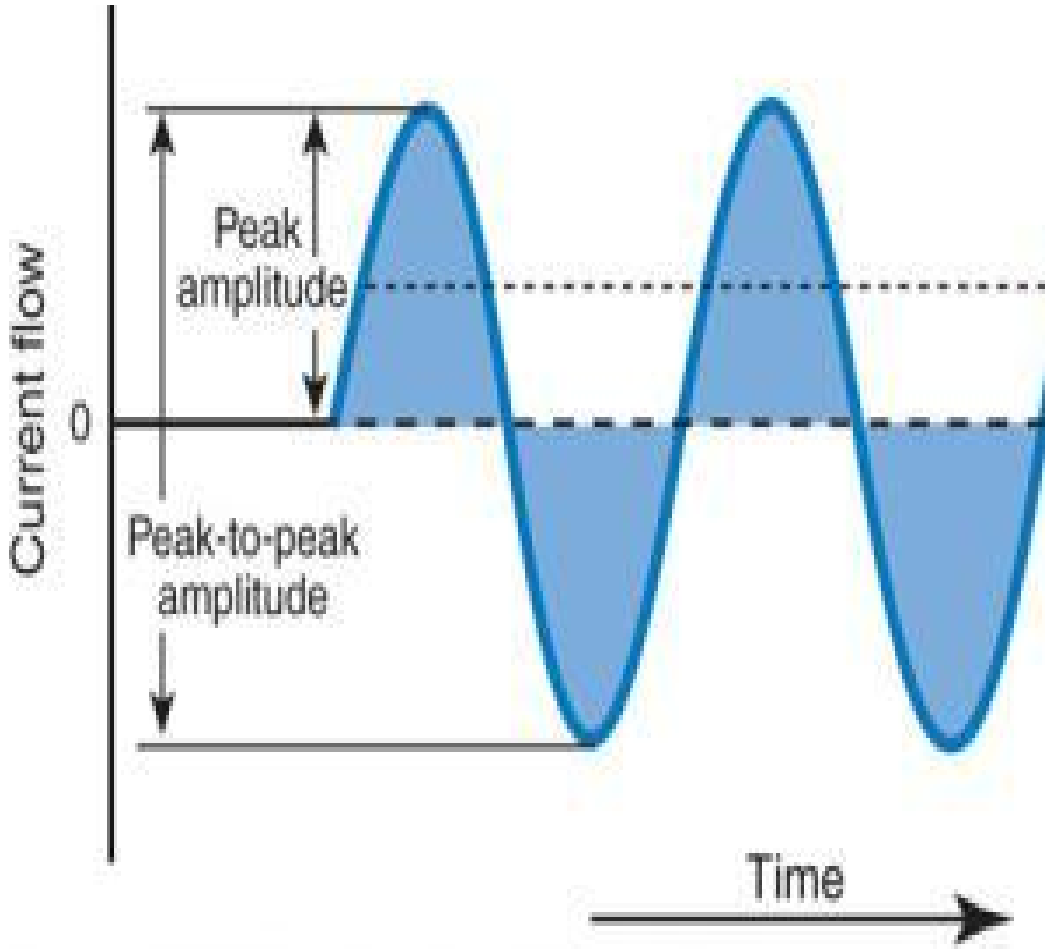
Effects of frequency on the pain modulation (sensory level)

1. Spinal pain modulation > 60-120Hz
2. Supra-spinal pain modulation ≤ 20Hz

3-Current Intensity=Amplitude

Peak current amplitude : is the maximum (highest) amplitude form 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 same order

- Sensory nerves
- Motor nerves
- Pain nerves
- Muscle fiber

Based on the cross-sectional diameter

Large-diameter nerves depolarize first

Location of the nerve

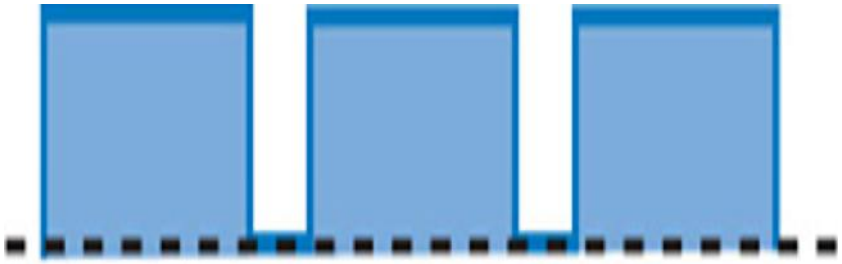
Superficial nerves depolarize first

4-Time dependent parameters

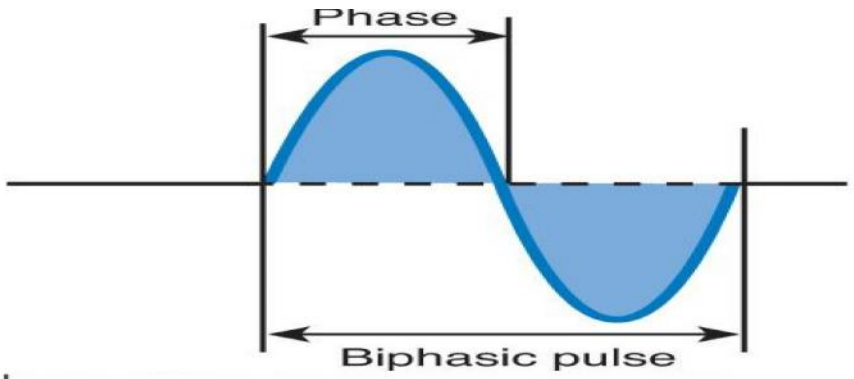
Pulse: An individual waveform is referred to a pulse It contains one , or more phases. It is measured in microseconds or milliseconds.

Pulse named by number of phases

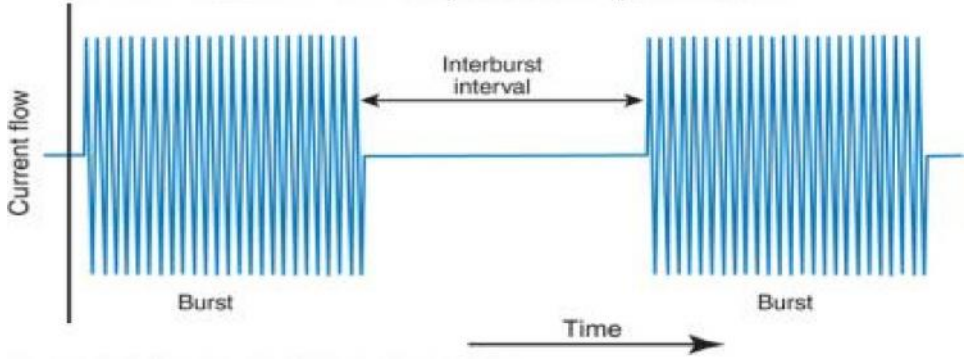
- Monophasic
  - One phase
  - Current flows in one direction only.



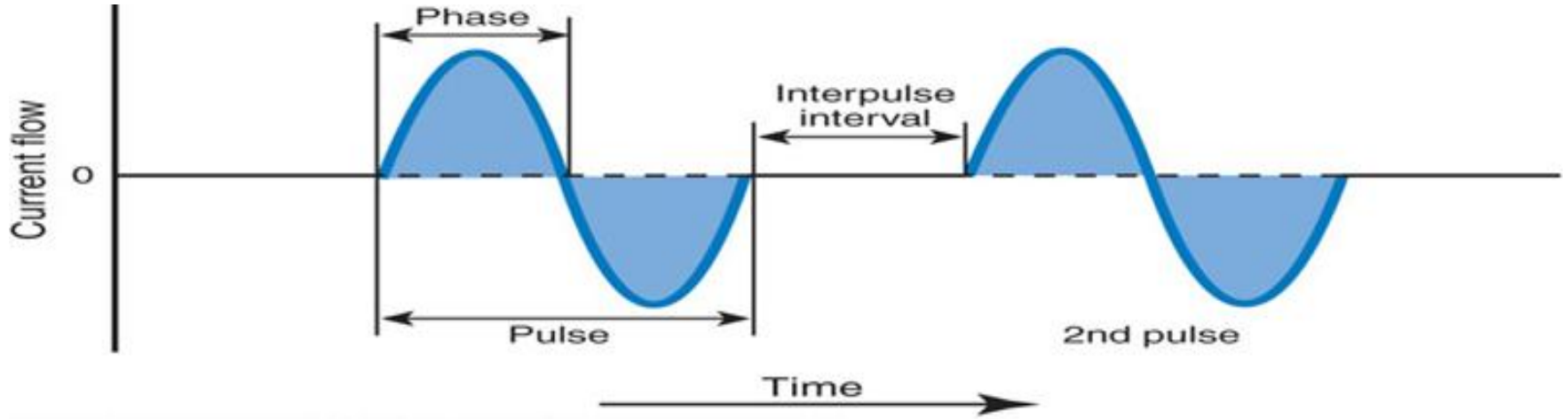
- Biphasic
  - Two phases
  - Current flows in both directions.



- Polyphasic
  - 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 between two successive pulses, 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

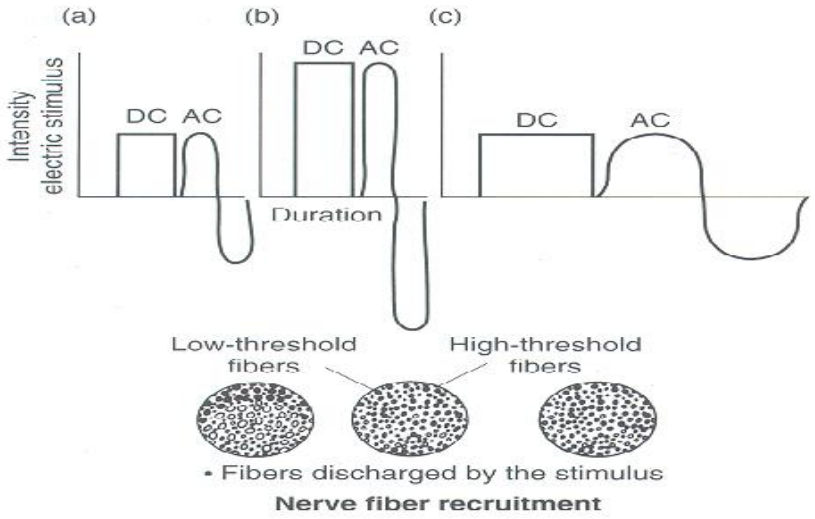
4-Time dependent parameters

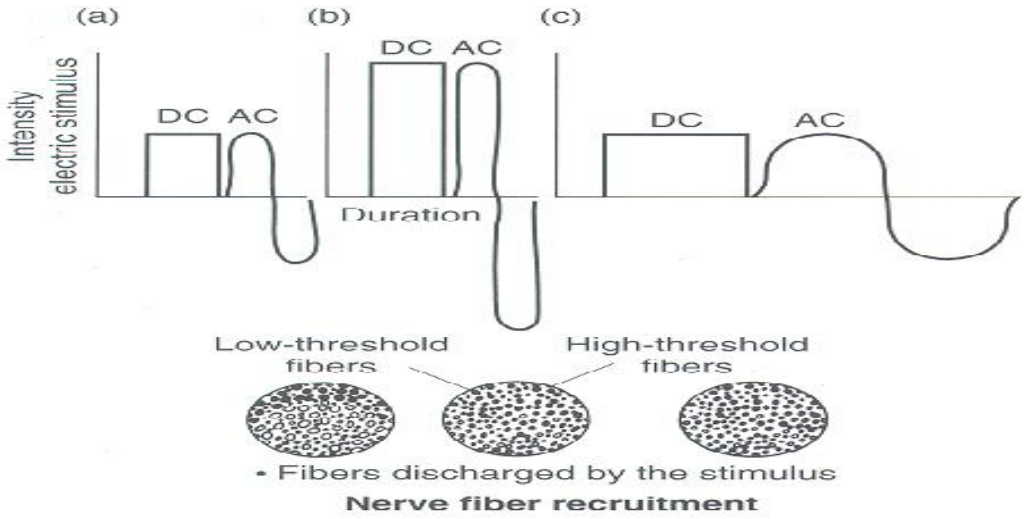
Shorter phase durations (150µsec) requires greater intensity (amplitude) to evoke an action potential.

Longer phase durations (200µsec) requires less intensity (amplitude) to evoke an action potential.

Muscle contraction: Optimum duration – 100-500µsec

Stimulation of denervated muscle: Optimum duration > 10msec





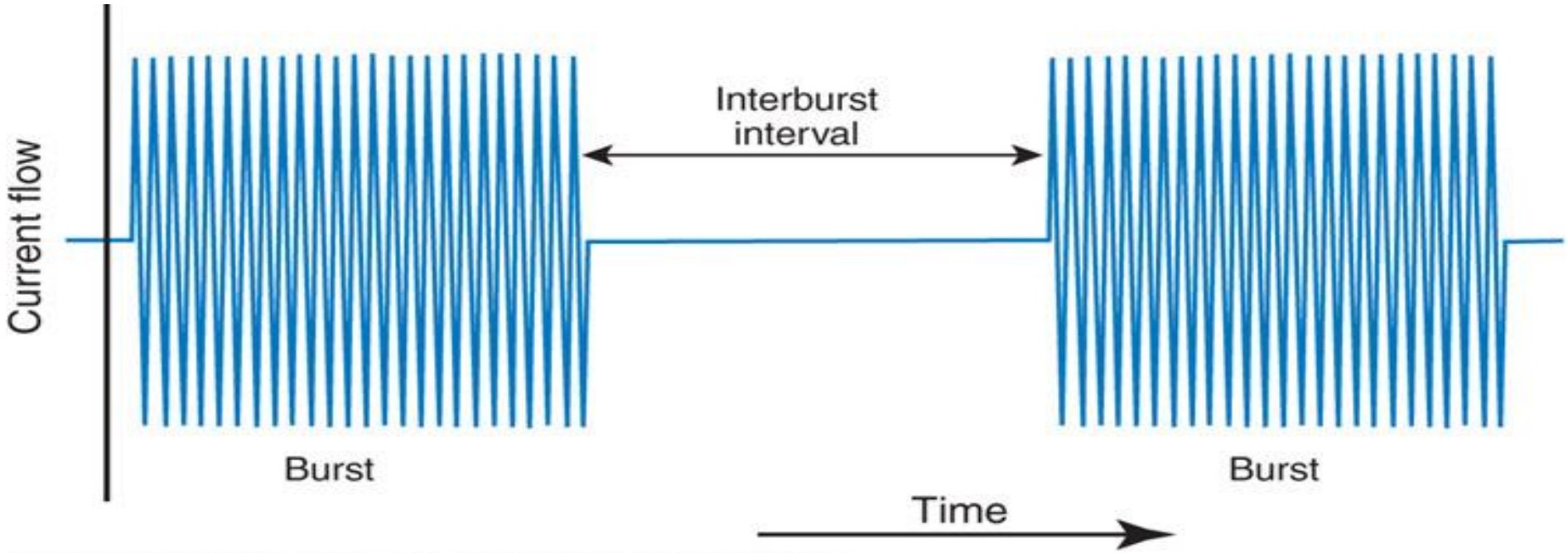
4-Time dependent parameters

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

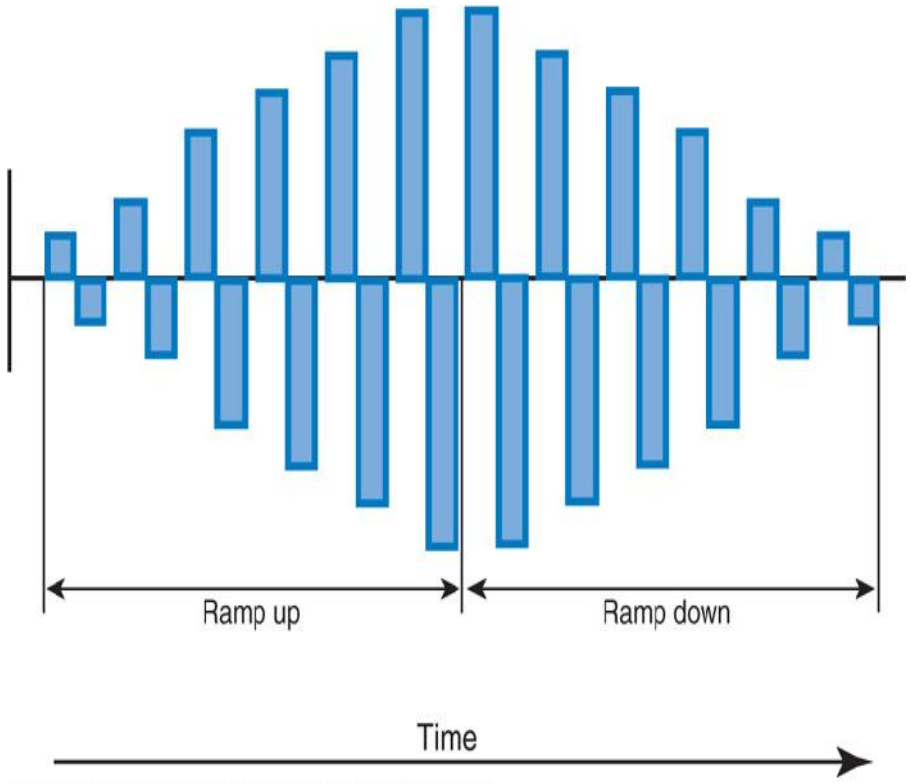
Time during which the intensity increases

Plateau

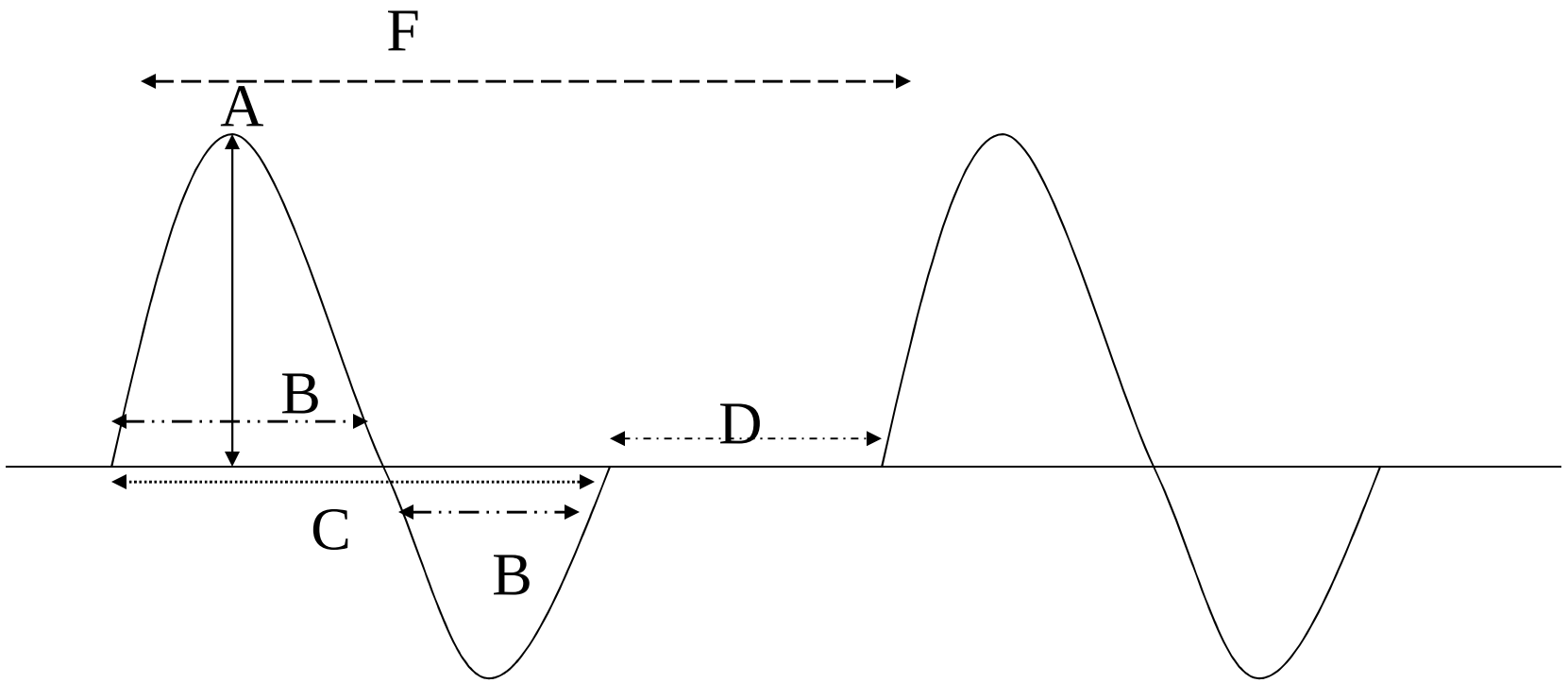
Time during which pulses remain at maximum preset intensity

Ramp down

Time during which the intensity decreases



Concept check



Give the name of each letter and define it, than explain it role in clinical application of electricity for electrotherapy

4-Pulse charge

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

5-Tissue impedance

Impedance is the resistance of the tissue to the passage of electrical current.

$$Z=1/2\pi FC$$

- High – impedance tissue ⟶ skin, bone & fat
- Low – impedance tissue ⟶ Nerve & muscle.
- 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)

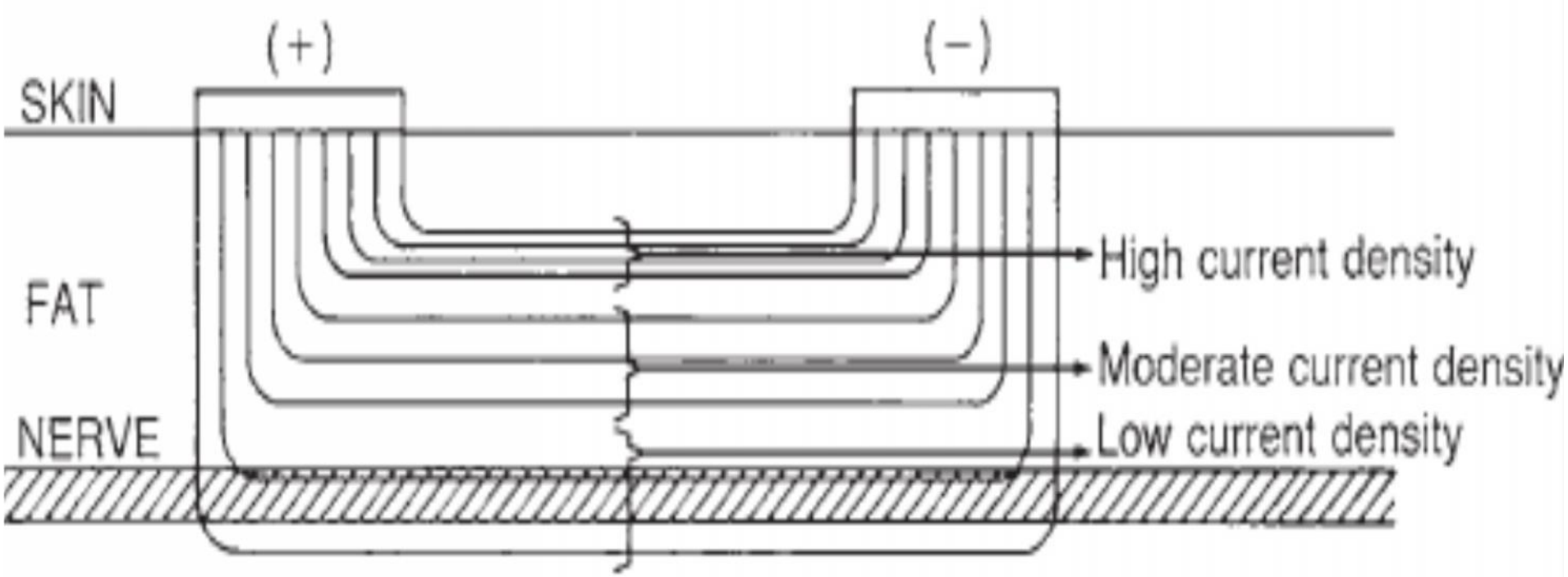
6-Current Density (CD)

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 2inches) distance of electrodes

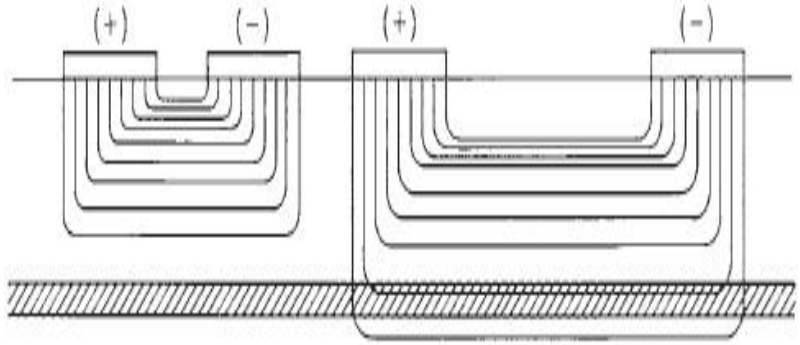


6-Current Density (CD)

Electrode Size/distance Determines the Current Density E

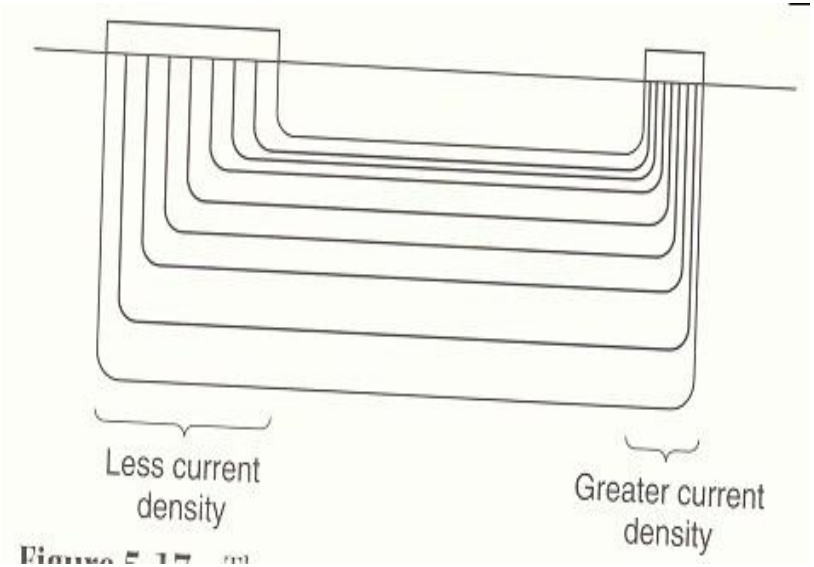
A placed closely electrodes produces high CD in superficial tissues.

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 (3-7days)
- Used in infected wound

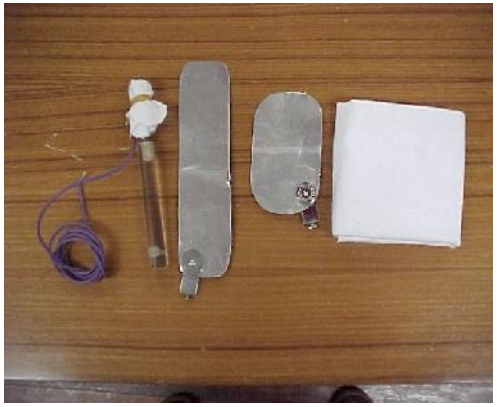
With AC Current and Interrupted DC Current Polarity Is Not Critical

- Select Negative Polarity For Muscle Contraction
  - Facilitates Membrane Depolarization
  - Usually Considered More Comfortable
- Negative Electrode Is Usually Positioned Distally

7-Electrodes

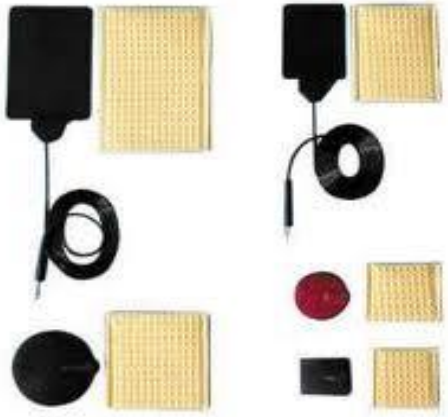
Electrodes are devices attached to the terminals of electrical stimulator through which current enters and leaves the body. Electrodes come in a variety of sizes, shapes, and materials, and are named according to their function. The three most popular electrode systems over the years have been

Metal-sponge electrodes



durable , reusable, inexpensive, inflexible

Carbone electrodes



Relatively inexpensive, fairly durable, gel or water required, may cause skin irritation

Self adhesive electrodes

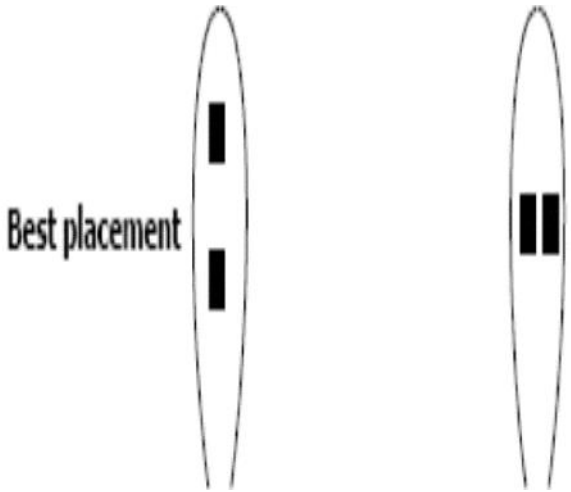
expensive, less durable, flexible, skin irritation Contamination

7-Electrodes

II-Locations/orientation

1. On and /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.
6. Motor point.
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,

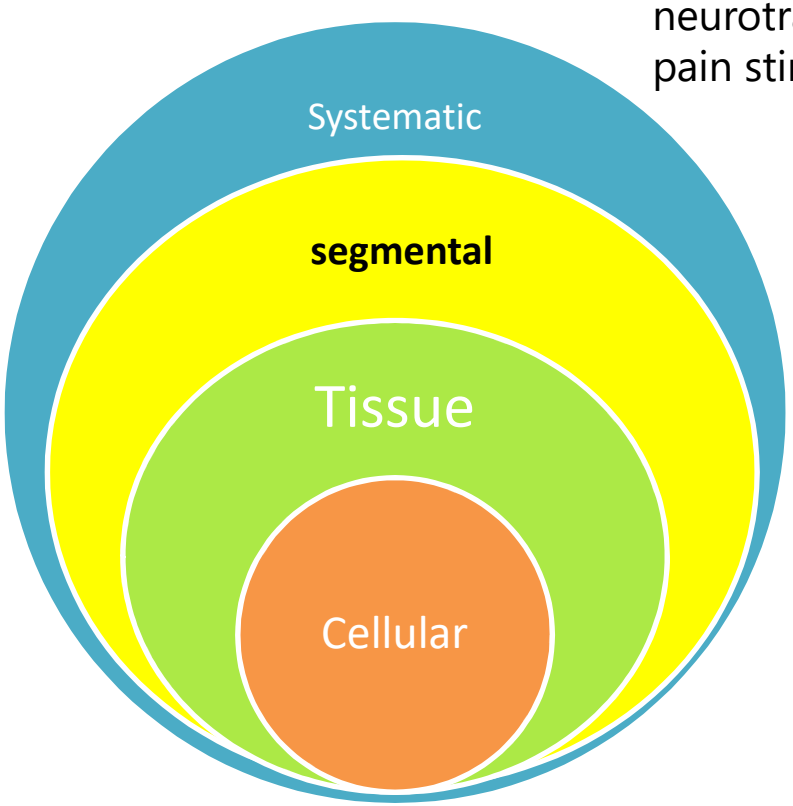
1. Active electrode (s) [smaller] is stimulating electrode and placed on the target muscle, greatest current density – treatment effect.
2. Dispersive electrode [larger] –required to complete the circuit, low current density – little or no sensation is felt from this electrode

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

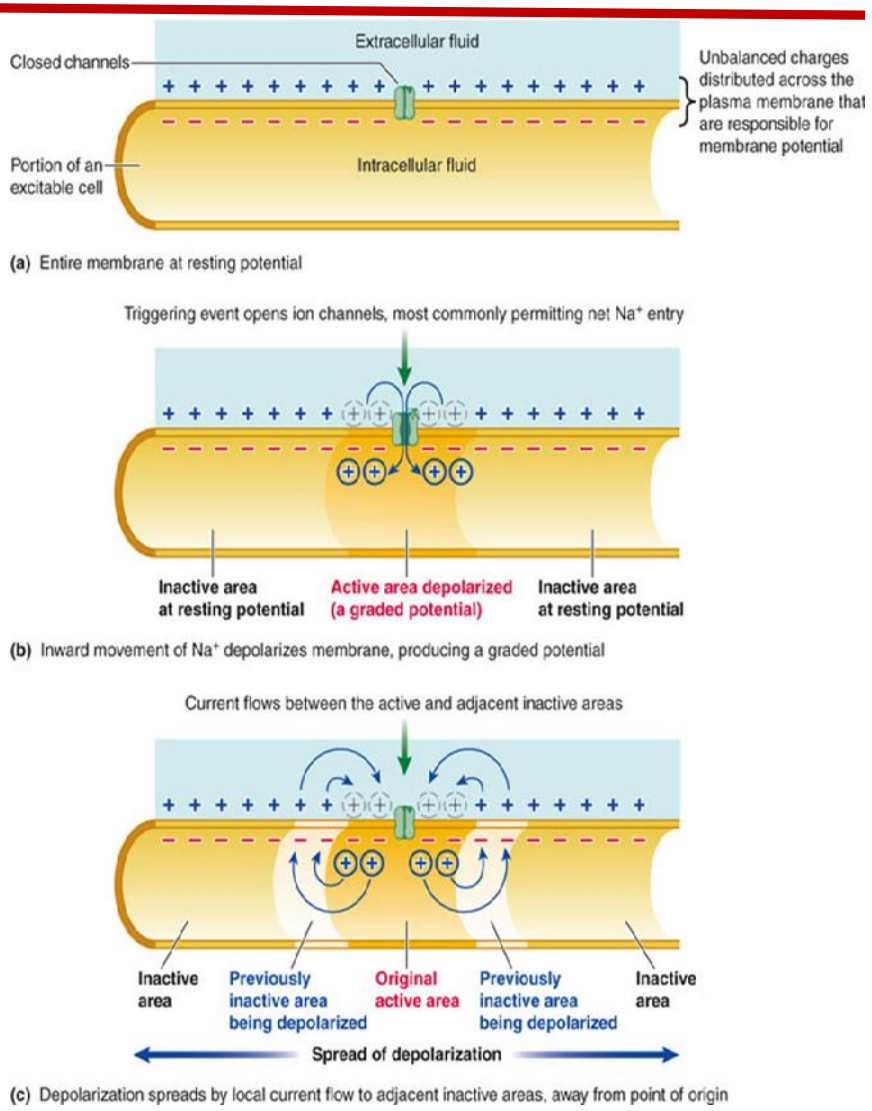
- Excitation of nerve cells
- Changes in cell membrane permeability
- Protein synthesis
- Stimulation of fibrobloast, osteoblast
- Modification of microcirculation

Nerve & Muscles Response to ES

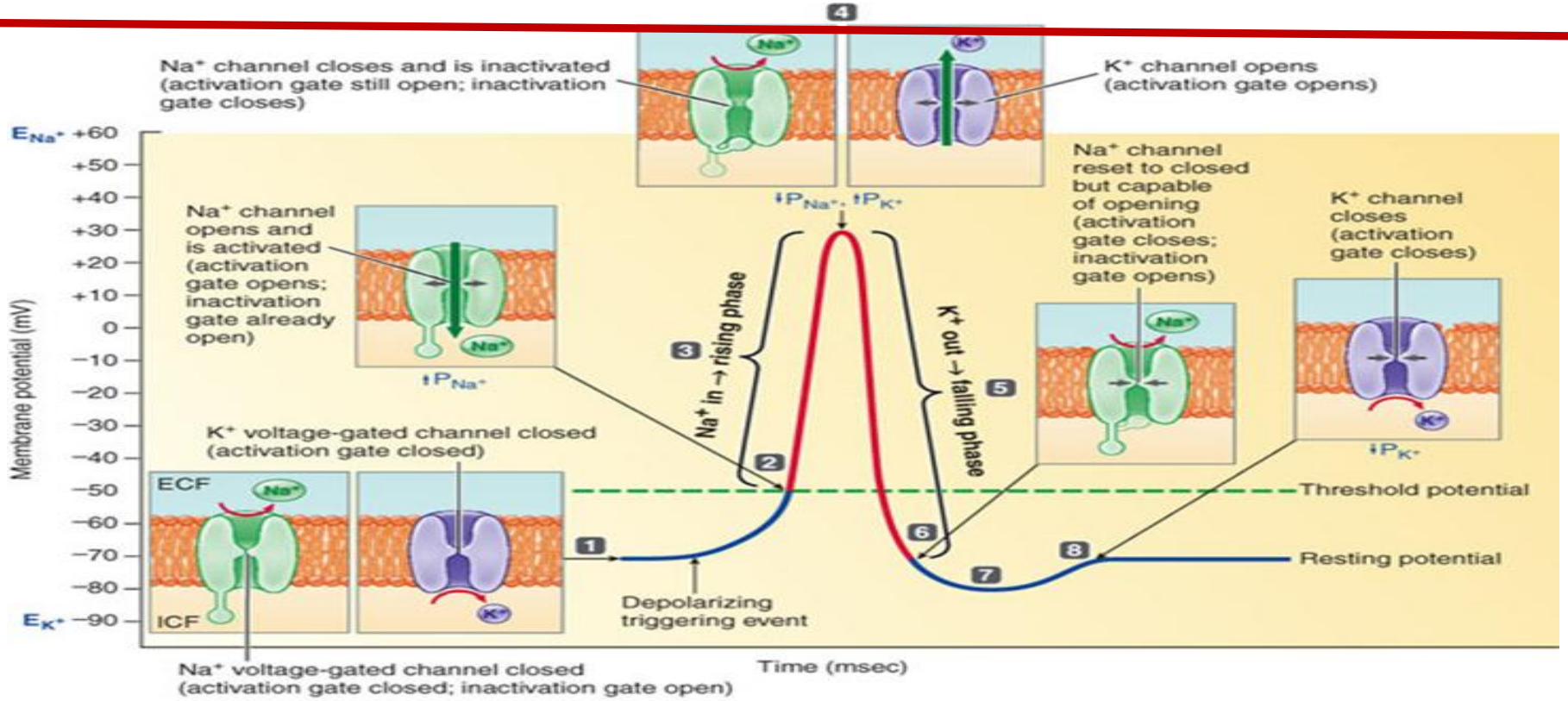
Resting potential
Action potential
Depolarization
Propagation of action potential
Absolute Refractory period
Re-polarization
All-or-none Principle

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 10–3 Properties of Skeletal Muscle Fiber Types

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

Effect of Electrical stimulation

Musculoskeletal System

Muscle excitation result 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

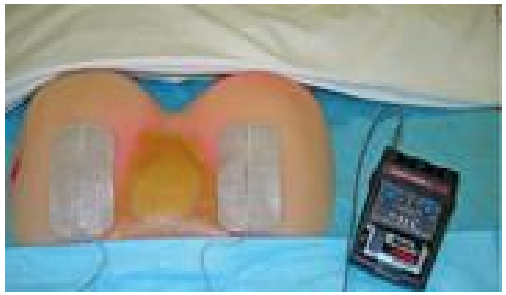
Increase capillary permeability and blood flow

Increase macrophage, leucocytes and activities.

Increase fibroblast & osteoblast activity.

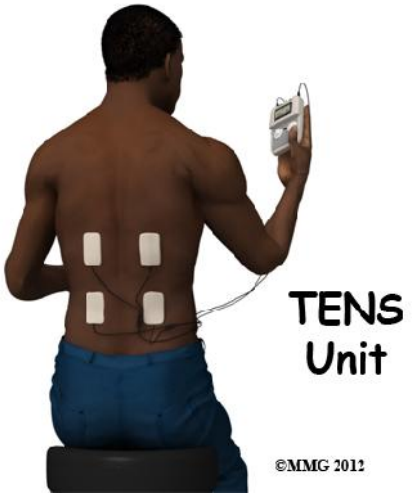
Induce bactericidal effects.

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 used to relive 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 cognation), frequent monitor

Safety in Clinical Environment

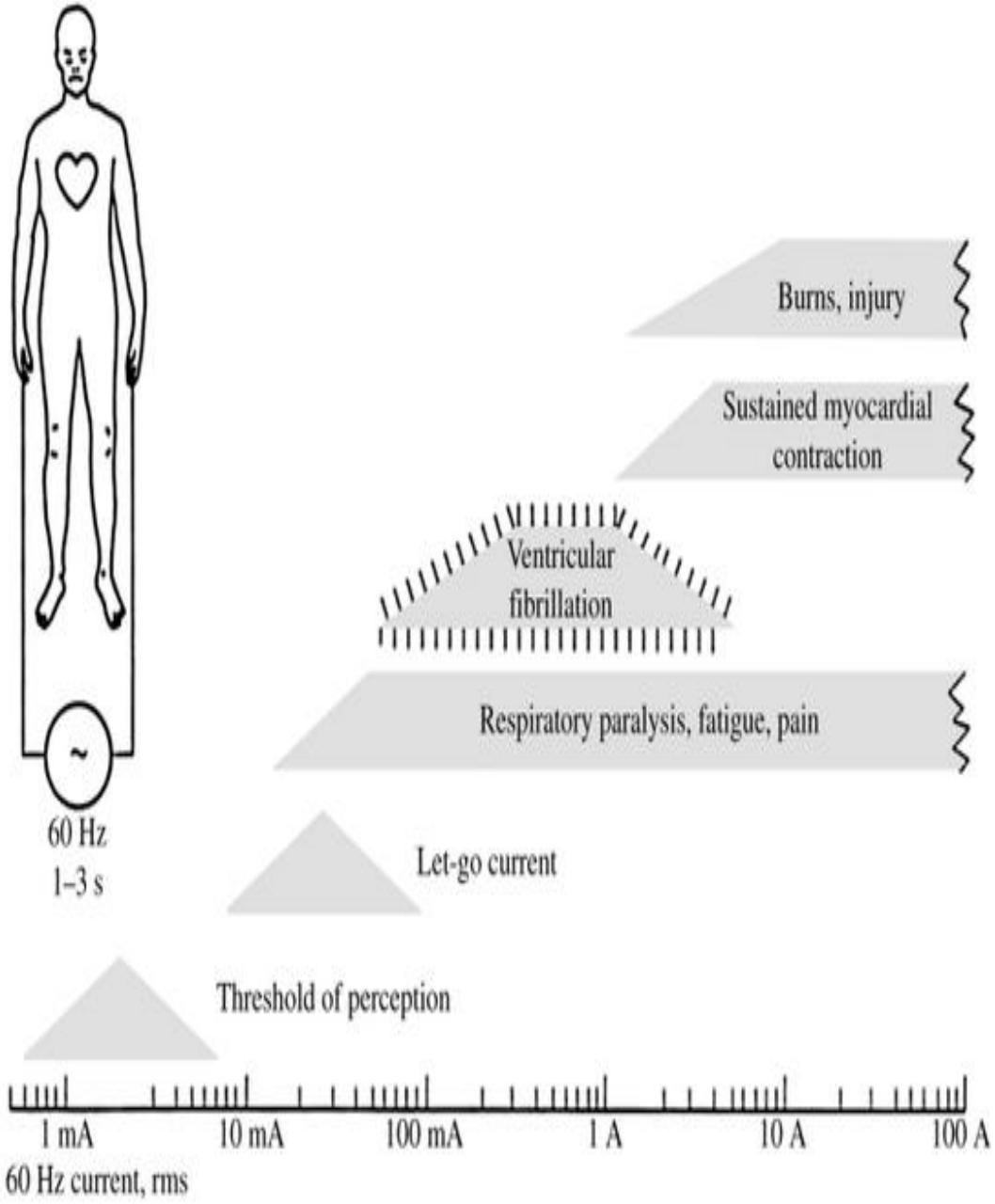
- **Safety** : freedom from unacceptable risk of harm.
- **Basic Safety** : Protection against direct physical hazards when medical electrical equipment is used under normal or other conditions.
- **Risk** : The probable rate of occurrence of a hazard causing harm and the degree of severity of the harm.

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.

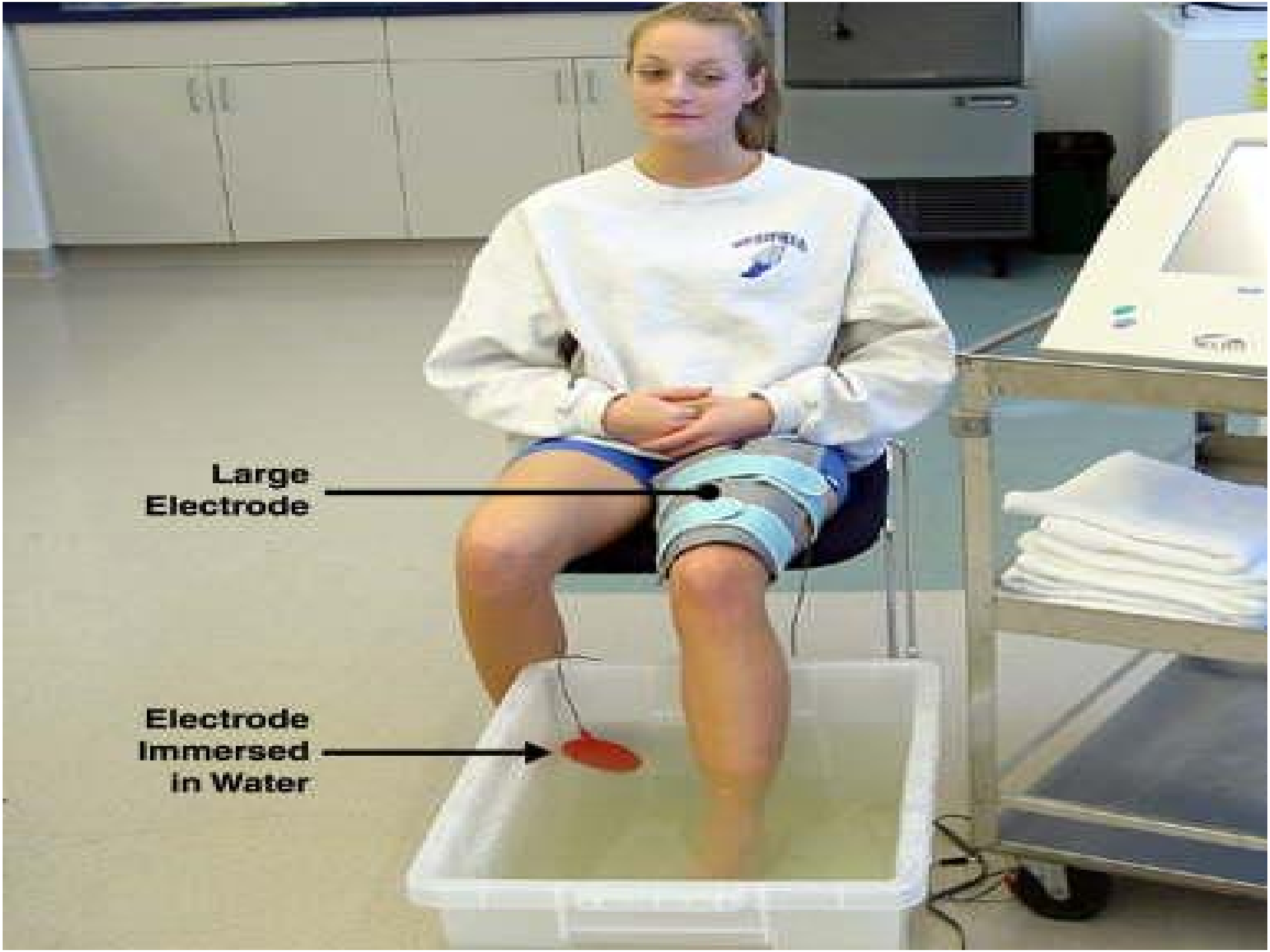
Safety tips

1-5mA	Tingling sensation
5-8mA	Intense or painful sensation
8-20mA	Threshold of involuntary muscle contraction



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


Large
Electrode
Electrode
Immersed
in Water


Compression
Wrap
2 Electrodes
on triceps surae
Edema
Elevation
2 Electrodes
on hamstrings