Basic principle of electricity and electrical stimulation current

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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

Electrical stimulation

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.

ACRONYM	Explanation
EMS	Electrical muscle stimulation
ESTR	Electrical stimulation for tissue repair
NMES	Neuromuscular electrical stimulation
TENS	Transcutaneous electrical nerve stimulation
FES	Functional electrical stimulation

Electrical Current Parameters

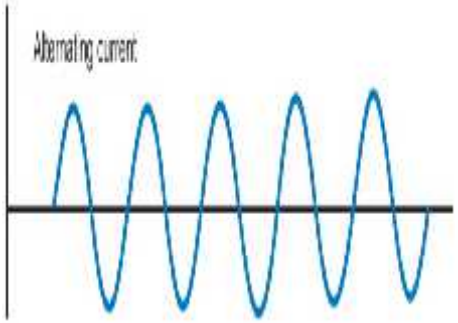
- Current types
- Waveforms
- Time-Dependent Parameters
- Other Electrical Current Parameters
  - Current density
  - Tissue impedance

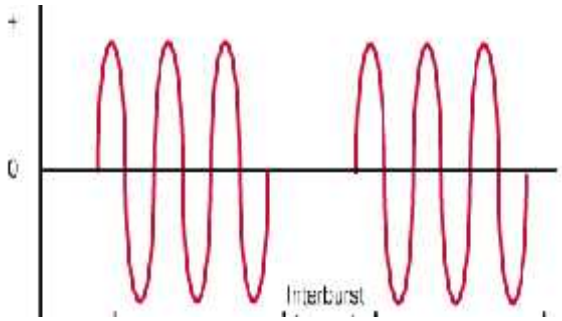
Current Types

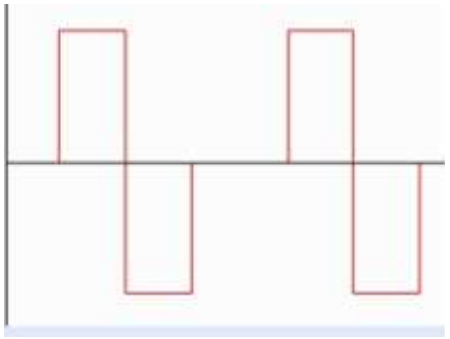
	Direct current (DC)	Alternating Current (AC)	Pulsed current (PC)
Def.	is continuous unidirectional flow of e-'s toward (+) pole	The e- flow in alternating directions in both sides of isoelectric line from (–) and (+) pole.	**pulsatile current** An interrupted current, whereby the current flows in a series of pulses separated by periods when no current flows. can take on the directionality characteristics of AC or DC current.
Shape	**Monophasic**	**Biphasic**	**Monophasic or biphasic**
Types	"Galvanic current" Interrupted direct current or " interrupted galvanic"	Current can be symmetrical, asymmetrical e.g. TENS,	Groups of pulses are interrupted for short periods of time (inter-pulse intervals) & repeat. Russian current Interferential current
Uses	Iontophoresis Stimulate of denervated muscle;	Pain relief Neuromuscular stimulation.	Pain relief Neuromuscular stimulation Wound healing

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

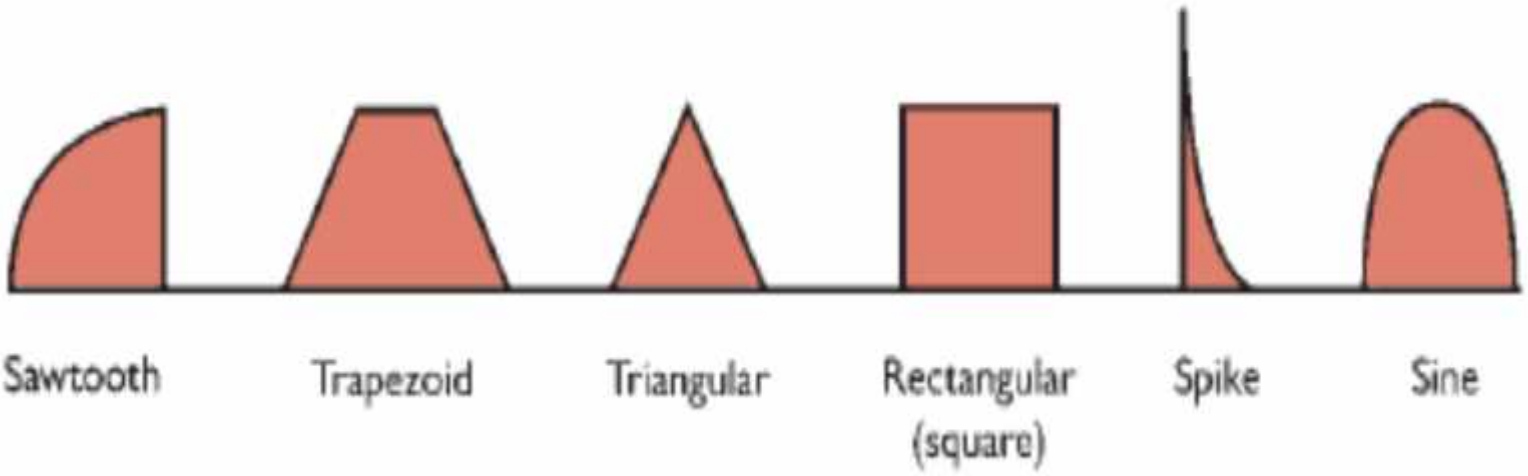
Very short pulse duration + Reversing polarity

No Chemical burn

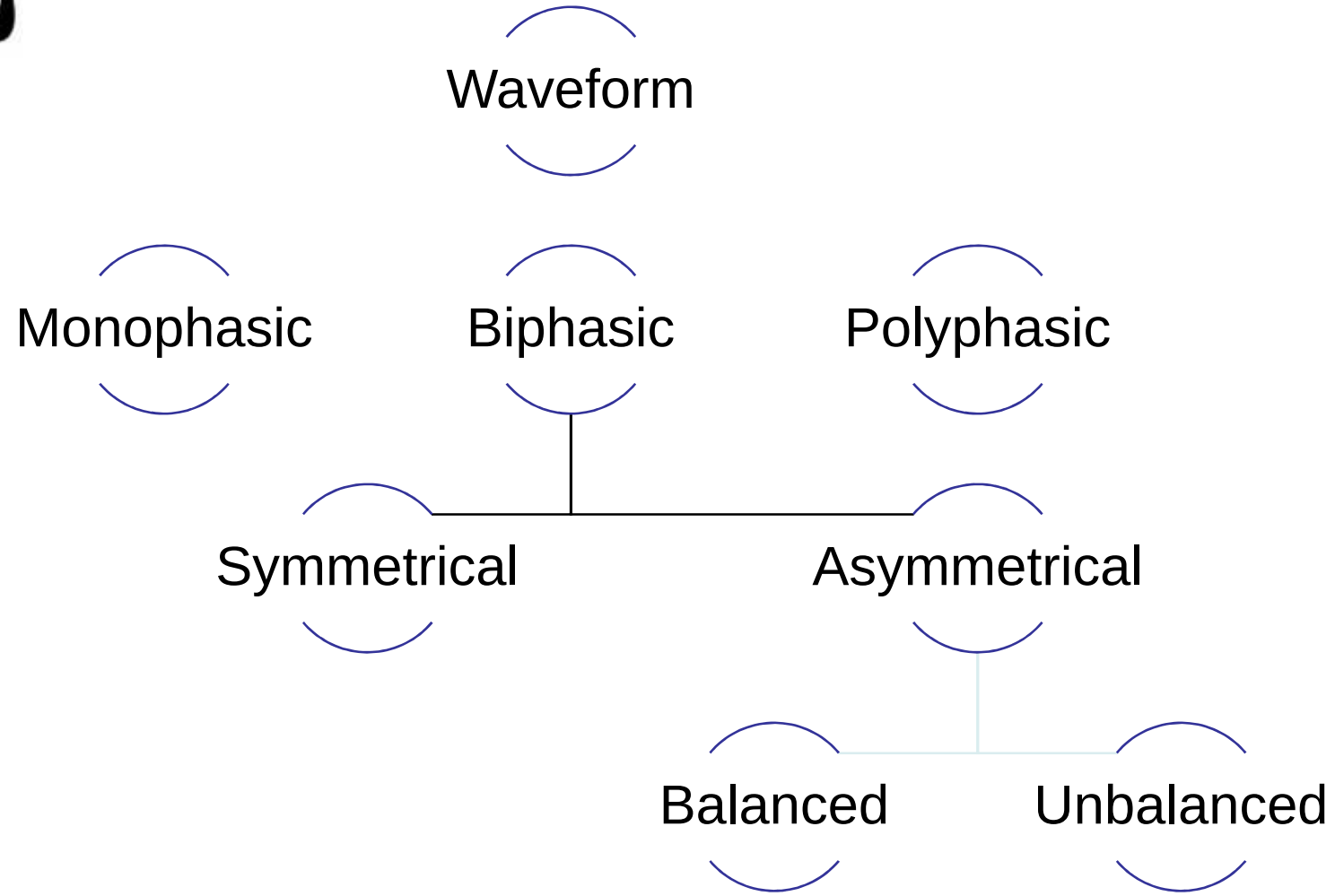
Waveforms

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

1-Waveforms Shape:



Waveforms Classification

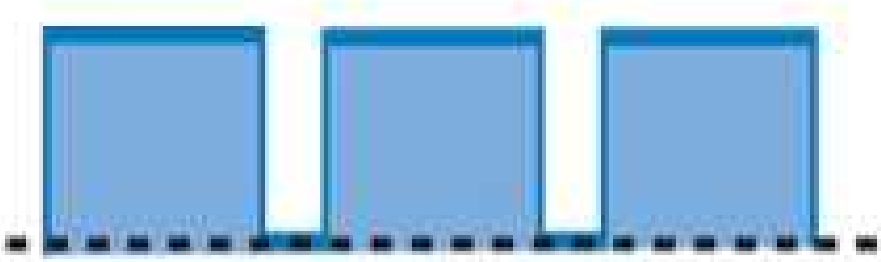


Waveforms Classification

Monophasic

One phase only **(+ or -)**

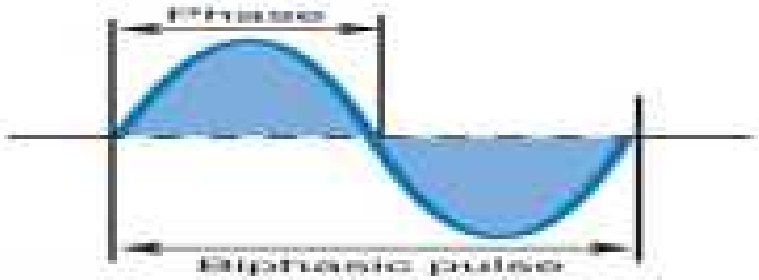
Current flows in one direction only.



Biphasic

Two phases **(+ and -)**

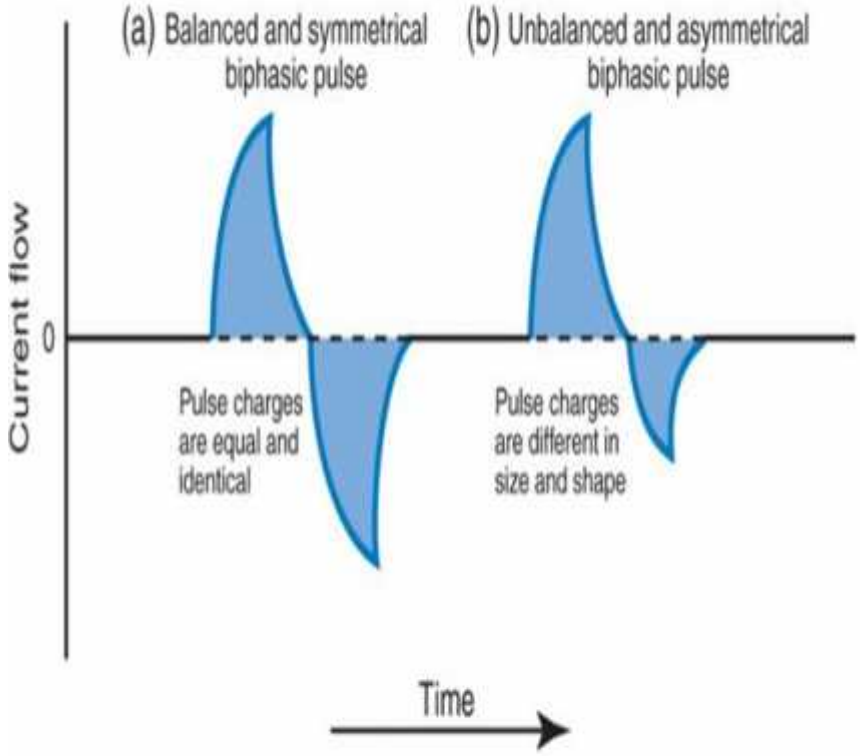
Current flows in both directions.

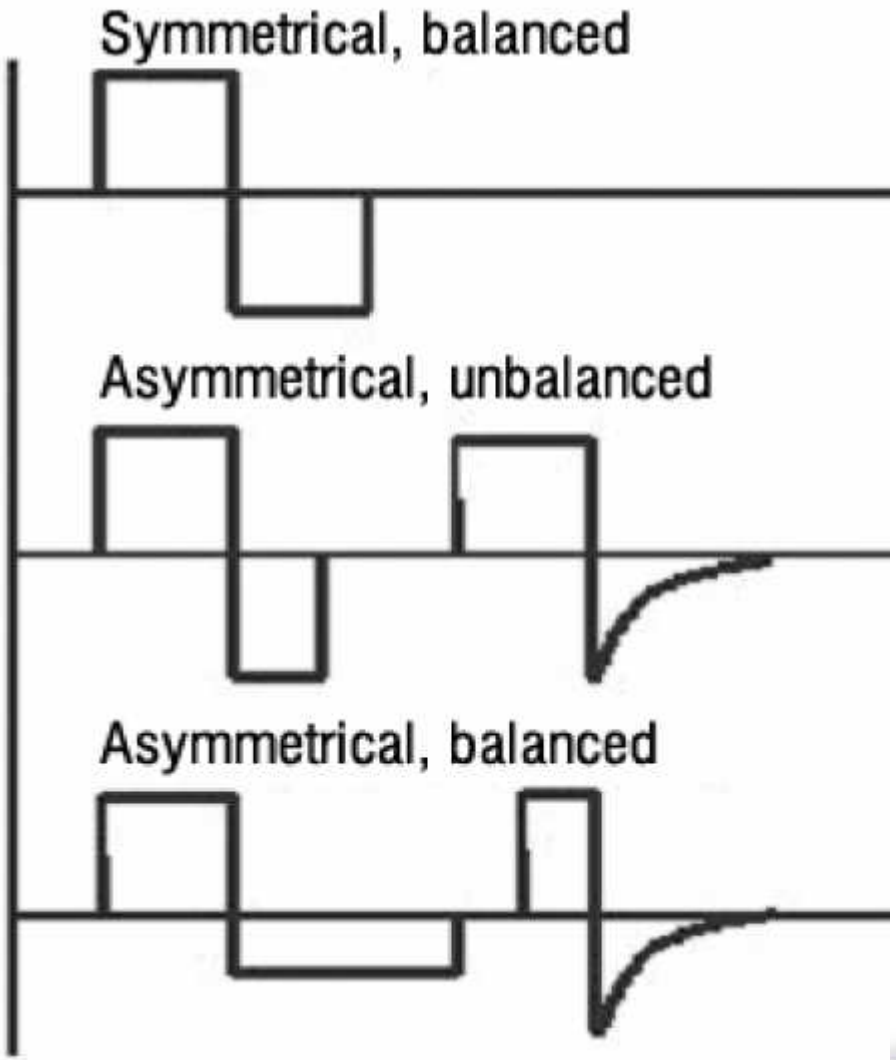


Polyphasic (pulsatile)

Many phases

Waveforms Classification





Time-Dependent Parameters

Pulse duration + Interpulse interval	Phase duration + Interphase interval	Burst duration + Inter-burst interval	Frequency

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
- Transcutenous 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

Frequency

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

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

Sensory level

Frequency

motor level

Types of muscles contraction and

< 20Hz	Individual twitch
20-35Hz	Individual twitches become less distinguishable summation
≥35Hz	Tetany muscle contraction

degree of mechanical adaption

fatigue ,

amount of tissue impedance

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 form beginning of first phase of pulse to the end of last phase of a pulse " On Time"

Interpulse interval

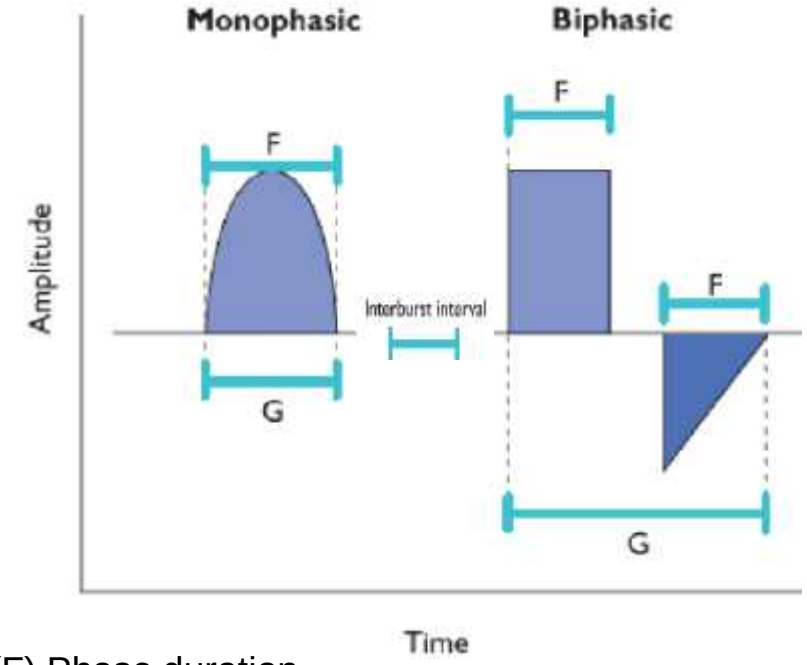
is the time between individual pulses "OFF Time"

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 (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-Pulse attributes

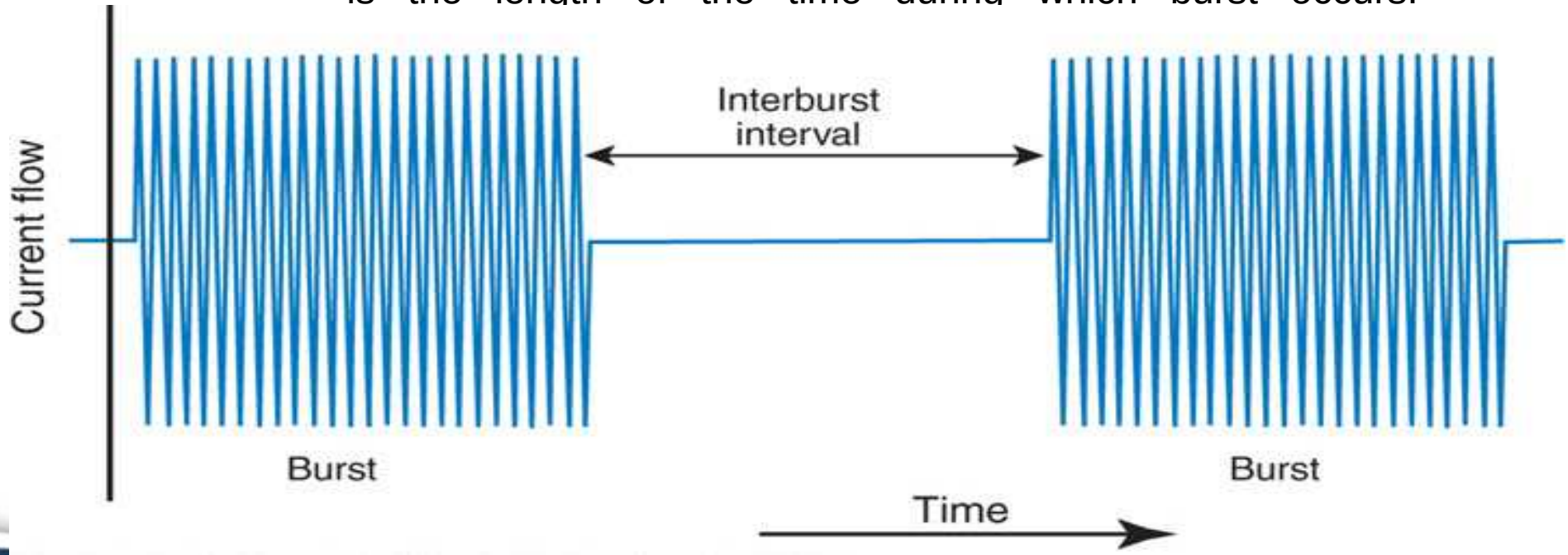
Burst

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)

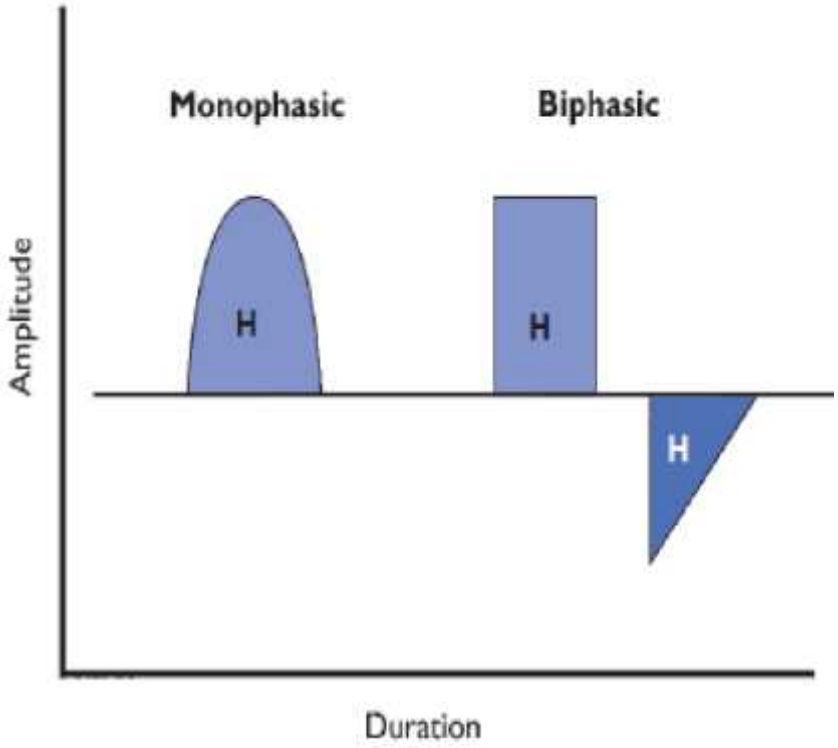
is the length of the time during which burst occurs.



4-Pulse Charge

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

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.

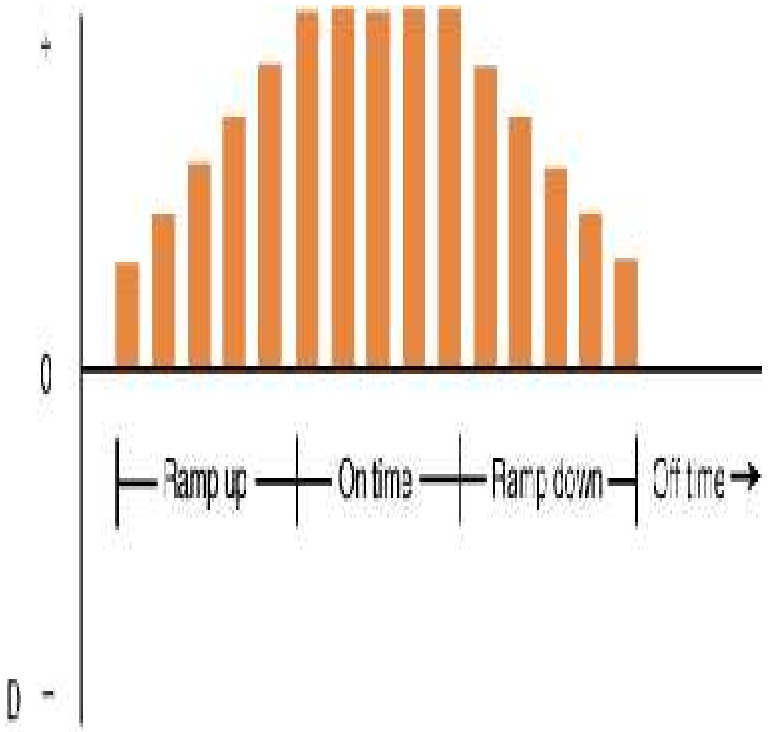
raneged 1-8seconds (2-second)

Plateau

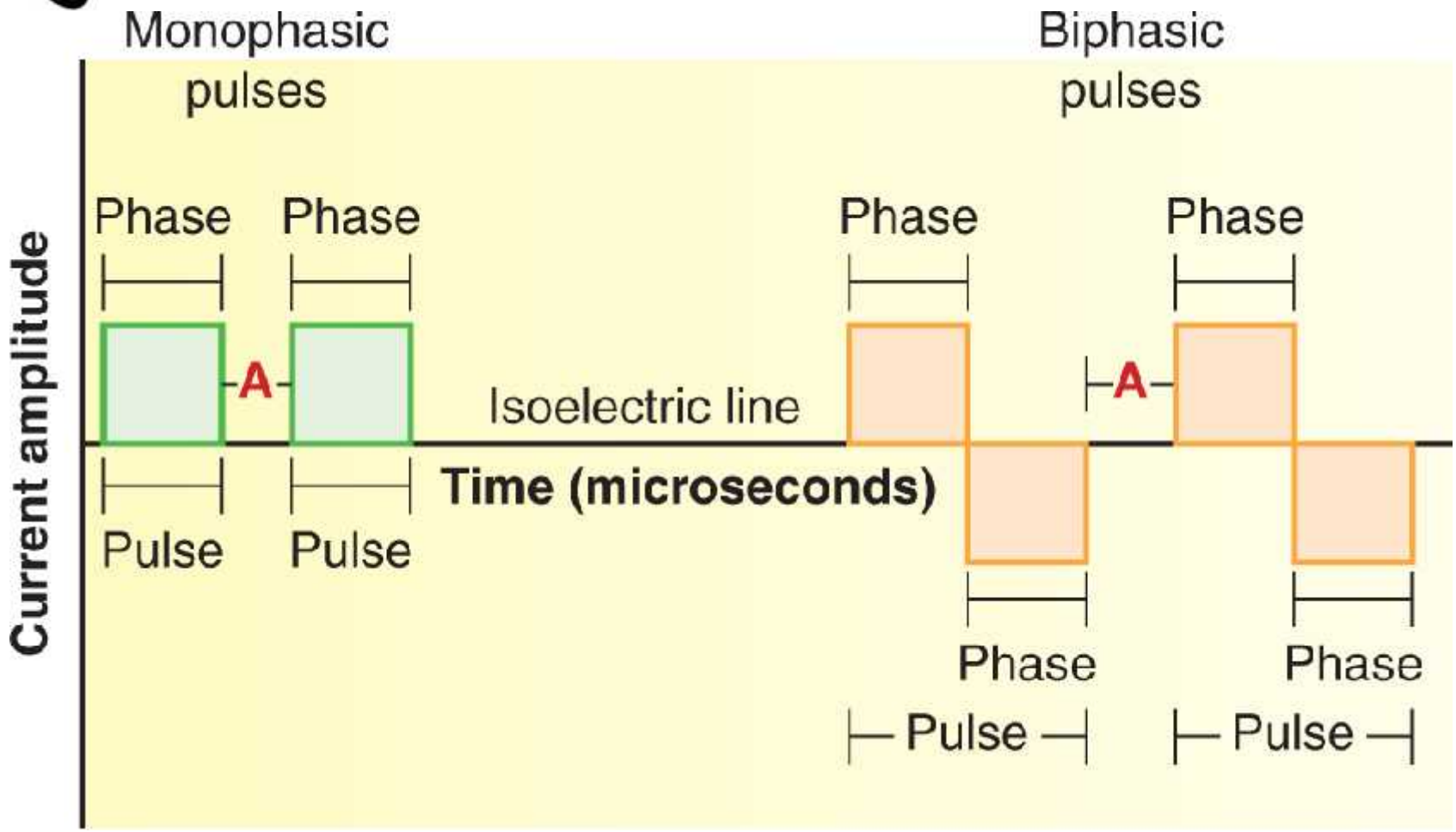
Time during which pulses remain at maximum preset intensity

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



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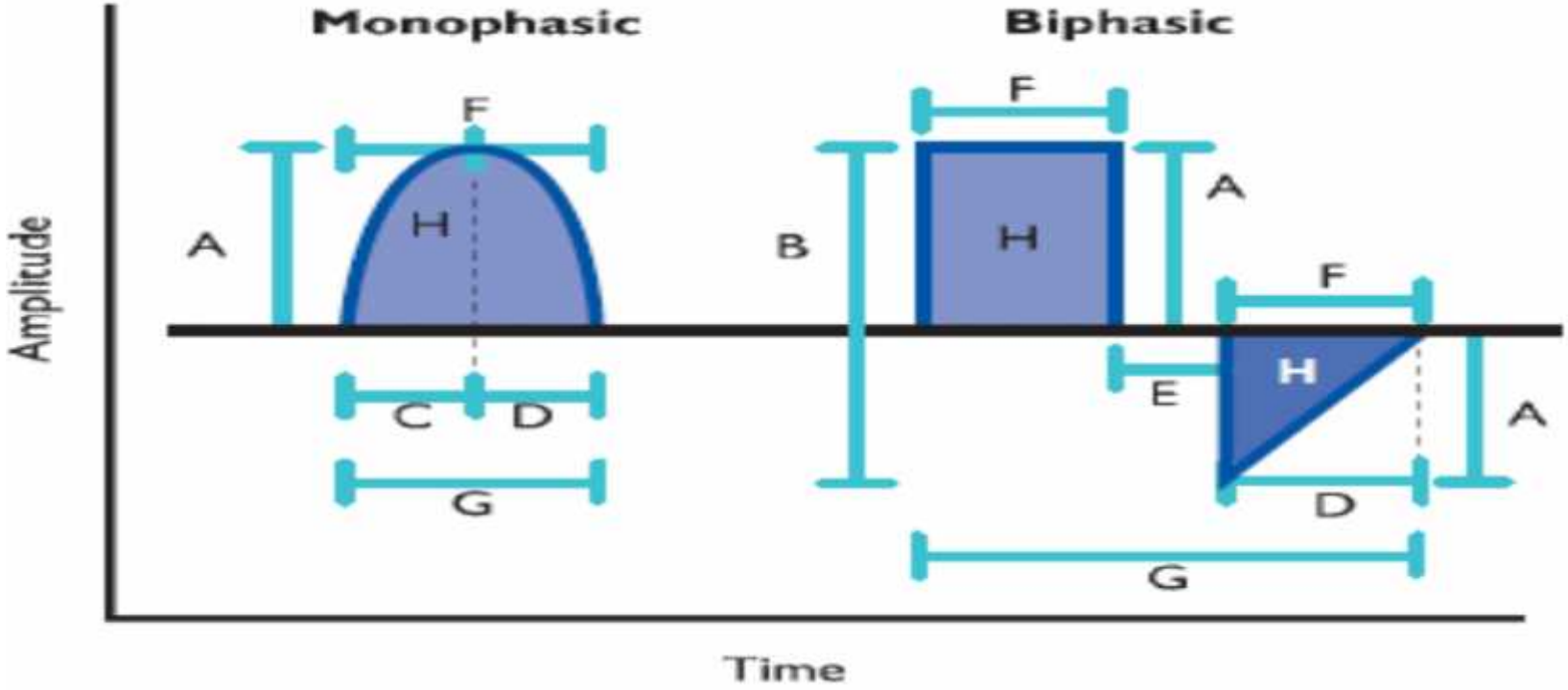
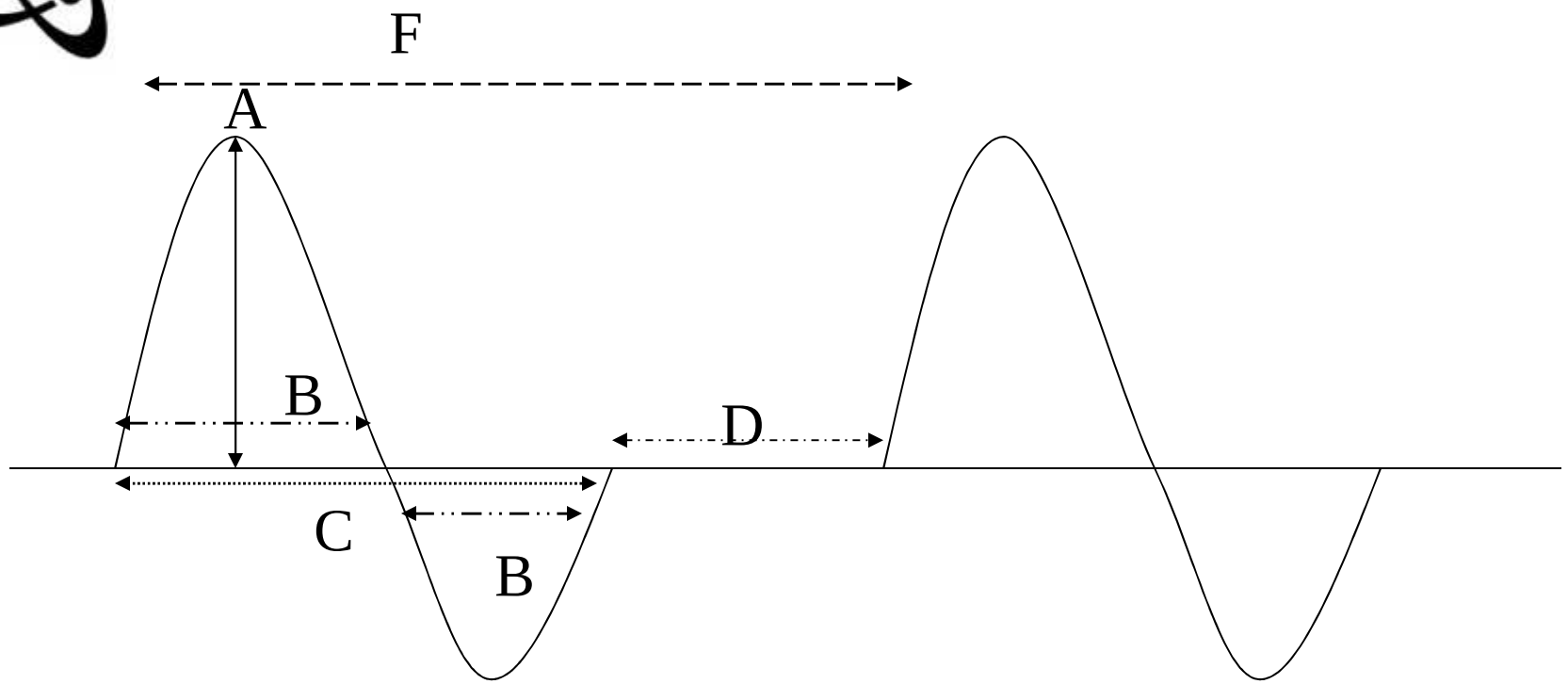


Give the name of each letter and define it, than explain it role in clinical application of electricity for electrotherapy

Concept check



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

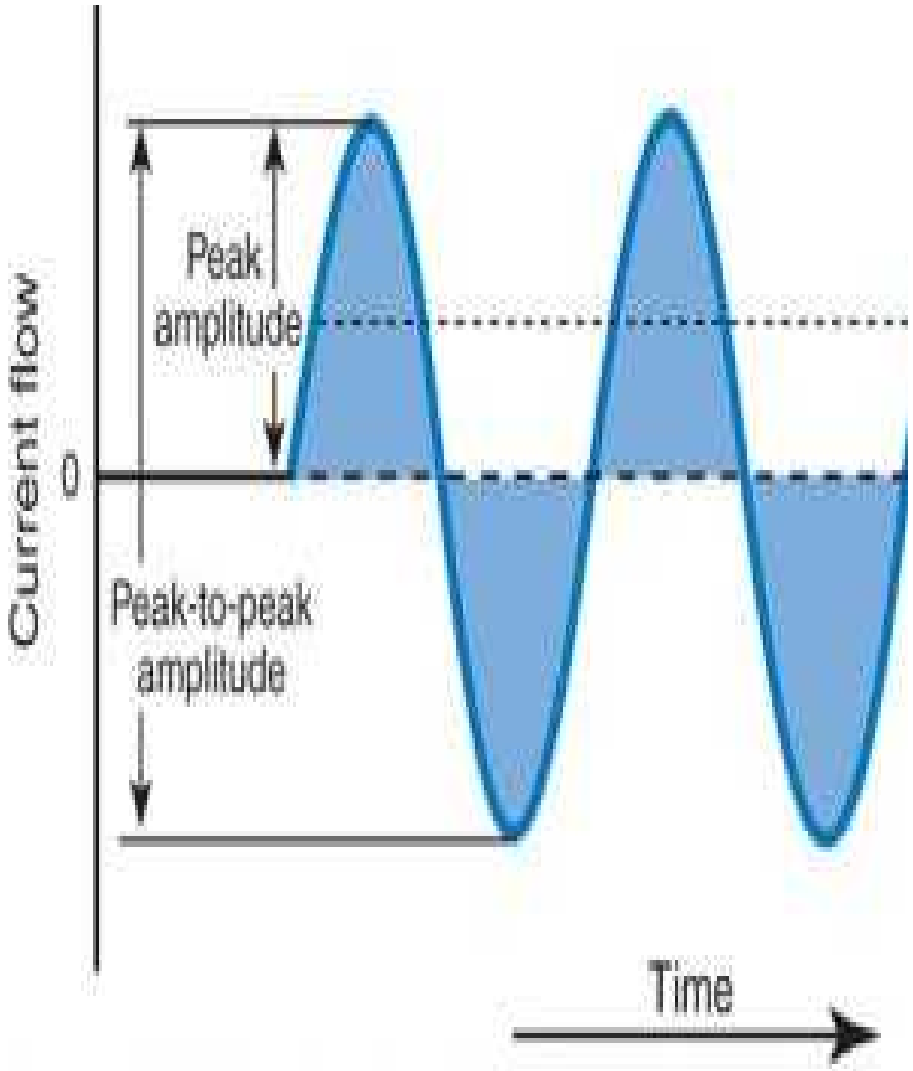
1 amp = 6.25×10^{18} e^- / sec

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



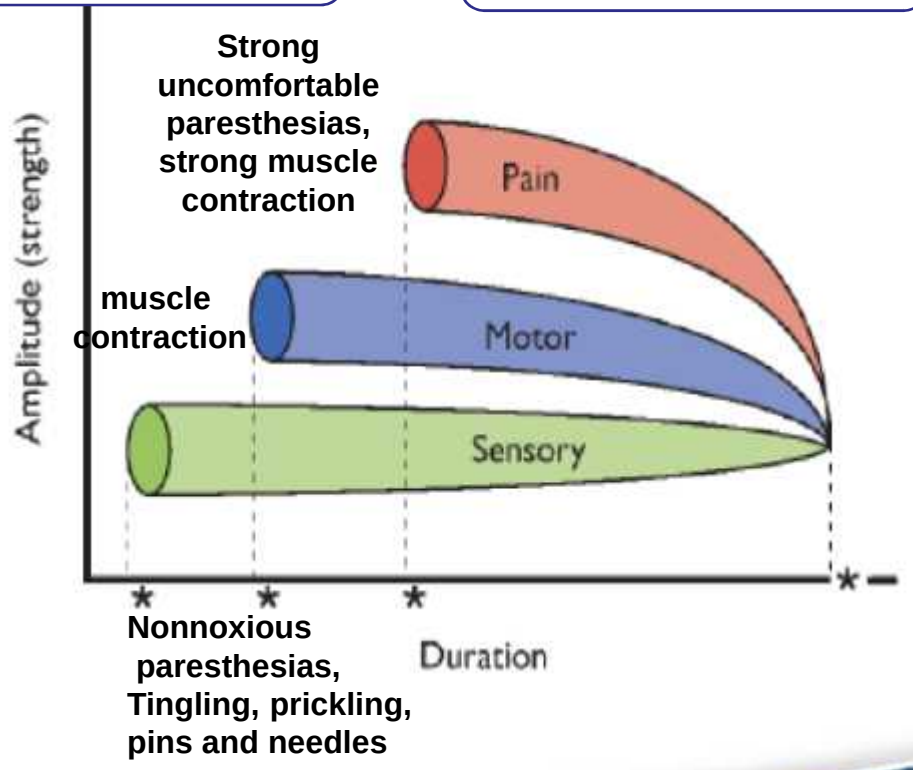
Current Amplitude

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

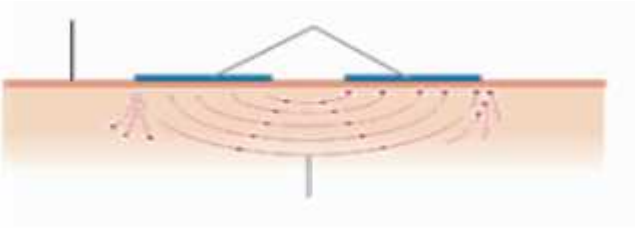
Location of the nerve: Superficial nerves depolarize first



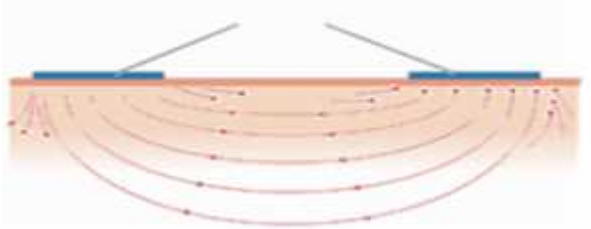
Current Density (CD)

The amount of current per unit area

Electrode distance
Determines the Current



A placed closely electrodes ,
high CD in
superficial tissues.



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

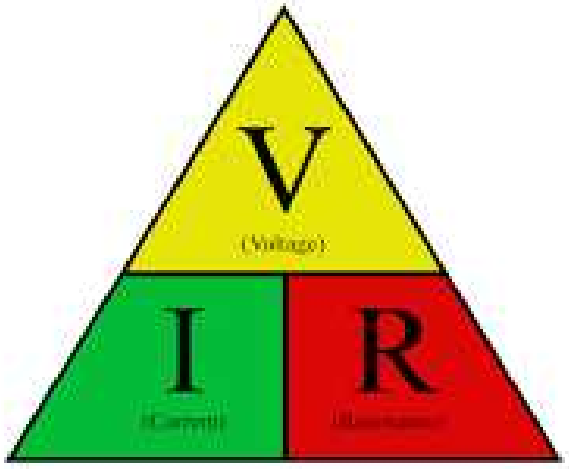
Electrode Size
Determines the Current Density

Tissue impedance

- **Ohm's law** showing a comparison of constant current and constant voltage stimulators: **I = V/R**

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 **(> 150V)** ,deeper penetration e.g. HVPC



I represents the Current
V represents Voltage
R represents Resistance

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?

Tissue impedance

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

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

- High – impedance tissue → skin & fat ← SERIES circuit
- Low – impedance tissue → Nerve & muscle. ← Parallel Circuit
- Dray skin resistance → (100.000-600,000Ω)
- 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.

Positive

Negative

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

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 (3-7days)
- Used in infected wound
- **Facilitates Membrane Depolarization**
- **Usually Considered More Comfortable**

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 fibrobloast, osteoblast
- Modification of microcirculation

- Skeletal muscle contraction
- Smooth muscle contraction
- Tissue regeneration

- Modification of joint mobility
- Change circulation & lymphatic activity

- Analgesic effects secondary

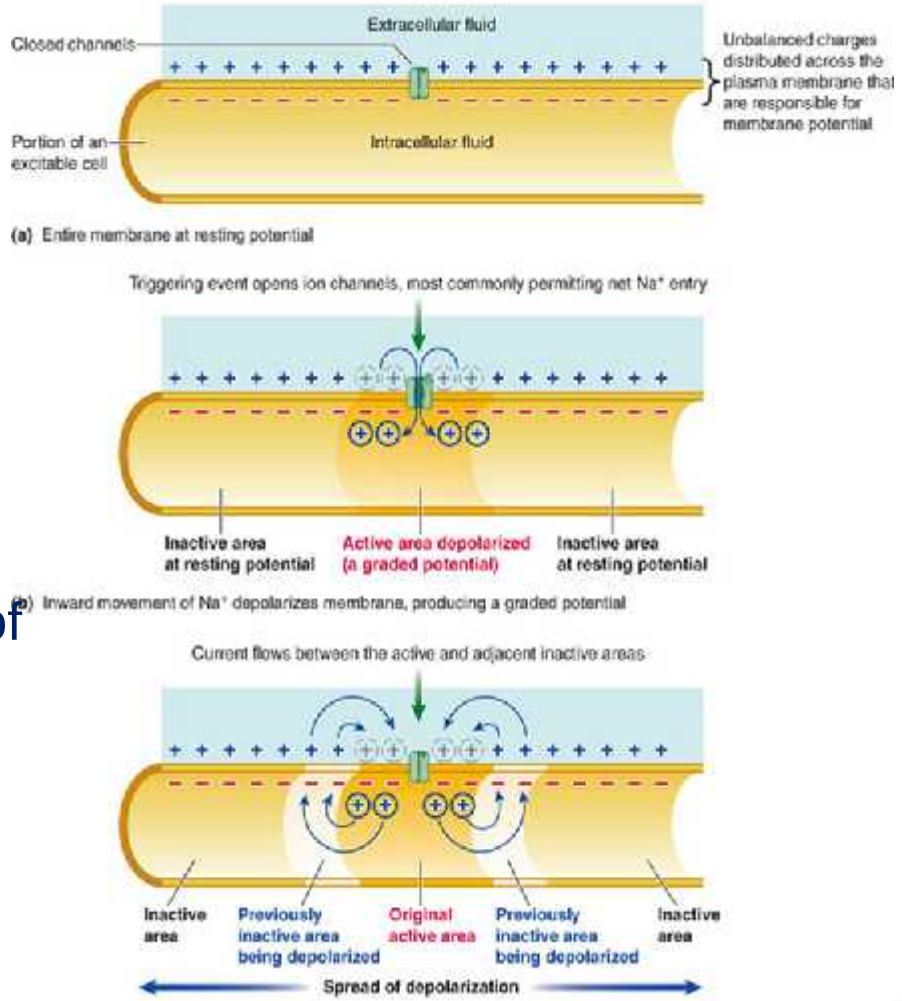
Stimulation of Action Potentials In Nerves

Muscle and Nerve Excitation: Concepts to Review

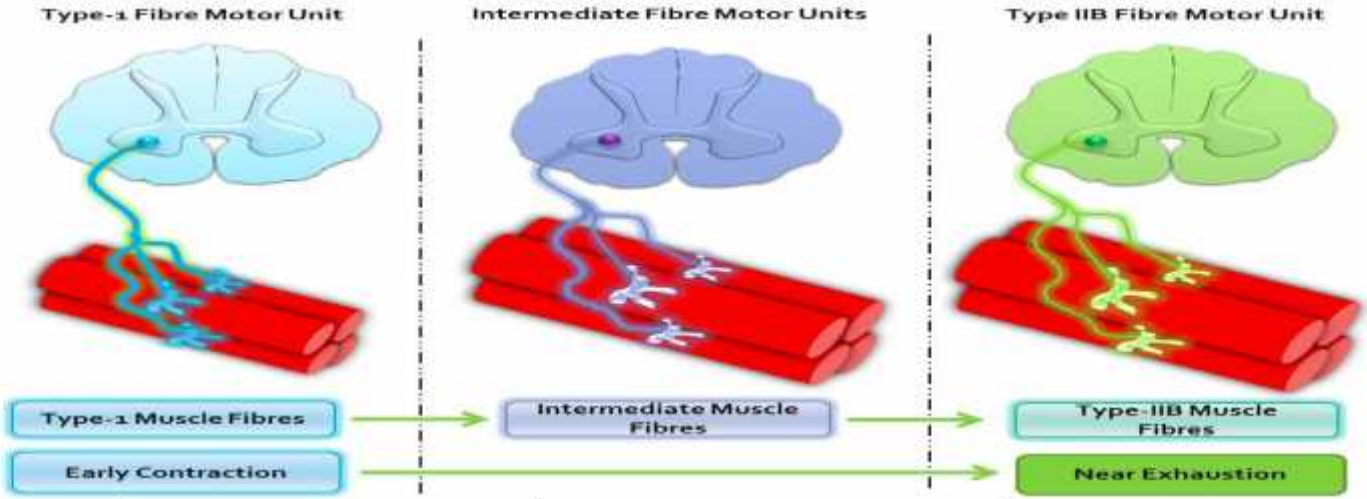
- Resting membrane potential
- Action potential generation and propagation
- Nerve and muscle structure
- Classification of peripheral nerves
- Muscle fiber type and recruitment pattern
- Structure of the motor unit
- Motor unit recruitment

Changing intensity and types of contraction influenced by;

- Frequency
- Intensity
- Pulse duration
- Number of motor unit recruited



Nerve & Muscles Response to **E-Stim**



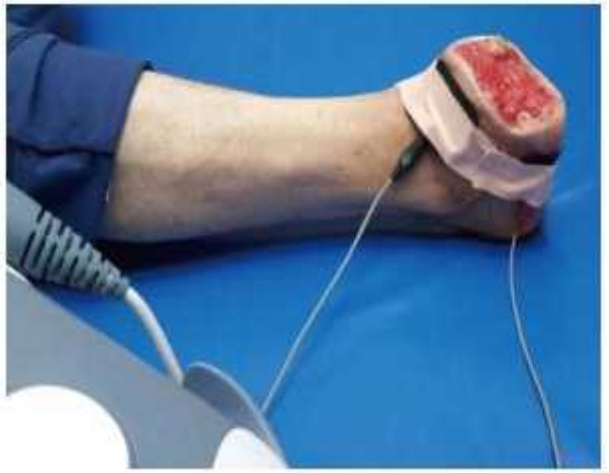
Fiber Type	Slow-Twitch (ST)	Fast-Twitch A (FT-A)	Fast-Twitch B (FT-B)
Contraction time	Slow	Fast	Very Fast
Size of motor neuron	Small	Large	Very Large
Resistance to fatigue	High	Intermediate	Low
Activity used for	Aerobic	Long-term Anaerobic	Short-term Anaerobic
Force production	Low	High	Very High
Mitochondrial density	High	High	Low
Capillary density	High	Intermediate	Low
Oxidative capacity	High	High	Low
Glycolytic capacity	Low	High	High
Major storage fuel	Triglycerides	CP, Glycogen	CP, Glycogen

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 o 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 cognation),

Currents Application Technique

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

Patient Positioning

Patient positioning is dictated by the	Patient comfort and modesty
	Area to be treated,
	Goal(s) of treatment, and
	Device used.

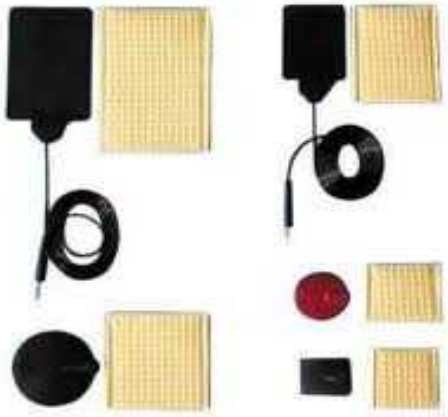
Electrodes

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

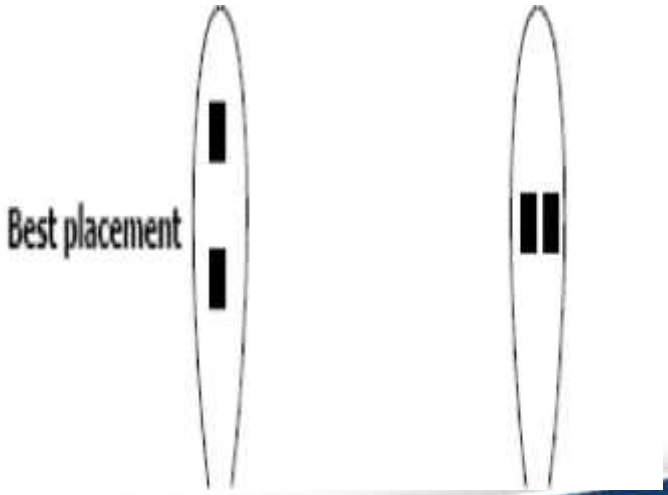
expensive, less durable, flexible, skin irritation Contamination

Electrodes

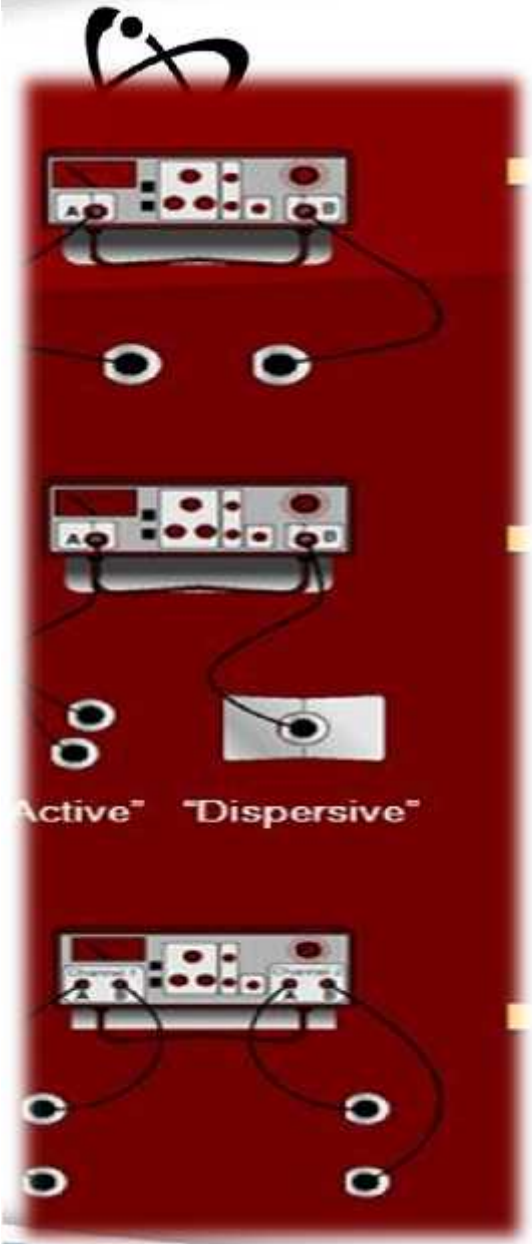
II-Locations/orientation

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.
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



Electrodes Configuration



Bipolar Configuration

- Equal electrodes size
- Equal Current density under each electrode

Monopolar,

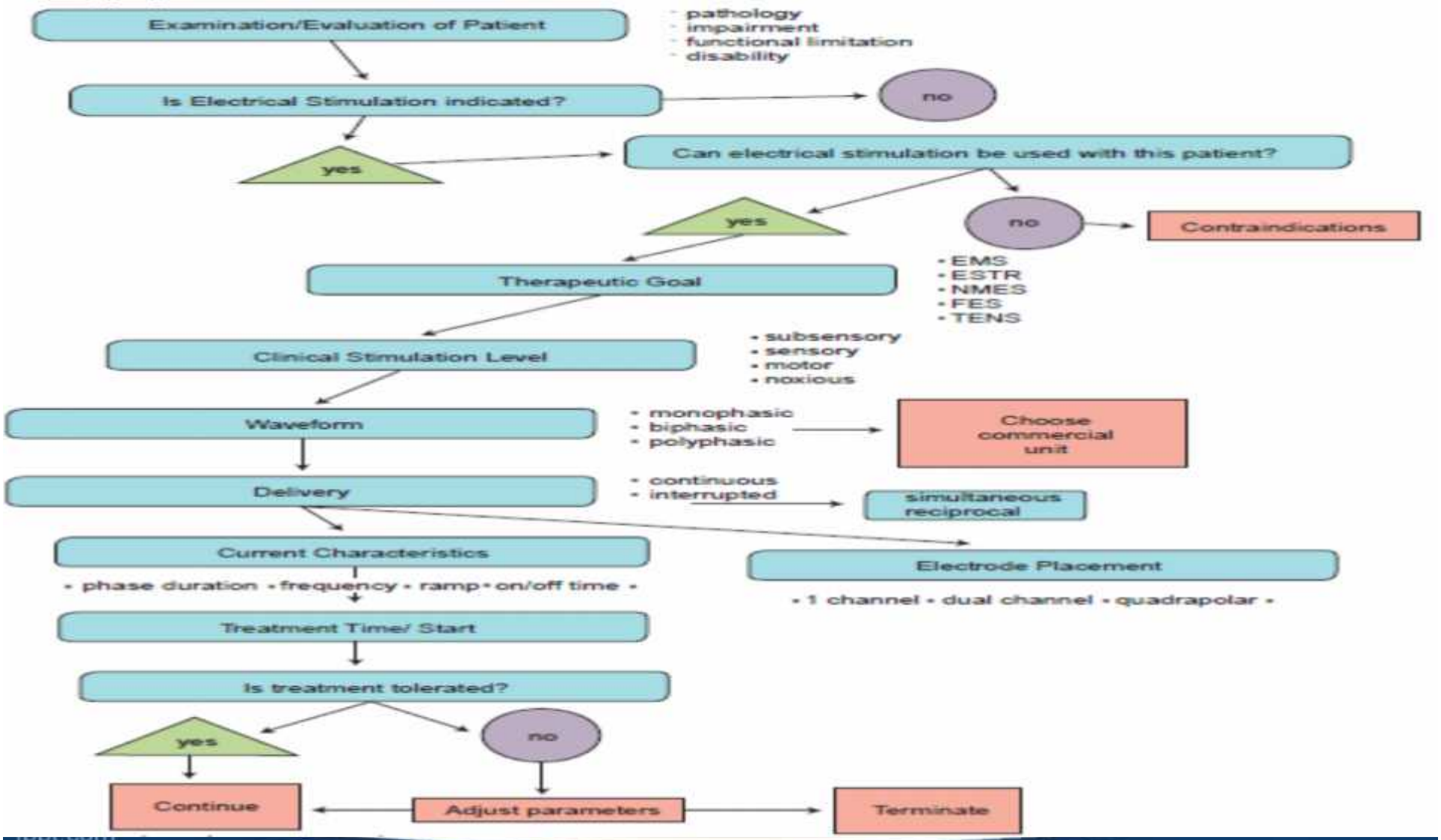
1. Active electrode (s) [smaller] is stimulating electrode and placed on the target muscle, greatest current density – treatment effect.
2. Dispersive electrode [larger] –required to complete the circuit, low current density – little or no sensation is felt from this electrode

Quadripolar Configuration

- Quadripolar: four electrodes are placed on the target tissue Interferential.

Check the Concept

E-stim Clinical Decision Making



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