- ELECTRICAL MODALITIES
BASIC PRINCIPLES OF ELECTRICITY -

OBJECTIVES

Following completion of this chapter, the student therapist will be able to:

- Define potential difference, ampere, volt, ohm, and watt.
- Differentiate between alternating, direct, and pulsitile currents.
- Categorize various waveforms and pulse characteristics.
- Contrast the various types of current modulation..
- Explain current flow through various types of biologic tissue.
- Be able to create a safe environment when using electrical equipment.

Understand the techniques of application of the electrodes

Introduction:

Electrical stimulation is one of the oldest and most effective modalities used in physical therapy. Nowadays, the wide variety of electrical stimulators has a single common purpose; the stimulation of tissue for therapeutic purposes. These tissues may be excitable or non excitable tissues**.** To understand the effect of electrical stimulating currents on different tissues of the body, it is very important to study the basic knowledge about electrical currents types, forms and characteristics.

COMPONENTS OF ELECTRICAL CURRENTS

All matter is composed of atoms that contain positively and negatively charged particles called **ions**. These charged particles possess electrical energy and thus have the ability to move about. They tend to move from an area of higher concentration toward an area of lower concentration. An electrical force is capable of propelling these particles from higher to lower energy levels, thus establishing **electrical potentials**. The more ions an object has, the higher its potential electrical energy. Particles with a positive charge tend to move toward negatively charged particles, and those that are negatively charged tend to move toward positively charged particles.

Electrons are particles of matter possessing a negative charge and very small mass. The net movement of electrons is referred to as an **electrical current**. The movement or flow of these electrons will always go from a higher potential to a lower potential (Fig. 1). An electrical force is oriented only in the direction of the applied force. This flow of electrons may be likened to a domino reaction.

Fig. 1: Electrical current.

The unit of measurement that indicates the rate at which electrical current flows is the **ampere (A)**; 1 A is defined as the movement of 1 **coulomb (C)**. Amperes indicate the rate of electron flow, whereas coulombs indicate the number of electrons. In the case of therapeutic modalities, **current** flow is generally described in milliamperes (1/1000 of an ampere, denoted as mA) or in microamperes (1/1,000,000 of an ampere, denoted as µA).

The electrons will not move unless an electrical potential difference in the concentration of these charged particles exists between two points. The electromotive force, which must be applied to produce a flow of electrons, is called a **volt (V)** and is defined as the difference in electron population (potential difference) between two points.

Voltage is the force resulting from an accumulation of electrons at one point in an electrical circuit, usually corresponding to a deficit of electrons at another point in the circuit. If the two points are connected by a suitable conductor, the potential difference (in electron population) will cause electrons to move from the area of higher population to the area of lower population.

Electrons can move in a current only if there is a relatively easy pathway to move along. Materials that permit this free movement of electrons are referred to as **conductors**. **Conductance** is a term that defines the ease with which current flows along a conducting medium and is measured in units called siemans. Metals (copper, gold, silver, aluminum) are good conductors of electricity, as are electrolyte solutions, because both are composed of large numbers of free electrons that are given up readily. Thus, materials that offer little opposition to current flow are good conductors. Materials that resist current flow are called **insulators**. Insulators contain relatively fewer free electrons and thus offer greater resistance to electron flow. Air, wood, and glass are all considered insulators. The number of amperes flowing in a given conductor is dependent both on the voltage applied and on the conduction characteristics of the material.

The opposition to electron flow in a conducting material is referred to as **resistance** or **electrical impedance** and is measured in a unit known as an **ohm**. Thus, an electrical circuit that has high resistance (ohms) will have less flow (amperes) than a circuit with less resistance and the same voltage. The mathematical relationship between current flow, voltage, and resistance is demonstrated in the following formula. This formula is the mathematical expression of **Ohm's law**, which states that the current in an electrical circuit is directly proportional to the voltage and inversely proportional to the resistance.

An analogy comparing the movement of water with the movement of electricity may help to clarify this relationship between current flow, voltage, and resistance. In order for water to flow, some type of pump must create a force to produce movement. Likewise, the volt is the pump that produces the electron flow. The resistance to water flow is dependent on the length, diameter, and smoothness of the water pipe. The resistance to electrical flow depends on the characteristics of the conductor. The amount of water flowing is measured in gallons, whereas the amount of electricity flowing is measured in amperes.

The amount of energy produced by flowing water is determined by two factors: (1) the number of gallons flowing per unit of time; and (2) the pressure created in the pipe. Electrical energy or power is a product of the voltage or electromotive force and the amount of current flowing. Electrical power is measured in a unit called a **watt**.

Watt = volt × ampere

Simply, the watt indicates the rate at which electrical power is being used. A watt is defined as the electrical power needed to produce a current flow of 1 A at a pressure of 1 V.

PRINCIPLES OF ELECTRICAL STIMULATING CURRENT

Types of Electrical Stimulating Currents

Electrical currents used in clinical electrotherapy can generally be divided into two types: direct current, alternating current (Fig, 2).

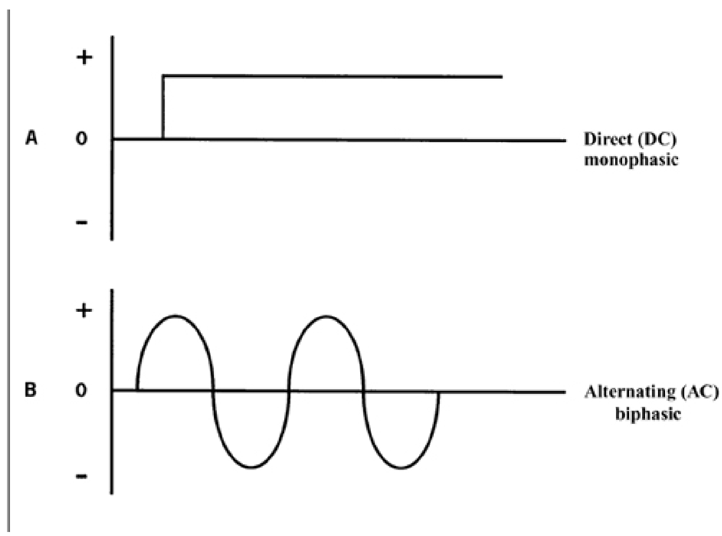


Fig. 2: Types of Electrical Stimulating Currents

Direct current (DC):

Is the continuous or uninterrupted unidirectional flow of charged particles. In the context of clinical applications, the flow of charged particles must continuous uninterrupted for at least 1 second to be considered as direct current. Direct current has traditionally been referred to as "galvanic" current.

Alternating Current (AC):

- Alternating Current is the continuous or uninterrupted bidirectional flow of charged particles.

- Electrons in the circuit first move in one direction, when the electric field is reversed, the electron move back toward their original position. The basic pattern of an alternating current is the sine wave.
- Alternating current is characterized by the frequency of oscillations, the amplitude of the electron or ionic movement, and wave form of the current. ***Frequency:*** is the number of cycle per second and expressed in hertz (Hz).

The cycle duration, is the amount of time required to complete one full cycle and is measured from the beginning point on the baseline to its terminating point.

Modes:

Each of the previously mentioned forms of current may be administered in two major modes:

- Continuous mode: If its rate (frequency) exceeds 50 Hz, it is then becoming tetanizing, being used for relaxation of muscle spasm.

- Interrupted or pulsed mode: The alternating current when interrupted sharply reaches peak intensity immediately, causing a brisk response in the muscle, being suitable for stimulation of fast fibers. Interruption at higher rates exceeding 50 Hz causes a tetanic type of contraction.

Electrical currents can also be classified according to their frequency.

The current frequency is very important factor to be considered as it determines which tissues to be stimulated**.**

1-Low Frequency Current

Current in which the direction of electron flow changes periodically with a frequency of 1-1000 Hz. Low frequency currents can stimulate both sensory and motor nerves, with the best effect form 1-100 Hz. Examples of low frequency currents are faradic current (FC), diadynamic current (DD), High voltage galvanic (HVG) current.

2-Medium Frequency Currents

Current with frequency of 1 KHz. These currents can only stimulate sensory and motor nerves to after modulation as in interefrential current (IF) or interrupted as in Russian current.

3-High frequency currents

Those current of 1000,000 (106) Hz or more. At this frequency the current has no effect on sensory and motor nerve. Example of high frequency currents are short wave (SW) and microwave (MW).

Wave forms:

- Sine wave: It usually offers equal energy levels under positive and negative phases (Fig, 3).

- Rectangular (square) wave: This form of wave describes usually the direct current with a rapid instantaneous rise, prolonged duration and a sharp drop-off.

- Spike wave: During such a waveform, the rise rate is rapid but not instantaneous, falling back rapidly to zero immediately after reaching the maximum.

- Combined waves: It resembles a combination form of both rectangular (square) and spike waves.

- Twin-spiked forms: With this waveform, more penetration is administered because of the extremely short-pulse width (microseconds), as in high-voltage galvanic stimulation.

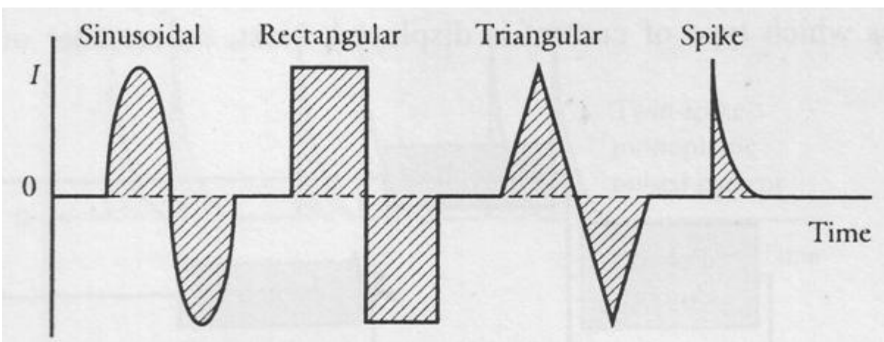


Fig.3: Waveforms.

There are some terms should be defined when using electrical current

- A ***single pulse*** is defined as a very brief period of charged particle movement followed by a very brief cessation of movement.
- The building block of pulsed currents is ***the phase***. A phase is the individual section of a pulse that rises above or below the baseline for a measurable period of time. The number and type of phases classify the type of pulse and ultimately the tissues' response. Pulsed

currents may be monophasic or biphasic, (fig 4). Waveforms of Pulsed current with three phases are called triphasic, and those with more than three are called polyphasic**.**

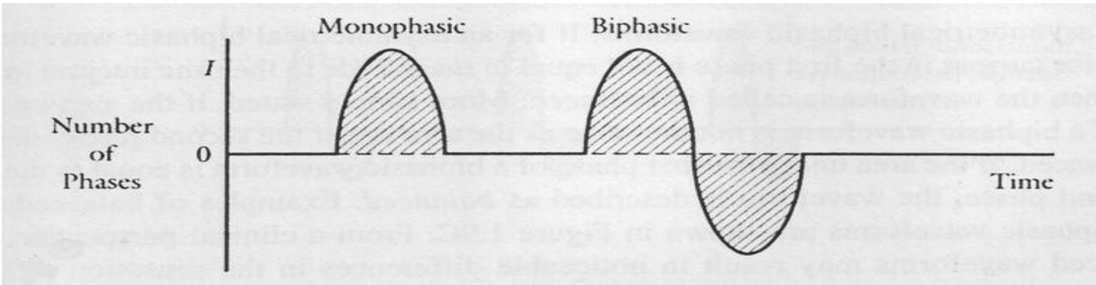


Fig 4: Number of phase of pulsed current

Monophasic currents:

Monophasic pulses have only one phase to a single pulse and the current flow is unidirectional and it remains on one side of the baseline. In this type the pulse duration is measured as the distance required to complete one full waveform. With monophasic current the terms pulse, phase, and waveform are synonymous (Fig. 5)

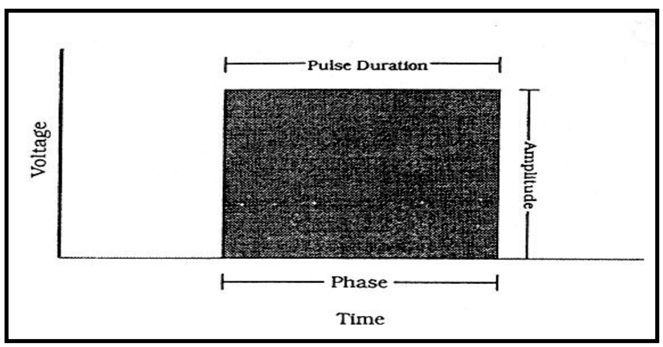


Fig. 5: Monophasic current.

Biphasic currents

Biphasic currents consists of two phases, each occurring on opposite side of the baseline. If the two phases are equal in their magnitude, duration and shape; it is considered as symmetrical biphasic pulses. When each phase in the pulse has a different shape it is considered as asymmetrical biphasic pulses, (fig 6).

However an asymmetrical pulse may be balanced or unbalanced. If the charges (area) under the curve in both negative and positive direction (both phases of biphasic pulses) are unequal, is termed unbalanced asymmetrical biphasic pulses. While, If the charges (area) under the curve in both negative and positive direction (both phases) are equal, is termed balanced asymmetrical biphasic pulses, (fig. 7, 8). Symmetrical biphasic waveforms fend to be the most comfortable because they deliver relatively lower charges per phase.

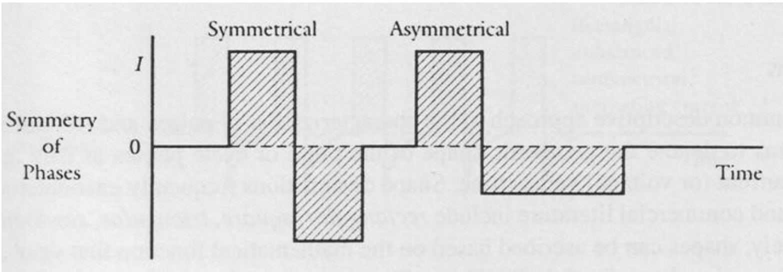
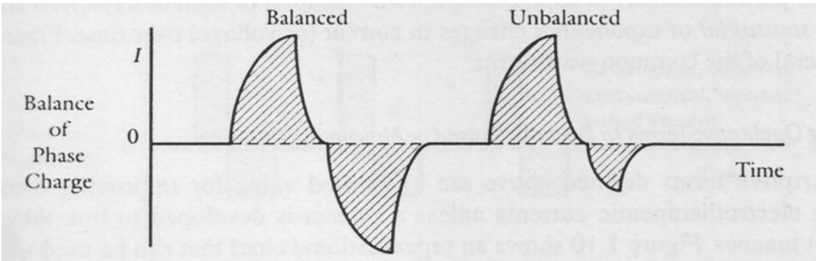


Fig. 6: Symmetry of biphasic Pulsed Current



Fig, 7: Balance of biphasic Pulsed Current

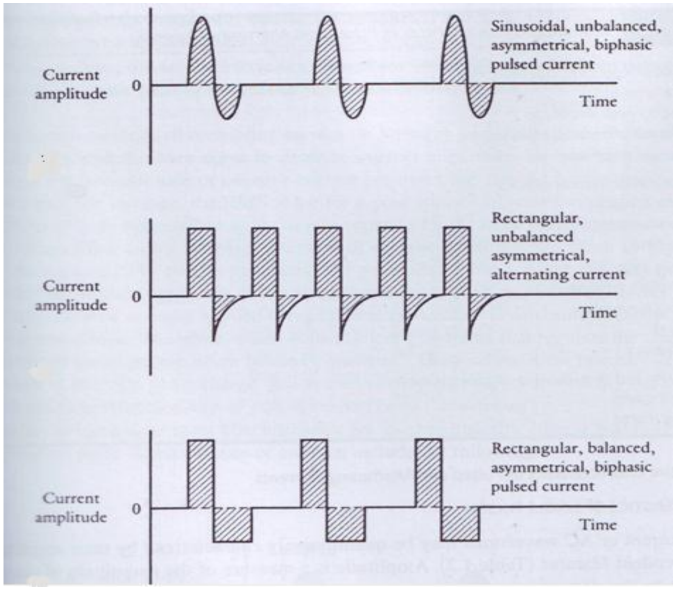


Fig (8): Wave form, Balance and Symmetry of biphasic Pulsed Current

BIPHASIC VERSUS MONOPHASIC CURRENT

The biggest difference in the effects of biphasic and monophasic currents is the ability of monophasic current to cause chemical changes. Chemical effects from using monophasic current usually occur only when the stimulus is continuous and applied over a period of time.

The electrical current parameters

1- ***THE CURRENT AMPLITUDE:***

- ***The current amplitude*** is determined by measuring the maximal distance to which the wave rises above or below the baseline (beak amplitude).
- ***The peak to peak amplitude:*** is the distance measured from the peak on the positive side to the peak on the negative side (Fig.9).

The amplitude of each pulse reflects the intensity of the current, the maximum amplitude being the tip or highest point of each phase. Amplitude is measured in amperes, microamps, or milliamps (mA). The term amplitude is synonymous with the terms voltage and current intensity. Voltage is measured in volts, microvolts, or millivolts (mV). The higher the amplitude, the greater the peak voltage or intensity. However, the peak amplitude should not be confused with the total amount of current being delivered to the tissues.

On electrical generators that produce short-duration pulses, the total current produced (c/sec) is low compared to peak current amplitudes owing to long interpulse intervals that have current amplitudes of zero. Thus, the **total current** (average), or the amount of current flowing per unit of time, is relatively low, ranging from as low as 2 to as high as 100 mA on some interferential generators. Total current can be increased by either increasing pulse duration or increasing pulse frequency or by some combination of the two.

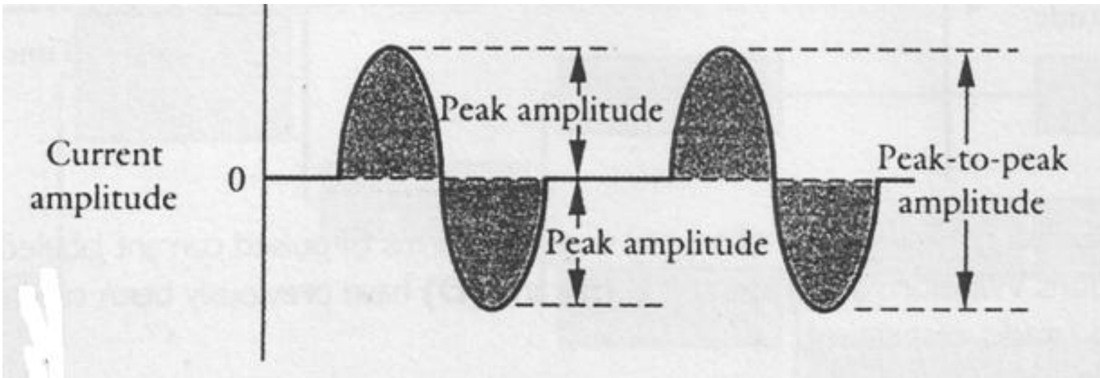


Fig. 9 Current Amplitude

2- PULSE CHARGE

The term **pulse charge** refers to the total amount of electricity being delivered to the patient during each pulse (measured in columbs or microcolumbs). With monophasic current, the phase charge and the pulse charge are the same and always greater than zero. With biphasic current, the pulse charge is equal to the sum of the phase charges. If the pulse is symmetric, the net pulse charge is zero. In asymmetric pulses the net pulse charge is greater than zero, which is a DC current by definition.

3- CURRENT DENSITY

The **current density** (amount of current flow per cubic volume) at the nerve or muscle must be high enough to cause depolarization. The current density is highest where the electrodes meet the skin and diminishes as the electricity penetrates into the deeper tissues. If there is a large fat layer between the electrodes and the nerve, the electrical energy may not have a high enough density to cause depolarization.

If the electrodes are spaced closely together, the area of highest-current density is relatively superficial. If the electrodes are spaced farther apart, the current density will be higher in the deeper tissues, including nerve and muscle. Electrode size will also change current density. As the size of one electrode relative to another is decreased, the current density beneath the smaller electrode is increased. The larger the electrode, the larger the area over which the current is spread, decreasing the current density.

Using a large (dispersive) electrode remote from the treatment area while placing a smaller (active) electrode as close as possible to the nerve or muscle motor point will give the greatest effect at the small electrode. The large electrode disperses the current over a large area; the small electrode concentrates the current in the area of the motor point.

Electrode size and placement are key elements which the therapist controls that will have great influence on your results. High-current density close to the neural structure you want to stimulate makes it more certain that you will be successful with the least amount of current. Electrode placement is probably one of the biggest causes of poor results from electrical therapy.

4- PULSE FREQUENCY:

The number of electrical pulses that occur in a 1 second period. It is expressed as pulse per second (pps) or as pulse frequency in Hz. An inverse relationship exists between the pulse frequency (pulse rate) and an electrical current and the resistance offered by the tissues. A current with lower pulse frequency i.e. 10 pps would meet resistance than a current with pulse frequency 1000 pps and would require an increased intensity to overcome the resistance.

5- PULSE DURATION:

- Sometimes referred to as pulse width. It is the amount of time from the beginning of a phase to the end of the final phase (to the return to a zero). The duration of a single pulse may be broken down into the time required for each component phase to complete its shape: the phase duration
- *Phase duration:* the amount of time for a single phase to complete its rout. Pulse duration and phase duration expressed in second (sec), millisecond (ms), or microsecond (μ sec).
- The duration of time between the end of one pulse and the initiation of the following pulse is known as *the interpulse interval*. A single pulse or phase may be interrupted by an *intrapulse interval*, however the duration of the intrapulse interval should not exceed the duration of the interpulse interval.

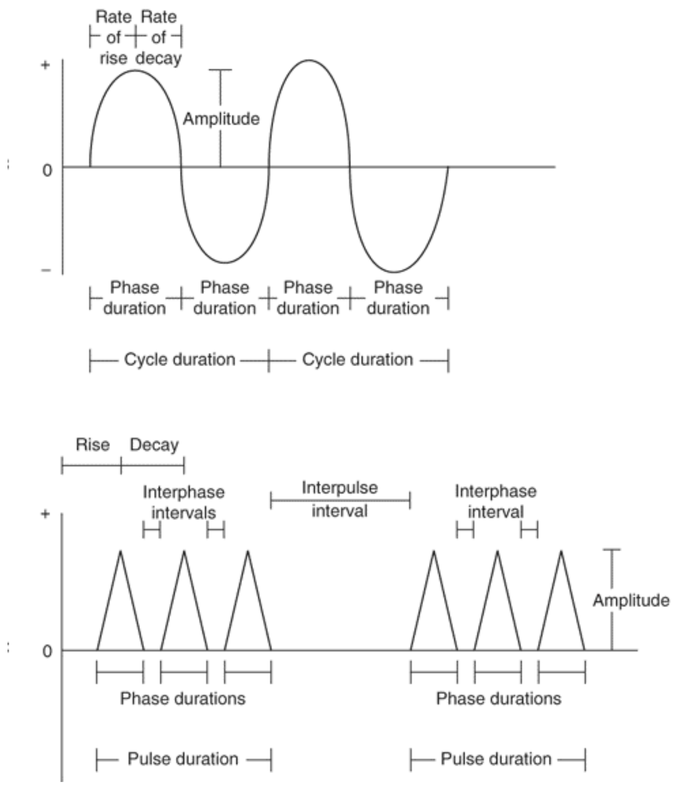


Fig. 10:

6- PULSE RATE OF RISE AND DECAY TIMES:

The **rate of rise** in amplitude, or the rise time, refers to how quickly the pulse reaches its maximum amplitude in each phase. Conversely, **decay time** refers to the time in which a pulse goes from peak amplitude to 0 V. The rate of rise is important physiologically because of the **accommodation** phenomenon, in which a fiber that has been subjected to a constant level of depolarization will become unexcitable at that same intensity or amplitude. Rate of rise and decay times are generally short, ranging from nanoseconds (billionths of a second) to milliseconds (thousandths of a second).

By observing the different waveforms, it is apparent that the sine wave has a gradual increase and decrease in amplitude for alternating, direct, and pulsatile currents. The rectangular wave has an almost instantaneous increase in amplitude, which plateaus for a period of time and then abruptly falls off. The spiked wave has a rapid increase and decrease in amplitude. The shape of these waveforms as they reach their maximum amplitude or intensity is directly related to the excitability of nervous tissue. The more rapid the increase in amplitude or the rate of rise, the greater the current's ability to excite nervous tissue.

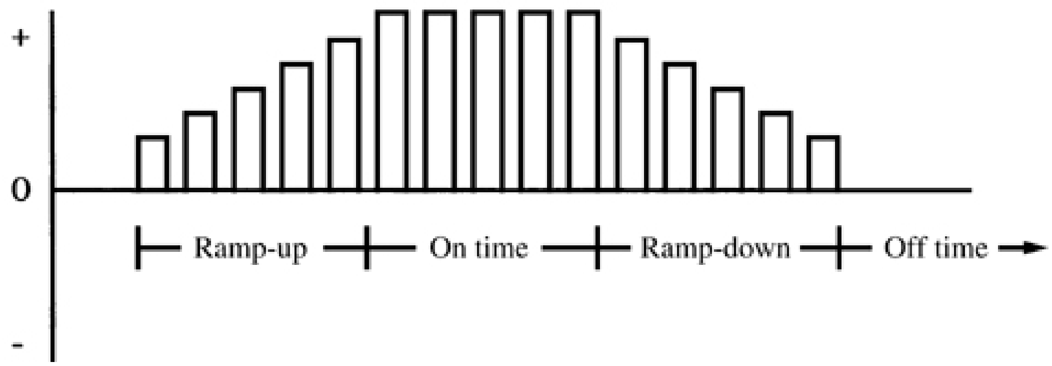


Fig. 11:

7- POLARITY

During the use of any stimulator, an electrode that has a greater level of electrons is called the negative electrode or the cathode. The other electrode in this system has a lower level of electrons and is called the positive electrode or the anode. The negative electrode attracts positive ions and the positive electrode attracts negative ions and electrons. With AC waves, these electrodes change polarity with each current cycle.

With a direct current generator, the therapist can designate one electrode as the negative and one as the positive, and for the duration of the treatment the electrodes will provide that polar effect. The polar effect can be thought of in terms of three characteristics: (1) chemical effects, (2) ease of excitation, and (3) direction of current flow.

Chemical changes occur only with long duration continuous current.

8- **DUTY CYCLE:**

The duty cycle is the ratio of the amount of time the current is flowing (ON) to the amount of time without current (OFF) and expressed as a percentage or ratio. Duty cycle is calculated by dividing the time the current is flowing by the total cycle time. Duly cycles play a role in neuromuscular stimulation by preventing muscle fatigue. Muscular stimulation is started with a 25% duty cycle and is progressively increased as the condition improves.

$$\text{Duty Cycle} = \frac{\text{On time}}{(\text{On time} + \text{Off time})} \times 100\%$$

For example, if the on time equals 10 seconds and the off time equals 30 seconds, the duty cycle such a pattern of stimulation would be 25%. A very different pattern of stimulation with an on time of 5 seconds and an off time of 15 seconds yields the same 25% duty cycle.

Current Modulation

Modulation is alteration in the current parameters in order to reduce or minimize accommodation.

- ***Amplitude modulations;*** Variations in the peak amplitude of a series of pulses.
- ***Pulse or phase duration modulations*****:** Regular changes in the time over which each pulse in a series acts.
- ***Frequency modulations*****:** consist of cyclic variations in the number of pulses applied per unit time.
- ***Surged (ramped) modulations***: are characterized by an increase (ramp up) or decrease (ramp down) of pulse amplitude, pulse duration, or both, over time.

Burst modulation:

a series of groups of pulses or groups of alternating current cycles delivered at a specified frequency over a specified time interval (Fig. 15A and B) followed by a brief time interval without charged particle movement. The time interval over which the finite series of pulses or AC cycles is delivered is called *the burst duration*. The time period between bursts is called *the interburst interval.* In contemporary clinical applications of such burst modulations, the burst duration and interburst interval are usually on the order of a few milliseconds. The number of bursts delivered per unit of time is called *the burst frequency*.

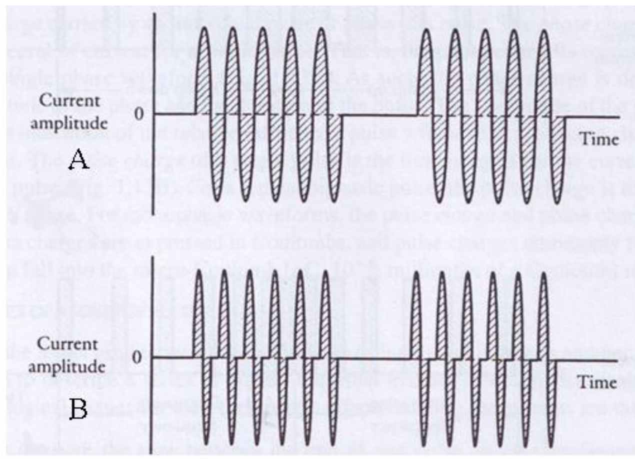


Fig 15. Examples of burst modulations. **A:** Burst-modulated, sinusoidal AC waveforms. **B:** Burst-modulated, sinusoidal pulsed current waveforms.

Fig. 12:

Pulse Train

Pulse train may be considered individual patterns of waveforms, duration and or frequency that are linked together. This linked patterns repeat at regular intervals.

Beat Modulation

A beat modulation will be produced when two interfering alternating current waveforms with differing frequencies are delivered to two separate pairs of electrodes through separate channels within the same generator. The two pairs of electrodes are set up in a crisscrossed or cloverleaf-like pattern so that the circuits interfere with one another. This interference pattern produces a beat frequency equal to the difference in frequency between the two alternataing current frequencies. As an example, one circuit may have a fixed frequency of 4000 Hz, while the other is set at a frequency of 4100 Hz, thus creating a beat frequency of 100 beats per second. This type of beat-modulated alternating current is referred to as interferential current and will be discussed further in

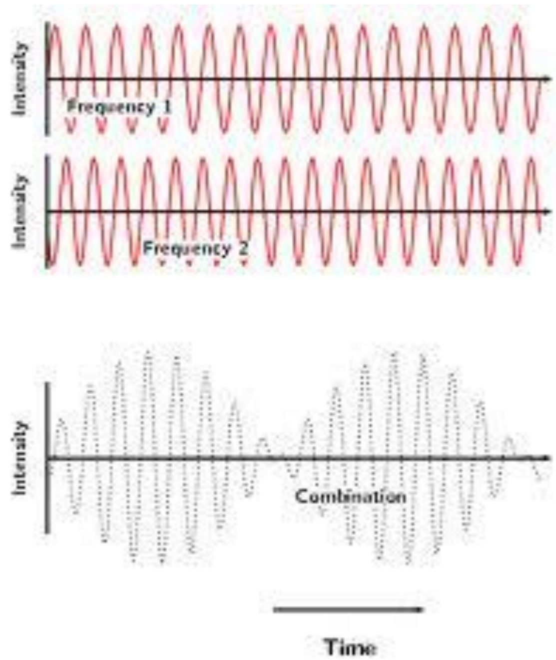


Fig. 13:

General Contraindications to Electrical stimulation:

1- Unreliable patient which not understand the command
2- Stimulation of the abdominal and pelvic region during pregnancy and menstruation
3- Stimulation of the thorax or neck may result in disruption of normal respiration or cardiac function.
4- Exposed metal implants
5- Areas of the carotid sinus, esophagus, larynx, or pharynx may affect respiration
6- Patient with pacemaker, as it may interfere with its function

Treatment procedures:

1. Preparation of the patient:

- The skin in the area of electrode placement should be cleaned thoroughly.
- Special gels, sprays or water is applied to the skin as a condition medium for better stimulation.
- Electrodes should be fixed in position, using mending tapes to maintain good contact throughout the treatment period.

2. ***Electrode placement***

When using any of the treatment protocols aimed at the electrical stimulation of sensory nerves for pain suppression, there are several guidelines that will help the therapist select the appropriate sites for electrode placement. Transcutaneous electrical nerve stimulation (TENS) uses similar-sized electrodes placed according to a pattern and moved in a trial-and-error pattern until pain is decreased. The following patterns may be used.

1. Electrodes may be placed on or around the painful area.

2. Electrodes may be placed over specific dermatomes, myotomes, or sclerotomes that correspond to the painful area.

3. Electrodes may be placed close to the spinal cord segment that innervates a painful area.

4. Peripheral nerves that innervate the painful area may be stimulated by placing electrodes over sites where the nerve becomes superficial and can be stimulated easily.

5. Vascular structures contain neural tissue as well as ionic fluids that would transmit electrical stimulating currents and may be most easily stimulated by electrode placement over superficial vascular structures.

6. Electrode placement over trigger point locations.

7. Both acupuncture and trigger points have been conveniently mapped out and illustrated. A reference on acupuncture and trigger areas is included in Appendix A. The therapist should systematically attempt to stimulate the points listed as successful for certain areas and types of pain. If they are effective, the patient will have decreased pain. These points also can be identified using an ohm meter point locator to determine areas of decreased skin resistance.

8. Combinations of any of the preceding systems and bilateral electrode placement also can be successful.

9. Crossing patterns, also referred to as an interferential technique, involve electrode application such that the electrical signals from each set of electrodes add together at some point in the body and the intensity accumulates. The electrodes are usually arranged in a crisscross pattern around the point to be stimulated (Fig. 6-20). If there is a specific superficial area (e.g., medial collateral acromioclavicular joint) that you wish to stimulate, your electrodes should be relatively close together. They should be located so the area to be treated is central to the location of the electrodes. If there is poorly localized pain (general shoulder pain) that seems to be deeper in the joint or muscle area, spread your electrodes farther apart to give more penetration to the current.

10- Trans-arthral: The electrodes are placed on both sides of the target joint. It should be clear in mind that the current does not pass across the joint, but instead flows around the joint between electrodes.

Electrode placemen techniques:

This is determined by the target muscle or muscle group, either single or in relation to other muscles. Placement alternatives recommended are:

- *Unilateral*: Unilateral placement often causes stimulation of one limb or one half of a muscle pair.

- *Bilateral*: It allows the stimulation of both limbs or both halves of a muscle pair.

- Unipolar: *sometime called MONOPOLAR:* Only one of the two essential leads and the electrode connected to it are placed over the target area affected by the stimulation. This electrode is called the treatment or stimulation electrode and is paired with a depressive or non treatment electrode which is usually larger .This technique is usually used with Trigger point and acupuncture point.

- *Bipolar*: In such a technique, two electrodes are placed on the target muscle, close to origin / insertion.

- Bilateral unipolar: The electrodes are placed on each of two separate muscles or muscle groups.

- ***Reciprocal:*** In which an active electrode is placed on each of two separate muscles or muscle groups, either agonist / antagonist or bilaterally, with the indifferent electrode placed elsewhere as in uniploar technique.

-***Quadripolar:*** involves the use of two sets of electrodes, each originating from its own channel. It may be considered the concurrent application of two bipolar circuit. This technique could be used with stimulation of agonist and antagonist stimulation. Also could be used in crossed pattern as in interferential current or in coplanar for large flat area as the back

Treatment Tip

When using interferential current, the four electrodes should be set up in a square pattern with the target treatment area being in the center of the square so that the maximum interference will take place where the electric field lines cross at the center of the pattern.

The physical therapist should not be limited to any one system but should evaluate electrode placement for each patient. The effectiveness of sensory stimulation is closely tied in with proper electrode placement. As in all trial-and-error treatment approaches, a systematic, organized search is always better than a "shotgun," hit-or-miss approach. Numerous articles have identified some of the best locations for common pain problems, and these may be used as a starting point for the first approach.[83] If the treatment is not achieving the desired results, the electrode placement should be reconsidered.

3. Monitoring the treatment:

- Turn on the equipment with the amplitude is on the zero position.
- The amplitude (intensity) should be increased slowly and gradually until a visible or palpable contraction is seen or felt, except in case of interferential current, in which the patient's sensation is the clinical guide.
- Treatment continues to the pre-determined duration, with suitable adjustment of various parameters if needed.
- On termination of treatment, the intensity should be reduced slowly till the zero position again.