Basic Concepts in Electricity and Electrotherapy

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4.1 Introduction

Electrotherapy is the use of electrical energy as a medical treatment. Although electrotherapy has been a component of clinical practice since the early days, its delivery has changed remarkably and continues to do so. The most popular modalities used these days are quite dissimilar to those of 50 or more years ago even if they are based on the same principles. Modern electrotherapy practice needs to be evidence based and used appropriately. Used at the right place and at the right time for the right reason, it has a phenomenal capacity to be effective. Used unwisely, it will either do no good at all or possibly make matters worse, as would be true for any other therapy. The skill of the practitioner using electrotherapy is to make the appropriate clinical decision as to which modality to use and when, and to use the best available evidence when making that decision.

The electrotherapy modalities involve the introduction of some physical energy into a biological system. This energy brings about one or more physiological changes, which are used for therapeutic benefit. Clinically, it is probably more useful to determine first the nature of the problem to be addressed and then establish the physiological changes that need to take place in order to achieve these effects and, lastly, the modality which is most able to bring about the changes in the target concerned [1].

The term "electrotherapy" is generally used in the widest sense. However, some modalities (e.g., ultrasound and laser) do not strictly fall into an "electrotherapy" grouping (they do not deliver an electric current), which is why some authorities prefer the term electrophysical agents [2].

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4.2 Electrotherapeutic Window

It has long been recognized that the amount of a treatment is a critical parameter. This is no less true for electrotherapy than for other interventions. There are literally hundreds of research papers that illustrate that the same modality applied in the same circumstances but at a different dose will produce a different outcome.

For example, an energy delivered at a particular amplitude has a beneficial effect, while the same energy at a lower amplitude may have no demonstrable effect.

Along similar lines, “frequency windows” are also evident. A modality applied at a specific frequency (pulsing regime) might have a measurable benefit, while the same modality applied using a different pulsing profile may not appear to achieve equivalent results.

Electrical stimulation frequency windows have been proposed, and there is clinical and laboratory evidence to suggest that there are frequency-dependent responses in clinical practice. Transcutaneous Electrical Nerve Stimulation (TENS) applied at frequency X appears to have a different outcome to TENS applied at frequency Y in an equivalent patient population. Studies by Sluka et al. [3], Kararmaz et al. [4], and Han et al. [5] are among the numerous studies that have demonstrated frequency-dependent effects of TENS.

Also for sacral nerve modulation, there are several examples of attempts to identify the best therapeutic window using the stimulation parameters [6–9].

It can be suggested that if the right amplitude and the right frequency are applied at the same time, then the maximally beneficial effect will be achieved. Unfortunately, there are clearly more ways to get this combination “wrong” than “right.” A modality applied at a less than ideal dose will not achieve best results. Again, this does not mean that the modality is ineffective, but more likely that the ideal window has been missed.

The situation is complicated by the apparent capacity of the windows to “move” with the patient condition. The position of the therapeutic window in the acute scenario appears to be different from the window position for the patient with a chronic version of the same problem. A treatment dose that might be very effective for an acute problem may fail to be beneficial with a chronic presentation.

Moreover, many other parameters need to be considered, such as the treatment characteristics (number of sessions, treatment intervals, energy, and time of exposure) or the patient’s features (age, sex, comorbidities).

In conclusion, despite the general rules, the best therapeutic outcome can be achieved only by selecting the best possible stimulation parameters individualized to each patient.

Moreover, when applying electromodalities to patients, it is essential to respect the electrical nature of the human body.

4.3 The Bioelectric Body and the Bioelectric Cell

The electrical activity of the body has been used for a long time for both diagnostic and monitoring purposes in medicine, largely in connection with the “excitable” tissues. Examples include ECG, EMG, and EEG. More recent developments have begun to look at the tissues which were not regarded as excitable, but in which endogenous electrical activity has been demonstrated. The endogenous electrical activity of the body arises from a variety of sources, some of which are well documented, while others remain more obscure in their origins and control mechanisms. The relationship between endogenous electrical activity (not exclusively potentials), injury, and healing has been researched in several areas of clinical practice and has been well documented in several publications [10].

Every living cell has a membrane potential, with the inside of the cell being negative relative to its external surface. Typically, the resting membrane potential of a healthy cell will be −60 to −80 mV, and during an action potential, the membrane potential might reach +40 mV. Relatively to the size of the cell, the membrane potential is massive. The membrane is on average 7–10 nm thick. The equivalent voltage is somewhere in the order of ten million volts per meter.

The cell membrane potential is strongly linked to the cell membrane transport mechanisms, and much of the material that passes across the membrane is ionic (charged particles); thus, if the movement of charged particles changes, then it will influence the membrane potential. Conversely, if the membrane potential changes, it will influence the movement of ions.

Membrane currents are the result of opening ion selective channels which causes ions to flow across cell membranes. This flow is spontaneous because all ion types are distributed unevenly between cellular and extracellular compartments. In general, cells contain high loads of K+, but low Na+ and Ca++ ions, while extracellular fluids contain high Na+ and Ca++ ions, but low K+ concentrations. When channels are activated, ions will always start diffusing through the pores in either direction, although more ions will flow from the high to the low concentration. This ion diffusion is an important part of bioelectricity maintaining resting potentials and generating action potentials. It is also used to couple the transport of secondary solutes that can be upconcentrated inside or outside according to metabolic needs. Finally, ATP-hydrolyzing pumps reverse the flow of ions regenerating the gradients dissipated by the activity of channels and secondary transporters.

Different cells and tissues respond preferentially to different types of energy and at different doses.

Given the natural energy systems of the living cell, there are two approaches to the application of electrotherapy modalities. First, one can deliver sufficient energy to overcome the energy of the membrane and thereby force it to change behavior. Second, one can deliver much smaller energy levels, and instead of forcing the membrane to change behavior, it can be just stimulated. Low-energy membrane stimulation produces membrane excitement, and membrane excitement produces cellular excitement (upregulation).

Electrical potentials exist across the membranes of virtually all cells of the body. In addition, some cells, such as nerve and muscle cells, are capable of generating rapidly changing electrochemical impulses at their membranes, and these impulses are used to transmit signals along the nerve or muscle membranes. In still other types of cells, such as glandular cells, macrophages, and ciliated cells, local changes in membrane potentials also activate many of the cells' functions.

The resting membrane potential of large nerve fibers when not transmitting nerve signals is about −90 mV.

Nerve signals are transmitted by action potentials, which are rapid changes in the membrane potential that spread rapidly along the nerve fiber membrane. Each action potential begins with a sudden change from the normal resting negative membrane potential to a positive potential and then ends with an almost equally rapid change back to the negative potential. To conduct a nerve signal, the action potential moves along the nerve fiber until it comes to the fiber's end.

An excitable membrane has no single direction of propagation, but the action potential travels in all directions away from the stimulus, even along all branches of a nerve fiber, until the entire membrane has become depolarized.

The large fibers are myelinated, and the small ones are unmyelinated. The average nerve trunk contains about twice as many unmyelinated fibers as myelinated fibers.

The central core of the fiber is the axon, and the membrane of the axon is the membrane that conducts the action potential. Surrounding the axon is a myelin sheath (Schwann cell rotates around the axon many times, laying down multiple layers of Schwann cell membrane containing the lipid substance sphingomyelin, which is an excellent electrical insulator that decreases ion flow through the membrane about 5,000-fold) that is often much thicker than the axon itself. About once every 1–3 mm along the length of the myelin sheath is a node of Ranvier, a small uninsulated area only 2–3 μm in length where ions still can flow with ease through the axon membrane between the extracellular fluid and the intracellular fluid inside the axon.

Even though almost no ions can flow through the thick myelin sheaths of myelinated nerves, they can flow with ease through the nodes of Ranvier. Therefore, action potentials occur only at the nodes (saltatory conduction).

A new action potential cannot occur in an excitable fiber as long as the membrane is still depolarized from the preceding action potential (refractory period).

Some signals need to be transmitted to or from the central nervous system extremely rapidly; otherwise, the information would be useless. An example of this is the sensory signals that apprise the brain of the momentary positions of the legs at each fraction of a second during running. At the other extreme, some types of sensory information, such as that depicting prolonged, aching pain, do not need to be transmitted rapidly, so that slowly conducting fibers will suffice.

A fibers are myelinated afferent or efferent fibers of the somatic nervous system having a diameter of 1–22 μm and a conduction velocity of 5–120 m per second. They include the alpha, beta, delta, and gamma fibers. Alpha fibers are motor and proprioceptive fibers, having conduction velocities of 70–120 m/s and ranging from 13 to 22 μm in diameter. Beta fibers are motor and proprioceptive fibers, having conduction velocities of 30–70 m/s and ranging from 8 to 13 μm in diameter. Gamma fibers conduct at velocities of 15–40 m/s and range from 3 to 7 μm in diameter, comprising the fusimotor fibers. Delta fibers are sensory and nociceptor fibers and conduct at velocities of 2–30 m/s and range from 2 to 5 μm in diameter.

B fibers are myelinated preganglionic autonomic axons having a fiber diameter of ≤ 3 μm and a conduction velocity of 3–15 m/s. They are both afferent and efferent and are mainly associated with visceral innervation.

C fibers are unmyelinated postganglionic fibers of the autonomic nervous system, at the dorsal roots and at free nerve endings, having a conduction velocity of 0.6–2.3 m/s and a diameter of 0.3–1.3 μm, that conduct impulses of prolonged, burning pain sensation from the viscera and periphery.

Basically, any factor that causes sodium ions to begin to diffuse inward through the membrane in sufficient numbers can set off automatic regenerative opening of the sodium channels. This can result from mechanical disturbance of the membrane, chemical effects on the membrane, or passage of electricity through the membrane. All these are used at different points in the body to elicit nerve or muscle action potentials: mechanical pressure to excite sensory nerve endings in the skin, chemical neurotransmitters to transmit signals from one neuron to the next in the brain, and electrical current to transmit signals between successive muscle cells in the heart and intestine.

When excitatory synapses are repetitively stimulated at a rapid rate, the number of discharges by the postsynaptic neuron is at first very great, but the firing rate becomes progressively less in succeeding milliseconds or seconds. This is called fatigue of synaptic transmission. Fatigue is an exceedingly important characteristic of synaptic function because when areas of the nervous system become overexcited, fatigue causes them to lose this excess excitability after a while [11].

4.4 Fundamental Concepts of Electricity

4.4.1 Electric Charge

In order for electricity to exist, there must be a source of electric charge. There are two types of charges, called positive and negative.

Ancient cultures around the Mediterranean knew that certain objects, such as rods of amber, could be rubbed with cat's fur to attract light objects like feathers. Thales of Miletos made a series of observations on static electricity around 600 BC, from which he believed that friction rendered amber magnetic, in contrast to minerals such as magnetite, which needed no rubbing.

Some further experimenters speculated that invisible "fluids" were being transferred from one object to another during the process of rubbing and that these "fluids" were able to effect a physical force over a distance. Charles Dufay was one of the early experimenters who demonstrated that there were definitely two different types of changes wrought by rubbing certain pairs of objects together. The fact that there was more than one type of change manifested in these materials was evident by the fact that there were two types of forces produced: *attraction* and *repulsion*.

The hypothetical fluid transfer became known as a *charge*.

Benjamin Franklin came to the conclusion that there was only one fluid exchanged between rubbed objects and that the two different "charges" were nothing more than either an excess or a deficiency of that one fluid.

Following Franklin's speculation of the wool rubbing something off of the wax, the type of charge that was associated with rubbed wax became known as "negative" (because it was supposed to have a deficiency of fluid), while the type of charge associated with the rubbing wool became known as "positive" (because it was supposed to have an excess of fluid). Precise measurements of electrical charge were carried out by the French physicist Charles Coulomb in the 1780s using a device called a *torsional balance* measuring the force generated between two electrically charged objects. The results of Coulomb's work led to the development of a unit of electrical charge named in his honor, the *coulomb* (C).

The coulomb is defined as the quantity of charge that has passed through the cross section of an electrical conductor carrying one ampere within one second.

It was discovered much later that this "fluid" was actually composed of extremely small bits of matter called *electrons* (J. J. Thomson, 1897), so named in honor of the ancient Greek word for amber. Experimentation has since revealed that all objects are composed of *atoms* and that these atoms are in turn composed of smaller components known as *particles*. The three fundamental particles comprising most atoms are called *protons*, *neutrons*, and *electrons*.

The tight binding of protons in the nucleus is responsible for the stable identity of chemical elements and the failure of alchemists to achieve their dream of creating gold from other minerals.

Neutrons are much less influential on the chemical character and identity of an atom than protons, although they are just as hard to add to or remove from the nucleus, being so tightly bound. If neutrons are added or gained, the atom will still retain the same chemical identity, but its mass will change slightly and it may acquire strange *nuclear* properties such as radioactivity.

However, electrons have significantly more freedom to move around in an atom than either protons or neutrons. In fact, they can be knocked out of their respective positions (even leaving the atom) by far less energy than what it takes to dislodge particles in the nucleus. If this happens, the atom still retains its chemical identity, but an important imbalance occurs. Electrons and protons are unique in the fact that they are attracted to one another over a distance. It is this attraction over distance which causes the attraction between rubbed objects, where electrons are moved away from their original atoms to reside around atoms of another object.

Electrons tend to repel other electrons over a distance, as do protons with other protons. Because of this attraction/repulsion behavior between individual particles, electrons and protons are said to have opposite electric charges. Each electron has a negative charge and each proton a positive charge. In equal numbers within an atom, they counteract each other's presence so that the net charge within the atom is zero.

An excess or a deficiency of electrons on an object gives that object a static electric charge, also called electrostatic charge. If an object contains more number of total electrons than the total protons, then that object is said to be negatively charged. If an object contains a fewer number of total electrons than the total protons, then that object is positively charged.

So "charge" is the technical term used to indicate that an object has been prepared so as to participate in electrical forces.

An electric field is a field around charged particles and changing magnetic fields which exerts a force on charges within the field. All charged objects create an electric field that extends outward into the space that surrounds it. The charge alters that space, causing any other charged object that enters the space to be affected by this field. The strength of the electric field is dependent upon how charged the object creating the field is and upon the distance of separation from the charged object.

4.4.2 Conductors and Insulators

The electrons of different types of atoms have different degrees of freedom to move around. With some types of materials, such as metals, the outermost electrons in the atoms are so loosely bound that they chaotically move in the space between the atoms of that material by nothing more than the influence of room-temperature heat energy. Because these virtually unbound electrons are free to leave their respective atoms and float around in the space between adjacent atoms, they are often called *free electrons*. Charged particles, such as electrons in metals or ions in solution, will tend to move or change position as a result of their interaction with other charged particles. In other words, charged particles will tend to move in matter when electrical potential differences exist.

This relative mobility within a material is known as electric *conductivity*. Conductivity is determined by the types of atoms in a material (the number of protons in each atom's nucleus, determining its chemical identity) and how the atoms are linked together with one another. Materials with high electron mobility (many free electrons), in which charged particles readily move when placed in an electric field, are called *conductors*, while materials with low electron mobility (few or no free electrons), which do not tend to allow free movement of ions or electrons, are called *insulators*.

Metals such as copper, silver, or gold are good conductors; rubber, glass, porcelain and many plastics are good insulators.

The atoms of metals tend to give up electrons from their outer orbital shell quite readily when placed in an electric field. If a negatively charged substance is brought near one end of a long metal wire, electrons closest to the substance will be displaced along the wire away from the mass of similar charge.

Biological tissues contain charged particles in solution in the form of ions such as sodium (Na+), potassium (K+), calcium (Ca++), or chloride (Cl−). Human tissues are conductors because the ions there are free to move in aqueous body fluids when exposed to electromotive forces. The ability of ions to move in human tissues varies from tissue to tissue. Muscle and nerves are good conductors, whereas skin and fat are poor conductors.

4.4.3 Electrical Current: Ampere and Voltage

The properties of electric charges in motion are more important to the understanding of therapeutic electrical stimulation than are properties of charges at rest. The movement of charged particles through a conductor in response to an applied electric field is called *current*. The conduction of electrical charge through matter from one point to another is the transfer of energy that brings about physiological change during the clinical application of electrical stimulation. Producing electrical current requires the presence of freely movable charged particles in some substance and the application of a driving force to move the particles. In metal circuits, electrons are the movable charged particles, whereas in biological systems, ions in body fluids (electrolytic solutions) are the charged particles. The forces that induce current in biological fields are the applied voltages. The magnitude of current induced in a conductive medium is directly proportional to the magnitude to the applied voltage.

Current is defined as the amount of charge moving past a plane in the conductor per unit of time.

The standard unit of measurement for current is the ampere (A). One ampere is equal to the movement of 1 C of charge past a point in a second. The current used in electrotherapeutic application is often very small and is generally measured in milliamperes (mA: 10^{-3}A) or in microamperes (μA: 10^{-6}A).

Electrons in a conductor can flow only if the electric charge at the extremities of the conductor differs, that is, when there is a potential difference between the two ends. When the charge builds up, with positive polarity (shortage of electrons) in one place and negative polarity (excess of electrons) in another place, a powerful electromotive force exists. The difference can also be provided by a buildup of electrostatic charges, as in the case of a lightning stroke. This force, also known as voltage or electrical potential, is expressed in volts (V). Without the presence of a voltage between the two extremities of a conductor, there can be no flow of electrons. Under this condition, current flow is equal to zero.

Current has a direction, and the direction could be defined as either the net rate of flow of negative charges or the net rate of flow of positive charges. The arbitrary convention is that current is the net rate of flow of positive charges. This convention is why diagrams are drawn showing current flowing from positive (+) leads to negative (−) leads.

4.4.4 Resistance and Conductance

The magnitude of charge flow is determined not only by the size of the driving force (voltage) but also by the relative ease with which electron or ions are allowed to move through the conductors.

The property of a conductor to oppose to movement of charged particles is called resistance (R), and, conversely, the property to ease the charged particles' movement in a medium is called conductance (G).

The standard unit of resistance is the ohm (Ω), and the magnitude of the current induced in a conductor is inversely proportional to the resistance of the conductor.

The standard unit of conductance is the siemens (S).

The relationship between voltage and resistance that determines the magnitude of current (I) is expressed in Ohm's law:

$$I = V / R \text{ or } V = I \times R$$

Ohm's law simply states that the current induced in a conductor increases as the applied driving force (*V*) is increased or as the opposition to charge movement (*R*) is decreased.

Alternatively, Ohm's law may be expressed in terms of conductance (*G*) rather than resistance:

$$I = V \times G \text{ or } V = I / G$$

4.4.5 Capacitance and Impedance

In order to understand current in biological tissues, two other electrical concepts must also be introduced. Capacitance is the property of a system of conductors and insulators that allows the system to store charge. Currents produced in biological tissues are influenced not only by tissue resistance but also by tissue capacitance.

The capacitance is expressed in farads (F); 1 F is the magnitude of capacitance as 1 C of charge is stored when 1 V of potential difference is applied.

The term impedance (Z) describes the opposition to alternating currents, analogous to the way resistance describes the opposition to direct currents, that a system presents when a voltage is applied. Alternating current could be defined as a continuous or uninterrupted bidirectional flow of charged particles.

Impedance takes into account both the capacitive and resistive opposition to the movement of charged particles. When dealing with clinical electrical stimulation, it is more appropriate to express the opposition to current in terms of impedance, because human tissues are better modeled as complex resistor and capacitor networks.

Because impedance depends on the capacitive nature of biological tissues, its magnitude depends on the frequency of applied stimulation. In general, the higher the frequency of stimulation, the lower the impedance of tissues. The standard unit of impedance is the ohm.

4.5 Intuitive Approach to Electric Parameters

The concepts of voltage, current, and impedance are easily related to more intuitive parameters, allowing basic understanding to grow from a conceptual basis as well as from quantitative analysis.

Mechanical systems, fluid flow, heat transfer, and electric systems are all described by the same differential equations. To understand any one of these processes is equivalent to understanding them all. The only difference is the parameters. Substituting voltage for pressure and electric current for fluid flow allows an electric engineer to work in fluid mechanics [12].

Voltage is a measure of electric potential energy just as height is a measure of gravitational potential energy in the approximately constant gravitational field near the earth's surface. The gravitational potential energy of an apple is realized when it drops from the tree. The apple's velocity, when it hits your head, depends on the difference between the original height of the apple and the height of your head. Both height and voltage are measured as a difference between two locations, rather than as absolute numbers.

Current is a measure of flow. A river current corresponds to the volume of water that flows in some amount of time (e.g., liters per second). The current is determined by the steepness of the river grade (voltage) and the friction of the water and riverbed (resistance). A wide river flowing from a steep mountain passes huge amounts of water, just as a small resistor and a large voltage results in a huge electric current.

The electrons in a conductor that are free to move are also analogous to water in a long, straight, horizontally positioned pipe. The water has the capability of flowing through the pipe, but it will only dribble out the ends as long as the pipe is exactly level. Only when one end of the pipe is raised above the other end will a flow occur.

For direct currents (DCs), impedance is the same as resistance and simply corresponds to friction in a mechanical system. When alternating currents (ACs) are used, however, some of the energy from one cycle can be stored for use in later cycles. This concept of energy storage forms the basis of capacitance and impedance. A classic example of capacitance/impedance could be considered the Newton's cradle. If one ball is pulled away and is let to fall, it strikes the first ball in the series and comes to nearly a dead stop. The ball on the opposite side acquires most of the velocity and almost instantly swings in an arc almost as high as the release height of the last ball. This shows that the final ball receives most of the energy and momentum that was in the first ball, with the results of bouncing forever. In this system, friction is virtually eliminated. This is impedance without resistance. Energy is simply shifted back and forth between the first and the last ball. If friction is introduced, then energy is dissipated as heat and, over time, the bouncing subsides.

In complete analogy to the electrical impedance could be defined the acoustic impedance, a complex number which describes how a medium absorbs sound by relating the amplitude and phase of an applied sound pressure to the amplitude and phase of the resulting sound flux.

4.6 Stimulation Parameters

4.6.1 Frequency

Frequency is the number of occurrences of a repeating event per unit time. The standard international unit for frequency is the hertz (Hz), named after the German physicist Heinrich Hertz; 1 Hz means that an event repeats once per second.

Electrical frequency refers to the pulses produced per second during stimulation (e.g., 40 Hz = 40 pulses per second).

Nerve activation in applications for functional electrical stimulation is usually restricted to frequencies below 50 Hz. It has been suggested that frequencies above 50 Hz may predispose to nerve damage with continuous stimulation [13]. Frequencies above 100 Hz have been defined as high frequency and such frequencies have often been reported to result in the failure of evoked neural responses [14, 15]. The blocking effects of high-frequency alternating current (HFAC) waveforms have been variously reported since 1939 [16]. Bowman and McNeal evaluated the effect of voltage-controlled biphasic rectangular pulses between 100 Hz and 10 kHz and achieved a nerve conduction block above 4 kHz [17]. Stimuli at 300 Hz applied to the pudendal nerves have been reported to show a pressure reduction of the urethral sphincter by 30–45 % [18]. Li et al. have used 200–300 Hz stimuli to cause sphincter fatigue prior to evoked voiding and suggested that the optimal parameters to induce sphincter fatigue were 3 V, 100–500 Hz, and 100 microseconds for 15–20 s [19, 20]. Applied frequencies of 600 Hz have been claimed to produce a conduction-type block [21]. Tai et al. have shown that in the pudendal nerve, isolated from the spinal cord, evoked responses could be blocked with HFAC above 7 kHz [22].

The changes in anal pressure could be obtained without fatigue at stimulation frequencies of 10–20 Hz [23].

The effect of sacral nerve stimulation on bladder function has been suggested to be dependent on stimulation frequency, with bladder excitation dominating at frequencies of 2–5 Hz and bladder inhibition dominating at 10 Hz [24].

Low-frequency TENS stimulation induces the selective release of endorphins in the central nervous system [25].

4.6.2 Pulse Width

Electrical stimulation devices deliver pulses in waveform patterns that are often represented by geometric shapes such as square, peaked, or sine wave. These shapes characterize electrical current that rises above a zero baseline for the extent of the stimulation paradigm (uniphasic; e.g., direct current) or current that alternates above and below the baseline (biphasic or alternating current) [26]. The time span of a single pulse is known as the pulse width or pulse duration, so the pulse width is how wide each pulse is. It is measured in microseconds. Generally speaking, the higher the pulse width, the more “aggressive” the stimulation feels.

Dudding and colleagues, which examined changes in rectal compliance following acute changes in stimulation parameters, observed an increase in rectal compliance when the pulse width was decreased to 90 μs or the frequency increased to 31 Hz, from the conventional SNS settings of 14 Hz and 210 μs [27].

Dinning and colleagues [28] found no differences between stimulation with a pulse width of 300 and 400 μs about colonic motor responses.

Alteration of amplitude, pulse width, and frequency will have different effects on different fiber types depending on their diameter and the presence or absence of myelination. Pulses of short duration will tend to excite large axons with fewer small fibers recruited [29].

The pulse width on TENS devices usually range from 1 to 250 μs. Walsh and colleagues [30] showed that TENS delivered at a frequency of 110 Hz and pulse width of 200 μs could better mediate hypoalgesia by increasing both peripheral nerve conduction latency and mechanical pain threshold compared to lower a frequency (4 Hz) and a shorter pulse width (110 μs).

4.6.3 Amplitude

Amplitude is sometimes called magnitude, level, or intensity and refers to the width of the electric wave. Depending on the quantity being measured, the magnitude of an ac wave might be given in amperes (for current), volts (for voltage), or watts (for power).

The peak amplitude of an AC wave is the maximum extent, either positive or negative, that the instantaneous amplitude attains. In many waves, the positive- and negative-peak amplitudes are the same. The peak-to-peak (pk-pk) amplitude of a wave is the net difference between the positive-peak amplitude and the negative-peak amplitude.

To simplify this, the amplitude is what you feel when you “turn the unit up.” It is what causes the “buzzing” sensation of the stimulation to go higher or lower.

The higher the intensity, the stronger the depolarizing effect in the structures underlying the electrodes [31].

Intensity will also factor into patient comfort with higher intensities being typically less tolerated. For this reason, it is usually set at the patient threshold.

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