

Current Concepts in Electrical Stimulation

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The general principles of electrical stimulation (whether using TENS, Interferential Therapy, Neuromuscular Electrical Stim – NMES or any of the other diverse stimulation modes) is based on the common model of electrotherapy outlined in the diagram below.

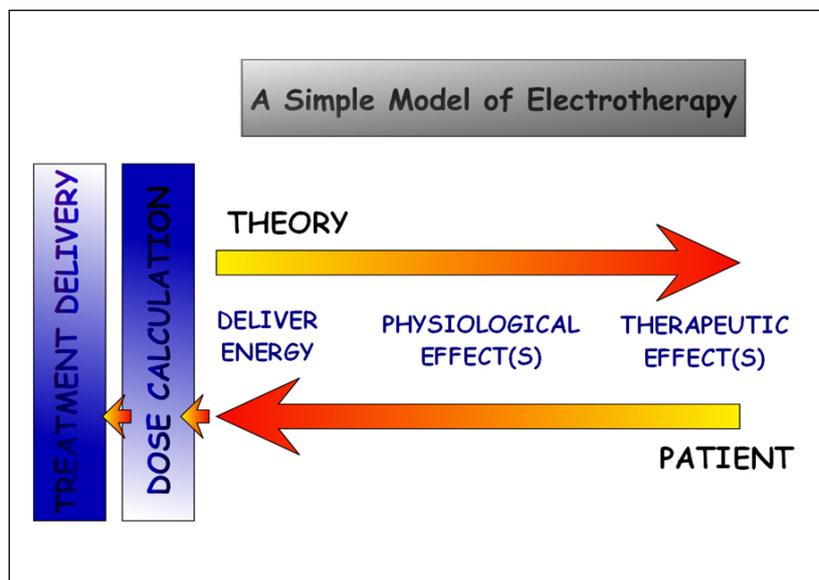


Figure 1 : General Model of Electrotherapy

The delivery of energy to the tissues (in this case a form of electric current) will bring about physiological changes in the tissues (nerve stimulation) and thereby achieve therapeutic benefit. The critical issues are to 'set' the machine in such a way as to stimulate the target nerves as effectively and as efficiently as possible. Stimulation of sensory nerves will achieve a sensory outcome, similarly, stimulation of motor nerves will bring about a motor effect. Clearly it is not possible to ONLY stimulate one type of nerve or another, BUT it is possible to primarily have an effect on a nerve type by setting appropriate parameters on the stimulation device.

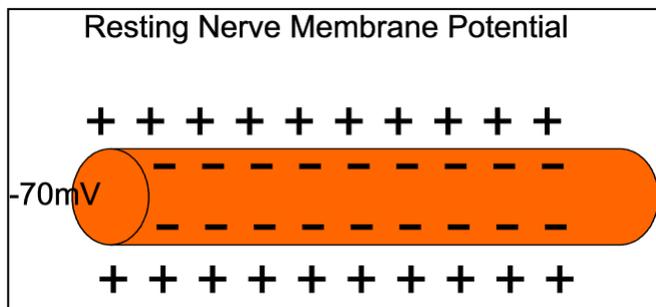
Some electrotherapy machines in this area are specific and dedicated to a particular task (e.g. TENS) whilst others offer numerous different stimulation modes, and a selection can be made typically from a menu system.

There is a developing range of research which is considering the effect of electrical stimulation intervention of physiological processes other than nerve stimulation (e.g. microcurrent therapy to enhance tissue repair) but this introduction will be confined to the nerve stimulation principles.

There are a couple of general principles that are worthy of consideration prior to detailed consideration of specific modalities, though there is a substantial volume of additional material available in the mainstream

electrotherapy texts – these notes are not intended to replace the texts, they are supplementary to the base information.

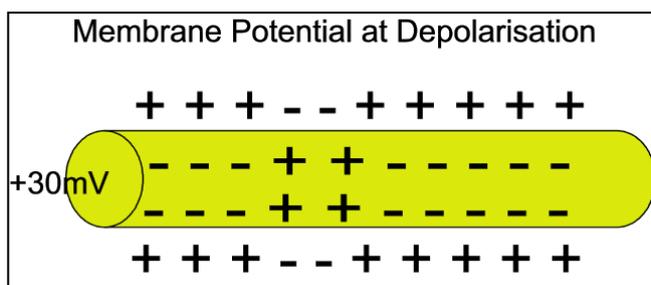
Nerve Membrane Potentials



Nerves, as we all know have a 'resting' membrane potential – such that the nerve membrane is effectively polarised (or charged up) even in its resting (quiescent) state. This polarisation of the membrane is achieved by the unequal movement (pumping) of ions across the membrane, and clearly therefore takes energy to create and to maintain this state.

Figure 2 : Resting nerve membrane potential

The result of the polarisation is that the nerve is always ready to 'fire' – i.e. to carry/transmit an action potential. An action potential (nerve impulse) is effectively a temporary change of state of the nerve membrane sequentially along its length, and is achieved by altering the pump and ion channel activity of the membrane. There is a tremendous volume of detailed information available with regards how this is achieved and controlled, and it is not the intention to try and explain this here.



The essential components are that the nerve impulse is initiated (sensory nerve ending or anterior horn cell for example) and thereafter, once initiated, follows an 'all or none' behaviour, with the impulse reaching its destination.

Figure 3 : Nerve membrane depolarisation

When considering this in relation to therapy and electrical stimulation, the only real difference is that the action potential is 'forced' or stimulated somehow along the length of the nerve. The electrical current (or pulse of electricity) is the external stimulus that initiates the action potential. Assuming that it is sufficiently large to overcome the threshold (see below), then the action potential that results from the electrical stimulation is not any different from one that is initiated 'naturally' – the initiation comes from outside the body, but once initiated, the outcome is the same.

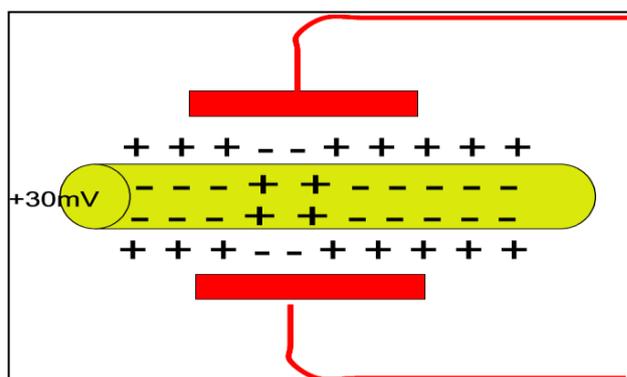


Figure 4 : Electrical pulse (stimulation) as an initiator of the action potential

There are some interesting issues developing with regards antidromic conduction (action potentials travelling the 'wrong way' along a stimulated nerve, but that is really a development in progress, and something to watch out for rather than concrete information that we can use in the clinical setting now.

Nerve Membrane Thresholds

It was identified (above) that the nerve will ‘fire’ so long as the applied stimulus is sufficient to push the membrane potential over its threshold value. There is little point worrying about numbers in this context as although we know the levels of thresholds in various types of nerves, these are values for the nerves in situ and do not relate directly to an applied clinical stimulation. What is relevant clinically. Is that one would need to apply a sufficiently large stimulus in order to achieve nerve activation. If a subthreshold stimulus is applied, the nerve threshold is not reached and although there are membrane changes, no action potential will result.

Once the threshold has been surpassed, it does not matter (in reality) how much stronger one makes the stimulus, the nerve will either fire or it will not (the ‘all or none’ bit of the law) and therefore increasing the stimulus strength might increase the number of fibres that will fire, but will not directly affect the action potential magnitude. The point is illustrated in the adjacent diagram.

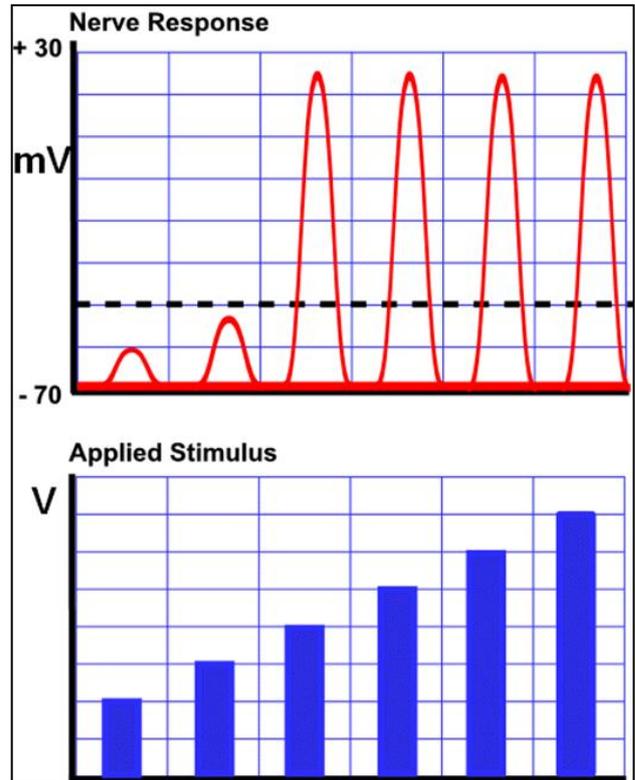


Figure 5 : Effect of applying subthreshold and suprathreshold stimuli on action potentials

Refractory Period(s)

Following action potential it is not possible for the nerve to carry another potential for a minimal amount of time (the ABSOLUTE refractory period) which is usually around 1ms though it varies between nerve types. Subsequently, there is a RELATIVE refractory period during which the nerve can be stimulated, but will

require a higher stimulus strength than usual to initiate the action potential (effectively, the nerve threshold is temporarily raised). It is of variable duration, but typical is about 10-15ms (Figure 6).

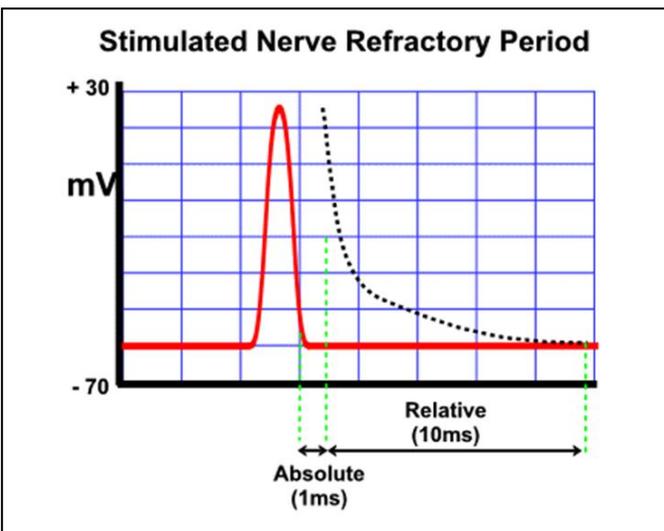
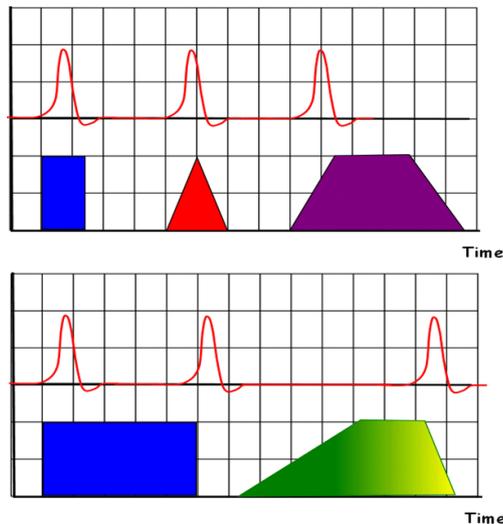


Figure 6 : Absolute and Relative Refractory Periods

The nerve can not (in theory at least) be stimulated more often than [the action potential duration + the absolute refractory period]. If you take a fast nerve action potential at 0.5ms and the absolute refractory period at 1ms, then the combined cycle will be 1.5ms and therefore that fastest that the nerve can ‘continuously fire’ will be $1000/1.5 = 666$ Hz. Although this is a simplistic calculation, it does illustrate the point that there is a limit as to how fast one can make a nerve fire, whatever the machine that you have.

Pulse Shape and Duration



The 'shape' of the delivered electrical pulse will have an effect or determining the behaviour of the stimulated nerve. Nerve membranes basically respond to a RAPID CHANGE in applied voltage and will accommodate to a slowly changing voltage.

There are whole chapters in books devoted to this subject, but essentially a rapidly changing applied voltage (rise or fall) will result in nerve membrane depolarisation (assuming above threshold of course) whether the pulse shape is 'rectangular' spiked. Or triangular to a large extent does not matter – it is the rate of change that is the most critical issue. In Figure 7, the first three pulses (top row) all generate an equivalent action potential even though the applied pulses are of very different shapes.

Figure 7 : The effect of pulse 'shape' on nerve action potentials initiated

The pulses on the lower row illustrate a couple of other issues. Firstly, the long duration rectangular pulse (lower left) will initiate a depolarisation on the initial rise, no action potential during the steady state (there is no change of applied voltage), but a further action potential at the 'far end' of the pulse (due to the rapid change in applied voltage – it just happens to be in a reverse direction). This assumes of course that the time between the initial pulse rise and the pulse fall is greater than the refractory periods for that nerve.

The somewhat strange pulse (lower right) is a hybrid type pulse with a slow rise (therefore no action potential), a sustained phase (no action potential) and a rapid fall (action potential realised) – it is not something that we would apply clinically, I am just illustrating a point..

One could look at any number of combinations, but the essentials of the issue are that for a normally behaving nerve, it is the rate of change of the applied voltage (current) that is the main (but not the only) determinant of whether a nerve will fire or not.

Types of Electrical Stimulation

There is little doubt that this is one area of electrotherapy where there appears to be a proliferation of machines or various and diverse properties. New machines seem to come out every couple of months and there is a degree of confusion with regards what they do, what they are best used for and how effective they are at doing that job.

Some manufacturers try and name the intervention modality the same as the machine – so you end up with Pulsed XXX Therapy. In reality, the most appropriate thing to do is to consider the various TYPES of simulation, and to put machines into the appropriate category / categories (in that some machines offer several different forms of stimulation). This is all very logical, but the problem is in coming up with a classification system that applies to all known modalities and is not ambiguous. Given that this is currently something that has not been universally agreed, the list below is an indication of the general types of electrical stimulation devices around out there. It is not THE classification that everybody would agree to – it is just a broad classification that is about right(ish). There is a current move to try and come up with an agreed International Classification and Terminology (under the auspices of the ISEPA), but this may be some way off being achieved.

Stimulation Mode	Abbrev	Summary
Transcutaneous electrical nerve stimulation	TENS	Sensory nerve stimulation used primarily for pain relief
Interferential therapy	IFT / IFC	A 'flexible stimulation modality which can be 'bent' to mimic other stimulation modes. Used for pain relief, increased circulation, and muscle stimulation
Neuromuscular electrical stimulation	NMES	Goal of treatment is to elicit a strong muscle contraction through stimulation of the motor nerve. Can be used to slow disuse atrophy in innervated muscle, to gain muscle 'strength' and bulk
Iontophoresis		Ions in solution are transferred through the intact skin via an electrical potential (like charges are repelled). Most commonly used to suppress inflammation and pain though has other potential uses.
Interrupted Direct Current	IDC	Direct stimulation of denervated muscle : Electrical stimulation does not bring about reinnervation, but is thought to maintain the contractile proteins in the muscle whilst awaiting reinnervation.
Microcurrent Therapy	MCT	Delivery of very small (literally several millions of an amp) continuous or pulsed current. Shown to be effective is in treatment of slow-healing wounds and fractures. Some developing applications in soft tissue injury and healing. Also potential as trigger point /acupuncture point stimulation. The current is applied 'sub threshold' in that the patient can not feel the stimulation and is therefore different from all others in the list as its primary mode of action is not thought to be nerve mediated.
Russian Stimulation		An alternating current with a carrier frequency of 2500Hz (described by many therapists as 'medium' frequency) is 'chopped' into short bursts at 50Hz with a 50% duty cycle. In this way, the motor nerves are able to respond and the discomfort associated with the therapy is diminished (as with Interferential Therapy) by virtue of the medium frequency carrier.
Diadynamic Therapy		It is a monophasic pulsed current. The carrier frequency is a sine wave, operating at 50Hz (or 60Hz USA) which is then rectified (full wave or half wave). The resulting monophasic pulses have a duration of 10 msec (milliseconds). It can be delivered in a variety of 'patterns'.