Electric Sympathetic Block

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ABSTRACT

When properly configured alternating electrical currents of sufficient strength, duration, and intensity are utilized in conjunction with correctly situated electrode size shape and placement, surface tissue electroporation, voltage gate inhibition and cell membrane conformational changes result in sympathetic ganglia block. The electrical currents needed to accomplish sympathetic block and clinical applications are reviewed.

KEYWORDS: Electrotherapy; Electric Sympathetic Block; Electroceuticals: Pain, RSD, CRPS

ELEKTRISCHE SYMPATHIKUSBLOCKADE

Richtig konfiguriert, können Wechselströme von ausreichender Intesität, Dauer und Feldstärke in Verbindung mit einer korrekten Elektrodengröße, Elektrodenform und -Platzierung zu einer Elektroporation der Gewebeoberfläche, einer Hemmung von Spannungs abhängigen Zell-Schleusen und zu Zellmembranveränderungen führen, die eine elektrische Ganglionblockade bedingen Die Stromeigenschaften, die für eine Blockade sympathischer Nerven notwendig sind, und klinische Anwendungen der Sympathikusblockade werden diskutiert.

Schlüsselwörter: Electrotherapie; Elektrische Sympathetikusblockade; Elektrozeutika, Schmerz, sympathische Reflexdystrophie, komplexes regionales Schmerzsyndrom

Introduction

Electroceutical medicine involves the use of electrical modalities of pharmaceutical strength in order to create sympathetic nerve blockade. Unlike traditional Transcutaneous Electric Nerve Stimulator (TENS) units that run off a 10 volt battery and are typically configured with a zero to 100Hz frequency range, electroceutical devices use a 110V supply and operate in the 20KHz frequency range. They also require electrode montages that are different then other electric therapy devices [1].

While the use of a 20KHz frequency allows for with human perception and let-go thresholds that will accommodate the current required for sympathetic blockade, when device design limits are set at 115 mA and 50 V safe electroporation without unwanted deep tissue burning is possible. In addition, transthoracic electrode placement cannot physiologically capture the ventricular rhythm or impact cardiac pacers within these parameters [2,3,4].

Through computerized manipulation of the current at specified intervals a slower modulated frequency rate can be superimposed upon the original carrier current [5]. By adjusting the modulation rate specificity for differing types and subsets of ion voltage gates at the cell membrane can be targeted.

This unique dual frequency configuration means a high frequency current of sufficient voltage can to be utilized to obtain depth of penetration concurrent with a slower modulated frequency current that can impact receptors within tissue. Sodium, potassium and calcium voltage dependant gates within nerve fibers respond to frequencies between 5 and 100 Hz. Due to their lack of myelination and relatively smaller fiber diameter, the C fiber membrane is more susceptible to an electroceutical current then larger fiber types.

Basic electricity

Current is the movement of charged particles (ions and electrons). Voltage is the tension that results from a difference in the supply of positive and negative charges between two points. Examples of voltage include electromagnetic forces created by different concentrations of Na, K, or Ca.

Resistance is the property that inhibits the flow of charged particles. Examples of resistant tissue include cell membranes, mesenchym, and skin. Typical values of tissue resistivity are: nerve 1, blood 1.6, muscle 5, skin 10, fat 20, and bone 160 (k Ω) [7,8]

Weaver, Prausnitz, Pliquett, and Kotnik [9-14] have demonstrated that currents with 50 –150 volts and short pulse lengths (100 –200 μs) can create reversible

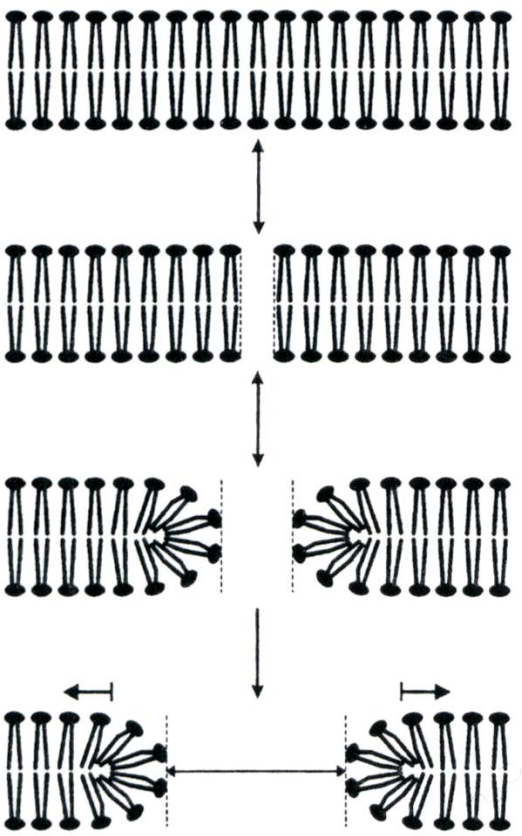

Figure 1.
Formation of an aqueous pour. The situation is shown for transmembrane voltage increasing from top to bottom: a nonporated membrane, formation of a hydrophobic pore, transformation into a hydrophilic pore (reversible electroporation) and enlargement beyond the stable size (irreversible electroporation).

From: Miklavcic D. Electroporation for Electrochemotherapy and Gene Therapy. In: Rosch, PJ Editor. Bioelectromagnetic Medicine, NY: Marcel Dekker, 2004:642

aqueous pores, or permeability channels, within the skin lipid bilayer (fig 1). Joule's law states that as the resistance of a tissue increases, there is more electrical energy converted into heat. In order to avoid tissue destruction, limits have to be placed upon the total energy delivered into the tissue [8].

This limit impacts electroceutical design since increasing current concentration and intensity is desired. It allows for greater electric density to be delivered into the depths of tissue and maximizes energy at the target. In practical terms this means that any current utilized for sympathetic block must be both strong enough to electroporate and within safety limits to avoid deep tissue burn.

In addition to keeping within the 20KHz carrier frequency range another way to work within these limits is to make use of the distinct strength -duration characteristics that all nerve fiber types have when fabricating the superimposed modulation waveform upon the carrier frequency. Dosing for a sufficient duration of time and incorporation of the slower modulation frequency also minimizes any unwanted elevation of nerve fiber threshold that may occur in the presence of the higher carrier frequency rate [4,15].

Molecular biochemistry and cell biology

The normal nerve cell has a transmembrane potential of – 70 mV. Voltage dependent gates are pores through cell membranes that have changing permeability when influenced by electromagnetic signals. A single photon of electromagnetic energy can produce a cascade of intracellular signals that initiate, accelerate or inhibit biologic processes [6].

The movement of less than 1 nmol of charged ion/mg of protein on the cell's surface can create a greater than 200 mV potential difference in cell surface energy. This is enough to generate conformational and chemical changes within the membrane, cytoplasm, and exoplasm [7, 16-20]. When trying to move an ion with an electroceutical the molecular weight of the ion whose movement is being influenced does impact efficacy. Targeting lower weight ions such as sodium or potassium, instead of heavier ions such as calcium, improves electrically induced blockade results.

While targeting lower molecular weight ions is advantageous, to maximize effectiveness it is equally important to choose nerve fibers that are likely to respond to electrically induced blockade. Due to their lack of myelination, normal firing rate, absolute refractory period, surface to volume ratio, and fiber diameter vibratory and sympathetic nerves are the most susceptible to 20KHz carrier currents [21-26].

In summary, Cell membrane receptor characteristics and electroporation explain why properly configured currents can penetrate skin, reach the depths of tissue and affect nerve cell membranes. A 20kHz carrier frequency with a 50 V output can electroporate surface tissue and create a response deep within tissue while remaining within federal safety guidelines and comfortable patient current perception thresholds.

Electromechanic
Currents and voltage-dependant gates

It is not necessary to deliver extremely high voltages into the depths of tissue to manipulate voltage gates at the cell membrane. Particle physics and cell membrane density theory explain the ability of electroceutical

currents to create direct conformational changes at the cell membrane level from both particle to receptor and direct electromagnetic interaction perspectives (fig 2 & 3) [1,20,27,28].

The literature is full of references concerning the effects of pharmaceuticals upon voltage-dependent gates found in cell membranes [29 –36]. Because voltage-dependent gates have specific voltage sensing proteins, they are highly selective for specific ions. Each type and subtype of voltage gate has its own threshold and inactivation range, agonist/antagonistic effects and specific functions [15,37-39].

Due to their lower molecular weight and size the K+ and Na+ dependant ion channels are easier to influence then Ca++ ion channels [40]. Sodium voltage-dependant gates are heavily concentrated at Nodes of Ranvier and at neuromuscular junctions. They are responsible for nerve hyperexcitability. Six Na ions must move from the extracellular to the intracellular side to open a Na+ ion dependant gate [37].

Potassium voltage-dependant gates are heavily concentrated at the paranodal (fast) and nodal (slow) areas and are the most responsive channel to an externally applied electrical stimulus. Slow channels regulate the rate of firing response to a repetitive stimulus and fast channels are required for intensity of response. Configuring a 20KHz carrier frequency with a K+ ion specific modulation frequency is what allows an electro-

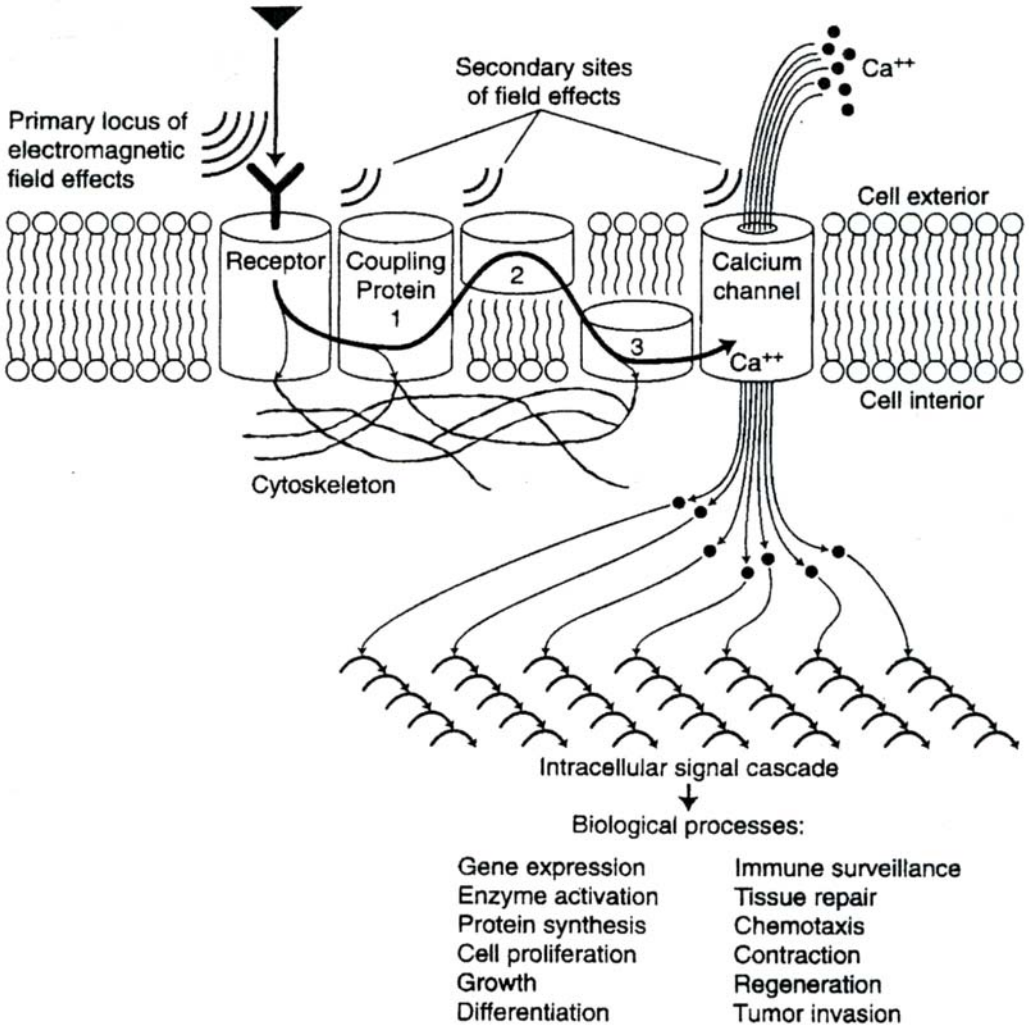

Figure 2.
The cellular cascade and amplification process that provides a basis for the effects of pulsing electromagnetic field therapies.

From: Oschman J. Recent Developments in bioeleectromagnetic Medicine. In: Rosch, PJ Editor. Bioelectromagnetic Medicine, NY: Marcel Dekker, 2004:81

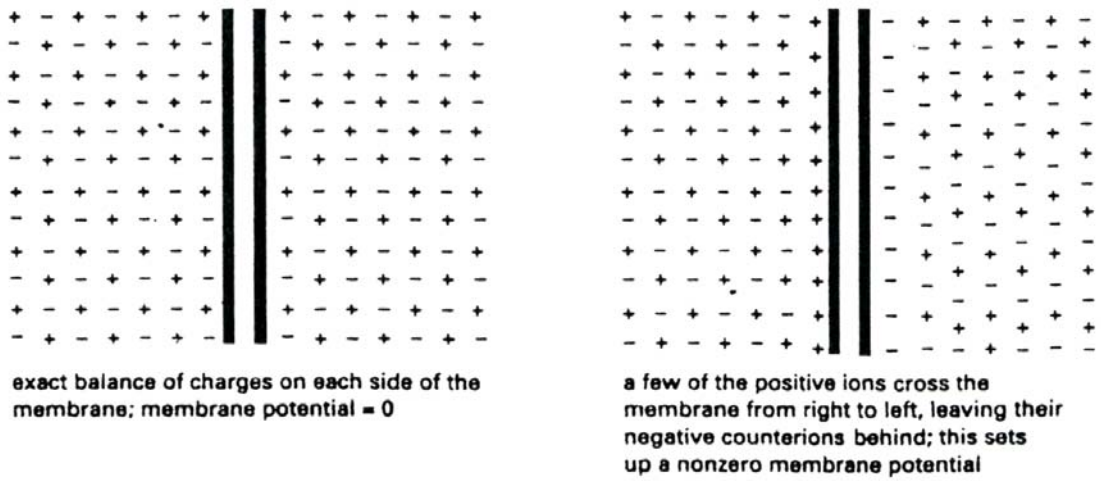

Figure 3.
Cell Membrane Density Theory

From: Alberts B, Bray D, Lewis J, Martin R, Roberts K, Watson j, editors. Membrane Transport, Molecular Biology of the Cell, 3rd edition, New, York: Garland Publishing, 1994:11-19

ceutical device to influence these nerve responsiveness characteristics [37,40,41].

Wedensky inhibition (block that abates upon removal of an electrical stimulus) and the post-hyperactivity depression (PHD) effect, a prolonged, hyopexcitable state that arises from the application of a relatively short duration electrical current, do not explain the method of action for electroceutically obtained alteration of nerve responsiveness. [14,15,21,22]. Central mechanisms of habituation also do not explain the pronounced effect on the C fiber [46,47].

The alteration of membrane physiology that results from application electric current to ion gates is, however, objectively measurable. While potassium is the most readily influenced by electroceutical application, there are numerous citations that demonstrate both conformational changes in the cell membrane and second messenger formation within the cell at various ion voltage gates when exposed to frequency specific electrical currents [42,43,44,45,46].

Pathology

The sympathetic nerves are responsible for cold or weather sensitive pain that is described as burning, achy, tingling and numbing in character [48]. Pathological pain complaints based in sympathetic nerve dysfunction are referred to as Reflex Sympathetic Dystrophy (RSD) or Chronic Regional Pain Syndrome Type I (CRPS I) [51].

In RSD, there is a decrease in the local blood flow to the injured part. If allowed to persist, cold, sweaty and swollen skin (stage 1) develops. It may progressively worsen until there is loss of range of motion or even loss of muscle mass (stage 2). In more severe cases, the bones may thin as well (stage 3) [50]. In RSD, the sympathetic nerve continues to overact, even when the injury itself is old or healed [51].

Subtypes of RSD exist; the abnormal sympathetic response is not always the same. With the Angry Backfiring 'C' (ABC) Syndrome the sympathetic nerve be. comes angry, or backfires, in response to an underlying injury. This axon reflex causes the C fiber to emit various vasoactive chemicals such as substance 'P', kinens and histamine. These patients are usually warm sensitive and the involved segment is vasodilated [52,53].

The Triple 'C' Syndrome variant occurs when the C fiber fires excessively, causing intense, local vasoconstriction. People with this problem complain of cold hypesthesia (abnormal cold perception), cold hyperalgesia (cold burns) and have regionalized hypothermia [52, 53]. Given the diverse nature of sympathetic pain syndromes it is not surprising that results of pain relief from blockade is not the same for all presentations [54].

Electric sympathetic block

Obtainment of sympathetic block can be objectively measured by three methods: skin galvanic impedance

studies, test of skin temperature and pain score tests. Masumoto has previously published that the obtainment of a Horner's Syndrome is an unreliable indicator of ipsilateral warming after chemical sympathetic block [55]. The achievement of ipsilateral warming instead of a Horner's is also a better objective measurement when monitoring for the obtainment of sympathetic block when performed electrically [1].

Utilizing skin galvanic impedance studies, pain score tests and thermography several studies have concluded that up to 75% relief in three-quarters of patients treated can be accomplished with electric sympathetic ganglia block [1,25,56,57,58,59,60,61,62,63,64,65]. This compares to chemically induced block where 60% of those treated report pain relief [55,66].

If a patient is vasodilated prior to treatment (as with the ABC syndrome), then sympathetic blockade should not be expected to produce relief [52]. While there are no long-term studies on the effectiveness of chemical block, at least one study of electrically induced block reported 68% having retaining some relief on 1-year follow-up [23].

Duration of application and electrode size, placement and configuration do influence outcome. Scudds [67] measured skin temperature with infrared thermography in patients receiving electric sympathetic block for 60-min periods of time. He concluded that the first 30 min of treatment resulted in the greatest increase in skin temperature ($t = 4.35$, $P = 0.001$).

Other studies have also concluded that 20 –30 minutes of electroceutical application time offers maximal results [56, 57, 70, 58, 67,69]. Beyond 20 min, the body's physiologic protection mechanisms begin to respond, attempting to regain normal homeostasis. This response is known as the Hunting Reaction and occurs maximally at 30 min [69, 70].

Jenkner [23,59] has done extensive work demonstrating the importance of proper electrode size, shape, configuration and placement. Electrodes of dissimilar size should be utilized. The small electrode should be placed over the ganglia and the large one over the opposing surface. This provides for the most efficient configuration to minimize nerve rheobase and helps focus the electroceutical onto the specified target (Fig. 4) [25,69,71,72].

Numerous disorders have been listed as indications for sympathetic block [73,74]. Clinical conditions include circulatory insufficiency (vasospasm, traumatic or embolic occlusion, scleroderma, frostbite and other occlusive vascular diseases), pain (including sympathetic syndromes and CRPS types I and II), shingles, phantom limb, paget's disease, neoplastic lesions, CNS lesions, myofascial pain, fibromyalgia) and miscellaneous conditions such as shoulder/hand syndrome, hyperhydrosis, stroke, Miniere's disease and tinnitus.

In April of 2000, the United Stated FDA allowed electroceutical devices that meet previously noted electrical criteria to include the following labeling: "With the advice and management of a licensed medical physician, this device is theorized to produce a nerve block reducing pain via electrical interruption of signals".

Side effects and indications

The most frequent side effect of electrical block is skin burn. The incidence has been estimated at 2-3%. The burn is usually first or second degree in nature, but third degree burns can occur. While slow to heal, as long as the wound is kept clean, closure is the expected result. A small area of disfigurement (usually ½ inch in diameter or less) may result, especially in patients with a history of easy keloid formation. Patients should be told of this potential side effect (and all other side effects typically reported with ganglia/neuron blockade) prior to treatment. The appropriate procedural releases should be signed.

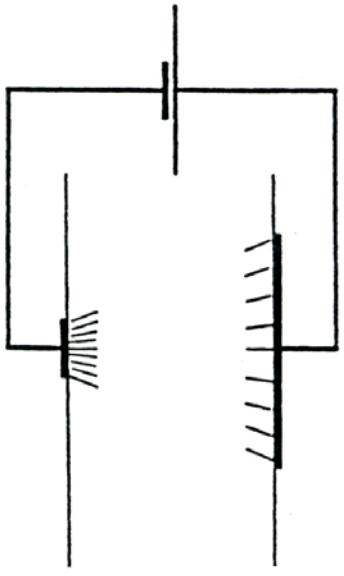

Figure 4.
Schematic graph showing density of field lines under a small and large electrode under assumed identical current flow (or potential). Greater density of field lines means that in this part of the field an anatomical structure (like a nerve) will be influenced to a greater degree by the field than if the field density were smaller

From: Jenker FL, Transcuatneous elecetric nerve block, New York:Springer-Verlag, 1986.

The same indications apply to both chemical and electric block; either should be considered as appropriate for painful or vascular conditions that have failed to respond to other interventions. Since electroporation instead of mechanical poration is used with electric sympathetic block, patients tend to prefer the electrical method. While anticoagulants are a relative contraindication for mechanically induced block, they are not with electrical block.

Conclusion

Electric sympathetic block is a safe and proven intervention for sympathetic and voltage dependant gate pain syndromes. Greatest efficacy should be expected when K+ ion voltage gate pathology such as excessive intensity of response or firing frequency to a response is involved. Only physicians who are knowledgeable about potential side effects of pharmacologic agents that produce similar effects should utilize electroceutical devices for this purpose.

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