

Review of Electrotherapy Devices for Use in Veterinary Medicine

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Electrotherapy devices used for rehabilitation provide an electrical current that activates sensory and motor neurons to reduce pain and improve tissue repair after injury or surgery. For most equine applications, neuromuscular electrical stimulators (NMES) are the most appropriate devices. NMES produce controlled motor and sensory responses both superficial and deep while maintaining a high level of compliance by the horse. Author's address: 8139 900th Street, River Falls, Wisconsin 54022; e-mail: sbschils@equinew.com. © 2009 AAEP.

1. Introduction

Decades of rehabilitation work, combined with research and practical experience, has shown that the body does not necessarily rehabilitate itself in an effective way.¹⁻³ To improve the outcome of rehabilitation, the use of electrotherapy has been widely accepted in human medicine and is now becoming available to equine practitioners.

Electrical current is applied to surface electrodes to produce controlled movement of the skin, muscle, tendon, and associated ligaments. Some of the important advantages of electrotherapy have included improved quality of healing and shortened rehabilitation time.¹ Veterinary practitioners have used electrotherapy in a limited manner and have reported successful outcomes.³⁻⁶

Examples of the benefits of electrotherapy treatments have included:

1. Pain relief caused by decreased spasticity of muscle.⁷⁻¹²
2. Improved range of motion caused by reduced muscle tension.^{13,14}
3. Reduction in swellings caused by injury.^{8,15}

4. Reduction of scar tissue during healing.^{16,17}
5. Re-education of muscle function to prevent further injury.¹⁸⁻²⁰
6. Strengthening of muscles and tendons.^{14,18,21,22}
7. Reversal of muscle wasting.²³⁻²⁵
8. Decreased rehabilitation time after injury and surgery.^{16,26,27}

Electrotherapy is a relatively new field to most equine practitioners. A veterinary electrical stimulation modality must be correctly designed to produce the desired results, because animals will not necessarily accept a system that may be well tolerated by humans. The purpose of this paper is to review and compare the major categories of electrotherapy devices available to assist the equine practitioner in understanding the attributes of each system.

2. Nerve and Muscle Responses to Electrotherapy

Most electrotherapy devices are designed to use an electrical current that results in depolarization of the sensory and motor nerves. During depolariza-

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tion, an influx of sodium ions from the extracellular space to the intracellular space produces an action potential. The action potential is transmitted across the neuromuscular junction and causes the muscle fiber to contract.

Appropriate electrical stimulation can produce action potentials in both nerve and muscle that are basically indistinguishable from those produced by the nervous system.^{1,8} The individual perceives the muscle stimulation as almost identical to voluntary contraction.¹

Nerve and muscle tissue respond differently to electrical stimulation. Peripheral nerve fibers are more excitable than muscle fibers, and therefore, amplitudes and durations that would activate nerve fibers will not necessarily activate muscle fibers. Peripheral nerves contain fibers of varying dimensions. The fibers with the largest diameter have the least resistance and are the most excitable. Therefore, the peripheral nerves require the lowest amplitude and/or duration of stimulus for response. Muscle fiber size was initially thought to be influential in the recruitment order of motor neurons during electrical stimulation. Originally, it was theorized that the muscle fiber recruitment during electrical stimulation was the opposite of the normal recruitment order with the large diameter fibers (fast twitch) being activated before the smaller diameter fibers (slow twitch). However, current research has shown that the recruitment pattern is non-selective during electrical stimulation, and therefore, all motor units are activated simultaneously.²⁸

Nerve tissue responds quickly to current but requires a current that rises rapidly to maximum intensity. Therefore, high frequencies over short durations are used. Even if the purpose of the electrotherapy is to activate motor nerves, the cutaneous sensory receptors are always activated as well. The rate of rise of the pulse, or ramping of the pulse, is also an important determinant of effectiveness and comfort of an electrotherapy device. Too slow of a rise in ramping can result in changes in the tissue membrane known as accommodation. Accommodation gradually elevates the threshold required for the nerve to fire. Therefore, higher amplitudes or other adjustments are necessary for the device to continue to activate the same nerves.

Muscle tissue responds with very slowly rising currents and a lower frequency compared with nerve tissue responses, and therefore, longer duration stimuli is used. The higher the stimulation frequency, the faster the muscle fatigues. Effective electrical muscle stimulation must be strong enough to reach threshold to obtain a muscle contraction.

3. Electrotherapy Devices

There are many types of electrotherapy devices that are commercially available, and the terminology used by manufacturers is not always standardized. In addition, attributes from several different classes

of electrotherapy devices can be combined, making the understanding of exactly what the system can and cannot do even more difficult. It is important to understand the basic mode of action of each class of stimulators and the distinctions and similarities between muscle stimulation and nerve stimulation devices to select the appropriate electrotherapy system for the needs.

Transcutaneous Electrical Nerve Stimulation

Transcutaneous electrical nerve stimulation (TENS) devices can be used to assist with short-term or long-term pain relief.

TENS units are designed to produce analgesia of pain and reduce responses of dorsal horn neurons to painful stimuli. The TENS systems activate the descending inhibitory pathway from the brain stem to the spinal cord. However, the means of reducing pain varies between the specific types of systems and includes activating spinal cord gating mechanisms, endogenous opiates, serotonin receptors, nor-adrenaline receptors, and muscarinic receptors.

The initial development of TENS technology was based on the gate-control theory of pain developed by Melzack and Wall²⁹ in 1965. The researchers found that pain transmission could be stopped when the "gate" closed, and therefore, the pain signal would not be felt by the patient. TENS units were developed to send an electrical impulse that confuses the pathways in sensory nerves by "gating" or blocking the sensation of pain. However, continued research has shown that there are many different methods the body uses to modulate pain. Therefore, reducing pain requires a multifaceted approach. The understanding of how TENS devices work continues to evolve, and one current piece of research has found that the blocking of pain may occur at deep tissue afferents.³⁰

Typically, the pain sensation is relieved while the TENS unit is on, but after the unit is removed, the pain can return.³¹ For this reason, TENS units may be worn continuously by many users. However, over time, the body can learn to accommodate to the TENS sensation, and adjustments to the parameters of the electrotherapy device are usually necessary to keep this from occurring.

Types of TENS Units

TENS units are typically about the size of a pack of cigarettes. There are usually several pre-determined stimulation options available with preset variables. This variety of parameters is used to reduce the problem of adaptation to one stimulus parameter, which reduces the effectiveness of the TENS units. There are typically two channels, and the user has the ability to control each channel separately; however, in most situations, the channels are set to be identical.

TENS devices are characterized based on the intensity of the stimulation. Intensity is basically a combination of the amplitude, duration, and fre-

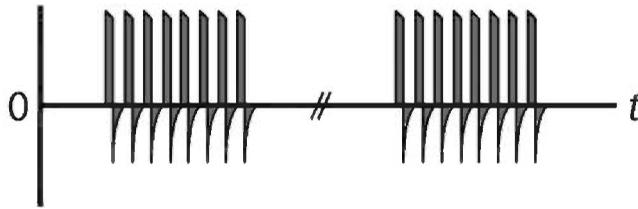


Fig. 1. Example of high-frequency TENS.

quency of the pulses. There are three major forms of TENS that are commonly referred to as high frequency, (Fig. 1) low frequency, (Fig. 2) and noxious. Within these three categories, there are sensory-level stimulators and motor-level stimulators. During sensory-level stimulation, the client will feel a slight tingling or buzzing to the skin, and during motor-level stimulation, the client will feel a muscle twitch or tremor. Motor-level stimulation is typically used for chronic pain.

Interferential Stimulators

Interferential electrical stimulation is used to control pain as an alternative to TENS units. This class of stimulators combines two higher frequency waveforms in a crossed pattern. Electrical signals with the same waveform are administered so that they arrive at the point to be stimulated from two directions. The area where the currents overlap is called the interference pattern and thus, the name "interferential" (Fig. 3). The high frequency is suggested to penetrate the skin more deeply with less user discomfort than TENS.

Interferential electrical stimulation consumes a large amount of energy because of the high frequencies and requires more electrodes or larger sized electrodes. These systems require large powerful batteries and are typically line powered.

Neuromuscular Electrical Stimulation

Neuromuscular electrical stimulation (NMES) devices are designed to stimulate motor nerves. Peripheral nerves are also stimulated when motor nerves are activated, so there is a combined effect. NMES provides a means to mobilize muscle, tendon, and the associated ligaments through the generation of controlled muscular contractions. Because the mobilization of injured tissues can be controlled

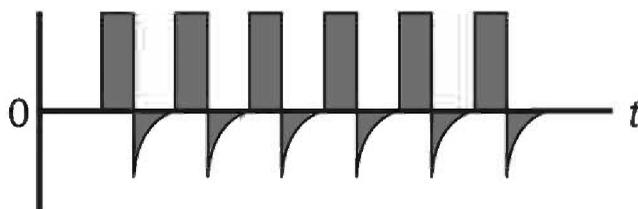


Fig. 2. Example of low-frequency TENS.

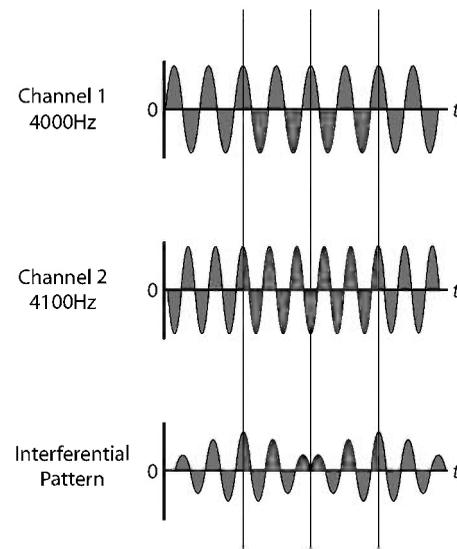


Fig. 3. Example of interferential stimulation.

by NMES, the rehabilitation process can begin earlier, and even acute injuries can be treated.

NMES can be used for stimulation of deeper tissues, and therefore, the attainment of strong muscular contractions is possible. Stronger contractions have been shown to be more effective in reducing pain,^{32,33} and the benefits have proven to be longer lasting than other forms of electrical stimulation.^{34,35}

One type of NMES that has been designed to replicate the body's motor neuron action is called functional electrical stimulation (FES) because of the body's "functional" response to the stimulation (Fig. 4). One of the most familiar forms of FES is the cardiac pacemaker, which is used to stimulate the heart to beat by releasing a specific series of electrical discharges. FES is also used to replace lost neurological function for spinal-cord injury patients so that muscle movement to prevent atrophy can be obtained, even with denervated muscle. FES has been designed for use at higher amplitudes without damage to tissue, which is especially important when deeper tissue stimulation is necessary.

Galvanic Muscle Stimulators

Galvanic stimulators were first developed in the 1940s and became popular in the 1970s. Some-

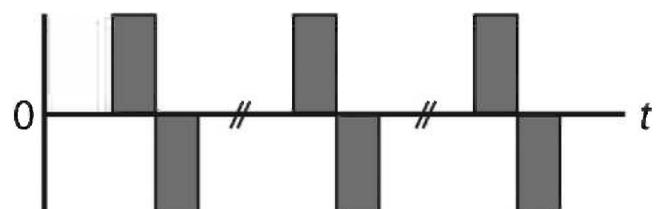


Fig. 4. Example of NMES stimulation.

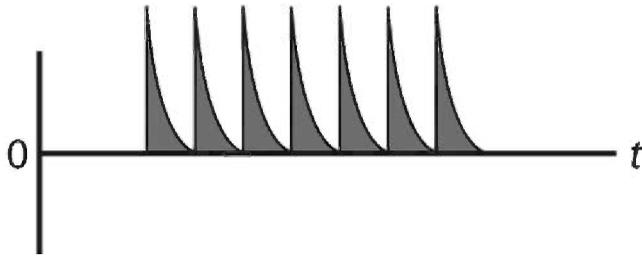


Fig. 5. Example of galvanic stimulation.

times galvanic stimulators are referred to as direct-current (DC) or uninterrupted DC stimulators. The galvanic stimulator was one of the first stimulators used for horses in the early 1960s. Because of this early use, galvanic stimulators have been referred to as “the muscle stimulator” in past equine literature.

Galvanic stimulation uses DC to create a unidirectional, continuous current. The waveform of galvanic devices is monophasic, meaning it has only one peak that is repeated over time (Fig. 5).

Galvanic stimulators are used to produce ionic movement within the tissues toward one of the electrodes. This accumulation of ions to one polarity results in reflex vasodilatation caused by the stimulation of the sensory nerve endings. However, the ion accumulation under the electrodes can create an unpleasant stinging sensation.³⁶

Trauma to tissue, typically the skin, can be caused by galvanic stimulators, even when used at low amplitudes because of the electrolytic reactions that occur when the current passes through the skin. The extent of tissue damage is also affected by the length of time of the treatment and the tissue impedance.¹

High-Voltage Pulsed-Current Stimulators

Because of the limited use of galvanic stimulators, another class was developed using a similar waveform pattern and is called high-voltage pulsed-current stimulators (HVPC). Sometimes the term “galvanic” is still included in the name; however, these stimulators are not DC devices, and the term is inaccurate.

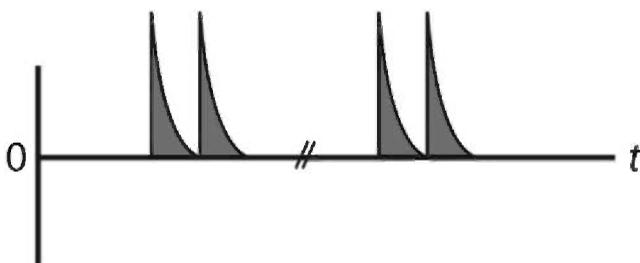


Fig. 6. Example of HVPC stimulation.

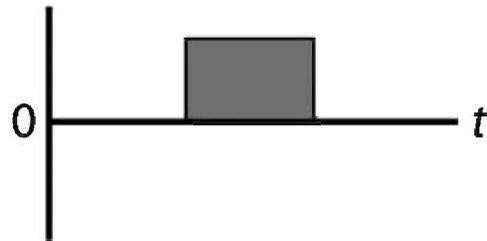


Fig. 7. Example of iontophoresis stimulation.

HVPC stimulators typically generate a twin-spike monophasic pulsed waveform (Fig. 6). Because of the monophasic waveform, the output polarity does not change during stimulation. Therefore, some forms of pulsed monophasic currents can have similar chemical effects to DC. However, very short duration monophasic pulsed currents reduce the negative electrochemical effects on the skin.³⁶ Timing between the twin spikes can be shortened so that the two waveforms overlap, providing a stronger stimulation sensation. Switches exist on some devices to allow the user to switch the polarity of the electrodes.

Iontophoresis

Iontophoresis has been used for decades and uses DC through electrodes to deliver medication to SC tissue (Fig. 7). Early systems were combined with galvanic stimulators, and the lower amplitudes were used for iontophoresis.

Diadynamic Stimulators

This class of electrical stimulators has been used in Europe and Canada; however, diadynamic stimulators may be unfamiliar to most practitioners in the United States. These devices use variations of the sine wave to produce monophasic (Fig. 8) and biphasic (Fig. 9) continuous or pulsed currents. Polarity reversing is recommended to reduce the undesirable effects of DC on the skin.

Microcurrent Electrical Stimulators

Microcurrent stimulators (MES; also called subliminal stimulation) are the most recent class of electrotherapy devices. MES are designed to mimic the weak electrical currents produced by tissue healing. These systems produce very low amplitude currents

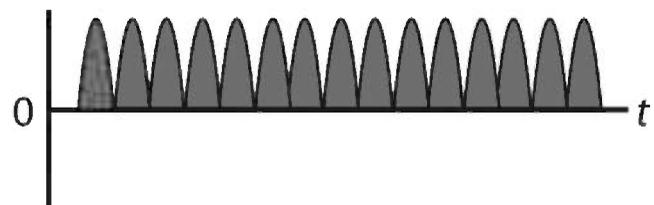


Fig. 8. Example of half-wave diadynamic stimulation.

of <1 mA of total current. Either short-pulse durations (Fig. 10) or a constant current is used.

Because of the low amplitude of these systems, there is no activation of nerve and muscle tissue. These devices deliver a level of stimulation below the threshold of peripheral nerve excitation, and therefore, the patient feels no tingling sensation.¹ Some stimulators are designated as microstimulators but produce amplitudes of >1 mA.

4. Summary

Electrotherapy devices can be placed into two categories of sensory nerve or motor nerve stimulators. Within these two classes are subcategories of stimulators, each with distinct modes of action. The terminology used by manufacturers is not always standardized, so the distinctions between the classes are not always apparent. In addition, parameters from several different subcategories of electrotherapy devices can be combined, making the interpretation of the characteristics of a particular system difficult. Some specific characteristics of the horse should be taken into consideration when selecting an electrotherapy device.

First, the tissue mass of the horse is much larger than that of humans. Because of this characteristic, the acceptance of the signal at higher amplitudes is important if deeper tissue is to be activated. In addition, the appropriate electrotherapy system should not cause irritation or trauma to the skin surface during administration.

Second, some rehabilitation modalities designed for humans may have stimulation parameters that are too uncomfortable for horses. Humans can rationalize the discomfort; however, horses will be skeptical of any feeling that is mildly uncomfortable. Ideally, electrotherapy treatments should be selected that can be used on the horse without the administration of tranquilizers.

Third, the electrotherapy devices must be safe and easy to apply to the horse. Safety features that have been designed for use specifically on horses are necessary. The administration of the therapy should be convenient for the user and comfortable for the horse.

The electrotherapy devices that may be well suited for human use may not be the appropriate choice for horses. Neuromuscular electrical stimulators (NMES) are generally the most appropriate class for equine use because of their ability to pro-

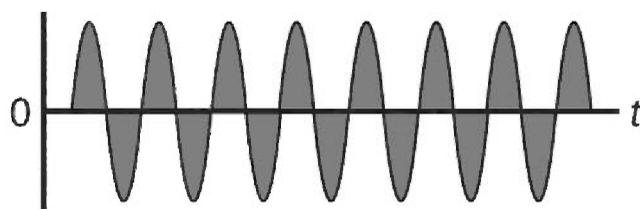


Fig. 9. Example of full-wave diadynamic stimulation.

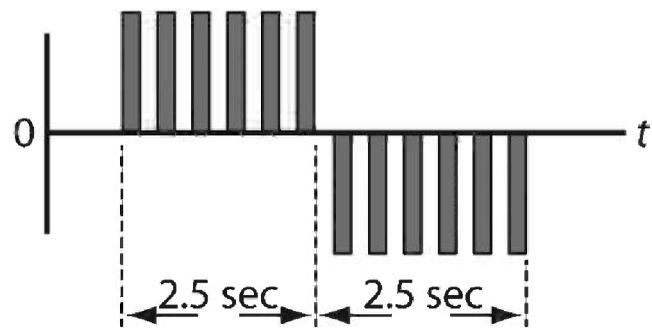


Fig. 10. Example of microcurrent stimulation.

duce controlled motor and sensory responses, both superficial and deep, while maintaining a high level of compliance by the horse.

Dr. Schils is currently a principle of EquiNew, LLC, an equine therapy company.

References

1. Robinson AJ, Snyder-Mackler L. *Clinical electrophysiology: electrotherapy and electrophysiologic testing*, 3rd ed. Baltimore: Lippincott, Williams, & Wilkins, 2008.
2. Bromiley MS. Physiotherapy for equine injuries. *Equine Vet Edu* 1994;6:241-244.
3. Bromiley MW. Physical therapy for the equine back. *Vet Clin North Am [Equine Pract]* 1999;15:223-246.
4. Denoix JM, Pailloux JP. *Electrotherapy and ultrasound in Physical therapy and massage for the horse*, 2nd ed. North Pomfret, VT: Trafalgar Square Publishing, 2005;131-133.
5. McGowan C, Goff L, Stubbs, N. Principles of electrotherapy in veterinary physiotherapy in *Animal physiotherapy: assessment, treatment and rehabilitation of animals*. McGowan C, Goff L, Stubbs N (eds) Ames, IA: Blackwell, 2007;177-186.
6. Porter M. Therapeutic electrical stimulation in *The new equine sports therapy*. Lexington, KY: The Blood-Horse Inc., 1988;83-124.
7. Loeser JD, Black RG, Christman A. Relief of pain by transcutaneous stimulation. *J Neurosurg* 1975;42:308-314.
8. Prentice W. *Electrical stimulating currents in Therapeutic modalities in sports medicine*. St Louis, MO: Times Mirror/Mosby College Publishing, 1986;56-68.
9. Moore SR, Shurman J. Combined neuromuscular electrical stimulation and transcutaneous electrical stimulation for treatment of chronic back pain: a double-blind repeated measures comparison. *Arch Phys Med Rehabil* 1997;78:55-60.
10. Repperger DW, Ho CC, Aukuthota P, et al. Microprocessor based spatial TENS (transcutaneous electric nerve stimulator) designed with waveform optimality for clinical evaluation in a pain study. *Comput Biol Med* 1997;27:493-505.
11. Billian C, Gorman PH. Upper extremity applications of functional neuromuscular stimulation. *Assistive Technology* 1992;4:31-39.
12. Scheker LR, Chesher SP, Ramirez S. Neuromuscular electrical stimulation and dynamic bracing as a treatment for upper-extremity spasticity in children with cerebral palsy. *J Hand Surg [Br]* 1999;24:226-232.
13. Pease WS. Therapeutic electrical stimulation for spasticity: quantitative gait analysis. *Am J Phys Med Rehabil* 1998; 77:351-355.
14. Bremner LA, Sloan KE, Day RE, et al. A clinical exercise system for paraplegics using functional electrical stimulation. *Paraplegia* 1992;30:647-655.
15. Mendel FC, Fish DR. New perspectives in edema control via electrical stimulation. *Journal of Athletic Training* 1993;28: 63-74.

16. Hainaut K, Duchateau J. Neuromuscular electrical stimulation and voluntary exercise. *Sports Med* 1992;14:100–113.
17. Kloth LC. Electrical stimulation in tissue repair. In: McCulloch JM, Kloth LC, Feeder FA, eds. *Wound healing alternatives in management*. Philadelphia: F.A. Davis, 1995;275–314.
18. Synder-Mackler L, Delitto A, Stralka SW, et al. Use of electrical stimulation to enhance recovery of quadriceps femoris muscle force production in patients following anterior cruciate ligament reconstruction. *Phys Ther* 1994;74:901–907.
19. Carmick J. Clinical use of neuromuscular electrical stimulation for children with cerebral palsy. Part 2: upper extremity. *Phys Ther* 1993;73:514–522.
20. Chae J, Yu DA. Critical review of neuromuscular electrical stimulation for treatment of motor dysfunction in hemiplegia. *Assistive Technology* 2000;12:33–49.
21. Delitto A, Snyder-Mackler L. Two theories of muscle strength augmentation using percutaneous electrical stimulation. *Phys Ther* 1990;70:158–164.
22. Glanz H, Klawansky S, Stason W, et al. Functional electrostimulation in poststroke rehabilitation: a meta-analysis of the randomized controlled trials. *Arch Phys Med Rehabil* 1996;77:549–553.
23. Eriksson E, Haggmark T. Comparison of isometric muscle training and electrical stimulation supplementing isometric muscle training in the recovery after major knee ligament surgery. *Am J Sports Med* 1979;7:169–171.
24. Scremin AM, Kurta L, Gentili A, et al. Increasing muscle mass in spinal cord injured persons with a functional electrical stimulation exercise program. *Arch Phys Med Rehabil* 1999;80:1531–1536.
25. Bélanger M, Stein RB, Wheeler GD, et al. Electrical stimulation: can it increase muscle strength and reverse osteopenia in spinal cord injured individuals? *Arch Phys Med Rehabil* 2000;81:1090–1098.
26. Delitto A, McKowen JM, McCarthy JA, et al. Electrically elicited co-contraction of thigh musculature after anterior cruciate ligament surgery: a description and single-case experiment. *Phys Ther* 1998;68:45–50.
27. Synder-Mackler L, Delitto A, Bailey SL, et al. Strength of the quadriceps femoris muscle and functional recovery after reconstruction of the anterior cruciate ligament. *J Bone Joint Surg Am ed.* 1995;77:1166–1173.
28. Gregory CM, Bickel CS. Recruitment patterns in human skeletal muscle during electrical stimulation. *Phys Ther* 2005;85:358–364.
29. Melzack R, Wall PD. Pain mechanisms: a new theory. *Science* 1965;150:971–978.
30. Radhakrishnan R, Sluka KA. Deep tissue afferents, but not cutaneous afferents, mediate TENS-induced antihyperalgesia. *J Pain* 2005;6:673–680.
31. Johnson MI, Ashton CH, Thompson JW. An in-depth study of long-term users of transcutaneous electrical nerve stimulation: implications for clinical use of TENS. *Pain* 1991;44:221–229.
32. Picker RI. Current trends: low-volt pulsed microamp stimulation, part I. *Clin Manage Phys Ther* 1988;9:10–14.
33. Picker RI. Current trends: low-volt pulsed microamp stimulation, part II. *Clin Manage Phys Ther* 1988;9:28–33.
34. Sjolund B, Ternis L, Eriksson M. Increased CSF of endorphins after electro-acupuncture. *Acta Physiol Scand* 1977;100:382–384.
35. Duranti R, Pantealeo T, Bellini F. Increase in muscular pain threshold following low frequency-high intensity peripheral conditioning stimulation in humans. *Brain Res* 1988;452:66–72.
36. Newton RA, Karelis TC. Skin pH following high voltage pulsed galvanic stimulation. *Phys Ther* 1983;63:1593–1596.