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Monochromatic Infrared Energy Versus Neuromuscular Electrical Stimulation In Post Burn Tarsal Tunnel Syndrome

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Abstract: Purpose: to evaluate the efficacy of monochromatic infrared energy (MIRE) versus neuromuscular electrical stimulation (NMES) in post burn tarsal tunnel syndrome. **Methods of evaluation** (Measurement of the motor and sensory conduction velocities of the medial and lateral plantar branches of the tibial nerve). **Methods:-** Forty patients with ages ranging from 20 to 35 years and suffering from burns at chronic phase (post-hospitalization period), affecting lower limbs, with the percentage of total body surface area (TBSA) ranging from 20% to 30% and their early diagnosis was a burn of 2nd or 3rd degree and complicated with post-burn tarsal tunnel syndrome. They were divided into two groups. Group (A) composed of 20 patients received the MIRE and the traditional physical therapy were applied. Group (B) received the NMES and the traditional physical therapy were applied. All patients received the traditional physical therapy in the form of ice massage, pulsed ultrasonic, stretching exercises for the cuff muscles and ankle pump exercises. The treatment program was conducted for 20 minutes, 3 times / week for six weeks. Measurements were conducted before starting the treatment as a first record and at the end of the six week of treatment as a second (final) record. **Results and conclusion:-** Results showed that application of both the MIRE and NMES had a valuable improving effects on the post burn tarsal tunnel syndrome as evidenced by the highly significant decreases in the prolonged motor distal latency and sensory distal latency of the medial and lateral plantar branches of the posterior tibial nerve. So both MIRE and NMES were effective and nearly equivalent in improving the post burn tarsal tunnel syndrome as manifested by the highly significant decreases in the prolonged motor distal latency and sensory distal latency of the medial and lateral plantar branches of the posterior tibial nerve.
Key words (Monochromatic infrared energy, Neuromuscular electrical stimulation, Post burn tarsal tunnel syndrome, Motor and sensory distal latencies and Posterior tibial nerve).

Introduction

Clinical electrophysiology began towards the end of eighteenth century with Galvani's discovery of animal electricity and has since progressed steadily during the past two centuries. Electrophysiological assessment of nerves and muscles are now considered indispensable in the practice of neurology, physical therapy and other related clinical disciplines, the clinical measurement of nerve conduction velocities has become increasingly popular since the late 1940s. A 1948 article by Hodes et al contained the first clinically relevant discussion of conduction velocity testing and created great interest in the subject of

electrophysiological testing. Electromyography is considered the most objective assessment tool in detecting entrapment neuropathy[3,4,8.]

Burn patients suffer from many problems due to disruption of the normal protective functions of the skin; injury to the vascular tree and blood elements, severe metabolic stress with abnormal capillary permeability, protein rich fluid extra vascular or edema and low cutaneous blood flow, a burn injury can have devastating effects on the neuromuscular system. Patient's complaints regarding weakness or lack of sensation often are rationalized as generalized sequelae of the burn injury and healing process. However, these symptoms may be due to peripheral neuropathies and entrapment syndromes resulting from impaired nerve axons, or myelin sheath or both [2,5,6.]

All of the above burn complications plus the lymphatic damage will delay healing of the burn wound in the acute phase (Before wound closure), as well as in the chronic phase which begins with wound closure and continues until full maturation of the wound (from 1 to 2 years post-hospitalization) and lead to the development of contractures which affect the physical function of the burned patient finally, mononeuropathies and entrapment syndromes have been observed following thermal injury and most often affect nerves under the area of the burn, and they are usually seen in patient with burn greater than 20% of total body surface area [2,3,5,8.]

The occurrence of entrapment syndromes or multiple mononeuropathies after thermal burns covered greater than 20% of total body surface area (TBSA) is common and the number of nerves involved per patient ranged from 3 to 7 nerves. The source was believed to be due to multiple crush syndromes, in which multiple different neuropathic factors in each patient summate to cause a multiple mononeuropathies or entrapment neuropathies. Burn-Associated polyneuropathy (BAPN) is common after thermal injury and the electrophysiological manifestations of BAPN are present within the first week Post burn in burned and even in unburned limbs, which, were attributed to an inflammatory cascade caused by thermal injuries and resulted in nerve function alterations, [3,4,6,8]. Anodyne® Therapy Systems that delivers Monochromatic Infrared Energy/ (MIRE™) received clearance from the US FDA in 1994, obtained CE Marking in 2005, and are compliant to the ISO 13485 International Standard. Monochromatic Infrared Energy/ (MIRE™) a non-pharmacological treatment for acute and chronic wounds, including ulcers, diabetic wounds, abdominal wounds, and traumatic wounds, it is primarily used for more complex chronic wounds, it has been suggested that Monochromatic Infrared Energy/ (MIRE™) is best suited for the management of large, stage 2 and stage 3 ulcers with inadequate or poor granulation tissue and heavy exudates[7,9,10.]

The effect of electrical stimulation on normally innervated muscle tissue has been recognized for more than a century. The physiological effects of electrical stimulation is the ability to stimulate nerves by producing a change in semi permeability of the cell membrane by altering the resting potential of the membrane, and when the cell membrane potential reaches the critical excitatory level, the muscles supplied by the nerve is activated to contract, a single brief stimulus is associated with a single contraction[1,11,19.]

Neuromuscular electrical stimulation (NMES) is used to increase the force output and strengthening, muscle endurance training, functional electrical stimulation, tissue healing, pain reduction and edema control. NMES theories of strength augmentation are based on the overload principle as well as the recruitment phenomenon, where NMES augment and recruit the large motor nerves[1,19,20,21,22.]

Material and Methods

Subjects:

Forty patients with ages ranging from 20 to 35 years and suffering from burns at chronic phase (post-hospitalization period), affecting lower limbs, with the percentage of total body surface area (TBSA) ranging from 20% to 30% and their early diagnosis was a burn of 2nd or 3rd degree and complicated with post-burn tarsal tunnel syndrome. They were selected from the selected from the out-clinics of Kasr-El-Aini (Cairo University hospitals) and Om-Al-Misrieen hospital (Ministry of Health). They were divided into two groups. Group (A) composed of 20 patients received the MIRE and the traditional physical therapy were applied. Group (B) received the NMES and the traditional physical therapy were applied. All patients received the traditional physical therapy in the form of ice massage, pulsed ultrasonic, stretching exercises for the cuff muscles and ankle pump exercises. The treatment program was conducted for 20 minutes, 3 times / week for six

weeks. Measurements were conducted before starting the treatment as a first record and at the end of the six week of treatment as a second (final) record.

Instrumentation:

In this study the measuring equipment were Neuropack 2 MEB-7102K-EMG unit for measuring the motor and sensory conduction velocities of the tibial nerve (medial and lateral plantar branches), The Neuropack 2 MEB-7102K, was utilized to obtain an objective evaluation of the motor and sensory conduction velocities, while the therapeutic equipment were the Anodyne® Therapy Systems-Model 480: that was used to administer the monochromatic Infrared Energy/ (MIRE™) and the Cs-210 NMES unit manufactured by Enraf-Holland that was used to administer the neuromuscular electrical stimulation (NMES) in this study [6,8,12,13,14,21,22.]

Procedures

Evaluation:

1- Motor conduction velocity measurement:

- **For the medial plantar branch (MPB):** The recording (negative) electrode was placed over the main bulk of the abductor hallucis muscle (ABH) (located in the medial aspect of the sole of the foot between heel and base of the first metatarsal bone).The reference (positive) electrode was placed distally over the ball of the big toe, while the ground electrode was placed around the ankle area, between the stimulating and recording electrodes[4,8.]

- **For the lateral plantar branch (LPB):** The recording (negative) electrode was placed over the main bulk of the adductor hallucis muscle (ADH) (located below the head of the third metatarsal bone).The reference (positive) electrode was placed distally over the tip of the third toe, while the ground electrode was placed around the ankle area, between the stimulating and recording electrodes[6,8.]

- **Stimulating electrodes: In the distal stimulation:** the stimulating cathode was placed 8 cm proximal to the active recording electrode to provide a standardized distal latency segment (behind and above the medial malleolus). **In the proximal stimulation:** The stimulating cathode was placed in the center of the popliteal fossa (little bit laterally). For both the stimulation sites the positive electrode was proximal to the negative electrode. Recording electrodes were moistened with jelly, while the ground electrode was socked in 1% saline solution and the three electrodes were firmly fixed in position[3,4,8.]

2-Sensory conduction velocity measurement:

- For the medial plantar branch (MPB):

The recording (negative) electrode was placed over the posterior tibial nerve (above and behind the medial malleolus), while the reference (positive) electrode was placed proximally 3 cm from the active recording electrode, but the ground electrode was placed around the ankle area, between the stimulating and recording electrodes [3,4,6]

- For the lateral plantar branch (LPB): T

He recording (negative) electrode was placed over the posterior tibial nerve (above and behind the medial malleolus).The reference (positive) electrode was placed proximally 3 cm from the active recording electrode, while the ground electrode was placed around the ankle area, between the stimulating and recording electrodes. Averaging recording technique was used in sensory recording [3,6,8.]

- Stimulating electrodes:

For the MPB:

The stimulating ring electrodes was placed around the big toe with the active electrode proximal to the reference one (averaging technique was used). **For the LPB:** The stimulating ring electrodes were placed around the little toe with the active electrode proximal to the reference one (repeated stimulation was used).

Recording and stimulating electrodes were moistened with jell, while the ground electrode was soaked in water and all electrodes were firmly fixed in their places [3,6,8.]

Treatment procedures of the MIRE and the NMES:

Position of subject and the MIRE therapy pads placement:

Subject was relaxed in supine position with the hips were adjusted in slightly flexed and laterally rotated position, knees were adjusted also in slightly flexed position (only 10o) and slightly planter flexed ankles, with a pillow under the subjects head and another under both knees, so the comfortable patient's position was obtained. Four therapy pads from two channels only were used, one pad (first channel) was positioned on the popliteal fossa while the other pad was positioned on the medial surface of the foot between the heel and base of the first metatarsal bone, both pads were firmly fixed by relevant adhesive tapes. While therapy pads of the second channel were one pad (second channel) was positioned on the popliteal fossa while the other pad was positioned on the plantar surface of the foot at the base of the third metatarsal bone, also both pads were firmly fixed by a relevant adhesive tapes[7,9,15,16,17]

Position of subject and the NMES electrodes placement:

Subject was relaxed in supine position with the hips will be adjusted in slightly flexed and laterally rotated position, knees were adjusted also in slightly flexed position (only 10^{o}) and slightly planter flexed ankles, with a pillow under the subjects head and another under both knees, so the comfortable patient's position was obtained. Four electrodes from two channels only were used, one electrode (first channel) was positioned on the popliteal fossa (black negative electrode) while the other electrode was positioned on the medial surface of the foot between the heel and base of the first metatarsal bone (red positive electrode), both electrodes were moistened with jelly and firmly fixed by a relevant adhesive tapes. While electrodes of the second channel were one electrode (second channel) was positioned on the popliteal fossa (black negative electrode) while the other electrode was positioned on the plantar surface of the foot at the base of the third metatarsal bone (red positive electrode), also both electrodes were moistened with jelly and firmly fixed by a relevant adhesive tapes [1, 11, 20,21,22.]

Data analysis:

Motor and sensory conduction velocities of the tibial nerve (medial and lateral plantar branches), were measured pre-treatment as a first record and after six weeks as a second final record in both groups. Collected data were fed into computer for the statistical analysis; descriptive statistics as mean, standard deviation, minimum and maximum were calculated for each group. The t-test was done to compare the mean difference of the two groups before and after application and within each group. Alpha point of 0.05 was used as a level of significance.[18.]

Results

As shown in table (1) and figure (1), the mean value of the motor distal latency of the medial plantar branch before treatment was (10.10 ± 1.17) msec in the first study group (MIRE), while after treatment was (4.48 ± 0.36) msec. These results revealed a highly significant reduction in the motor distal latency of the medial plantar branch ($P < 0.0001$). While in the second study group (NMES), the mean value of the motor distal latency of the medial plantar branch before treatment was (10.09 ± 1.15) msec, while after treatment was (4.45 ± 0.33) msec. Also these results revealed a highly significant reduction in the motor distal latency of the medial plantar branch ($P > 0.0001$).

Table (1): Comparison of the mean values of the motor distal latency of the medial plantar branch in msec of the 2 records of the two study groups.

	Before treatment		After treatment		Mean difference	T-value	P.value	Level of significance
	Mean in msec	SD	Mean in msec	SD				
MIRE Group	10.10	1.17	4.48	0.36	5.62000	20.53	0.0001	Highly significant decrease
NMES Group	10.09	1.15	4.45	0.33	5.64000	21.08	0.0001	Highly significant decrease

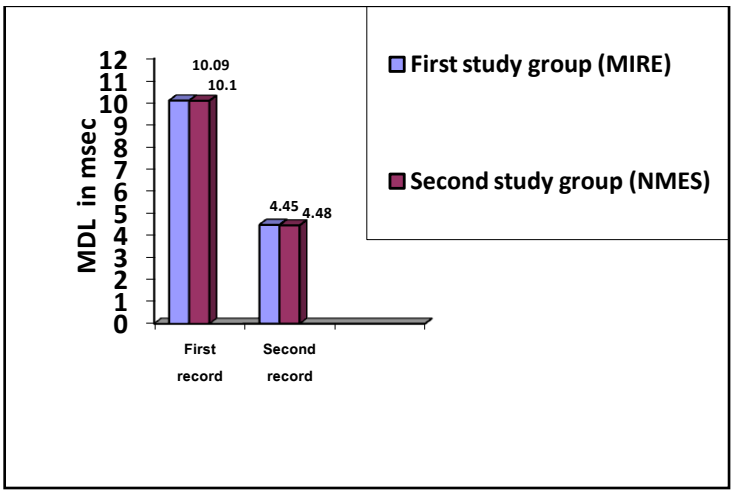

Fig (1): Mean values of the motor distal latency of the medial plantar branch in msec of the 2 records of the two study groups.

As shown in table (2) and figure (2), the mean value of the mean values of the sensory distal latency of the medial plantar branch before treatment was (10.04 ± 1.14) msec in the first study group (MIRE), while after treatment was (4.35 ± 0.26) msec. These results revealed a highly significant reduction in the mean values of the sensory distal latency of the medial plantar branch, ($P < 0.0001$), while in the second study group (NMES), the mean value of the mean values of the sensory distal latency of the medial plantar branch before treatment was (10.02 ± 1.11) msec, while after treatment was (4.31 ± 0.23) msec, also these results revealed a highly significant reduction in the mean values of the sensory distal latency of the medial plantar branch ($P > 0.0001$).

Table (2): Comparison of the mean values of the sensory distal latency of the medial plantar branch in msec of the 2 records of the two study groups.

	Before treatment		After treatment		Mean difference	T-value	P.value	Level of significance
	Mean in msec	SD	Mean in msec	SD				
MIRE Group	10.04	1.14	4.35	0.26	5.69000	21.76	0.0001	Highly significant decrease
NMES Group	10.02	1.11	4.31	0.23	5.71000	22.53	0.0001	Highly significant decrease

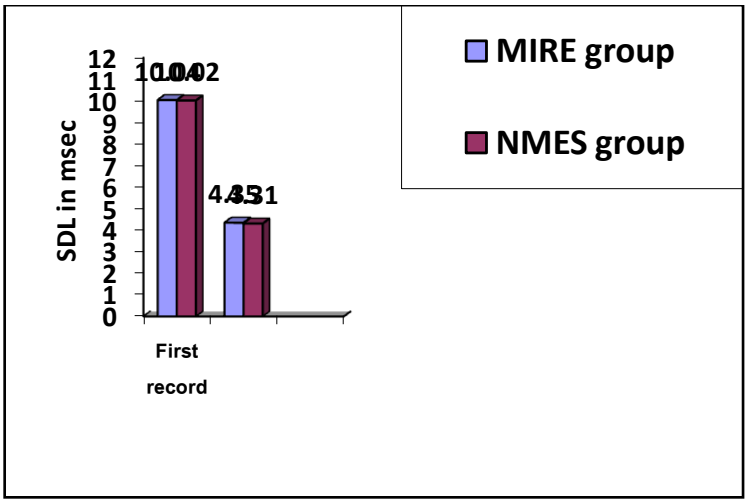

Fig (2): Mean values of the sensory distal latency of the medial plantar branch in msec of the 2 records of the two study groups.

As shown in table (3) and figure (3), the mean value of the motor distal latency of the lateral plantar branch before treatment was (9.98 ± 1.18) msec in the first study group (MIRE), while after treatment was (4.47 ± 0.22) msec. These results revealed a highly significant reduction in the motor distal latency of the lateral plantar branch ($P < 0.0001$). While in the second study group (NMES), the mean value of the motor distal latency of the lateral plantar branch before treatment was (9.97 ± 1.16) msec, while after treatment was (4.44 ± 0.19) msec. Also these results revealed a highly significant reduction in the motor distal latency of the lateral plantar branch ($P > 0.0001$).

Table (3): Comparison of the mean values of the motor distal latency of the lateral plantar branch in msec of the 2 records of the two study groups.

	Before treatment		After treatment		Mean difference	T-value	P.value	Level of significance
	Mean in msec	SD	Mean in msec	SD				
MIRE Group	9.98	1.18	4.47	0.22	5.51000	20.53	0.0001	Highly significant decrease
NMES Group	9.97	1.16	4.44	0.19	5.53000	21.04	0.0001	Highly significant decrease

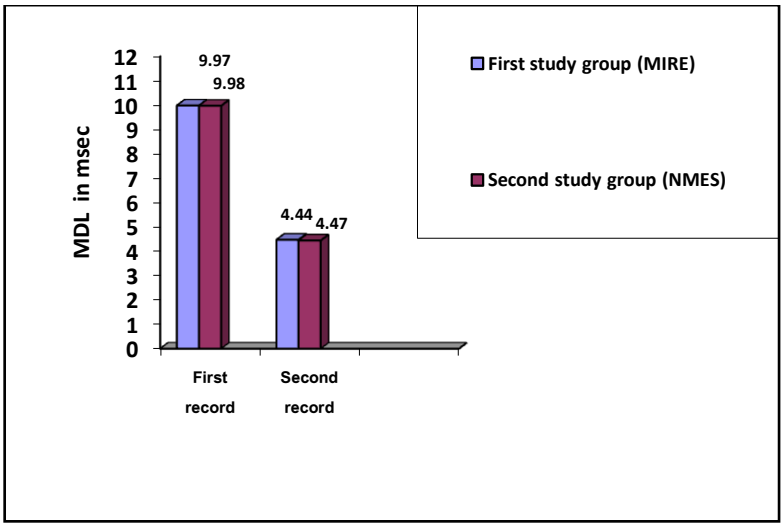

Fig (3): Mean values of the motor distal latency of the lateral plantar branch in msec of the 2 records of the two study groups.

As shown in table (4) and figure (4), the mean value of the mean values of the sensory distal latency of the lateral plantar branch before treatment was (10.08 ± 0.92) msec in the first study group (MIRE), while after treatment was (4.30 ± 0.24) msec. These results revealed a highly significant reduction in the mean values of the sensory distal latency of the lateral plantar branch, ($P < 0.0001$), while in the second study group (NMES), the mean value of the mean values of the sensory distal latency of the lateral plantar branch before treatment was (10.06 ± 0.90) msec, while after treatment was (4.26 ± 0.20) msec, also these results revealed a highly significant reduction in the mean values of the sensory distal latency of the lateral plantar branch ($P > 0.0001$).

Table (4): Comparison of the mean values of the sensory distal latency of the lateral plantar branch in msec of the 2 records of the two study groups.

	Before treatment		After treatment		Mean difference	T-value	P.value	Level of significance
	Mean in Msec	SD	Mean in msec	SD				
MIRE Group	10.08	0.92	4.30	0.24	5.78000	27.19	0.0001	Highly significant decrease
NMES Group	10.06	0.90	4.26	0.20	5.80000	28.13	0.0001	Highly significant decrease

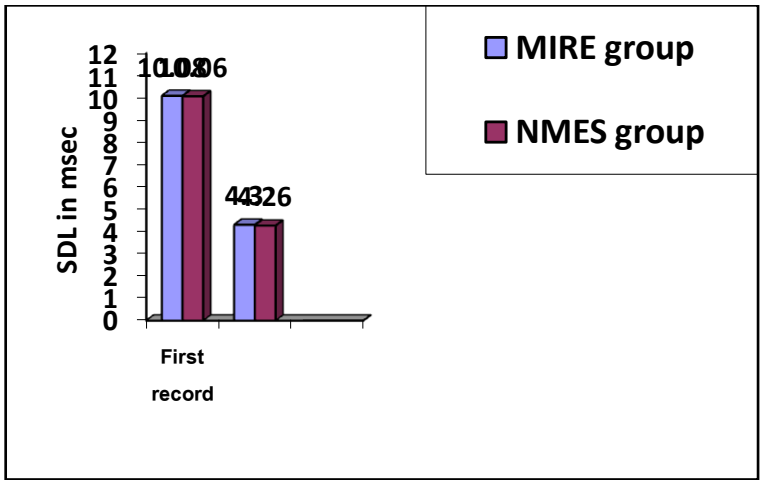

Fig (4): Mean values of the sensory distal latency of the lateral plantar branch in msec of the 2 records of the two study groups.

Discussion

Burn injuries vary in severity, depending on the amount of the total body surface area "TBSA" that has been damaged. Even the smallest burn causes discomfort that can be relieved by rapid first aid. The severe or dangerous burn involving more than 30 % of the (TBSA) may be life threatens. Burn injury primarily results in disruption and destruction of the normal protective functions of the skin. Skin is composed of epidermis and the corium (dermis or the true skin). The epidermis and its appendages (hair, sweat and sebaceous glands) are derived from the embryonic ectoderm while dermis is derived from the mesoderm. Epidermis is the most superficial part of the skin and it's composed of stratified squamous epithelial cells laid on top of each other like the bricks in a wall. Epidermis differs in its thickness from one part of the body to another; it's thicker on the palms of hands and the soles of feet,[2, 3,5.]

The basic pathophysiological consequence of the burn injury is the loss of the capillary integrity, localized increase in the micro vascular permeability, generalized impairment in the cell membrane resulting in cell swelling and increase osmotic pressure of the burned tissues leading to further fluid accumulation and oedema formation, which is a result of the outpouring of the intravascular fluid into the interstitial spaces. This process occurs at all areas of partial skin thickness burns and at the areas which are adjacent to and subjacent to the full skin thickness burns, [2, 4, 5.]

The immediate post-burn period is known as the ebb phase, as nutrient flow and oxygen delivery to cells is decreased, leading to a decrease in the basal metabolic rate (B.M.R), then there is a gradual increase in the metabolic rate reaching the normal B.M.R (40 ± 10 % C/m^2/hr) and exceeding this normal level up to twice or twice and half the normal value and this is the flow phase. This flow phase is due to the massive catecholamine release from the adrenal medulla and from the nerve endings of the sympathetic division of the autonomic nervous system, leading to systematic vasoconstriction, increased vascular resistance and poor peripheral circulation affecting skin, muscle and nerve, resulting in nerve function alterations[, 4,5.]

EMG and tibial nerve stimulation studies are of value in establishing the diagnosis of tarsal tunnel syndrome. The tibial nerve should be stimulated at the level of the superior border of the medial malleolus to ensure its being proximal to the flexor retinaculum. Motor latencies to the abductor hallucis and abductor digiti quinti pedis muscles may be easily recorded with surface electrodes. Assuming a normal conduction velocity in the proximal segment of the tibial nerve, the latency should not exceed 6.1msec for the medial plantar and 6.7msec for the lateral plantar branch, [3, 4,8.]

Monochromatic infrared energy therapy is a therapy that utilizes infrared light therapy through contact with the skin. This therapy may also be referred to as infrared therapy, near-infrared light therapy, and infrared light treatment. It is also known as monochromatic, near-infrared photo energy (MIRE™) (Anodyne Therapy LLC, Tampa, FL). The Anodyne® Therapy System (ATS) (Anodyne Therapy LLC, Tampa, FL) is one type of devices that utilizes MIRE. With Anodyne devices, light is emitted by an array of 60 superluminous gallium aluminum diodes located on a flexible pad. According to the manufacturer website the mechanism of action is a combination of topical heat and an increased local release of nitric oxide with use of wavelength (890nm) of near infrared light energy, [13, 14,15,16.]

Electrical stimulation, designed to excite peripheral sensory and motor nerves (also called Neuromuscular Electrical Stimulation [NMES]), is gradually becoming a recognized treatment option in neurorehabilitation. Two basic generic paradigms apply; (A) Neuromuscular retraining, this paradigm uses the NMES to minimize impairments and dysfunctions and eventually relearn to perform specific tasks and functions without electrical stimulation. (B) Neuroprosthesis (also termed "neuro-orthosis"). With this paradigm, the NMES enables the patient to perform specific tasks and functions considerably better but only during stimulation, [1, 19,20,21,22.]

Findings of the present study showed non-significant differences in the pre-treatment records of motor and sensory conduction velocities of the tibial nerve (medial and lateral plantar branches) between the mean values of the first and second study groups.

Results of the first study group revealed a highly significant decrease in the mean values of motor and sensory conduction velocities of the tibial nerve (medial and lateral plantar branches), after application of the

MIRE, when compared against the pre-application results. Also results of the second study group revealed a highly significant decrease in the mean values of the motor and sensory conduction velocities of the tibial nerve (medial and lateral plantar branches), after application of the NMES, when compared against the pre-application results.

Significant differences showed in the first and second study groups were consistent with those observed and recorded by Erickson and Haggard, 2002; Franson and Baravarian, 2006; Jianping et al., 2005; Kochman, 2004; Lavery et al., 2008; Lewek and Stevens, 2001; Li et al., 2008; Liu et al., 2005; Mitchell et al., 2010; Moro et al., 2012; Nather et al., 2007; Noble et al., 2001; Romero et al., 2002 and Wakim, 2005.

Results of this study support the expectation that application of both the MIRE and NMES had a valuable improving effects on the post burn tarsal tunnel syndrome as evidenced by the highly significant decreases in the prolonged motor distal latency and sensory distal latency of the medial and lateral plantar branches of the posterior tibial nerve. So both MIRE and NMES were effective and nearly equivalent in improving the post burn tarsal tunnel syndrome as manifested by the highly significant decreases in the prolonged motor distal latency and sensory distal latency of the medial and lateral plantar branches of the posterior tibial nerve.

Conclusion

Application of both MIRE and NMES were effective and nearly equivalent in improving the post burn tarsal tunnel syndrome as manifested by the highly significant decreases in the prolonged motor distal latency and sensory distal latency of the medial and lateral plantar branches of the posterior tibial nerve.

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