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Carpal Tunnel Syndrome Treated with a Diode Laser: A Controlled Treatment of the Transverse Carpal Ligament

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Abstract

Objective: The purpose of this placebo-controlled study was to investigate the therapeutic effects of the 830-nm diode laser on carpal tunnel syndrome (CTS). ***Background Data:*** Many articles in the literature have demonstrated that low-level laser therapy (LLLT) may help to alleviate various types of nerve pain, especially for CTS treatment. We placed an 830-nm laser directly above the transverse carpal ligament, which is between the pisiform and navicular bones of the tested patients, to determine the therapeutic effect of LLLT. ***Materials and Methods:*** Thirty-six patients with mild to moderate degree of CTS were randomly divided into two groups. The laser group received laser treatment (10 Hz, 50% duty cycle, 60 mW, 9.7 J/cm^2, at 830 nm), and the placebo group received sham laser treatment. Both groups received treatment for 2 wk consisting of a 10-min laser irradiation session each day, 5 d a week. The therapeutic effects were assessed on symptoms and functional changes, and with nerve conduction studies (NCS), grip strength assessment, and with a visual analogue scale (VAS), soon after treatment and at 2-wk follow-up. ***Results:*** Before treatment, there were no significant differences between the two groups for all assessments ($p > 0.05$). The VAS scores were significantly lower in the laser group than the placebo group after treatment and at follow-up ($p < 0.05$). After 2 wk of treatment, no significant differences were found in grip strengths or for symptoms and functional assessments ($p > 0.05$). However, there were statistically significant differences in these variables at 2-wk follow-up ($p < 0.05$). Regarding the findings of NCS, there was no statistically significant difference between groups after treatment and at 2-wk follow-up. ***Conclusions:*** LLLT was effective in alleviating pain and symptoms, and in improving functional ability and finger and hand strength for mild and moderate CTS patients with no side effects.

Introduction

CARPAL TUNNEL SYNDROME (CTS), a neural disease, is caused when the median nerve is entrapped by an inflamed and swollen transverse carpal ligament from above as it goes through the carpal tunnel, along with the tendons of the hand and fingers.[1] A thickening transverse carpal ligament due to chronic inflammation and swelling is the major source of CTS and causes entrapment of the nerve and the consequent pain and possible paralysis. Clinical symptoms and signs include numbness and tingling of the first three fingers and radial side of the ring finger, nocturnal awakening due to pain, and impaired fine motor control because of weakness of the hand.[2] Electromyographic and physical examinations (i.e., Phalen's maneuver and Tinel's test), can be used to confirm the diagnosis. Neural paralysis due to diabetes mellitus or other metabolic problems should be ruled out.[3] Symptoms are usually caused by high pressure on the median nerve in the carpal tunnel, rather than to damage to the nerve. Factors leading to inflammation and swelling of the carpal ligaments include trauma to the wrist, rheumatoid arthritis, operating vibrating machines by hand, tasks requiring repetitive wrist movements, and wrist edema during pregnancy.[1] Previous studies have proven that repetitive and forceful movements of the hand and wrist may lead to CTS.[4] Due to their smaller carpal tunnels, three times as many women suffer from CTS than do men.[4] Mayo found that 7 h of repetitive typing may increase the risk of CTS.[5]

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The National Institute of Neurological Disorders and Stroke estimates that about 3 out of 10,000 workers were forced to take sick leave because of CTS in 1998.[4] Half of them were off work for more than 10 d. The average expenses, including medical treatment and sick leave, were estimated to be about US$30,000 for each worker.

Lasers have played an important role in contemporary medicine. High-energy lasers have partially replaced traditional scalpels,[6] while low-level laser therapy (LLLT) has been used to speed wound healing after surgery, for pain relief, and for biological stimulation.[7] Therefore, this study explored the use of LLLT as a treatment to reduce CTS-induced pain and unnecessary costs. With its effects on internal tissues and endocrine disorders, laser energy has been applied to tender points,[8] acupuncture points,[9] and local trigger points (Ashi points)[10] as a conservative treatment for CTS. LLLT can be also applied to the distal branches of the median nerve to reduce pain due to CTS. In this study, we implement laser energy to facilitate the repair of damaged tissues (i.e., the transverse carpal ligament) based on its photobiostimulating effect. Therefore we applied the laser energy to the carpal tunnel itself instead of treating the nerve. The purpose of this study was to test the therapeutic effects of LLLT on CTS patients.

Materials and Methods

For this study, we recruited patients who were diagnosed with mild to moderate CTS in the rehabilitation center of Da Chien General Hospital. The recruited patients were chosen using the following criteria: (1) no surgery on the wrist, (2) first onset of CTS more than 1 year ago with repeated episodes, and (3) never having had laser treatment before. Patients with rheumatoid arthritis, a history of metabolic disease, and those with paralyzed limbs caused by stroke were excluded. The volunteers who met the criteria and agreed to participate in our 4-wk study were instructed to stop taking any anti-inflammatory drugs they were on. Moreover, other treatments, such as acupuncture, physical therapy, and wearing orthotics, were also forbidden. All the volunteers signed consent forms and were informed about the study.

Study design

Double-blind experiments were conducted in this study and the patient group was randomly divided into two groups. Patients in the laser group received diode laser treatment, and those in the placebo group received sham laser treatment (without laser output). The Institutional Review Board on Human Subject Research in the Chung Shan Medical University Hospital approved this study. After receiving a detailed explanation about the study, all patients signed the informed consent forms as approved. The treatments were conducted for two successive weeks. For each patient, the LLLT treatment was given once a day, five days per week, and the treatment course was continued for 2 wk. The assessments were made prior to treatment, immediately after the 2-wk treatment period, and after another 2 wk of follow-up.

Diagnosis of CTS

On physical examination, the diagnosis of carpal tunnel syndrome was based on the evidence of two or more positive findings for the following items: Phalen's maneuver, Tinel's sign, nocturnal awakening, wrist pain, and abnormal sensation of the first three fingers including tingling and/or numbness in the territory of median nerve distribution (excluding the palmar cutaneous branch).

The nerve conduction studies (NCS) of the median nerves were performed with a portable electromyograph (Medelec Synergy; Oxford Instruments Medical, Surrey, UK). The room temperature was maintained around 30–31°C. For the motor nerve conduction studies, compound muscle action potentials were recorded with a pair of surface recording electrodes placed on the abductor pollicis brevis muscle. The stimulating electrodes were placed at the wrist proximal to carpal tunnel for the distal segment stimulation, and at the elbow for the proximal segment stimulation. The distal motor latency was measured from the onset of the stimulating artifact to the onset of the compound muscle action potential. The nerve conduction velocity was also calculated to rule out any median nerve lesions such as polyneuropathy. In the study of sensory nerve conduction, a pair of ring electrodes

Table 1. Symptom Severity Scale[13]

Questions	*Answers*
1. How severe is the hand or wrist pain that you have at night?	1–5
2. How often did hand or wrist pain wake you up during a typical night in the past 2 weeks?	1–5
3. Do you typically have pain in your hand or wrist during the daytime?	1–5
4. How often do you have hand or wrist pain during the daytime?	1–5
5. How long, on average, does an episode of pain last during the daytime?	1–5
6. Do you have numbness (loss of sensation) in your hand?	1–5
7. Do you have weakness in your hand and/or wrist?	1–5
8. Do you have tingling sensations in your hand?	1–5
9. How severe is the numbness (loss of sensation) or tingling at night?	1–5
10. How often did hand numbness or tingling wake you up during a typical night during the past 2 weeks?	1–5
11. Do you have difficulty with grasping and using small objects such as keys or pens?	1–5

Answer range: 1 = none or very mild and rare, to 5 = very severe and frequent.

Table 2. Functional Status Scale[13]

Items	*Answers*
1. Writing	1–5
2. Buttoning clothing	1–5
3. Holding a book while reading	1–5
4. Gripping a telephone	1–5
5. Opening jars	1–5
6. Household chores	1–5
7. Carrying grocery bags	1–5
8. Bathing and dressing	1–5

Answer range: 1 = no difficulty, to 5 = severe difficulty.

were placed on the index finger for recording, and the sensory nerve was stimulated antidromically at the same site used for distal motor stimulation. Sensory peak latency was measured from the stimulating artifact to the peak of the sensory nerve action potential.

Based on the nerve conduction data, the patients were divided into two groups. For the patients in the group with mild CTS,[11] only sensory NCS abnormalities (increased distal latency) were detected. In these patients, their sensory peak latency of the median nerve was more than 3.6 msec, but the motor latency was less than 4.3 msec. The patients in the group with moderate CTS[11] had both sensory and motor NCS abnormalities. Sensory peak latency of the median nerve was more than 3.6 msec, and motor latency more than 4.3 msec. The same rehabilitation physician conducted the physical examinations and NCS testing.

Assessments

Pain measurement. Pain intensity was assessed using a visual analog scale (VAS), which was a calibrated scale ranging from 0 to 10 on the front side of the VAS (with 0 representing no pain and 10 representing the worst imaginable pain), and a corresponding 10-cm ruler was printed on the other side (with each centimeter representing one pain level increment). Each patient subjectively estimated his or her pain level by drawing marks along the scale between 0 and 10. Then the exact value of pain intensity could be obtained by referring the calibrated scale to the ruler on the back of the VAS. The post-treatment and follow-up scores were recorded and compared to assess the treatment's effectiveness.

Hand and finger grip strength. Hand grip strength was measured by a Jamar Hydraulic Hand Dynamometer (Lafayette Instrument Company, Lafayette, IN, USA). Each patient sat on a chair to keep his or her elbow flexed at 90°.[12] The finger grip strength was measured in both lateral prehension and digital prehension (i.e., via measuring the power of thumb adduction grip and tri-digital pinch grip)[12] using a Jamar Hydraulic Pinch Gauge (Lafayette Instrument Company). For all tests, mean scores of three measurements were calculated, and the resting interval between each test was 5 min.

Symptoms and functional assessment. A self-administered questionnaire was used to assess symptom severity (Symptom Severity Scale; Table 1) consisting of 11 questions. Eight other activities comprised the Functional Status Scale (Table 2). The severities of both scales were quantified to range from 1 (mildest) to 5 (most severe), and scores were calculated for each item on both scales.[13]

Nerve conduction assessment. Follow-up studies of nerve conduction were performed using the same procedures as those described above.

All these evaluations were done at baseline, after the 2-wk treatment period, and at 2 wk of follow-up.

Treatment procedure

The low-level laser instrument (Painless Light PL-830; Advanced Chips & Products Corp., Hillside, NJ) emitted two light beams spaced 2.5 cm apart via two laser diodes. The operational wavelength of the PL-830 was 830 nm. Its output frequency and output power were set to be 10 Hz and 60 (2×30) mW, respectively, and the treatment dose was 9.7 J/cm^2. The laser was placed directly above the transverse carpal ligament (between the pisiform and navicular bones) on the patient's affected wrist. A belt was used to fix the

Table 3. Demographic Data and Baseline Results of Nerve Conduction Studies and Physical Examinations in the Two Study Groups

	Laser group n = *20* *Mean ± SD*	*Placebo group* n = *20* *Mean ± SD*
Age	46.01 ± 11.65	49.07 ± 11.28
Right/left wrist	2/18	2/18
Onset (wk)	12.71 ± 9.43	15.07 ± 9.14
SPL (ms)	3.92 ± 0.16	3.85 ± 0.13
ML (ms)	4.23 ± 0.18	4.15 ± 0.20
Positive Phalen's maneuver (%)	64	71
Positive Tinel's sign (%)	57	57
Nocturnal awakening (%)	86	79
Wrist pain (%)	50	57
Abnormal sensation (%)	93	100

SPL, sensory peak latency; ML, motor latency.

Table 4. Results of Pre-Treatment Evaluation of Symptoms and Functional Assessments, and Hand and Finger Grip Strength in the Two Study Groups

	Laser group n = *20* *Mean ± SD*	*Placebo group* n = *20* *Mean ± SD*	p *Value*
Symptom Severity Scale scores	30.80 ± 0.75	27.51 ± 0.50	0.226
Functional Status Scale scores	18.72 ± 0.84	18.72 ± 0.68	0.997
Grip strength (kg)	17.77 ± 4.37	18.34 ± 5.17	0.748
Lateral prehension (kg)	4.46 ± 1.36	4.57 ± 1.35	0.842
Digital prehension (kg)	4.33 ± 1.37	4.69 ± 1.20	0.466

diode laser above the transverse carpal ligament. The treatments were conducted by the same physical therapist over a course of 2 wk for 10 min a day, 5 d per week.

Statistical analysis

The data were managed and analyzed using SPSS version 11 (SPSS, Inc, Chicago, IL, USA). The means and standard deviations were used as descriptive statistics. The Mann-Whitney U test was chosen to check the basic data, such as age, onset of CTS, duration of pain, NCS, VAS scores, and physical examination results to compare the baseline data between the groups, and to assess the outcomes of hand and finger grip strength, pain measurements, symptoms, and functional assessment at baseline. The Wilcoxon test was used to compare the outcomes of NCS, hand and finger grip strength testing, pain measurements, symptoms, and functional assessment immediately after treatment and at 2 wk of follow-up. The between-group differences in the number of cases with a positive Phalen's maneuver and Tinel's sign, nocturnal awakening, and wrist pain, and abnormal sensation of the first three fingers before treatment were converted to percentages and analyzed using Fisher's exact test. All statistical tests were two-tailed with a p value of <0.05 deemed statistically significant.

Results

Thirty-two patients with unilateral CTS and four patients with bilateral CTS were recruited into this study. All of them had mild to moderate degrees of CTS. Twenty wrists in the laser group were compared with 20 wrists in the placebo group at baseline before treatment, and their data are shown in Tables 3 and 4. No significant differences were found between the groups ($p > 0.05$).

Nerve conduction study

There were no significant changes in nerve conduction findings after the 2-wk treatment period and at 2-wk follow-up in both the experimental and control groups. When the groups were compared after treatment and at 2-wk follow-up, there were no significant differences seen in motor latency and sensory peak latency between the groups ($p > 0.05$; Table 5).

Hand and finger grip strength

In both groups, the grip strength increased after the 2-wk treatment period and at 2-wk follow-up. Comparing the two groups, there were no significant differences in hand and finger grip strength before treatment between the groups ($p > 0.05$; Table 4). After treatment, there were also no significant differences ($p > 0.05$; Table 5), but after the 2-wk follow-up period, hand and finger grip strength were statistically significantly improved in the laser group ($p < 0.05$; Table 5).

Pain measurement

Before treatment, no significant differences were found in VAS scores between the groups ($p > 0.05$; Fig. 1). There was

Table 5. Results of Post-Treatment and Two-Week Follow-Up Evaluation of Symptom and Functional Assessment, Hand and Finger Grip Strength, and Nerve Conduction in the Two Study Groups

	After 2 wk of treatment			*At 2-wk follow-up*		
	Laser group n = *20* *Mean ± SD*	*Placebo group* n = *20* *Mean ± SD*	p *Value*	*Laser group* n = *20* *Mean ± SD*	*Placebo group* n = *20* *Mean ± SD*	p *Value*
Symptom Severity Scale	21.67 ± 0.58	25.53 ± 0.62	0.138	19.35 ± 0.63	28.71 ± 0.85	0.006[a]
Functional Status Scale score	13.11 ± 0.63	17.04 ± 0.70	0.121	11.04 ± 0.43	19.60 ± 1.02	0.022[a]
Grip strength (kg)	19.71 ± 4.67	18.26 ± 4.55	0.415	21.19 ± 4.12	17.38 ± 3.56	0.014[a]
Lateral prehension (kg)	5.36 ± 1.56	4.62 ± 1.38	0.201	5.33 ± 1.33	4.35 ± 1.09	0.043[a]
Digital prehension (kg)	4.95 ± 1.30	4.70 ± 1.17	0.583	5.20 ± 0.83	4.43 ± 1.06	0.041[a]
SPL (ms)	3.75 ± 0.21	3.81 ± 0.11	0.243	3.67 ± 0.21	3.80 ± 0.11	0.065[a]
ML (ms)	4.03 ± 0.33	4.14 ± 0.18	0.364	3.87 ± 0.30	4.10 ± 0.21	0.053

[a] $p < 0.05$ on the Mann-Whitney U test.
SPL, sensory peak latency; ML, motor latency.

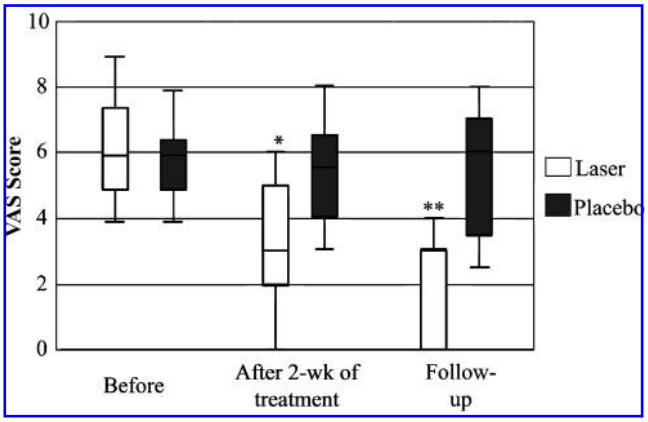

FIG. 1. Changes in VAS pre- and post-treatment and during follow-up in both of the groups (*p = 0.006 and **p = 0.001 on the Wilcoxon test; VAS , Visual Analog Scale).

a statistically significant reduction in VAS scores in the laser group after treatment ($p < 0.05$; Fig. 1) and at 2-wk follow-up ($p < 0.05$l; Fig. 1). Comparing the two groups, there were statistically significantly lower VAS scores in the laser group than the placebo group ($p < 0.05$).

Symptom and functional assessment

There were significant increases in functional scale scores after treatment in the experimental group but not in the control group ($p > 0.05$). The Symptom Severity Scale and Functional Status Scale for evaluating symptom severity showed no statistically significant differences between the groups before and after treatment ($p > 0.05$; Table 4). However, at 2-wk follow-up, there were statistically significant differences in the reductions in both scale scores between the groups ($p < 0.05$; Table 5).

Discussion

This is the first study using a band-shaped 830-nm laser in a placebo-controlled study to treat CTS by irradiating the wrist above the transverse carpal ligament. We used a low-level laser with a wavelength of 830 nm, output frequency of 10 Hz, output power of 60 (2 × 30) mW, and energy dose of 9.7 J/cm^2, to administer the treatment for 10 min.

In a previous study, Ohshiro investigated the relationship between the wavelength of laser energy and its penetration.[14] *In vivo*, he evaluated the comparative transmission of different laser wavelengths through tissues, and concluded that a laser with a wavelength range from 830–904 nm had the best absorption and penetration characteristics, and it was preferred for use as a clinical treatment tool. Therefore, we used an 830-nm diode laser to treat CTS. The 830-nm diode laser was placed directly above the transverse carpal ligament, which is between the pisiform and navicular bones, of the tested patients. In a previous study, a rotating and oscillating prism was used to scan the light beams over a larger area at a distance of 3–50 cm from the treatment location to hasten wound healing.[15] In such a treatment protocol, the light would be scattered and the dose per unit area would be reduced. On the other hand, another design, the spot laser, focuses energy on a spot by placing a needle directly onto the skin, and is mainly used to treat acupuncture points or Ashi points.[10,16,17] Furthermore, in previous studies using an 830-nm laser found that it was effective in treating pain and neural symptoms.[17,18]

The efficacy of a laser depends mainly on its treatment method and dose. In some studies, lasers were used on acupuncture points. However, they were ineffective and were not based on the acupoints as defined in the Channels theory of Traditional Chinese Medicine, because they usually were used on a single point.[9] Some treatment programs applied laser energy to local tender points (Ashi points), and these were also ineffective, perhaps because they were used on the wrong locations or at insufficient dosages.[10,16,17] Despite direct contact with the skin, the energy from a single-point laser may not reach the damaged tissue adequately, and thus the low efficacy of low-level laser therapy is thought to be due to an insufficient dosage.[17,18] However, the type of the laser we used in our study was different from the above-mentioned designs. We found a positive effect of irradiating the transverse carpal ligament with an 830-nm laser.

Chou and Hsieh used a laser on the carpal tunnel and hand area innervated by the median nerve.[19] Padua et al. also chose an 830-nm laser, but they used three laser beams with a diameter of 3 cm and an output power of 30 mW on the carpal area innervated by the median nerve.[20] In our study we used an 830-nm laser at 60 mW directly on the wrist above the transverse carpal ligament and achieved similar effects of pain relief. Wong et al. used a spot 830-nm laser at a power output of 100 mW on acupuncture points of the hand, chest, and neck.[4] The dose at each point was between 12 and 30 J/cm^2. However, a laser delivering a dosage from 8–10 J/cm^2 was recommended for clinical use to provide stimulating effects on damaged tissues, while a laser with a dosage of over 10 J/cm^2 could delay healing or cause new damage.[21] Therefore, a spot laser with high energy could provide healing effects, but may also damage normal tissues. In this study we used an 830-nm laser at a dose of 9.7 J/cm^2 for 2 wk of treatment, and the results showed that pain scores in those with mild to moderate CTS were reduced significantly. The laser we used may have healing effects on CTS and aid in healing a damaged transverse carpal ligament. Previous studies have shown that laser energy may increase production of adenosine triphosphate,[22] which increases cell metabolism, and increases the production of serotonin and endorphins, and may thereby decrease the inflammatory response.[23] The healing of damaged tissues depends on continuous and accelerated repair,[24] which was confirmed in this study by the pain-relieving effect of laser therapy. Therefore, the dosage and treatment time with the 830-nm laser used in our study may be sufficient to provide continuous energy to accelerate repair, and to decrease the inflammatory response. Hence, the healing effects exceeded the degree of damage done during the 2 wk of treatment, and the damage was decreased to such a degree that the tissue could repair by itself in the absence of laser therapy. Unfortunately, we were unable to prove this in the nerve conduction studies. In summary, the non-thermal effects of pain relief extended beyond the end of laser treatment, and continued until the 2-wk follow-up assessment.

Gigo-Benato et al. found that using an 808-nm laser at a dosage of 29 J/cm^2 and a treatment duration of 39 sec, to ir-

radiate neural axons of rat median nerves enhanced the growth and the healing of nerves after end-to-side neurorrhaphy.[25] Accordingly, the use of laser energy to irradiate nerves may facilitate nerve repair. However, it remains unclear whether laser energy administered to the human wrist is able to reach the nerves within the soft tissues. The actual laser energy absorbed by the median nerve, which affects the first four fingers through the palmar side of the wrist, may be limited because of the soft tissues surrounding the nerve. Bakhtiary and Rashidy-Pour also used an 830-nm laser, but they applied it at five different points, at a dose of 1.8 J for each point, to the area innervated by the median nerve.[10] The results were unsatisfactory in treating CTS. Furthermore, the distribution of the median nerve varies in different people, so it would be difficult to apply the appropriate dosages precisely to the damaged sections, and to assure the effectiveness of the laser energy on the median nerve.[26] Naeser et al. divided the hand and wrist into 1-cm^2 squares and applied equal an amount of laser energy to each square.[9] Despite a 50% improvement in general symptoms, no significant differences were seen on any objective evaluation. It may be that the damaged neural areas did not receive an adequate dosage. Upon statistical analysis, however, in our study we found that the results were the same after treatment and at 2-wk follow-up.

For the laser group, the pain scores of CTS patients had reduced significantly after 2 wk of treatment, but no between-group differences were found in symptoms and functional scores. However, after 2 wk of follow-up, there were significant changes in symptoms in the laser group. We found the same outcome in hand and finger grip strength testing, and they also had significant differences at 2-wk follow-up, but not immediately after treatment. The duration of treatment in previous studies using the 830-nm laser was 4–5 wk, and all of them showed significant improvements.[7,19,21] This fact indicates that the repair of nerves was connected with the relief of inflammation and swelling of the transverse carpal ligament. Effective repair of this ligament would relieve symptoms and improve hand function and grip strength, and this was supported by the significant improvements in those with mild to moderate CTS assessed in this study after 2 wk of follow-up.

Conclusion

LLLT was effective in alleviating pain and symptoms, and in improving functional ability, as well as finger and hand strength, in those with mild to moderate CTS, and the therapy had no side effects. These biological and clinical effects of LLLT may be best explained by the Arndt-Schultz law, which describes the photobiostimulating effect of laser energy.[23] This theory indicates that no biological effects can be induced unless the stimulation is above a certain threshold, but stimulation that is too strong may have inhibitory effects. Furthermore, different types of lasers may have differing penetration depths and treatment effects, which are also dependent on the dosage and mode of the laser used. By choosing the appropriate parameters and treatment locations, improved efficacy may be achieved with lower dosages and shorter treatment sessions. In the future, further comparisons should be made with other treatment methods and locations, to provide practitioners better therapeutic programs for those with CTS.

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Disclosure Statement

No competing financial interests exist.

References

1. Prakash, K.M., Fook-Chong, S., Leoh, T.H., et al. (2006). Sensitivities of sensory nerve conduction study parameters in carpal tunnel syndrome. J. Clin. Neurophysiol. 23, 565–567.
2. Clark Gaylord, L. (1998). *Hand Rehabilitation: A Practical Guide*. New York: Churchill Livingstone, pp. 216–230.
3. Flak, M., Durmala, J., Czernicki, K., et al. (2006). Double crush syndrome evaluation in the median nerve in clinical, radiological and electrophysiological examination. Stud. Health Technol. Inform,. 123, 435–441.
4. Wong, E., Lee, G., Zucherman, J., and Mason, D.T. (1995). Successful management of female office workers with "repetitive stress injury" or "carpal tunnel syndrome" by a new treatment modality—application of low level laser. Int. J. Clin. Pharmacol. Ther. 33, 208–211.
5. National Institute of Neurological Disorders and Stroke (NINDS). (2002). Carpal tunnel syndrome fact sheet. Accessed December 12, 1995, from http://www.ninds.nih.gov.
6. Coats, D.K., Miller, A.M., Hussein, M.A., et al. (2005). Involution of retinopathy of prematurity after laser treatment: factors associated with development of retinal detachment. Am. J. Ophthalmol. 140, 214–222.
7. Ailioaie, C., and Lupusoru-Ailioaie, L.M. (1999). Beneficial effects of laser therapy in the early stages of rheumatoid arthritis onset. J. Laser Ther. 11, 79–87.
8. Sterling, M., and Maher, C. (2006). The effect of 300 mW, 830 nm laser on chronic neck pain. Aust. J. Physiother. 52, 302–303.
9. Naeser, M.A., Hahn, K.A., Lieberman, B.E., et al. (2002). Carpal tunnel syndrome: clinical outcome after low-level laser acupuncture, microamps transcutaneous electrical nerve stimulation, and other alternative therapies: an open protocol study. J. Altern. Complement Med. 5, 5–26.
10. Bakhtiary, A.H., and Rashidy-Pour, A. (2004). Ultrasound and laser therapy in the treatment of carpal tunnel syndrome. Aust. J. Physiother. 50, 147–151.
11. Jablecki, C.K., Andary, M.T., and Floeter, M.K. (2002). Practice parameter: Electrodiagnostic studies in carpal tunnel syndrome. Report of the American Association of Electrodiagnostic Medicine, American Academy of Neurology, and the American Academy of Physical Medicine and Rehabilitation. Neurology. 58, 1589–1592.
12. Jones, L.A. (1989). The assessment of hand function: a critical review of techniques. J. Hand Surg. 14A, 221–228.
13. Levine, D.W., Simmons, B.P., Koris, M.J., et al. (1993). A self administered questionnaire for the assessment of severity of symptoms and functional status in carpal tunnel syndrome. J. Bone Joint Surg. Am. 75, 1585–1592.
14. Ohshiro, T. (1988). *Low Level Laser Therapy*. Avon, U.K.: Wiley and Sons, pp. 16–30.

15. Bond, T.J., and Lundy, J. (2006). Physical therapy following peripheral nerve surgeries. Clin. Podiatr. Med. Surg. 23, 651–666.
16. Gerritsen, A.A., de Krom, M.C., Struijs, M.A., et al. (2002). Conservative treatment options for carpal tunnel syndrome: a systematic review of randomised controlled trials. J. Neurol. 249, 272–280.
17. Irvine, J., Chong, S.L., Amirjani, N., et al. (2004). Double-blind randomized controlled trial of low-level laser therapy in carpal tunnel syndrome. Muscle Nerve. 30, 182–187.
18. Naeser, M.A. (2006). Photobiomodulation of pain in carpal tunnel syndrome: review of seven laser therapy studies. Photomed. Laser Surg, 24, 101–110.
19. Chou Y.J., and Hsieh, L.F. (1996). Low power laser in the treatment of carpal tunnel syndrome. Am. J. Phys. Med. Rehabil. 24, 29–33.
20. Padua, L., Padua, R., Aprile, I., and Tonali, P. (1997). Non-invasive laser neurolysis in carpal tunnel syndrome. Muscle Nerve. 20, 1029–1031.
21. Hecox, B., Andemicael Mehreteab, T., and Weisberg, J. (1994). Physical agents: a comprehensive text for physical therapists. Norwalk, CT: Appleton & Lange, pp. 391–396.
22. Amat, A., Rigau, J., Waynant, R.W., et al. (2005). Modification of the intrinsic fluorescence and the biochemical behavior of ATP after irradiation with visible and near-infrared laser light. J. Photochem. Photobiol. B. 81, 26–32.
23. Master, E., Master, A.F., and Master, A. (1985). The biomedical effects of laser application. Lasers Surg. Med. 5, 31–39.
24. Douglas, S.J. (2003). Low-level laser therapy in the treatment of carpal tunnel syndrome. Athletic Therapy Today. 8, 30–31.
25. Gigo-Benato, D., Geuna, S., de Castro Rodrigues, A., et al. (2004). Low-power laser biostimulation enhances nerve repair after end-to-side neurorrhaphy: a double-blind randomized study in the rat median nerve model. Lasers Med. Sci. 19, 57–65.
26. Jenp, Y.N., Lan, C., and Lien, I.N. (1991). Effect of low power laser irradiation on nerve conduction velocity of median nerve. Am. J. Phys. Med. Rehabil. 19, 9–14.

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