

Ultrasound and laser therapy in the treatment of carpal tunnel syndrome

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This study was designed to compare the efficacy of ultrasound and laser treatment for mild to moderate idiopathic carpal tunnel syndrome. Ninety hands in 50 consecutive patients with carpal tunnel syndrome confirmed by electromyography were allocated randomly in two experimental groups. One group received ultrasound therapy and the other group received low level laser therapy. Ultrasound treatment (1 MHz, 1.0 W/cm², pulse 1:4, 15 min/session) and low level laser therapy (9 joules, 830 nm infrared laser at five points) were applied to the carpal tunnel for 15 daily treatment sessions (5 sessions/week). Measurements were performed before and after treatment and at follow up four weeks later, and included pain assessment by visual analogue scale; electroneurographic measurement (motor and sensory latency, motor and sensory action potential amplitude); and pinch and grip strength. Improvement was significantly more pronounced in the ultrasound group than in low level laser therapy group for motor latency (mean difference 0.8 m/s, 95% CI 0.6 to 1.0), motor action potential amplitude (2.0 mV, 95% CI 0.9 to 3.1), finger pinch strength (6.7 N, 95% CI 5.0 to 8.2), and pain relief (3.1 points on a 10-point scale, 95% CI 2.5 to 3.7). Effects were sustained in the follow-up period. Ultrasound treatment was more effective than laser therapy for treatment of carpal tunnel syndrome. Further study is needed to investigate the combination therapy effects of these treatments in carpal tunnel syndrome patients. [Bakhtiary AH and Rashidy-Pour A (2004): Ultrasound and laser therapy in the treatment of carpal tunnel syndrome. *Australian Journal of Physiotherapy* 50: 147–151]

Key words: Carpal Tunnel Syndrome, Low Level Laser Treatment, Ultrasound Treatment

Introduction

Carpal tunnel syndrome is the entrapment mononeuropathy seen most frequently in clinical practice, caused by compression of the median nerves at the wrist (Phalen 1966, Gelberman et al 1998). Usually, patients show one or more symptoms of hand weakness, pain, numbness or tingling in the hand, especially in the thumb, index and middle fingers (Simovic and Weinberg 2000). Symptoms are worst at night and often wake the patient.

A number of treatments are used for carpal tunnel syndrome, with considerable controversy surrounding optimal management of the disorder (Swart 1998). Standard treatments include splints, local injection of corticosteroids, and surgical decompression. The benefit of non-surgical treatment seems to be limited (Dawson 1993), although not all patients respond to surgery (Cotton 1991). On the other hand, the efficacy of most conservative treatment options for carpal tunnel syndrome is still little known (Gerritsen et al 2002). Among the different options for conservative treatment, low-level laser therapy and ultrasound therapy may have the potential to induce biophysical effects within the nerve tissue (Ebinbichler 1998). Experiments on the stimulation of nerve regeneration and on nerve conduction by low level laser therapy (Stolk and Seifert 1989, Basford et al 1993) and also by ultrasound therapy (Hong et al 1988, Kramer 1989) support the concept that these treatments might facilitate recovery from nerve compression. There are some reports of therapeutic benefits of low level laser therapy (Naeser et al 2002, Wong et al 1995) or ultrasound therapy in the treatment of carpal tunnel syndrome under clinical conditions.

Recently, the effects of ultrasound treatment for treating carpal tunnel syndrome were compared with sham treatment,

and the authors reported satisfying short to medium term effects of ultrasound treatment in patient with mild to moderate idiopathic carpal tunnel syndrome (Ebinbichler 1998). In a more recent study, Naeser et al (2002) compared the effects of real low level laser therapy and sham treatment on acupuncture points located in the fingers, hand, elbow, shoulder, upper back, and cervical paraspinal area in patients with mild to moderate carpal tunnel syndrome. They found relatively stable results (one to three years) with real treatment; there was more than 50% pain reduction in seven of eight cases, a success rate of 87.5%. The difference between this study and other low level laser therapy studies was that low level laser therapy was applied on acupuncture points instead of along the median nerve at the wrist/hand. Weintraub (1998) treated 30 hands with a near infrared 830 nm 30 mW laser (9 J over 5 points, along the median nerve at the wrist) and reported photobiological responses in 80% of nerves. Mechanisms suggested as underlying therapeutic effects with low level laser therapy included increased ATP production by the mitochondria (Passarella 1998) and increased cellular oxygen consumption (Yu et al 1997), increased serotonin (Walker 1983) and endorphins (Clokie et al 1988), anti-inflammatory effects (Ailioaie Lupusoru-Ailioaie 1999), and improved blood circulation in some cases (Kemmotu et al 1991).

This clinical trial compared the efficacy of low level laser therapy and ultrasound therapy in the treatment of carpal tunnel syndrome.

Method

Patients The study protocol was approved by the ethical committee of the University. Sample size was the same as that used in an earlier study (Ebenbichler et al 1998) that used 45 independent observations in two groups. All patients were

right handed, and gave their consent to participate in the study. Fifty patients (40 patients with both wrists affected and 10 patients with one wrist affected on the right side) with clinically diagnosed carpal tunnel syndrome referred to the rehabilitation clinic of the Semnan Medical Sciences University were invited to participate in this randomised trial. All patients with numbness in the median nerve distribution and night waking lasting more than one month were enrolled in the study. Inclusion criteria were: 1) positive Phalen's test, 2) positive Tinnel's test, and 3) standard electrophysiological criteria including prolongation of nerve conduction velocity (i.e., motor latency > 4 ms or sensory latency > 3.5 ms). Patients were excluded if they had secondary entrapment neuropathies, electroneurographic and clinical signs of axonal degeneration of the median nerve, if they had been treated with ultrasound or low level laser therapy for the syndrome, or had required regular analgesic or anti-inflammatory drugs. Patients with a history of steroid injection into the carpal tunnel, thyroid disease, diabetes, or systemic peripheral neuropathy were excluded as well.

As there were two categories of carpal tunnel syndrome patients, patients with bilateral involvement ($n = 40$), and patients with unilateral involvement ($n = 10$), a computer-generated randomisation list was drawn up by the statistician for each category. It was given to the physiotherapy department in two sets of sealed numbered envelopes, one set for bilateral carpal tunnel syndrome patients and one set for unilateral carpal tunnel syndrome patients. When the patients qualified to enter the study and had signed informed consent, according to their bilateral or unilateral involvement the appropriate numbered envelope was opened at the reception; the card inside indicated the patient's allocation to a treatment group. This information was then given to the physiotherapist to administer appropriate intervention. Thus patients with both wrists affected were assigned randomly to one of the two following treatment groups: Group A, who received ultrasound in the right hand and low level laser therapy in the left hand; or Group B, who received low level laser therapy in the right hand and ultrasound in the left hand. The patients with one wrist affected were also assigned randomly to the following treatment groups: Group C, who received ultrasound treatment; and Group D, who received low level laser therapy treatment. The affected side in all patients with one wrist involved was the right side. By using these randomisation procedures, forty-five wrists were randomly enrolled in each of the treatment protocols, low level laser therapy or ultrasound therapy, and the numbers of dominant and non-dominant hands in each treatment group were equal.

Intervention Ultrasound treatment was administered for 15 minutes per session to the area over the carpal tunnel at a frequency of 1 MHz and an intensity of 1.0 W/cm², with pulsed mode duty cycle of 1:4 and a transducer area of 5 cm², using an Enraf Sonopuls 434 machine with aquasonic gel as the couplant. The apparatus was initially standard and the output was controlled regularly by a simple under-water radiation balance. A total of 15 ultrasound treatments were performed once a day, five times a week for three weeks.

Low-level laser therapy was administered by applying a low intensity (9 J), infrared laser diode (Enraf, Endolaser 830 nm) at five points (1.8 J/point) over the course of the median nerve at the wrist. The output of the laser beam was controlled each session by a simple infrared photocell. A total of 15 laser therapies were performed once a day, 5 times a week for 3 weeks.

Outcome measures The staff who assessed the outcomes were different from the staff administering the treatments, and they were blinded to the type of treatment (low level laser therapy or ultrasound) each patient had received. Outcome measures for each wrist consisted of: a) pain measurement by means of a visual analogue scale (VAS), on which the patients could indicate their assessment along a 10 cm line ranging from 0 ('no pain at all') to 10 ('the most severe pain that I can imagine'); b) pinch strength measured with a standard dynamometer between the tips of the thumb and the little finger; and c) hand grip strength measured with a handheld dynamometer. The patient's positioning was standardised and the average force of three consecutive trials was calculated. The dynamometers were initially standard and their sensitivity was controlled regularly by standard weights.

All electroneurographic measurements were performed with a portable Dantec electromyography device (Keypoint Portable). Briefly, median motor nerve conduction and distal motor latency were measured with a bipolar stimulating electrode at the wrist and a bipolar surface recording electrode placed on the abductor pollicis muscle 7 cm from the stimulus electrodes at the wrist. The active electrode was placed halfway between the metacarpophalangeal joint of the thumb and the midpoint of the distal wrist crease, so the recorded site was the same for all recording sessions.

Antidromic sensory nerve action potentials evoked at the wrist were recorded from the thumb and index finger with ring electrodes placed around the thumb proximal and distal interphalangeal joints. A standard distance (14 cm) was maintained between the stimulator and recording electrodes. At least 20 sensory nerve action potentials were averaged and antidromic sensory nerve latencies were calculated as appropriate. Measures were obtained of peak to peak amplitude of compound muscle action potentials and sensory action potential. The skin temperature of the forearm and wrist were kept at 32–33° C during all measurements.

All measurements were performed before the first treatment session, at the end of therapy, and after four weeks follow up to compare the effects of the two different treatments. In order to reduce the number lost to follow-up, we guaranteed to complete the treatment regimen with more effective treatments if there was no benefit from the applied treatment at the end of the study. Thus, all patients completed the study to the end of the four-week follow up period.

Statistics To compare the possible treatment effects, an intention to treat analysis was used which involved all patients who were randomly assigned to their groups. Student's *t* tests were used to compare the means of the electrophysiological values, pain, finger pinch and hand grip strength between the treatment groups, before and immediately after the treatment, and then four weeks later.

Results

Baseline evaluation Forty patients with bilateral carpal tunnel syndrome and ten patients with unilateral carpal tunnel syndrome (90 wrists) fulfilled all inclusion criteria. Thus, 45 wrists treated with low level laser therapy and 45 wrists treated with ultrasound therapy completed a three-week treatment protocol and four week follow-up period.

The wrists in each group were similar in terms of the duration of the current main complaints and baseline values of outcome measures. No significant difference was seen

Table 1. Demographic data and baseline characteristics of patients in both experimental groups. Data are means (SD), except where indicated.

Variable	Treatment group	
	Laser	Ultrasound
Number of wrists	45	45
Age (years)	48 (13.4)	45 (17.1)
Number of wrist with pain or paraesthesia	43	41
Number of wrists with sensory loss	28	33
Duration of current main complaints (months)	6.7 (6.5)	7.1 (6.9)
Pain (Visual analogue score/10)	6.9 (2)	6.8 (1.8)
Handgrip strength (N)	204.2 (64.7)	190.9 (63.9)
Finger pinch (N)	17.6 (9.8)	14.7(7.8)
Motor distal latency (ms)	4.7 (0.7)	5 (0.7)
Peak to peak CMAP amplitude (mA)	7.5 (2.7)	7.1 (3.2)
Antidromic thumb sensory latency (ms)	3.8 (1.1)	4.1 (0.8)
Thumb SAP amplitude (μ A)	15.4 (8.1)	15.6 (8.5)
Antidromic index sensory latency (ms)	4.2 (1.4)	4.4 (1.2)
Index SAP amplitude (μ A)	23.2 (16.0)	20.8 (11.8)

CMAP = compound motor action potential. SAP = sensory action potential.

between the demographic data and baseline characteristics of patients in the two experimental groups (Table 1).

Effect of treatment Table 2 shows the mean changes in the subjective and objective measurements at the end of the therapy and four weeks later. Significant differences were seen in the mean changes of all measurements between the two experimental groups.

Physical functioning Measures of finger pinch and hand grip strength showed significant improvement in both groups, but the mean changes were significantly higher with ultrasound treatment at the end and also at four weeks follow up (Table 2).

Pain perception Patients' ratings of pain at the end of treatment and 4 weeks later significantly favored ultrasound over laser treatment ($p < 0.001$).

Electroneurography The results of electroneurography are shown in Table 2. Motor distal latency decreased in both treatment groups, but the mean changes were significantly greater with ultrasound treatment both at the end of treatment and at four weeks follow up ($p < 0.001$ for both periods). Similar significant changes in the sensory distal latency were observed with ultrasound treatment, whereas sensory distal latency remained unchanged or only slightly changed with laser therapy ($p = 0.004$).

The amplitude of the motor and sensory action potentials increased in both groups, but the mean changes were significantly higher at the end of treatment and at four weeks follow-up in the ultrasound group (Table 2).

Discussion

This study examined the results of ultrasound treatment and laser treatment in patients who had carpal tunnel syndrome confirmed by clinical examination and electroneurography. There were significantly greater changes in all parameters for the ultrasound treatment group compared to the low level

laser therapy group. Although greater mean changes were found consistently in the ultrasound group, the size of mean differences was different for different outcomes. For example, while the mean differences in effects on motor and sensory latencies were big, the mean differences on motor and sensory amplitudes were small (Table 2). The differences between treatment effects on latencies and amplitudes may be because there is myelin involvement in most patients with carpal tunnel syndrome but axonal involvement is not always seen with mild or moderate carpal tunnel syndrome (Caetano 2003).

Different effects were also found between pinch and grip strength, which may be due to the different muscles involved. For example the main muscle to produce the force in a pinch between the thumb and little finger is opponens pollicis, which is innervated only by the median nerve. In grip strength, different types of muscles with different innervations are responsible for the generated force (Kozin et al 1999), so this measurement could be varied according to the patient's ability to use other muscles innervated by the ulnar nerve to overcome the grip weakness caused by median nerve involvement. This uncontrolled variable may interfere with the recorded values and may cause smaller mean differences with grip strength compared to pinch strength.

Conservative treatment approaches seem to offer clear advantages over surgical treatment in patients with mild or moderate carpal tunnel syndrome. Recent studies have shown short term effects of steroid injections into the carpal tunnel, with modest or complete pain relief in up to 92% of the patients, although long term recurrence rates seem variable (Giannini et al 1991, Girlanda et al 1993, Gonzales and Bylak 2001). The value of this treatment has been limited by potential adverse effects to nerves and tendons with repeated injections (McConnel and Bush 1990). Wearing wrist splints at night seems suitable only when symptoms are mainly nocturnal (Burk et al 1994).

Some studies have reported some beneficial effects of other

Table 2. Mean changes from baseline values for pain, force measures, and recorded electrophysiological parameters at the end of therapy and four weeks later.

	End of therapy			Four week follow-up		
	Ultrasound mean (SD)	Laser mean (SD)	Difference (95% CI; <i>p</i>)	Ultrasound mean (SD)	Laser mean (SD)	Difference (95% CI; <i>p</i>)
Pain (VAS;10 cm scale)	-5.6 (1.5)	-2.4 (1.2)	-3.1 (-3.7 to -2.5) <i>p</i> < 0.001	-6.3 (1.6)	-2.0 (1.3)	-4.4 (-4.9 to -3.1) <i>p</i> < 0.001
Handgrip strength (N)	36.6 (19.1)	19.4 (15.3)	17.2 (4.5 to 29.9) <i>p</i> = 0.008	39.3 (21.5)	21.2 (18.4)	12.1(5.7 to 27.6) <i>p</i> < 0.001 -
Finger pinch (N)	9.1 (4.1)	2.6 (1.0)	6.7 (5.0 to 8.2) <i>p</i> < 0.001	9.9 (5.5)	2.9 (1.5)	7.0 (5.1 to 8.5) <i>p</i> < 0.001
Motor distal latency (msec)	-1.0 (0.6)	-0.3 (0.3)	-0.8 (-1.0 to -0.6) <i>p</i> < 0.001	-1.1 (0.5)	-0.2 (0.2)	-0.9 (-1.0 to -0.8) <i>p</i> < 0.001
CMAP amplitude (mV)	3.0 (1.6)	1.0 (2.9)	2.0 (0.9 to 3.1) <i>p</i> < 0.001	3.6 (1.5)	1.1 (2.9)	2.5 (1.2 to 3.3) <i>p</i> < 0.001
Thumb sensory latency (ms)	-0.7 (0.5)	-0.2 (0.7)	-0.5 (-0.8 to -0.2) <i>p</i> < 0.001	-0.7 (0.5)	-0.2 (0.6)	-0.6 (-0.8 to -0.2) <i>p</i> = 0.003
Thumb SAP amplitude (µV)	9.5 (7.3)	4.5 (7.6)	5.0 (1.6 to 8.3) <i>p</i> = 0.004	10.1 (6.9)	4.4 (7.4)	5.7 (2.0 to 8.5) <i>p</i> < 0.001
Index sensory latency (ms)	-0.8 (1.0)	0.1 (1.2)	-0.8 (-1.3 to -0.3) <i>p</i> = 0.003	-0.8 (1.0)	0.1 (1.1)	-0.9 (-1.4 to -0.3) <i>p</i> = 0.004
Index SAP amplitude (µV)	16.1 (16.4)	7.0 (14.2)	9.1 (2.9 to 15.9) <i>p</i> = 0.007	16.8 (15.2)	6.5 (11.9)	10.3 (3.1 to 16.3) <i>p</i> = 0.003

VAS = visual analogue scale. CMAP = compound muscle action potential. SAP = sensory action potential.

conservative treatments such as ultrasound therapy (Mayr and Ammer 1994, Ebenbichler et al 1998) and laser therapy (Basford et al 1993, Weintraub 1998). They have claimed that these physical agents may facilitate the recovery from carpal tunnel syndrome, although there are some contradictory results from other studies (Viera et al 2001, Edel and Bergmann 1970).

The findings of the present study confirm that ultrasound treatment is more effective than laser treatment in patients with carpal tunnel syndrome. The rate of improvement from ultrasound treatment was similar to that reported in other studies (Ebenbichler et al 1998, Walling 1998) and may indicate its similar effectiveness to steroid injection or wrist splinting (Girlanda et al 1993, Gonzales and Bylak 2001), but without their complications (McConnel and Bush 1990) or limits (Burk et al 1994).

Previous studies on the effects of laser therapy have been performed with a wide range of therapeutic parameters such as wave length, exposure intensity and different methods of local or acupuncture application. For example, Viera et al (2001) reported no significant changes in electrophysiological parameters with exposure to laser radiation with wavelength of 940 nm on the median nerves, while Baxter et al (1994) showed that motor distal latency can be increased by direct irradiation with laser (830 nm, total energy of 9.6 J) on the median nerve. In a study by Basford et al (1993), the radiation of infrared laser (830 nm, 1.2 J/cm² over 10 points of the median nerve path) caused reduced motor and sensory distal latency. In a recent study, Naeser et al (2002) used the wavelengths of 632.8 nm and 904 nm with intensities of 15 mW and 9.4 mW on the acupuncture points of the median nerve in the fingers, hand, forearm, elbow and

shoulder, and reported remarkable pain relief.

Such different reports on the effects of laser therapy may be due to the different therapeutic parameters which have been applied in these studies and it seems that there is no general agreement on the therapeutic parameters of laser therapy for treatment of carpal tunnel syndrome. In our study, the comparison between the findings from low level laser therapy and those from ultrasound therapy illustrates the superior effect of ultrasound on recovery, which has also been reported by other studies (Gerritsen et al 2002, Edel and Bergmann 1970).

Ultrasound could elicit anti-inflammatory and tissue stimulating effects, as already shown in clinical trials (El Hag et al 1985, Binder et al 1985) and experimentally (Byl et al 1992, Young and Dyson 1990). In this way, ultrasound has the potential to accelerate normal resolution of inflammation (Dyson, 1987). The results of these studies confirm that ultrasound therapy may accelerate the healing process in damaged tissues. These mechanisms may explain our findings that showed ultrasound therapy relieved pain, increased grip strength, and changed electrophysiological parameters toward normal values better than laser therapy in patient with mild to moderate carpal tunnel syndrome diagnosis.

Conclusion

Our clinical trials showed that ultrasound treatment is more effective than low level laser treatment in patients with mild to moderate carpal tunnel syndrome. Further research is required to investigate the long-term efficacy of ultrasound versus laser, and whether the combination of these two treatments is superior to either treatment alone.

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References

- Alilioaie C and Lupusoru-Ailioaie LM (1999): Beneficial effects of laser therapy in the early stages of rheumatoid arthritis onset. *Journal of Laser Therapy* 11: 79–87.
- Basford JR, Hallman HO, Matsomoto JY, Moyer SK, Buss JM and Baxter GD (1993): Effects of 830 nm continuous wave laser diode irradiation on median nerve function in normal subjects. *Lasers in Surgery and Medicine* 13: 597–604.
- Baxter GD, Walsh DM, Allen JM, Lowe AS and Bell AJ (1994): Effects of low intensity infrared laser irradiation upon conduction in human median nerve in vivo. *Experimental Physiology* 79: 227–234.
- Binder A, Hodge G, Greenwood AM, Hazelman BL and Page Thomas DP (1985): Is therapeutic ultrasound effective in treating soft tissue lesions? *BMJ* 290: 512–514.
- Burk DT, McHarl Burke M, Stewart GW and Cambre A (1994): Splinting in carpal tunnel syndrome: In search of the optimal angle. *Archives of Physical Medicine and Rehabilitation* 73: 1241–1244.
- Byl NN, McKenzie AI, West JM, Whitney JAD, Hunt T and Scheuenstuhl H (1992): Low-dose ultrasound effects on wound healing. A controlled study with Yucatan pig. *Archives of Physical Medicine and Rehabilitation* 3: 656–664.
- Caetano MR (2003): Axonal degeneration in association with carpal tunnel syndrome. *Arquivos de Neuro-Psiquiatria* 61: 48–50. [Spanish.]
- Clokic C, Bentley KC and Head TW (1991): The effects of the helium-neon laser on postsurgical discomfort: A pilot study. *Journal of the Canadian Dental Association* 57: 584–586.
- Cotton P (1991): Symptoms may return after carpal tunnel surgery. *JAMA* 265: 1922, 1925.
- Dawson DM (1993): Entrapment neuropathies of the upper extremities. *New England Journal of Medicine* 329: 2013–2018.
- Dyson M (1987): Mechanisms involved in therapeutic ultrasound. *Physiotherapy* 73: 116–120.
- Ebenbichler GR, Resch KL, Nicolakis P, Wiesinger GF, Uhl F, Ghanem A and Fialka V (1998): Ultrasound treatment for treating the carpal tunnel syndrome: randomised “sham” controlled trial. *BMJ* 316: 731–735.
- Edel H, Bergmann P (1970): Studies on the effect of ultrasonic in different dosage on the neural-conduction velocity in man. *Archives of Physical Therapy (Leipzig)* 22: 255–259. [German.]
- El Hag M, Coghlan K, Christmas P, Harvey W and Harris M (1985): The anti-inflammatory effects of dexamethazone and therapeutic ultrasound in oral surgery. *British Journal of Oral and Maxillofacial Surgery* 23: 17–23.
- Gelberman RH, Rydevik BL, Pess GM, Szabo RM and Lundburg G (1998): Carpal tunnel syndrome. *Orthopedic Clinics of North America* 19: 115–124.
- Gerritsen AA, de Krom MC, Struijs MA, Scholten RJ, de Vet HC and Bouter LM (2002): Conservative treatment options for carpal tunnel syndrome: A systematic review of randomized controlled trials. *Journal of Neurology* 294: 772–780.
- Giannini F, Passero S, Gioni R, Paradiso C, Batistini N and Giordano N (1991): Electrophysiologic evaluation of local steroid injection in carpal tunnel syndrome. *Archives of Physical Medicine and Rehabilitation* 72: 738–742.
- Girlanda P, Dattola R, Venuto C, Mangiapane R, Nicolosi C and Messina C (1993): Local steroid treatment in idiopathic carpal tunnel syndrome: short and long term efficacy. *Journal of Neurology* 240: 187–190.
- Gonzales MH and Bylak J (2001): Steroid injection and splinting in treatment of carpal tunnel syndrome. *Orthopedics* 24: 479–481.
- Hong CZ, Lau HH and Yu J (1988): Ultrasound thermotherapy effect on the recovery of nerve conduction in experimental compression neuropathy. *Archives of Physical Medicine and Rehabilitation* 69: 410–414.
- Kemmotsu O, Sato K, Furumido H, Harada K, Takigawa-C and Kaseno S (1991): Efficacy of low reactive-level laser therapy for pain attenuation of posttherapeutic neuralgia. *Journal of Laser Therapy* 3: 71–76.
- Kozin SH, Porter S, Clark P and Thoder JJ (1999): The contribution of the intrinsic muscles to grip and pinch strength. *Journal of Hand Surgery* 24: 64–72.
- Kramer JF (1989): Effect of therapeutic ultrasound intensity on subcutaneous tissue temperature and ulnar nerve conduction velocity. *Archives of Physical Medicine and Rehabilitation* 64: 1–9.
- Mayr H and Ammer K (1994): Impulsgalvanisation und ultraschall zur therapie des carpal tunnel syndrome. *Osterreichische Zeitschrift für Physikalische Medizin* 4: 95–99. [German.]
- McConnell JR and Bush DC (1990): Intraneural steroid injection as a complication in the management of carpal tunnel syndrome. A report of three cases. *Clinical Orthopaedics and Related Research* 250: 181–184.
- Naeser MA, Hahn KA, Lieberman BE and Branco KF (2002): Carpal tunnel syndrome pain treated with low-level laser and microamperes transcutaneous nerve stimulation: A controlled study. *Archives of Physical Medicine and Rehabilitation* 83: 978–988.
- Passarella S (1989): He-Ne laser irradiation of isolated mitochondria. *Photochemistry and Photobiology. B—Biology* 3: 642–643.
- Phalen GS (1966): The carpal-tunnel syndrome: 17 years experience in diagnosis and treatment of 654 hands. *Journal of Bone and Joint Surgery* 48A: 211–228.
- Simovic D and Weinberg DH (2000): Carpal tunnel syndrome. *Archives of Neurology* 57: 754–755.
- Stolke D and Seifert V (1989): Clinical use of a new method in microsurgical transplantation of peripheral nerves. *Neurochirurgia* 32: 177–179.
- Swart MA (1998): Carpal tunnel syndrome: An investigation into the pain. *Ergonomics* Dec: 28–30.
- Viera Aleman C, Puron E, Hamilton ML, Santos Anzorandia C, Navarro A and Pineda Ortiz I (2001): Evaluation of motor and sensory neuroconduction of the median nerve in patients with carpal tunnel syndrome treated with non-coherent light emitted by gallium arsenic diodes. *Revue Neurologique* 32: 717–720.
- Walker J (1983): Relief from chronic pain by low power laser irradiation. *Neuroscience Letters* 43: 339–344.
- Walling AD (1998): Effects of ultrasound treatment in carpal tunnel syndrome. *American Family Physician* 58: 961.
- Weintraub MI (1998): Noninvasive laser neurolysis in carpal tunnel syndrome. *Muscle and Nerve* 21: 1232–1233.
- Wong E, Lee G, Zucherman J and Mason DT (1995): Successful management of female office worker with repetitive stress injury or carpal tunnel syndrome by a new treatment modality – Application of low level laser. *International Journal of Clinical Pharmacology and Therapeutics* 33: 208–211.
- Young SR and Dyson M (1990): Macrophage responsiveness to therapeutic ultrasound. *Ultrasound in Medicine and Biology* 16:261–269.
- Yu W, Naim JO, McGowan M, Ippolito K and Lanzafame RJ (1997): Photomodulation of oxidative metabolism and electron chain enzymes in rat liver mitochondria. *Photochemistry and Photobiology* 66: 866–871.