Original Article

The Effect of Light Therapy on Superficial Radial Nerve Conduction Using a Clustered Array of Infrared Super luminous Diodes and Red Light Emitting Diodes

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Abstract:

Introduction: Lasers, light emitting diodes (LEDs) and super luminous diodes (SLDs) are widely used to treat selected musculoskeletal, integumentary and neurological conditions. The mechanisms underlying the reported treatment effects of light therapy are unclear and the physiologic effect of light on a variety of tissues, particularly neurological, is mostly unknown. A few researchers have reported on the effects of lasers and to a lesser extent infrared LEDs on nerve conduction in superficial nerves, but there is little evidence of the effects of SLDs and red LEDs on conduction parameters of peripheral nerves. The purpose of this study was to examine the effects of a light therapy generated by cluster probe containing an array of infrared super luminous and red light emitting diodes on superficial radial nerve conduction.

Methods: This was a single blind, randomized controlled trial conducted in an academic clinical laboratory. Thirty-two healthy participants (mean age = 25 years) were randomized to a treatment group or a placebo group. The treatment group received light irradiation through the application of a cluster probe containing 32 infrared (880nm) SLDs and 4 red (660nm) LEDs for 30 seconds at a dose of 6 J/cm^2 to each of the two 5 cm^2 segments of skin overlying the superficial radial nerve. The placebo group received identical set-up without the application of light irradiation. Negative peak latency (NPL) and conduction velocity (NCV) for the superficial radial nerve were measured before treatment and for 10-minutes following treatment at 2-minute intervals. Skin temperature was monitored throughout.

Results: No significant differences between groups and over time for NPL, NCV, or temperature difference scores were identified. However, a significant increase in skin temperature was measured over time at each time point compared to baseline

Conclusion: Light irradiation using a cluster probe containing infrared super luminous and red light emitting diodes does not impact the neurophysiological properties of the superficial radial nerve.

Keywords: phototherapy; neural conductions; radial nerve

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Introduction

Since the introduction of light as a modality in rehabilitative medicine, the light source has varied in characteristics. Initially, the therapeutic effects of light were attributed to the properties of laser light (1) which led to a variety of terms intended to describe

the benefits of lasers, including low level lasers, low intensity lasers and cold lasers. However, subsequent research efforts attributed the therapeutic effects of light in these devices to the wavelength and dose of the light, rather than to the light source itself (2). This in turn led to the development of other less expensive light sources that were capable of producing near monochromatic light in the range of 600-1000 nm. Today, light therapy or phototherapy encompasses a wide variety of light sources including lasers, polarized light, light emitting diodes (LEDs) and super luminous diodes (SLDs).

In rehabilitative medicine, research and clinical application of these light modalities have focused on the treatment of tendonitis (3-7), wound healing (1,8-11), pain (12-15) and peripheral neuropathies (16-18). Review of the literature related to soft tissue repair and wound healing suggests that the magnitude of the cellular response to phototherapy appears to depend on the physiological state of the cellular tissue at the moment of irradiation (12,13,15,19). That is, monochromatic light appears to stimulate a therapeutic effect primarily when the underlying cellular process for tissue repair and healing becomes dysfunctional. The mechanism related to the effect of light therapy on the neurological system is less clear. With respect to painful conditions, the benefit of light therapy may be related to a direct effect of light on the involved tissues (14,15,20-24). Other studies, involving peripheral neuropathies (16,18,25), suggest that a neurophysiological effect related to light therapy may be attributed to a direct effect on peripheral nerve function.

In assessing the putative neurophysiologic effects of light therapy on the peripheral nervous system, research efforts have focused on parameters measured by nerve conduction studies (NCS) of several different peripheral nerves. The majority of the studies examining the effects of light therapy on neurophysiological properties use the median (14,15,26,27), sural (28-31) and superficial radial nerves (32,33) because they are commonly tested in routine clinical electrophysiological examinations and responses to stimulation are readily obtainable. Even with this approach, a debate regarding the direct effects of light therapy on the peripheral nervous system endures. Our review of the literature suggests that this dispute is a result of the divergent findings in several studies. For example, the results of some studies suggest that light therapy increases the latency of the evoked potentials while, in others either the opposite neurophysiological phenomenon was reported or no significant findings were found.

The majority of the previous research using NCS to study possible mechanisms focused on the effects of laser and to lesser extent infrared light emitting diodes. However, none of the studies examined the neurophysiological effects of irradiating peripheral nerves with light arrays containing a combination of infrared SLDs and red LEDs. Therefore the purpose of the current investigation was to examine the effects of a light therapy generated by a cluster probe containing an array of infrared super luminous and red light emitting diodes on superficial radial nerve conduction.

Method

Subjects

All subjects were informed about the experimental protocol and potential risks; and provided written consent prior to participation. The Institutional Review Board at Shenandoah University approved this study and all data was collected in the Department of Physical Therapy clinical research center. Thirty-four subjects were screened for participation in this study. Prior to testing, each subject underwent a brief physical examination to screen for neurological deficits in the upper and lower extremities. The examination consisted of: 1) muscle stretch reflexes, 2) myotomal gross motor assessment, 3) sensory responses to light touch and pin prick, and 4) Babinski's and Hoffman's tests for upper motor neuron assessment. A brief medical history was obtained from each subject in order to rule out underlying neurological conditions that may affect sensory nerve conduction of the superficial radial nerve. Two subjects were excluded from this study because they had previous upper extremity neurological injury and did not meet the inclusion criteria. Thirty-two healthy graduate students (7 males and 25 females) ranging in age from 21 to 37 years old (mean age = 25 years) participated in this study.

The subjects were randomly assigned into either the placebo group or the treatment group. The placebo group (n=16) received sham light therapy irradiation for 30 seconds to each of the two 5 cm^2 segments of skin overlying the superficial radial nerve. The treatment group (n=16) received light therapy irradiation to each of the two 5 cm^2 segments of skin overlying the superficial radial nerve. Both groups were measured for sensory nerve conduction characteristics. All participants were blinded to group assignment.

Procedure

All procedures including sham irradiation, light therapy irradiation and neurophysiologic testing were performed on the subject's dominant hand. Testing was conducted at room temperature (21°C -23°C) in the research laboratory at the Shenandoah University, Division of Physical Therapy. All subjects were comfortably positioned in supine on a treatment table and their hands were warmed to at least 30°C prior to baseline nerve conduction velocities. Their dominant hand was kept in the moist heat pack throughout the experiment to maintain skin temperature above the minimum of 30°C. Nerve conduction testing was performed by two experienced licensed physical therapists that were blinded to the group assignments of subjects. In a pilot study, inter-rater reliability for measurement of negative peak latency (NPL) and nerve conduction velocity (NCV) between the two therapists was good (ICC=0.75) and the intra-rater reliability for measurement of these measurements was moderate for each therapist (ICC=0.71 for investigator 1 and ICC=0.61 for investigator 2).

A rigid protocol was followed to allow quantification of the NPL and NCV of the superficial radial nerve. Placement of the stimulating and recording electrodes along the course of the superficial radial nerve was followed in a manner similar to the placement described by Downie and Scott (34-37). The placement sites for the stimulating, recording and ground electrodes were cleansed with alcohol prior to their application. The ground electrode (Cadwell Laboratories, Inc., Kennewick, WA) was a disposable silver/silver chloride contact (4.5 cm × 3.1 cm) placed on the dorsum of the hand. The recording electrode was a disposable (4 cm × 1.5 cm) bar electrode (Cadwell Laboratories, Inc., Kennewick, WA) made of silver/silver chloride contacts spaced three centimeters apart measured center-to-center. The active (negative) recording contact was placed over the largest palpable branch of the radial nerve as it crossed the tendon of the extensor pollicis longus. The distal (positive) recording contact was placed over the first dorsal interossei. The ground electrode and the recording electrodes were connected to the signal amplifier using 18-inch mini-crocodile clip lead wire. Stainless steel stimulating electrodes on the Constant Current StimTroller™ from Cadwell Laboratories were used. The negative stimulating electrode was placed on the skin overlying the superficial radial nerve 10 cm proximal to the negative recording electrode along the lateral border of the radius. The stimulating probe was moved medially, laterally or rotated about the negative stimulating electrode until a consistent amplitude action potential was obtained. The stimulus was a monophasic pulse of 0.1 msec. The frequency response of the amplifier was 0.01 kHz to 2 kHz.

After securing all recording equipment on the subject, baseline temperature, NPL and NCV were recorded using a Cadwell Sierra Wave EMG unit (Kennewick, WA). To ensure that the hand temperature remained above the minimum threshold of 30°C, temperature was monitored on the dorsum of the hand using a surface skin temperature probe (Cadwell Laboratories, Inc., Kennewick, WA), sensitive to temperature changes of 0.1°C. The NPL was measured from the start of the negative portion of the evoked sensory nerve action potential. The EMG unit calculated the NCV of the evoked response by dividing the recorded latency by the distance between the negative stimulating electrode and the negative recording electrode (10 cm). A supramaximal stimulus intensity was used to produce each evoked sensory potential. The supramaximal stimulation intensity was found by stimulating the nerve and increasing the intensity of the stimulus until the amplitude of the response was maximized.

The area of skin chosen for application of the light therapy corresponded to the course of the superficial radial nerve. The light therapy wand containing the array of infrared SLDs and Red LEDs was held on the skin overlying the course of the superficial radial nerve at 3 cm and 7 cm distal to the stimulating electrode. At each site, the light therapy wand was held stationary at a right angle to the surface of the skin for 30 seconds, delivering a dose of 6 J/cm^2. The Solaris D880 Infrared Cluster Probe Plus (Solaris Model 708, Dynatronics Corporation, Salt Lake City, UT) contains 32 infrared super luminous diodes emitting a wavelength of 880nm and 4 red diodes emitting a wavelength of 660nm. Subjects receiving the placebo treatment were set up in the same manner as those receiving the light treatment, with the exception that the machine was not turned on.

Upon completion of the light therapy or placebo (sham light therapy) treatment to the last site, the superficial radial nerve was stimulated. The latency of the evoked sensory response was recorded and the conduction velocity was calculated following the same procedure as the pretest measurements. Measurements were obtained immediately after treatment and at 2, 4, 6, 8, and 10-minute intervals post-treatment.

Data Analysis

Prior to data analysis, two subjects from the placebo group and two subjects from the light therapy group were excluded from the analysis because we were unable to elevate their skin temperature to a minimum of 30°C during the treatment. Therefore, for the purposes of data analysis, negative peak latency (NPL), nerve conduction velocity (NCV) and temperature were collected from the stored records of only twenty-eight participants (n=14 for each group). Difference scores, i.e. variation from baseline, were calculated for all data and used as the basis of statistical analysis. A positive variance for all difference scores represents a value that is greater than baseline. For example, a positive variance in the difference score for NPL represents an increase from baseline, which can be interpreted as being a slower or prolonged latency. Similarly, a positive variance from baseline for NCV also represents an increase from baseline, but should be interpreted as being a faster velocity. Positive variances in temperature represent a warming of the skin. Separate two-way analyses of variance (ANOVA) with repeated measures were used to examine the effects of time and group assignment on the negative peak latency and nerve conduction velocity change scores. (Sigma Stat 4.0, Systat Software, Inc., San Jose, CA). Statistical significance was accepted at $P<0.05$.

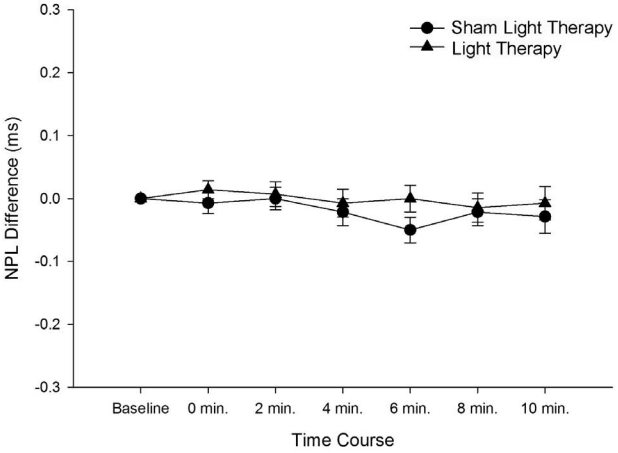

Figure 1. Negative peak latency difference scores (NPLDs; msec) against time. Baseline represents time immediately prior to treatment (sham light therapy or light therapy), all others represent time (in minutes) following treatment (points represent means (SD); n=14 for both groups).

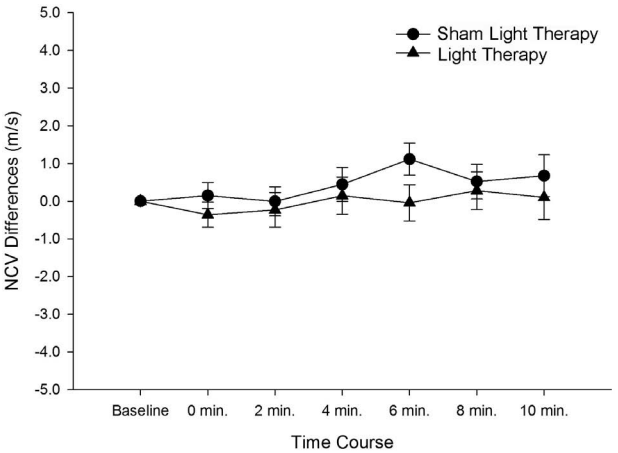

Figure 2. Nerve conduction velocity difference scores (NCVDs, m/sec) against time. Baseline represents time immediately prior to treatment (sham light therapy or light therapy), all others represent time (in minutes) following treatment (points represent means (SD); n=14 for both groups).

Results

Sensory Negative Peak Latency

Difference scores for NPL (ms; mean (SD)) are plotted against time for the placebo group and the experimental groups in Figure 1.

The light therapy treatment group had slightly higher NPL difference scores as compared to the placebo group at all time points throughout the experiment. This figure also shows a small decrease in NPL for the sham light therapy group at 6 min. However, these differences were not found to be statistically significant. There were no significant differences between groups ($P=0.44$) or over time ($P=0.124$). Nor was there a significant interaction ($P=0.55$).

Nerve Conduction Velocity

Figure 2 shows NCV differences (m/s; mean (SD)) plotted against time for both treatment groups. The light therapy group had expected slight decreases in the NCV difference scores throughout the experiment. Additionally, a similar decrease in the NCV difference score at 6-minutes was observed. However, there were no significant differences between groups ($P=0.38$), over time ($P=0.10$), or an interaction effect ($P=0.51$).

Skin Temperature

At baseline the mean (SD) skin temperature for the light therapy group was 32.4 (0.6)°C and the sham light therapy group was 31.7 (0.4)°C, and at 10-minutes post irradiation the mean value was 33.1 (0.6)°C and

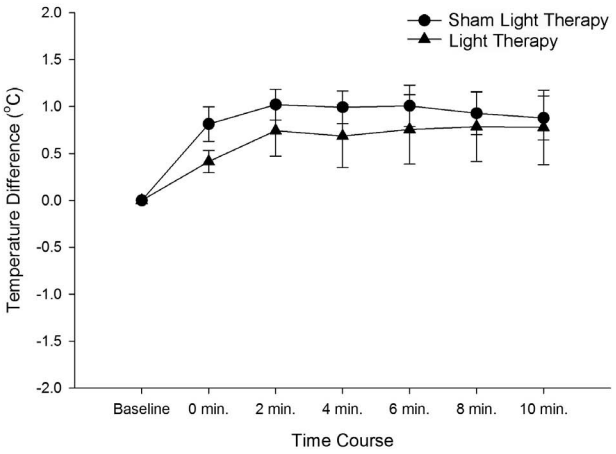

Figure 3. Skin temperature differences (°C) against time. Baseline represents time immediately prior to treatment (sham light therapy or light therapy), all others represent time (in minutes) following treatment (points represent means (SD); n=15 for both groups). The increases in temperature at each time point after treatment were statistically different (P<0.001) from baseline for light therapy and sham light therapy groups. However, there was no statistical difference between groups at each time point.

32.6 (0.8)°C. Concomitant skin temperature recordings for both groups are summarized in Figure 3, which shows temperature differences (°C; mean (SD)) plotted against time in minutes. This figure shows an increase in the temperature difference from baseline to each time point for both groups. The peak temperature for both groups was achieved at 2-minutes post irradiation and remained relatively stable after this time point for both groups. Statistical analysis demonstrated significant increase in skin temperature over time (P=<0.001) at each time point when compared to baseline. However, statistical analysis did not detect significant differences between groups (P=0.49) or an interaction effect (P=0.82).

Discussion

Our study was undertaken to assess the effects of a light therapy generated by a cluster probe containing an array of infrared super luminous and red light emitting diodes on conduction parameters in the superficial radial nerve. Although some trends in negative peak latency (NPL, Figure 1) and nerve conduction velocity (NCV, Figure 2) were observed in the data, no significant light-mediated effects were found with the current model of nerve conduction. Our results raise several issues that need to be considered.

Figure 1 shows that the light therapy irradiated group had a slight increase or prolonging of the NPL at all time points as compared to the sham light therapy group. Additionally, Figure 2 demonstrates the corresponding negative correlation of the NCV in relationship to the prolonged NPL. At each time point, the NCV for the light therapy group was slightly decreased as compared to the placebo group. Although these trends were not significant, they were similar to the NPL and NCV trends observed in previous studies (38) using the superficial radial nerve model of nerve conduction. Our observed trends were also consistent with observations in studies using other peripheral nerve models of nerve conduction such as the median (34,36,37) or sural nerves (29,30). Despite such trends, the non-significant results reported here are in keeping with previous findings for other studies (32) that examined the putative effects of light therapy on the conduction of the superficial radial nerve. Our findings do contradict other studies that suggest light therapy modalities, such as laser and light emitting diodes, alter conduction properties of the superficial radial (34,37), median (36) and sural nerves (28-31).

A confounding variable in the literature that impacts the interpretation of and comparison between conduction studies is skin temperature. Previous literature demonstrates that there is a negative correlation between distal latency and temperature while a positive correlation exists between nerve conduction velocity and temperature. In the present study we artificially manipulated the temperature to maintain the limb skin temperature and prevent the previously reported 0.2 msec increase in the distal negative peak latency per degree (°C) lowering of temperature (32,33). However, the manipulation of skin temperature may have masked alterations in conduction induced through the application of light therapy. Several studies have demonstrated alterations in latency and conduction velocity after the application of light therapy without manipulation of skin temperature. Snyder-Mackler and Bork (32,33,39) reported a significant increase in latency with a corresponding decrease in the nerve conduction velocity for the superficial radial nerve after cold laser irradiation. In their study they maintained the room temperature at 23°C and showed a 0.37 msec increase in the latency from pre- to post-test. This observation would have required a 3.7°C drop in temperature to account for the reported difference. Since a large temperature drop in such a short treatment time (20 sec) was unlikely, they concluded that the difference in latency and NCV velocity was likely

due to direct effects of the laser.

Other authors (36) advocate the use of corrective factors to adjust recorded latencies toward a reference skin temperature of 32°C. In the present study we did not report skin temperatures prior to the application of the heat source, therefore we are unable to determine if the use of a corrective factor would have been required. The use of temperature correction formula for latency and conduction velocity has been suggested for patients with skin temperatures that fall outside a 29.6 - 36.4°C temperature range (32,33,39). Since other studies have demonstrated a significant increase in the latency (39) and corresponding decrease in the conduction velocity (32,33) when a temperature correction factor is applied, an improved experimental design would have been to include an additional group that did not receive the artificial skin temperature manipulation prior to and during the super luminous diode therapy. Therefore, further research needs to be performed to determine if super luminous diode light irradiation alters conduction parameters in the superficial radial and median nerve models with temperature correction factors used when skin temperatures fall outside the temperature range of 29.6 - 34.6°C.

A likely hypothesis explaining our non-significant results is: by warming the skin, and presumably the underlying nervous tissue, optimizes the conduction parameters, in this case, of the superficial radial nerve. Taking into consideration this hypothesis, our data suggest that irradiation of the superficial radial nerve with the array of infrared SLDs and red LEDs, using our treatment parameters, does not alter normal conduction properties. This hypothesis might explain the variable data regarding the effects of light therapy on peripheral nerve function. Collectively, the electrophysiologic studies on the effects of light therapy to date have focused on irradiating peripheral nerves in normal subjects. Subjects without peripheral nerve dysfunction will possibly display abnormal conduction parameters when exposed to cold (33). Therefore, in the presence of cool limb conditions, a temporary pathological model is created. For example, Greathouse et al. (34) discounted their significant findings because the limb cooled over time. It is certainly possible that the significant findings of increased latency and decreased nerve conduction velocity were only detected because the nerve was not functioning at optimal levels and that the application of pulsed laser (non-thermal) altered the conduction properties further. Additionally, the two studies (40) that used temperature correction factors did so because the temperatures fell below the acceptable temperature range and they both reported significant changes in latency and conduction velocity following light therapy intervention. Taken together these reports suggest that light therapy modalities may only have an effect on peripheral nerves that are not functioning under the most favorable conditions. Future research should focus on determining differences between peripheral nerves models that are maintained at optimal conditions and non-optimal conditions following super luminous diode irradiation and other light therapy sources.

Conclusion

Our data suggest that light therapy utilizing an array of SLDs (880nm) and LEDs (660nm) as the light source with an exposure dose of 6J/cm^2 do not impact the normal neurophysiological properties of the superficial radial nerve, when the skin temperature is artificially manipulated.

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References

1. Mester E, Spiry T, Szende B, Tota JG. Effect of laser rays on wound healing. *Am. J. Surg* 1971;122(4):532–5.
2. Sommer AP, Pinheiro AL, Mester AR, Franke RP, Whelan HT. Biostimulatory windows in low-intensity laser activation: lasers, scanners, and NASA's light-emitting diode array system. *J Clin Laser Med Surg* 2001;19(1):29–33.
3. Chang W-D, Wu J-H, Yang W-J, Jiang J-A. Therapeutic effects of low-level laser on lateral epicondylitis from differential interventions of Chinese-Western medicine: systematic review. *Photomed Laser Surg* 2010;28(3):327–36.
4. Lam LK, Cheing GL. Effects of 904-nm low-level laser therapy in the management of lateral epicondylitis: a randomized controlled trial. *Photomed Laser Surg* 2007;25(2):65–71.
5. Lundeberg T, Haker E, Thomas M. Effect of laser versus placebo in tennis elbow. *Scand J Rehabil Med* 1987;19(3):135–8.
6. Simunovic Z, Trobonjaca T, Trobonjaca Z. Treatment of medial and lateral epicondylitis--tennis and golfer's elbow--with low level laser therapy: a multicenter double

blind, placebo-controlled clinical study on 324 patients. *J Clin Laser Med Surg* 1998;16(3):145–51.

7. Vasseljen O Jr, Høeg N, Kjeldstad B, Johnsson A, Larsen S. Low level laser versus placebo in the treatment of tennis elbow. *Scand J Rehabil Med* 1992;24(1):37–42.
8. Caetano KS, Frade MA, Minatel DG, Santana LA, Enwemeka CS. Phototherapy improves healing of chronic venous ulcers. *Photomed Laser Surg* 2009;27(1):111–8.
9. Enwemeka CS, Parker JC, Dowdy DS, Harkness EE, Sanford LE, Woodruff LD. The efficacy of low-power lasers in tissue repair and pain control: a meta-analysis study. *Photomed Laser Surg* 2004;22(4):323–9.
10. Minatel DG, Frade MA, França SC, Enwemeka CS. Phototherapy promotes healing of chronic diabetic leg ulcers that failed to respond to other therapies. *Lasers Surg Med* 2009;41(6):433–41.
11. Minatel DG, Enwemeka CS, França SC, Frade MA. Phototherapy (LEDs 660/890nm) in the treatment of leg ulcers in diabetic patients: case study. *An Bras Dermatol* 2009;84(3):279–83.
12. Enwemeka CS. The place of coherence in light induced tissue repair and pain modulation. *Photomed Laser Surg* 2006;24(4):457.
13. Enwemeka CS. Intricacies of dose in laser phototherapy for tissue repair and pain relief. *Photomed Laser Surg* 2009;27(3):387–93.
14. Konstantinovic LM, Kanjuh ZM, Milovanovic AN, Cutovic MR, Djurovic AG, Savic VG, et al. Acute low back pain with radiculopathy: a double-blind, randomized, placebo-controlled study. *Photomed Laser Surg* 2010;28(4):553–60.
15. Konstantinovic LM, Cutovic MR, Milovanovic AN, Jovic SJ, Dragin AS, Letic MDj, et al. Low-level laser therapy for acute neck pain with radiculopathy: a double-blind placebo-controlled randomized study. *Pain Med* 2010;11(8):1169–78.
16. Powell MW, Carnegie DE, Burke TJ. Reversal of diabetic peripheral neuropathy and new wound incidence: the role of MIRE. *Adv Skin Wound Care* 2004;17(6):295–300.
17. DeLellis SL, Carnegie DH, Burke TJ. Improved sensitivity in patients with peripheral neuropathy: effects of monochromatic infrared photo energy. *J Am Podiatr Med Assoc* 2005;95(2):143–7.
18. Leonard DR, Farooqi MH, Myers S. Restoration of sensation, reduced pain, and improved balance in subjects with diabetic peripheral neuropathy: a double-blind, randomized, placebo-controlled study with monochromatic near-infrared treatment. *Diabetes Care* 2004;27(1):168–72.
19. Vinck E, Cagnie B, Coorevits P, Vanderstraeten G, Cambier D. Pain reduction by infrared light-emitting diode irradiation: a pilot study on experimentally induced delayed-onset muscle soreness in humans. *Lasers in Medical Science* 2006;21(1):11–8.
20. Brosseau L, Robinson V, Wells G, Debie R, Gam A, Harman K, et al. Low level laser therapy (Classes I, II and III) for treating rheumatoid arthritis. *Cochrane Database Syst Rev* 2005;(4):CD002049.
21. Brosseau L, Welch V, Wells G, Tugwell P, de Bie R, Gam A, et al. Low level laser therapy for osteoarthritis and rheumatoid arthritis: a metaanalysis. *J. Rheumatol* 2000;27(8):1961–9.
22. Gur A, Cosut A, Sarac AJ, Cevik R, Nas K, Uyar A. Efficacy of different therapy regimes of low-power laser in painful osteoarthritis of the knee: a double-blind and randomized-controlled trial. *Lasers Surg Med* 2003;33(5):330–8.
23. Hegedus B, Viharos L, Gervain M, Gálfi M. The effect of low-level laser in knee osteoarthritis: a double-blind, randomized, placebo-controlled trial. *Photomed Laser Surg* 2009;27(4):577–84.
24. Juhl C. Short term beneficial effects of low level laser therapy for patients with rheumatoid arthritis. *Aust J Physiother* 2006;52(3):224.
25. Harkless LB, DeLellis S, Carnegie DH, Burke TJ. Improved foot sensitivity and pain reduction in patients with peripheral neuropathy after treatment with monochromatic infrared photo energy--MIRE. *J. Diabetes Complicat* 2006;20(2):81–7.
26. Chang W-D, Wu J-H, Jiang J-A, Yeh C-Y, Tsai C-T. Carpal tunnel syndrome treated with a diode laser: a controlled treatment of the transverse carpal ligament. *Photomed Laser Surg* 2008;26(6):551–7.
27. Shooshtari SMJ, Badiee V, Taghizadeh SH, Nematollahi AH, Amanollahi AH, Grami MT. The effects of low level laser in clinical outcome and neurophysiological results of carpal tunnel syndrome. *Electromyogr Clin Neurophysiol* 2008;48(5):229–31.
28. Basford JR, Hallman HO, Matsumoto JY, Moyer SK, Buss JM, Baxter GD. Effects of 830 nm continuous wave laser diode irradiation on median nerve function in normal subjects. *Lasers Surg Med* 1993;13(6):597–604.
29. Baxter GD, Walsh DM, Allen JM, Lowe AS, Bell AJ. Effects of low intensity infrared laser irradiation upon conduction in the human median nerve in vivo. *Exp. Physiol* 1994;79(2):227–34.
30. Lowe AS, Baxter GD, Walsh DM, Allen JM. Effect of low intensity laser (830 nm) irradiation on skin temperature and antidromic conduction latencies in the human median nerve: relevance of radiant exposure. *Lasers Surg Med* 1994;14(1):40–6.
31. Noble JG, Lowe AS, Baxter GD. Monochromatic infrared irradiation (890 nm): effect of a multisource array upon conduction in the human median nerve. *J Clin Laser Med Surg* 2001;19(6):291–5.
32. Cambier D, Blom K, Witvrouw E, Ollevier G, De Muynck M, Vanderstraeten G. The Influence of Low Intensity Infrared Laser Irradiation on Conduction Characteristics of Peripheral Nerve: A Randomised, Controlled, Double Blind Study on the Sural Nerve. *Lasers in Medical Science* 2000;15:195–200.
33. Vinck E, Coorevits P, Cagnie B, De Muynck M, Vanderstraeten G, Cambier D. Evidence of changes in sural nerve conduction mediated by light emitting diode

irradiation. *Lasers in Medical Science* 2005;20(1):35–40.

34. Greathouse DG, Currier DP, Gilmore RL. Effects of clinical infrared laser on superficial radial nerve conduction. *Phys Ther* 1985;65(8):1184–7.
35. Safavi-Farokhi Z, Bakhtiary AH. The effect of infrared laser on sensory radial nerve electrophysiological parameters. *Electromyogr Clin Neurophysiol* 2005;45(6):353–6.
36. Snyder-Mackler L, Bork CE. Effect of helium-neon laser irradiation on peripheral sensory nerve latency. *Phys Ther* 1988;68(2):223–5.
37. Walsh DM, Baxter GD, Allen JM. Lack of effect of pulsed low-intensity infrared (820 nm) laser irradiation on nerve conduction in the human superficial radial nerve. *Lasers Surg Med* 2000;26(5):485–90.
38. Downie AW, Scott TR. An improved technique for radial nerve conduction studies. *J. Neurol. Neurosurg. Psychiatr* 1967;30(4):332–6.
39. Halar EM, DeLisa JA, Soine TL. Nerve conduction studies in upper extremities: skin temperature corrections. *Arch Phys Med Rehabil* 1983;64(9):412–6.
40. Lee HJ, DeLisa JA, Bach JR. The effect of temperature on antidromic median sensory conduction. *Electromyogr Clin Neurophysiol* 1993;33(2):125–8.