MEDICAL SCIENCE MONITOR

CLINICAL RESEARCH

e-ISSN 1643-3750
© Med Sci Monit, 2015; 21: 446-451
DOI: 10.12659/MSM.892462

Received: 2014.09.12
Accepted: 2014.11.17
Published: 2015.02.11

Effect of Heat, Cold, and Pressure on the Transverse Carpal Ligament and Median Nerve: A Pilot Study

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

ABCDEF 1 **Michael Laymon**
ABCDEF 2 **Jerrold Petrofsky**
ABCDEF 1 **James McKivigan**
ABCDE 2 **Haneul Lee**
ABCDEF 3 **JongEun Yim**

1 School of Physical Therapy, Touro University Nevada, Henderson, NV, U.S.A.
2 Department of Physical Therapy, School of Allied Health Professions, Loma Linda University, Loma Linda, CA, U.S.A.
3 Department of Physical Therapy, Sahmyook University, Seoul, Republic of Korea

Corresponding Author: Jongeun Yim, e-mail: jeyim@syu.ac.kr
Source of support: This work was supported by a contract from Pfizer pharmaceuticals, Inc., IIR175215

Background: This study quantified the effects of heat, cold, and pressure on the median nerve and transverse carpal ligament in subjects without carpal tunnel syndrome.

Material/Methods: Subjects were individuals ages 20–50 who had no symptoms of carpal tunnel disease. Imaging ultrasound was used to measure the clearance around the median nerve, transverse ligament elasticity, nerve conduction velocity, thickness of the carpal ligament, and area of the median nerve. Pressure was applied to the carpal ligament to assess the effects of increasing pressure on these structures. On 3 separate days, 10 subjects had ThermaCare heat or cold packs applied, for either 60 or 120 minutes for heat or 20 minutes for cold, to the palmer surface of the hand.

Results: Tissue changes were recorded as a response to pressure applied at 0, 5, 10, and 20 N. The size of the nerve and ligaments were not significantly altered by pressure with the hand at room temperature and after cold exposure. After heat, the nerve, ligaments, and tendons showed significantly more elasticity.

Conclusions: Application of cold to the hand may reduce compression of the carpal ligament and nerve.

MeSH Keywords: **Carpal Tunnel Syndrome • Cold Temperature • Median Nerve • Thermal Conductivity**

Full-text PDF: http://www.medscimonit.com/abstract/index/idArt/892462

2310 1 6 33

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS] [Index Copernicus]

Background

Carpal tunnel syndrome (CTS) is a common pathology [1]. Its epidemiology is associated with a thickening of the transverse carpal ligament [2], which entraps the underlying median nerve [2]. The resulting compression can cause paresthesia, pain, and numbness in the fingers and the thumb through the distribution of the median nerve [3]. Heat has been used to treat carpal tunnel syndrome with some success, but often mixed with other modalities [4,5]. Here, we studied heat and cold applied to normal hands to see what physiological effects heat and cold would have on the carpal ligament and nerve absent disease and other modalities.

Numerous types of therapy have been used for mild to severe CST [6,7]. One potential type of therapy is therapeutic ultrasound [8–10], which has the potential benefit of warming deep tissues [11–14]. It is believed that this heating of local tissues increases blood flow, promotes healing, and reduces inflammation[15,16], as well as possibly increasing nerve and tendon flexibility [17,18].

Other studies have used low-level continuous heat and shown good results. In a study within the last 10 years, continuous low-level heat was applied using ThermaCare heat wraps for 8 hours on patients with a variety of wrist impairments, including CTS [4,5,19]. The results showed that the greatest benefit in the first 3 days of use was a reduction in the pain scales and reduced joint stiffness in people with wrist pain. For patients with CTS, relief was evident at 1–3 hours, with greater functional status and carryover effect for 5 days after treatment. This is similar to other studies using low-level heat wraps applied to the back to reduce back pain, which reported immediate pain relief and a carryover effect after the treatment was over [20,21].

However, most of the studies cited above used combined interventions such as splinting of the wrist and manual hand therapy. The effect of heat or cold alone on carpal tunnel ligament properties and on nerve mobility has not been determined. It has been established that warming tendons generally increases elasticity and flexibility [17], but most of these studies have been done on rat tendons or ligaments or on human cadaver tissue. Therefore, the present study used a more comprehensive analysis accomplished on living human tissue with no symptoms of CTS. This was a pilot study to see if these properties can be assessed prior to patient trials. Variables included the effect of heat and cold on the size of the carpal tunnel, flexibility of the carpal ligament, and the effect of heat and cold on the median nerve itself.

Table 1. General characteristic of subjects.

	Age	Height (cm)	Weight (kg)
Mean	25.8	177.0	70.0
Standard deviation (SD)	4.8	3.9	11.7

Material and Methods

Subjects

Ten subjects with an average body mass index (BMI) of 22.3±5.6 were recruited as a sample of convenience. Subjects with a history of carpal tunnel disease or currently taking medications that might alter cardiovascular function were excluded. The general characteristics of the subjects are listed in Table 1. There were 5 female and 5 male subjects. Subjects were not on high doses of alpha or beta agonist/antagonists, any type of NSAID, Cox 2 inhibitors, calcium channel blockers, Pregabalin (Lyrica), or pain reducers. Screening was done by taking a history and performing a physical exam. All methods and procedures were approved by the Solutions Institutional Review Board and all subjects signed a statement of informed consent.

Procedure

All subjects sat in a temperature-controlled room each day, which was maintained at 22±1°C and 30% humidity for 60 minutes before measures were taken or before heat or cold was applied. They all wore short-sleeved shirts. The average core body temperature, measured by infrared tympanic temperature, was 37±0.2°C for all 3 days. On day 1, ThermaCare cold packs were applied to the palmer surface of the hand for 20 minutes directly against the skin. These packs are kept at 0°C. On day 2 and 3, subjects had a ThermaCare heat wrap, which is a low-level heat wrap whose temperature is 41°C, applied for 60 or 120 minutes [22–25]

Measurement of the transverse carpal ligament thickness, diameter of the median nerve just under the transverse carpal ligament, and median nerve canal diameter thickness were measured by a Mindray M7 diagnostic ultrasound device at the first harmonic of 10 MHz with a linear array transducer. Measurements were taken at baseline and after application of heat and cold. Subjects were placed in an environmentally controlled room for 60 minutes to acclimate prior to baseline measurements. Baseline measurements were taken, heat or cold applied, and measurements were retaken immediately after removal of heat or cold.

Statistical analysis

Statistical analysis was performed using SPSS 22 software (SPSS Inc., Chicago, IL, USA). Data analysis was accomplished by calculating means and standard deviations (SD). The

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System]
[ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica]
[Chemical Abstracts/CAS] [Index Copernicus]

Figure 1. The device developed to apply pressure to the wrist and hand consisted of an algometer in series with an ultrasound imaging probe. By pressure being applied through the algometer, the pressure under the ultrasound probe could be measured and correlated to changes in the internal structures in the hand.

Kolmogorov-Smirnov test was used to examine the distribution of outcome measures. The general characteristics of the subjects are listed in Table 1. Mean conduction velocity of the median nerve at 4 different pressures and temperatures were examined by using non-parametric statistics (Friedman 1-way analysis of variance [ANOVA]). Mixed factorial ANOVA was used to examine mean thickness of transverse carpal ligament, wrist flexor tendon, and median nerve at 4 different pressures at 4 different temperatures. The level of significance was $p<0.05$.

Methods

Median nerve conduction velocity (NCV)

Median nerve conduction velocity (NCV) was determined before and after application of heat and cold. A Nomad Express (WD medical systems, Stillwater, MN) was used to determine median nerve NCV. The stimulus pulse width was 100 usec and square-wave monophasic pulses were manually triggered at an amplitude to recruit the nerve axons fully by increasing pulse amplitude until the nerve compound action potential peaked (usually at less than 10 ma). The stimulus was applied through a surface probe just below the antecubital fascia on the median nerve. For recording, 2 surface electrodes were placed at each of 3 sites: proximal median nerve at the elbow, volar surface of the wrist proximal to the transverse carpal ligament, and distal volar surface of the wrist distal to the transverse carpal ligament. Nerve conduction of the median nerve through the carpal tunnel was determined before and after application of heat and cold.

Elasticity of the transverse carpal ligament

Elasticity of the transverse carpal ligament was measured by a custom-developed device equipped with a pressure transducer integral to the linear array 10-MHz imaging ultrasound probe. The device, which held the transducer, was integrated with a pressure algometer (Wagner Instruments, Greenwich, CT). Pressure was applied through the algometer onto the transducer, which then showed any change in size of the median nerve, area around the median nerve, and the carpal ligament by imaging ultrasound after pressure was applied (Figure 1). Pressure was applied for 30 seconds to allow structural changes to be seen. In pilot experiments, 15 seconds was sufficient; therefore, we used 30 seconds for safety. The algometer was tested and calibration checked by placing weights of 1, 3, 6, and 10 newtons on the algometer and recording the displayed weight *vs.* the applied standard weights. The weights were applied 3 times each in a random sequence. The algometer reading was always within 2% accuracy. The accuracy and reliability of the Mindray ultrasound for measuring anatomical structures in the hand has been tested and reported by the manufacturer in its FDA approval process. The same investigator made all measurements and was an expert in musculoskeletal ultrasound. Reliability testing on the entire device consisted of having this same investigator make 5 measurements on 5 subjects at 3 different pressures 3 days in a row. The measures were carpal ligament displacement with pressure, nerve displacement with pressure, and tunnel size. The coefficient of variation of each measure was less than 5%.

Imaging of the hand

Imaging of the hand was accomplished with a Mindray M-7 clinical imaging ultrasound (Mindray America, Mahwah, NJ). The probe used was a 38-mm linear probe operated at the first harmonic of 10 MHz.

Results

The conduction velocity at 4 different pressures

As shown in Figure 2, as the pressure was increased to 20 newtons (N), the conduction velocity of the median nerve was reduced. This reduction in conduction velocity of the median nerve was significant at 4 different pressures (ANOVA $P<0.01$).

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS] [Index Copernicus]

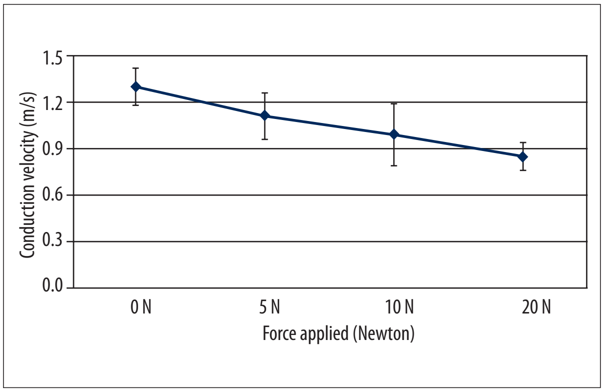

Figure 2. Mean ±SD of the conduction velocity of the median nerve measured during the application of 4 different pressures. Each point is the average of 10 subjects.

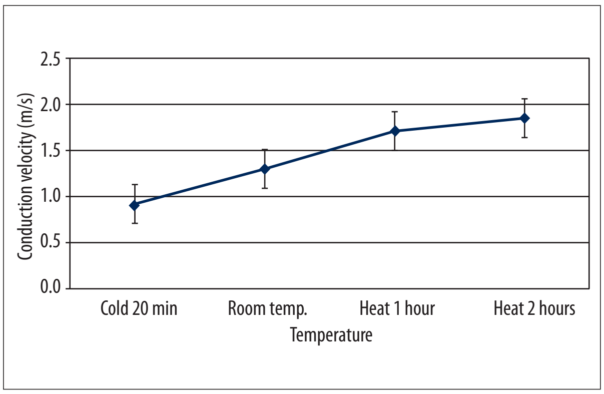

Figure 3. Mean ±SD of the conduction velocity of the median nerve measured after cold- and hot-packs were applied to the palmer surface of the hand. Each point is the average of 10 subjects.

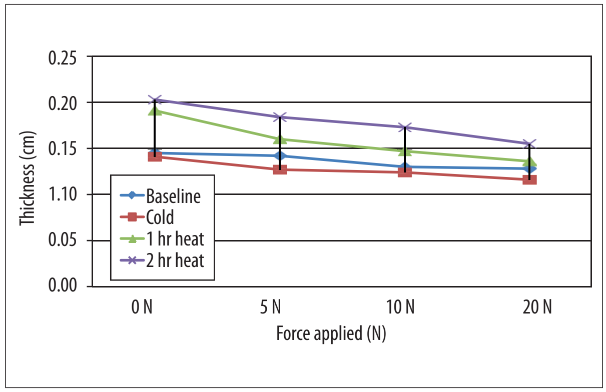

Figure 4. The thickness of the transverse carpal ligament in relation to temperature and pressure applied through the ultrasound transducer. Each point is the average of 10 subjects.

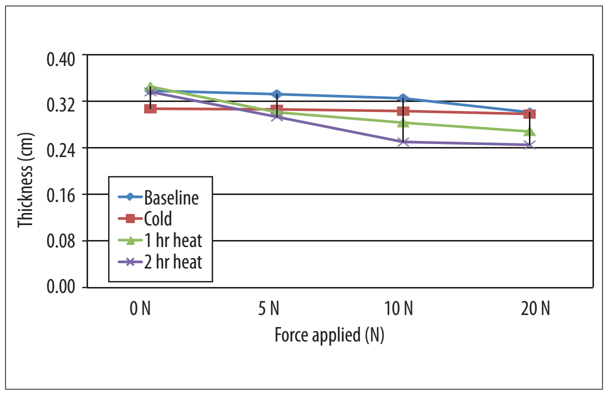

Figure 5. Mean thickness of the wrist flexor tendon in relation to temperature and pressure. Each point is the average of 10 subjects.

It was interesting that even a small increase in pressure could reduce conduction velocity. Over the range of pressures that were applied, from no pressure to 20 N there was a 34.5% reduction in conduction velocity.

The conduction velocity at 4 different temperatures

The effect of heat and cold on nerve conduction velocity in the median nerve is shown in Figure 3, showing that the longest heat-pack exposure to the hand resulted in the fastest nerve conduction in the median nerve (ANOVA $P<0.01$). It is unknown what the actual temperature of the nerve was after cold and heat exposure, but due to the thinness of the tissue, it should have been close to the cold- and heat-pack temperatures.

The thickness of the transverse carpal ligament in relation to pressure

The thickness of the transverse carpal ligament in response to pressure is shown in Figure 4, showing that the hand at room temperature and after cold-pack application showed very little change in the carpal ligament thickness with pressure (i.e., it was very inelastic). However, after 1 or 2 hours of heat, the change in ligament thickness with pressure was almost 3 times as much as in the cool hand (ie, it was more elastic). For each condition, the reduction in ligament thickness with increasing pressure was significant (ANOVA $P<0.01$), but comparing each condition, there was no significant difference between the cold exposure and room-temperature conditions. The 2 warm conditions were significantly greater than the cold and room-temperature conditions ($p<0.01$), while the 2 warm conditions were significantly greater than each other ($p<0.05$).

The thickness of the wrist flexor tendon in relation to pressure

As shown in Figure 5, exposure of the hand to room-temperature and cold had little effect on the wrist flexor tendon in relation to pressure ($p>0.05$). With pressure and heat for 1 or 2 hours, there was a dramatic decrease in the thickness of the

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System]
[ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica]
[Chemical Abstracts/CAS] [Index Copernicus]

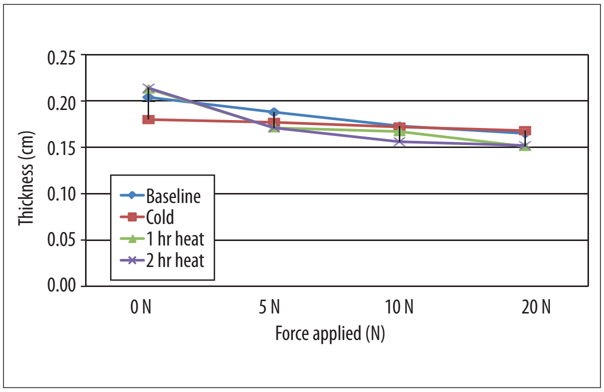

Figure 6. Mean thickness of the median nerve in relation to temperature and pressure. Each point is the average of 10 subjects.

tendon, showing stretching of the tendon with forces of 10 N and 20 N ($p<0.05$) but not 0 N or 5 N ($p>0.05$).

The thickness of the median nerve in relation to pressure

As shown in Figure 6, there was a reduction in the thickness of the median nerve in response to pressure in the 2 heated conditions and for the room-temperature condition (ANOVA $p<0.05$). With cold, the nerve size was very stable with pressure, and pressure had no significant effect on nerve size (ANOVA $p>0.05$).

Discussion

With increasing use of the hands as computers continue to be a part of everyday life, CTS is on the increase [26–28]. The swelling of the transverse carpal ligament traps the median nerve and causes neurological damage from the pressure [29,30]. For mild CTS, alternative treatments are commonly used, such as splinting, heat, and cold [15,29–31].

Here, we conducted a pilot study to examine: 1) how much pressure would reduce nerve conduction velocity, 2) the effect of temperature on conduction velocity, and 3) the effect of pressure, heat, and cold on the anatomical structures in and around the median nerve. In normal tissue, the nerve was very sensitive to pressure, heat, and cold. Interestingly, cold and room-temperature data showed very little elasticity of the carpal ligament and tendons and nerve with applied pressure, but heat dramatically increased the elasticity of these structures when responding to vertical pressure. Therefore, cold application to the carpal tunnel prior to performing activities that transfer compressive forces to the tissues may provide a protective effect.

This is supported in studies using vibration to test for CTS. When vibration is applied externally to the carpal ligament, pain is felt [32], but if the probe used for vibration is heated, there is a great deal more pain with the same stimulus [33]. Cooling the probe reduces the pain during vibration. If the ligament is more elastic at warmer temperatures, then there would be little protection for the median nerve and pain should be greater with a warm carpel ligament. Conversely, with a cool and stiffer ligament, the nerve is protected [33]. Part of the pain with heat may also be due to changes in the conduction velocity of the median nerve with heating. As shown in this study, heat increases conduction velocity of the median nerve. Other studies also showed a reduction in nerve impulse amplitude of the median nerve with warming of the hand for 20 minutes [26]. However, both heat and cold sensitivity are increased with CTS [33]. Cold may be beneficial, but too much cold from a pack applied to the skin may be painful. Further investigation as to the exact temperature for cold is needed. This is especially true because cold pain sensitivity increases with the pain intensity of CTS [33]. This is not to say that heat is bad. Continuous low-level heat therapy has been shown to reduce pain in CTS patients [19], but these patients were tested without hand movement and vibration. It may be good to use continuous low-level heat wraps at night and cold-packs during the day, but this has not been investigated.

In the present investigation, the nerves and ligaments were not swollen. With swelling, the internal pressure under the carpal ligament exerts pressure on the nerve and could contribute to significant damage. The purpose of this study was to examine the effect of cold and heat on normal carpal tunnel tissues. Future studies need to investigate swollen tissue to determine the true effects of heat, cold, and pressure on pathological tissues.

Conclusions

Application of cold and heat had measureable effects on nerve and ligament elasticity and median nerve conduction velocity. These techniques should be tested to understand the effect of heat and cold on the median nerve and carpal ligament in patients with carpal tunnel syndrome.

References:

1. Burnham RS, Burnham TR: Effect of hand warming on electrodiagnostic testing results and diagnosis in patients with suspected carpal tunnel syndrome. Arch Phys Med Rehabil, 2009; 90(12): 2062–65
2. Maghsoudipour M, Moghimi S, Dehghaan F et al: Association of occupational and non-occupational risk factors with the prevalence of work related carpal tunnel syndrome. J Occup Rehabil, 2008; 18(2): 152–56

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS] [Index Copernicus]

3. Page MJ, Massy-Westropp N, O'Connor D et al: Splinting for carpal tunnel syndrome. Cochrane Database Syst Rev, 2012; 7: CD010003
4. Michlovitz S, Hun L, Erasala GN et al: Continuous low-level heat wrap therapy is effective for treating wrist pain. Arch Phys Med Rehabil, 2004; 85(9): 1409–16
5. Michlovitz SL: Conservative interventions for carpal tunnel syndrome. J Orthop Sports Phys Ther, 2004; 34(10): 589–600
6. Maddali Bongi S, Signorini M, Bassetti M et al: A manual therapy intervention improves symptoms in patients with carpal tunnel syndrome: a pilot study. Rheumatol Int, 2013; 33(5): 1233–41
7. Manente G, Melchionda D, Staniscia T et al: Changes in the carpal tunnel while wearing the Manu(R) soft hand brace: a sonographic study. J Hand Surg Eur Vol, 2013; 38(1): 57–60
8. Koyama S, Kawanami T, Kurokawa K et al: Carpal tunnel syndrome as an initial manifestation in a case of transthyretin-related familial amyloid polyneuropathy with a novel A120T mutation. Clin Neurol Neurosurg, 2012; 114(6): 707–9
9. Kerasnoudis A: Ultrasonographic assessment of longitudinal median nerve and hand flexor tendon dynamics in carpal tunnel syndrome. Muscle Nerve, 2012; 46(6): 981–82; author reply 82
10. Ladak A, Spinner RJ: Carpal tunnel syndrome: when excellent is not good enough. World Neurosurg, 2013; 79(5–6): 655–57
11. Page MJ, O'Connor D, Pitt V et al: Therapeutic ultrasound for carpal tunnel syndrome. Cochrane Database Syst Rev, 2013; 3: CD009601
12. Lange J: Carpal tunnel syndrome diagnosed using ultrasound as a first-line exam by the surgeon. J Hand Surg Eur Vol, 2013; 38(6): 627–32
13. Fowler JR, Maltenfort MG, Ilyas AM: Ultrasound as a first-line test in the diagnosis of carpal tunnel syndrome: a cost-effectiveness analysis. Clin Orthop Relat Res, 2013; 471(3): 932–37
14. Kerasnoudis A: Ultrasound and MRI in carpal tunnel syndrome: the dilemma of simplifying the approach to a complex disease or making complex assessments of a simple problem. J Hand Surg Am, 2012; 37(10): 2200–1; author reply 2201
15. Tanner MA, Conrad BP, Dell PC et al: The Effect of an Open Carpal Tunnel Release on Thumb CMC Biomechanics. Adv Orthop, 2012; 2012: 151348
16. Petrofsky JS: Resting blood flow in the skin: does it exist, and what is the influence of temperature, aging, and diabetes? J Diabetes Sci Technol, 2012; 6(3): 674–85
17. Funk D, Swank AM, Adams KJ et al: Efficacy of moist heat pack application over static stretching on hamstring flexibility. J Strength Cond Res, 2001; 15(1): 123–26
18. Lehmann JF, Masock A, Warren C et al: Effect of therapeutic temperatures on tendon extensibility. Arch Phys Med Rehabil, 1970; 51(8): 481–87
19. Michlovitz S, Hun L, Erasala GN et al: Continuous low-level heat wrap therapy is effective for treating wrist pain. Arch Phys Med Rehabil, 2004; 85(9): 1409–16
20. Nadler SF, Steiner DJ, Petty SR et al: Overnight use of continuous low-level heatwrap therapy for relief of low back pain. Arch Phys Med Rehabil, 2003; 84(3): 335–42
21. Nadler SF, Steiner DJ, Erasala GN et al: Continuous low-level heatwrap therapy for treating acute nonspecific low back pain. Arch Phys Med Rehabil, 2003; 84(3): 329–34
22. Nadler SF, Steiner DJ, Erasala GN et al: Continuous low-level heat wrap therapy provides more efficacy than Ibuprofen and acetaminophen for acute low back pain. Spine (Phila Pa 1976), 2002; 27(10): 1012–17
23. Petrofsky J, Alshahmmari F, Yim JE et al: The interrealtionship between locally applied heat, ageing and skin blood flow on heat transfer into and from the skin. J Med Eng Technol, 2011; 35(5): 262–74
24. Petrofsky J, Batt J, Bollinger JN et al: Comparison of different heat modalities for treating delayed-onset muscle soreness in people with diabetes. Diabetes Technol Ther, 2011; 13(6): 645–55
25. Petrofsky J, Batt J, Bollinger JN et al: Comparison of different heat modalities for treating delayed-onset muscle soreness in people with diabetes. Diabetes Technol Ther, 2011; 13(6): 645–55
25. Burnham RS, Burnham TR: Effect of Hand Warming on Electrodiagnostic Testing Results and Diagnosis in Patients With Suspected Carpal Tunnel Syndrome. Arch Phys Med Rehabil, 2009; 90(12): 2062–65
26. Tanaka S, Midorikawa T, Tokura H: Effects of pressure exerted on the skin by elastic cord on the core temperature, body weight loss and salivary secretion rate at 35 C. Eur J Appl Physiol, 2006; 96(4): 471–76
27. Tanaka S, Barron KW, Chandler MJ et al: Local cooling alters neural mechanisms producing changes in peripheral blood flow by spinal cord stimulation. Auton Neurosci, 2003; 104(2): 117–27
28. Page MJ, Massy-Westropp N, O'Connor D et al: Splinting for carpal tunnel syndrome. The Cochrane Library, 2012
29. Korstanje JWH, Boer MSD, Blok JH et al: Ultrasonographic assessment of longitudinal median nerve and hand flexor tendon dynamics in carpal tunnel syndrome. Muscle Nerve, 2012; 45(5): 721–29
30. Haghighat A, Khosrawi S, Kelishadi A et al: Prevalence of clinical findings of carpal tunnel syndrome in Isfahanian dentists. Adv Biomed Res, 2012; 1: 13
31. Gerr F, Letz R: Vibrotactile threshold testing in occupational health: a review of current issues and limitations. Environ Res, 1993; 60(1): 145–59
32. Parsons EM, Redd C, Gandhi MS et al: Liquid cooling system for the vibro-tactile threshold device. Conf Proc IEEE Eng Med Biol Soc, 2011; 2011: 6813–16
33. de la Llave-Rincón AI, Fernández-de-las-Peñas C, Fernández-Carnero J et al: Bilateral hand/wrist heat and cold hyperalgesia, but not hypoesthesia, in unilateral carpal tunnel syndrome. Exp Brain Res, 2009; 198(4): 455–63

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS] [Index Copernicus]