Thermography Applied During Exercises With or Without Infrared Light-Emitting Diode Irradiation: Individual and Comparative Analysis

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Abstract

Objective: The aim of our study was to evaluate the cutaneous temperature during an exercise on a treadmill with or without infrared light-emitting diode (LED) irradiation in postmenopausal women. **Background data:** Thermography is an imaging technique in which radiation emitted by a body in the middle and far infrared spectrum is detected and associated with the temperature of the body's surface. **Materials and methods:** Eighteen postmenopausal women were randomly divided into two groups: (1) the LED group, which performed the exercises on a treadmill associated with phototherapy ($n=9$) and; (2) the exercise group, which performed the exercises on a treadmill without additional phototherapy ($n=9$). The irradiation parameters for each women's thigh were: array of 2000 infrared LEDs (850 nm) with an area of 1,110 cm², 100 mW, 39 mW/cm², and 108 J/cm² for 45 min. The submaximal constant-speed exercise on the treadmill at intensities between 85% and 90% maximal heart rate (HR_{max}) with or without phototherapy were performed during 45 min, to perform the thermographic analysis. Thermography images were captured before the exercise ($t=0$), after 10, 35, and 45 min of exercising ($t=10$, $t=35$, and $t=45$) and at 5 min post-exercising ($t=50$). **Results:** The LED group showed an increased cutaneous thigh temperature during the exercise (from $33.5 \pm 0.8^\circ\text{C}$ to $34.6 \pm 0.9^\circ\text{C}$, $p=0.03$), whereas the exercise group showed a reduced cutaneous temperature (from 33.5 ± 0.6 to $32.7 \pm 0.7^\circ\text{C}$, $p=0.02$). The difference between the groups was significant ($p < 0.05$) at $t=35$, $t=45$, and $t=50$. **Conclusions:** These data indicate an improved microcirculation, and can explain one possible mechanism of action of phototherapy associated with physical exercises.

Introduction

THE HUMAN BODY transforms the chemically bonded energy of adenosine triphosphate (ATP) into mechanical work, as the result of a heat release through the aerobic and anaerobic metabolism. Thermogenesis can occur during muscle work as well as during rest, with the release of vasoconstrictors, such as norepinephrine, and increases the metabolic rate. Thermoregulation occurs to maintain a constant body temperature. Thermoregulation is managed by the hypothalamus through the autonomic nervous system, with its vasoconstriction and vasodilatation of the blood vessels. Heat is exchanged with the environment by means of physical mechanisms (conduction, convection, evaporation, radiation).^{1–3} Infrared thermography is an accurate method to measure the cutaneous temperature.

When used in medical diagnostics, thermography⁴ reveals anatomic structures under the skin, metabolic information about a patient, or an inflammatory process associated with diseases. Kohler et al.⁵ used thermography to pre-clinically detect deep vein thrombosis after proximal femur fractures. In a study by Ohsawa et al.,⁶ the amputation level of the limb was determined by thermography, in order to avoid repeat amputation. In another study,⁷ thermography was performed to diagnose musculoskeletal disorders of workers' upper extremities during pre-typing and post-typing.

Only one study has investigated the effects of infrared laser (780 nm) irradiation and a stretching exercise program specified for the trapezius or levator scapulae muscles on cutaneous temperature via a thermographic evaluation in patients with myofascial pain syndrome.⁸ However, the thermal effects of the infrared light-emitting diode (LED)

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irradiation during physical exercises need to be investigated. To our knowledge, no previous studies have assessed the synergistic effects of phototherapy on cutaneous temperature during exercises. Previous work from our group has found infrared LED irradiation to significantly improve physical performance^{9,10} and body aesthetics¹¹ in postmenopausal women participating in a high-intensity training program. Therefore, the aim of this study was to evaluate the cutaneous temperature during exercises on treadmill with or without infrared LED irradiation in postmenopausal women. Our hypothesis was that the cutaneous temperature in postmenopausal women would be increased during the physical exercise with or without infrared LED irradiation.

The current research was approved by the National Ethics Committee of the Ministry of Health in Brasilia, Brazil and by the Ethics Committee of the Federal University of São Carlos (UFSCar) in São Carlos, Brazil. The study was registered with the NIH ClinicalTrials (NCT01610232). All subjects signed written informed consents before their participation in the study.

Materials and Methods

A cross-sectional study was conducted. Eighteen postmenopausal Caucasian women between 50 and 60 years of age, who were not users of any hormone replacement therapy, participated in this study. "Postmenopausal" was defined as the absence of menstruation for >12 months. Women who had neurological, metabolic, inflammatory, endocrinopathic, pulmonary, malignant, and heart diseases were excluded from this study. The 18 postmenopausal women were randomly divided into two groups: (1) the LED group, which performed the exercises on a treadmill associated with phototherapy ($n=9$); and (2) the exercise group that performed exercises on a treadmill without any additional phototherapy ($n=9$).

Evaluations were conducted in a laboratory always at the same time of the day (beginning at 8 a.m.) at controlled air temperature (between 22°C and 24°C) and relative humidity controlled between 50% and 60%. Anthropometric data were performed to determine the Body Mass Index (BMI: body weight [in Kg] divided by height [in m] squared).¹² The maximal exercise testing on treadmill using the Modified Bruce Protocol^{9,13} was performed to elaborate the submaximal exercise intensity based on the maximal heart rate (HR_{max}). The electrocardiogram system model Ergo (HW Systems; HeartWare Ltda., Belo Horizonte, MG, Brazil) and the cardiofrequencímetro model Polar S830i (Polar Electro Inc., Woodbury, NY) were used to acquire the HR_{max} . Submaximal constant speed exercises on a treadmill^{13,14} at intensities between 85% and 90% HR_{max} with or without phototherapy were performed during 45 min for the thermographic analysis. The cardiofrequencímetro model Polar A3 (Polar Electro Inc., Woodbury, NY) was used to monitor the HR.

According to Ferreira et al.,¹⁵ the women were instructed: (1) to eat 2 h before the assessment; (2) not to drink either alcohol or any caffeine; (3) not to practice any kind of physical exercise 24 h prior to the evaluation; (4) not to apply hydrating lotion or any similar product on the lower limbs; and (5) prior to starting the temperature recordings to remain in the examination room for 10 min in order to acclimatize to the room temperature (thermalization). Regarding the

acquisition of the thermal images, all the women wore swimwear, which allowed the complete exposure of the lower limbs. Moreover, the women in the LED group wore safety glasses to ensure biosecurity during the phototherapy.

Instrumentation to perform phototherapy and thermography

In order to perform the phototherapy on the patients during the exercise on a treadmill, a homemade system based on near infrared (NIR) LED (array of 2000 LEDs [850 nm $\pm$ 15 nm] with an area of 1110 cm² to illuminate each the subjects' thigh) was developed by researchers of the Optics Group of the Physics Institute of São Carlos (IFSC), University of São Paulo (USP) as previously described.⁹⁻¹¹ An optical power meter model FieldMaster TO-II (Coherent Inc., Santa Clara, CA) linked to a VIS/NIR sensor (head) was used to calibrate this system, and to reveal a 100 mW average optical power and a 39 mW/cm² average optical power density on the patient's skin. Phototherapy was applied bilaterally on both thighs for 45 min, which led to an energy density (radiation dose) delivered close to 108 J/cm²/per limb.⁹

To perform imaging, the thermographic camera model IR810 (FLUKE Corp., Washington) was used. This model detects infrared radiation in the spectral range between 8 μ m and 14 μ m, and composes thermographic images with 0.1°C sensibility, and a 0–50°C measuring range was used to perform the thermographic measurements of the cutaneous surface temperature. The camera connected to a the computer and the software Pixel View Play TV Pro v8.01b (ProLink Microsystems Corporation, Taiwan, China) were used for acquisition, screening, and storage of the thermal images. Regarding the calibration procedure, the camera automatically calibrates between two points of temperature (minimal and maximal) for gray scale distribution. The Optics Group of the IFSC, USP, developed a system based on sensors, controllers, and actuators (two peltiers that were placed on each side of the women's bodies) to obtain the temperature values. This system controls two peltiers, which have a fixed temperature at $\sim$ 30°C and 40°C (minimal and maximal point). The temperatures of each peltier were measured using a digital thermometer (MV 362, MINIPA Co Ltd, Shanghai, China) to compare the temperature values obtained by the camera. Figure 1 shows the schematic representation of the experimental setup.

The camera was maintained at a distance of 180 cm from the women, and at a height of 75 cm from the floor. This position of the camera allowed the subjects' lower limbs to be adequately captured. The measurements were performed during rest in the standing position during a pre-exercise period (0'), during 10, 35, and 45 min of the submaximal constant speed exercise (10', 35', and 45') and after 5 min of the post-exercise recovery period in the standing position (50'). Following Ferreira et al.,¹⁵ we did not place any marker around the area of interest, to avoid temperature shifts by conduction or any other possible interference. The regions of interest for cutaneous temperature analyses were: (1) at an equidistant position between the knee and superior limits of the right and left thighs and between the lateral and the medial limits of the right and left thighs (quadriceps); and (2) at an equidistant position between the knee and the half

FIG. 1. The schematic representation of the experimental setup used for the measurements. The thermal camera was kept at a fixed position, 75 cm from the floor, 180 cm from the subject, and centered relative to the thighs. The thermal image was displayed on a computer screen and recorded. The thermal image shows (1) the light-emitting diode (LED) devices next to the woman and (2) two peltiers that were placed on each side of the woman's body to obtain the temperature. The distance between the LED devices (modified from Paolillo et al.)¹⁰ and the subject was ~15 cm.

limits of the right and left lower legs and between the lateral and the medial limits of the right and left lower legs (superior half of the tibialis anterior muscle).

A homemade image processing was developed and applied over each of the thermal images. This simple computational routine was developed in Matlab® 7.0.4 - R14 (The MathWorks, Inc., Natick, MA) and allows the user to select a region of interest of the image followed by a calculation of an average and standard deviation of the temperature inside the region of interest. According to Ferreira et al.,¹⁵ the use of the calculated average temperature of the area minimizes positioning errors. This is important, because we performed measurements with the subjects at rest as well as during physical exercises in real time, and the major limitation of thermography is that the acquisitions are a two-dimensional representation of a three-dimensional surface of a three-dimensional structure.¹⁶ The average temperature and standard deviation were plotted as a function of time for the physical exercise with or without infrared LED irradiation, and reveal the dynamic behavior of the cutaneous temperature.

Statistical analysis

The data were expressed as mean and standard deviations. The Shapiro-Wilk test was used to analyze data normality. Repeated measures ANOVA with Bonferroni adjustments was used to compare changes of temperature as a function of time. The temperature was compared to each measurement of the immediately prior period, and all temperatures were compared to the pre-exercise period (0'). One-way ANOVA with Bonferroni adjustments was used to compare the temperatures between the groups. The Statistica for Windows Release 7 software (Statsoft Inc., Tulsa, OK) was used for the statistical analysis, and the significance level was set at 5% ($p < 0.05$).

Results

The clinical characteristics of the postmenopausal women are shown in Table 1. The mean values and standard deviation were 8 ± 5 years for the duration of the menopause. The statistical results of the cutaneous temperature can be seen in the Table 2. The thermal images before, during and after physical exercises with or without infrared LED irradiation can be seen in Figs. 2A and B. The dynamic behavior of the cutaneous temperature of the thighs (Fig. 3A) and of the lower legs (Fig. 3B) before, during, and after physical exercise with or without infrared LED irradiation can also be observed.

TABLE 1. VALUES OF MEAN AND STANDARD DEVIATION AND STATISTICAL RESULTS OF THE CLINICAL CHARACTERISTICS OF THE WOMEN

	LED group (n=9)	Exercise group (n=9)
Anthropometry		
Body mass (kg)	70 ± 10	67 ± 9
Height (cm)	153 ± 7	157 ± 5
BMI (kg/m^2)	30 ± 4	27 ± 3
Rest		
HR (bpm)	72 ± 9	73 ± 10
Maximal exercise testing		
HR _{max} (bpm)	161 ± 9	160 ± 13
Bruce (stage)	2.5 ± 0.5	2.5 ± 0.5
Submaximal constant speed exercise		
HR (bpm)	146 ± 11	142 ± 7
Velocity (km/h)	6 ± 1	6 ± 1

The groups were not significantly different ($p \geq 0.05$)

LED, light-emitting diode; BMI, body mass index; HR, heart rate.

TABLE 2. CUTANEOUS TEMPERATURE OF THE THIGHS AND THE LOWER LEGS BEFORE, DURING, AND AFTER PHYSICAL EXERCISE WITH AND WITHOUT INFRARED LED IRRADIATION

	Pre-exercise 0'	Exercise			Post-exercise 50'
		10'	35'	45'	
Thigh temperature (°C)					
LED group	33.5±0.8	34.1±0.5	34.5±0.9 ^a	34.6±0.9 ^{a,b}	34.5±0.9 ^a
Exercise group	33.5±0.6	33.7±0.6	32.9±0.9 ^{b,c}	32.7±0.7 ^b	33.1±0.5
Lower leg temperature (°C)					
LED group	33.7±0.8	34.3±0.7	34.7±0.9 ^d	34.9±0.9 ^a	34.7±0.9 ^d
Exercise group	33.7±0.7	34.1±0.8	33.7±0.5	33.6±0.6	33.8±0.5

^aSignificant intergroup difference ($p < 0.01$).

^bSignificant intragroup difference compared with instance 0' ($p < 0.05$).

^cSignificant intragroup difference compared with the period immediately beforehand ($p < 0.05$).

^dSignificant intergroup difference ($p < 0.05$).

LED, light-emitting diode.

No significant difference was found for the temperature of the thighs for each measurement compared with the prior period for the LED group ($p \geq 0.05$), whereas the exercise group showed a significant reduction of the thighs' temperature at instance 35' compared with instance 10' ($p = 0.03$). The LED group showed a significant increase of the thighs' temperature at instance 45' compared with instance 0' ($p = 0.03$), whereas the exercise group showed significant reduction of the thighs' temperature at instance 35' ($p = 0.03$) and 45' ($p = 0.02$) compared with instance 0'. The LED group showed higher values of the thighs' temperature compared with the exercise group at instance 35' ($p = 0.0003$), 45' ($p = 0.00005$), and 50' ($p = 0.006$).

No significant difference was found for the lower leg temperatures for each measurement compared with the prior period or compared with instance 0' for both the LED group and the exercise group ($p \geq 0.05$). However, the LED group showed significantly higher temperatures compared with the exercise group at instances 35' ($p = 0.01$), 45' ($p = 0.006$), and 50' ($p = 0.04$).

Discussion

The main finding of this study was that the LED group showed an increased cutaneous temperature during the ex-

ercises, whereas the exercise group showed a reduced cutaneous temperature. These data are relevant because they can explain one possible mechanisms of action of phototherapy.

The increase of the initial cutaneous temperature observed in our study is similar to the discussion by Reilly and Waterhouse.¹⁷ During the exercises, the set points for heat storage and heat loss have been reported as 3 and 10 min, respectively. The blood flow to the active muscles is increased in order to boost the transport of oxygen to them. The body acts at first as a heat sink, until a portion of the increased cardiac output is shunted to the skin to transfer heat to the environment. As the internal temperature begins to rise, the vasodilatory response is increased by secretion of sweat to the skin surface to produce evaporative cooling.¹⁷ After this period (10 min) the response to exercise differs between the LED group and the exercise group.

The LED group showed an increased cutaneous temperature during the exercises. The infrared radiation is absorbed by water and produces heat. Moreover, Makihara et al.¹⁸ showed that phototherapy applied with a CO₂ laser (1.0 W) positioned 10 cm above the skin, increased the facial temperature because it improved the microcirculation via the vasodilator reflex and warmed the face. Another study Makihara and Masumi¹⁹ showed that phototherapy on one side of the face

FIG. 2. Thermal images before, during, and after the physical exercises (A) with or (B) without infrared light-emitting diode (LED) irradiation.

FIG. 3. Dynamic behavior of the cutaneous temperature of the (A) thighs and of the (B) lower legs before, during, and after physical exercise with or without light-emitting diode (LED) irradiation.

induced a significant increase of the diameter and blood flow volume of superficial temporal artery 10 min after stopping the irradiation, compared with the situation before the irradiation. These changes also occurred on the opposite side of the face.

On the other hand, similar results to those observed in the exercise group were obtained by Merla and collaborators.¹⁶ Their study showed a reduced cutaneous temperature of the thighs, forearms, and trunk during a graded exercise testing, compared with that during rest and post-exercise recovery. The authors suggested a continuous cutaneous vasoconstrictor response, attributable to an increase in catecholamine and other vasoconstrictor hormones released as the exercise intensity increased.¹⁶

In a study by Zontak et al.,²⁰ it was shown that the cutaneous temperature of the hands during exercises depended upon the type of exercises (graded vs. constant load). During a graded load exercise, there was increased metabolic demand from the working organs (e.g., leg muscles) and the temperature of the hands continuously decreased throughout the exercise period. During constant load exercise, there was an initial temperature decrease followed by the re-warming of the hands, which reflected a dominance of the thermoregulatory reflexes at a later stage of the exercise.²⁰

Our results of the exercise group are different of the results obtained by Zontak et al.,²⁰ because these evaluated the response thermodynamics of the hands of young men during the exercise on a bicycle ergometer (without weight-bearing effects) performed with different intensities and duration than in the current study. Moreover, the hands are not main actuators during exercise, and have no skeletal muscle pump. Our study, however, evaluated the region related to a presence of the main muscle actuators (legs) of postmenopausal women, during an exercise on a treadmill.

During a post-exercise recovery, our results were similar to those observed in the study of Merla et al.¹⁶ The high cutaneous temperature post-exercise is a consequence of peripheral vasodilatation. This is indicated by the presence of hyperthermal spots. The authors suggested that these spots were indicators for a diffusion of heat from the hyperthermal spots to the surrounding cutaneous tissue, suggesting a

possible hemodynamic and thermoregulatory role of the perforator vessels for the transition from exercise to rest.¹⁶

Although in the current study, the body core temperature (e.g., rectal, tympanic, or esophageal) had not been measured, probably hyperthermia (when a heat production exceeds a loss of heat and results in core temperature of $\sim 40^{\circ}\text{C}$)²¹ did not occur because there was no reduction of physical performance. In addition, an artificial heat was applied locally only in the thighs. The infrared LEDs at a power of 100 mW during 45 min produced heat exerting a biological effect, but not a hyperthermic effect, on promoting and improving skin microcirculation. These therapeutic effects can be associated with vasodilatation and angiogenesis caused by action of infrared LEDs on nitric oxide (NO).²²⁻²⁴

Human²⁵ and animal²⁶ studies have shown increased skin temperatures when phototherapy was applied; however, darker skin showed a higher cutaneous temperature than did lighter skin. According to the authors,^{25,26} the heat induced in the skin during application of phototherapy is strongly related to skin color, and the lowest thermal effect in light skin may be caused by light reflection.

Thermal effects can explain the treatment of the pain when phototherapy is applied. Infrared radiation (Ga-As-Al laser, 780 nm) with muscle-stretching exercises had superior significant effects on feeling pain in active myofascial trigger points with thermographic changes 3 weeks after a treatment.⁶ Furthermore, Hegedus et al.²⁷ showed that thermographic measurements had at least a 0.58°C increase in temperature, and, therefore, an improvement in circulation compared with the initial values and improvement of the joint range-of-motion, pain, and pressure sensitivity in patients with knee osteoarthritis who had received phototherapy (Ga-Al-As diode laser, 830 nm), in comparison with a placebo group.

The thermal effect observed in the current study can explain the performance improvement with LED infrared irradiation during treadmill exercises,^{9,10} as higher circulation induced by an increasing muscle temperature can improve oxygen supply as well as transport and utilize metabolic substrates, mainly when phototherapy is combined with skeletal muscle contractions during a physical exercise.

This thermal effect also can explain the treatment of cellulite and the reduction of the perimeter of the thighs in both young and middle-aged women who underwent LED infrared irradiation during treadmill exercises.¹¹ The reduction of the thigh circumference may be related to infrared LED effects, resulting in increased microcirculation and lymphatic drainage,²⁸ because cellulite is characterized by alterations of the microcirculation and the lymphatic system, in addition to a dysfunction of cutaneous and adipose tissue with a fibrotic reaction.²⁹

Future studies should be performed using a large sample size, different ages and genders, and a large post-exercise period in order to investigate cutaneous temperature, body core temperature, and microcirculation in more detail (e.g., diameter and blood flow volume of the femoral artery).

Conclusions

To conclude, the results of our study showed that the LED group showed increases of the cutaneous temperature of the lower limbs during the exercise, whereas the exercise group experienced reduced temperatures. This intergroup difference can explain one of the possible mechanisms of phototherapy associated with physical exercises in improving physical performance, body aesthetic, and health.

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Author Disclosure Statement

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References

- Miland, A.O., and Mercer, J.B. (2006). Effect of a short period of abstinence from smoking on rewarming patterns of the hands following local cooling. *Eur. J. Appl. Physiol.* 98, 161–168.
- Roelands, B., and Meeusen, B. (2010). Alterations in central fatigue by pharmacological manipulations of neurotransmitters in normal and high ambient temperature. *Sports Med.* 40, 229–246.
- Schlader, Z.J., Stannard, S.R., and Mündel, T. (2010). Human thermoregulatory behavior during rest and exercise – a prospective review. *Physiol. Behav.* 99, 269–275.
- Barnes, R.B. (1963). Thermography of the human body. Infrared-radiant energy provides new concepts and instrumentation for medical diagnosis. *Science* 140, 870–877.
- Kohler, A., Holfmann, R., Platz, A., and Bino, M. (1998). Diagnostic value of duplex ultrasound and liquid crystal contact thermography in preclinical detection of deep vein thrombosis after proximal femur fractures. *Arch. Orthop. Trauma Surg.* 117, 39–42.
- Ohsawa, S., Inamori, Y., Fukuda, K., and Hirotsuji, M. (2001). Lower limb amputation for diabetic foot. *Arch. Orthop. Trauma Surg.* 121, 186–190.
- Gold, J.E., Cherniack, M., Hanlon, A., Dennerlein, J.T., and Dropkin, J. (2009). Skin temperature in the dorsal hand of office workers and severity of upper extremity musculoskeletal disorders. *Int. Arch. Occup. Environ. Health* 82, 1281–1292.
- Hakgüder, A., Birtane, M., Gürcan, S., Kokino, S., and Turan, F.N. (2003). Efficacy of low level laser therapy in myofascial pain syndrome: an algometric and thermographic evaluation. *Lasers Surg. Med.* 33, 339–343.
- Paolillo, F.R., Corazza, A.V., Borghi-Silva, A., Parizotto, N.A., Kurachi, C., and Bagnato, V.S. (2013). Infrared-LED applied during high-intensity treadmill training improved maximal exercise tolerance in postmenopausal women: a 6-month longitudinal study. *Lasers Med. Sci.* 28, 415–422.
- Paolillo, F.R., Milan, J.C., Aniceto, I.V., Barreto, S.G., Rebelatto, J.R., Borghi-Silva, A., Parizotto, N.A., Kurachi, C., and Bagnato, V.S. (2011). Effects of infrared-LED illumination applied during high-intensity treadmill training in postmenopausal women. *Photomed. Laser Surg.* 29, 639–645.
- Paolillo, F.R., Borghi-Silva, A., Parizotto, N.A., Kurachi, C., and Bagnato, V.S. (2011). New treatment of cellulite with infrared-LED illumination applied during high-intensity treadmill training. *J. Cosmet. Laser Ther.* 13, 166–171.
- Ebrahimpour, P., Fakhrzadeh, H., Heshmat, R., Ghodsi, M., Bandarian, F., and Larijani, B. (2010). Metabolic syndrome and menopause: a population-based study. *Diabetes Metab. Syndr.* 4, 5–9.
- Fletcher, G.F., Balady, G.J., Amsterdam, E.A., Chaitman, B., Eckel, R., Fleg, J., Froelicher, V.F., Leon, A.S., Piña, I.L., Rodney, R., Simons-Morton, D.A., Williams, M.A., and Bazzarre, T. (2011). Exercise standards for testing and training: a statement for healthcare professionals from the American Heart Association. *Circulation* 124, 1694–1740.
- Noonan, V., and Dean, E. (2000). Submaximal exercise testing: clinical application and interpretation. *Phys. Ther.* 80, 782–807.
- Ferreira, J.J.A., Mendonça, L.C.S., Nunes, L.A.O., Andrade Filho, A.C.C., Rebelatto, J.R., and Salvini, T.F. (2008). Exercise-associated thermographic changes in young and elderly subjects. *Ann. Biomed. Eng.* 36, 1420–1427.
- Merla, A., Mattei, P.A., Di Donato, L., and Romani, G.L. (2010). Thermal imaging of cutaneous temperature modifications in runners during graded exercise. *Ann. Biomed. Eng.* 38, 158–163.
- Reilly, T., and Waterhouse, J. (2009). Circadian aspects of body temperature regulation in exercise. *J. Therm. Biol.* 34, 161–170.
- Makihara, E., Makihara, M., Masumi, S.I., and Sakamoto, E. (2005). Evaluation of facial thermographic changes before and after low-level laser irradiation. *Photomed. Laser Surg.* 23, 191–195.
- Makihara, E., and Masumi, S.I. (2008). Blood flow changes of a superficial temporal artery before and after low-level laser irradiation applied to the temporomandibular joint area. *Nihon Hotetsu Shika Gakkai Zasshi.* 52, 167–170.
- Zontak, A., Sideman, S., Verbitsky, O., and Beyar, R. (1998). Dynamic thermography: analysis of hand temperature during exercise. *Ann. Biomed. Eng.* 26, 988–993.
- Brotherhood, J.R. (2008). Heat stress and strain in exercise and sport. *J. Sci. Med. Sport* 11, 6–19.
- Yu, S.Y., Chiu, J.H., Yang, S.D., et al. (2006). Biological effect of far-infrared therapy on increasing skin microcirculation in rats. *Photodermatol. Photoimmunol. Photomed.* 22, 78–86.

23. Karu, T.I., Piatybrat, L.V., and Afanasyeva, N.I. (2004). A novel mitochondrial signaling pathway activated by visible-to-near infrared radiation. *Photochem. Photobiol.* 80, 366–372.
24. Karu, T.I., Piatybrat, L.V., and Afanasyeva, N.I. (2005). Cellular effects of low power laser therapy can be mediated by nitric oxide. *Lasers Surg. Med.* 36, 307–314.
25. Joensen, J., Demmink, J.H., Johnson, M.I., Iversen, V.V., Lopes-Martins, R.A.B., and Bjordal, J.M. (2011). The thermal effects of therapeutic lasers with 810 and 904 nm wavelengths on human skin. *Photomed. Laser Surg.* 29, 145–153.
26. Stadler, I., Lanzafame, R.J., Oskoui, P., Zhang, R.Y., Coleman, J., and Whittaker, M. (2004). Alteration of skin temperature during low-level laser irradiation at 830 nm in a mouse model. *Photomed. Laser Surg.* 22, 227–231.
27. Hegédus, B., Viharos, L., Gervain, M., and Gálfi, M. (2009). The effect of low-level laser in knee osteoarthritis: a double-blind, randomized, placebo-controlled trial. *Photomed. Laser Surg.* 27, 577–584.
28. Kaviani, A., Fateh, M., Nooraie, R.Y., Alinagi-Zadeh, M., and Ataie-Fashtami, L. (2006). Low-level laser therapy in management of postmastectomy lymphedema. *Lasers Med. Sci.* 21, 90–94.
29. Rawlings, A.V. (2006). Cellulite and its treatment. *Int. J. Cosmet. Sci.* 28, 175–190.

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