Lasers Med Sci (2015) 30:815–822
DOI 10.1007/s10103-013-1444-9

ORIGINAL ARTICLE

Comparative clinical study of light analgesic effect on temporomandibular disorder (TMD) using red and infrared led therapy

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Received: 30 April 2013 / Accepted: 16 September 2013 / Published online: 3 October 2013

Abstract Low-level laser therapy (LLLT) has been widely applied in pain relief in several clinical situations, including temporomandibular disorders (TMD). However, the effects of LED therapy on TMD has not been investigated. This study aims to evaluate the effects of red and infrared LEDs on: (1) tissue temperature in ex vivo and (2) pain relief and mandibular range of motion in patients with TMD. Thirty patients between 18 and 40 years old were included and randomly assigned to three groups. The two experimental groups were: the red LED (630±10 nm) group and the infrared LED (850±10 nm) group. The irradiation parameters were 150 mW, 300 mW/cm^2, 18 J/cm^2, and 9 J/point. The positive control group received an infrared laser (780 nm) with 70 mW, 1.7 W/cm^2, 105 J/cm^2, and 4.2 J/point. LED and laser therapies were applied bilaterally to the face for 60 s/point. Five points were irradiated: three points around the temporomandibular joint (TMJ), one point for the temporalis, and one near the masseter. Eight sessions of phototherapy were performed, twice a week for 4 weeks. Pain induced by palpating the masseter muscle and mandibular range of motion (maximum oral aperture) were measured at baseline, immediately after treatment, 7 days after treatment, and 30 days after treatment. There was an increase in tissue temperature during both the red and the infrared LED irradiation in ex vivo. There was a significant reduction of pain and increase of the maximum oral aperture for all groups ($p \geq 0.05$). There was no significant difference in pain scores and maximum oral aperture between groups at baseline or any periods after treatment ($p \geq 0.05$). The current study showed that red and infrared LED therapy can be useful in improving outcomes related to pain relief and orofacial function for TMD patients. We conclude that LED devices constitute an attractive alternative for LLLT.

Keywords Laser therapy · LED therapy · TMD · Pain relief · Oral aperture

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Introduction

Temporomandibular disorder (TMD) is a common clinical complaint among patients in dental practices. TMD occurs as a result of malfunction in the jaw, jaw joint, and or surrounding facial muscles, and it is characterized by pain and discomfort in facial muscles mostly, when chewing or during

jaw movement. TMDs fall into three main categories: (1) myofascial pain, is the most common form of TMD, which is characterized by discomfort or pain in the masticatory muscles and sometimes in the neck and shoulder muscles; (2) internal derangement of the joint associated with a dislocated jaw or displaced disc and an injury to the condyle; and (3) degenerative joint disease, including osteoarthritis or rheumatoid arthritis in the jaw joint [1, 2].

Managing TMD is a challenge for dental practitioners; often analgesics are prescribed to ameliorate acute pain, but the long-term treatment is difficult to project [3]. TMD also has a psychological component. Therefore, the guidelines for TMD treatment recommend noninvasive approaches to managing this condition. Low-level laser therapy (LLLT) is considered a viable noninvasive and nonpharmacological alternative.

LLLT has been reported as an analgesia for several different painful conditions, such as cervical dentin hypersensitivity, trigeminal neuralgia, headaches, and especially TMD. Previous studies have shown the beneficial effects of red [4–6] and infrared [7–11] lasers in TMD management. Therapeutic "optical window" corresponds to red and near-infrared wavelengths, where the effective tissue penetration of light is maximal [12]. For this reason, red and infrared wavelengths are used to relieve both acute and chronic pain and inflammation [13, 14].

The analgesic mechanisms of light is not clearly understood although several have been proposed, including the gate control theory, modulation of endogenous opioids production, anti-inflammatory effects, direct inhibition of neural activity and slowed conduction velocity in peripheral nerves [15]. However, several factors may influence an analgesic response: patient diagnoses, symptoms, pain duration, laser irradiation location, distance from laser probe to skin, laser type, wavelength, laser mode (continuous or pulsed), average power, power density, energy, fluence, number of sessions, laser irradiation point size, and co-interventions (e.g., exercises, dry needling, and drugs) [14].

Regarding output power, clinical studies use red laser with an average power of 15 [5] or 30 mW [6] as well as infrared laser with an average power of 17 [16], 40 [9], 50 [10, 17], 70 [18], or 100 mW [13] for reduced pain and increased orofacial function for TMD management. Moreover, infrared laser with higher power, for example, 400 mW [11, 19, 20] has also been used to relieve pain and improve mobility of the joint for TMD treatment. However, it is a well-known fact that increasing laser power and exposure time may lead to higher local temperature and risk of tissue damage [21, 22].

In contemporary research, the use of LEDs for therapeutic treatment is growing. Studies have shown that lasers and LEDs operating at similar parameters produce equivalent effects [23–26]. A review of the literature shows the effectiveness of LEDs in dentistry [26], dermatology and aesthetic medicine [24, 27–29], sport medicine [30, 31], and especially for pain relief [32].

However, to our knowledge, no previous studies have assessed the effects of LED therapy on TMD management. Therefore, this study aims to evaluate the effects of red and infrared LEDs on: (1) tissue temperature in ex vivo human hemi-head and (2) pain relief and mandibular range of motion in patients with TMD. Our hypothesis was that the use of LEDs may present a new approach for therapeutic treatment of TMD, when compared with LLLT.

Materials and methods

This study is part of a larger project that aims to develop clinical protocols LED systems for therapy. All procedures were approved by the Ethics Committee of the Federal University of São Carlos, São Carlos, Brazil (approval no. 23112.004838/2010-28). All subjects provided written informed consent and agreed to participate in the study. The study was registered with NIH ClinicalTrials (NCT01873937).

Devices used in this study

To perform LED irradiation, a prototype device (Fisioled, MM Optics Ltda, São Carlos, São Paulo, Brazil) was developed specifically for this project. The device includes two handpieces with polished acrylic tips. Each handpiece includes one red (630±10 nm) or one infrared (850±10 nm) LED with a fixed output power of 150 mW and illumination area of 0.5 cm^2.

For this clinical trial, the positive control group was treated, as suggested by the ethical committee. A 780-nm laser (Twin Laser, MM Optics Ltda, São Carlos, São Paulo, Brazil) was used, because infrared lasers are a well-accepted and efficient therapy for pain relief [33]. This wavelength is commonly used for TMD treatment [7–11]. This device has adjustable output power ranging from 5 to 70 mW and a spot area of 0.04 cm^2.

A FieldMaster TO-II optical power meter (Coherent Inc., Santa Clara, CA, USA) linked to a photodetector was used to calibrate these systems.

Thermal mapping

Thermal mapping during LED irradiation was performed on an ex vivo human hemi-head (Fig. 1a) provided by the laboratory of anatomy at the University of São Paulo's (Ribeirão Preto, SP, Brazil campus) dental school.

Subcutaneous temperature measurements were performed in the anatomical specimen. A high-precision digital thermometer (MT 600, Minipa, São Paulo, Brazil) coupled with a computer program that captured the electrical signals, was

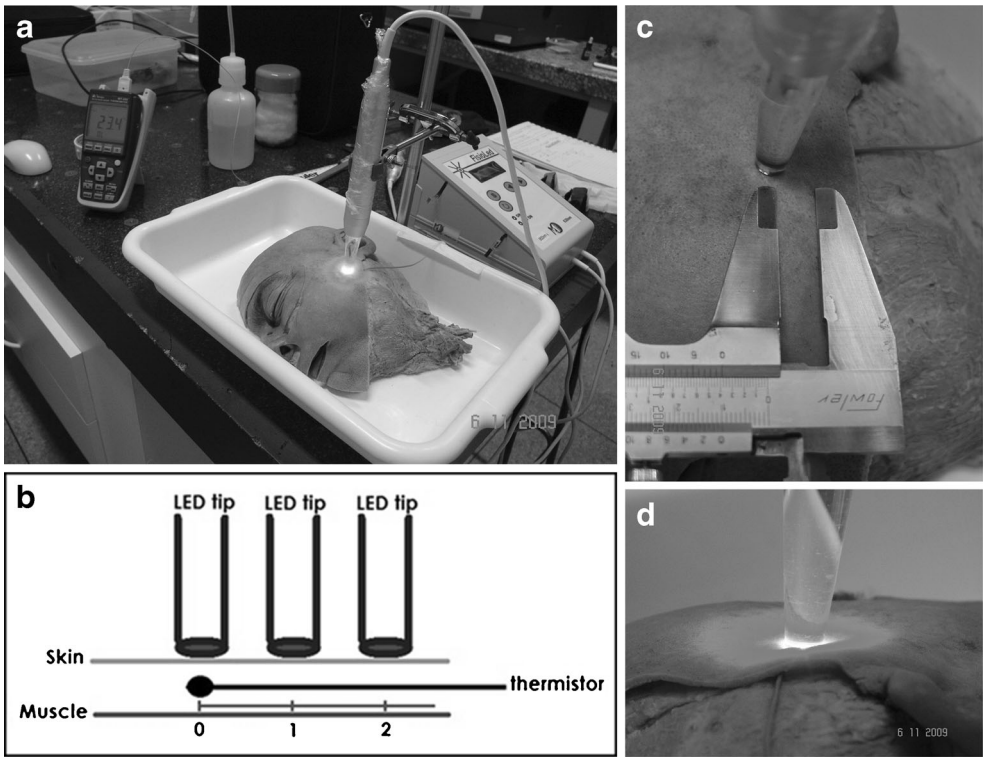

Fig. 1 The schematic representation of the experimental setup used for the measurements. Thermal map setup in the anatomical specimen (**a**); scheme showing the three positions (0, 1, and 2) of the LED considering thermistor location (**b**); pachymeter was used to determine position of the LED (**c**) and; close view of the LED tip (**d**)

positioned between the subcutaneous and muscle tissues (Fig. 1b). Three fixed distances were chosen to evaluate the thermal effect: (*d*0), 1 (*d*1), or 2 cm (d2) from the irradiation tip to subcutaneous tissue (Fig. 1c).

The irradiation was performed with red LED or infrared LED (prototype device) for 3 min. The measurements were performed three times and the mean temperature was recorded. As the same anatomical piece (Fig. 1d) was used each measurement was followed by a 5-min interval to allow the tissue to cool completely (thermal relaxation).

It is well-known that LEDs operating at higher output powers, around or above 100 mW, can generate heat [31]. Therefore, we investigated the effect of the LEDs on tissue temperature prior to the start of the clinical trial.

Clinical study

A randomized, single-blind, cross-sectional, and longitudinal clinical trial was conducted. A computer program was used for the randomization. Patients who received care at a private dental office in Ribeirão Preto, São Paulo, Brazil (NILO-Integrated Center for Laser Dentistry) were invited to participate in the study. The inclusion criteria were patients aged between 18 and 50 years with signs and symptoms of TMD. The diagnosis was made through a standard and comprehensive clinical examination based upon the research diagnostic criteria for temporomandiublar disorders [9, 10, 34]. This protocol was translated into Portuguese [35, 36] and was performed to obtain information about myofascial pain and arthralgia. The signs and symptoms were evaluated by a trained professional using the following procedures: pain during palpation of the temporomandibular joint (TMJ) area, pain on associated muscles (masseter and temporal), and limited or painful jaw movement with impaired oral aperture. The exclusion criteria were current or recent orthodontic and/or orthopedic treatment, degenerative joint disease, or patients treated with systemic medication (e.g., sedatives, muscle relaxants, analgesics, corticosteroids, or nonsteroidal anti-inflammatory agents).

Thirty patients between 18 and 40 years old (8 males and 22 females) were included and randomly assigned to three groups with ten patients in each group. The two experimental groups were: the red LED (630±10 nm) group and the infrared LED (850±10 nm) group. The patients in both groups were exposed to the LED prototype devices, with an average optical power of 150 mW, irradiance of 300 mW/cm^2, 9 J per point and fluence of 18 J/cm^2. The third group, the positive control, received the infrared laser (780 nm), with an average optical power of 70 mW, irradiance of 1.7 W/cm^2, energy of 4.2 J per point and fluence of 105 J/cm2. The LED and laser therapies were applied bilaterally to the face for 60 s/point. Five points were irradiated: three points around the TMJ, one point on the temporalis and one on the masseter (Fig. 2). Eight sessions of the phototherapy were performed, twice a week for 4 weeks.

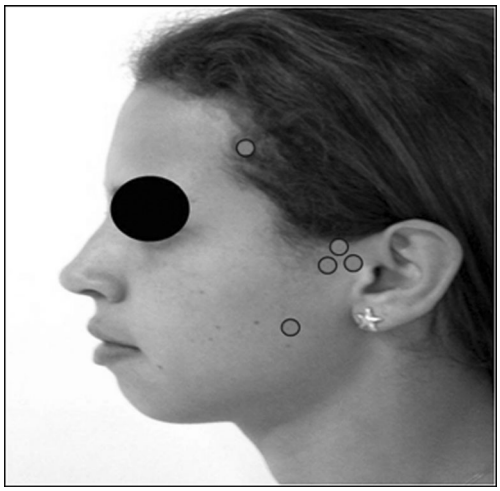

Fig. 2 Irradiation points: three points around the TMJ and one point for the temporalis and the masseter, respectively

Clinical measurements

Two parameters were used to evaluate the efficiency of the proposed treatments: range of motion (total aperture) and pain in the masseter muscle [9, 10, 35, 36]. To measure the jaw movement, a rule developed by a researcher from the Department of Oral Physiology, Institute of Head-UNIFESP (Escola Paulista de Medicina, São Paulo, adapted from the school of Gothenburg, Sweden) was used. To evaluate pain, the researcher palpited the masseter with a finger. Pain was evaluated using a numerical scale that ranged from 0 to 3: 0 (no pain), 1 (mild pain), 2 (moderate pain), and 3 (strong pain). The pain scores [35, 36] are shown in Table 1. The patients were evaluated at baseline (B), immediately after treatment, 7 days 7AT, and 30 days after treatment (30AT). During this time frame, we evaluated the progression of the treatment and classified it as an improvement, worsening or maintenance of both orofacial pain and function.

Statistical analysis

The data were expressed as mean and standard deviations. The Shapiro–Wilk test was used to analyze data normality and the homogeneity of variances using Levene's test. Two-way ANOVA with repeated measures was used to compare changes in pain score and orofacial aperture, before and after the treatment. The independent factors were group (with three levels: red LED, infrared LED, and infrared laser groups) and time (with four levels: baseline, immediately after treatment, 7 days after treatment, and 30 days after treatment), which was also considered a repeated measurement (intragroup differences). The change between baseline and all periods after treatment (delta=after treatment minus baseline) was used to compare groups using a one-way ANOVA (intergroup differences). When significant differences were found, Tukey's post-hoc test was applied. Statistica for Windows 7 (Statsoft Inc., Tulsa, Ok) was used for the statistical analysis. The significance level was set at 5 % ($p<0.05$).

Table 1 Pain scores

Degrees	Sensitivity
0	Without significant discomfort
1	Discomfort with mild pain
2	Sharp pain solely during the application of stimulus
3	Sharp pain during the application of stimulus and continuous after its removal

Results

The measurements of the subcutaneous temperatures for red and infrared LEDs are shown in Fig. 3a, b, respectively. The curves represent the heating and thermal relaxation during and immediately after LED irradiation. There was an increase in temperature during irradiation (3 min), represented by an exponential curve. The irradiation is followed by an exponential decay (cooling), which occurs for 3 to 4 min, until the initial temperature is reached (for both red and infrared wavelengths).

At position $d0$, the red LED reached a maximal temperature of 5.7 °C. There was no thermal change at positions $d1$ and $d2$. After 3 min under the infrared LED at position $d0$, subcutaneous temperatures reached 2 °C, where the largest energy deposition occurred. The maximal temperature of 0.5 °C occurred at position $d1$ (1.0 cm away) and, there was no thermal change at position $d2$.

The pain score can be seen in Fig. 4 compared with baseline, the results for all groups showed a significant reduction of pain on the right and left side of the face ($p<0.05$) at the period immediately after treatment, as well as 7 and 30 days after treatment. No significant difference was found for the pain score of each measurement compared with the prior period, except for the left side of patients in the red LED group at the period between immediately after treatment and 7 days after treatment ($p=0.04$).

There was a significant increase of the maximum oral aperture for all groups (Fig. 5). The patients that received LED therapy showed significant improvement of aperture ($p<0.05$) at the period immediately after treatment, as well as 7 and 30 days after treatment, compared with baseline. The infrared laser group only showed significant improvement 30 days after treatment ($p=0.01$). No significant difference was found for maximum orofacial aperture of each measurement compared with the prior period, except for the period between immediately after treatment and 7 days after treatment in the infrared LED ($p=0.04$) and infrared laser groups ($p=0.02$).

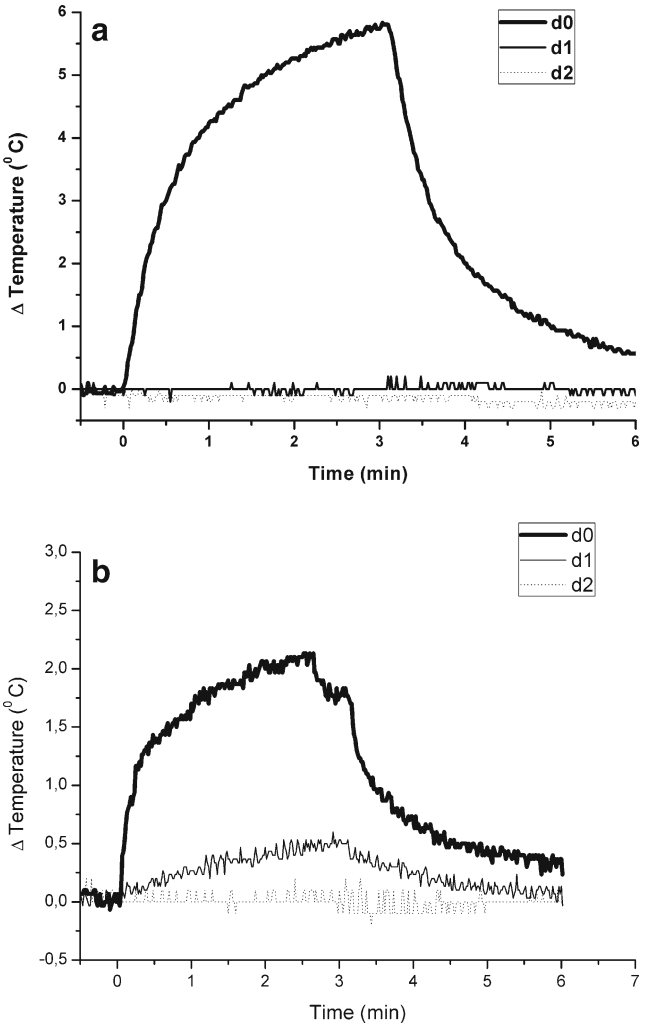

Fig. 3 Thermal map with application of the red LED (**a**) and infrared LED (**b**). The legends *d0*, *d1*, and *d2* represent the distances from the LED tip to the tissue in a vertical direction with a 90° angle. They represent the distance between the tip and the thermistor at zero, 1 cm, and 2 cm, respectively

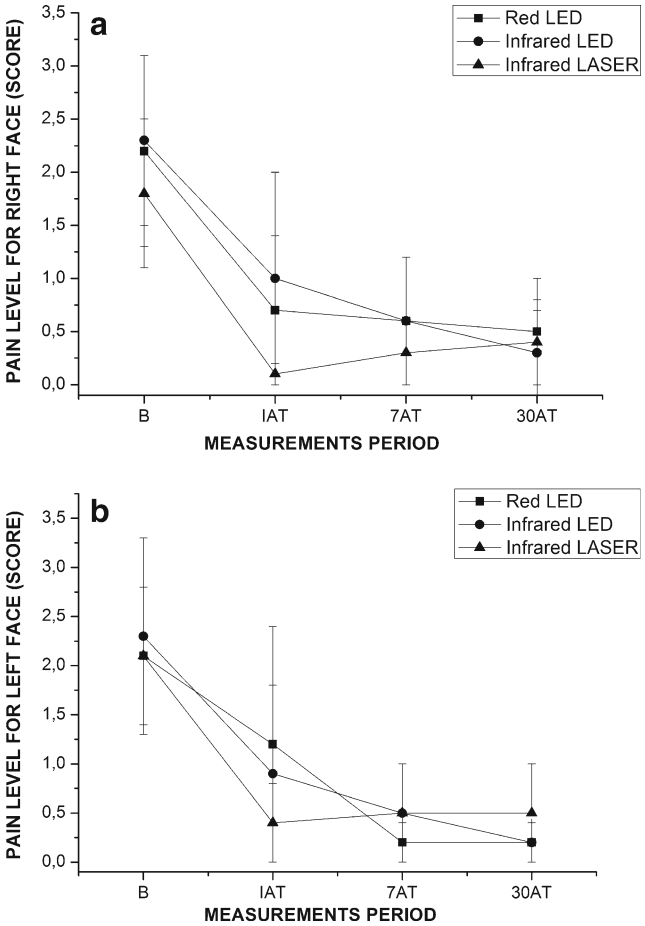

Fig. 4 Pain score for the right (**a**) and left (**b**) face. Significant intragroup differences compared with instance baseline ($p < 0.05$, two-way ANOVA with Tukey's post-hoc). No significant intergroup differences ($p \geq 0.05$, one-way ANOVA). *B* baseline, *IAT* immediately after treatment, *7AT* 7 days after treatment, *30AT* 30 days after treatment

There was no significant difference in pain scores and maximum oral aperture between groups at baseline or any periods after treatment (delta value; $p \geq 0.05$).

Discussion

This is the first study evaluating the effects of LED therapy on TMD management. The main findings of this study were: (1) that the red and infrared LED irradiation showed an increased subcutaneous temperature in the anatomical specimen, a higher temperature for the red wavelength; (2) the red and infrared LED therapy resulted in reduced pain and improved orofacial function similar to the LLLT. These data are relevant because they realize the potential development of new clinical protocols with LEDs for pain relief and improved orofacial function.

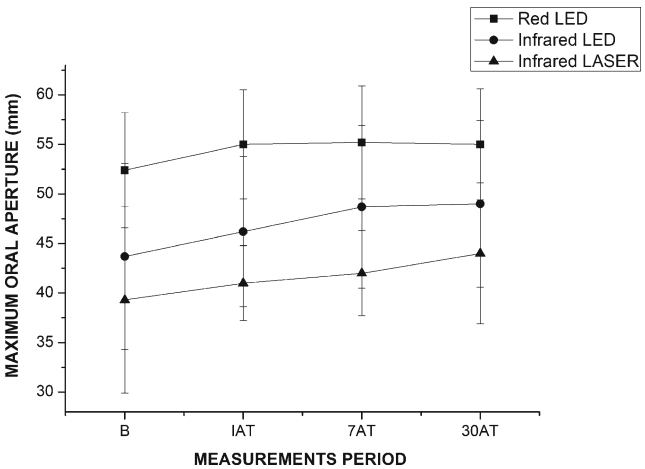

Fig. 5 Maximun oral aperture. Significant intragroup differences compared with instance baseline ($p < 0.05$, two-way ANOVA with Tukey's post-hoc). No significant intergroup differences ($p \geq 0.05$, one-way ANOVA). *B* baseline, *IAT* immediately after treatment, *7AT* 7 days after treatment, *30AT* 30 days after treatment

Although the current study applied LED therapy for TMD treatment, LEDs with higher output power reaching 3 W have been used for other purposes in dental patients without side effects, such as photo activation of dental bleaching gel [37] and curing of composite resins [38].

According to thermal map, LEDs with higher power increased tissue temperature; however, the red radiation produced higher temperatures compared with infrared radiation. In this context, red wavelengths are more absorbed by tissue surface components than infrared wavelengths. The absorbed energy can be dissipated in the form of heat around the skin surface. Conversely, the infrared wavelengths can penetrate deeply into the body tissues which has lower scattering and absorption properties [39]. Remarkably, the heat remains localized. This finding is very interesting and presents an appealing clinical approach application geometry. Considering the clinical effectiveness, it would suggest performing punctual irradiation on the target area, especially when dealing with a large area (larger than the beam diameter); the points must be equidistant for red LED, at a maximum of 1.0 cm, to ensure the uniform irradiation of the entire region. It is important to emphasize that we analyzed ex vivo specimen prior to clinical trials and living tissues is highly complex and has optical properties defined by varying rates of absorption, scattering, transmission, and reflection. Moreover, patients have the ability to thermoregulate and, therefore, the parameters of LED therapy used in the current study were safe during TMD treatment.

Clinical trials have been performed to investigate the TMJ area temperature when applying a CO_2 laser (1.0 W) positioned 10 cm above the skin [40, 41]. This laser caused a significant increase in facial temperature because it improved the microcirculation via the vasodilator reflex [40]. Moreover, after the TMJ area was exposed to phototherapy, there was a significant increase in the diameter and blood flow volume of superficial temporal artery, compared with the baseline [41].

Thermal effects can explain the reduced pain and the increased functionality, because phototherapy can lead to lymphatic drainage, improve oxygen supply and transport, and utilization of metabolic substrates [31].

Several studies [42–44] have shown that temperature changes induced by phototherapy can be associated with alteration in nerve conduction velocities which result in analgesic effects [15]. Regarding nerve conduction, in a study of Vinck et al. [32], infrared LED therapy, with an average power of 160 mW, was performed on healthy subjects and showed an immediate and localized effect on the conduction characteristics of nerves, with a reduced number of impulses per unit of time for pain relief [32]. In the current study, we used similar average power as Vinck et al. [32] (150×160 mW), but the device's geometry (probe area of 0.5×18 cm^2) is different and, consequently, the fluences are different as well. For the same reason, the LEDs and laser parameters used in our study are different.

Concerning fluence parameters, we chose the applied dose based on typical doses used in regular practice (around 100 J/cm^2 seemed reasonable). Pöntinen [45] showed that a fluence of 4 J/cm^2 at skin level will maintain an irradiance at depths in the range of 0.5–2.5 cm. When irradiating joints or muscles, a fluence of 100–300 J/cm^2 was attenuated to 2 J/cm^2 and irradiance can be maintained at certain depths [31, 45].

One of the limitations of the current study is the difference between laser and LED parameters. LED and laser prototype devices with the same geometry and parameters should be developed for future studies. However, our study showed similar effects for LED and laser therapies on TMD management.

LEDs are not monochromatic, nor coherent, and cover a much broader range of wavelengths. Whereas lasers are monochromatic, coherent, and preserve collimation during propagation. Additionally, coherence is not lost in lasers upon entering tissue, but the length of coherence is reduced and split up into small speckles throughout the irradiated volume [46]. However, our study showed that the coherence property of light was not exclusively responsible for cellular response and the outcomes of phototherapy. Therefore, LED devices constitute an attractive alternative for phototherapy. In this context, LEDs have a comparably low operational cost, allow irradiation of larger areas, and can be configured to produce multiple wavelengths with an absorption of photons by several chromophores [29, 30].

Concerning different wavelengths, red and infrared radiation can act on different sites of the tissue. For example, red light acts on mitochondria, whereas infrared acts on both mitochondria and cellular membrane [47]. The combined effects of both wavelengths can be advantageous for tissue biostimulation or biomodulation. Future studies should be performed combining red and infrared radiation for TMD treatment.

Only one clinical trial [48] has investigated the immediate effects of red LED therapy (640±10 nm) on masseter muscles of subjects with healthy TMJ. However, long-term effects were not investigated and subjects with TMD were excluded from the study. In this study, compared with the results in a placebo group, the subjects who received LED therapy showed increased muscle activity and fatigue resistance.

Future studies investigating the effects of different parameters of irradiation on pain relief and improvement of orofacial function should be performed.

Conclusions

The current study showed that red and infrared LED therapy can be useful in improving outcomes related to pain relief and mandibular range of motion for TMD patients. In addition, LED and laser therapy showed similar results. In this context,

LEDs can be considered as an attractive alternative to the use of LLLT.

Acknowledgments We would like to thank the National Council for Scientific and Technological Development (CNPq)—grant no. 552720/2009-7 and the São Paulo Research Foundation (FAPESP)—grant no. 2013/07276-1 for financial support.

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