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ORIGINAL ARTICLE

Light-emitting diode phototherapy improves muscle recovery after a damaging exercise

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Abstract The goal of the present study was to determine the effect of light-emitting diode phototherapy (LEDT) at 630 nm on muscle recovery after a damaging eccentric exercise bout. Seventeen healthy young male volunteers, without previous experience with eccentric exercise, were included in a randomized double-blinded placebo-controlled trial. They were divided into a LEDT ($n=8$) and a PLACEBO group ($n=9$). To induce muscle damage, subjects performed 30 eccentric contractions with a load of 100 % of maximal voluntary isometric contraction strength of the elbow flexors of the non-dominant arm. LEDT group subjects received biceps brachii phototherapy (λ 630 nm; total energy density, 20.4 J/cm2) immediately after the exercise bout. The LEDT in the placebo group was aimed at the muscle, but it remained turned off. Isometric muscle strength, muscle soreness, and elbow range of motion (ROM) were measured before and at 24, 48, 72, and 96 h the after eccentric exercise bout and compared between groups. Our results showed that the muscle soreness, muscle strength loss, and ROM impairments were significantly reduced up to 96 h after a damaging eccentric exercise bout for the LEDT group compared with the PLACEBO group. A single LEDT (630 nm) intervention immediately after a damaging eccentric exercise bout was effective in terms of attenuating the muscle soreness and muscle strength loss and ROM impairments.

Keywords Phototherapy · Exercise-induced muscle damage · Muscle strength · Delayed onset muscle soreness · Elbow flexors

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Introduction

Exercise-induced muscle damage after eccentric contractions is observed in the Z-line, sarcoplasmic membrane, sarcoplasmic reticulum, T-tubules, myofibrils, and cytoskeletal system [1–4]. These structural damages commonly induce an inflammatory process and delayed onset muscle soreness (DOMS) to athletes, causing functional impairments such as decreased maximal force production capacity, changes in force production optimal length, increased passive tension, and decreased joint range of motion [1, 3, 5–7]. These impairments lead to limitation of athletic performance [8, 9] and increased injury risk [10].

Numerous strategies have been proposed to promote the recovery of muscle function after damage events [9]. Contrast water therapy, compression garment, low-intensity active exercise, and massage are some recovery strategies employed after muscle efforts to accelerate muscle damage recovery [9, 11]. Phototherapy interventions have emerged as a promising strategy to improve the muscle damage recovery, especially when red irradiation (630–660 nm) is applied immediately after high-intensity physical exercise [12, 13]. It has been

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proposed that phototherapy with red wavelength range (630–660 nm) has anti-inflammatory, analgesic, and reparative properties [14–18].

Phototherapy intervention immediately before a high-intensity physical exercise acts as a preventative measure against muscle damage [19, 20], which may differ from an intervention post-damage events. Beneficial effect of phototherapy with near-infrared irradiation (805–904 nm) and combined wavelength irradiation (i.e., red [630–660 nm] and infrared irradiation [805–904 nm]) before high-intensity physical exercise were observed in athletes and non-athletes [19, 20], and include the attenuation of exercise-induced muscle damage. Interestingly, beneficial effects of phototherapy, especially red irradiation (630–660 nm), applied after high-intensity physical exercise (i.e., exercise-mediated damage) has not been studied in humans. Results from animal experiments have shown that red irradiation (630–660 nm) applied immediately after high-intensity physical exercise may exert therapeutic effects on injured muscle [12, 13], but the reproduction of this condition (wavelength irradiation and moment of treatment) has not been tested in humans. Thus, a basic question related to the phototherapy and muscle recovery has yet no clear answer: is phototherapy with the 630 nm (red) wavelength, applied immediately after an eccentric exercise muscle bout, effective for muscle damage recovery in humans?

Therefore, the purpose of this study is to determine the effects of phototherapy with red irradiation (630 nm) immediately after an eccentric exercise bout on indirect markers of muscle damage up to 96 h after exercise. We hypothesized that, as observed in animal models, irradiation of exercise-damaged muscle tissue with red light phototherapy at 630 nm may exert therapeutic effects on injured muscle when applied immediately after a muscle damage event.

Materials and methods

Subjects

Seventeen subjects without previous experience with eccentric exercises and who had not regularly participated in resistance training in the previous 6 months provided informed consent to participate in the study. Ethical approval (protocol # 001/2012) was provided by the ethics committee of the State University of Southwest Bahia, Brazil.

Subjects were screened to confirm that they did not have any neuromuscular diseases and musculoskeletal problems for the non-dominant upper extremity before their participation in this study. Additionally, they were asked to refrain from unaccustomed exercise or vigorous physical activity and not to take any anti-inflammatory drugs or other therapeutic modalities during the experimental period.

Experimental design

This study was a randomized double-blind placebo-controlled trial to verify the effects of light-emitting diode phototherapy (LEDT) on muscle recovery after an eccentric exercise bout. Subjects were randomly placed into two groups: LEDT ($n=8$; 21.5±1.0 year, 171.7±3.0 cm, 66.8±3.8 kg) and PLACEBO ($n=9$; 21.5±0.7 year, 175.1±1.8 cm, and 77.1+4.3 kg). No significant differences in age, height, and body mass were evident between the groups ($P>0.05$). A crossover experimental design was not used because of the frequent reports about the protective effect promoted by repeated bouts of eccentric exercise [7, 21].

Volunteers were randomized by using a simple drawing of lots (A and B). Volunteers allocated into the lot A received LEDT while those into the lot B received placebo treatment. The group allocation code from the drawing of lots was performed by the therapist who set the control unit accordingly to either an LEDT or a placebo mode. This therapist was instructed not to communicate the type of treatment given to either the participants or the researchers responsible for the data collection of the variables of interest. Researchers were not present in the room during LEDT or placebo treatments. Thus, the treatment allocation was concealed from participants and researchers.

Eccentric exercise bout

An eccentric exercise protocol, using weighted dumbbells, was adopted from previous studies [5, 7]. To determine the dumbbell weight for eccentric exercise, each subject was requested to sit on a custom made preacher curl bench with his shoulder joint angle at 45° (0.79 rad) flexion with 0° abduction, and pull a handle attached to a load cell (EMG System, São Jose dos Campos, Sao Paulo, Brazil) using the non-dominant arm.

The elbow joint angle was set at 90° (1.57 rad), and the subject was asked to flex the elbow joint maximally while keeping the forearm supinated. This measurement was taken three times immediately before the eccentric exercise, with a 45-s rest between trials. The average peak force from the three trials was used to determine the dumbbell weight. No significant differences in dumbbell weight was found between the groups (LEDT=22±2 kg; PLACEBO=24±2 kg; $P>0.05$).

Once the load of the dumbbell was determined, the subjects were instructed to lower the dumbbell from an elbow flexion of 50° (0.87 rad) to an extended position of 170° (2.97 rad) in approximately 4–5 s. Subsequently, the investigator removed the dumbbell from the arm, and the subject returned the arm to the start position for the next eccentric contraction. Subjects were verbally encouraged and guided to lower the dumbbell at a consistent velocity by following a count given by the

investigator. The movement was repeated 30 times with a 45-s rest between contractions.

Intervention

Immediately after the eccentric exercise bout, the biceps muscle of the volunteers received a single treatment of active LEDT (group LEDT) or placebo LEDT (group PLACEBO). LEDT was administered by a single diode of 630 nm (BIOS therapy II, manufactured by BIOS® Medical Equipment Industry, Sao Jose dos Campos, São Paulo, Brazil). The parameters for the LEDT are summarized in Table 1. To keep LEDT and placebo procedures similar, a small protective shield was placed over the tip of the probe for those receiving placebo LEDT, thereby blocking the irradiation from reaching the subject's skin. To insure that LEDT radiation was delivered to most of the muscle belly, the biceps muscle belly of the non-dominant arm was divided into four parts providing four irradiation points evenly distributed along the ventral side of the muscle belly. An experienced therapist administrated the LEDT, and the irradiation was performed with the probe in direct contact with the skin applying slight pressure, and held stationary perpendicular to the skin. The volunteers used opaque goggles during the therapy to protect their eyes from the treatment and to help in the blindness of the study.

Dependent variables

The dependent variables consisted of elbow flexion peak force with the elbow joint angle set at 90° (1.57 rad), active range of motion (ROM) of the elbow joint and muscle soreness. The isometric muscle strength, elbow ROM, and muscle soreness measures were taken before and at 24, 48, 72, and 96 h after eccentric exercise.

Table 1 LEDT parameters

Parameters for LEDT
Wavelength, 630 nm
Frequency, Continuous output
Optical output, 300 mW
LED spot size, 1.77 cm^2
Treatment time, 30 s at each point
Number of irradiation sites, 4 points
Energy density in each point, 5.1 J/cm^2
Total energy density, 20.4 J/cm^2
Application mode, Stationary in skin contact with a 90° angle and slight pressure

Isometric muscle strength

The isometric muscle strength was recorded as described previously to determine the dumbbell weight. All isometric muscle strength measures were taken before, and at 24, 48, 72, and 96 h after the eccentric exercise bout. The highest peak force among the three trials from each day was used for statistical comparisons. The isometric muscle strength recorded at 24 to 96 h after exercise bout was normalized by the measure recorded before the exercise bout to allow comparisons between groups.

Elbow joint angles and ROM

On the basis of previous studies [7, 22], flexed elbow joint angle (FANG) was measured when the subject tried to touch his shoulder of the same side by flexing the elbow joint maximally while keeping the elbow joint at the side of the body. Extended elbow joint angle (EANG) was measured when the subject attempted to extend his elbow joint as much as possible with the elbow held by his side and the hand in mid pronation. Three photos were taken from each maximum active elbow joint flexion and extension using a digital camera (14.1 megapixels). The acromion, lateral epicondyle, dorsal tubercle of radius, and radial styloid process were used as anatomical landmarks. The photos taken were processed using the Image J software (NHI, Bethesda, MD, USA) to assess the FANG and EANG, and the average of the three measurements for flexion and extension was calculated to obtain the ROM, which was the difference between FANG and EANG. For the statistical analysis, the elbow ROM obtained between 24 and 96 h after exercise bout was normalized by the measure recorded before exercise bout.

Muscle soreness

The level of muscle soreness of the exercised arm was assessed using a visual analog scale (VAS) consisting of a 100-mm line representing "no pain" at one end (0 mm) and "very, very painful" at the other end (100 mm). The subjects were asked to indicate the level of pain on the line when the investigator extended the elbow joint maximally. The same investigator assessed the muscle soreness over time for all subjects, and the procedure was standardized as described in previous studies [5, 7].

Statistical analysis

For elbow flexion peak force and ROM, the measures after exercise bout and intervention were normalized using each subject's own initial baseline (i.e., measure before exercise bout and intervention) measurement as reference. Dependent variables were assessed with a two-way mixed model analysis

of variance (2 groups×5 times) with repeated measures over time points and group as between-subjects factors to compare the normalized force, normalized ROM, and VAS for the groups LEDT and PLACEBO following the exercise bout. Mauchly's sphericity test was performed, and the results are reported based on Greenhouse–Geisser correction because the sphericity was not established. Multiple comparisons were made according to Bonferroni's method (0.05/number of comparisons). A significance level of $p<0.05$ was used for all statistical procedures. Results are presented as mean ± SE. Statistical analysis was completed using the PASW 18 statistical package (SPSS Inc., Chicago, IL, USA).

Results

Anthropometric characteristics and the exercise load (i.e., dumbbell weight for the exercise bout) ($P>0.05$) from the LEDT and PLACEBO groups were similar ($P>0.05$). Similar baseline values were also observed for muscle soreness and elbow ROM ($P>0.05$) (see Table 2).

Normalized force decreased significantly after the eccentric exercise bout for both groups, reaching impairments of ~42 and ~23 %, for the PLACEBO and LEDT groups, respectively, 24 h after exercise. The normalized force showed a significant main effect for group ($F_{1,15}=4.83$, $p=0.04$) and time ($F_{1.33,19.95}=23.05$, $p=0.001$). A significant group×time ($F_{1.33,19.95}=4.28$, $p=0.04$) interaction was also observed. The PLACEBO group showed greater strength impairment than the LEDT group after the eccentric exercise bout (see Fig. 1).

As the normalized force, normalized ROM showed a significant main effect for group ($F_{1,15}=5.49$, $p=0.03$) and time ($F_{2.33,34.47}=30.61$, $p=0.001$). A significant group×time ($F_{2.33,34.47}=3.84$, $p=0.01$) interaction was also observed. The PLACEBO group showed greater impairment on the elbow range of motion than the LEDT group after the eccentric exercise bout (see Fig. 2).

Table 2 Mean ± SE of anthropometric characteristics, exercise load, and baseline values of muscle soreness and elbow ROM from LEDT and PLACEBO groups

	LEDT	PLACEBO
Age (years)	22±1	21±2
Height (cm)	172±4	175±2
Weight (kg)	67±4	76±4
Isometric muscle strength (N)	224±25	240±24
exercise load (kg)	22±2	24±2
muscle soreness (cm)	0±0	0±0
elbow ROM (deg)	134±2	131±4

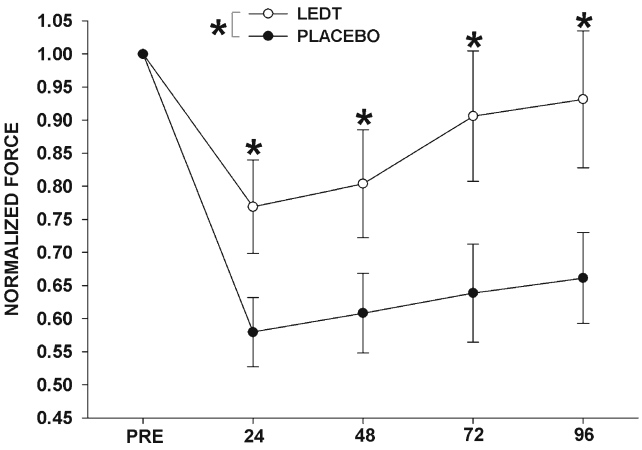

Fig. 1 Normalized force (mean ± SE) from LEDT and PLACEBO groups before (PRE), and 24, 48, 72, and 96 h after an eccentric exercise bout. (*) Significant difference between groups ($p<0.05$)

Muscle soreness, assessed using a visual analog scale (VAS), showed a significant main effect for group ($F_{1,15}=6.04$, $p=0.03$) and time ($F_{2.24,33.6}=11.05$, $p=0.001$). A significant group×time ($F_{2.33,34.47}=4.03$, $p=0.02$) interaction was also observed. The PLACEBO group showed greater muscle soreness than the LEDT group after the eccentric exercise bout (see Fig. 3).

Discussion

The goal of this study was to determine the effects of LEDT (630 nm) immediately after an eccentric exercise bout on indirect markers of muscle damage up to 96 h after exercise. Our results indicate a significant improvement on the muscle damage recovery for the group treated with a single LEDT (630 nm) immediately after an eccentric exercise bout.

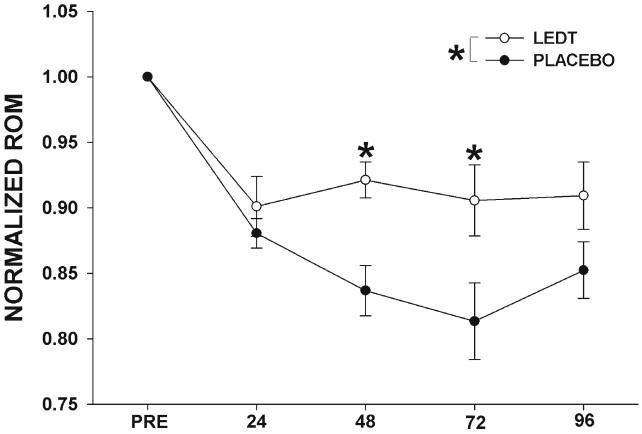

Fig. 2 Normalized range of motion (ROM) (mean ± SE) from LEDT and PLACEBO groups before (PRE), and 24, 48, 72, and 96 h after an eccentric exercise bout. (*) Significant difference between groups ($p<0.05$)

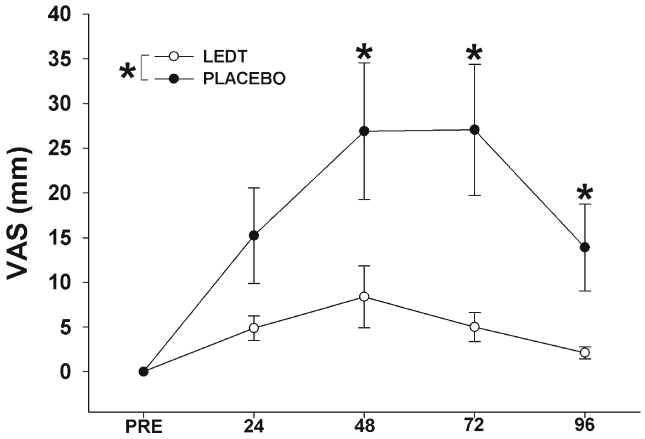

Fig. 3 Muscle soreness evaluated through visual analogic scale (VAS) (mean ± SE) from LEDT and PLACEBO groups before (PRE), and 24, 48, 72, and 96 h after an eccentric exercise bout. (*) Significant difference between groups ($p < 0.05$)

Muscle strength recovery

Loss of maximal voluntary contraction force is considered one of the best clinical methods for quantifying muscle injury [6, 23]. Inflammatory mediators, as TNF-α, may inhibit the force of contraction in skeletal muscles [24] and partially explain the muscle strength loss. Interestingly, Mesquita-Ferrari et al. [18] showed that phototherapy with a wavelength in the red waveband may modulate cytokine expression during the muscle repair process, inducing a decrease in TNF-α. Our results from maximal voluntary contraction force along the recovery time (i.e., 24 to 96 h post-eccentric exercise bout) may be explained by this effect of phototherapy on the inflammatory process. We showed that a single LEDT (630 nm) immediately after the eccentric exercise bout promoted the lowest muscle strength decrement after exercise and the fastest muscle strength recovery within the recovery time.

A fast muscle recovery is important to athletes, especially during competition, since athletes commonly return to training approximately 48 h following competition [11]. The ability to train consistently at high levels is important for athletes, and the potential advantage offered by LEDT (630 nm) for muscle strength recovery after exercise-induced muscle damage should be considered.

An innovative aspect of our study was the use of phototherapy with a wavelength in the red waveband only (630 nm) to exercise-damaged muscle in humans, which was done previously only in animal models. Considering the challenges of translational methods, like the skin differences and muscle dimensions, our results corroborate previous results from animal models [12, 13, 17] about the beneficial effect of phototherapy with a visible red wavelength on muscle recovery.

Previous studies determined the beneficial effect of phototherapy with near-infrared irradiation (805–904 nm) and combined wavelength irradiation (i.e., red [630–660 nm] and infrared irradiation [805–904 nm]) [19, 20, 25] on muscle recovery, but two main differences between these studies and the present study should be noted: (1) the wavelength range used was different and (2) the moment at which irradiation was applied was also different. As used in animal models [12, 13, 17], we applied phototherapy in an injured muscle, which may be different from the irradiation of intact muscle as was the case when phototherapy was applied previously following potentially damage-causing exercise. Despite the methodological differences (i.e., wavelength range used and moment of irradiation), our results corroborate the findings of Baroni et al. [20], showing a beneficial effect of phototherapy to muscle recovery after damaging exercises. Further studies should investigate the cellular and molecular mechanisms of muscle recovery when phototherapy is applied before or after damaging exercise.

Muscle soreness relief and range of movement recovery

Muscle soreness and reduced range of movement are common deleterious events observed after damaging exercises. These events seem to be related to the inflammatory process and subsequent swelling and activation of pain receptors [26]. Due to negative effect on movement and muscle function, several strategies to ameliorate these events have been proposed [9, 10, 25]. Based on its known anti-inflammatory effect [16], phototherapy is a useful intervention to minimize muscle soreness and swelling after damaging exercises.

Douris et al. [25] used phototherapy with combined wavelength (diodes with wavelengths of 880 and 660 nm) after an exercise-induced muscle damage bout and observed a significant muscle soreness relief, but not range of movement recovery, up till 96 h after the damage-inducing exercise. In the cited study, subjects received 8 J/cm^2 of phototherapy each day for five consecutive days, starting therapy immediately after the damage-inducing exercise. Despite the differences used in the wavelength range and number of treatments, our results corroborate the findings of Douris et al. [25]. Our results showed that a single LEDT (630 nm) intervention was sufficient to significantly relieve muscle soreness and improve the range of motion up till 96 h after damage-inducing exercise.

Differently from Douris et al. [25], we used phototherapy with a single visible red wavelength (630 nm), which ensured that the beneficial effect observed here was related to this wavelength range. Unfortunately, Douris et al. [25] gave no information regarding the individual energy density from either the red or the infrared diodes, so it is not possible to make direct comparisons between our and their results.

The findings from Glasgow et al. [27] could increase the debate about the influence of wavelength range used in phototherapy on muscle soreness and functional impairment, since they observed that phototherapy with an infrared

wavelength range (840 nm; 3.0 J/cm^2, pulse frequency 1 kHz) was ineffective in the management of DOMS after a damaging exercise bout. The differences in phototherapy parameters (i.e., beam mode, optical output, total energy density) should not be neglected, but it is possible to postulate that our promising results from a single LEDT (630 nm) intervention immediately after a damage-inducing exercise could be explained by the highest effectiveness of red wavelength range than infrared wavelength range to tissue repair [16], which involve the inflammatory process. However, further studies should be developed comparing phototherapy interventions with single red and infrared wavelength range applied with similar dose.

The current study showed that a single LEDT (630 nm) intervention immediately after a damaging exercise bout improved the muscle recovery up till 96 h after exercise. As observed in animal models, phototherapy with light energy in the red waveband may have a beneficial effect on muscle repair through anti-inflammatory mechanisms and tissue repair stimulation.

Further studies should investigate if multiple LEDT (630 nm) interventions (e.g., interventions with 24 h intervals), starting immediately after damaging exercise, can be better than a single intervention to improve the muscle recovery.

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Conflict of interest There are no conflicts of interest among any of the authors of this manuscript.

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