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ORIGINAL ARTICLE

Effect of 830 nm low-level laser therapy in exercise-induced skeletal muscle fatigue in humans

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Abstract This study aimed to investigate the effect of 830 nm low-level laser therapy (LLLT) on skeletal muscle fatigue. Ten healthy male professional volleyball players entered a crossover randomized double-blinded placebo-controlled trial. Active LLLT (830 nm wavelength, 100 mW output, spot size 0.0028 cm^2, 200 s total irradiation time) or an identical placebo LLLT was delivered to four points on the biceps humeri muscle immediately before exercises. All subjects performed voluntary biceps humeri contractions with a load of 75% of the maximum voluntary contraction (MVC) force until exhaustion. After active LLLT the mean number of repetitions was significantly higher than after placebo irradiation [mean difference 4.5, standard deviation (SD) ±6.0, P=0.042], the blood lactate levels increased after exercises, but there was no significant difference between the treatments. We concluded that 830 nm LLLT can delay the onset of skeletal muscle fatigue in high-intensity exercises, in spite of increased blood lactate levels.

Keywords Low-level laser therapy · Skeletal muscle · Muscle fatigue · Blood lactate

Introduction

Skeletal muscle fatigue is a common experience in daily life, although the mechanisms of action, development or prevention are not fully understood. Commonly observed features of skeletal muscle fatigue are decreased muscle strength, impaired motor control and subsequent muscular pain [1].

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The mechanisms that contribute to muscle fatigue during sustained submaximal contractions include several processes, e.g., input of the motor cortex, transmission by motor spinal neurons, local neuromuscular activation and capacity to generate force by contractile proteins in the muscle [2]. Muscle fatigue can be divided into a central component and a peripheral component. Peripheral factors that affect force production during muscle activity are the type and intensity of exercise, the muscle groups involved, and the local physical and biochemical environment. In this way, muscle fatigue is a complex and multifaceted process, involving physiological, biomechanical, and psychological elements [3]. Age and gender are also important factors which determine our ability to contract skeletal muscle and to withstand fatigue development [4]. There are some indications that exerted force declines rapidly in male subjects during the development of skeletal fatigue [5]. In clinical settings, skeletal muscle fatigue may also subsequently contribute to the development of muscle pain [6].

There are several different types of muscle fatigue, and the contribution of each to the overall decline in muscle performance depends on the muscle fiber type and the intensity and duration of the activity [7]. One type is caused by the buildup of potassium ions (K+) in the transverse-tubular T system in the immediate vicinity of the muscle fibers. The other major type of fatigue is the metabolic fatigue due to direct or indirect effects of the accumulation of metabolites, such as inorganic phosphate (Pi), adenosine diphosphate (ADP), magnesium ions (Mg^{2+}) and reactive oxygen species, and decrease in substrates [adenosine triphosphate (ATP), creatine phosphate and glycogen] [8].

The decrease in force generation in anaerobic conditions such as extensive exercise, would inevitably generate a large number of reactive oxygen species and disrupt mitochondrial function, which is known to cause muscle depolarization and reduced force [9]. Lactic acid accumulation alone inside the muscle fiber may not be responsible for decreased muscle performance, and its physiological role in muscle fatigue remains controversial [10]. However, in most of the high-level sports modalities, monitoring of blood lactic acid concentrations is still the main tool used to plan training programs [11].

Skeletal muscle fatigue is a novel area of low-level laser therapy (LLLT) research, and the optimal parameters of application are not fully understood. In clinical settings, LLLT has been used in the treatment of muscle pain, and some positive findings have been found for neck muscle pain [12] and conditions like fibromyalgia [13], which may be related to skeletal muscle fatigue.

In a previous animal experiment we found that LLLT could delay the inevitable decline in maximal contraction during repeated electrically induced tetanic contractions [14]. Specific doses of LLLT reduced muscle creatine kinase activity levels, thus indicating a decrease in muscle damage when compared with that in non-irradiated groups. In that particular animal experiment we dissected the anterior tibialis muscle from the distal insertion and removed the skin before irradiating the muscle with red LLLT. Later, we tried to translate this knowledge to a small (n=12) parallel-group study with professional volleyball players. In that trial we used the same laser wavelength of 655 nm and 50 mW output, applied at 5 J to each of four points along the ventral side of the biceps humeri muscle belly. We observed a small increase in the number of elbow flexion contractions performed and in the time used to perform the contractions, in spite of increased blood lactate levels [15].

Laser light penetration through human skin may pose a problem in clinical settings, and infrared wavelengths have better skin penetration than red wavelengths [16]. In addition, there are some indications from animal experiments that infrared laser wavelengths may be effective in reducing the release of reactive oxygen species (ROS) and increase the number of antioxidants and heat shock proteins [17, 18]. For these reasons we decided to investigate whether an infrared wavelength (830 nm) would have similar effects of LLLT on skeletal muscle fatigue, and whether there were differences in effects between active LLLT and placebo LLLT in the same persons in a crossover design.

Methods

The study was approved by the ethics committee of the Vale do Paraíba University (protocol number H141/CEP/2006). All subjects signed an informed consent declaration. The volunteers were recruited from professional male volleyball players from Rio Grande do Sul State (Brazil) at the same sporting level.

Randomization

All participants were subjected to LLLT procedures and a performance test two times. They were randomly allocated to the LLLT procedure by the simple drawing of lots (A or B), which determined whether they should first receive active LLLT or placebo LLLT. For participants drawing lot A, active LLLT was given at the first session and placebo LLLT was given at the second session. For participants drawing lot B, placebo LLLT was given at the first session and active LLLT at the second session. All participants were crossed over during the experiment, so that we could compare the outcomes after active LLLT and placebo LLLT, respectively, for each participant. The group allocation code from the drawing of lots was delivered to a technician who pre-set the laser control unit accordingly to

either an active LLLT or placebo LLLT mode. In this way, participants who had drawn A received active LLLT at the first session, and placebo LLLT at the second session, while participants who drew B, received placebo LLLT at the first session and active LLLT at the second session. The technician was also instructed not to communicate the type of treatment given to either the participants or the therapist applying the laser source to the biceps, or to the observers. Thus, the allocation to treatments was concealed to participants, therapist and observers.

Inclusion criteria

1. Male volleyball players
2. Having played volleyball at a professional level for at least 2 years
3. Aged between 18 years and 36 years

Exclusion criteria

1. Any previous musculoskeletal injury to the shoulder or elbow regions
2. Participation in fewer than 80% of the regularly scheduled physical training and volleyball sessions for the professional volleyball team
3. Use of any kind of nutritional supplements or pharmacological agents

Procedures

In order to provide a stable condition for the elbow, we used a Scott chair with an inclination of 45°. For the measurement of the time of irradiation and total time of repetitions, a Nike® chronometer with a two-decimal scale was used.

Maximum voluntary contraction test Athletes were familiarized with elbow flexion–extension exercises with an adaptation and standardization period of 2 weeks. After 2 weeks of familiarization with the exercises, they were given a maximal contraction force test that consisted of one single repetition of flexion to 90° from full extension of the elbow, so that we could evaluate the strength of the biceps muscle while the subject was seated in the Scott chair. Free weights (halters) were used, and the specific individual weight (load) corresponding to 75% of the maximum voluntary contraction (MVC), was established for each subject.

Period of evaluation Care was taken in obtaining standardization in the execution of the exercise protocols. The participants performed the exercises in the standard sitting position at approximately the same time of the day (to control for the circadian rhythm). Also, muscle strength training was performed in the same manner each time, at 75% of maximal load. The exercises were performed and evaluated in two sessions (day 1 and day 8) on the same day of the week (Monday) at the same time of day (between 8:30 and 11:00 A.M.). Any hard physical activity was not permitted during the weekend before testing. The timeline of the experiment is shown in Fig. 1.

Fatigue protocol At the first (day 1) and second (day 8) exercise test sessions of the study, basal lactate measurements were obtained for each subject from the second finger, on the arm involved in the fatigue exercises. Immediately after, all ten subjects were submitted to a series of muscle stretching exercises involving all the major muscles of the upper extremities (two rounds of 60 s for each muscle group) and finishing with the flexor muscles of the elbow. Then, each subject was seated in the Scott chair, with the knee and the hip flexed at 90°. Using a free weight halter, we ensured that the previously defined personal weight load (= 75% of maximal load) was attained for each subject. A goniometer was fixed to the Scott chair to measure the flexion angle and was controlled by an observer (E.L.J.). The number of repetitions in the exercise fatigue test was counted by the same observer (E.L.J.), and the total time each participant took to finish the effort was measured by a second observer (T.D.M.).

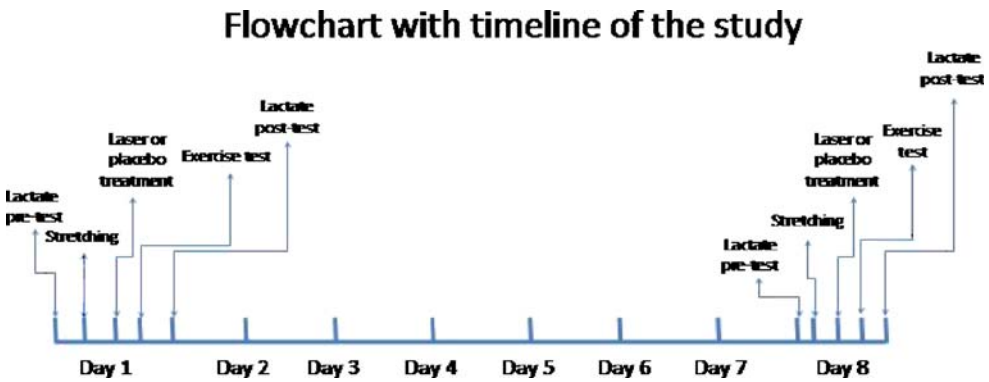

Fig. 1 Time flow chart of the study

LLLT protocol

All participants received both active LLLT and placebo LLLT. At both LLLT sessions (day 1 and day 8), the participants either received a single treatment of active LLLT or a single treatment of placebo LLLT (both with an 830 nm Thera Lase; DMC® São Carlos, SP, Brazil). Active LLLT or placebo LLLT was administered after the stretching regimen but immediately before the exercise fatigue test. All active LLLT and placebo LLLT procedures, were administered by a single therapist (A.A.V.). Blinding was maintained by the participants', the therapist's and the observers' use of opaque goggles during active and placebo LLLT. In addition, the 830 nm infrared laser wavelength is invisible, and the laser was not turned on before the tip of the laser probe was put in contact with the skin over the biceps muscle. The biceps muscle belly was divided into four irradiation points, evenly distributed along the ventral side of the muscle belly, in order to deliver LLLT irradiation to most of the muscle belly (Fig. 2).

The irradiation was performed in contact mode with the laser probe held stationary with slight pressure at a 90° angle on each of the four treatment points. Each subject received two different treatment sessions, 1 week apart, with either active LLLT or placebo LLLT before the exercise tests. The laser parameters are summarized in Table 1.

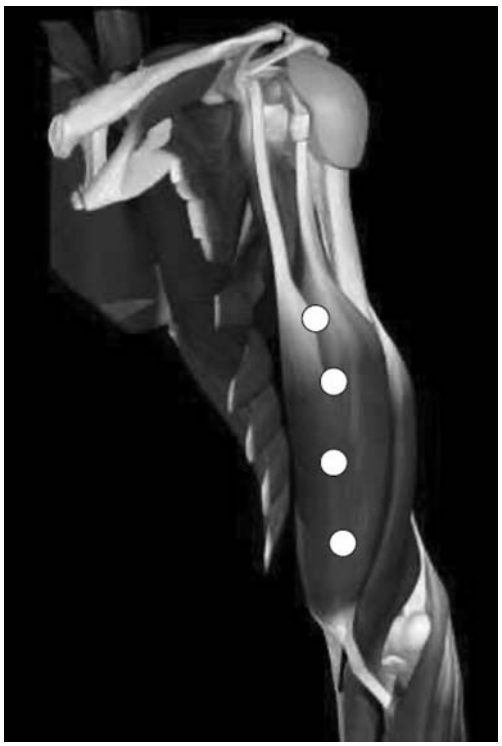

Fig. 2 Laser irradiation points (*white circles*) used for laser or placebo laser

Table 1 Laser parameters

Parameters	
Wavelength	830 nm (infrared)
Laser frequency	Continuous output
Optical output	100 mW
Spot diameter	0.06 cm
Spot size	0.0028 cm^2
Power density[2]	35.7 W/cm^2
Energy	5 J to each point
Energy density	1,785 J/cm^2 at each point
Treatment time	50 s at each point
Number of points	4
Total energy delivered	20 J
Application mode	Probe held stationary in skin contact with a 90° angle and slight pressure

Immediately after LLLT, the participants were repositioned and started on the fatigue exercise test within 60 s.

Blood samples and lactate concentration

In order to measure blood lactate concentrations, following aseptic cleaning of the finger, a qualified nurse, who was unaware of the group allocation, took one blood sample before and another 3 min after the exercises had been completed. This was done before the exercise tests, 1 week apart. The finger from which the blood sample was taken was on the same side that was holding the free weight for the biceps contraction in all subjects. Accu-Chek Soft Clix® lancets were used, and the samples were immediately analyzed with a portable Accutrend Lactate® analyzer by an observer who was unaware of the group allocations.

Statistical analysis

Group means and their respective standard deviations were used for statistical analysis. We used a two-sided paired *t*-test to test if there was a significant difference in change between active LLLT or placebo LLLT. The significance level was set at $P<0.05$.

Results

Ten healthy male professional volleyball players were recruited, who met the inclusion criteria. Their average age was 22.30 (±6.09) years; their body weight was a mean of 87.78 kg (±9.27 kg) and their height was 193.90 cm (± 7.14 cm).

The mean number of repetitions performed in the exercise test was 25.60 (±6.15) when the subjects received

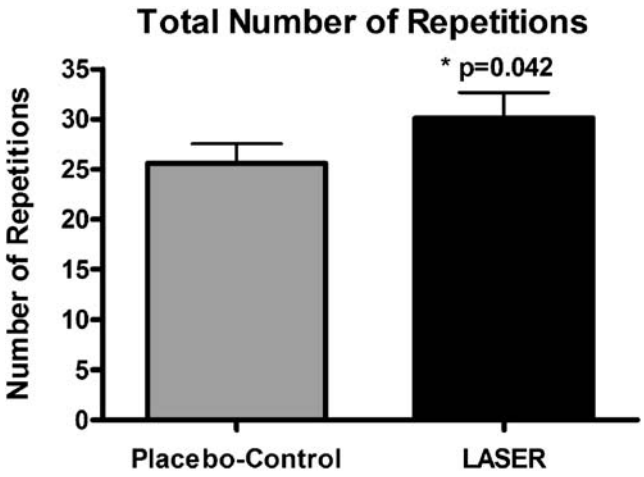

Fig. 3 Number of biceps muscle contractions

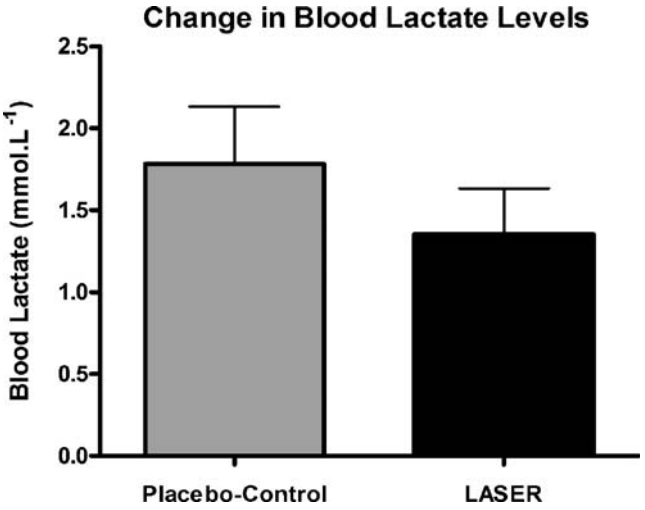

Fig. 5 Change in blood lactate levels after the exercises

placebo LLLT, and 30.10 (±8.08) when the subjects received active LLLT before the exercise fatigue tests (P= 0.042). The results are summarized in Fig. 3.

The time taken to perform the exercise tests was slightly longer after active LLLT (37.15 ±6.45 s) than after placebo LLLT (34.34 ±6.77 s), but this difference did not reach statistical significance (P=0.096). The results for elapsed time are summarized in Fig. 4.

The blood lactate levels before exercise tests were 2.31 mmol l^{-1} (±0.36 mmol l^{-1}) and 2.16 mmol l^{-1} (± 0.37 mmol l^{-1}), respectively, and the blood lactate level increased during exercise in all groups. However, there was no significant difference in the change in blood lactate levels from pre-exercise tests to post-exercise tests (P= 0.200) between active LLLT, at 1.35 mmol l^{-1} (± 0.90 mmol l^{-1}), or placebo LLLT, at 1.78 mmol l^{-1} (± 1.10 mmol l^{-1}). The results are summarized in Fig. 5.

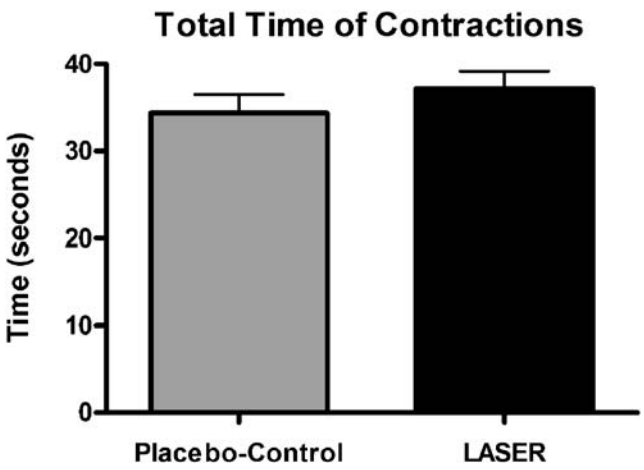

Fig. 4 Time elapsed for biceps muscle contractions

Discussion

In this small trial we found some indication that LLLT might be able to delay the onset of a skeletal muscle fatigue response during high-intensity exercises, by significantly increasing the number of repetitions after pre-treatment with active LLLT in comparison with placebo LLLT. The results for this infrared wavelength (830 nm) are slightly poorer than the results we observed in our previous LLLT studies with red 655 nm wavelength. There may be several reasons for that. The doses we used in the animal study were “in situ” doses, because the muscles were dissected and the animal skin was removed [14]. Another possibility is that the modulatory effect of LLLT on reactive species could be partly wavelength-specific. However, we find this unlikely, because previous animal studies have shown that infrared LLLT can prevent ischemic muscle injuries by reducing the release of reactive oxygen species (ROS) and creatine phosphokinase activity, while increasing levels of antioxidants and heat shock proteins [17, 18]. Another possibility is that the very small spot size of the infrared laser (0.0028 cm^2), in comparison with the red wavelength spot size (0.08 cm^2), and consequently the higher power density, may have contributed in a negative direction. It may also be that the four points we chose for irradiation covered an insufficient area for achieving optimal treatment effects. These issues illustrate the difficult transition of positive findings in animal studies to a clinically relevant treatment situation. Our findings clearly suggest that both more dose-finding studies and studies investigating LLLT mechanisms need to be performed in this novel area of LLLT research.

The lack of differences in the blood lactate levels after treatments may indicate that the mechanisms behind the observed effect are not associated with a delayed shift from

aerobic to anaerobic muscle metabolism. Several authors have reported that decline in muscle force or power output leading to impaired exercise performance is not associated with the accumulation of lactic acid or hydrogen ions [19, 20]. It has also been shown that contractions of a highly aerobic muscle under anaerobic conditions will generate large amounts of ROS, leading to muscle depolarization and reduced force [21]. In this way, LLLT could be useful in preventing fatigue, in order to improve muscle performance. Our findings of a delayed onset of skeletal muscle fatigue are consistent with previous findings in an animal study [14] and must be considered as a first step in a novel area of LLLT research where many questions are, as yet, unanswered. The clinical impact of our findings is also limited by the fact that the observed effects were measured within a few minutes after irradiation (200 s of LLLT, 60 s for repositioning, and 28–40 s for exercise fatigue testing).

Clinical studies have previously demonstrated that active LLLT with a greater dose of 8.9 J increased post-exercise microcirculation, but did not reduce spontaneous pain, in the masseter muscle [22]. A positive LLLT effect on delayed onset muscle soreness has also been described in one trial with an optimal LLLT dose [23], while others have failed to find such effects with non-optimal doses [24, 25]. In our study, we made a few considerations for optimizing clinical use in humans. Our findings may be relevant to other areas, such as chronic muscle pain syndromes. Several treatment options are available for the treatment of chronic muscle pain, but currently none seems to provide the ultimate balance between benefit and harm. In addition, some disorders such as chronic neck muscle pain and fibromyalgia may be recalcitrant, as no single treatment appears to provide convincing results. There seems to be a majority of positive LLLT results in common muscle pain syndromes such as neck pain [26], but the possible mechanisms seem to be poorly understood. Our study primarily investigated the effects of LLLT on muscle tissue, and a possible systemic effect. Recently, another novel LLLT mechanism was observed in an animal study where LLLT blocked the axonal flow of small diameter nerves [27]. Common treatments for muscle pain are often associated with transient painful perceptions, such as massage and acupuncture, and pharmaceutical muscle relaxants may cause addiction and inflict poorer prognosis in low back pain [28]. Fibromyalgia is another chronic condition where fatigue and oxidative stress seem to play important roles. Two clinical studies have already found beneficial effects from LLLT in fibromyalgia [13, 29]. Exercise therapy has been used with some long-term success in fibromyalgia, but the intensity of the exercise must be increased slowly so that episodes of increased pain and setback can be avoided [30, 31]. Exercise-induced fatigue is often associated with painful reactions in fibromyalgia patients, and LLLT may have a potential role in reducing post-exercise pain in these patients.

Conclusion

We conclude that LLLT can delay the perceived onset of muscle fatigue and exhaustion, probably by local mechanisms that may include the reduction of oxidative stress or the decreased production of reactive oxygen species. Blood lactate concentrations were similar immediately after the muscle performance test, but we cannot rule out that the accumulation of lactate may have been slightly delayed by LLLT. Further studies are needed to clarify this matter. The clinical impact of our findings may be limited by the experimental model, which only measured the immediate effects on muscle performance within 2 min of irradiation. However, the study may open another clinical avenue to treatment of musculoskeletal conditions where muscle fatigue is a precursor of pain.

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