

Effect of 830 nm low-level laser therapy applied before high-intensity exercises on skeletal muscle recovery in athletes

Ernesto Cesar Pinto Leal Junior ·
Rodrigo Álvaro Brandão Lopes-Martins ·
Bruno Manfredini Baroni · Thiago De Marchi ·
Dajana Taufer · Débora Sgandella Manfro ·
Morgana Rech · Vanessa Danna · Douglas Grosselli ·
Rafael Abeche Generosi · Rodrigo Labat Marcos ·
Luciano Ramos · Jan Magnus Bjordal

Received: 22 September 2008 / Accepted: 31 October 2008
© Springer-Verlag London Ltd 2008

Abstract Our aim was to investigate the immediate effects of bilateral, 830 nm, low-level laser therapy (LLLT) on high-intensity exercise and biochemical markers of skeletal muscle recovery, in a randomised, double-blind, placebo-controlled, crossover trial set in a sports physiotherapy clinic. Twenty male athletes (nine professional volleyball players and eleven adolescent soccer players) participated. Active LLLT (830 nm wavelength, 100 mW, spot size 0.0028 cm², 3–4 J per point) or an identical placebo LLLT was delivered to five points in the rectus femoris muscle (bilaterally). The main outcome measures were the work performed in the Wingate test: 30 s

of maximum cycling with a load of 7.5% of body weight, and the measurement of blood lactate (BL) and creatine kinase (CK) levels before and after exercise. There was no significant difference in the work performed during the Wingate test ($P>0.05$) between subjects given active LLLT and those given placebo LLLT. For volleyball athletes, the change in CK levels from before to after the exercise test was significantly lower ($P=0.0133$) for those given active LLLT ($2.52 \text{ U l}^{-1} \pm 7.04 \text{ U l}^{-1}$) than for those given placebo LLLT ($28.49 \text{ U l}^{-1} \pm 22.62 \text{ U l}^{-1}$). For the soccer athletes, the change in blood lactate levels from before exercise to

E. C. P. Leal Junior (✉) · B. M. Baroni · T. De Marchi ·
D. Grosselli · R. A. Generosi
Laboratory of Human Movement (LMH),
Sports Medicine Institute (IME),
University of Caxias do Sul (UCS),
Rua Francisco Getúlio Vargas, 1130,
95070-560 Caxias do Sul, RS, Brazil
e-mail: ecplealj@ucs.br

E. C. P. Leal Junior · B. M. Baroni · R. A. Generosi
Sports Medicine Institute (IME),
University of Caxias do Sul (UCS),
Caxias do Sul, RS, Brazil

E. C. P. Leal Junior · J. M. Bjordal
Section for Physiotherapy Science,
Institute of Public Health and Primary Health Care,
University of Bergen,
Bergen, Norway

R. Á. B. Lopes-Martins · R. L. Marcos · L. Ramos
Laboratory of Pharmacology and Phototherapy of Inflammation,
Department of Pharmacology, Institute of Biomedical Sciences,
University of São Paulo (USP),
São Paulo, SP, Brazil

T. De Marchi · D. Taufer · D. S. Manfro · M. Rech · V. Danna
Faculty of Physiotherapy, University of Caxias do Sul (UCS),
Caxias do Sul, RS, Brazil

R. A. Generosi
Federal University of Rio Grande do Sul (UFRGS),
Porto Alegre, RS, Brazil

D. Grosselli
Faculty of Physical Education, University of Caxias do Sul (UCS),
Caxias do Sul, RS, Brazil

J. M. Bjordal
Institute for Physical Therapy, Bergen University College,
Bergen, Norway

15 min after exercise was significantly lower ($P < 0.01$) in the group subjected to active LLLT ($8.55 \text{ mmol l}^{-1} \pm 2.14 \text{ mmol l}^{-1}$) than in the group subjected to placebo LLLT ($10.52 \text{ mmol l}^{-1} \pm 1.82 \text{ mmol l}^{-1}$). LLLT irradiation before the Wingate test seemed to inhibit an expected post-exercise increase in CK level and to accelerate post-exercise lactate removal without affecting test performance. These findings suggest that LLLT may be of benefit in accelerating post-exercise recovery.

Keywords LLLT · Skeletal muscle · Skeletal muscle recovery · Blood lactate · Creatine kinase · Muscle damage · Sports

Introduction

Skeletal muscle fatigue is an inevitable phenomenon in the training and competition routine for most athletes and can impair their performance and predispose the athlete to a variety of musculoskeletal disorders. This kind of harm may be transient, lasting minutes or hours after exercise, but it can also last for several days [1]. In the first few hours physical performance is impaired by metabolic disturbances that occur after high-intensity exercises [2]. When physical performance is impaired for days, this may be related to tissue injuries caused by exercise and the phenomenon known as delayed-onset muscle soreness (DOMS) [3].

A large number of therapeutic modalities are used in sports rehabilitation to accelerate muscle recovery after exercises, such as: active recovery [4–6] cryotherapy [3, 7, 8], massage [5, 9], contrast heat therapy (immersion in hot and cold water) [10, 11], hydrotherapy [12], stretching [1], hyperbaric oxygen therapy [13], non-steroidal anti-inflammatory drugs (NSAIDs) [14] and electrostimulation [15].

While some authors [1, 2, 16] discuss the validity of the blood lactate concentration as a parameter to determine the muscle recovery after exercise, this method has been widely used for this purpose [4–6]. For example, active recovery through low-intensity exercises seems to accelerate lactate removal from the muscle and increase blood circulation [5, 17], and some studies [4, 18] also suggest that this therapeutic modality can improve performance.

Serum levels of skeletal muscle enzymes are markers of the functional status of muscle tissue and vary widely in both pathological and physiological conditions. Early increased levels of some of these enzymes are associated with later cellular necrosis and tissue damage in acute and chronic muscle injuries [19].

The changes in serum levels of muscular enzymes and isoenzymes are also found in healthy subjects and in athletes after strenuous exercise [20, 21], and the levels of enzymes from muscle tissue in blood can be influenced by

physical exercise [22]. The activity of creatine kinase (CK), measured from muscle needle biopsies, changes during and after training bouts [23], and the serum level of CK changes according to different training protocols and their respective intensities and types of training [24, 25].

CK levels are important in sport medicine for obtaining information on the current state of the muscle integrity [26]. High levels of serum CK in apparently healthy subjects is normal after physical work. However, if a high level persists at rest, it may be a sign of subclinical muscle disease, which may trigger the onset of symptoms such as profound fatigue when physical work is performed [27].

Skeletal muscle fatigue is a novel area of research in low-level laser therapy (LLLT), and the optimal parameters of LLLT application are not fully understood. In clinical settings, LLLT has been used in the treatment of musculo-skeletal pain. Some positive findings in conditions such as neck muscle pain [28] and fibromyalgia [29] may be related to the same mechanisms that cause skeletal muscle fatigue.

In a previous experiment on animals, we dissected the anterior tibialis muscle from the distal insertion and removed the skin before irradiating the muscle with red LLLT (655 nm). In this experimental set-up we found that some doses of LLLT delayed the inevitable decline in maximal contraction during repeated electrically induced tetanic contractions [30]. Specific doses of LLLT also significantly reduced muscle CK activity when compared with that in non-irradiated groups.

Laser light penetration through human skin may pose a problem in clinical settings, and infrared wavelengths have better skin penetration ability than red wavelengths have [31]. In addition, there are some indications from animal studies that infrared laser wavelengths may be effective in reducing the release of reactive oxygen species (ROS) and may increase the content of antioxidants and heat shock proteins [32, 33]. For these reasons we decided to investigate if an infrared wavelength (830 nm) would have effects on skeletal muscle recovery in a homogeneous sample of elite athletes, and if there were differences in effects between active LLLT and placebo LLLT in the same athletes in a crossover design.

Methods

We performed a crossover, randomised, double-blind, placebo-controlled trial. The study was approved by the ethics committee of the Vale do Paraíba University (protocol number H260/CEP/2006 and H262/CEP/2006). All subjects or one their parents signed written informed consents before their participation in the experiment. The volunteers were recruited among professional male volleyball players ($n=9$) and young male soccer players ($n=11$)

from Rio Grande do Sul State (Brazil) at the same sporting level (highest national level), and they were scheduled to receive either active LLLT or placebo LLLT before an exercise session.

Randomisation procedure

Randomisation was performed by a simple drawing of lots (A or B), which determined if participants should receive active LLLT or placebo LLLT in the first session. The randomisation procedure was administered by an assistant not involved in the experiment. The allocation code was then delivered to a technician who preset the laser control unit to active or placebo LLLT mode. He then delivered the preset laser unit to the therapist. The technician was instructed not to communicate the type of treatment given to either the patients or the therapist, or to the observers. Thus, the allocation to treatments was concealed from participants, therapist and observers.

Blinding procedure

Careful attention was paid to the blinding procedure, which was composed of several measures to ensure complete blinding. The infrared wavelength (830 nm) is invisible to the human eye. The laser was only activated after the laser probe had been placed on the skin, and the laser probe was not removed before the irradiation was over and the laser probe deactivated. This procedure hid sight of the laser beam from both the therapist and the participants. To ensure blinding further, both therapist and participants used dark laser goggles for eye protection. Observers and analysts were also blinded to the type of treatment given.

All athletes performed the same exercise test, but for the volleyball athletes we analysed the creatine kinase levels and for the soccer athletes we analysed the levels and removal of blood lactate.

Inclusion criteria for volleyball players

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

Inclusion criteria for soccer players

1. Male soccer players
2. Having played soccer for at least 4 years and with at least 5 days of training per week
3. Aged between 15 and 18 years

Exclusion criteria for both

1. Any previous musculoskeletal injury to the hip, knee or ankle regions
2. Participation in fewer than 80% of the regularly scheduled physical training and soccer sessions for the soccer team or volleyball sessions for the volleyball team
3. Players using any kind of nutritional supplements or pharmacological agents

Test procedures

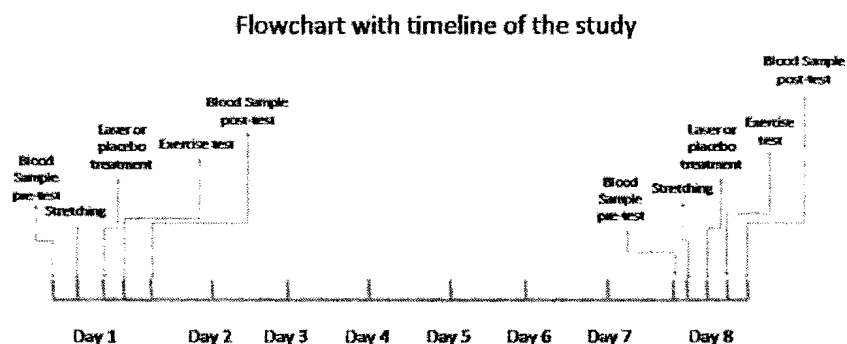
Period of evaluation We took care to obtain standardisation in the execution of the exercise protocols. The subjects performed the exercises in a standard sitting position at approximately the same time of the day (to control for the circadian rhythm). The exercises were performed and evaluated in two sessions (day 1 and day 8) on the same day of the week (Monday) during the same period of the day (between 08:30 a.m. and 11:30 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 test protocol At the first session (day 1) and second session (day 8) of the study, basal blood measurements (creatine kinase or lactate) were obtained for each subject. Immediately after this the test observer instructed the athletes and supervised their conduct in a series of muscle-stretching exercises. Stretching exercises involved all the major muscles of the lower extremities (one round of 60 s for each muscle group). Then, the observer seated each subject on the ergometer cycle and fixed their feet to the pedals. Instructions for the Wingate test were then delivered to the athletes. For each athlete, the test consisted of cycling at maximum speed for 30 s against a load of 7.5% of the athlete's body weight.

Protocol for low-level laser therapy

At both sessions (day 1 and day 8), the participants were given either a single treatment of active LLLT or a placebo LLLT (both with 830 nm Thera Lase; DMC® São Carlos, SP, Brazil), according to the result of the randomisation procedure. Active LLLT or placebo LLLT was administered after the stretching regimen but immediately before the exercise fatigue test. Active LLLT and placebo LLLT were administered by a therapist (M.R.). The laser was not turned on until the tip of the laser probe had been put into contact with the skin over the rectus femoris muscle. The

Fig. 1 Time flow chart of the study



belly of the rectus femoris muscle was divided into five irradiation points evenly distributed along the ventral middle line of the muscle belly so that we could deliver LLLT to most of the muscle belly. The laser irradiation was performed bilaterally, and thus ten points in total were irradiated (Fig. 2).

The laser irradiation was performed in contact mode, with the laser probe held stationary under slight pressure at a 90° angle to the skin surface. The laser unit incorporated a timer, which automatically shut off the laser beam while giving a sound signal when the preset irradiation time had been finished. The laser probe was not removed from skin

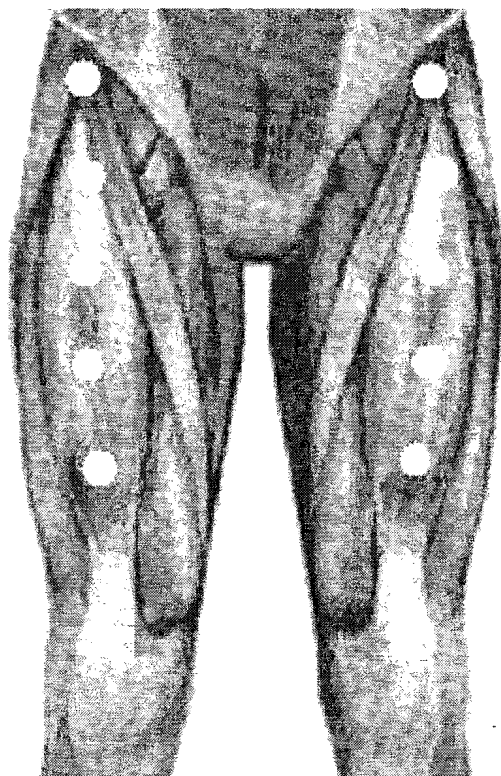


Fig. 2 Laser irradiation points (white circles) used for active LLLT or placebo LLLT

contact until the timer had shut off the laser. All subjects received active LLLT and placebo LLLT 1 week apart and immediately before undergoing the Wingate tests. Because the soccer athletes at hand were adolescents and performed less work in the Wingate test, we decided to use lower LLLT doses for these athletes. The laser parameters are summarised in Table 1.

After active LLLT or placebo LLLT had been administered, the participants were immediately repositioned, and they started the fatigue exercise protocol within an interval of 180 s.

Blood samples and creatine kinase analysis (volleyball athletes)

In order to measure blood CK, we took blood samples after aseptic cleaning of the ventral side of the dominant arm. The procedure was performed by a qualified nurse (unaware of the group allocation), who took one sample before the exercises were started and another blood sample 3 min after the exercises had been completed. The blood analysis was performed by infrared spectrophotometry.

Blood samples and lactate concentration (soccer athletes)

In order to measure blood lactate concentrations, we took blood samples after aseptic cleaning of the second finger of the dominant arm. The procedure was performed by a qualified nurse (unaware of the group allocation), who took one sample before the exercises were started and another blood sample 3 min, 10 min and 15 min after the exercises had been completed. Accu-Chek Soft Clix® lancets were used, and the samples were immediately analysed with the portable Accutrend Lactate® analyser.

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 the muscle

Table 1 Laser parameters

Laser parameters
Wavelength: 830 nm (infrared)
Frequency: continuous output
Optical output: 100 mW
Spot diameter: 0.0006 cm
Spot size: 0.0028 cm ²
Power density: 35.71 W/cm ²
Energy: 4 J at each point (volleyball players), 3 J at each point (soccer players)
Energy density: 1,428.57 J/cm ² at each point (volleyball players), 1,071.43 J/cm ² at each point (soccer players)
Treatment time: 40 s at each point (volleyball players), 30 s (soccer players)
Number of points: 10
Total energy delivered: 40 J (volleyball players), 30 J (soccer players)
Application mode: probe held stationary in skin contact with a 90° angle and slight pressure

work during the Wingate test and change in CK levels between the group undergoing active LLLT and those receiving placebo LLLT, and we used analysis of variance (ANOVA) with a Student–Newman–Keuls post-test to test if there was a significant difference in the change in blood lactate levels between the group subjected to active LLLT and those undergoing placebo LLLT. The significance level was set at $P < 0.05$.

Results

There were nine healthy male professional volleyball players recruited who met the inclusion criteria. Their average age was 20.67 (± 2.96) years, their weight was a mean 91.67 kg (± 7.84 kg), and their height was 195.33 cm (± 6.28 cm).

There were 11 healthy young male soccer players recruited who met the inclusion criteria. Their average age was 16.18 (± 0.75) years, their weight was a mean 66.82 kg (± 6.68 kg), and their height was 175.82 cm (± 5.83 cm).

The Wingate test (undertaken immediately after active LLLT or placebo LLLT) revealed a non-significant difference in muscle work between the active LLLT group (21,888.31 J \pm 2,062.98 J) and the placebo LLLT group (22,429.79 J \pm 2,842.71 J), $P = 0.3583$, for volleyball players, and 16,214.97 J (\pm 1,639.88 J) for the active LLLT group and 16,289.21 J (\pm 1,700.34 J) for the placebo LLLT group ($P = 0.8681$) for soccer players. The results are summarised in Fig. 3.

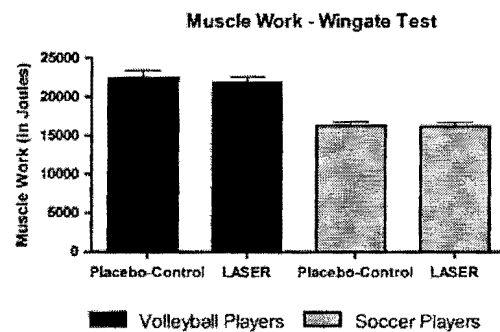


Fig. 3 Muscle work performed by volleyball athletes and soccer athletes during the Wingate test

Before both treatments the volleyball players showed similar creatine kinase levels at the pre-exercise test; before the active LLLT the athletes had a mean level of 108.64 U l⁻¹ (± 33.68 U l⁻¹) and before the placebo LLLT the athletes had a mean level of 107.72 U l⁻¹ (± 41.12 U l⁻¹) ($P = 0.7737$).

The results of the creatine kinase tests after the exercises showed that the active LLLT treatment promoted a lower change (2.52 U l⁻¹ \pm 7.04 U l⁻¹) in the muscle damage than the did the placebo LLLT (28.49 U l⁻¹ \pm 22.62 U l⁻¹) ($P = 0.0133$). The results are summarised in Fig. 4.

For both treatments the soccer players presented similar blood lactate levels at the pre-exercise tests, with a mean of 2.52 mmol l⁻¹ (± 0.52 mmol l⁻¹) for active LLLT and 2.24 mmol l⁻¹ (± 0.33 mmol l⁻¹) for placebo LLLT, with no statistical difference ($P > 0.05$).

The results of blood lactate tests showed that both treatments increased the blood lactate levels from baseline assessments to post-exercise assessments. There were, however, no significant differences between the two treatments in the change in lactate levels 3 min after exercise (active LLLT 10.75 mmol l⁻¹ \pm 2.11 mmol l⁻¹; placebo

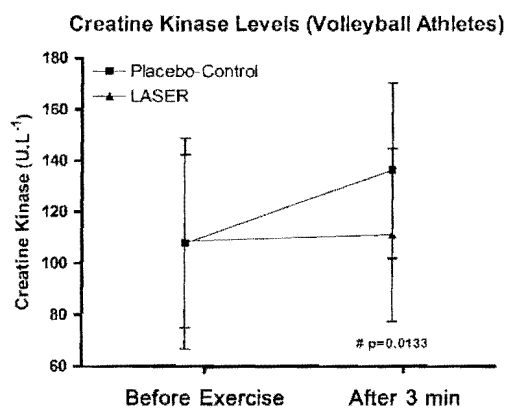


Fig. 4 Creatine kinase levels

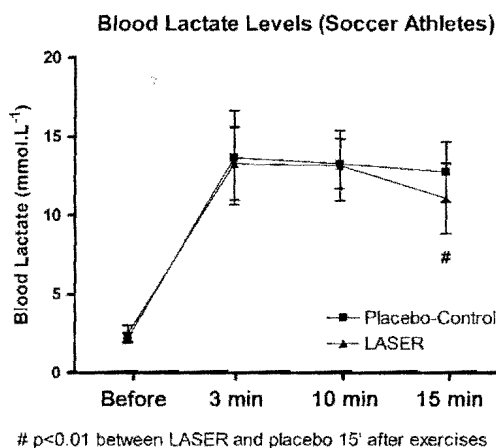


Fig. 5 Blood lactate levels (# $P < 0.01$ between laser and placebo 15 min after exercise)

LLLT $11.42 \text{ mmol l}^{-1} \pm 2.89 \text{ mmol l}^{-1}$; $P > 0.05$) and 10 min after exercise (active LLLT $10.63 \text{ mmol l}^{-1} \pm 2.17$; placebo LLLT $11.04 \text{ mmol l}^{-1} \pm 1.42 \text{ mmol l}^{-1}$; $P > 0.05$). However, 15 min after exercise, the active LLLT group with a mean of $8.55 \text{ mmol l}^{-1} (\pm 2.14 \text{ mmol l}^{-1})$ presented a lower significant value than did the placebo LLLT group with a mean of $10.52 \text{ mmol l}^{-1} (\pm 1.82 \text{ mmol l}^{-1})$ with $P < 0.01$. The results are summarised in Fig. 5.

Discussion

In this clinical trial we evaluated the effect of LLLT, applied before high-intensity exercises, on the production and removal of blood lactate and on muscle damage in athletes. In a previous study using a rat model, Lopes-Martins et al. [30] found that LLLT seemed to attenuate skeletal muscle fatigue and reduced the muscle damage caused by tetanic contractions induced by electrical stimulation. Our previous studies demonstrated that LLLT at 655 nm [34] and 830 nm [35] wavelengths can delay skeletal muscle fatigue in humans, with increased voluntary muscle contractions without increased blood lactate levels when compared with placebo LLLT treatment.

In the study described now we used the Wingate test to increase the blood lactate levels and induce muscle damage, to verify the effect of LLLT application before high-intensity exercises in preventing muscles disorders. The reason we used different blood analyses for the two types of athletes (volleyball players and soccer players) was because we had suffered some problems during data acquisition, and it was a limitation of our research. Therefore, in further studies, we recommend that both analyses should be performed for all subjects.

Our results demonstrated that LLLT applied before exercise was able to reduce muscle damage and increase the removal of blood lactate. The decrease observed in the levels of CK and blood lactate under active LLLT compared with placebo LLLT could be related to the ability of LLLT to prevent muscle ischaemia by reducing both the release of reactive oxygen species (ROS) and the activity of creatine phosphokinase, while levels of antioxidants and heat shock proteins increase [32–33]. In a recent study [36], LLLT improved mitochondrial function in muscle cells at doses of $0.33\text{--}8.22 \text{ J/cm}^2$, and LLLT doses of 0.33 J/cm^2 and 1.338 J/cm^2 reversed the dysfunctional state induced by electrical stimulation. This effect could, in turn, possibly contribute to the observed decrease in CK levels in our study. The LLLT increase the microcirculation, and it could be the responsible to increase the blood lactate removal [37].

The majority of therapeutic modalities are applied after the exercises; however, in this study, we aimed to evaluate also the effect of a novel therapeutic modality on previous sports recovery exercises to prevent injuries and increase muscle recovery after high-intensity exercises. These findings could help the physiotherapist to increase athlete's recovery between exercise sessions, reducing the injuries, mainly muscle injuries, and, consequently, increasing the athlete's performance.

The clinical impact of our findings is limited by the fact that the observed effects were measured within a few minutes after irradiation (300–400 s of LLLT, 180 s for repositioning, and 30 s for exercise fatigue testing). Other factors were the very small spot size of the infrared laser (0.0028 cm^2) and the small area irradiated by five points (bilaterally) in this clinical trial. Possibly, with a large area of irradiated muscle, the results might have been increased. These issues illustrate the difficult transition of positive findings in animal studies to a clinically relevant treatment.

Further studies need to be performed to evaluate the optimal doses of LLLT in this novel area of research, evaluating different biochemical parameters and irradiating different muscle areas.

Conclusion

We conclude that LLLT applied before high-intensity exercises can increase the removal of blood lactate and can reduce muscle damage, providing athletes with fast muscle recovery between exercises sessions. These findings may indicate that LLLT before exercise can protect muscles against minor damage and inflammatory reactions after heavy exercise. Further research is necessary to define the optimal laser parameters for this use.

References

- Barnett A (2006) Using recovery modalities between training sessions in elite athletes: does it help? *Sports Med* 36:781–796. doi:10.2165/00007256-200636090-00005
- Westerblad H, Allen DG, Lannergren J (2002) Muscle fatigue: lactic acid or inorganic phosphate the major cause? *News Physiol Sci* 17:17–21
- Cheung K, Hume P, Maxwell L (2003) Delayed onset muscle soreness: treatment strategies and performance factors. *Sports Med* 33:145–164. doi:10.2165/00007256-200333020-00005
- Ahmaidi S, Granier P, Taoutaou Z et al (1996) Effects of active recovery on plasma lactate and anaerobic power following repeated intensive exercise. *Med Sci Sports Exerc* 28:450–456. doi:10.1097/00005768-199604000-00009
- Martin NA, Zoeller RF, Robertson RJ et al (1998) The comparative effects of sports massage, active recovery, and rest in promoting blood lactate clearance after supramaximal leg exercise. *J Athl Train* 33:30–35
- Baldari C (2004) Lactate removal during active recovery related to the individual anaerobic and ventilatory thresholds in soccer players. *Eur J Appl Physiol* 93:224–230. doi:10.1007/s00421-004-1203-5
- Howatson G, Gaze D, van Someren KA (2005) The efficacy of ice massage in the treatment of exercise-induced muscle damage. *Scand J Med Sci Sports* 15:416–422. doi:10.1111/j.1600-0838.2005.00437.x
- Sellwood KL, Brukner P, Williams D et al (2007) Ice-water immersion and delayed-onset muscle soreness: a randomised controlled trial. *Br J Sports Med* 41:392–397. doi:10.1136/bjism.2006.033985
- Weerapong P, Hume PA, Kolt GS (2005) The mechanisms of massage and effects on performance, muscle recovery and injury prevention. *Sports Med* 35:235–256. doi:10.2165/00007256-200535030-00004
- Coffey V, Leveritt M, Gill N (2004) Effect of recovery modality on 4-hour repeated treadmill running performance and changes in physiological variables. *J Sci Med Sport* 7:1–10. doi:10.1016/S1440-2440(04)80038-0
- Gill ND, Beaven CM, Cook C (2006) Effectiveness of post-match recovery strategies in rugby players. *Br J Sports Med* 40:260–263. doi:10.1136/bjism.2005.022483
- Dowzer CN, Reilly T, Cable NT (1998) Effects of deep and shallow water running on spinal shrinkage. *Br J Sports Med* 32:44–48
- Mekjavic IB, Exner JA, Tesch PA et al (2000) Hyperbaric oxygen therapy does not affect recovery from delayed onset muscle soreness. *Med Sci Sports Exerc* 32:558–563. doi:10.1097/00005768-200003000-00002
- Baldwin Lanier A (2003) Use of nonsteroidal anti-inflammatory drugs following exercise-induced muscle injury. *Sports Med* 33:177–185. doi:10.2165/00007256-200333030-00002
- Lattier G, Millet GY, Martin A et al (2004) Fatigue and recovery after high-intensity exercise. Part II: Recovery interventions. *Int J Sports Med* 25:509–515. doi:10.1055/s-2004-820946
- Cairns SP (2006) Lactic acid and exercise performance: culprit or friend? *Sports Med* 36:279–291. doi:10.2165/00007256-200636040-00001
- Reilly T, Ekblom B (2005) The use of recovery methods post-exercise. *J Sports Sci* 23:619–627. doi:10.1080/02640410400021302
- Spierer DK, Goldsmith R, Baran DA et al (2004) Effects of active vs passive recovery on work performed during serial supra-maximal exercise tests. *Int J Sports Med* 25:109–114. doi:10.1055/s-2004-819954
- Szumilak D, Sulowicz W, Walatek B (1998) Rhabdomyolysis: clinical features, causes, complications and treatment. *Przegl Lek* 55:274–279
- Wolf PL, Lott JA, Nitti GJ et al (1987) Changes in serum enzymes, lactate, and haptoglobin following acute physical stress in international-class athletes. *Clin Biochem* 20:73–77. doi:10.1016/S0009-9120(87)80102-9
- Ide M, Tajima F, Furusawa K et al (1999) Wheelchair marathon racing causes striated muscle distress in individuals with spinal cord injury. *Arch Phys Med Rehabil* 80:324–327. doi:10.1016/S0003-9993(99)90145-4
- Boros-Hatfaludy S, Fekete G, Apor P (1986) Metabolic enzyme activity patterns in muscle biopsy samples in different athletes. *Eur J Appl Physiol Occup Physiol* 55:334–338. doi:10.1007/BF02343809
- MacDougall JD, Hicks AL, MacDonald JR et al (1998) Muscle performance and enzymatic adaptations to sprint interval training. *J Appl Physiol* 84:2138–2142
- Klapinska B, Iskra J, Poprzecki S et al (2001) The effects of sprint (300 m) running on plasma lactate, uric acid, creatine kinase and lactate dehydrogenase in competitive hurdlers and untrained men. *J Sports Med Phys Fitness* 41:306–311
- Szabo A, Romvári R, Bogner P et al (2003) Metabolic changes induced by regular submaximal aerobic exercise in meat-type rabbits. *Acta Vet Hung* 51:503–512. doi:10.1556/AVet.51.2003.4.8
- Brancaccio P, Maffulli N, Limongelli FM (2007) Creatine kinase monitoring in sport medicine. *Br Med Bull* 81–82:209–230. doi:10.1093/bmb/ldm014
- Angelini C (2004) Limb-girdle muscular dystrophies: heterogeneity of clinical phenotypes and pathogenetic mechanisms. *Acta Myol* 23:130–136
- Chow RT, Heller GZ, Barnsley L (2006) The effect of 300 mW, 830 nm laser on chronic neck pain: a double-blind, randomized, placebo-controlled study. *Pain* 124:201–210. doi:10.1016/j.pain.2006.05.018
- Gur A, Karakoç M, Nas K et al (2002) Efficacy of low power laser therapy in fibromyalgia: a single-blind, placebo-controlled trial. *Lasers Med Sci* 17:57–61. doi:10.1007/s10103-002-8267-4
- Lopes-Martins RA, Marcos RL, Leonardo PS et al (2006) Effect of low-level laser (Ga-Al-As 655 nm) on skeletal muscle fatigue induced by electrical stimulation in rats. *J Appl Physiol* 101:283–288. doi:10.1152/jappphysiol.01318.2005
- Enwemeka CS (2001) Attenuation and penetration depth of red 632.8 nm and invisible infrared 904 nm light in soft tissues. *Laser Ther* 13:95–101
- Avni D, Levkovitz S, Maltz L et al (2005) Protection of skeletal muscles from ischemic injury: low-level laser therapy increases antioxidant activity. *Photomed Laser Surg* 23:273–277. doi:10.1089/pho.2005.23.273
- Rizzi CF, Mauriz JL, Freitas Corrêa DS et al (2006) Effects of low-level laser therapy (LLLT) on the nuclear factor (NF)-kappaB signaling pathway in traumatized muscle. *Lasers Surg Med* 38:704–713. doi:10.1002/lsm.20371
- Leal Junior ECP, Lopes-Martins R, Dalan F et al (2008) Effect of 655 nm low level laser therapy (LLLT) in exercise-induced skeletal muscle fatigue in humans. *Photomed Laser Surg* 26:419–424. doi:10.1089/pho.2007.2160
- Leal Junior ECP, Lopes-Martins R, Vanin A et al (2008) Effect of 830 nm low level laser therapy (LLLT) in exercise-induced skeletal muscle fatigue in humans (in press). *Lasers Med Sci*. doi:10.1007/s10103-008-0592-9
- Xu X, Zhao X, Liu TC, Pan H (2008) Low-intensity laser irradiation improves the mitochondrial dysfunction of C2C12 induced by electrical stimulation. *Photomed Laser Surg* 26:197–202. doi:10.1089/pho.2007.2125
- Tullberg M, Alstergren PJ, Ernberg MM (2003) Effects of low-power laser exposure on masseter muscle pain and microcirculation. *Pain* 105:89–96. doi:10.1016/S0304-3959(03)00166-0