Research Article

Effects of 830 nm Light-Emitting Diode Therapy on Delayed-Onset Muscle Soreness

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Received 7 November 2020; Revised 4 January 2021; Accepted 11 January 2021; Published 19 January 2021

Academic Editor: Muhammad Nabeel Ghayur

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Objectives. Our study investigated the effects of 830 nm light-emitting diode therapy (LEDT) for postexercise delayed-onset muscle soreness (DOMS). **Methods.** In this randomized control study, healthy participants were randomized into LEDT and placebo groups. LEDT (output frequency = 10 Hz; wavelength = 830 nm; total output power = 210 mW; and dose = 315 J/cm²) was applied to six sites in the damaged quadriceps for 10 min. The placebo group received sham LEDT with no energy output. The nondominant leg was chosen for DOMS induction, using an eccentric exercise. Visual analog scale (VAS) scores for muscle soreness, pressure pain threshold (PPT), thigh circumference, joint range of motion, and muscle strength were assessed before and immediately after exercise and at 24, 48, 72, and 96 h postexercise. **Results.** Forty participants were divided into the LEDT group ($n = 20$) and the placebo group ($n = 20$). Compared with the placebo group, the LEDT group exhibited significant increases in PPT values at 48, 72, and 96 h postexercise ($p < 0.05$). The joint range of motion was significantly different between the LEDT and placebo groups at 72 and 96 h postexercise ($p < 0.05$). No significant intergroup differences were noted in thigh circumference and muscle strength ($p < 0.05$). **Conclusion.** The application of 830 nm LEDT on postexercise DOMS pain exerted an analgesic effect but did not affect the muscle repair process. Future studies should elucidate the beneficial effects of 830 nm LEDT on muscle recovery or performance.

1. Introduction

Delayed-onset muscle soreness (DOMS) is a short-term muscular condition occurring due to engagement in unaccustomed exercise, especially high-intensity eccentric contractions. Its symptoms include muscle tenderness and stiffness, swelling, and decreased muscle strength. These symptoms often occur at least 12–24 h after exercise, tend to peak at 24–48 h, and alleviate over time. Athletes often experience DOMS because of repetitive and high-intensity eccentric muscle contractions [1]. DOMS causes muscle fatigue, thereby increasing sports injury risk and affecting body recovery [2]. Many therapeutic modalities have been applied to overcome muscle fatigue in athletes, such as

vibrating foam roller, low-level laser, cold water immersion, and kinesiology tape. Although they may improve muscle damage recovery or increase fatigue recovery in athletes, these applications should be focused not only on alleviating DOMS but also on improving muscle strength recovery. The muscular discomfort associated with DOMS influences athletes' sports performance and training schedules [3]. Acceleration of muscle damage recovery can help athletes quickly recover their sports ability [4]. Therefore, effective strategies for managing and decreasing DOMS might benefit athletes.

Low-level phototherapy has been recommended for muscle soreness and recovery after high-intensity exercise [5]. Photobiomodulation can stimulate the mitochondrial

respiratory chain to decrease tissue inflammation and release pain mediators [6]. Light-emitting diode therapy (LEDT) is a common phototherapeutic instrument at rehabilitation or sports medicine centers. Its application after exercise has been suggested to decrease muscular pain [6, 7]. A systematic review revealed that LEDT caused significant pain relief in DOMS muscles at 24 h, 48 h, 72 h, and 96 h post-exercise [8]. Studies have evaluated the beneficial effects of LEDT at single or dual wavelengths of 630 nm [6], 660/850 nm [7], and 660/880 nm [9, 10] on pain and creatine kinase levels for people with DOMS. LEDT at near-infrared wavelengths of 805–904 nm after high-intensity exercise has superior effects due to the higher penetration rate [7, 9, 10]. Some studies have indicated that phototherapy at a wavelength of 830 nm achieves deep tissue penetration and satisfactory absorption [11, 12]. However, the effects of LEDT at 830 nm on postexercise DOMS have not been studied in a clinical trial. In this study, we investigated the effects of 830 nm LEDT on DOMS. We hypothesized that 830 nm LEDT would decrease muscle pain and swelling and increase muscle strength in people with damaged muscles experiencing DOMS.

2. Methods

This randomized control study recruited participants from the sports teams of a university. The study trial was approved by the Institutional Review Board at CMU Hospital. The volunteers were informed of the procedure and agreed to participate in this study. For inclusion, participants had to be healthy and not have eccentric exercise training of the lower extremities in less than four weeks before starting the study trial. The exclusion criteria were injuries or surgery on the lower extremity, musculoskeletal system diseases, and use of phototherapy. All volunteers were randomly divided into LEDT and placebo groups. The estimated sample size was set as 20 per group, following Chang et al. [13].

The study procedure is illustrated in Figure 1. The participants' quadriceps muscles were subjected to the DOMS-inducing protocol. The visual analog scale (VAS), pressure pain threshold (PPT), thigh circumference, joint range of motion, and muscle strength were assessed before and immediately after exercise and at 24 h, 48 h, 72 h, and 96 h postexercise. All tests and interventions were performed by the same therapist, and data were analyzed by the same analyst. All researchers were blinded to participant allocation and intervention.

2.1. Induction of DOMS. The dominant leg was determined by the foot used to kick a ball [14], and the nondominant leg was chosen for DOMS induction, which was effected using an isokinetic dynamometer (Biodex System Pro 3, Biodex Medical System, New York, USA). The isokinetic dynamometer is often used for eccentric muscle training and can facilitate intense muscle contraction to induce DOMS. The participant assumed a sitting position with 90° flexion in the knee and hip with their trunk and thigh fixed to the dynamometer chair. The axis of the knee was placed at the same level as the rotation axis of the dynamometer, and the range

FIGURE 1: Flowchart of this study.

of motion of knee flexion was set from 0° to 90°. The DOMS-inducing protocol consisted of 5 × 10 eccentric quadriceps muscle contraction at 75% of the one-repetition maximum, and the peak torque value was recorded. All participants completed a pilot session of 5 sets of 15 repetitions of eccentric knee extension at a velocity of 60°/s with a 3 min rest period between sets.

LEDT was applied to the damaged quadriceps muscle after the DOMS-inducing protocol using a LEDT instrument (iRestore Multi-Channel Laser Therapy System, Jin-Cian Technology, Taoyuan, Taiwan). The output head had seven embedded diode laser spots, and the application mode of the laser instrument was an output frequency of 10 Hz, a wavelength of 830 nm, a total output power of 210 mW, and a dose of 315 J/cm². The output head of the diode laser instrument was applied to six sites on the quadriceps muscle, and overall irradiation time was 10 min in direct contact with the skin of the thigh: two sites were located centrally on the rectus femoris and vastus intermedius (Points 1 and 2), two were laterally on the vastus lateralis (Points 3 and 4), and two were medially on the vastus medialis (Points 5 and 6) (Figure 2), following De Paiva et al. [15]. The study procedures for the LEDT and placebo groups were the same, except that in the placebo group, the laser irradiation output of the laser instrument was turned off. All of the participants were blinded to the treatment.

2.2. Assessments

2.2.1. Visual Analog Scale. The VAS is used for the subjective measurement of a symptom, including DOMS [16]. It consists of a straight 10 cm line, with 0 representing no pain

FIGURE 2: Sites of LEDT irradiation on quadriceps muscle.

and 10 representing extreme pain. The participants rated the magnitude of perceived muscle soreness on a scale of 0 to 10 and drew with a vertical line on the VAS line to indicate the subjective level of pain.

2.2.2. Pressure Pain Threshold. A PPT meter (Model PTHAF2; Pain Diagnostics & Thermography, New York, USA) was used to measure the minimal amount of pressure to cause muscle tenderness [17]. The participants sat in a relaxed position, and the pressure was applied at the mid-point of the midline between the iliac crest and the superior border of the patella. The pressure was increased gradually, and the PPT value (kg/cm^2) was recorded when participants expressed that muscle soreness was felt. The measurements were repeated three times, with 1 min intervals between measurements, and the mean values were noted.

2.2.3. Thigh Circumference. A nonstretch anthropometric measuring tape (F10-02; Muratec-KDS, Kyoto, Japan) was used to measure thigh circumference, which represented acute changes in thigh volume after eccentric exercise [18]. With the participant in a relaxed supine position, thigh circumference was measured 10 and 20 cm above the knee. The measured sites were marked with permanent markers for repeat measurements, and three measurements were recorded. The mean values of thigh circumference (cm) were calculated and used for analysis.

2.2.4. Joint Range of Motion. A plastic goniometer (Model 01135; Lafayette Instrument, Indiana, USA) was used to

measure the knee joint range of motion from extension to flexion. It could be used to assess the muscle length of the rectus femoris [19]. The participants were in a prone position, and the axis of the goniometer was placed on the lateral epicondyle of the femur. The stationary arm of the goniometer was aligned with the greater trochanter, and the moving arm was aligned with the lateral malleolus. Starting from full extension, the knees were passively bent until perceived muscle soreness occurred. The measurements were taken twice, and the mean value of the joint range of motion (degree) was calculated.

2.2.5. Muscle Strength. The MicroFET-3 dynamometer (Hoggan Health Industries, Draper, Utah, USA) was used to measure the maximal voluntary isometric contraction strength of the quadriceps muscle. This dynamometer is a handheld transducer that measures muscle force in a perpendicular direction and has high accuracy ($r > 0.95$) [20]. The participants were seated, and the isometric force for knee extension with the knee at 90° flexion was measured. The dynamometer was applied to the anterior tibia at the lower third shank, and the maximum force was measured. The procedure was repeated twice with 1 min intervals between measurements, and the mean values of muscle strength (lb) were calculated.

2.3. Statistical Analysis. SPSS version 25.0 (SPSS, Chicago, USA) was used for all statistical analyses. The Shapiro–Wilk test was used to determine the normality of distribution: all measured data were normally distributed ($p > 0.05$). All values are presented as mean $\pm$ standard deviation. The t -test and chi-squared test were used to analyze the differences in basic information and baseline measures pre-exercise between the LEDT and placebo groups. The VAS, PPT, thigh circumference, muscle length, and strength were analyzed using a two-way repeated-measures analysis of variance (group $\times$ time) and Bonferroni post hoc test. Cohen's d was used to assess the effect sizes of therapeutic effects between postexercise and four assessed times (24, 48, 72, and 96 h postexercise). Effect sizes (d) were classified as small (0.2–0.5), moderate (0.5–0.8), and large (≥ 0.8) [21]. Statistical significance was set at $\alpha = 0.05$.

3. Results

Forty participants were included in our study and were randomly divided into the LEDT group ($n = 20$) and the placebo group ($n = 20$). All of them completed the study process; no dropouts occurred, and no adverse reactions were reported. Age, height, weight, body mass index, dominant leg, body fat, and muscle mass were not significantly different between the LEDT and placebo groups (all $p > 0.05$). The baseline measures of quadriceps muscle length, thigh circumference, and quadriceps muscle strength were also not significantly different between the groups (all $p > 0.05$, Table 1).

The changes in VAS score for the LEDT and placebo groups are shown in Figure 3. The main effects of group (F_1 ,

TABLE 1: Demographic characteristics and baseline measures of the participants.

Items	LEDT group (<i>n</i> = 20)	Placebo group (<i>n</i> = 20)
Age (years)	20.38 ± 1.65	20.17 ± 1.46
Height (cm)	167.88 ± 9.09	171.17 ± 10.09
Weight (kg)	65.16 ± 12.77	64.58 ± 11.25
BMI (kg/m ²)	23.05 ± 3.97	21.95 ± 2.93
Right/left dominant leg	17/3	18/2
Body fat (%)	25.36 ± 8.86	21.28 ± 7.68
Muscle mass (kg)	45.91 ± 10.48	48.28 ± 10.12
Quadriceps muscle length (cm)	49.53 ± 2.21	49.78 ± 4.27
Thigh circumference above 10 cm (cm)	46.67 ± 4.53	45.78 ± 5.43
Thigh circumference above 20 cm (cm)	53.12 ± 3.67	53.11 ± 3.78
Muscle strength of quadriceps (Ib)	55.63 ± 17.34	53.62 ± 11.75

FIGURE 3: VAS from the LEDT and placebo groups before and immediately after exercise and at 24, 48, 72, and 96 h postexercise.

38 = 0.31, $p = 0.58$), time ($F_{1, 38} = 11.46$, $p = 0.01$), and group $\times$ time interaction ($F_{1, 38} = 0.25$, $p = 0.27$) are presented. No significant intergroup and intragroup differences were observed in VAS before and immediately after exercise and at 24, 48, 72, and 96 h postexercise ($p > 0.05$). However, we found that the VAS score was lower in the LEDT group than in the placebo group at 48 h (3.53 ± 0.87 vs. 4.23 ± 0.94), 72 h (1.24 ± 0.83 vs. 1.91 ± 1.13), and 96 h (0.44 ± 0.56 vs. 0.91 ± 0.74) postexercise.

For the measurement of PPT (Figure 4), we found significant main effects of group ($F_{1, 38} = 33.28$, $p = 0.01$), time ($F_{1, 38} = 35.79$, $p = 0.001$), and group $\times$ time interaction ($F_{1, 38} = 37.61$, $p = 0.01$). No significant differences in PPT were noted between the two groups before and immediately after exercise and at 24 h postexercise ($p > 0.05$). The PPT was significantly higher in the LEDT group than in the placebo group at 48 h (1.27 ± 0.32 vs. 1.05 ± 0.31 , $d = 0.69$, $p = 0.04$), 72 h (1.43 ± 0.47 vs. 1.15 ± 0.30 , $d = 0.72$, $p = 0.03$), and 96 h (1.78 ± 0.30 vs. 1.39 ± 0.46 , $d = 0.92$, $p = 0.01$) postexercise, indicating less muscle tenderness in the LEDT group.

The thigh circumference and muscle strength data in the LEDT and placebo groups are presented in Table 2. No significant main effects of group, time, or group $\times$ time interaction ($p > 0.05$) were noted for either parameter. No significant between-group differences were reported in thigh circumference and muscle strength immediately after

FIGURE 4: Pressure pain threshold (PPT) between the LEDT and placebo groups before and immediately after exercise and at 24, 48, 72, and 96 h postexercise; * $p < 0.05$.

exercise and at 24, 48, 72, and 96 h postexercise compared with before exercise ($p > 0.05$).

For muscle length (Figure 5), we noted no significant main effects of group or group $\times$ time interaction ($p > 0.05$), but a significant main effect ($F_{1, 38} = 6.87$, $p = 0.01$) of time was identified. No significant differences in muscle length were found between the two groups before and immediately after exercise and at 24 and 48 h postexercise ($p > 0.05$). Muscle length significantly improved in the LEDT group compared with the placebo group at 72 h (107.68 ± 8.68 vs. 112.30 ± 7.64 , $d = 0.56$, $p = 0.04$) and 96 h (103.80 ± 6.10 vs. 107.53 ± 5.79 , $d = 0.62$, $p = 0.03$) postexercise.

4. Discussion

We determined the effects of 830 nm LEDT on muscle pain, swelling, and strength by assessing changes in VAS scores, PPT values, thigh circumference, joint range of motion, and muscle strength before and immediately after exercise and at 24, 48, 72, and 96 h after exercise. The outcomes indicated a significant decrease in muscle soreness and improvement in the knee joint range of motion in participants treated with 830 nm LEDT to the damaged quadriceps muscle. The effects on pain relief and muscle damage recovery were found at 48–92 h after exercise.

TABLE 2: Thigh circumference and muscle strength in the LEDT and placebo groups before and immediately after exercise and at 24, 48, 72, and 96 h postexercise.

Outcome measures	LEDT group (<i>n</i> = 20)	Placebo group (<i>n</i> = 20)
Thigh circumference above 10 cm (cm)		
Before exercise	46.24 ± 2.95	46.17 ± 5.39
Immediately after exercise	45.89 ± 3.19	46.40 ± 5.77
24 h postexercise	45.71 ± 4.12	46.38 ± 5.91
48 h postexercise	45.69 ± 3.28	46.23 ± 5.44
72 h postexercise	45.91 ± 3.40	46.29 ± 5.78
96 h postexercise	46.09 ± 3.78	46.77 ± 4.48
Thigh circumference above 20 cm (cm)		
Before exercise	53.76 ± 3.85	53.79 ± 6.52
Immediately after exercise	52.21 ± 4.80	53.70 ± 7.53
24 h postexercise	52.13 ± 5.23	53.56 ± 6.98
48 h postexercise	52.03 ± 5.06	53.64 ± 6.86
72 h postexercise	52.07 ± 4.96	53.45 ± 5.80
96 h postexercise	53.95 ± 4.99	53.33 ± 6.94
Muscle strength (lb)		
Before exercise	46.97 ± 14.12	44.72 ± 12.25
Immediately after exercise	50.25 ± 17.57	48.48 ± 11.31
24 h postexercise	51.22 ± 15.43	47.91 ± 12.12
48 h postexercise	51.32 ± 14.51	46.55 ± 15.27
72 h postexercise	51.67 ± 12.53	47.78 ± 11.76
96 h postexercise	52.63 ± 17.34	49.52 ± 11.75

FIGURE 5: Muscle length in the LEDT and placebo groups before and immediately after exercise and at 24, 48, 72, and 96 h postexercise; * $p < 0.05$.

To the best of our knowledge, our study is the first randomized controlled trial to use 830 nm LEDT for DOMS of the quadriceps. Systematic reviews have demonstrated that LEDT applied for DOMS after exercise can decrease muscle soreness [8, 22]. Borges et al. used 630 nm and 20.4 J/cm² LEDT for participants damaged biceps and continuously irradiated four points on the muscle for 30 s per point [6]. Significant pain reduction and joint range of motion recovery were noted at 48, 72, and 96 h after exercise. Douris et al. used LEDT with a dual wavelength of 660/880 nm on damaged biceps and continuously irradiated three points on the muscle for 80 s per point [7]. They observed that DOMS decreased 48 h after exercise. Leal et al. used dual 660/850 nm LEDT to continuously irradiate one point of a biceps for 30 s and found that the creatine kinase level was reduced postexercise [10]. We used 830 nm LEDT with an output

frequency of 10 Hz for 10 min to irradiate six points on the quadriceps. Compared with the placebo group, the LEDT group exhibited improvements in PPT values for muscle tenderness at 48–96 h after exercise and recovery of the joint range of motion at 76 and 96 h after exercise. We believe that using a suitable wavelength, allowing better penetration, and providing adequate irradiation times contributed to the beneficial effects of LEDT for DOMS. This explains why our application had better outcomes than those of the aforementioned studies [6, 7, 10].

Baroni et al. indicated that wavelength-specific phototherapy, especially 830 nm wavelength, decided a modulatory effect on the recovery of damaged muscle [23]. An animal study proved that 830 nm phototherapy could decrease the activity of creatine phosphokinase and release of reactive oxygen species in muscles with ischemic injury [24]. Phototherapy with 830 nm wavelength could decrease tumor necrosis factor- α (TNF- α) levels and improve cytokine expression during muscle damage repair after exercise [25]. In the current study, we detected that 830 nm LEDT had a moderate-to-large effect on pain relief, accompanied by a significant improvement in PPT values at 48–96 h after exercise. PPT is used to detect muscle tenderness as a pain threshold for minimum stimulus intensity, and VAS is a self-report to represent subjective pain intensity [26]. PPT had high sensitivity to assess the repair condition of damaged muscle and represents the time course of changes in DOMS. We also found that the VAS score was lower in the LEDT group than in the placebo group at 48–96 h postexercise, but they did not have statistically significant. Taken together, the findings suggest that the analgesic effect of the LEDT may be through anti-inflammatory mechanisms.

In the current study, 830 nm LEDT applied to the damaged quadriceps muscle also improved the recovery of

the knee range of motion, with a moderate effect on muscle flexibility recovery. However, the recovery of muscle strength and swelling were not significant after exercise. DOMS often reduces the joint range of movement and muscle strength [27] and is accompanied by swelling in the injured muscle, due to pain receptor activation and inflammation [28]. Borges et al. applied LEDT to the biceps muscle with DOMS and noted improvements in the elbow's active range of motion after exercise [6]. However, Douris et al. did not find a significant difference in the effects of phototherapy between the LEDT and placebo groups [7]. However, a meta-analysis by Nampo et al. revealed that LEDT on DOMS after exercise did not influence the recovery of muscle movement and function [8].

Poor muscle contraction and motor function due to DOMS often affect athletes' sports performance, so determining approaches to decrease DOMS are critical [29]. A strategy to promote muscle recovery is very important for athletes. Some studies have indicated that phototherapy can decrease oxidative stress and have antioxidative or anti-inflammatory effects [7, 30]. De Brito Vieira et al. stated that phototherapy can improve strength performance [31]. Loss of muscle strength and swelling were common symptoms observed after damaging exercises. These are related to the inflammatory process, which increased TNF- α release. The TNF- α is an inflammatory mediator and affected muscle swelling and muscle contraction [32]. Enwemeka et al. indicated that phototherapy had positive effects on the proliferation of mast cells to promote activities of interleukin-6 [33]. Their results also revealed that the wavelengths between 780 nm and 632 nm of phototherapy had therapeutic effects on tissue repair [33]. Some studies supported the anti-inflammatory effects of phototherapy in decreasing the reactive oxygen species release [34] and improving antioxidant capacity and mitochondrial function [35]. However, our results did not demonstrate improvements in muscle strength and swelling, except for the joint range of movement. The joint range of movement, as with muscle pain assessment, is a subjective measurement for muscle flexibility. A decrease in subjective DOMS may have occurred because participants felt better during the joint range of movement testing. Another reason may be that the selected assessments for muscle strength and swelling were not sufficiently sensitive to quantify our outcomes.

Our study had some limitations. First, measurements for the repair of muscle injury are not adequately sensitive, and this may have influenced our results. Second, because of insufficient research on 830 nm LEDT for DOMS, we did not identify sufficient parameters to optimize LEDT application. Further research should compare the effects of multiple wavelengths of LEDT on DOMS after exercise and determine the ideal parameters of phototherapy.

5. Conclusion

In summary, the application of 830 nm LEDT on sites of DOMS after exercise provided pain relief. However, the effects on the muscle repair process were not observed.

Researchers elucidate the effects of 830 nm LEDT on post-exercise muscle recovery or performance.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

- [1] T. J. Allen, T. L. Dumont, and D. L. MacIntyre, "Exercise-induced muscle damage: mechanisms, prevention, and treatment," *Physiotherapy Canada*, vol. 56, no. 02, pp. 67–79, 2004.
- [2] K. Cheung, P. A. Hume, and L. Maxwell, "Delayed onset muscle soreness," *Sports Medicine*, vol. 33, no. 2, pp. 145–164, 2003.
- [3] K. M. Keane, R. Salicki, S. Goodall, K. Thomas, and G. Howatson, "Muscle damage response in female collegiate athletes after repeated sprint activity," *Journal of Strength and Conditioning Research*, vol. 29, no. 10, pp. 2802–2807, 2015.
- [4] N. D. Gill, C. M. Beaven, and C. Cook, "Effectiveness of post-match recovery strategies in rugby players," *British Journal of Sports Medicine*, vol. 40, no. 3, pp. 260–263, 2006.
- [5] S. R. Fisher, J. H. Rigby, J. A. Mettler, and K. W. McCurdy, "The effectiveness of photobiomodulation therapy versus cryotherapy for skeletal muscle recovery: a critically appraised topic," *Journal of Sport Rehabilitation*, vol. 28, no. 5, pp. 526–531, 2019.
- [6] L. S. Borges, M. S. Cerqueira, J. A. Dos Santos Rocha et al., "Light-emitting diode phototherapy improves muscle recovery after a damaging exercise," *Lasers in Medical Science*, vol. 29, no. 3, pp. 1139–1144, 2014.
- [7] P. Douris, V. Southard, R. Ferrigi et al., "Effect of phototherapy on delayed onset muscle soreness," *Photomedicine and Laser Surgery*, vol. 24, no. 3, pp. 377–382, 2006.
- [8] F. K. Nampo, V. Cavalheri, S. D. P. Ramos, and E. A. Camargo, "Effect of low-level phototherapy on delayed onset muscle soreness: a systematic review and meta-analysis," *Lasers in Medical Science*, vol. 31, no. 1, pp. 165–177, 2016.
- [9] E. C. Leal Junior, V. de Godoi, J. L. Mancalossi et al., "Comparison between cold water immersion therapy (CWIT) and light emitting diode therapy (LEDT) in short-term skeletal muscle recovery after high-intensity exercise in athletes-preliminary results," *Lasers in Medical Science*, vol. 26, no. 4, pp. 493–501, 2011.
- [10] E. C. P. Leal Junior, R. Á. B. Lopes-Martins, R. P. Rossi et al., "Effect of cluster multi-diode light emitting diode therapy (LEDT) on exercise-induced skeletal muscle fatigue and skeletal muscle recovery in humans," *Lasers in Surgery and Medicine*, vol. 41, no. 8, pp. 572–577, 2009.
- [11] J. M. Bjordal, C. Couppe, R. T. Chow, J. Tunér, and E. A. Ljunggren, "A systematic review of low level laser therapy with location-specific doses for pain from chronic joint disorders," *Australian Journal of Physiotherapy*, vol. 49, no. 2, pp. 107–116, 2003.
- [12] J. M. Bjordal, M. I. Johnson, V. Iversen, F. Aimbre, and R. A. B. Lopes-Martins, "Low-level laser therapy in acute pain: a systematic review of possible mechanisms of action and clinical effects in randomized placebo-controlled trials,"

- Photomedicine and Laser Surgery*, vol. 24, no. 2, pp. 158–168, 2006.
- [13] W. D. Chang, J. H. Wu, N. J. Chang, C. L. Lee, and S. Chen, “Effects of laser acupuncture on delayed onset muscle soreness of the biceps brachii muscle: a randomized controlled trial,” *Evidence-based Complementary and Alternative Medicine*, vol. 2019, Article ID 6568976, 2019.
 - [14] R. Van Den Tillaar and A. Ulvik, “Influence of instruction on velocity and accuracy in soccer kicking of experienced soccer players,” *Journal of Motor Behavior*, vol. 46, no. 5, pp. 287–291, 2014.
 - [15] P. R. V. De Paiva, S. S. Tomazoni, D. S. Johnson et al., “Photobiomodulation therapy (PBMT) and/or cryotherapy in skeletal muscle restitution, what is better? a randomized, double-blinded, placebo-controlled clinical trial,” *Lasers in Medical Science*, vol. 31, no. 9, pp. 1925–1933, 2016.
 - [16] T. C. Chen, H.-L. Chen, M.-J. Lin, C.-J. Wu, and K. Nosaka, “Potent protective effect conferred by four bouts of low-intensity eccentric exercise,” *Medicine & Science in Sports & Exercise*, vol. 42, no. 5, pp. 1004–1012, 2010.
 - [17] R. Rolke, R. Baron, C. Maier et al., “Quantitative sensory testing in the German Research Network on Neuropathic Pain (DFNS): standardized protocol and reference values,” *Pain*, vol. 123, no. 3, pp. 231–243, 2006.
 - [18] J. Vaile, S. Halson, N. Gill, and B. Dawson, “Effect of hydrotherapy on the signs and symptoms of delayed onset muscle soreness,” *European Journal of Applied Physiology*, vol. 102, no. 4, pp. 447–455, 2008.
 - [19] N. C. Dabbs, C. D. Black, and J. Garner, “Whole-body vibration while squatting and delayed-onset muscle soreness in women,” *Journal of Athletic Training*, vol. 50, no. 12, pp. 1233–1239, 2015.
 - [20] D. T. Gulick, I. F. Kimura, M. Sitler, A. Paolone, and J. D. Kelly, “Various treatment techniques on signs and symptoms of delayed onset muscle soreness,” *Journal of Athletic Training*, vol. 31, no. 2, pp. 145–152, 1996.
 - [21] J. Cohen, *Statistical Power Analysis for the Behavioral Sciences*, Lawrence Erlbaum Associates, Hillsdale, NJ, USA, 2nd edition, 1988.
 - [22] C. Ferraresi, Y. Y. Huang, and M. R. Hamblin, “Photobiomodulation in human muscle tissue: an advantage in sports performance?” *Journal of Biophotonics*, vol. 9, no. 11–12, pp. 1273–1299, 2016.
 - [23] B. M. Baroni, D. Grosselli, T. De Marchi, V. V. Iversen, and J. M. Bjordal, “Effect of 830 nm low-level laser therapy in exercise-induced skeletal muscle fatigue in humans,” *Lasers in Medical Science*, vol. 24, no. 3, pp. 425–431, 2009.
 - [24] D. Avni, S. Levkovitz, L. Maltz, and U. Oron, “Protection of skeletal muscles from ischemic injury: low-level laser therapy increases antioxidant activity,” *Photomedicine and Laser Surgery*, vol. 23, no. 3, pp. 273–277, 2005.
 - [25] R. A. Mesquita-Ferrari, M. D. Martins, J. A. Silva et al., “Effects of low-level laser therapy on expression of TNF- α and TGF- β in skeletal muscle during the repair process,” *Lasers in Medical Science*, vol. 26, no. 3, pp. 335–340, 2011.
 - [26] W. Y. Lau, A. J. Blazevich, M. J. Newton, S. S. X. Wu, and K. Nosaka, “Assessment of muscle pain induced by elbow-flexor eccentric exercise,” *Journal of Athletic Training*, vol. 50, no. 11, pp. 1140–1148, 2015.
 - [27] R. A. Fielding, M. A. Violan, L. Svetkey et al., “Effects of prior exercise on eccentric exercise-induced neutrophilia and enzyme release,” *Medicine & Science in Sports & Exercise*, vol. 32, no. 2, pp. 359–364, 2000.
 - [28] D. T. Gulick and I. F. Kimura, “Delayed onset muscle soreness: what is it and how do we treat it?” *Journal of Sport Rehabilitation*, vol. 5, no. 3, pp. 234–243, 1996.
 - [29] J. R. Jakeman, C. Byrne, and R. G. Eston, “Lower limb compression garment improves recovery from exercise-induced muscle damage in young, active females,” *European Journal of Applied Physiology*, vol. 109, no. 6, pp. 1137–1144, 2010.
 - [30] E. C. P. Leal, R. Á. B. Lopes-Martins, L. Frigo et al., “Effects of low-level laser therapy (LLLT) in the development of exercise-induced skeletal muscle fatigue and changes in biochemical markers related to postexercise recovery,” *Journal of Orthopaedic & Sports Physical Therapy*, vol. 40, no. 8, pp. 524–532, 2010.
 - [31] W. H. De Brito Vieira, C. Ferraresi, S. E. De Andrade Perez, V. Baldissera, and N. A. Parizotto, “Effects of low-level laser therapy (808 nm) on isokinetic muscle performance of young women submitted to endurance training: a randomized controlled clinical trial,” *Lasers in Medical Science*, vol. 27, no. 2, pp. 497–504, 2012.
 - [32] P. Wilcox, S. Osborne, and B. Bressler, “Monocyte inflammatory mediators impair In Vitro Hamster diaphragm contractility,” *American Review of Respiratory Disease*, vol. 146, no. 2, pp. 462–466, 1992.
 - [33] C. S. Enwemeka, J. C. Parker, D. S. Dowdy, E. E. Harkness, L. E. Harkness, and L. D. Woodruff, “The efficacy of low-power lasers in tissue repair and pain control: a meta-analysis study,” *Photomedicine and Laser Surgery*, vol. 22, no. 4, pp. 323–329, 2004.
 - [34] B. M. Baroni, E. C. P. Leal Junior, T. De Marchi, A. L. Lopes, M. Salvador, and M. A. Vaz, “Low level laser therapy before eccentric exercise reduces muscle damage markers in humans,” *European Journal of Applied Physiology*, vol. 110, no. 4, pp. 789–796, 2010.
 - [35] M. Lunova, B. Smolková, M. Uzhytchak et al., “Light-induced modulation of the mitochondrial respiratory chain activity: possibilities and limitations,” *Cellular and Molecular Life Sciences*, vol. 77, no. 14, pp. 2815–2838, 2020.