Effects of Low-Level Laser Therapy on Muscular Performance and Soreness Recovery in Athletes: A Meta-analysis of Randomized Controlled Trials

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Context: Athletes must maintain their peak state of strength. Previous studies have investigated the effect of low-level laser therapy (LLLT) on muscular performance. A previous systematic review and meta-analysis has investigated this issue in healthy participants but not in physically active athletes.

Objective: To investigate whether LLLT can improve muscular performance and soreness recovery in athletes.

Data Sources: PubMed, EMBASE, and Cochrane Library.

Study Selection: Published randomized controlled trials and crossover studies till December 2020.

Study Design: Systematic review and meta-analysis.

Level of Evidence: Level 3.

Data Extraction: Assessment of study quality was rated using the risk of bias assessment method for randomized trials (Cochrane Handbook for Systematic Reviews of Interventions).

Results: A total of 24 studies were included. LLLT application before exercise significantly improved lower-limb muscle strength in 24-hour, 48-hour, 96-hour, and 8-week follow-up groups. Furthermore, decreased soreness index, serum creatine kinase concentrations, interleukin-6, and thiobarbituric acid reactive substance concentrations and a trend toward the improvement of contract repetition number and VO_2 kinetic outcomes were observed.

Conclusion: Although a definite therapeutic effect of LLLT is yet to be established, the current evidence supports that LLLT use improves muscular performance in physically active athletes. Additional trials with large sample sizes and robust design should be conducted before strong recommendations are made.

Keywords: low-level laser therapy; athlete; muscular performance; meta-analysis

In certain high-level sport activities, such as rugby, soccer, and other collective sports, athletes must maintain their peak state of strength. However, athletes have only a limited time frame to recover from intensive training sessions and matches,[37] and failure to regain their prime performance state in the given time may result in soreness and severe decline in muscular performance. Moreover, when conducting sporting activities, such as jumping and sprinting,[35] athletes' muscle strength is strongly associated with their overall status. Thus, athletes must seek an effective method for improving their muscular performance.

Common methods for improving muscular performance or accelerating soreness recovery include anti-inflammatory analgesics, massage, or ice bath.[11] Although these methods may

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seem effective, there is still room for improvement. Although the side effects of drug use are unignorable, sophisticated massage therapists and adequate equipment are required to perform massages or ice baths in a proper manner. In addition to common methods, alternative therapies, such as acupuncture, are used to relieve muscle soreness.[15] However, the intervention is invasive. Recently, a noninvasive and nonpharmacological therapy, namely low-level laser therapy (LLLT), has become increasingly popular throughout the world. Because the effect of LLLT on muscular performance is unclear, this can be a promising study.

To date, de Oliveira et al,[6] Denis et al,[7] and Dornelles et al[8] have investigated the effect of LLLT on muscular performance and soreness recovery.[30,31,39] However, none of them have focused on physically active athletes. Thus, we conducted a systematic review and meta-analysis of randomized controlled trials (RCTs) and crossover studies to evaluate the effects of LLLT on muscular performance and soreness recovery in athletes.

METHODS

Selection Criteria

Published RCTs and crossover studies that evaluated the effects of LLLT on muscular performance or soreness recovery were included. Furthermore, studies were selected if they met the following criteria: inclusion and exclusion criteria were used for selecting patients, used the LLLT technique, and defined and evaluated muscular performance. Reports were excluded from our analysis in case of the following: participants were not athletes, the soreness was not caused by sports-related issues, or outcomes were not clearly reported. The study was registered with PROSPERO (No. CRD42020200740).

Search Strategy and Study Selection

Studies were identified through computerized searches on PubMed, EMBASE, and Cochrane Library. The following terms were used for Medical Subject Headings and free-text searches: *low-level laser therapy* or *LLLT*, *photobiomodulation*, *muscle*, *athlete*, and *sport* or *exercise*. In addition, the "related articles" facility in PubMed was used to broaden the search, and we reviewed all abstracts, studies, and citations retrieved. The last search was performed in December 2020.

Data Extraction

Three independent reviewers extracted trial details pertaining to participants, inclusion and exclusion criteria, LLLT techniques used, and the parameters of muscular performance and soreness. The individually recorded decisions of the 3 reviewers were compared, and any disagreements were resolved by the fourth reviewer.

Methodological Quality Appraisal

Three reviewers independently appraised the methodological quality of each study based on the risk assessment tool of bias in randomized trials described in the Cochrane Handbook for Systematic Reviews of Interventions.[34] We reported the following domains: risk of bias arising from the randomization process, risk of bias due to deviations from the intended interventions, risk of bias due to missing outcome data, risk of bias in the measurement of the outcome, and risk of bias in the selection of the reported result.

Outcome Assessments

The efficacy of LLLT was evaluated through several outcomes. The primary outcome was muscle strength measured with a dynamometer. Other outcomes included contract repetition number, soreness index, time to fatigue, serum creatine kinase (CK) concentrations, lactate, thiobarbituric acid reactive substances (TBARS), and inflammation-related biomarkers.

Statistical Analysis

Statistical analysis was conducted using the Review Manager Version 5.4 (Cochrane Collaboration). Meta-analysis was performed according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.[23] When necessary, standard deviations were estimated from the provided confidence interval limits and standard error or range values.[13] The precision of effect size was reported as a 95% CI. Data were pooled only for studies that exhibited adequate clinical and methodological similarity. Statistical heterogeneity was assessed using the I^2 test, with I^2 quantifying the proportion of the total outcome variability attributable to variability among the studies. If multiple doses were tested in a study, the dose with the most prominent effect was chosen for meta-analysis. Moreover, if multiple time points were tested in a study, the time point closest to the LLLT intervention was chosen.

RESULTS

Trial Characteristics

Figure 1 shows a flowchart describing the process through which we screened and selected trials. Our initial search yielded 2095 citations, of which 70 were deemed eligible based on the screening of titles and abstracts. We thus retrieved the full text of 70 reports. Most of these were excluded from our final review for the following reasons: 37 recruited nonathlete participants, 4 were review articles, 4 were conference abstracts, and 1 contained unclear intervention protocol. The elimination process left 24 eligible trials.[2-10,12,16-22,25-27,32,35,37,39]

The characteristics of the 24 included trials are shown in Appendix Table A1 (available in the online version of this article). Ten of them were RCTs,[2-4,6,9,10,19,27,36,40] whereas others were crossover trials. These trials were published between 2008 and 2020, with sample sizes ranging from 6 to 40. All participants were athletes, with an age range of 15 to 40 years. All trials recruited male athletes, except those conducted by Hemmings et al,[12] Maciel et al,[26] and Takenori et al.[36] The LLLT parameters varied across trials. Furthermore, the sport involved and laser application site varied across trials.

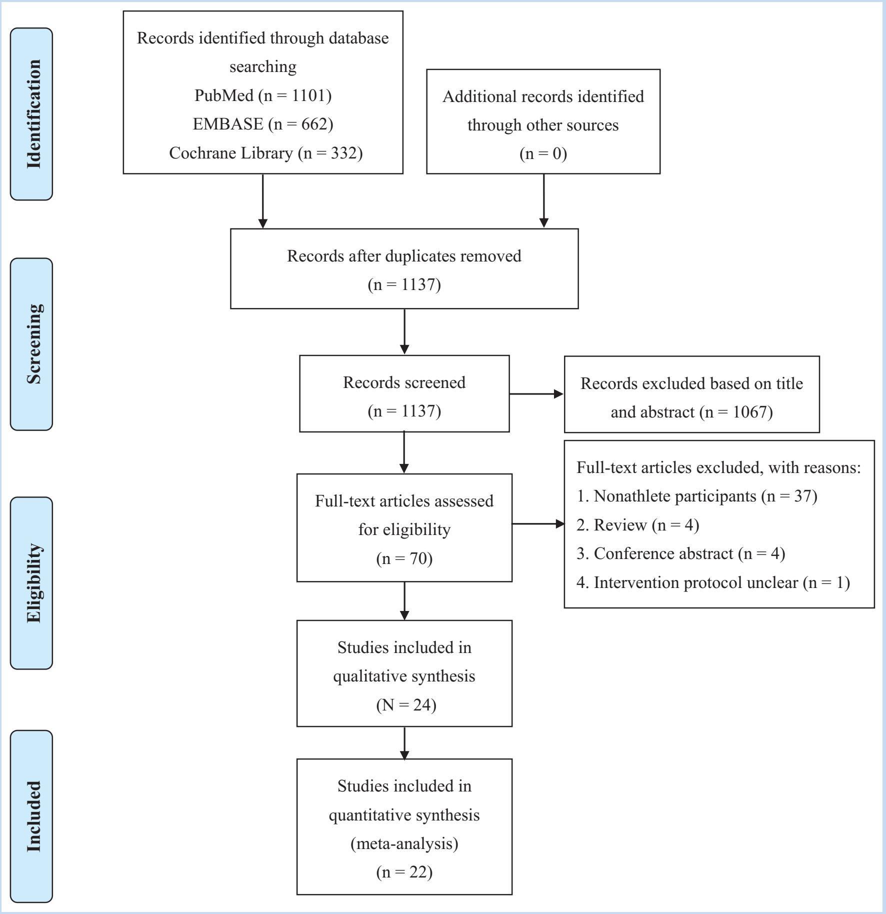

Figure 1. Flowchart of study selection.

The methodological quality of the included trials is summarized in Appendix Table A2 (available online). Most trials had a low bias risk in the randomizing process, whereas 8 trials[4,7,12,16,25,26,36,40] had insufficient information regarding the concealment and allocation of participants. Two trials[16,26] deviated from the intended treatment because they had a short washout period, leading to concern regarding the carryover effect. One trial[7] had a bias in missing outcome data because of missing data without an apparent reason. One trial[36] did not reveal the blinding method to assessors, leading to possible assessment bias. Most trials had a low bias risk in the selection of the reported result, whereas 2 trials[16,26] had a short washout period, leading to concern regarding the carryover effect; 1 trial[9] showed incomplete data of some results, and 1 trial[10] had multiple outcome measurements.

In summary, 14 trials were graded as low risk for overall bias risk[2,3,5,6,8,17-22,27,32,38]; the other 10 trials had overall bias risk.[4,7,9,10,12,16,25,26,36,40]

Muscle Strength

Muscle strength was measured in 5 trials using a dynamometer.[2-4,6,8] All the trials measured the muscle strength of lower limbs except the study conducted by Chang et al,[3] which focused on biceps brachii. Muscle strength was measured after exercise in 4 trials[2,4,6,8]; 2 trials[2,6] conducted a follow-up test at 24, 48, and 96 hours after exercise, and 1 trial[4] conducted an 8-week follow-up test. These trials were categorized into subgroups according to the follow-up time. The LLLT group demonstrated a significantly high lower-limb muscle strength in 24-hour (SMD, 1.97; 95% CI, 1.01 to 2.93), 48-hour (SMD, 2.02; 95% CI, 1.04 to 2.99), 96-hour (SMD, 2.68; 95% CI, 1.57 to 3.79), and 8-week (SMD, 2.99; 95% CI, 1.76 to 4.21) follow-up groups but showed no significant difference in the postexercise group (SMD, 0.59; 95% CI, −0.18 to 1.37) compared with the control group (Appendix Figure A1, available online).

As mentioned earlier, only Chang et al[3] applied the laser to the upper limb and did not observe any difference compared with control in all the follow-up groups.

Contract Repetition Number

Contract repetition number was measured in 6 trials with muscle fatigue protocols.[9,12,19-22] The laser was applied before exercise in all the trials and was also applied after exercise in the study by Dos Reis et al.[9] These trials were categorized into subgroups according to the laser application time. The LLLT group demonstrated a significantly higher contract repetition number in the preexercise laser group (SMD, 0.92; 95% CI, 0.03 to 1.81) but showed no significant difference in the postexercise laser group (SMD, 0.02; 95% CI, −0.90 to 0.95) compared with the control group (Appendix Figure A2, available online).

Soreness Index

The soreness index was measured in 4 trials by using the visual analog scale (VAS) or modified Numerical Rating Scale score.[2,3,6,36] In all trials, outcomes were measured after exercise[2,3,6,36]; 3 trials conducted a follow-up test at 24, 48, and 96 hours after exercise.[2,3,6] These trials were categorized into subgroups according to the follow-up time. The LLLT group demonstrated a significantly lower soreness index after exercise (SMD, −1.54; 95% CI, −2.90 to −0.19) but showed no significant difference in 24-hour (SMD, −0.27; 95% CI, −0.87 to 0.32), 48-hour (SMD, 0.31; 95% CI, −0.48 to 1.09), and 96-hour (SMD, 0.46; 95% CI, −0.40 to 1.31) follow-up groups compared with the control group (Appendix Figure A3, available online). Among the included trials, only the study by Takenori et al[36] applied laser after exercise, showing a significant effect on soreness relief calculated in pain relief rate (laser vs placebo: 36.94% [95% CI, 25.81 to 48.07] vs 8.20 [95% CI, 2.43 to 13.98]).

Time to Fatigue

Time to fatigue was measured in 6 trials.[5,9,20-22,26] The fatigue time was estimated using the time on court in the study by de Marchi et al,[5] whereas others used a fatigue protocol. The laser was applied before exercise in all trials and was also applied after exercise in the study by Dos Reis et al.[9] The trials were categorized into subgroups according to laser application time. The LLLT group did not demonstrate a significantly higher time to fatigue in the preexercise (SMD, 0.30; 95% CI, −0.22 to 0.82) and postexercise (SMD, −0.19; 95% CI, −1.12 to 0.73) laser groups than did the control group (Appendix Figure A4, available online).

Serum CK Concentration

The serum CK concentration was measured in 11 trials.[2,5,6,9,10,17,18,20,21,38,40] Laser was applied before exercise in all the trials except Zagatto et al[40] and was applied after exercise in studies conducted by Dos Reis et al[9] and Zagatto et al. These trials were categorized into subgroups according to the laser application time. The LLLT group demonstrated a significantly lower CK concentration in the preexercise laser group (SMD, −0.89; 95% CI, −1.49 to −0.29) but no significant difference in the postexercise laser group (SMD, −1.76; 95% CI, −5.42 to 1.89) compared with the control group (Appendix Figure A5, available online).

Appendix Figure A6 (available online) shows the serum CK concentration 48 hours after exercise. Four studies were included.[2,5,6,40] The LLLT group demonstrated a significantly lower CK concentration in the preexercise laser group (SMD, −2.91; 95% CI, −4.70 to −1.12) but no significant difference in the postexercise laser group (SMD, −0.13; 95% CI, −1.00 to 0.75) compared with the control group.

Serum Lactate Concentration

The serum lactate concentration was measured in 11 trials.[5,7,12,17-22,25,32] The LLLT group demonstrated a significantly lower serum lactate concentration (SMD, −0.45; 95% CI, −0.78 to −0.13) than did the control group (Appendix Figure A7, available online).

Inflammation-Related Factors

Inflammation-related factors, including interleukin (IL)-1β, IL-6, and tumor necrosis factor (TNF)-α, were measured in 4 trials.[2,6,38,40] These trials were categorized into subgroups according to the factors. The LLLT group demonstrated a significantly lower IL-6 concentration (SMD, −1.98; 95% CI, −3.14 to −0.81) but showed no significant effect on IL-1β (SMD, −0.03; 95% CI, −0.55 to 0.50) and TNF-α (SMD, −0.03; 95% CI, −0.55 to 0.50) concentrations compared with the control group (Appendix Figure A8, available online).

Serum TBARS Concentration

The serum TBARS concentration was measured in 3 trials.[5,6,38] The LLLT group demonstrated a significantly lower TBARS concentration (mean difference, −1.53; 95% CI, −2.55 to −0.51) than did the control group (Appendix Figure A9, available online).

Other Exercise Ability Tests

Jumping height tests were conducted in studies conducted by da Cunha et al,[4] Dornelles et al,[8] and Maciel et al,[26] and all the trials showed no difference in jumping height between the LLLT and control groups.

VO_2 test was conducted by 2 studies.[16,38] In the study by Lanferdini et al,[16] the amplitude VO_2 test (SMD, 0.43; 95% CI, −0.83 to 1.69) and deficit O_2 test (SMD, −0.75; 95% CI, −2.06 to 0.56) showed a slightly higher amplitude VO_2 and lower deficit O_2 in the LLLT group than in the control group. In the study by Tavares et al,[37] the relative VO_2 test (SMD, 0.67; 95% CI, −0.19 to 1.53) and absolute VO_2 test (SMD, 0.84; 95% CI, −0.04 to 1.72) showed a slightly higher relative VO_2 and absolute VO_2 in the LLLT group than in the control group.

The effect of LLLT use on hamstring strain injury recovery was investigated in the study by Medeiros et al.[27] The straight leg raise test results, knee extension test, maximal hip flexion active knee extension test, and range of motion demonstrated no difference between the LLLT and control groups.

DISCUSSION

We observed that LLLT application before exercise significantly affected lower-limb muscle strength improvement. In addition to the strengthening effect, LLLT significantly reduced the soreness index in the postexercise group, reduced CK, IL-6, and TBARS concentrations after exercise, and showed a trend toward improving contract repetition number and VO_2 kinetic outcomes.

We attempted to determine the ideal dose of LLLT. A previous study[2] that reviewed 39 trials suggested that <60 J should be applied to small muscle groups and >60 J to large muscle groups. However, the latest trials have reported a different result. For example, although Chang et al[3] applied 36 J to biceps, almost no effect was observed on muscular performance. By contrast, Takenori et al[36] applied 5.4 J on pain sites and showed significant effects on soreness relief, whereas Dos Reis et al[9] applied 25.2 J on the quadriceps and showed a low serum CK concentration. Thus, a low laser dose can be used to obtain a strong effect.

To determine the dose effect, several trials included in the present review had used multiple doses. These trials targeted large muscle groups, such as the quadriceps and hamstring muscles. Ferraresi et al[10] showed effects in most of the experiments applying 630 or 945 J, whereas Lanferdini et al[16] showed effects with application of 135, 270, or 405 J. Interestingly, Aver Vanin et al[2] showed a significant effect with 60 or 300 J, but showed no effect with 180 J. To explain this phenomenon, Aver Vanin et al hypothesized that different muscle groups have different therapeutic windows. The therapy would be effective only when the dose applied is in the therapeutic window. However, the hypothesis requires further research for confirmation. We attempted to determine the therapeutic window by using 11 trials[2,5,6,9,10,17,18,20,21,38,40] that provided serum CK data. Dos Reis et al[9] and Tomazoni et al[38] showed significant effects with 25.2 and 810 J laser, respectively. Leal Junior et al[17] showed a trend toward significance with 15 or 20 J. The finding suggests that although dose can affect trial outcomes, it may not be the only influencing factor because a definite therapeutic window is still not established.

In addition to the dose effect, the "delay effect" is a concern. In the study by Aver Vanin et al,[2] the 300-J group always had a slower muscular effect than did the 60-J group. This delay effect could also be observed in the study conducted by de Oliveira et al,[6] because the 200-mW group always had a slower effect on the VAS change than the 100-mW group. However, studies that focused on the time effect were still rare. If the delay effect could be clarified in the future, it could be applied to athletes who need different recovery protocols; for example, applying 60 and 300 J of laser to those who do not need a rapid soreness recovery, respectively. To sum up, different doses applied can lead to variation in onset time, and further investigation is imperative to clarify the relationship.

We carefully reviewed the techniques of each study to judge the body areas suitable for the techniques. Interestingly, 4 trials that applied LLLT on the rectus femoris, vastus lateralis, and vastus medialis with 2 positions on each muscle showed improvements in muscle strength or contract repetition number.[2,4,6,12] Moreover, according to de Oliveira et al[6] and Aver Vanin et al,[2] 300 J could be a feasible dose. In contrast, Dos Reis et al[9] applied LLLT to the same muscles but with multiple positions, showing no effect on muscular performance. That is to say, the current evidence is more solid in increasing muscle strength when applying LLLT on the rectus femoris, lateral femoris, and medial femoris, with 2 positions on each muscle.

Among 3 inflammation-related factors, all the trials indicated a significantly lower IL-6 concentration in the LLLT group and no difference in IL-1β and TNF-α concentrations between the LLLT and control groups. The phenomenon revealed in the study by Aver Vanin et al[2] was observed to be related to a decreased C-reactive protein level. Recently, several human and animal studies have investigated the mechanism and relationship between LLLT and inflammatory factors. Mojarad et al[29] demonstrated that LLLT application could lower the IL-6 concentration in spinal cord injury patients, relieving neuropathic pain. Lima et al[24] suggested that the effect of 660 nm of LLLT in enhancing cell proliferation does not require cytochrome *c* oxidase. Because studies in the field remain scant, additional studies would be required to clarify this condition.

We aimed to compare the effects between pre- and postexercise laser. However, few studies have focused on this comparison. For example, in the study by Dos Reis et al,[9] serum CK and lactate concentrations were compared, which demonstrated that both pre- and postexercise laser lower the concentrations, but the result was more pronounced with postexercise laser. Most trials in our study applied laser before exercise, whereas 5 trials applied laser after exercise or injury.[7,9,27,36,40] Takenori et al[36] showed a significant effect on soreness recovery, whereas Dos Reis et al showed a lower CK concentration after laser application. However, other trials did not show significant changes in muscular performance. Owing to limited studies, we could not confirm whether a significant difference exists between preexercise laser and postexercise laser, and more studies in this context would be required.

Seven trials in our study applied red light together with infrared light, whereas other trials applied only infrared light.[5,7,10,12,18,21,32] Albuquerque-Pontes et al[1] suggested that combining different wavelengths in LLLT could enhance the effects on skeletal muscle performance. They suggested that different wavelengths of LLLT stimulate cytochrome *c* oxidase at a different pace; thus, combining different wavelengths can synergistically affect muscular performance improvement. Among the 7 trials mentioned, de Marchi et al[5] showed a trend of a lower TBARS concentration, whereas Leal Junior et al[18,21] showed a lower lactate concentration. These findings suggest that the usage of multiple wavelengths does not lead to enhanced effects. However, these trials did not have a follow-up protocol; thus, we could not determine if the use of multiple wavelengths can lengthen the effect of LLLT. Additional studies with follow-up protocols can give us a precise answer.

Several studies have demonstrated the effects of LLLT on muscular performance. In a 24-participant randomized crossover trial involving moderately active and healthy men aged 21 to 22 years, Jówko et al[14] demonstrated beneficial effects of LLLT against inflammation. Furthermore, in a 20-participant crossover study, Miranda et al[28] indicated that a longer distance could be covered on a treadmill after LLLT therapy, with increased pulmonary ventilation and decreased dyspnea sensation. Sarilho de Mendonça et al[33] conducted a 20-participant randomized crossover trial and demonstrated that LLLT significantly reduced the amplitude of the surface electromyography signal of the upper trapezius muscle in young women. Although the aforementioned studies recommended LLLT application, none of them focused on athletes and were therefore excluded from our study.

Some studies included in our review demonstrated moderate heterogeneity. As aforementioned, we assumed that each muscle group had its best LLLT dose; because the ideal dose is unknown, we could not design LLLT parameters with a precise method, leading to increased heterogeneity. Moreover, exercise protocols slightly differed between trials. Furthermore, the ideal site for LLLT application is still undefined, leading to different experimental designs and results. Additionally, all trials in our study had located the site of laser application, except the study conducted by Takenori et al.[36]

The strengths of the present review are that we performed a comprehensive search for eligible studies, systematically and explicitly applied eligibility criteria, carefully considered study quality, and involved a rigorous analytical approach. In addition, as the first review study focusing on athletes, the results may serve as a reference in further training or recovery plans. However, this study has several limitations. First, the small sample size of the trials limited the strength of evidence. Moreover, only 3 trials included female athletes. Finally, no information regarding side effects was mentioned in any of the trials, which leads to safety concerns.

CONCLUSION

Athletes need to recover quickly from their exhaustion. Winning and maintaining the best physical conditions are equally important. Our findings indicate that LLLT improves muscular performance and accelerates soreness recovery in athletes. More solid evidence is found for the application on the rectus femoris, lateral femoris, and medial femoris, with 2 positions on each muscle. We recommend LLLT use before or after competition, allowing the athletes to regain their capacity faster without side effects.

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