# DOES PHOTOBIOMODULATION IMPROVE MUSCLE PERFORMANCE AND RECOVERY? A SYSTEMATIC REVIEW

*A FOTOBIOMODULAÇÃO MELHORA O DESEMPENHO E A RECUPERAÇÃO MUSCULAR? UMA REVISÃO SISTEMÁTICA*

*¿LA FOTOBIOMODULACIÓN MEJORA EL DESEMPEÑO Y LA RECUPERACIÓN MUSCULAR? UNA REVISIÓN SISTEMÁTICA*

SYSTEMATIC REVIEW
*REVISÃO SISTEMÁTICA*
*REVISIÓN SISTEMÁTICA*

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## ABSTRACT

Photobiomodulation (PBM) appears to limit exercise-induced muscle damage, improve biochemical and functional recovery, and reduce inflammation and oxidative stress. This systematic review aimed to evaluate the effectiveness of photobiomodulation (PBM) in skeletal muscle recovery after exercise, addressing the different types of lasers and parameters used. Randomized clinical trials (RCTs) comparing the effects of PBM were included. The primary outcome evaluated was performance, and the secondary was inflammatory marker expression. The searches were conducted in March 2021. Fifteen RCTs that met the inclusion criteria were included. There was significant variability regarding the doses and wavelengths used, as well as in the types of lasers. However, in most studies, PBM promoted improvement of maximum voluntary contraction, better oxygen consumption, increased time to achieve exhaustion and fatigue, and decreased creatine kinase (CK), oxidative stress, and fatigue markers, mainly when used before exercise. Photobiomodulation applied before exercise, regardless of variations in doses and wavelengths, improves muscle performance and decreases levels of inflammation and fatigue markers. ***Evidence level II; Systematic review of level II studies.***

**Keywords:** Low-level laser therapy; Laser therapy; muscle function.

## *RESUMO*

*A fotobiomodulação (PBM) parece amenizar o dano muscular induzido pelo exercício, melhorando a recuperação bioquímica e funcional e reduzindo a inflamação e o estresse oxidativo. Esta revisão sistemática teve como objetivo avaliar a eficácia da fotobiomodulação (PBM) na recuperação do músculo esquelético depois do exercício, abordando os diferentes tipos de lasers e parâmetros utilizados. Foram incluídos estudos clínicos randomizados (RCTs) que comparam os efeitos da PBM. O desfecho primário avaliado foi o desempenho e o secundário foi a expressão de marcadores inflamatórios. Foram analisados estudos publicados até março de 2021. Foram incluídos 15 RCTs que atenderam aos critérios de inclusão. Houve variabilidade significativa quanto às doses e comprimentos de onda usados, bem como aos tipos de laser. Porém, na maioria dos estudos, a PBM promoveu melhora da contração voluntária máxima, melhor consumo de oxigênio, aumento do tempo para atingir exaustão e fadiga, e diminuição dos níveis de creatina quinase (CK), estresse oxidativo e marcadores de fadiga, principalmente quando usado antes do exercício. A fotobiomodulação aplicada antes do exercício, apesar de apresentar grande variabilidade de doses e comprimentos de onda, melhora o desempenho muscular e diminui os níveis de marcados inflamatórios e de fadiga.* **Nível de evidência II; Revisão sistemática de estudos de Nível II.**

***Descritores****: Terapia a laser de baixa intensidade; Terapia a laser; Função muscular.*

## *RESUMEN*

*La fotobiomodulación (PBM) parece aliviar el daño muscular inducido por el ejercicio, mejorando la recuperación bioquímica y funcional y reduciendo la inflamación y el estrés oxidativo. Esta revisión sistemática tuvo como objetivo evaluar la eficacia de la fotobiomodulación (PBM) en la recuperación del músculo esquelético después del ejercicio, abordando los diferentes tipos de láseres y parámetros utilizados. Se incluyeron ensayos clínicos aleatorizados (ECA) que compararon los efectos de la PBM. El resultado primario evaluado fue el desempeño y el secundario fue la expresión de marcadores inflamatorios. Se analizaron los estudios publicados hasta marzo de 2021. Resultados: Se incluyeron quince ensayos clínicos aleatorizados que cumplían los criterios de inclusión. Hubo una importante variabilidad en cuanto a las dosis y longitudes de onda utilizadas, así como al tipo de láser. Sin embargo, en la mayoría de los estudios, la PBM promovió una mejor contracción voluntaria máxima, un mejor consumo de oxígeno, un mayor tiempo para alcanzar el agotamiento y la fatiga, y una disminución de los niveles de creatina quinasa (CK), del estrés oxidativo y de los marcadores de fatiga,*


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*especialmente cuando se utiliza antes del ejercicio. La fotobiomodulación aplicada antes del ejercicio, a pesar de presentar gran variabilidad de dosis y longitudes de onda, ha demostrado mejorar el desempeño muscular y disminuir los niveles de marcadores inflamatorios y de fatiga.* ***Nivel de evidencia II; Revisión sistemática de estudios de nivel II.***

***Descriptores:*** *Terapia por láser de bajo nivel; Terapia por láser; Función muscular.*

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## INTRODUCTION

The practice of physical activity promotes health and quality of life. However, there is a wide range of risks involved according to each sport's physical demand on its practitioners.[1] Thus, many therapeutic modalities have been used after sports activities to improve skeletal muscle recovery, and one of them is Photobiomodulation (PBM). PBM is a non-pharmacological treatment aimed at decreasing the duration of the muscle recovery period.[1-4] However, the scientific evidence on the efficacy of this treatment is limited.[3,5,6]

It is known that exercise increases the flow of mitochondrial oxygen and the production of adenosine triphosphate (ATP) in skeletal muscle. As the main chromophores of PBM are located within the mitochondria, cells with many mitochondria and high metabolic activity are particularly responsive to light. Thus, it is hypothesized that PBM use in sports and exercises increases cytochrome c-oxidase in skeletal muscle fibers, leading to positive mitochondrial regulation, increasing ATP production.[7,8] The increase in ATP production increases energy production and decreases oxidative stress and the production of reactive oxygen species, delaying muscle fatigue and improving the status of biochemical markers related to skeletal muscle recovery. When PBM is applied, an extra amount of Calcium ($Ca^{2+}$) is transported to the cytoplasm through a process that promotes cell mitosis, RNA and DNA synthesis and cell proliferation.[3]

In this context, studies have shown that PBM can limit exercise-induced muscle damage, improving biochemical and functional recovery and reducing inflammation and oxidative stress.[3,4,9–14] However, it is not yet a consensus on the literature since some studies showed no results or even worse results after PBM on muscle recovery after fatigue induction.[2,4,5] Besides, there is great variability in the application parameters (such as power, wavelength, irradiation time and energy) used in the studies, making it challenging to interpret the results and use them in clinical practice, even in sporting environments.[3,15] Therefore, considering the divergence among the available results, a systematic review in this field is extremely important to determine the best criteria to be used so that it is possible to obtain a rapid muscle recovery and the return of sports activities.

Although there are some systematic reviews in this field,[16–18] there are many gaps in this knowledge since many studies analyzed different variables or had a limited search strategy. This fact does not allow the conclusion regarding the efficacy of PBM on muscle performance and inflammatory or fatigue markers. Additionally, some new high-quality studies are available, which could contribute to the clinical use of PBM.

Therefore, this systematic review aimed to evaluate the effectiveness of PBM with low-level laser therapy (LLLT) in skeletal muscle recovery after exercise, addressing the different types of lasers and parameters used.

## METHODS

This systematic review is based on Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) checklist structure[18] and was conducted following the methodology described in the Cochrane Handbook of Systematic Reviews of Interventions.[19] A specific question was formulated based on population, intervention, control, and outcome (PICO) criteria. The focus question was: "What is the effect of PBM on skeletal muscle function?" According to these criteria, the population consisted of healthy participants, and the comparative intervention was the PBM compared to no treatment or placebo. The primary outcome was the performance (assessed by maximum voluntary contraction, peak strength, time to reach exhaustion, isometric capacity, time on the pitch, time to achieve fatigue/exhaustion), and the secondary outcome was the expression of inflammatory markers.

### Identification and selection of studies

Two independent researchers conducted an electronic search of articles published until March 2021, in the databases PubMed/MEDLINE, EMBASE, LILACS, Scielo, using the following search strategy: "(laser therapy OR low-level laser therapy OR low-intensity laser therapy OR phototherapy OR photobiomodulation) AND (repair OR regeneration OR rehabilitation) AND (skeletal muscle)".

The studies were selected and classified as "included" or "excluded", based on the reading of the title and summary of the articles by the two reviewers, working separately. A third researcher analyzed all inconsistencies in the choices of the articles by the other two researchers, and a consensus was reached through discussion. The studies selected as "included" were randomized clinical trials, with healthy participants, an experimental group with laser treatment, the presence of a control group without treatment or placebo and in all idioms. Exclusion criteria were: studies in which the intervention group received PBM associated with another therapy; studies that do not specify the intervention protocol; studies that include participants with any kind of disease or pathology; letters, case reports, short communication and studies in animal and in vitro models.

### Data extraction

The relevant data extracted from every study included: the author name; year of publication; sample size; characteristics of the participants (gender, age, height, weight, trained or untrained); type of laser used, wavelength, energy, time of application, power, application protocol and outcome measures.

### Assessment of quality and risk of bias

After selecting the studies, two reviewers independently evaluated the quality of each study included by using the PEDro Scale (Centre for Evidence-Based Physiotherapy), in which the studies are classified with scores from 0 to 10. The risk of bias in individual studies was evaluated according to the Cochrane Collaboration's tool.[20] This tool comprises seven evaluation domains: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessors, incomplete outcome data, selective out- come reporting and other sources of bias. The risk of bias assessment for each of the domains involves classification into three categories: (1) low risk of bias, when the domain described by the study is considered adequate; (2) high risk of bias, when the domain described by the study is considered inadequate; and (3) unclear risk of bias when the study presents insufficient information for assessing the risk of bias.

## RESULTS

The combined total number of studies obtained through the electronic search strategy was 4174 references, including 3660 from PubMed/MEDLINE, 27 from LILACS, seven from Scielo and 480 from EMBASE. A total of 2 publications were obtained in duplicate and eliminated from the analysis. After exclusions based on the title and abstract, 41 studies were selected and evaluated for eligibility. Thus, 15 RCTs[1-15] were included in this systematic review (Figure 1).

### Risk of bias assessment

#### Effects of intervention

There was a great variability regarding the doses and wavelengths used and the type of laser. In each variation, different results were obtained, showing that other PBM parameters may provide distinct effects on muscle tissue. The heterogeneity of the studies, especially on laser parameters and treated muscles, did not allow comparisons of the result, and the meta-analyzes of these data could therefore be questionable due to a possible bias.

### Risk of bias

According to the PEDro scale score, most studies showed high quality, with eight of them reaching the maximum score. Only one study had a mean score (5/10) because it did not present the randomization and blinding process of the sample in the internal validity and did not present the variability of the data in the external validity, which can be seen in Table 1. The same can be observed in the Cochrane Collaboration's tool, represented in Figure 2.

### Characteristics of the included studies

We included fifteen RCTs published from 2012 to 2018 in English, being all conducted in Brazil. Table 2 shows the characteristics of the participants in the included studies. The studies involved a total of 428 participants, with samples ranging from 6 to 96. The mean age ranged from 18 to 35 years, while the mean height ranged from 169 to 178.8 cm, and the mean weight ranged from 63.58 to 86 kg. The studies involved participants of both sexes; most of them included trained volunteers, while two included only untrained volunteers. The characteristics of the laser can be seen in Table 3, which involves many different types and brands, with wavelength ranging from 640 to 905 nm, energy ranging from 5 to 480 J and power ranging from 0,05 to 400 w. Table 3 also presents the protocols for exercises, laser application and evaluation of the outcomes of strength, fatigue and inflammatory markers.

Five studies used the red band[1,7,9,13,15] with energy densities ranging from 5 to 100 J. In contrast, most studies used the infrared band[1-7,9-11,13,15]

**Table 1.** Study scores according to the PEDro scale criteria.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Antonialli et al.[9] | S | S | S | S | S | S | S | S | S | S | S | 10/10 |
| Almeida et al.[15] | S | S | S | S | S | S | S | S | S | N | N | 8/10 |
| Dellagrana et al.[7] | S | S | S | S | S | S | S | S | S | S | S | 10/10 |
| De Marchi et al.[10] | S | S | S | S | S | S | S | S | S | S | S | 10/10 |
| De Marchi et al.[1] | S | S | S | S | S | S | S | S | S | S | S | 10/10 |
| De Marchi et al.[11] | S | S | S | S | S | S | S | S | S | S | S | 10/10 |
| De Godoy et al.[2] | S | S | S | S | S | N | N | S | S | N | S | 7/10 |
| Larkin-Kaiser et al.[14] | S | S | S | S | S | N | N | S | S | N | S | 7/10 |
| Larkin-Kaiser et al.[5] | S | S | S | S | S | S | N | S | S | N | S | 8/10 |
| Miranda et al.[13] | S | N | N | S | S | S | N | S | S | N | N | 5/10 |
| Oliveira et al.[3] | S | S | S | S | S | S | S | N | N | S | S | 8/10 |
| Pinto et al.[4] | S | S | S | S | S | S | S | S | S | N | S | 9/10 |
| Vanin et al.[6] | S | S | S | S | S | S | S | S | S | S | S | 10/10 |
| Zagatto et al.[12] | S | S | S | S | S | S | S | S | S | S | S | 10/10 |
| | S | S | S | S | S | S | S | S | S | S | S | 10/10 |

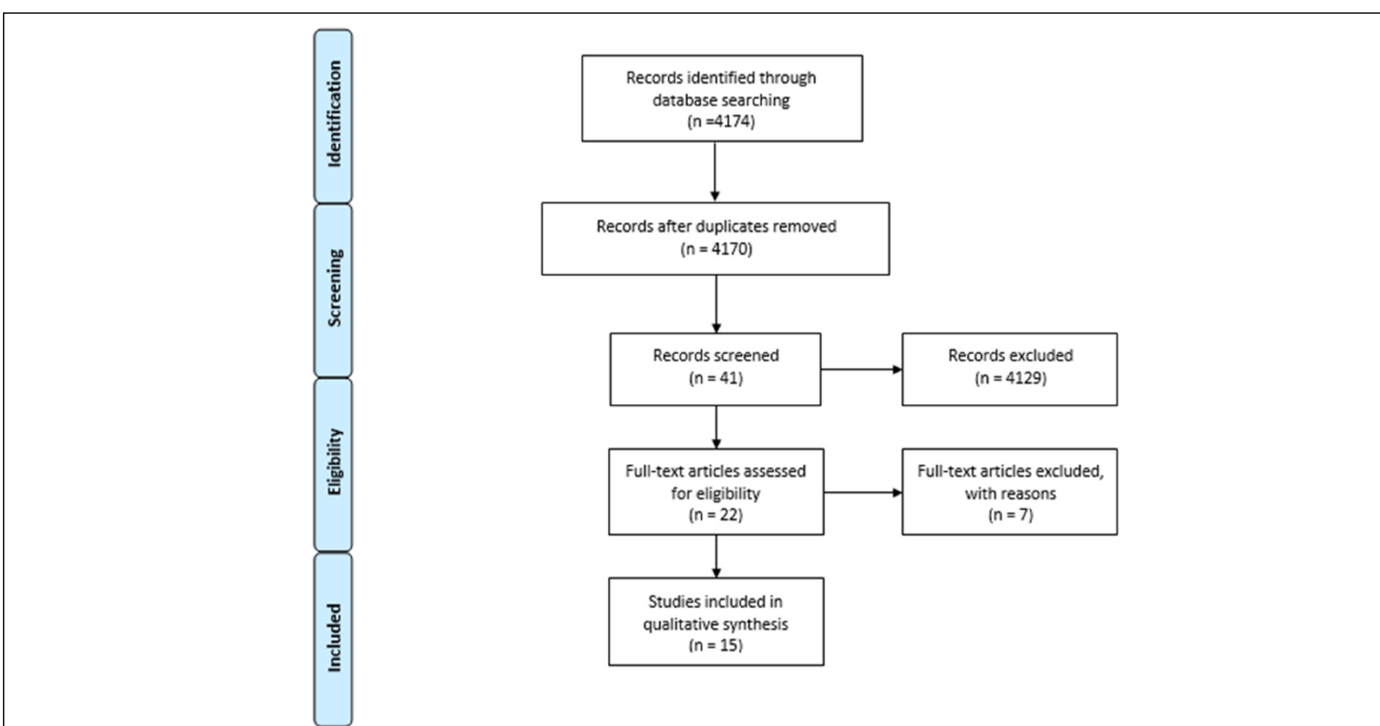


**Figure 1.** PRISMA flow Diagram of the study selection process.

| | Random sequence generation (selection bias) | Allocation concealment (selection bias) | Blinding of participants and personnel (performance bias) | Blinding of outcome assessment (detection bias) | Incomplete outcome data (attrition bias) | Selective reporting (reporting bias) | Other bias |
|---|---|---|---|---|---|---|---|
| Antonialli et al.[9] | + | + | + | + | + | + | + |
| Almeida et al.[15] | + | + | + | + | - | + | + |
| Dellagrana et al.[7] | + | + | + | + | + | + | + |
| De Marchi et al.[10] | + | + | + | + | + | + | + |
| De Marchi et al.[1] | + | + | + | - | + | + | + |
| De Marchi et. al.[11] | + | + | + | + | + | + | + |
| De Godoy et al.[2] | + | + | + | - | + | - | + |
| Larkin-Kaiser et al.[14] | + | + | + | - | + | + | + |
| Larkin-Kaiser et al.[5] | + | + | + | - | + | + | + |
| Miranda et al.,[13] | + | + | + | + | + | + | + |
| Pinto et al.[4] | + | + | + | + | + | + | + |
| Oliveira et al.[3] | + | + | + | + | + | + | + |
| Vanin et al.[6] | + | + | + | + | + | + | + |
| Zagatto et al.[12] | + | + | + | + | + | + | + |

(+) = low risk of bias; (-) = high risk of bias.

**Figure 2.** Risk of bias summary of the included studies for each domain, according to Cochrane Collaboration tool.

**Table 2.** Characterization of the sample.

| | N | Gender | Trained/Untrained | Characteristics of the sample |
|---|---|---|---|---|
| Antonialli et al.[9] | 40 | Male | Untrained | 24.10 ± 1.52 years, 171,44 ± 6,22 cm, 67,05 ± 5,38 kg |
| Almeida et al.[15] | 10 | Male | Untrained | 19 to 27 yeas |
| Dellagrana et al.[7] | 18 | Male | Runners | 20,7 ± 4,7 years, 178,8 ± 5,5 cm, 76,2 ± 7,2 kg |
| De Marchi et al.[10] | 22 | Male | Untrained | 20 to 25 years. |
| De Marchi et al.[1] | 40 | Male | Active | 19 to 29 years. |
| De Marchi et al.[11] | 6 | Male | Football players | 18 a 35 years. |
| De Godoy et al.[2] | 52 | Male and Female | - | 18 to 23 years. |
| Larkin-Kaiser et al.[14] | 39 | Male and Female | Active | 20,0 ± 0,2 years, 169 ± 2,0 cm, 68,4 ± 1,8 kg |
| Larkin-Kaiser et al.[5] | 9 | Male and Female | - | 24,3 ± 4,97 years, 171 ± 7,78 cm, 71,2 ± 11,6 kg |
| Miranda et al.[13] | 96 | Male and Female | Untrained | 18 to 35 years |
| Oliveira et al.[3] | 28 | Male | Football players | 18 to 35 years |
| Pinto et al.[4] | 20 | Male | Rugby players | 23,50 ± 2,32 years, 178 ± 4,79 cm, 86,00 ± 7,63 kg |
| Vanin et al.[6] | 28 | Male | Football players | 18,81 ± 0,80 years, 172,94 ± 4,78 cm, 63,58 ± 4,46 kg |
| Zagatto et al.[12] | 20 | Male | Water Polo players | 15,4 ± 1,2 years, 173,9 ± 5,9 cm, 68,3 ± 10,5 kg |

with energy densities between 5 and 480 J. Regarding the moment of application, most studies applied the PBM before the exercise,[4-7,9-11,13-15] while two studies applied it both, before and after exercise,[3,12] and one of the studies did not report the moment that PBM was applied.[2]

Table 3 also shows the application area, being them quadriceps,[3,6,9] lower limbs, including quadriceps, hamstrings and gastrocnemius,[4,7,10,11,13] biceps brachii,[1,14,15] masseter and anterior temporal[2] e adductor longus.[12] Only one study did not inform the area of application.[5]

The observed outcomes were maximum voluntary contraction,[6,7,9] peak strength[15] e peak torque,[7] time to reach exhaustion,[4,5,10] oxygen consumption,[10,13] inflammatory markers and oxidative stress,[1,3,4] blood lactate levels and fatigue markers[4] e CK activity.[3,6,9-12]

## DISCUSSION

Several studies have been published investigating the effects of PBM on exercise performance and post-exercise recovery, and there is some systematic review on this field available in the literature. Leal-Junior et al.,[16] for example, concluded that the number for repetitions and the time until exhaustion increased after phototherapy, mainly when it was applied before exercises, independent of the wavelength used. Corroborating to these findings, Borsa et al.,[17] found that exposing skeletal muscle to single-diode and multidiode laser or multidiode LED therapy was shown to positively affect physical performance by delaying the onset of fatigue, reducing the fatigue response, improving postexercise recovery, and protecting cells from exercise-induced damage. The present study updates the knowledge in this field, besides presenting strength outcomes, such as time to fatigue and exhaustion, oxygen consumption, inflammatory and oxidative stress markers and CK activity.

### Strength Outcomes

Most studies analyzed the strength outcome, which was evaluated by maximum voluntary contraction or peak torque. Antonialli et al.[9] using 640, 875 and 905 wavelength combination increased maximal voluntary contraction with 10 and 30 J by applying PBM on quadriceps. Similarly, Vanin et al.[6] obtained an increase in the maximum voluntary contraction, using a dose of 10 and 50 J also on quadriceps, but with 810 nm wavelength only.

De Marchi et al.[11] analyzed the isometric capacity with laser application in the biceps brachii, with an increase in the same with wavelength 660 and 850 with dose 41,7 J. Almeida et al.,[15] analyzing the peak force, used wavelength of 660 and 830 nm and, unlike other studies, using a lower dose of 5J. However, it also showed an increase in mean peak strength with PBM applications in biceps brachii.

Meanwhile, Dellagrana et al.[7] found no difference in peak torque during maximum isometric contraction with wavelength 670, 850, 880 and 950 and dE 15, 30 and 60 J. This same study used a different protocol, performing four sessions of PBM in quadriceps, hamstring and gastrocnemius regions, with seven days of interval between them.

### Time to fatigue and exhaustion

Among the studies that analyzed the time to reach exhaustion, all obtained an increase in time to reach fatigue, suggesting an improvement in performance. De Marchi et al.,[10] De Marchi et al.[11] and Pinto et al.[4] used a dose of 30 J, with wavelengths 810 nm, 905 nm and a cluster of 640, 875 and 905 nm, respectively. All of them applied PBM before the exercise protocol in the lower limbs.

In the same way, Zagatto et al.[2] applied PBM in long adductor, using a wavelength of 810 nm and dose 48J, and Larkin Kaiser et al.[14] used higher doses (240 and 480J) with the same wavelength, both of them also demonstrated an increase in time to reach fatigue.

**Table 3.** Laser parameters, application protocol and results.

| | Kind of the laser | Wavelength (nm) | Energy density (J) | Time of application (s) | Power density (w) | Application Protocol | Application Site | Results |
|---|---|---|---|---|---|---|---|---|
| Antonialli *et al.*[9] | MR4 LaserShower 50 4D emitter (Multi Radiance Medical): Cluster de 12 diodos | 640, 875, 905 | 10, 30, 50 | 76, 228, 381 | 0,07, 16,66, 19,44 | One application 3 minutes before exercise protocol. | 6 sites of quadriceps. | ↑ Maximum voluntary contraction with 10 and 30 J. ↓ CK activity except for only the 50J dose in 96 hours. |
| Almeida *et al.*[15] | Thera Lase (DMC) | 660, 830 | 5 | 100 | 17,85 | Tree applications with seven days between them, 3 minutes before fatigue exercise. | 4 sites of biceps brachii. | ↑ Average peak strength after red (12.14%) and infrared (14.49%). |
| Dellagrana *et al.*[7] | Chatanooga Intelect Mobile Laser 2779 system | 670, 850, 880, 950 | 15, 30, 60 | 64 | | Four applications, being one placebo, with 7 days between them, before strength and run tests. | 14 sites of lower limbs (8 quadriceps, 4 hamstrings, 2 gastrocnemius) | ↔ Peak torque during maximum voluntary isometric contraction. The 15 J dose showed beneficial effects on the neuromuscular economy during the 8km and 9km run. The doses 30 and 60 J showed benefits only in the 9 km h run. |
| De Marchi *et al.*[10] | Multi-Diodo Cluster 5 diodos | 810 | 30 | 30 | 5,495 | One application, 5 minutes before the run test. | 12 sites of lower limbs (6 quadriceps, 4 hamstrings, 2 gastrocnemius) | ↑ total time to reach exhaustion and ↑ oxygen consumption by pre-exercise irradiation. ↓ Lipid (TBARS), SOD and CK activity. |
| De Marchi *et al.*[1] | Cluster (34 LED vermelho e 35 LED infravermelho) | 660, 850 | 41,7 | 30 | 0,05 and 0,15 | One application 2 minutes after maximum voluntary contraction. | Muscular womb of biceps brachii. | ↑ isometric capacity ↓ oxidative stress (TBARS and PC) and CK |
| De Marchi *et al.*[11] | Cluster (4 super-pulsed infrared) | 905 | 30 | 228 | 19,44 | One application 40 minutes before exercise. | 9 different knee extensor and hip flexor muscle locations, 6 knee flexor muscles and hip extensor muscle locations, and 2 plantar flexor muscles. | ↑ time on the pitch ↔ distance covered by the athlete on the pitch ↓ of CK 18,41% in 48 h |
| De Godoy *et al.*[2] | Twin Flex Evolution (MM Optics) | 780 | 25 | 20 | 1,25 | | 3 sites of masseter and anterior temporal. | ↔ |
| Larkin-Kaiser *et al.*[14] | K-Laser (near-infrared laser) | 800, 970 | 360 | 240 | 3 | One application, before resistance protocol. | 15 sites of biceps brachii. | ↔ |
| Larkin-Kaiser *et al.*[5] | Lite Cure (near-infrared laser) | 810, 980 | 240, 480 | 120 | 1,16, 2,33 | One application of each dose with 48 hours between them, before fatigue protocol. | - | ↑ the time to achieve fatigue |
| Miranda *et al.*[13] | MR4 Laser Therapy Sistens Cluster 12 diodes | 640, 875, 905 | 30 | 228 | 0,71 | One application 5 to 10 minutes before and after aerobic test. | 9 sites of quadriceps, 6 sites of hamstring and 2 of the gastrocnemius. | ↑ percentage of oxygen consumption and time to exhaustion |
| Oliveira *et al.*[3] | Cluster 5 diodes | 810 | 10 | 100, 50, 25 e 60 | 100, 200, 400 e 0 | The application was 2 minutes before exercise and 3 minutes after exercise. | 6 sites of quadriceps of non-dominant lower limb. | ↓ LDH and CK at 24, 48.72 and 96 hours after the protocol. ↓ LDG and CK at 200mW and 400mW. ↔ inflammatory markers and oxidative stress. |
| Pinto *et al.*[4] | MR4 Laser Therapy Systems - Cluster com 12 diodes (Multi raiance Medical) | 905, 875 e 640 | 30 | 228 | 0,3125, 15 e 17,5 | One application before exercise protocol. | 9 sites of quadriceps, 6 sites of hamstrings and 2 sites of the gastrocnemius. | ↑ Average sprint time and fatigue index. ↓ Blood lactate levels and fatigue markers. |
| Vanin *et al.*[6] | Thor Photomedicine - Cluster 5 diodes | 810 | 10, 30, 50 | 60, 180, 300 | 5,495 | Two minutes before maximum voluntary contraction test. | 6 sites of quadriceps. | ↑ Maximum voluntary contraction after exercise for up to 24 hours with 50J dose and after 24 to 96 hours with 10J dose. ↓ CK and IL6 at 10J and 50J ↔ J 30J. |
| Zagatto *et al.*[12] | Laser infravermelho (DMC) | 810 | 48 | 30 | 3,57 | Six applications, 5 to 40 minutes after each training session. | 8 sites of adductor longus. | ↔ 200-meter shot ↑ 30-second performance after 48 hours. ↓ CK |

↑ increase; ↓ decrease; ↔ no difference.

## Oxygen consumption

Regarding oxygen consumption, both studies that analyzed this variable obtained an increase in oxygen consumption.[10,13] De Marchi et al.[10] used a single wavelength of 810 nm with dose 30J, PBM was applied in quadriceps, hamstrings and gastrocnemius, while Miranda et al.[13] used wavelengths of 640, 875 and 905 nm, with the same dose of 30 J and regions of application.

## CK activity and inflammatory markers

Most studies analyzed the outcome of CK activity, inflammatory and oxidative stress markers. Among all the studies that investigated the outcome of inflammatory and oxidative stress markers, only one found no difference in inflammatory markers but showed a decrease in CK activity, using 810 nm and dE 10 J in quadriceps.

Antonialli et al.[9] applied PBM in quadriceps with wavelengths of 640, 875 and 905 nm and dose 10, 30 and 50J, and also demonstrated a decrease in CK activity only with dose 50J. On the other hand, De Marchi et al.[11] only noted a reduction in CK in one time of analysis, being that in 48 hours, applying PBM with 905 nm and dose 30J in lower limbs.

With this same dose, 30 J, De Marchi et al.[10] and Pinto et al.[4] demonstrated a decrease in oxidative stress (TBARS and PC), CK activity and blood lactate and fatigue markers, using a wavelength of 810 nm and 640, 875 and 905 nm, respectively. De Marchi et al.[1] also analyzed oxidative stress markers (TBARS and PC) and CK activity with PBM applied in biceps brachii using 660 and 850 nm and dose 41,7 J and demonstrated a decrease in these markers.

Zagatto et al.,[12] despite performing different application protocols, with six application sessions after exercise, also presented a decrease in CK activity with 810 nm and dose 48J.

## Aerobic Training

The study of De Marchi et al.[11] was conducted with six professional athletes, performing phototherapy treatments before matches (40 minutes) and using 905 nm and 30 J. Blood samples were collected before treatments and immediately and 48 h after the end of the matches. The authors showed that PBM significantly increased staying in the pitch and improved all the biochemical markers evaluated. No statistically significant difference was found for the distance covered. The study suggests that pre-exercise PBM can enhance performance and accelerate the recovery of high-level futsal players.

## Moment of Application

Regarding the moment of application, ten articles applied PBM before exercise,[4-7,9-11,13-15] while two applied after[1,12] and two performed before and after.[3,13] Only one study did not inform the time of application, but also showed no significant differences.[2]

Of the studies that applied PBM before exercise or fatigue protocol, only one reported no significant differences,[14] two others reported less effect on maximal voluntary contraction and time to exhaustion.[5,7] While other studies have reported beneficial effects such as increased maximal voluntary contraction, increased peak strength, neuromuscular economy while running, increased oxygen uptake and time to exhaustion, and decreased CK activity, blood lactate levels. and markers of fatigue.[4,6,7,9,10,15]

Analyzing the studies that applied PBM after exercise, both showed a decrease in the concentrations of biochemical markers of oxidative stress (TBARS and PC) and CK levels. De Marchi et al.[1] specifically presented an increase in isometric capacity assessment, while Zagatto et al.[12] reported that there was no significant difference in the 200 meters shot, but there was a moderate increase in 30-second performance after 48 hours.

Only two studies performed irradiation before and after exercise or phage protocols. Oliveira et al.[3] applied PBM 2 minutes pre-exercise and 3 minutes post-exercise and demonstrated decreased CK activity, and improved maximum voluntary isometric contraction at all post-exercise analyzed times (24, 48, 72 and 96 hours). Miranda et al.[13] applied PBM 5 to 10 minutes before and immediately after the treadmill aerobic test. It could be observed that the laser applied before and after aerobic exercise led to a significant increase in the percentage of oxygen consumption and time to exhaustion.

## Limitation of study

One limitation of this systematic review is that despite the studies included had good quality, data showed great variance in laser parameters and treated muscle. This heterogeneity of the data made statistical analysis impossible by meta-analysis.

# CONCLUSION

These findings demonstrate that PBM showed good results in skeletal muscle recovery after exercise. In most studies, it promoted improvement of maximum voluntary contraction, better oxygen consumption, increased time to achieve exhaustion and fatigue, and decreased the levels of CK and oxidative stress and fatigue markers. Even considering that the red band has a more superficial effect, better results were observed when the PBM was applied before exercise in both wavelengths.

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# REFERENCES

1. De Marchi T, Schmitt VM, Machado GP, et al. Does photobiomodulation therapy is better than cryotherapy in muscle recovery after a high-intensity exercise? A randomized, double-blind, placebo-controlled clinical trial. *Lasers Med Sci*. 2017;32(2):429-437. doi:10.1007/s10103-016-2139-9
2. De Godoy CHL, Motta LJ, Steagall Júnior W, et al. Effect of Phototherapy on Masseter and Anterior Temporal Muscles before Induction of Fatigue: A Randomized, Sham-Controlled, Blind Clinical Trial. *Photomed Laser Surg*. 2018;36(7):370-376. doi:10.1089/pho.2017.4396
3. De Oliveira AR, Vanin AA, Tomazoni SS, et al. Pre-Exercise Infrared Photobiomodulation Therapy (810 nm) in Skeletal Muscle Performance and Postexercise Recovery in Humans: What Is the Optimal Power Output? *Photomed Laser Surg*. 2017;35(11):595-603. doi:10.1089/pho.2017.4343
4. Pinto HD, Vanin AA, Miranda EF, et al. Photobiomodulation Therapy Improves Performance and Accelerates Recovery of High-Level Rugby Players in Field Test: A Randomized, Crossover, Double-Blind, Placebo-Controlled Clinical Study. *J Strength Cond Res*. 2016;30(12):3329-3338. doi:10.1519/JSC.0000000000001439
5. Larkin-Kaiser KA, Borsa PA, Baweja HS, et al. Photobiomodulation delays the onset of skeletal muscle fatigue in a dose-dependent manner. *Lasers Med Sci*. 2016;31(7):1325-1332. doi:10.1007/s10103-016-1979-7
6. Vanin AA, De Marchi T, Tomazoni SS, et al. Pre-Exercise Infrared Low-Level Laser Therapy (810 nm) in Skeletal Muscle Performance and Postexercise Recovery in Humans, What Is the Optimal Dose? A Randomized, Double-Blind, Placebo-Controlled Clinical Trial. *Photomed Laser Surg*. 2016;34(10):473-482. doi:10.1089/pho.2015.3992
7. Dellagrana RA, Rossato M, Sakugawa RL, Lazzari CD, Baroni BM, Diefenthaeler F. Dose-response effect of photobiomodulation therapy on neuromuscular economy during submaximal running. *Lasers Med Sci*. 2018;33(2):329-336. doi:10.1007/s10103-017-2378-4
8. Ferraresi C, Oliveira TDB, Zafalon LDO. Effects of low level laser therapy (808 nm) on physical strength training in humans. *Lasers Med Sci*. 2011:349-358. doi:10.1007/s10103-010-0855-0
9. Antonialli FC, De Marchi T, Tomazoni SS, et al. Phototherapy in skeletal muscle performance and recovery after exercise: effect of combination of super-pulsed laser and light-emitting diodes. *Lasers Med Sci*. 2014;29(6):1967-1976. doi:10.1007/s10103-014-1611-7
10. Marchi T De, Cesar E, Leal P, Lopes-martins RÁB, Salvador M. Low-level laser therapy (LLLT) in human progressive-intensity running : effects on exercise performance, skeletal muscle status, and oxidative stress. *Lasers Med Sci*. 2012:231-236. doi:10.1007/s10103-011-0955-5
11. Marchi T De, Leal-junior ECP, Lando KC, et al. Photobiomodulation therapy before futsal matches improves the staying time of athletes in the court and accelerates post-exercise recovery. *Lasers Med Sci*. 2019 Feb;34(1):139-148. doi: 10.1007/s10103-018-2643-1
12. Zagatto AM, de Paula Ramos S, Nakamura FY, de Lira FS, Lopes-Martins RÁB, de Paiva Carvalho RL. Effects

of low-level laser therapy on performance, inflammatory markers, and muscle damage in young water polo athletes: a double-blind, randomized, placebo-controlled study. *Lasers Med Sci*. 2016;31(3):511-521. doi:10.1007/s10103-016-1875-1

13. Miranda EF, Tomazoni SS, Roberto P, et al. When is the best moment to apply photobiomodulation therapy (PBMT) when associated to a treadmill endurance-training program? A randomized , triple-blinded , placebo-controlled clinical trial. *Lasers Med Sci.* 2018 May;33(4):719-727. doi: 10.1007/s10103-017-2396-2.
14. Larkin-Kaiser KA, Christou E, Tillman M, George S, Borsa PA. Near-infrared light therapy to attenuate strength loss after strenuous resistance exercise. *J Athl Train*. 2015;50(1):45-50. doi:10.4085/1062-6050-49.3.82
15. Almeida P De, Lopes-martins RÁB, Marchi T De, et al. Red (660 nm) and infrared (830 nm) low-level laser therapy in skeletal muscle fatigue in humans: what is better? *Lasers Med Sci*. 2012;27(2):453-458. doi:10.1007/s10103-011-0957-3
16. Leal-junior ECP, Vanin AA, Miranda EF, et al. Effect of phototherapy ( low-level laser therapy and light-emitting diode therapy ) on exercise performance and markers of exercise recovery: a systematic review with meta-analysis. *Lasers Med Sci*. 2015 Feb;30(2):925-39. doi: 10.1007/s10103-013-1465-4.
17. Borsa PA, Larkin KA, Cat C, True JM. Does Phototherapy Enhance Skeletal Muscle Contractile Function and Postexercise Recovery? A Systematic Review. 2013;48(1):57-67. doi:10.4085/1062-6050-48.1.12
18. Moher D, Liberati A, Tetzlaff J, Altman DG, Group TP. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. 2009;6(7). doi:10.1371/journal.pmed.1000097
19. Higgins JPT, Altman DG, Gøtzsche PC, Jüni P, Moher D, Oxman AD. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. Published online 2011:1-9. doi:10.1136/bmj.d5928
20. Higgins JPT, Altman DG, Gøtzsche PC, Jüni P, Moher D, Oxman AD et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials BMJ 2011; 343:d5928.