REVIEW ARTICLE

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Photobiomodulation in aspects of muscle function – a scoping review

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Abstract

Introduction and Objective. Aspects of muscle function (AoMF), such as strength, power, torque, local muscle endurance, and hypertrophy, have a major influence on physical fitness and functional performance. Photobiomodulation (PBM) has been used to improve performance in resistance exercise. The aim of this study was to identify the effects of PBM on the AOMF, and to verify the dosimetric parameters of the intervention.

Review Methods. The review followed the PRISMA guidelines. The databases used were PubMed, Web of Science, Scopus, Embase, Lilacs, Cochrane, LIVIVO, CINAHL, PeDro, Open Grey, Google Scholar, and CAPES Thesis and Dissertation. To be included, the studies had to be applied to healthy humans of either grender or age group, report the effects of PBM, present variables of muscle strength, torque, power, and hypertrophy.

Brief description of the state of knowledge. The database search resulted in 3,092 records, as well as additional records identified through other sources – PEDro with 793 records and Capes Thesis and Dissertation with 1,492 records, a total of 5,377 records. After removing duplicates, 4,796 records remained. After reading the titles and abstracts, 56 records remained, which were read in full and evaluated according to the review criteria. 29 studies were eligible for inclusion based on the inclusion and exclusion criteria of this scoping review.

Conclusion. It was possible to observe similarities in the studies, especially the moment of application being the pre-exertion moment, the dose of energy applied per point was 30J, and the wavelength – 808–810nm.

Key words

muscle strength, laser therapy, low-level light therapy

INTRODUCTION

Aspects of muscle function (AoMF), such as strength, power, torque, local muscle endurance, and hypertrophy, have a major influence on physical fitness and functional performance [1–3]. Muscle strength is defined as the ability of muscle to develop effort against a given resistance, and is an important component of health-related fitness [4]. Counter-resistance training increases the muscle cross-sectional area (hypertrophy) which, together with neural adaptation, enhances motor unit recruitment, optimizing muscle force production and performance [5].

Used in association with counter-resistance training, photobiomodulation (PBM) is a non-invasive, non-pharmacological therapy widely used to treat a variety of musculoskeletal disorders [6,7] PBM encompasses the application of low-level laser therapy (LLLT) and/or light-emitting diodes (LEDs) on a target tissue [8]. PBM has emerged as an intervention modality in which photons interact with biological tissues, producing physiological and therapeutic effects that positively influence muscle performance [9].

PBM has been used to improve performance in resistance exercises. Photon energy interacts with cell mitochondria, promoting structural changes (appearance of giant mitochondria) and metabolic changes (increased oxidation of enzymatic activities), increasing energy synthesis (ATP) [6]. It is also possible that PBM potentiates the hypertrophic response by stimulating satellite cell proliferation and, consequently, muscle strength gains resulting in increased muscle capacity to overcome a maximum load [10, 11].

However, there are contradictory effects of this AoMF optimization, such as strength, torque, power, and hypertrophy, as well as functional capacity; a possible explanation for these discrepancies may be the methodological difference between the studies, including the experimental design, sample characteristics, muscle performance measurement, and inclusion (or not) of resistance training [12]. Furthermore, it is speculated that these contradictory findings are due to the biphasic characteristic of the tissue response produced by the dose of PBM, which generates null, positive, or inhibitory effects according to the amount of energy delivered to the target tissue [13]. Factors such as wavelength, irradiation dose, treatment frequency, and application sites can influence therapeutic results, as tissue depth and attenuation determine the quality of the therapeutic effect on tissue [6,14].

Thus, the objective of this scoping review was to identify the PBM effects on the AoMF determinants of functionality, as well as to verify the dosimetric parameters of the intervention.

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MATERIALS AND METHOD

Sources of information from research strategy. The presented review systematically followed the Scope Review (PRISMA) format guidelines. PICO (population, intervention, comparator/control, and outcomes) was used to develop the search strategy. In early June 2021, medical databases with the following libraries were searched: PubMed, Web of Science, Scopus, Embase, Lilacs, Cochrane, LIVIVO, CINAHL, PeDro, Open Grey, Google Scholar, and CAPES Thesis and Dissertation were included for the review The terms used to search the manuscripts: optimization of muscle function aspects/photobiomodulation/control, placebo/ AoMF (Tabl.1). The search strategy had no restriction on language, date or publication status.

Table 1. Article PICO search strategy

	PICO	Search Terms
1	Problem	Optimization of muscle function aspects
2	Intervention	Photobiomodulation
3	Comparison	Control/Placebo
4	Results	Strength, torque, power and muscle hypertrophy

Study Selection. Two reviewers independently screened the titles and abstracts to determine the eligibility of the studies. A third reviewer resolved any disagreements. Full texts of published articles related to the titles that examined the effects of FBM on AoMFs were identified and included. For inclusion in this review, articles had to meet the following criteria: 1) healthy persons, 2) any age group and gender, 3) report effects of PBM, 4) variables of muscle strength, torque, power, and hypertrophy. Studies with other modalities except exercise, traditional treatment, and other electrotherapy modalities combined with PBM, were excluded. Studies on protocol and books were also excluded.

Outcomes. Changes in muscle strength, muscle hypertrophy, power, and torque were the main result of this study. The review attempted to address the following questions:
- Does PBM produce positive effects on the AoMF of muscle strength, power, torque and hypertrophy?
- What are the most effective doses for AoMF?

Data Extraction. Two reviewers independently extracted data using a standardized form. Disagreements were resolved by discussion or, when necessary, by a third reviewer.

Details of the studies on baseline demographic data, treatment prescription (type of PBM and dosimetric parameters), participant characteristics, and outcomes (muscle strength, muscle hypertrophy, power and torque) were preferably extracted from published data. Where necessary, an e-mail was sent to the corresponding author for further information. If no response was obtained within a week or no information was available, contact with other authors was sought. If after three weeks the authors did not respond to contact attempts, data from their studies were not included in the analysis.

RESULTS

Study Flow. The database search resulted in 3,092 records; additional records were identified through other sources – PEDro with 793 records and Capes Thesis and Dissertation with 1,492 records, a total of 5,377 records. After removing duplicates, 4,796 records remained. After reading the titles and abstracts, 56 records remained, which were read in full and evaluated according to the review criteria. Finally, 29 studies were eligible for inclusion, based on the inclusion and exclusion criteria of this scoping review (Fig. 1).

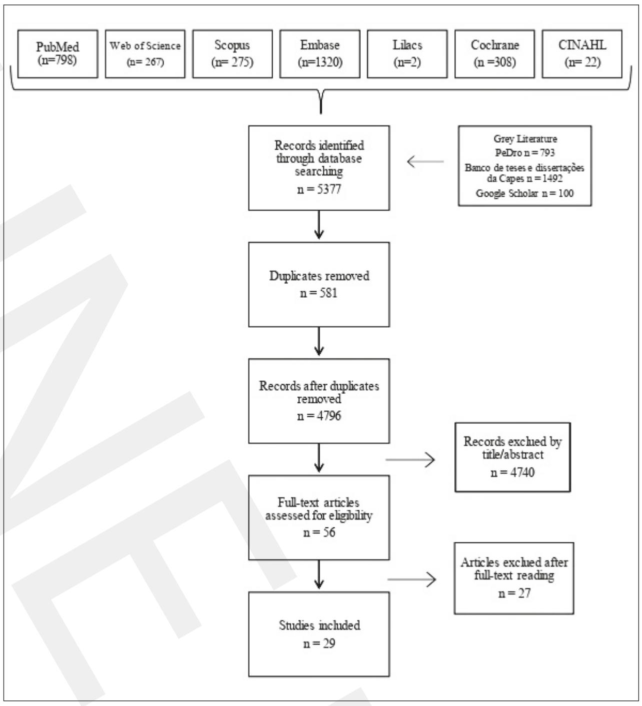

Figure 1. Flow of studies through the review

Study Characteristics. This review comprised 29 studies, totalling 859 participants, of whom 324 were women, 455 were men, and 80 were unspecified. The sample size ranged from 12–60 participants, aged 18–70 years (Tab. 2).

SYNTHESIZED RESULTS

Torque. Fourteen studies analyzed the variable torque and peak torque (Nm). Nine studies showed favourable results, i.e., with a significant difference of PBM on this outcome [6, 8–11, 15–18] and five studies showed no significant differences [13,19–22]. Almeida et al. [11] cited torque, but presented unit of force (kg/f).

Power. Four studies analyzed the power ($W.kg^{-1}$ ou W); two studies showed favourable PBM results on this endpoint [9,18]; two studies did not show significant differences [22,23] (Fig. 2).

Strength. Seven studies analyzed the effects of PBM on strength (normalized, Ib, or N). One study showed favourable results [24]. Four studies did not show significant differences [14, 25–27]. One study showed unfavorable results [28]. Another study analyzed grip strength (N) and showed

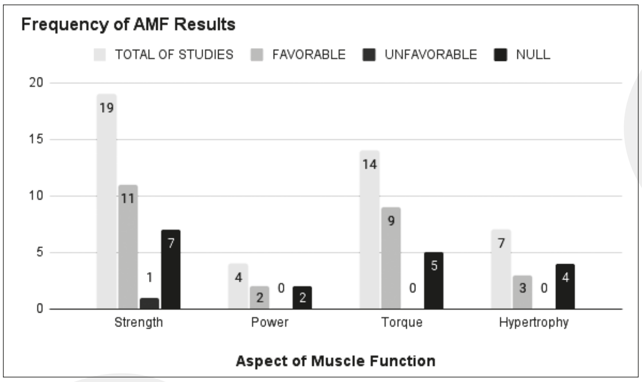

Figure 2. Frequency of AoMF results

favourable results [29] (Fig. 2).

Seven studies analyzed strength through 1 RM (1 repetition maximum in Kg), and five studies showed favourable results of MBF on this outcome [6, 11, 18, 30, 31]. Two studies did not show significant differences [19, 32].

Five studies analyzed force by means of maximum voluntary contraction (N or Nm), three studies showed favourable results [31, 33, 34]. One study showed no significant differences [12]. One study showed unfavourable results within 24 hours and favourable results after 48 and 74 hours [35].

Hypertrophy. Seven studies analyzed the effects of PBM on hypertrophy (normalized diameter/perimetry or in cm or thickness in cm). Three studies showed favourable results [6,10,33]. Four studies did not show significant differences [19, 25, 26, 31] (Fig. 2).

Treatment protocol. Regarding the type of PBM, 19 studies applied laser treatment, five applied LED, and five applied cluster – laser and LED together. One study performed laser acupuncture treatment [26].

The wavelengths used for low-power laser application ranged from 655nm [17], 660nm [23], 800nm [28], 804nm [18], 808nm [6, 12, 21, 22, 32, 33], 810nm [10, 15, 34, 35], 820nm [36], 830nm [20, 26] and 970nm 1[6,28]. Wavelengths used in LED include 630nm [24], 638nm [29], 830nm [25], 850nm [30] and 880nm [8]. Among the wavelengths used in clustering are 850nm (laser) and 630nm (LED) [11], 850nm (laser) with 670nm, 880nm, and 950nm (LED) [13, 27], 850nm (laser) [35], and 905nm (laser) with 875nm and 640nm (LED) [31].

The output parameters of power, energy, and power density varied widely. The output power ranged from 10 mW – 720 W. The delivered energy ranged from 1.92 J – 1,680 J total energy. The energy density ranged from 0.9933 J/cm^2 – 357.14 J/cm^2. Regarding emission frequency, 16 studies showed continuous emission, other studies showed 10 Hz [25, 26], 5 Hz [28], 250 Hz [9], 2000Hz [33], 13 KHz [21], seven studies did not report [10, 14–16, 23, 32, 34].

Regarding the timing of MBF application, 14 studies applied MBF before exercise [8–11, 15–17, 19, 22, 26, 27, 29, 33, 34] and seven studies applied it after exercise [6, 18, 21, 24, 25, 28, 30]. In two studies, there was no exercise protocol 12,13. One study performed the application between exercise series [32], two studies performed application before and/or after exercise [31, 35], one study presented a protocol with neuromuscular electrical stimulation to simulate exercise, the application of the intervention occurred before this protocol [20], another study performed the application before and during exercise [23], and one study did not report [14].

DISCUSSION

The objective of this scoping review was to identify the effects of the PBM on the determinants of functionality of AoMF, as well as to verify the most appropriate dosimetric parameters for this intervention. Of the 29 included studies, 16 were identified as favourable to the use of PBM in AoMF, which influences muscle performance.

The hypotheses pointed out by Baroni et al. [10] to explain the results related to the improvement in muscle performance are mainly based on evidence regarding the effects of the laser beam on mitochondrial function, since photons that penetrate the cell membrane are absorbed by specific enzymes in this cell organelle (such as cytochrome C oxidase), and for generating physiological responses, such as increased ATP production rates a few minutes after laser irradiation [38, 39]. In addition, it could contribute to an ergogenic effect during exercise by increasing intramuscular microcirculation, decreasing lactic acid production, and improving the anti-oxidant capacity of exercising muscles [10]. Ferraresi et al. [6] indicate that improved physical performance is provided by decreased creatine kinase activity, increases in antioxidant levels, and improved microcirculation and lactate removal.

Another factor stimulated by PBM is the acute increase in intravascular nitric oxide concentration, which may be a possible mechanism of performance improvement, since it causes vasodilation and increased tissue temperature and oxygenation, with a subsequent increase in neurotransmitters and an improvement in muscle fibre contraction [29]. Furthermore, PBM-treated muscles have less resistance capacity decrease during exercise, allowing greater muscle work per workout, generating greater mechanical tension, being a primary factor responsible for initiating the hypertrophic response and muscle mass gain, information that contributes to the result of strength gain [10].

Loss of muscle strength and oedema are common signs observed after excessive exercise and are related to an inflammatory process that increases the release of tumour necrosis factor alpha (TNF- α). TNF- α is an inflammatory mediator and affects muscle oedema and muscle contraction [25, 40]. Phototherapy with a wavelength of 830nm can decrease TNF-α levels, and enhance cytokine expression during muscle damage repair after exercise [41], thus disrupting the signalling response of the inflammatory process response to muscle remodeling through activation of satellite cells, which could explain the lack of positive results for post-exercise phototherapy [31]. This would also explain the findings that most of the studies that showed favourable results used PBM at the time before exercise; however, it should be taken into consideration that the number of studies that performed the intervention before exercise was twice as many as those that used it post exercise.

Vassão et al. [22] postulated that PBM prevents reductions in muscle membrane potential excitation, likely due to increased electron transport and mitochondrial respiratory chain ATP synthesis, providing more energy for muscle control. Thus, providing a positive effect on biochemical changes in mitochondria, improving the oxidative characteristics of muscle fibres, and controlling the redox balance that could have contributed to increased ATP availability [18].

In addition, muscle contractile function may be associated with inadequate blood flow, and the laser provides a median vasodilation that may be responsible for increased skeletal muscle function and attenuated force loss, where it increases the supply of oxygen and other substrates to exercise muscle, increasing its ability to perform work [16]. Finally, the frequency of energy use at or near 30J per spot (approximately 31% of favourable studies), usually before exercise, demonstrates satisfactory results with respect to AoMF, which appears to be an adequate dose for such effects. However, regarding the wavelength of the low power laser, it is hypothesized that wavelengths of 808 – 810nm promote more satisfactory results for AoMF, as approximately 37.5% of favourable studies used this wavelength. It is believed that optimal wavelengths are near 810 – 840 nm, since in these regions the surface chromophores have weak absorption, and therefore there is maximum penetration of light into the skin, generating an optimal window of penetration and absorption by organic molecules [38].

One point to be highlighted is that among the studies analyzed, only one showed unfavourable results of the PBM in relation to the strength developed, but 11 studies showed advantages of the use of PBM and seven showed no results. Analyzing hypertrophy, four studies showed no advantageous effects from the use of PBM, but three indicated greater muscle hypertrophy. There was a balance of two articles indicating power gains and two did not; nine studies showed torque gains, while five studies did not go in this direction.

Therefore, since this type of review addressed broad questions with different study designs and the dosimetric issues were not well elucidated, future research should focus on the dosimetry of PBM over AoMF. Although a complex search strategy was performed, there is a lack of standardization in the nomenclature of the types of PBM therapy among the published articles. Therefore, some studies may not have been found or evaluated due to this variation.

CONCLUSION

After analyzing the extent of the literature on the use of PBM in AoMF, it was possible to conclude that there are beneficial and favourable effects in AoMF. It is noteworthy that the application at the pre-exercise moment, with an applied energy dose per point of 30J and wavelength of 808 – 810nm, proved to be advantageous; however, clarification is still needed on dosimetric issues and standardizations, since there are still several studies, mainly with dosimetric parameters different from those indicated above, which do not show advantages of PBM.

REFERENCES

1. Fukumoto Y, Tateuchi H, Ikezoe T, et al. Effects of high-velocity resistance training on muscle function, muscle properties, and physical performance in individuals with hip osteoarthritis: A randomized controlled trial. Clinical Rehabilitation. 2014;28(1):48–58. doi:10.1177/0269215513492161
2. Bartoszewska M, Kamboj M, Patel DR. Vitamin D, muscle function, and exercise performance. Pediatric Clinics of North America. 2010;57(3):849–861. doi:10.1016/j.pcl.2010.03.008
3. Lee HC, Lee ML, Kim SR. Effect of exercise performance by elderly women on balance ability and muscle function. Journal of Physical Therapy Science. 2015;27(4):989–992. doi:10.1589/jpts.27.989
4. Wang DXM, Yao J, Zirek Y, Reijnierse EM, Maier AB. Muscle mass, strength, and physical performance predicting activities of daily living: a meta-analysis. Journal of Cachexia, Sarcopenia and Muscle. 2020;11(1):3–25. doi:10.1002/jcsm.12502
5. Krzysztofik M, Wilk M, Wojdała G, Gołaś A. Maximizing muscle hypertrophy: A systematic review of advanced resistance training techniques and methods. International Journal of Environmental Research and Public Health. 2019;16(24):4897. doi:10.3390/ijerph16244897
6. Ferraresi C, De Brito Oliveira T, De Oliveira Zafalon L, et al. Effects of low level laser therapy (808 nm) on physical strength training in humans. Lasers in Medical Science. 2011;26(3):349–358. doi:10.1007/s10103–010–0855–0
7. Clijsen R, Brunner A, Barbero M, Clarys P, Taeymans J. Effects of low-level laser therapy on pain in patients with musculoskeletal disorders: A systematic review and meta-analysis. European Journal of Physical and Rehabilitation Medicine. 2017;53(4):603–610. doi:10.23736/S1973–9087.17.04432-X
8. Dornelles MP, Fritsch CG, Sonda FC, et al. Photobiomodulation therapy as a tool to prevent hamstring strain injuries by reducing soccer-induced fatigue on hamstring muscles. Lasers in Medical Science. 2019;34(6):1177–1184. doi:10.1007/s10103–018–02709-w
9. Toma RL, Oliveira MX, Renno ACM, Laakso EL. Photobiomodulation (PBM) therapy at 904 nm mitigates effects of exercise-induced skeletal muscle fatigue in young women. Lasers in Medical Science. 2018;33(6):1197–1205. doi:10.1007/s10103–018–2454–4
10. Baroni BM, Rodrigues R, Freire BB, Franke R de A, Geremia JM, Vaz MA. Effect of low-level laser therapy on muscle adaptation to knee extensor eccentric training. European Journal of Applied Physiology. 2015;115(3):639–647. doi:10.1007/s00421–014–3055-y
11. Almeida JN, Prado WL, Terra CM, et al. Effects of photobiomodulation on muscle strength in post-menopausal women submitted to a resistance training program. Lasers in Medical Science. 2020;35(2):355–363. doi:10.1007/s10103–019–02822–4
12. Rodrigues CP, Jacinto JL, Roveratti MC, et al. Effects of laser photobiomodulation therapy at 808nm on muscle performance and perceived exertion in elderly women. Topics in Geriatric Rehabilitation. 2020;36(4):237–245. doi:10.1097/TGR.0000000000000288
13. 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 in Medical Science. 2018;33(2):329–336. doi:10.1007/s10103–017–2378–4
14. Mendonça FS de, de Tarso Camillo de Carvalho P, Biasotto-Gonzalez DA, et al. Muscle fiber conduction velocity and EMG amplitude of the upper trapezius muscle in healthy subjects after low-level laser irradiation: a randomized, double-blind, placebo-controlled, crossover study. Lasers in Medical Science. 2018;33(4):737–744. doi:10.1007/s10103–017–2404–6
15. Baroni BM, Leal Junior ECP, De Marchi T, Lopes AL, Salvador M, Vaz MA. Low level laser therapy before eccentric exercise reduces muscle damage markers in humans. European Journal of Applied Physiology. 2010;110(4):789–796. doi:10.1007/s00421–010–1562-z
16. Larkin-Kaiser KA, Christou E, Tillman M, George S, Borsa PA. Near-infrared light therapy to attenuate strength loss after strenuous resistance exercise. Journal of Athletic Training. 2015;50(1):45–50. doi:10.4085/1062–6050–49.3.82
17. Leal Jr ECP, Lopes-Martins RÁBAB, Frigo L, 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. J Orthop Sports Phys Ther. 2010;40(8):524–532. doi:10.2519/jospt.2010.3294
18. Toma RL, Vassão PG, Assis L, Antunes HKM, Renno ACM. Low level laser therapy associated with a strength training program on muscle performance in elderly women: a randomized double blind control study. Lasers in Medical Science. 2016;31(6):1219–1229. doi:10.1007/s10103–016–1967-y
19. Fritsch CG, Dornelles MP, Teodoro JL, et al. Effects of photobiomodulation therapy associated with resistance training in elderly men: a randomized double-blinded placebo-controlled trial. European Journal of Applied Physiology. 2019;119(1):279–289. doi:10.1007/s00421–018–4023–8
20. Jówko E, Płaszewski M, Cieśliński M, Sacewicz T, Cieśliński I, Jarocka M. The effect of low level laser irradiation on oxidative stress, muscle damage and function following neuromuscular electrical stimulation. A double blind, randomised, crossover trial. BMC Sports Science,

Medicine and Rehabilitation. 2019;11(1):38. doi:10.1186/s13102–019–0147–3
21. Tsuk S, Lev YH, Fox O, Carasso R, Dunsky A. Does photobiomodulation therapy enhance maximal muscle strength and muscle recovery? Journal of Human Kinetics. 2020;73(1):135–144. doi:10.2478/hukin-2019–0138
22. Vassão PG, Toma RL, Antunes HKM, Tucci HT, Renno ACM. Effects of photobiomodulation on the fatigue level in elderly women: an isokinetic dynamometry evaluation. Lasers in Medical Science. 2016;31(2):275–282. doi:10.1007/s10103–015–1858–7
23. Kakihata CMM, Malanotte JA, Higa JY, Errero TK, Balbo SL, Bertolini GRF. Influence of low-level laser therapy on vertical jump in sedentary individuals. Einstein (São Paulo). 2015;13(1):41–46. doi:10.1590/S1679–45082015AO3243
24. Borges LS, Cerqueira MS, Dos Santos Rocha JA, et al. Light-emitting diode phototherapy improves muscle recovery after a damaging exercise. Lasers in Medical Science. 2014;29(3):1139–1144. doi:10.1007/s10103–013–1486-z
25. Chang WD, Lin HY, Chang NJ, Wu JH. Effects of 830nm light-emitting diodo therapy on delayed-onset muscle soreness. Ghayur MN, ed. Evidence-Based Complementary and Alternative Medicine. 2021;2021:6690572. doi:10.1155/2021/6690572
26. Chang WD, Wu JH, Chang NJ, Lee CL, Chen S. Effects of laser acupuncture on delayed onset muscle soreness of the bíceps brachii muscle: a randomized controlled trial. Evidence-Based Complementary and Alternative Medicine. 2019;2019:6568976. doi:10.1155/2019/6568976
27. Orssatto LBR, Rossato M, Vargas M, Diefenthaeler F, De La Rocha Freitas C. Photobiomodulation therapy effects on resistance training volume and discomfort in well-trained adults: A randomized, double-blind, placebo-controlled trial. Photobiomodulation, Photomedicine, and Laser Surgery. 2020;38(12):720–726. doi:10.1089/photob.2019.4777
28. Parr JJ, Larkin KA, Borsa PA. Effects of class IV laser therapy on exercise-induced muscle injury. Athletic Training & Sports Health Care. 2010;2(6):267–276. doi:10.3928/19425864–20100630–04
29. Matos AP, Navarro RS, Lombardi I, Brugnera A, Munin E, Villaverde AB. Pre-exercise LED phototherapy (638 nm) prevents grip strength loss in elderly women: A double-blind randomized controlled trial. Isokinetics and Exercise Science. 2016;24(2):83–89. doi:10.3233/IES-150604
30. Vieira KVSG, Ciol MA, Azevedo PH, et al. Effects of light-emitting diode therapy on the performance of biceps brachii muscle of young healthy males after 8 weeks of strength training: a randomized controlled clinical trial. Journal of strength and conditioning research. 2019;33(2):433–442. doi:10.1519/JSC.0000000000002021
31. Vanin AA, Miranda EF, Machado CSM, et al. What is the best moment to apply phototherapy when associated to a strength training program? A randomized, double-blinded, placebo-controlled trial: Phototherapy in association to strength training. Lasers in Medical Science. 2016;31(8):1555–1564. doi:10.1007/s10103–016–2015–7
32. Felismino AS, Costa EC, Aoki MS, Ferraresi C, De Araújo Moura Lemos TM, De Brito Vieira WH. Effect of low-level laser therapy (808 nm) on markers of muscle damage: A randomized double-blind placebo-controlled trial. Lasers in Medical Science. 2014;29(3):933–938. doi:10.1007/s10103–013–1430–2
33. Nausheen S, Moiz JA, Raza S, Shareef MY, Anwer S, Alghadir A. Preconditioning by light-load eccentric exercise is equally effective as low-level laser therapy in attenuating exercise-induced muscle damage in collegiate men. Journal of Pain Research. 2017;10:2213–2221. doi:10.2147/JPR.S139615
34. Vanin AA, De Marchi T, Silva Tomazoni S, 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. Photomedicine and Laser Surgery. 2016;34(10):473–482. doi:10.1089/pho.2015.3992
35. Fritsch CG, Dornelles MP, Severo-Silveira L, Marques VB, Rosso I de A, Baroni BM. Effects of low-level laser therapy applied before or after plyometric exercise on muscle damage markers: randomized, double-blind, placebo-controlled trial. Lasers in Medical Science. 2016;31(9):1935–1942. doi:10.1007/s10103–016–2072-y
36. Radominski SC, Bernardo W, Paula AP de, et al. Brazilian guidelines for the diagnosis and treatment of postmenopausal osteoporosis. Revista Brasileira de Reumatologia (English Edition). 2017;7(S2):452–466. doi:10.1016/j.rbre.2017.07.001
37. Ferraresi C, Hamblin MR, Parizotto NA. Low-level laser (light) therapy (LLLT) on muscle tissue: performance, fatigue and repair benefited by the power of light. Photonics & lasers in medicine. 2012;1(4):267–286. doi:10.1515/plm-2012–0032
38. Karu T. Primary and secondary mechanisms of action of visible to near-IR radiation on cells. J Photochem Photobiol B. 1999;49(1):1–17.
39. Karu TI, Pyatibrat L V, Kalendo GS. Photobiological modulation of cell attachment via cytochrome c oxidase. Photochem Photobiol Sci. 2004;3(2):211–216. doi:10.1039/b306126d
40. Wilcox P, Osborne S, Bressler B. Monocyte inflammatory mediators impair in vitro hamster diaphragm contractility. American Review of Respiratory Disease. 1992;146(2):462–466. doi:10.1164/ajrccm/146.2.462
41. Mesquita-Ferrari RA, Martins MD, Silva JA, 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. 2011;26(3):335–340. doi:10.1007/s10103–010–0850–5