Journal of Athletic Training 2017;52(5):429–438
doi: 10.4085/1062-6050-52.2.09

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Phototherapy for Improvement of Performance and Exercise Recovery: Comparison of 3 Commercially Available Devices

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Context: Recent studies suggest the prophylactic use of low-powered laser/light has ergogenic effects on athletic performance and postactivity recovery. Manufacturers of high-powered lasers/light devices claim that these can produce the same clinical benefits with increased power and decreased irradiation time; however, research with high-powered lasers is lacking.

Objective: To evaluate the magnitude of observed phototherapeutic effects with 3 commercially available devices.

Design: Randomized double-blind placebo-controlled study.

Setting: Laboratory.

Patients or Other Participants: Forty healthy untrained male participants.

Intervention(s): Participants were randomized into 4 groups: placebo, high-powered continuous laser/light, low-powered continuous laser/light, or low-powered pulsed laser/light (comprising both lasers and light-emitting diodes). A single dose of 180 J or placebo was applied to the quadriceps.

Main Outcome Measure(s): Maximum voluntary contraction, delayed-onset muscle soreness (DOMS), and creatine kinase (CK) activity from baseline to 96 hours after the eccentric exercise protocol.

Results: Maximum voluntary contraction was maintained in the low-powered pulsed laser/light group compared with placebo and high-powered continuous laser/light groups in all time points ($P < .05$). Low-powered pulsed laser/light demonstrated less DOMS than all groups at all time points ($P < .05$). High-powered continuous laser/light did not demonstrate any positive effects on maximum voluntary contraction, CK activity, or DOMS compared with any group at any time point. Creatine kinase activity was decreased in low-powered pulsed laser/light compared with placebo ($P < .05$) and high-powered continuous laser/light ($P < .05$) at all time points. High-powered continuous laser/light resulted in increased CK activity compared with placebo from 1 to 24 hours ($P < .05$).

Conclusions: Low-powered pulsed laser/light demonstrated better results than either low-powered continuous laser/light or high-powered continuous laser/light in all outcome measures when compared with placebo. The increase in CK activity using the high-powered continuous laser/light compared with placebo warrants further research to investigate its effect on other factors related to muscle damage.

Key Words: skeletal muscle performance, low-level laser therapy, light-emitting diode therapy, high-intensity laser therapy, photobiomodulation therapy

Key Points

- Phototherapy (or photobiomodulation therapy) had ergogenic and protective effects on skeletal muscles only if applied with the correct settings.
- The combination of low-powered pulsed laser and red and infrared light-emitting diodes was more effective than low-powered continuous infrared laser or high-powered continuous infrared laser.
- Increased power did not result in increased efficacy.

Achieving optimal athletic performance is the desire of all athletes from the recreational to the professional. Performance is influenced by a combination of physiological, psychological, and sociocultural factors. *Fatigue* is described as a failure to maintain the expected force, or the inability to maintain a given exercise intensity or power output level.[1] It results when muscle activity exceeds tissue substrate and oxygenation capacity. Previous researchers[2,3] have also shown that injury rates increase with the accumulation of fatigue, and fatigue has been identified as a limiting factor in performance in almost every individual in every sport. Fatigued participants demonstrated reduced voluntary force production in fatigued muscles (measured with concentric, eccentric, and isometric contractions).[4,5]

The positive evidence for the role of phototherapy or photobiomodulation (PBM) in improving exercise performance and markers related to exercise recovery has expanded its potential for widespread use to address fatigue-related injuries. Recent systematic reviews[6,7] demonstrated the ergogenic effects of phototherapy using lasers and/or light-emitting diodes (LEDs) administered immedi-

ately before resistance exercise, suggesting that preexercise exposure with PBM may protect exposed muscles from exercise-induced damage and speed recovery.

With the current focus on preventive measures to reduce the risk of injuries in sports, PBM offers a unique, noninvasive, nonpharmacologic means of reducing muscular fatigue. In turn, physical performance and recovery rate have improved postexercise. The positive effects seen in recent studies were obtained with red[8,9] and infrared wavelengths[9–13] generated by both laser[8–14] and LED[14–17] devices. Various exercises that represent sport-specific activities have been tested: repeated contractions,[8,10,11,13,15] isometric sustained contraction,[9,16,17] cycling,[14] and running.[12]

Only a few investigators have compared PBM with other physical agents[18,19] and addressed the effectiveness of laser versus LEDs.[14,20] Studies of commercially available devices are lacking, which complicates clinical decision-making processes and direct product comparisons. Several mixes of settings (wavelengths, powers, sources) have resulted in positive effects on performance and recovery. To our knowledge, no direct comparison of commercially available devices exists. Despite some manufacturers' claims that high-powered lasers produce similar or greater effects than low-level lasers, we believed that the same dose delivered to a target area using increased power output (and consequently with less irradiation time) would not increase clinical effects.

With this perspective in mind, our aim was to evaluate the effects of phototherapy (or PBM) on skeletal muscle performance and postexercise recovery using 3 commercially available devices to determine how the ergogenic and protective effects on skeletal muscle tissue would be affected by different device settings. This area of research provides the greatest benefit to clinicians by ensuring optimal device and setting identification.

METHODS

Study Design and Ethics Statement

A double-blind, placebo-controlled, randomized clinical trial was conducted at the Sports Medicine Institute at the University of Caxias do Sul. The study received approval from the research ethics committee (protocol number 642.595).

Participants

Forty healthy untrained males recruited from the university staff and student body participated in the study. All participants signed the informed consent statement. A priori, an intention-to-treat protocol would be followed; however, it was not needed because there were no dropouts. The Consolidated Standards of Reporting Trials (CONSORT) flowchart summarizing experimental procedures and participants is displayed in Figure 1.

Inclusion Criteria and Exclusion Criteria

The inclusion criteria were male participants between 18 and 35 years old who had been performing up to 1 session of exercise weekly for the previous 6 months. Any volunteer who presented with a preexisting musculoskeletal injury to the hips or knees in the previous 2 months, used any pharmacologic agents or nutritional supplements regularly, or was injured during the study was excluded. All aspects except the last were evaluated during an initial interview used to recruit participants.

Because the available literature showed damaging thermal effects due to certain PBM settings (wavelengths, power outputs, etc) in participants with dark skin pigmentation, only participants with light and intermediate skin pigmentation (assessed through the Von Luschan chromatic scale) were accepted into the study to maximize safety and minimize discomfort.[21–23]

Composition of Groups and Randomization Process

The 40 participants had an average age of 23.14 ± 2.34 years, height of 176.08 ± 11.03 cm, and body mass of 71.08 ± 6.09 kg. We used the same study design as previous authors in this field.[24–26] For the sample-size calculation, we set the β value at 20% and α at 5%. In a study[25] used as a reference for sample-size calculation, phototherapy led to increased maximum voluntary contraction (MVC; our primary outcome) of 336.88 ± 27.92 N·m at 96 hours postexercise (Cohen d = 1.485 145), compared with baseline (286.63 ± 38.86). Thus, 10 volunteers per group and 40 volunteers in total were needed.

The participants were randomly allocated to 4 experimental groups (n = 10 per group) according to the phototherapy dose. A blinded researcher drew lots for randomization.

For placebo treatments, all 3 devices were used. Three participants were treated with the placebo mode of the high-powered continuous laser/light device, 3 with the placebo mode of the low-powered continuous laser/light device, and 4 with the placebo mode of the low-powered pulsed laser/light device. Randomization labels were created using a randomization table at a central office, where a series of sealed, opaque, numbered envelopes ensured confidentiality. A researcher who programmed the devices for either active or placebo mode based on the randomization results was instructed to not inform the participants or other researchers regarding the settings and was blinded to the group allocation.

Experimental Protocol

Blood Samples and Biochemical Analyses. Blood samples (10 mL) were taken from the antecubital vein of each participant before and 1 minute after the eccentric-contraction protocol by a qualified nurse blinded to the allocation of the participants in the 4 experimental groups. One hour after collection, each sample was centrifuged at 3000 rpm for 20 minutes. Pipettes were used to transfer the serum to Eppendorf tubes (Eppendorf AG, Hamburg, Germany), which were stored at –80°C until analysis. Additional blood samples were collected 1, 24, 48, 72, and 96 hours after the exercise protocol.

Creatine kinase (CK) activity was determined using spectrophotometry and specific reagent kits (model No. 117; Labtest, São Paulo, Brazil). The CK activity analysis was performed by a blinded researcher.

Evaluation of Delayed-Onset Muscle Soreness. With the assistance of a blinded researcher, participants used a visual analogue scale (VAS) of 100 mm to self-rate

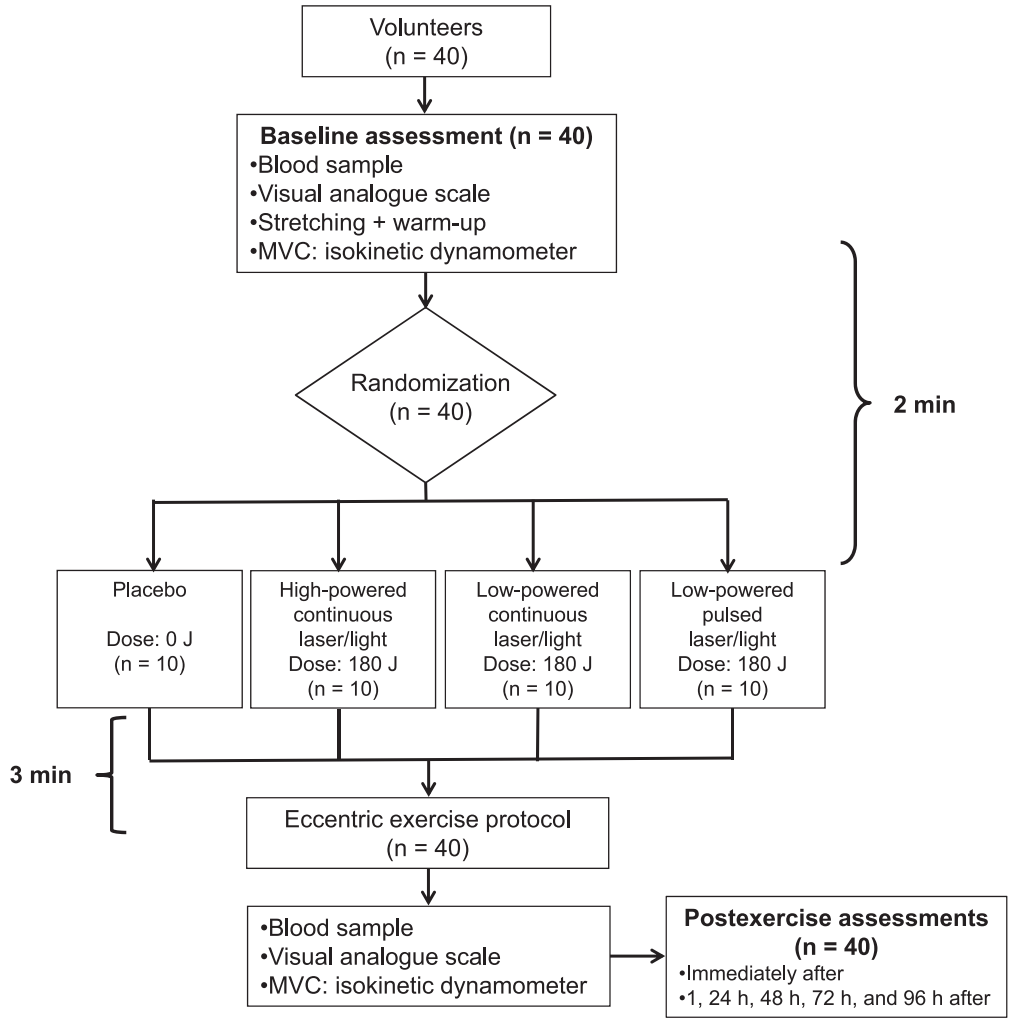

Figure 1. Consolidated Standards of Reporting Trials (CONSORT) flowchart. Abbreviation: MVC, maximum voluntary contraction.

delayed-onset muscle soreness (DOMS). The DOMS assessments were obtained at baseline and immediately and 1, 24, 48, 72, and 96 hours after the eccentric-exercise protocol (1 minute).

Stretching and Warm-Up. Before the isokinetic protocol, each participant actively stretched the nondominant knee extensors 3 times for 60 seconds each. Pedaling of a stationary bicycle (Inbramed, Porto Alegre, Brazil) set at 100 rpm and without load for 5 minutes was used as a general warm-up activity.

Maximum Voluntary Contraction. After warm-up, MVC tests were performed using an isokinetic dynamometer (model System 4; Biodex Medical Systems, Inc, Shirley, NY) to assess muscle function; this is currently considered the method with the greatest reliability for studying musculoskeletal performance.[24–26] Each participant was positioned in the dynamometer with an angle of 100° between the trunk and hip and instructed to cross his arms. The nondominant leg was positioned at 60° of knee flexion (0° corresponds to complete knee extension) and the dominant leg at 100° of hip flexion.

The MVC test consisted of three 5-second isometric contractions of the knee extensors of the nondominant leg. The highest peak torque was used for the statistical analysis. The MVC was also performed immediately (1 minute) and 1, 24, 48, 72, and 96 hours after the eccentric-contraction protocol. The researcher performing the MVC assessment was blinded to randomization and allocation.

Phototherapy. The 3 devices we selected represented those commercially available to clinicians. The devices were a high-powered continuous laser/light device (model LiteForce; LiteCure, Newark, DE), a low-powered continuous laser/light device (model LX2; Thor Photomedicine Ltd, Chesham, United Kingdom), and a low-powered pulsed laser/light device (model MR4 Console with a LaserShower 50 4D emitter; Multi Radiance Medical, Solon, OH). The dose (180 J) was selected based on current literature in this field.[6,7,24,25,27,28] Both low-powered devices were applied in direct contact with the skin at 6 sites on the quadriceps femoris (2 centrally: rectus femoris and vastus intermedius; 2 laterally: vastus lateralis; and 2 medially: vastus medialis; Figure 2).

Although the same dose was also applied to the high-powered continuous laser/light group, the application was performed using skin contact and slight pressure in a scanning method. This was according to the manufacturer's specific instructions to avoid any potentially damaging thermal effects. The full description of the phototherapy settings is provided in Tables 1 through 3.

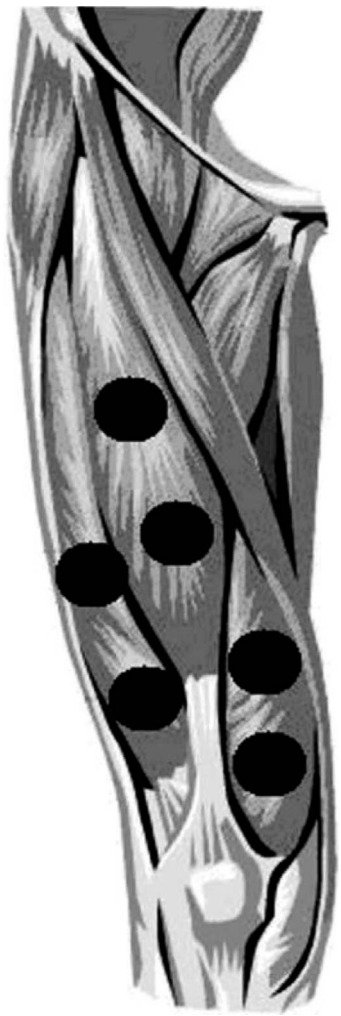

Figure 2. Sites of phototherapy irradiation on quadriceps for low-powered pulsed laser/light group and low-powered continuous laser/light group.

To ensure blinding, the active and placebo modes of each device emitted the same sounds regardless of the programmed mode or dose, and opaque goggles were worn by participants for safety and to maintain the double-blinded condition. Optical power was calibrated before irradiation for each participant using a thermal power meter (model S322C; Thorlabs, Newton, NJ). The researcher who performed the phototherapy was blinded to the randomization and allocation of participants.

Eccentric-Contraction Protocol

After treatment, participants performed the protocol of 75 eccentric isokinetic contractions of the knee extensors of the nondominant leg (5 sets of 15 repetitions, 30-second rest interval between sets) at a velocity of $60°{\cdot}s^{-1}$ both eccentrically and concentrically in a 60° range of motion (between 90° and 30° of knee flexion). For each contraction, the dynamometer automatically (passively) positioned the knee at 30°; the dynamometer then flexed the knee to 90°. The participants were instructed to resist with maximum force the knee-flexion movement imposed by the dynamometer. This eccentric-contraction protocol was based on prior optimization studies[24,25] with the low-powered continuous laser/light and low-powered pulsed laser/light devices that used the same exercise and study protocol. The researcher performing the protocol was blinded to the randomization and allocation of participants.

Table 1. Settings for High-Powered Continuous Laser/Light

Parameter	Value or Description
Class	4
No. of laser diodes	1
Wavelength, nm, mean ± SD	980 ± 10
Frequency, Hz	Continuous output
Optical output, mW	9000
Spot size, cm^2	15.90
Power density, W/cm^2	0.566
Energy density, J/cm^2	11.32
Irradiation time, s	20
Total dose applied in muscular group, J	180
Application mode	Scanning probe in contact with skin at a 90° angle and using slight pressure

Statistical Analysis

A priori, an intention-to-treat analysis would have been followed; however, there were no dropouts. The primary outcome was the peak torque obtained from MVC at the different time points. Secondary outcomes were CK activity and VAS rating. A blinded researcher performed the statistical analysis. Data were expressed as mean ± standard deviation and were first tested for normal distribution using the Shapiro-Wilk test. Analysis of variance with repeated measures for time was performed to test between-groups differences (followed by a Bonferroni-corrected post hoc test). The significance level was set at $P < .05$.

RESULTS

All recruited participants completed all assessments. The functional and biochemical performance and recovery outcomes of all groups are detailed in Table 4. As shown in Figure 3, only the low-powered pulsed laser/light group was able to maintain the MVC compared with the placebo ($P < .05$) and high-powered continuous laser/light ($P < .05$) groups immediately after the active treatment and up to 96 hours later, and MVC increased at the 48-, 72-, and 96-hour time points. The low-powered continuous laser/light group was also better than the placebo ($P < .05$), but only in the time frame between 24 and 72 hours after eccentric exercise, and was also better than the high-powered continuous laser/light group ($P < .05$) at all time points.

Regarding DOMS measured by VAS, only the low-powered pulsed laser/light group was able to minimize pain compared with the placebo ($P < .05$), low-powered continuous laser/light ($P < .05$), and high-powered continuous laser/light ($P < .05$) groups beginning at the 24-hour time point until the end of data collection at 96 hours. The results are summarized in Figure 4.

The low-powered pulsed laser/light group was able to prevent the exercise-induced increase in CK activity starting at 24 hours until 96 hours postexercise ($P < .05$) compared with the placebo and at all experimental times

Table 2. Settings for Low-Powered Continuous Laser/Light

Parameter	Value or Description
Class	3B
No. of laser diodes	5
Wavelength, nm	810
Frequency, Hz	Continuous output
Optical output, mW each	200
Spot size, cm^2 each	0.0364
Power density, W/cm^2 each	5.495
Energy density, J/cm^2 each	164.85
Dose, J each	6
Irradiation time per site, s	30
Total dose per site, J	30
Total dose applied in muscular group, J	180
Application mode	Cluster probe held stationary in contact with skin at a 90° angle and using slight pressure

compared with the high-powered continuous laser/light group ($P < .05$). The low-powered continuous laser/light device was able to decrease CK activity compared with the placebo ($P < .05$) at 48 hours postexercise and also when compared with the high-powered continuous laser/light group ($P < .05$) at 24 and 48 hours.

Finally, the high-powered continuous laser/light group did not demonstrate a positive effect ($P > .05$) on CK activity compared with any of the low-powered laser groups. In fact, the high-powered continuous laser/light group demonstrated a statistically significant increase in CK activity ($P < .05$) when compared with the placebo group at 1 and 24 hours postexercise. Results of the CK analysis are summarized in Figure 5.

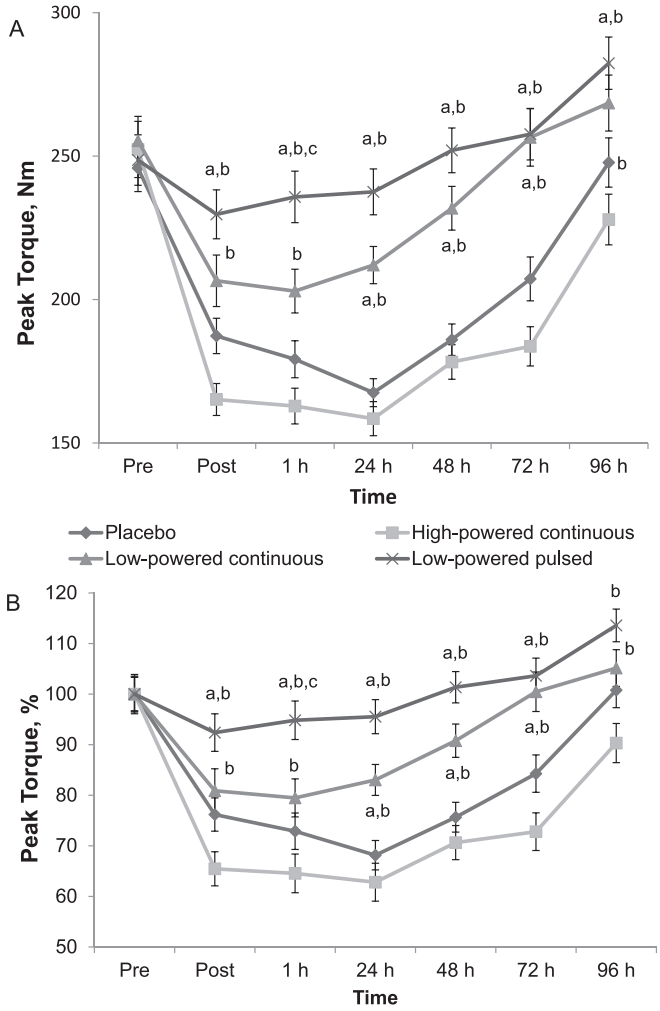

Figure 3. Maximum voluntary contraction in A, absolute, and B, percentage values. Values are means and error bars are standard errors of the mean. [a] Indicates difference compared with placebo ($P < .05$). [b] Indicates difference compared with high-powered continuous laser/light group ($P < .05$). [c] Indicates difference compared with low-powered continuous laser/light group ($P < .05$).

DISCUSSION

Fatigue is an often-forgotten aspect of an athlete's risk of injury. Fatigued muscles in the lower extremity require less force to reach muscle failure under high-intensity eccentric-loading conditions[29,30] and to display negative effects on lower extremity biomechanics and neuromuscular fatigue.[31,32]

Phototherapeutic effects linked to reinforcement of microcirculation,[33] enhanced adenosine triphosphate synthesis,[34] and mitochondrial function[35] have been observed after exposure to light. Reduced reactive oxygen species release and creatine phosphokinase activity and increased production of antioxidants and heat shock proteins have also been reported after PBM.[36,37] Albuquerque-Pontes et al[38] demonstrated that PBM in intact skeletal muscle can increase cytochrome c oxidase activity, which up-regulates mitochondrial activity to increase adenosine triphosphate production, and decrease oxidative stress and reactive oxygen species production. These findings support the ergogenic effects seen in healthy individuals.

The device settings we chose were based on scientific evidence in the currently published literature.[6,7] We sought to minimize manufacturer bias by using only doses and wavelengths described in the literature. Two recent systematic reviews,[6,7] one including a meta-analysis,[7] demonstrated positive outcomes on physical performance using single-diode and multidiode laser, multidiode LEDs, and combinations of both devices.

The low-powered pulsed laser/light group demonstrated preservation of muscle performance compared with the placebo group at all time points measured; the low-powered continuous laser/light group did so after the time points beyond 24 hours. The low-powered pulsed laser/light group experienced less muscle fatigue than the low-powered continuous laser group, although the difference was significant only at the 1-hour time point. Interestingly, the MVC results were similar to those previously observed using the low-powered continuous laser/light device[24] and those seen by Antonialli et al[25] using the low-powered pulsed laser/light device.

Previous researchers[32] have also shown that injury rates increase with the accumulation of fatigue and have negative effects on biomechanics. Full recovery can take several days.[39] Fatigue is an often-neglected aspect of the decision to return an athlete to sport or the assessment of an athlete's risk for injury. Preservation of strength, as seen in both low-

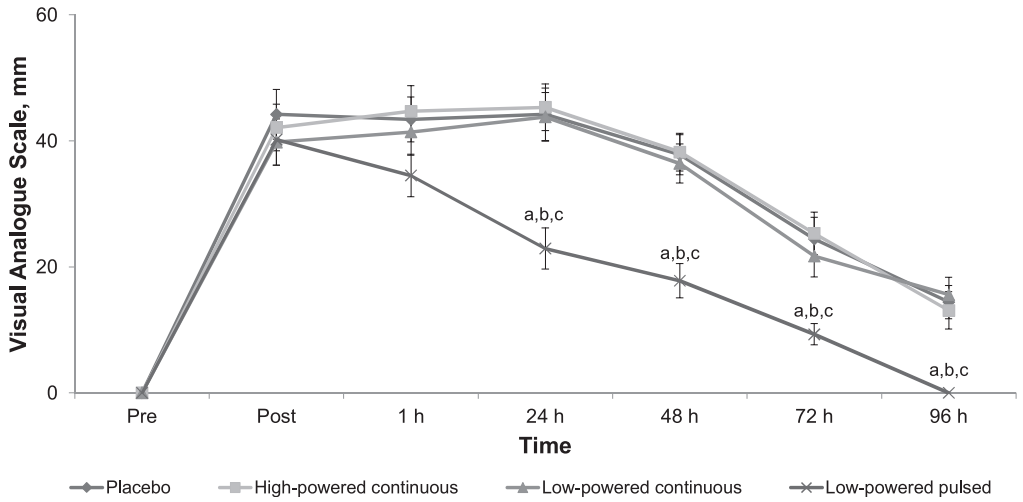

Figure 4. Delayed-onset muscle soreness assessment using 100-mm visual analogue scale. Values are means and error bars are standard errors of the mean. [a] Indicates difference compared with placebo ($P < .05$). [b] Indicates difference compared with high-powered continuous laser/light group ($P < .05$). [c] Indicates difference compared with low-powered continuous laser/light group ($P < .05$).

powered groups (low-powered pulsed laser/light and low-powered continuous laser/light), results in a reduction in fatigue and in the increased ability of the quadriceps muscle to exert maximal or near-maximal force. Sport-specific movements may be performed with better neuromuscular control, which can reduce the risk for both acute and overuse injuries.

Fatigue or a decline in performance may occur more rapidly at high temperatures.[40] Muscle temperature depends on many factors, including activity, blood flow, core temperature, proximity to the skin surface, and environmental temperature. Participants reported feeling heating during the high-powered continuous laser/light treatment even though the evaluators "scanned" the tissue as directed in the operator's manual. When higher-powered lasers are used to deliver energy, a corresponding increase in the surface temperature is recorded. This can create up to 6 times more heat in darker-pigmented skin than in lighter-pigmented skin-color groups.[21] The temperature increase may be related to the mean output of power, the mode of delivery, and the wavelength used in the high-powered continuous laser/light group.

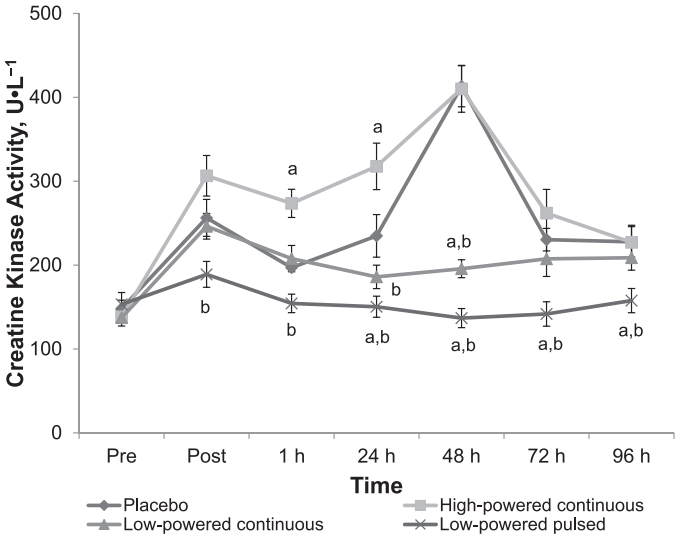

Figure 5. Creatine kinase activity. Values are means and error bars are standard errors of the mean. [a] Indicates difference compared with placebo ($P < .05$). [b] Indicates difference compared with high-powered continuous laser/light group ($P < .05$).

Table 3. Settings for Low-Powered Pulsed Laser/Light

Parameter	Value or Description
Class	1M
No. of lasers	4 Superpulsed infrared
Wavelength, nm, mean ± SD	905 ± 1
Frequency, Hz	250
Peak power, W each	12.5
Average mean optical output, mW each	0.3125
Power density, mW/cm^2 each	0.71
Energy density, J/cm^2 each	0.162
Dose, J each	0.07125
Spot size of laser, cm^2 each	0.44
No. of red LEDs	4
Wavelength of red LEDs, nm	640 ± 10
Frequency, Hz	2
Average optical output, mW each	15
Power density, mW/cm^2 each	16.66
Energy density, J/cm^2 each	3.8
Dose, J each	3.42
Spot size of red LED, cm^2 each	0.9
No. of infrared LEDs	4
Wavelength of infrared LEDs, nm	875 ± 10
Frequency, Hz	16
Average optical output, mW each	17.5
Power density, mW/cm^2 each	19.44
Energy density, J/cm^2 each	4.43
Dose, J each	3.99
Spot size of LED, cm^2 each	0.9
Magnetic field, mT	35
Irradiation time per site, s	228
Total dose per site, J	30
Total dose applied in muscular group, J	180
Aperture of device, cm^2	20
Application mode	Cluster probe held stationary in contact with skin at a 90° angle and using slight pressure

Abbreviation: LED, light-emitting diode.

Table 4. Functional and Biochemical Markers of Performance and Recovery, Mean ± SD (95% Confidence Interval)

Variable	Time						
	Pre-exercise	Postexercise	1 h	24 h	48 h	72 h	96 h
Maximum voluntary contraction, N·m							
Placebo	245.84 ± 25.94 (227.30, 264.40)	187.31 ± 19.50 (173.40, 201.30)	179.19 ± 20.41 (164.60, 193.80)	167.54 ± 15.40 (156.50, 178.60)	186.00 ± 17.35 (173.60, 198.40)	207.19 ± 24.20 (189.90, 224.50)	247.76 ± 27.15 (228.30, 267.20)
HPC	252.31 ± 30.98 (230.10, 274.50)	165.16 ± 17.62 (152.60, 177.80)	162.87 ± 19.69 (148.80, 177.00)	158.48 ± 18.80 (145.00, 171.90)	178.23 ± 19.02 (164.60, 191.80)	183.68 ± 21.64 (168.20, 199.20)	227.89 ± 27.92 (207.90, 247.90)
LPC	255.34 ± 26.91 (236.10, 274.60)	206.54 ± 28.38[a] (186.20, 226.80)	202.94 ± 24.11[a] (185.70, 220.20)	212.01 ± 20.52[a,b] (197.30, 226.70)	231.82 ± 24.11[a,b] (214.60, 249.10)	256.51 ± 31.65[a,b] (233.90, 279.20)	268.49 ± 30.85[b] (246.40, 290.60)
LPP	248.62 ± 27.80 (228.70, 268.50)	229.70 ± 26.97[a,b] (210.40, 249.00)	235.77 ± 28.39[a,b,c] (215.50, 256.10)	237.53 ± 25.30[a,b] (219.40, 255.60)	252.00 ± 24.65[a,b] (234.40, 269.60)	257.64 ± 28.39[a,b] (237.30, 277.90)	282.38 ± 28.86[a,b] (261.70, 303.00)
Visual analogue scale, mm							
Placebo	0.00 ± 0.00 (0.00, 0.00)	44.20 ± 12.47 (35.28, 53.12)	43.40 ± 11.24 (35.36, 51.44)	44.20 ± 13.13 (34.81, 53.59)	37.80 ± 10.12 (30.56, 45.04)	24.40 ± 11.04 (16.50, 32.30)	14.40 ± 8.28 (8.48, 20.32)
HPC	0.00 ± 0.00 (0.00, 0.00)	42.10 ± 11.69 (33.74, 50.46)	44.70 ± 12.86 (35.50, 53.90)	45.30 ± 11.70 (36.93, 53.67)	38.20 ± 9.46 (31.43, 44.97)	25.30 ± 10.66 (17.67, 32.93)	13.10 ± 9.43 (6.35, 19.85)
LPC	0.00 ± 0.00 (0.00, 0.00)	39.80 ± 11.66 (31.46, 48.14)	41.40 ± 11.61 (33.09, 49.71)	43.80 ± 12.16 (35.10, 52.50)	36.40 ± 9.85 (29.35, 43.45)	21.69 ± 10.40 (14.25, 29.13)	15.60 ± 8.63 (9.43, 21.77)
LPP	0.00 ± 0.00 (0.00, 0.00)	40.20 ± 12.80 (31.04, 49.36)	34.50 ± 10.72 (26.83, 42.17)	22.90 ± 10.33[a,b,c] (15.51, 30.29)	17.80 ± 8.55[a,b,c] (11.68, 23.92)	9.30 ± 5.32[a,b,c] (5.49, 13.11)	0.00 ± 0.00[a,b,c] (0.00, 0.00)
Creatine kinase, $U \cdot L^{-1}$							
Placebo	148.06 ± 32.12 (125.10, 171.00)	256.30 ± 69.63 (206.50, 306.10)	196.95 ± 6.56 (192.30, 201.60)	234.85 ± 80.26 (177.40, 292.30)	413.20 ± 77.36 (357.90, 468.50)	230.35 ± 42.51 (199.90, 260.80)	227.75 ± 57.21 (186.80, 268.70)
HPC	138.30 ± 34.49 (113.60, 163.00)	306.51 ± 76.41 (251.80, 361.20)	273.62 ± 53.14[b] (235.60, 311.60)	317.70 ± 87.65[b] (255.00, 380.40)	410.18 ± 88.38 (347.00, 473.40)	261.97 ± 89.53 (197.90, 326.00)	227.08 ± 64.64 (180.80, 273.30)
LPC	137.29 ± 17.04 (125.10, 149.50)	246.28 ± 48.24 (211.80, 280.80)	207.76 ± 49.58 (172.30, 243.20)	185.97 ± 44.23[a] (154.30, 217.60)	195.71 ± 33.84[a,b] (171.50, 219.90)	207.47 ± 66.35 (160.00, 254.90)	208.78 ± 46.94 (175.20, 242.40)
LPP	153.23 ± 44.60 (121.30, 185.10)	188.98 ± 48.72[a] (154.10, 223.80)	154.35 ± 34.89[a] (129.40, 179.30)	150.41 ± 39.76[a,b] (122.00, 178.90)	136.84 ± 36.02[a,b] (111.10, 162.60)	141.76 ± 46.02[a,b] (108.80, 174.70)	157.69 ± 45.73[a,b] (125.00, 190.40)

Abbreviations: HPC, high-powered continuous laser/light; LPC, low-powered continuous laser/light; LPP, low-powered pulsed laser/light.

[a] Different from HPC ($P < .05$).

[b] Different from placebo ($P < .05$).

[c] Different from LPC ($P < .05$).

When using a high-powered laser, Kim and Jeong[23] noted that if the hyperthermia lasts for several minutes, significant thermal damage may occur in biological tissues. The increase in human skin temperature can be significantly underestimated if the dependence of the optical properties of human skin on temperature is ignored during PBM treatments.[21] Total irradiation time was substantially lower; however, participants discerned appreciable heat during the application.

Both low-powered laser devices (pulsed laser/light and continuous laser/light) improved recovery times. The low-powered pulsed laser/light group demonstrated accelerated recovery to baseline that was nearly 100% faster than the placebo group, and the low-powered continuous laser/light group demonstrated a 50% acceleration. The low-powered pulsed laser/light group returned to baseline at 48 hours compared with 72 hours for the low-powered continuous laser/light group and 96 hours for the placebo group. The low-powered pulsed laser/light group maintained strength at almost 100% from immediately after to 48 hours after eccentric exercise; from 48 to 96 hours after eccentric exercise, participants were able to perform with 5% to 15% more strength over the baseline measurement. Tissue heating may have negatively affected the phototherapeutic outcome in the high-powered continuous laser/light group, as indicated by the increase in CK activity. The "pulsing" of the low-powered pulsed laser/light device and the low power of the low-powered continuous laser/light device may explain the superior results compared with the high-powered continuous laser/light treatment, because both devices generate only a small amount of superficial heat.[21,22]

The MVC results of the high-powered continuous laser/light group are similar to those of Larkin-Kaiser et al,[28] who applied 360 J using a high-powered laser and demonstrated a small, nonsignificant difference between placebo and the active groups at 24 hours and no difference at 48 hours after the treatment. However, we delivered nearly 50% of that dose and found similar reductions in MVC, which were not reversed during the course of the study.

Although the dose we selected for the high-powered continuous laser/light group (the power density was between both low-powered pulsed laser/light and low-powered continuous laser/light groups) did not exhibit a positive effect on muscle performance or pain compared with placebo, it did demonstrate an effect on CK activity ($P < .05$). Therefore, the selected dose for the high-powered continuous laser/light group cannot be considered too low to achieve biological effects. Laboratory studies have shown that more is not necessarily better and that the positive effects may, in fact, be lost when overdosing or overpowering (or both) PBM.[41]

Normal recovery occurs between 24 and 48 hours. However, participants in the high-powered continuous laser/light group did not fully recover to baseline; in fact, they recovered only 60% to 70% of their original MVC. Individuals being treated with this type of high-powered device may exhibit a decreased level of performance. Moreover, the incidence of overuse injuries may increase. These would be alarming findings because in many sports, daily practices including multiple events are common.

The low-powered pulsed laser/light group maintained CK activity levels near baseline from 24 to 96 hours, even though the placebo group increased nearly 50% at 24 hours and experienced a marked increase of 215% at 48 hours using the same eccentric-exercise protocol. The low-powered continuous laser/light group demonstrated decreased CK activity at 24 hours, which was 35% less than the decrease seen in the low-powered pulsed laser/light group at the same time point. Compared with placebo, an increase in CK activity was evident, indicating additional muscle damage from the high-powered continuous laser/light treatment.

Although the literature suggests a range between 125 and 180 J, the dose delivered by the high-powered continuous laser/light did not exhibit the same prophylactic and stimulatory effects on muscle performance and recovery.[6,7] The additional CK activity in the high-powered continuous laser/light group correlates with the decreased muscle strength noted in MVC. These participants fatigued faster than those in the other groups, which may have caused the muscles to work harder and experience catabolic effects. No participants dropped out of our study, but Larkin-Kaiser et al[28] had 1 participant drop out because of excessive arm pain. This corresponds with our finding that the high-powered continuous laser/light treatment did not improve muscle performance or modulate the pain associated with DOMS. Further studies of the effects and mechanisms behind high-powered laser/light may provide optimal settings; insufficient data have been published to date for high-powered lasers.[42] Finally, it is important to highlight that for time points when differences ($P < .05$) were observed in favor of the low-powered pulsed laser/light compared with both the placebo and high-powered continuous laser/light conditions, confidence intervals among treatments tested did not overlap. This leads us to believe that the observed differences are clinically meaningful and can help health care professionals to make better clinical decisions.

We conclude that low-powered pulsed laser/light (with a combination of different wavelengths and light sources) showed better effects on performance enhancement and postexercise recovery than low-powered or high-powered continuous laser/light. Additionally, high-powered continuous laser/light did not have any effect on performance enhancement or postexercise recovery. Our findings can help clinicians make better decisions regarding device choice in this field.

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