Lasers Med Sci
DOI 10.1007/s10103-015-1832-4

REVIEW ARTICLE

Effect of low-level phototherapy on delayed onset muscle soreness: a systematic review and meta-analysis

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Received: 23 February 2015 / Accepted: 28 October 2015

Abstract To determine the effectiveness of low-level phototherapy (i.e. light-emitting diode therapy [LEDtherapy] or light amplification by stimulated emission of radiation therapy [LASERtherapy]) on pain, skeletal muscle injury (creatine kinase [CK] levels and edema) and skeletal muscle function (range of movement and strength) in people undergoing an exercise protocol. (Cochrane Central Register of Controlled Trials, MEDLINE, EMBASE, PEDro, SciELO and LILACS up to May 2014), we included randomized controlled trials, quasi-randomized controlled trials and crossover studies in which study participants were allocated to receive either low-level phototherapy or placebo treatment. Phototherapy should have been applied in a single treatment session, either before or after an exercise protocol. We identified 15 studies involving 317 participants. Meta-analyses were limited by substantial heterogeneity. Compared to the placebo group, reduction in CK levels was only observed when LASERtherapy was applied before an exercise protocol (standardized mean difference=−0.66; 95 % CI=-1.30, −0.02). No between-group difference in edema, range of movement and strength were detected when phototherapy was applied before or after exercise. Evidence from this review suggests that low-level phototherapy may not have substantial effect in the treatment of skeletal muscle injury and pain caused by exercise. Definitive conclusions are limited due to the small number of included studies in each meta-analysis, disparities across the included studies and small sample sizes.

Keywords Low-level laser therapy · Phototherapy · Skeletal muscle · Muscle soreness · Exercise

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Introduction

Delayed onset muscle soreness (DOMS) due to muscle strain is defined as the soreness perceived while or after participating in exercises [1]. Specifically, high load or eccentric exercise training may lead to mechanical disruption of skeletal muscle fibres, damage of connective tissues, or metabolic dysfunction that can cause muscle injury, impaired muscle function and a local inflammatory response [2, 3]. Muscle soreness presents with muscle stiffness, aching pain, muscular tenderness, swelling, joint stiffness, reduction in muscle strength and elevated creatine kinase (CK) levels, reducing exercise capacity for up to 7 days [1] regardless of the individual's physical condition [4].

Efforts have been made to prevent muscle soreness and accelerate muscle recovery. Skeletal muscle protection and recovery are relevant to elite athletes, as minimal differences in performance distinguish success from failure [5]. Prevention of muscle soreness is also important to patients, because physical discomfort can increase treatment dropout [6]. Therapeutic strategies that have

Published online: 12 November 2015

demonstrated limited success on prevention of muscle soreness include non-steroidal anti-inflammatory, stretching, therapeutic ultrasound, homeopathy, acupuncture, massage, electrical stimulation, exercise and cold water immersion [7, 8].

Low-level phototherapy using either light amplification by stimulated emission of radiation therapy (LASERtherapy) or light-emitting diode therapy (LEDtherapy) has been suggested as treatment options for muscle soreness, muscle recovery and prevention of muscle damage after intense efforts [9, 10]. Phototherapy seems to stimulate mitochondrial respiratory chain, specifically the cytochrome c oxidase (complex IV) increasing the rate of mitochondrial electron transport [11, 12]. It is suggested that phototherapy may cause the photolysis of nitric oxide complex, a suppressor of cytochrome c oxidase [11, 12]. Changes in cellular redox status and ATP synthesis promote biomodulation, which increases extracellular matrix and growth factor production, reduces oxidative stress, activates anti-inflammatory and anti-apoptotic pathways, and reduces pain [13–15]. Also, low-level phototherapy is thought to promote pain relief by decreasing the inflammatory reaction and decreasing nerve conductance and the release of pain mediators [13–15].

The interest on the investigation of the effectiveness of phototherapy to prevent or treat muscle soreness has grown, as it is a non-drug, local, conservative intervention, with no side effects. Additionally, it can be used during competition or concomitant to other treatment options. However, to date, no comprehensive systematic review and meta-analysis have been published that investigated the effects of LED or LASER applied either immediately before or after exercise on outcomes related to DOMS.

If phototherapy is shown to be effective against DOMS, it will provide evidence base to stimulate its use on the clinical setting. This review will also identify the strengths and limitations of the studies in this area, as well as gaps in the literature. Therefore, the results will be of use when designing future trials aimed at determining the effectiveness of low-level phototherapy to prevent or treat exercise-related muscle injury and soreness. Therefore, the research question for this systematic review was the following: Compared to a placebo treatment, does a single session of low-level phototherapy applied either before or after exercise reduces DOMS in people undergoing an exercise protocol?

Methods

Protocol and registration

Although a research protocol had been established, this review lacks a protocol registration.

Type of studies

This systematic review has been undertaken according to the Cochrane Collaboration Handbook [16] and PRISMA Statement [17] recommendations. It included randomized controlled trials (RCTs), quasi-randomized controlled trials and crossover trials in which participants were allocated to receive low-level phototherapy (LED or LASER) or placebo treatment either immediately before or after exercise.

Only studies in which phototherapy was applied in upper or lower limbs, during a single treatment session, either before or after an exercise protocol, were eligible to be included in this systematic review. Further, assessments should have been undertaken within 96 h following the exercise protocol. There was no limit regarding age, gender, physical condition or health status. Studies and abstracts published in any language were eligible for inclusion.

Primary outcomes

- Pain measured by visual analogue scale (VAS), either stimulated or under rest
- Skeletal muscle injury measured by serum CK concentration

Secondary outcomes

- Skeletal muscle performance in terms of range of movement (ROM) and strength
- Edema formation as edema volume measured directly or indirectly (e.g. pletismography or girth)

Search strategy

Trials were identified using electronic bibliographic databases including the Cochrane Central Register of Controlled Trials (CENTRAL) (*The Cochrane Library* 2014, issue 5 of 12), MEDLINE (via PubMed) (1966 to May 2014), EMBASE (via Ovid) (1974 to May 2014), Physiotherapy Evidence Database (PEDro) (1980 to May 2014), The Scientific Electronic Library Online (SciELO) (1978 to May 2014) and Latin-American and Caribbean Center on Health Sciences Information (LILACS) (1982 to May 2014).

The full electronic search strategy used for MEDLINE and adapted to the other databases was as follows:

1. Injur* OR lesion OR trauma OR recover* OR regeneration OR cicatrisation OR cicatrization OR repair* OR fatigu*
2. Muscle
3. Nos. 1 AND 2
4. Laser[tiab] OR ledt[tiab] OR light emitting diode[tiab] OR phototherapy
5. Nos. 3 AND 4
6. Randomi*
7. Nos. 5 AND 6

Data collection and analysis

Every retrieved article was examined to determine their eligibility for inclusion in the review. Their reference list was also screened for further references of interest. Attention was paid to avoid redundant publication.

Risk of bias

Risk of bias for included studies was assessed as high, low or unclear, with the last category indicating either a lack of information or uncertainty regarding the potential for bias according to Cochrane Collaboration's 'seven evidence-based domains' tables (random sequence generation, allocation concealment, blinding of participants, blinding of outcome assessment, incomplete outcome data, selective reporting and other possible sources of bias) [16].

Data extraction

Details of the studies, characteristics of the participants and results were extracted preferably from published data. Whenever necessary, an electronic mail was sent to the correspondent author for further information. If no answer was obtained within a week or there was no contact information, other authors were randomly contacted. After 5 weeks, should authors had not responded to our contact attempt, data of their study were not included in the analyses. All obtained or extracted data were entered into Review Manager 5.1 software.

Data synthesis and analysis

Descriptive results were displayed in table. Review Manager 5.1 was used to conduct the statistical analyses and generate forest plots. Mean differences and 95 % confidence intervals were calculated for all the variables. Random effects model was used when substantial heterogeneity was found (I^2>50 %) [18]. Otherwise, a fixed-effect model was applied. Subgroup analyses were conducted to evaluate the effect of the intervention on different time points, such as immediately, 24, 48, 72 and 96 h after exercise or intervention.

Results

Search results

Database search yielded 433 records: 93 from EMBASE, 76 from MEDLINE, 50 from CENTRAL, 82 from PEDro, 43 from SciELO and 89 from LILACS. After removing duplicates and including results of the handsearch (n=2), 315 records remained, of which 292 were excluded based on title and abstract. Twenty-three full texts were assessed and eight studies were excluded as they either did not meet review criteria (n=7) [19–25], or the authors did not reply to contact attempts requesting missing data (n=1) [26] (Fig. 1). Authors from six studies successfully provided requested information [27–32].

Included studies

This review comprised 15 studies, totalling 317 participants (270 men [85 %]). Sample size ranged from six to 60 participants aged 15 to 36 years. Twelve studies took place in Brazil [27, 30, 32–41] and the others were based in UK [28, 29] and the USA [31]. For further details on characteristics of included studies, see Table 1.

Risk of bias in included studies

Two studies presented high risk of bias in three of seven domains included in the Cochrane Collaboration's 'seven evidence-based domains' [32, 41]. Once they did not significantly changed overall meta-analysis results, they were kept during analysis. To the best of our knowledge, all studies presented high risk of bias pertaining to 'allocation concealment', although some of them stated that allocation was concealed (Fig. 2).

Exercise protocol

Isotonic or isometric elbow flexors exercises were performed in eight studies [27–29, 31, 32, 38–40]. Seven studies have chosen lower limb protocols, including isotonic or isometric knee extensors exercises [30, 33], cycling [35–37], treadmill running [34] or jumping [41].

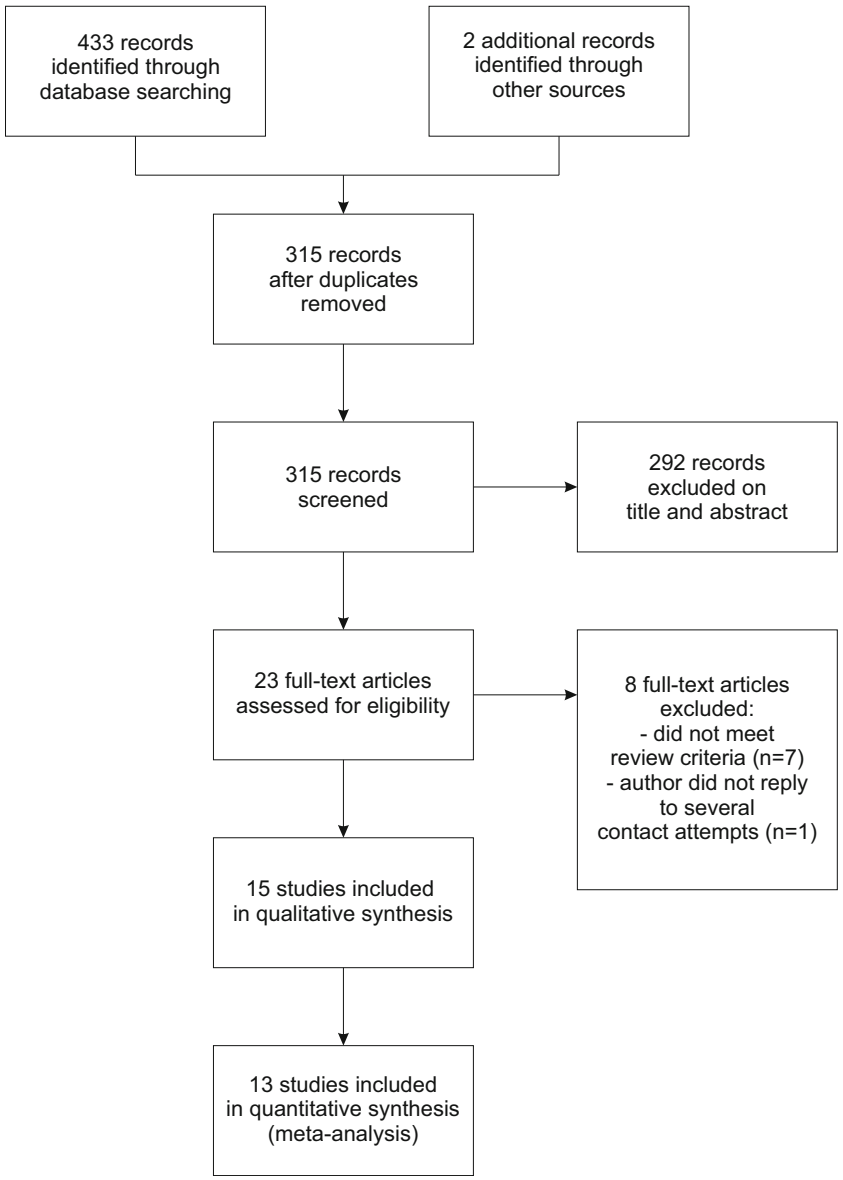

Fig. 1 Study flow diagram

Treatment protocol

Eleven studies applied LASERtherapy [28–30, 32–34, 36–38, 40, 41] and five applied LEDtherapy [27, 31, 35, 36, 39]. Eight of the 11 studies that applied LASERtherapy used it before exercise [30, 33, 34, 36–38, 40, 41]. Two of the five studies that applied LEDtherapy used it before exercise [36, 39]. Of note, one study had both a LASERtherapy and a LEDtherapy group [36]. There was also one study that had one group treated with pre-exercise LASERtherapy and another group treated with post-exercise LASERtherapy [30].

Two studies applied only red spectrum wavelength (652 to 700 nm) [27, 40], seven applied only near infrared spectrum (higher than 700 nm) [30, 32–34, 37, 38, 41], five applied combined therapy (red+near infrared) [28, 29, 31, 35, 39] and one study applied near infrared to one group and a combination of red and near infrared to another group [36]. Regarding emission frequency, 10 studies investigated continuous emission [27, 30, 34–41], two investigated pulsed emission [28, 29] and three did not specify emission frequency [31–33].

Outcomes

Pain

No study investigated the effect of pre-exercise LEDtherapy on pain. Two RCTs with similar risk of bias investigated the effect of post-exercise LEDtherapy on pain, using VAS [27, 31], after eccentric elbow flexors exercise. Borges et al. [27] applied red wavelength LED (630 nm, 36 J), whereas Douris et al. [31] applied a

Table 1 Characteristics of included studies

Study ID	Participants	Intervention	Exercise	Comparison	Outcomes	Results
Baroni 2010a [33]	36 M (19–35 years)	LASER before exercise @ 810 nm, 200 mW, 5 LASERs, 6 points, 30 s per point, N/A frequency. Energy: 180 J, 206.89 J/cm^2. Dominant quadriceps.	15 quadriceps maximum eccentric contractions @ 60°/s and 60° range of movement	RCT	CK (U/L) Pain (VAS)	Favours LASER ns
Borges 2014 [27]	17 M (range n/a)	LED after exercise @ 630 nm, 300 mW, 1 LED, 4 points, 30 s per point, continuous. Energy: 36 J, 20.4 J/cm^2. Non-dominant biceps.	30 eccentric biceps contractions during 4–5 s each and 45 s rest between contractions @ 100 % MVIC.	RCT	Pain (VAS) ROM (degrees) Strength (MVIC, N)	Favours LED @ 48, 72 and 96 h Favours LED @ 48 and 72 h Favours LED
Craig 1996 [28]	60 M (19–25 years)	LASER after exercise @ 660/950 nm, 534 mW, 31 LASERs, N/A points (12 cm^2), 720 s therapy, 2.5 Hz (group 1) or 5 Hz (group 2) or 20 Hz (group 3). Energy: 380.4 J, 31.7 J/cm^2. Non-dominant biceps.	Eccentric biceps contraction @ 100 % MVCC to exhaustion	RCT	Pain (VAS) ROM (degress)	ns ns
Craig 1999 [29]	18 M, 18 F (19–25 years)	LASER after exercise @ 660–950 nm, 534 mW, 31 LASERs, N/A points; 240 s therapy, 73 Hz. Energy: 128.16 J, 11 J/cm^2. Non-dominant biceps.	Eccentric biceps contraction @ 100 % MVCC to exhaustion	RCT	Pain (VAS) ROM (degrees)	ns ns
De Almeida 2012 [40]	10 M (19–27 years)	LASER before exercise @ 660 nm (group 1) or 830 nm (group 2), 50 mW, 1 LASER, 4 points per limb, 100 s per point, continuous. Energy: 20 J, 1,785 J/cm^2. Non-dominant biceps	One minute biceps MVIC @ 90°	RCT	Strength (MVIC, kgf)	Favours LASER
De Marchi 2012 [34]	22 M (20–25 years)	LASER before exercise @ 810 nm, 200 mW, 5 LASERs, 12 points per limb, 30 s per point, continuous. Energy: 360 J per limb, 164.88 J/cm^2. Bilateral quadriceps.	Treadmill @ 1 % inclination and 3 km/h for 3 min. + 1 km/h every minute up to 16 km/h	Crossover	CK (U/L)	Favours LASER
Dos Reis 2014 [30]	27 M soccer (15–30 years)	LASER before (group 1) or LASER after (group 2) exercise @ 830 nm, 60 mW, 6 LASERs, 7 points, 10 s per point, continuous. Energy: 25.2 J per limb, 214.28 J/cm^2. Bilateral quadriceps.	Isotonic quadriceps contraction @ 75 % MVCC to exhaustion	RCT	CK (UI/L)	ns
Douris 2006 [31]	5 M, 22 F (21–35 years)	LED after exercise @ 660/880 nm, 500 mW per point, 4+32 LEDs, 3 points, 80 s per point, N/A frequency. Energy: 120 J, 8 J/cm^2. Non-dominant biceps.	Eccentric biceps contraction @ 100 % MVCC to exhaustion Swelling	RCT	Pain (VAS) ROM (degrees) Girth (cm)	Favours LED @ 48 h ns ns
Felismino 2013 [32]	22 M (20–35 years)	LASER after exercise @ 808 nm, 100 mW, 1 LASER, 4 points per limb, 10 s per point, N/A frequency. Energy: 4 J per limb, 357.14 J/cm^2. Bilateral biceps.	10x 10 isotonic biceps contraction @ 50 % MVCC with 2 min rest between series	RCT	CK (% pre) Strength (MVCC, % pre)	Favours LED @ 72 h ns
Leal Jr. 2009a [36]	8 M volleyball	LASER before exercise (group 1) @810 nm, 200 mW, 1 LASER,	Wingate	Crossover	CK (U/L)	Favours LED/LASER vs placebo

Table 1 (continued)

Study ID	Participants	Intervention	Exercise	Comparison	Outcomes	Results
	(17–20 years)	2 points per limb, 30 s per point, continuous. Energy: 12 J per limb, 164.84 J/cm^2. LED before exercise (group 2) @ 660/850 nm, 10/30 mW, 34+35 LEDs, 2 points per limb, 30 s per point, continuous. Energy: 83.4 J per limb, 1.5/4.5 J/cm^2. Bilateral quadriceps.				Favours LED vs LASER
Leal Jr. 2009b [37]	9 M volleyball (18–36 years) + 11 M soccer (15–18 years)	LASER before exercise @ 830 nm, 100 mW, 1 LASER, 5 points per limb, 40/30 s per point, continuous. Energy: 20/15 J per limb, 1,428.57/1,071.43 J/cm^2. Bilateral quadriceps	Wingate	Crossover	CK (U/L)	Favours LASER
Leal Jr. 2009c [39]	10 M volleyball (18–36 years)	LED before exercise @ 660/850 nm, 10/30 mW, 34+35 LEDs, 1 point, 30 s per point, continuous. Energy: 83.4 J, 1.5/4.5 J/cm^2. Non-dominant biceps.	Isotonic biceps contraction @ 75 % MVCC to exhaustion	Crossover	CK (U/L)	Favours LED
Leal Jr. 2010a [38]	9 M volleyball (18–20 years)	LASER before exercise @ 810 nm, 200 mW, 5 LASERs, 2 points, 30 s per point, continuous. Energy: 60 J, 164.84 J/cm^2. Non-dominant biceps.	Isotonic biceps contraction @ 75 % MVCC to exhaustion	Crossover	CK (U/L)	Favours LASER
Leal Jr. 2011 [35]	6 M futsal (17–25 years)	LED after exercise @ 660/850 nm, 10/30 mW, 34+35 LEDs, 5 points per limb, 30 s per point, continuous. Energy: 208.5 J per limb, 1.5/4.5 J/cm^2. Bilateral lower limbs (thigh and leg).	Wingate	Crossover	CK (U/L)	ns
Maciel 2013 [41]	7 F volleyball (18–27 years)	LASER before exercise @ 830 nm, 30 mW, 1 LASER, ±20 points, 22 s per point, continuous. Energy: 11 J, 5.68 J/cm^2. Dominant gastrocnemius	Three horizontal jumps+three vertical jumps+3x1 min isometric contraction	RCT	Strength (peak force, N)	ns

M male, *F* female, *LED* light-emitting diode, *LASER* light amplification by stimulated emission of radiation, *MVIC* maximum voluntary isometric contraction, *MVCC* maximum voluntary concentric contraction, *RCT* randomized controlled trial, *CK* creatine kinase, *VAS* visual analogue scale, *ns* difference statistically not significant

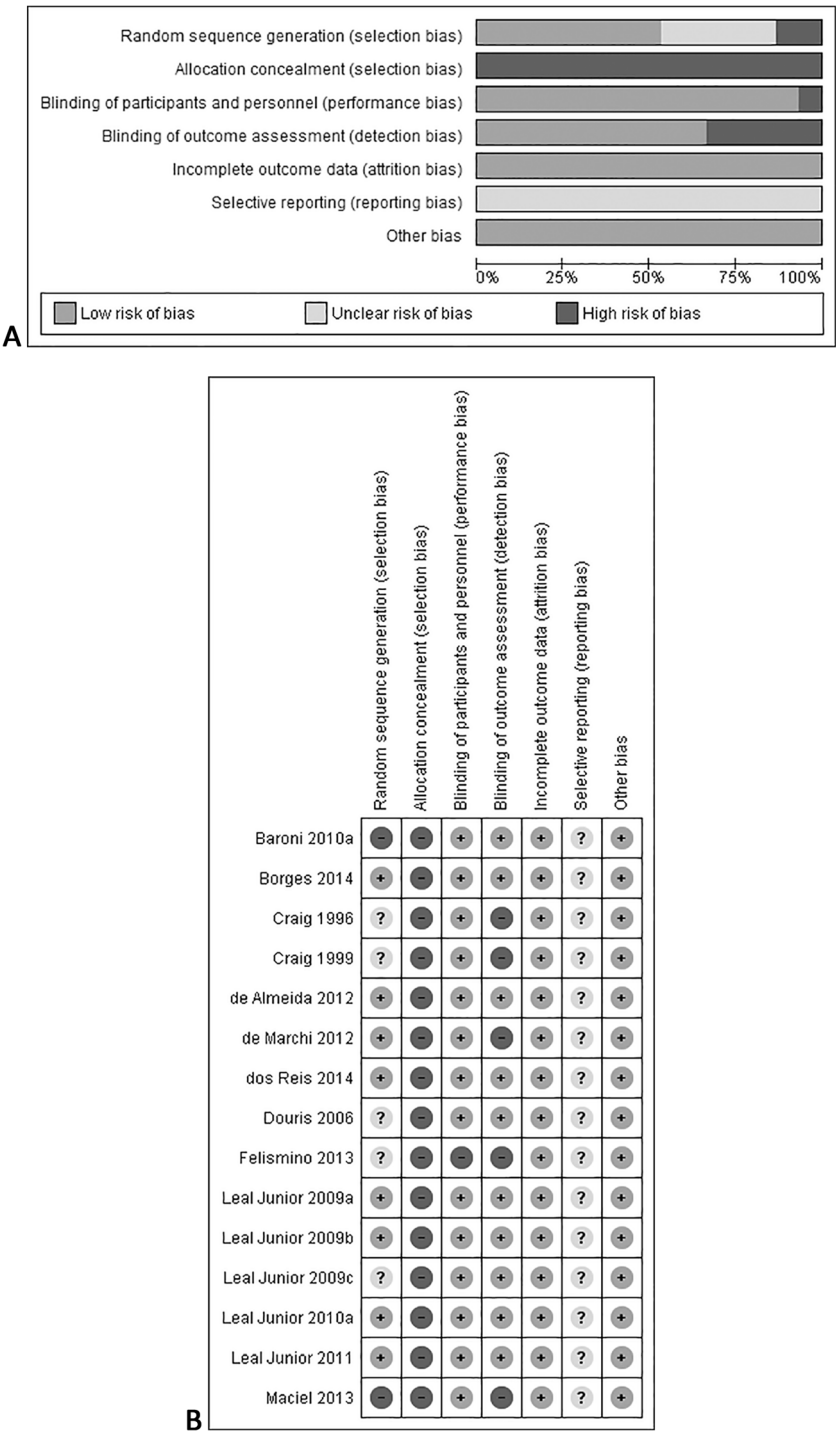

Fig. 2 **a** Risk of bias graph. **b** Risk of bias summary

probe with four red and 32 infrared LEDs (660 and 880 nm, 120 J). Participants were evaluated 24, 48, 72 and 96 h after exercise, totalling 68 evaluations in intervention group and 72 in placebo group. Subgroup analyses revealed no difference between groups in any of the time points (Fig. 3).

One RCT investigated the effect of pre-exercise LASERtherapy on skeletal muscle pain [33]. Baroni et al. [33] applied infrared LASER (810 nm, 180 J) before eccentric knee extensor exercise and demonstrated no difference between groups (Table 1).

Two RCTs with identical risk of bias investigated the effect of LASERtherapy after elbow eccentric exercise on pain, using VAS [28, 29]. Both studies applied 660–950 nm LASERtherapy, but one study delivered 380.4 J [28] and the other delivered 128.16 J [29]. Participants were evaluated

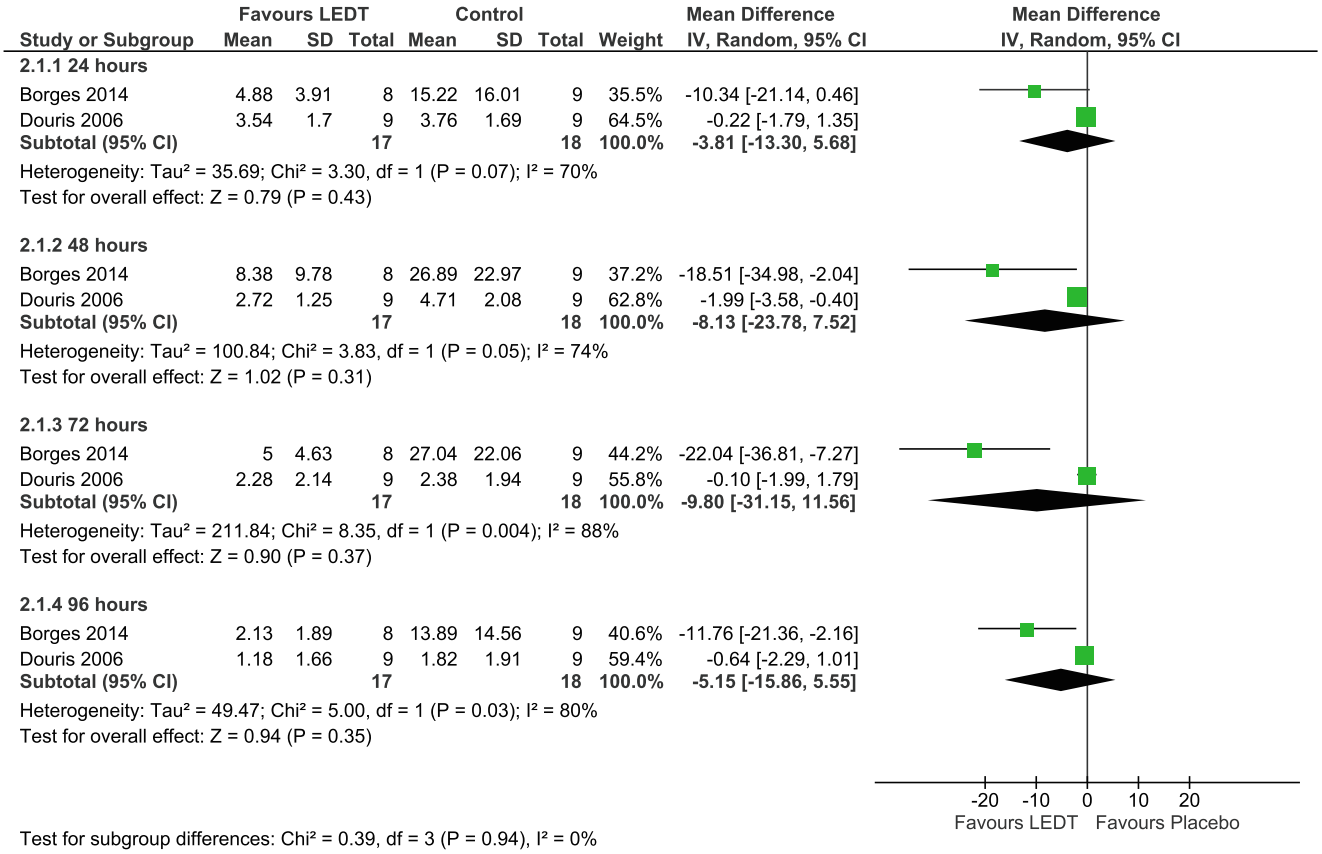

Fig. 3 Forest plot of comparison postexercise LEDtherapy vs placebo group. Outcome: pain (VAS in millimetres)

immediately and 24 h after treatment, totalling 96 evaluations in the intervention group and 48 in the placebo group. Overall, no difference was found between groups (MD=1.96; 95 % CI=−8.11, 12.03; *P*=0.70; data not shown).

Skeletal muscle injury: creatine kinase

Two crossover studies with similar risk of bias investigated the effect of pre-exercise LEDtherapy on CK levels [36, 39]. Both studies measured CK as difference to basal values (U/L). Participants were evaluated immediately after Wingate test [36] or isotonic biceps exercise [39], totalling 18 evaluations in each group. There was no difference on serum levels of CK between groups (MD=−23.51 U/L; 95 % CI=−60.65 U/L, 13.63 U/L; *P*=0.21; data not shown).

One crossover study investigated the effect of post-exercise LEDtherapy on CK levels following Wingate test [35]. Participants were evaluated 20 min after treatment with a probe with four red and 32 infrared LEDs (660 and 850 nm multi LED probe, 208.5 J). No difference between groups was found (Table 1).

Four crossover studies [34, 36–38] and one RCT [30] with similar risk of bias investigated the effect of pre-exercise LASERtherapy on CK levels [34, 36–38]. Three studies measured CK raw values (U/L) [30, 34, 38] and two as the difference to basal values (U/L) [36, 37]. Exercise protocol varied between Wingate test [36, 37], quadriceps exercise [30, 33], treadmill [34] and biceps exercise [38]. All studies applied infrared wavelength of 810 nm [34, 36, 38] or 830 nm [30, 37] with total energy ranging from 83.4 to 360 J. Participants were evaluated immediately after exercise, totalling 57 evaluations in each group. Overall, CK levels were lower in intervention group (SMD=−0.66; 95 % CI=−1.30, −0.02; *P*=0.04; Fig. 4).

One RCT investigated the effect of pre-exercise LASERtherapy on CK levels 24 and 48 h after exercise [33]. Serum levels of CK were better controlled in intervention group (Table 1).

Two RCTs investigated the effect of post-exercise LASERtherapy on CK levels [30, 32]. Dos Reis et al. [30] measured CK raw value (U/L) after isotonic quadriceps exercise and applied infrared LASER (810 nm, 25.2 J). Felismino et al. [32] measured CK levels as percentage of basal value after isotonic biceps exercise and also applied infrared LASER (808 nm, 4 J). Participants were evaluated immediately after treatment, totalling 20 evaluations in each group. Overall, there was no difference between groups (SMD=−0.21; 95 % CI=−0.83, 0.42; *P*=0.51; data not shown).

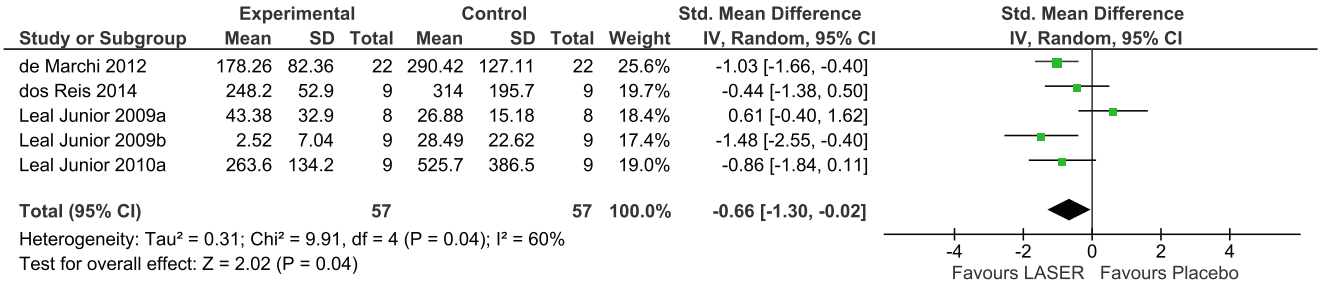

Fig. 4 Forest plot of comparison pre-exercise LASERtherapy vs placebo group. Outcome: skeletal muscle injury (CK in U/L)

Felismino et al. [32] also investigated the effect of post-exercise LASERtherapy 24, 48 and 72 h after treatment and demonstrated better results in intervention group only 72 h after treatment (Table 1).

Skeletal muscle injury: edema

No study investigated the effect of pre-exercise LEDtherapy on edema. Douris et al. [31] investigated the effect of post-exercise LEDtherapy on arm girth following eccentric biceps exercise. Participants were evaluated 24, 48, 72 and 96 h after intervention, totalling 36 evaluations in each group. No difference was found between groups (Table 1). No study evaluated the effects of LASERtherapy on edema.

Skeletal muscle function: range of movement

No study investigated the effect of pre-exercise LEDtherapy on ROM. Two RCTs with similar risk of bias investigated the effect of post-exercise LEDtherapy on non-dominant elbow ROM [27, 31]. Borges et al. [27] applied red wavelength LEDtherapy (630 nm, 36 J) and measured ROM as percentage of basal values, whereas Douris et al. [31] applied a probe with four red and 32 infrared LEDs (660 and 880 nm, 120 J) and measured ROM in raw values (degrees). Participants were evaluated 24, 48 and 72 h after eccentric biceps exercise on both studies, totalling 68 evaluations in the treatment group and 72 in the placebo group. Overall, no difference was found between groups (SMD=0.34; 95 % CI=−0.21, 0.89; P=0.22; data not shown).

No study investigated the effect of pre-exercise LASERtherapy on ROM. Two single-blinded RCTs with similar risk of bias investigated the effect of post-exercise LASERtherapy on non-dominant elbow extension angle (degrees) after eccentric biceps exercise [28, 29]. Both studies used a cluster multi-diode array with red and infrared wavelength LASERs (660 and 950 nm), with total delivered energy of 380.4 J [28] and 128.16 J [29]. Participants were evaluated immediately and 24 h after intervention, totalling 96 evaluations in the intervention group and 48 in the placebo group [28, 29]. Subgroup analysis pointed to greater ROM value in the intervention group only 24 h after treatment (MD=2.10°; 95 % CI=0.13°, 4.08°; P=0.04; Fig. 5).

Skeletal muscle function: strength

No study investigated the effect of pre-exercise LEDtherapy on muscular strength. One RCT investigated the effect of pre-

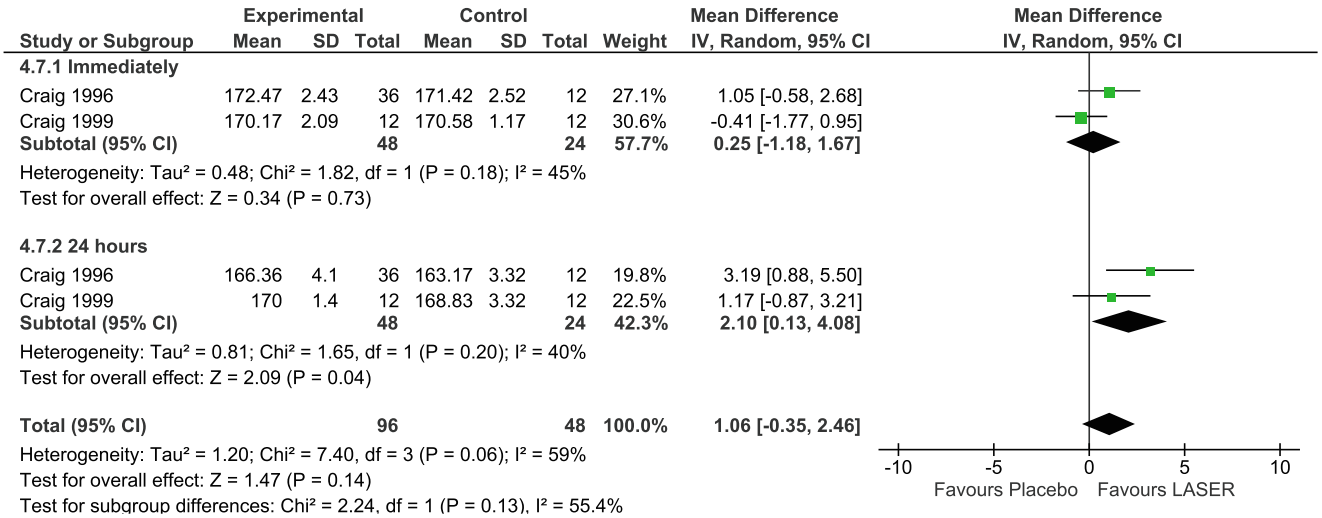

Fig. 5 Forest plot of comparison post-exercise LASERtherapy vs placebo group. Outcome: skeletal muscle function (ROM in degrees)

exercise LEDtherapy on muscular strength following eccentric biceps exercise [27]. Borges et al. [27] evaluated non-dominant elbow flexors maximum voluntary isometric contraction (N) 24, 48 and 72 h after eccentric exercise. Overall, strength values were higher in intervention group (Table 1).

Two RCTs investigated the effect of pre-exercise LASERtherapy on muscular strength [40, 41]. De Almeida et al. [40] applied red or infrared wavelength (660 or 830 nm, 20 J) on non-dominant biceps and evaluated strength as maximal voluntary isometric contraction in Newtons (N), whereas Maciel et al. [41] applied infrared wavelength (830 nm, 11 J) on dominant gastrocnemius and evaluated strength as peak force in kilogram-force (kgf). Participants were evaluated immediately after isometric biceps contraction [40] or jumping [41], totalling 26 evaluations in the intervention group and 17 in the placebo group. Overall, no difference was found between groups (SMD=0.38; 95 % CI=−0.25, 1.02; P=0.23; data not shown).

Felismino et al. [32] investigated the effect of post-exercise LASERtherapy on biceps maximal voluntary concentric contraction as percentage of basal value immediately and 24, 48 and 72 h after isotonic biceps exercise. This study demonstrated no difference between groups (Table 1).

Discussion

Phototherapy for prevention of muscle damage is advocated by studies that demonstrated its capacity of preserving or enhancing post-exercise skeletal muscle contractile performance; at the same time, it lowers blood levels of CK, lactate dehydrogenase, lactate and final products of oxidative stress [11, 12, 33, 39]. This systematic review evaluated the effectiveness of phototherapy in controlling DOMS. Fifteen clinical trials with a total of 317 participants were included. Results from the meta-analyses demonstrated that LASERtherapy applied prior to an exercise protocol can potentially reduce CK levels, whereas LEDtherapy applied after an exercise protocol can potentially reduce muscular pain. Overall, the methodological quality of the included trials was moderate, and LASERtherapy was applied in two thirds of the trials. There was heterogeneity in phototherapy parameters (wavelength, power, energy density, treatment area and total energy delivered), exercise protocol, outcomes and evaluation methods.

Although low-level phototherapy promotes ATP synthesis through respiratory chain acting on mitochondrial c cytochrome enzyme [11, 12], it is interestingly that only De Marchi et al. [34] selected a predominantly aerobic exercise protocol (treadmill). It may be hypothesized that oxidative metabolism improvement before exercise due to phototherapy increases phosphocreatine resynthesis and blunts inflammatory signalling pathways. A better energetic balance and reduced inflammatory damage may limit oxidative damage, cell membrane disruption and delayed inflammatory damage. Consequently, muscle could preserve function and be less susceptible to oxidative and inflammatory damage [10].

Two systematic reviews were published in 2013 evaluating the effects of phototherapy (LED and LASER) on exercise recovery and performance [42, 43]. The main difference between our systematic review and the two previous ones is that in our review, LASERtherapy and LEDtherapy were not grouped as phototherapy treatment. This was due to the knowledge that, despite sharing some photobiomodulation principles, LASERtherapy and LEDtherapy not always produce similar results [36, 44]. For instance, an RCT with volleyball players demonstrated that the application of LEDtherapy induced lower levels of CK compared to LASERtherapy [36]. Another difference between this systematic review and those published by Leal Junior et al. [42] and Borsa et al. [43] is that we only included studies that investigated lower and upper limb muscles as they are more commonly involved during physical exercises that may lead to muscle soreness. Therefore, the study by Kelencz et al. [45] which investigated masticatory muscles was not included in this review. Nevertheless, our systematic review encompassed 15 studies, while those reviews included 13 [42] and 10 studies [43]. Further, Leal Junior et al. [42] presented only two forest plots, both reporting positive ergogenic effects of phototherapy, and Borsa et al. [43] concluded that pre-exercise phototherapy protects skeletal muscle from exercise damage even though no meta-analysis was undertaken.

Although only RCTs, crossover or quasi-randomized clinical trials were included in our review, the quality of the evidence was affected by small sample sizes, lack of allocation concealment and frequent blinding flaws. Further, sample size calculation was not performed in any of the included studies. Therefore, our results should be interpreted with caution.

Pre-exercise phototherapy

Our review demonstrated that pre-exercise LASERtherapy controls CK levels measured immediately after exercise (MD=−0.66 U/L; 95 % CI=−1.30 U/L, −0.02 U/L), indicating some muscular protection. Cell membrane rupture leads to intracellular calcium release with activation of cellular signalling followed by cell necrosis or apoptosis [46, 47]. This process causes CK and other muscle enzymes to be released, which can be detected on blood serum and indicates loss of cellular membrane integrity after intense physical exercises [46, 47]. The mechanism underlying the decreased levels of CK found after phototherapy is still not clear.

Post-exercise phototherapy

Subgroup analyses of different time points demonstrated no difference between post-exercise LEDtherapy and placebo treatment in pain at any time point. Although the analysis showed that overall post-exercise LEDtherapy reduced pain caused by exercise (data not shown), we acknowledge the unit of analysis issue in this finding and, thus, omitted such analysis.

Post-exercise LEDtherapy has been shown not to improve ROM. Borges et al. [27] demonstrated improvement on active elbow ROM (maximum flexion to maximum extension) following LEDtherapy, but Douris et al. [31] evaluated only rest elbow angle and found no difference between intervention, placebo and control groups. Taken as a whole, pain and ROM results suggest that selected exercises were not strenuous enough to produce neither great pain nor stiffness at rest or the selected measurement was not sensitive enough to quantify these outcomes.

Post-exercise LASERtherapy did not improve ROM, pain or CK levels. Taken together, these results agree with each other once muscle cell disruption releases CK and other muscle enzymes related to post-exercise pain [46, 47] and, thus, reduced ROM [48].

Strengths and limitations

Strengths of this review relate to our extensive electronic search and search strategy with no language limitation, as well as our success with contacting the authors of six studies to provide additional data.

Risk of bias due to not including all relevant studies is a common characteristic to all systematic reviews. Our first search returned studies from four decades (1974 to 2014). Considering the range of time investigated and exponentially increasing number of publications related to phototherapy, there is an obvious risk of missing some studies despite our efforts to conduct a comprehensive and detailed search. Risk of publication bias is also common to reviews; however, negative results were not uncommon among the included studies.

There was notable heterogeneity in treatment parameters, exercise protocols, population and outcomes measured. Phototherapy encompasses many therapy parameters, and establishing a protocol seems to be distant. Nine different exercises were used, varying in metabolic characteristics, intensity, duration and muscle group. Participants were sedentary, physically active or even athletes with age ranging from 15 to 36 years. It explains at least partially the moderate to high heterogeneity found in six of the eight meta-analyses (I^2>50 %) [16]. Due to the variety of outcomes evaluated, only one of the eight meta-analyses was performed with more than two studies.

Some data grouping was necessary to run meta-analysis. Craig et al. [28] studied three groups with different LASERtherapy protocols, but all with similar results on biceps pain and elbow ROM and were grouped. De Almeida et al. [40] compared red wavelength with infrared wavelength with similar results on biceps strength and were also grouped. All grouping followed Cochrane recommendation [16]. Although Craig et al. [28] applied a 3-day protocol, we included only data collected before the second treatment because we aimed to evaluate the effectiveness of a single treatment session.

Conclusions

Implication for practice

Current evidence supports that low-level phototherapy has limited effectiveness when utilized to treat DOMS. Caution is needed when interpreting the results of this review, especially due to the small number of included studies in each meta-analysis and small sample sizes and lack of sample size calculation in the included studies, which may have led those studies to type II error.

Implications for research

This systematic review emphasizes the need for larger RCTs with adequate sample size calculation. In order to advance knowledge in this field, future RCTs should consider the following:

- Collecting outcome measures immediately after exercise or treatment and at regular intervals up to five or more days.
- Evaluate phototherapy on exercise protocols with different levels of intensity and energetic sources (i.e. aerobic versus anaerobic).
- Choose specific muscle soreness outcomes as stated elsewhere.
- Better selection bias control.

Compliance with ethical standards

Funding EAC is beneficiary of *Conselho Nacional de Pesquisa e Desenvolvimento Científico* (CNPq) productivity grant. Remaining authors had no financial support for the submitted work.

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