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Pain reduction by infrared light-emitting diode irradiation: a pilot study on experimentally induced delayed-onset muscle soreness in humans

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Abstract The present pilot study investigated the analgesic efficacy of light-emitting diode (LED). In view of a standardised and controlled pain reduction study design, this *in vivo* trial was conducted on experimentally induced delayed-onset muscle soreness (DOMS). Thirty-two eligible human volunteers were randomly assigned to either an experimental ($n=16$) or placebo group ($n=16$). Immediately following the induction of muscle soreness, perceived pain was measured by means of a visual analog scale (VAS), followed by a more objective mechanical pain threshold (MPT) measurement and finally an eccentric/concentric isokinetic peak torque (IPT) assessment. The experimental group was treated with infrared LED at one of both arms, the other arm served as control. Irradiation lasted 6 min at a continuous power output of 160 mW, resulting in an energy density of 3.2 J/cm^2 . The subjects of the placebo group received sham irradiation at both sides. In post-treatment, a second daily assessment of MPT and VAS took place. The treatment and assessment procedure (MPT, VAS and IPT) was performed during 4 consecutive days. Statistical analysis (a general linear model followed by post hoc least significant difference) revealed no apparent significant analgesic effects of LED at the above-described light parameters and treatment procedure for none of the three outcome measures. However, as the means of all VAS and MPT variables disclose a general analgesic effect of LED

irradiation in favour of the experimental group, precaution should be taken in view of any clinical decision on LED. Future research should therefore focus on the investigation of the mechanisms of LED action and on the exploration of the analgesic effects of LED in a larger randomised clinical trial and eventually in more clinical settings.

Keywords Light-emitting diode · Infrared · Analgesic effect · Delayed-onset muscle soreness · *Musculus biceps brachii*

Introduction

The analgesic efficacy of light-emitting diode (LED) irradiation is recently being investigated by means of a nerve conduction study on the superficial peripheral sural nerve [1]. It was demonstrated that LED irradiation at clinical applied densities produces an immediate and localized effect upon conduction characteristics in underlying nerves. More specifically, LED induces a decreased number of sensory impulses per unit of time, thus possibly inducing pain relief [1]. Given the established influence of this treatment modality on the nerve conduction velocity and thereby its potential analgesic ability, the current investigation was designed.

Studies investigating the efficacy of a therapeutic modality on pain often experience difficulties regarding standardisation of the population, as analysis or comparison of pain with different aetiologies is almost impossible. Therefore, we opted to measure the analgesic effects of LED in a laboratory setting on a sample with experimentally induced delayed-onset muscle soreness (DOMS).

Muscle soreness usually occurs at the musculotendinous junction 8–24 h after the induction exercise and then spreads throughout the muscle [2–4]. The correlates of DOMS reach peak intensity at 24–48 h, with symptoms disappearing around days 5–10 [2, 3, 5–10]. The cardinal signs, characterising DOMS, are reduced muscle force, decreased range of motion and, in particular, muscle pain which is more pronounced during movement and palpation

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[8, 11]. Despite the large volume of research that has been undertaken to identify the underlying pathophysiology of DOMS, the precise mechanism is not yet universally accepted. Several theories, such as the torn-tissue theory, the connective tissue damage theory, the muscle spasm theory and the inflammation theory, still remain viable, though the current opinion states that DOMS arises from a sequence of events in which several theories occupy an important place [2, 6, 12, 13].

DOMS has been used as a representative model of musculoskeletal pain and stiffness in a number of studies [4, 7, 11, 14, 15], as it has a number of advantages: it can be induced in a relatively easy and standardised manner in a group of healthy subjects, the time-course is relatively predictable, and the symptoms have the same aetiology and are of transitory nature [14, 16]. Nevertheless, it should be emphasised that the use of this particular experimental model to test the effectiveness of LED does not mean that this treatment modality is necessarily advocated for the treatment of DOMS, but merely that it may be helpful in documenting the efficacy of LED in a clinical model of musculoskeletal pain and stiffness. In addition, studies based on the induction of DOMS under carefully controlled laboratory conditions cannot replace research involving actual patients, but offer the opportunity to assess the effectiveness of particular therapeutic interventions and might help to define additional clinical research [14].

The experimental hypothesis of the current study postulates that infrared LED reduces pain and muscle sensitivity associated with DOMS.

Materials and methods

The study was approved by the ethical committee of the Ghent University Hospital. After providing information regarding the study design and possible consequences related to participation at the study, written informed consent was obtained from each subject.

Subjects

Healthy human volunteers were recruited from the university population. Individuals with any upper limb pathology, neurological deficit and recent injury to either upper extremity or undiagnosed pain were excluded. Other exclusion criteria were contra-indications to LED irradiation (such as light hypersensitivity, fluctuating blood pressure, insufficient blood circulation, fever and inflammation of the skin) or conditions in which physical exertion is contraindicated (such as cardiovascular deficits, hypertension and respiratory problems).

Thirty-two eligible subjects (16 males and 16 females), aged 19–35 years (mean age 23±4 years), were enrolled. All subjects were randomly assigned, using a random table of numbers, to the experimental or placebo group. Each group of 16 subjects consisted, by stratification, of equal

numbers of men and women. Age, height and weight did not differ significantly between the three groups.

All subjects were physically active; however, none performed on a regular basis any type of upper body weight-training. Subjects were requested to refrain from any form of strenuous physical activity, and they were asked to avoid any form of medication, including anti-inflammatory agents, as well as alcohol for 2 days before testing and for the duration of the study.

Overview of experimental design

The study lasted 4 consecutive days. On day 1, isokinetic exercise was performed to induce pain related to DOMS. Immediately following induction exercise, an initial assessment of the outcome measures (visual analog scale or VAS, mechanical pain threshold or MPT and isokinetic peak torque or IPT) occurred. Subsequently, the subjects were treated under blinded conditions, according to the randomised group allocation. In post-treatment, the MPT was re-recorded and perceived pain was reassessed with a VAS. Contrary to these outcome measures, the muscle strength was only measured in pre-treatment, at the one hand, because short-term effects of LED on muscle strength were not postulated and, on the other hand, because post-treatment muscle strength can be influenced by too many different physiological factors related to the pre-treatment measurement.

On the succeeding days (days 2, 3, and 4), the treatment and assessment procedure was similar, with approximately 24 h separating each treatment.

In both of the groups, the two arms of the participants were included in the study. In the experimental group, an equal number of dominant and non-dominant arms were treated. The non-treated arm served as control arm. In the placebo group, also an equal number of dominant and non-dominant arms were considered as treated arm, and the other arm was classified in the non-treated group. The procedure was identical for both conditions, but the subjects in the placebo group received sham LED irradiation on both arms.

Specific aspects of the experimental design and procedures are detailed below.

Pain induction

Muscle soreness was induced in a standardised fashion via a daily calibrated computer-operated Biodex isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, NY, USA). Induction occurred separately and in random order in the elbow flexors of both arms. Therefore, the subjects were seated as described by the users' manual of Biodex. Prior to induction of DOMS, the subjects were allowed an initial familiarization session to become comfortable performing maximum voluntary contractions at the required angular velocities. This was immediately followed by determination of the maximum eccentric and concentric peak

torque at an angular velocity of 60°/s and 120°/s. Subsequently, four sessions of eccentric/concentric work were performed with each arm. The first two sessions consisted of elbow flexion at an angular velocity of 60°/s, first of all, along an arch of 120°, from full extension (designated as 0°) through 120°, and second of all, elbow flexion over a range of 60°, from 30° to 90° of flexion (mid-range), followed by two sessions at an angular velocity of 120°/s, again the first time along an arch of 120° and followed by the mid-range performance. The subjects were asked to accomplish maximum voluntary contractions during all the sessions. Each session was performed until exhaustion, which was defined as the point when the subject lost 70% of the initial eccentric and concentric peak torque. There was a 1-min rest between each session. This procedure was based on a pilot study and previously described induction protocols [17–21].

Outcome measures

Outcome measures of subjective pain measurements, MPT and muscle strength were measured in this order on days 1–4. Subjective pain measurements and MPT occurred immediately prior to and following irradiation, whereas muscle strength measurements only took place before LED treatment.

Measurement of subjective pain Perceived muscle soreness was measured subjectively by means of a 100-mm VAS. A series of scales were completed separately for each arm: pain at rest, followed by pain perception associated with full extension of the arms and finally with maximal flexion of the arms. The subjects were not allowed to compare one VAS result with another.

This assessment tool, commonly used in measuring experimentally induced pain [22, 23], has been found to be a reliable and valid method [24–26].

MPT/tenderness MPT, used as a more objective correlate of muscle tenderness, has been demonstrated to be a reliable method to measure experimental induced muscle soreness [27]. This outcome measure was assessed by using a handheld pressure algometer with a 1.2-cm diameter head (Microfet 2; Hoggan Health Industries, South Jordan, USA). On day 1, three points were marked at 4-cm intervals [8] along a line from the radial insertion of the musculus biceps brachii at the elbow to the intertubercular groove of the humerus, thus resulting in three measure points, one at the musculotendinous junction (4 cm) and two at the muscle belly (8 and 12 cm). A pressure of 4 N/s was delivered. The subjects were instructed to say *yes* at the exact moment the pressure perceived became painful. Each point was recorded three times in pre-treatment as well as in post-treatment. The average MPT score for each point in pre- and post-treatments was used for statistical analyses.

Muscle strength assessment Eccentric and concentric IPT were measured on the same computerised dynamometer as was used for the induction of pain, and an identical standardisation procedure regarding positioning was followed.

A warm-up session of two maximum voluntary contractions at the required angular velocities was followed by determination of the eccentric and concentric peak torque. The first session, at 60°/s, consisted of three repetitions, followed by a 1-min during rest, and for the second session, at 120°/s, five repetitions were performed. The subjects were instructed to flex and extend the elbow through the entire range of motion as forcefully and rapidly as possible for each repetition. The maximum eccentric and concentric torque produced during the respective repetitions was used for statistical analysis.

Light source specifications and treatment procedure

Light treatment was applied daily according to group allocation. Irradiation occurred with a LED device (BIO-DIO preprototype; MDB-Laser, Ekeren, Belgium). The probe used emitted infrared light with a wavelength of 950 nm (power range 80–160 mW). The area of the probe was 18 cm², and consisted of 32 single LEDs. The frequency was variable within the range of 0–1,500 Hz.

During the complete irradiation procedure, the LED probe was held in contact with the skin, perpendicular to the skin surface and at the exact midpoint between the MPT mark at 4 cm and the one at 8 cm. Light source properties were identical for all subjects of the experimental group and consisted of 6-min lasting irradiation at a continuous power output of 160 mW, resulting in an energy density of 3.2 J/cm². To conceal the treated side and condition, the subjects were blinded to the treatment status. For the experimental condition, a probe was held in contact with each arm, but only one of the two probes was attached to the LED device. The subjects of the placebo group received sham irradiation at both sides.

The selected parameters are within the scope of previously described light source characteristics for pain reduction [1, 28–30], and they are appropriate for the treatment of pain in a clinical setting because the duration of the treatment is clinically feasible.

Statistical analysis

The three outcome measures were analysed separately. For the VAS and MPT measurements, the same procedure was followed: a general linear model (GLM) for repeated measures with two within-subjects factors (time: days 1, 2, 3 and 4 and pre–post: preceding and following LED irradiation) and one between-subject factor (group: placebo or infrared LED irradiated) was performed. If necessary, the GLM was followed by appropriate pairwise comparisons (post hoc least significant difference or LSD) to determine whether any differences between measurements

Table 1 Mean scores and standard errors for the visual analog scale of the treated and the control arm of the placebo and the light-emitting-diode (LED)-irradiated group

	Day 1		Day 2		Day 3		Day 4	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Treated arm								
Placebo								
Rest	0.55±0.28	0.61±0.27	0.68±0.26	0.52±0.21	1.25±0.42	1.14±0.35	0.99±0.37	0.84±0.30
Eccentric	0.79±0.42	1.08±0.39	2.67±0.38	2.16±0.40	3.96±0.57	3.84±0.51	3.25±0.529	2.96±0.47
Concentric	0.92±0.35	1.04±0.35	1.76±0.34	1.80±0.33	3.18±0.46	3.13±0.40	2.51±0.47	2.41±0.42
Irradiated								
Rest	0.51±0.28	0.51±0.27	0.66±0.26	0.44±0.21	0.86±0.42	0.56±0.35	0.49±0.37	0.31±0.30
Eccentric	0.91±0.42	0.78±0.39	2.33±0.38	1.91±0.40	3.00±0.57	2.30±0.51	2.22±0.529	1.68±0.47
Concentric	0.82±0.35	0.74±0.35	1.32±0.34	1.22±0.33	2.08±0.46	1.66±0.40	1.42±0.47	1.03±0.42
Control arm								
Placebo								
Rest	0.32±0.25	0.44±0.24	0.74±0.23	0.46±0.16	1.32±0.42	1.05±0.34	0.88±0.37	0.68±0.24
Eccentric	0.64±0.42	0.64±0.32	2.34±0.42	1.76±0.34	3.55±0.48	3.55±0.49	3.01±0.48	2.8±0.43
Concentric	0.81±0.36	0.94±0.34	1.84±0.33	1.64±0.30	3.02±0.44	2.72±0.42	2.15±0.42	2.08±0.36
Irradiated								
Rest	0.51±0.25	0.48±0.24	0.56±0.23	0.36±0.16	0.69±0.42	0.49±0.34	0.37±0.37	0.26±0.24
Eccentric	0.98±0.42	0.79±0.32	2.18±0.42	1.95±0.34	2.84±0.48	2.46±0.49	1.72±0.48	1.61±0.43
Concentric	0.89±0.36	0.70±0.34	1.22±0.33	1.06±0.30	1.92±0.44	1.61±0.42	1.11±0.42	0.94±0.36

were statistically significant. A similar model was carried out separately for both the treated and the control arm.

In contrast to MPT and VAS, the muscle strength was analysed differently. The peak torque values recomputed towards body weight of the subjects were statistically analysed using a GLM for repeated measures. This model

consisted of one within-subject factor (time: days 1, 2, 3 and 4) and one between-subject factor (group: placebo or infrared LED irradiated). The model was completed twice, first for the treated arm and consequently for the control arm.

The statistical package for social sciences (SPSS 11.0; SPSS, Inc., Chicago, IL, USA) was used for analysis, and

Table 2 Mean scores and standard errors for the mechanical pain threshold of the treated and the control arm of the placebo and the LED-irradiated group

	Day 1		Day 2		Day 3		Day 4	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Treated arm								
Placebo								
4 cm	15.77±1.47	12.84±1.59	10.45±2.52	11.94±2.37	10.98±1.94	12.01±2.74	14.36±2.17	15.15±2.12
8 cm	17.61±1.47	16.59±1.56	12.89±2.46	13.90±2.45	13.51±1.85	14.21±2.27	17.11±2.05	17.80±2.14
12 cm	17.04±1.84	16.74±2.10	11.19±2.86	12.12±2.80	12.02±2.39	13.09±2.82	15.87±2.45	15.38±2.57
Irradiated								
4 cm	15.15±1.47	18.51±1.59	17.38±2.52	18.52±2.37	17.19±1.94	19.25±2.74	20.04±2.17	20.05±2.12
8 cm	17.08±1.47	16.75±1.56	16.40±2.46	16.82±2.45	14.78±1.85	16.20±2.27	18.24±2.05	19.67±2.14
12 cm	16.97±1.84	17.75±2.10	16.37±2.86	16.42±2.80	15.40±2.39	16.63±2.82	18.64±2.45	20.21±2.57
Control arm								
Placebo								
4 cm	15.56±1.60	12.94±1.77	11.12±2.02	12.46±2.39	10.91±2.29	11.84±2.24	14.34±2.17	14.04±2.08
8 cm	17.68±1.52	16.60±1.49	13.69±2.05	14.16±2.21	13.66±2.06	14.42±2.48	17.83±2.54	17.98±2.09
12 cm	17.32±1.90	15.66±1.90	11.77±2.39	12.92±3.10	12.55±2.48	12.83±2.98	16.71±2.85	15.50±2.49
Irradiated								
4 cm	15.20±1.60	18.50±1.77	15.87±2.02	17.25±2.39	17.18±2.29	17.78±2.24	20.68±2.17	20.26±2.08
8 cm	16.97±1.52	17.52±1.49	15.06±2.05	15.86±2.21	15.63±2.06	16.46±2.48	21.58±2.54	19.58±2.09
12 cm	17.12±1.90	18.35±1.90	14.32±2.39	16.70±3.10	15.55±2.48	17.07±2.98	19.81±2.85	20.56±2.49

Table 3 Mean scores and standard errors for the isokinetic peak torque of the treated and the control arm of the placebo and the LED-irradiated group

	Day 1	Day 2	Day 3	Day 4
Treated arm				
Placebo				
Eccentric 60°/s	0.50±0.05	0.54±0.05	0.47±0.04	0.49±0.05
Concentric 60°/s	0.43±0.04	0.39±0.04	0.40±0.04	0.40±0.04
Eccentric 120°/s	0.45±0.04	0.48±0.04	0.48±0.05	0.46±0.05
Concentric 120°/s	0.37±0.04	0.37±0.03	0.34±0.04	0.34±0.04
Irradiated				
Eccentric 60°/s	0.50±0.05	0.57±0.05	0.54±0.04	0.58±0.05
Concentric 60°/s	0.42±0.04	0.43±0.04	0.41±0.04	0.45±0.04
Eccentric 120°/s	0.47±0.04	0.51±0.04	0.52±0.05	0.57±0.05
Concentric 120°/s	0.41±0.04	0.38±0.03	0.38±0.04	0.41±0.04
Control arm				
Placebo				
Eccentric 60°/s	0.54±0.05	0.54±0.05	0.48±0.05	0.53±0.06
Concentric 60°/s	0.44±0.04	0.45±0.04	0.40±0.04	0.43±0.05
Eccentric 120°/s	0.49±0.04	0.54±0.05	0.48±0.05	0.51±0.04
Concentric 120°/s	0.40±0.04	0.35±0.03	0.35±0.04	0.40±0.04
Irradiated				
Eccentric 60°/s	0.55±0.05	0.54±0.05	0.57±0.05	0.59±0.56
Concentric 60°/s	0.44±0.04	0.43±0.04	0.38±0.04	0.46±0.05
Eccentric 120°/s	0.48±0.04	0.54±0.05	0.55±0.05	0.58±0.04
Concentric 120°/s	0.38±0.04	0.36±0.03	0.42±0.04	0.43±0.04

statistical significance for all tests was accepted at the 0.05 level.

Results

Statistical analysis of all variables of the three outcome measures revealed no significant interactive effects of the main interaction (time × group × pre–post). The means and standard deviations of the variables for both the treated and the control arm are outlined in Table 1 for the VAS, Table 2 for the MPT and Table 3 for the IPT. The means of all VAS and MPT variables disclose a non-statistical significant general analgesic effect of LED irradiation, conveyed by lower subjective pain rates and higher MPT values in the irradiated group than in the placebo group. The lower VAS rates are present from day 1 until the last day of the study, but they are more clearly present from day 3 pre-treatment. The higher MPT values are present from day 1 post-irradiation until the last day, and they are more visible at 4 cm, followed by 12 cm and finally at 8 cm. In addition to the analgesic influence of LED, an increased convalescence of muscle strength was noted. It should be remarked that this outcome is similar for the treated as well as for the control arm of the irradiated group. The findings are also illustrated by Figs. 1, 2 and 3; depicting the time-course for both arms of VAS at rest, MPT at 4 cm and IPT for eccentric contraction at 60°/s, respectively. Graphical presentation of the other variables shows a similar course.

Despite the absence of significant main interaction effects, the remaining interactions as well as the main

effects were statistically significant for some variables. Only the significant interactions including the between-subject factor *group* as well as the main-effect *group* will be discussed. The other interactions and effects establish the successful induction of DOMS but are not relevant in view of the postulated hypothesis.

The interaction between *group* and *time* is significant ($p=0.014$) for the VAS in association with full extension for the control arm. Post hoc LSD reveals no difference between both groups; a significant effect over time for both groups is found. Consequently, this will not be further evaluated.

A second significant interaction ($p=0.002$) is the one among the within-subject factor *pre–post* and the between-subject factor *group* for the MPT at 12 cm for the control arm. Post hoc LSD ($p=0.001$) reveals that the LED-irradiated subjects tolerate more pressure after than before the treatment, whereas, in the placebo group, a not significant decrease of supported pressure is noted.

Finally, GLM analysis revealed that, at the treated arm, the irradiated group tolerates significantly ($p=0.047$) more pressure than the placebo group (MPT at 4 cm).

Discussion

It has previously been demonstrated that the LED source used might assist in accelerating wound healing [31], that it has a direct cellular effect [32, 33] and that it changes nerve conduction characteristics [1]. Nevertheless, LED-treated experimental induced DOMS failed to prove the analgesic

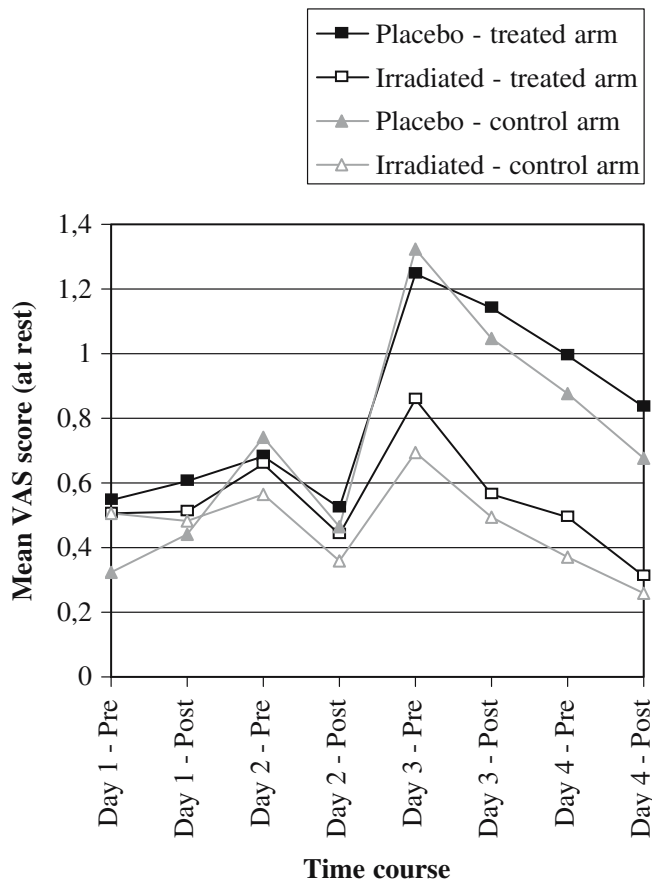


Fig. 1 Mean visual analog scale (VAS) score (at rest) of the treated and the control arm of the placebo and the light-emitting-diode (LED)-irradiated group, plotted against time (day and pre-post)

efficacy of LED at the above-described light parameters and treatment procedure. The current outcome concurs with other research that demonstrated a lack of effect of various forms of light therapy on DOMS [8, 11, 15]. However, despite the absence of an apparent and overall definitive finding, the present results cannot exclude favourable effects of LED treatment on pain. Since, first of all, an isolated statistical significant pre-post difference between groups (control arm, MPT at 12 cm) and a significant group difference (treated arm, MPT at 4 cm) revealed that subjects of the irradiated group tolerate more pressure than the subjects of the placebo group. Second of all, the overall means identified generally lower VAS scores, higher MPT values and higher peak torques in the irradiated group. This implied that the treated subjects experienced noticeable less pain, supported more pressure on the painful muscle and generated more force than the non-treated participants. However, these results are not statistically significant; consequently, it is possible that these differences were found by coincidence and that there is no relationship between the treatment and the described results of the three outcome measures, though it should be mentioned that the absence of significant findings is more probably attributable to the small sample size involved in this study. This assumption is based on a post hoc power

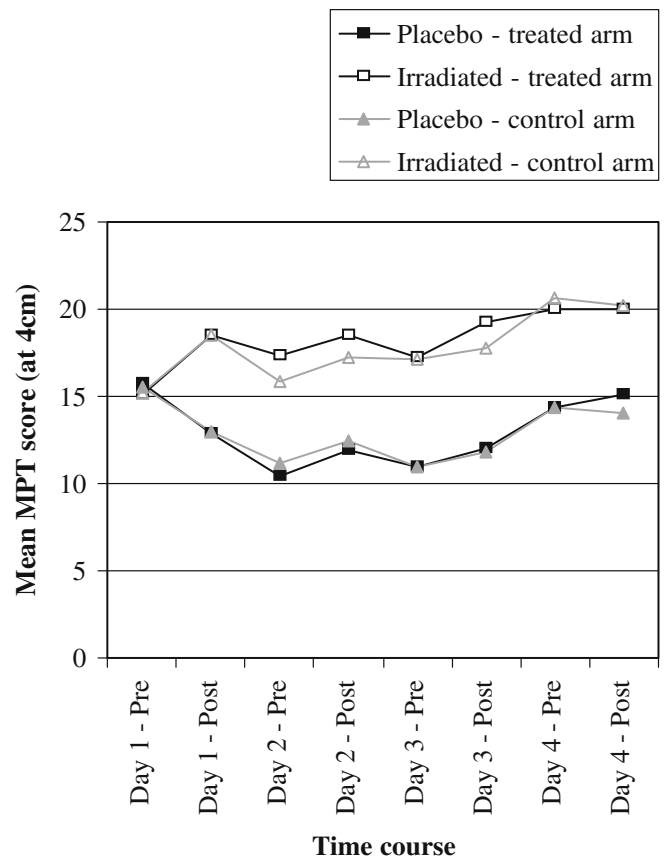


Fig. 2 Mean mechanical pain threshold (MPT) score (at 4 cm) of the treated and the control arm of the placebo and the LED-irradiated group, plotted against time (day and pre-post)

analysis. It was calculated that for the small effect size measured after treatment and for the measured control group event rate, a sample size of 80 subjects in each group was required, at $\alpha=0.05$ and power=0.80 (two-sided), to reveal significant results.

Another factor conceivably responsible for the lack of solid evidence of the beneficial effects of LED treatment upon DOMS-associated pain is related to the size of the treatment effect in relation to the severity of the induced DOMS. It is possible that, by using multiple exhaustive sets of exercise, severe DOMS were induced which masked relatively small but apparent treatment effects [4, 11]. In this same context, it is possible that the results only become significantly different after a prolonged treatment and follow-up period, as previous research noticed that recuperation subsequent to DOMS induction can last up to 10 days [8].

Although it needs to be stressed that these results are not statistically significant, critical analysis of the overall means leads up to three additional remarks. A primary comment relates to the pre- and post-treatment courses of the results. Starting at day 2, a clear reduction of pain and muscle sensitivity was observed immediately post-treatment. Still, one cannot conclude that this is indicative for the analgesic effect of LED irradiation, as a similar increase in VAS and decrease in MPT values was noted in the treated and the control arm of the placebo group. Perhaps,

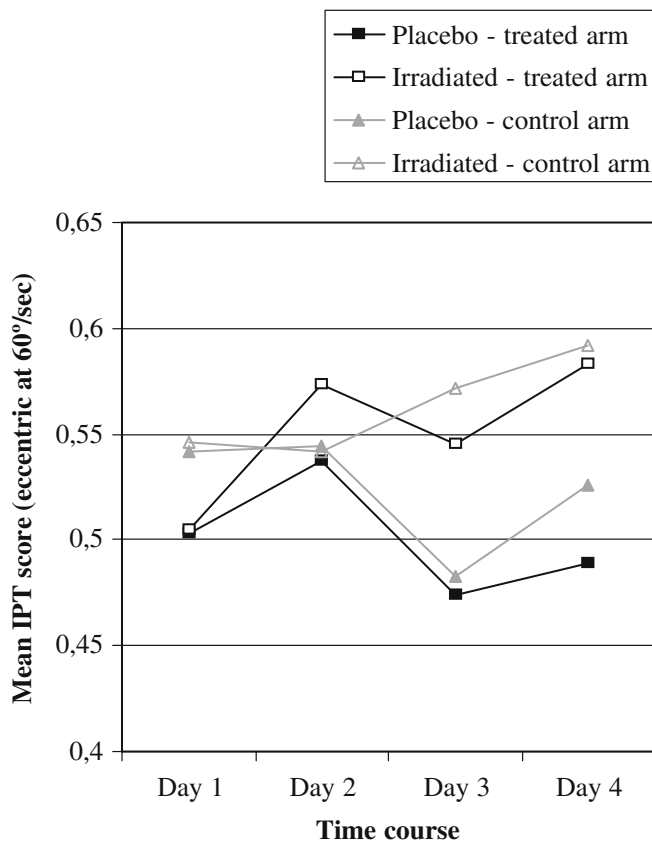


Fig. 3 Mean isokinetic peak torque (IPT) score (eccentric at 60°/s) of the treated and the control arm of the placebo and the LED-irradiated group, plotted against time (day and pre-post)

this was caused by placebo effect, as reported by Pollo et al. [34]; the expectation of the participant can easily result in pain relief, but it can only be elucidated by implementation of a control group. Nevertheless, in the current study, this particular finding can be most probably attributed to the physiological effects of the peak torque measurement, performed between the pre- and post-treatment recordings of VAS and MPT, on the painful flexor muscle of the upper arm. For the assessment of muscle strength, two short series of alternative concentric and eccentric efforts were performed in succession, involving elevation of muscle blood flow [20]. Increase of muscle blood flow can assist in the removal of inflammatory markers and exudate, consequently reducing local tenderness [4]. In addition, the force assessment can be considered as a form of active warming-up, resulting in an increased muscle temperature which can reduce muscle viscosity [35], bring about smoother muscle contractions and diminish muscle stiffness [35, 36], thus decreasing the sensitivity of the muscle and moderating pain during movement. In any case, the beneficial influence of LED immediately after irradiation cannot be securely interpreted due to the sequential assessment of the outcome measures.

A second additional remark considers the fact that both arms of the irradiated subjects demonstrated evidence of the beneficial effects of LED, as a similar reduction of pain

and muscle sensitivity and higher peak torques were found in course of time at the treated arm, as well as at the control arm of the irradiated subjects. This ascertainment points to the possibility that infrared LED induces systemic effects [37, 38]. Ernst [16] stated that in case LED works via systemic effects, the use of the contralateral side as a control arm might be ill-advised. Thus, reinforcing that future research should include a control group to bring clarification [4, 7, 16].

Finally, it needs to be mentioned that, although the extent of DOMS was probably relatively high for investigating the postulated hypothesis, the time-course of the present study corresponds to that reported by other investigators [2, 3, 5–10]. Significant time effects in many of the variables revealed that muscle damage was evident, diffuse muscle soreness became progressively worse 24–48 h after DOMS induction, followed by a small amelioration after 72 h [3, 5, 9, 10]. After 72 h, the follow-up was ceased; consequently, further regain of force and attenuation of pain and muscle sensitivity could not be evaluated. Extending the duration of the assessment period could be useful in assessing any longer-term effects of LED treatment, particularly because, as mentioned above, differences between both groups are more clearly present from day 3 pre-treatment and also because DOMS may last for up to 10 days when induced with the described protocol [7, 15].

Lack of knowledge regarding both the precise mechanism of action of LED and the specific pathophysiology of DOMS hampers the way to offer a definitive explanation for the absence of more obvious statistically significant differences. Still, the small number of significant findings and the mean values suggest that possible analgesic effects of infrared LED may not be excluded yet, but to be able to estimate the real value of LED, further research is necessary. A large-scaled, randomised clinical trial which takes the above-mentioned remarks into consideration should be performed.

Conclusion

Regardless of the reasons for the absence of statistical significant effects reported here and although LED may have some potential in the management of pain and functional impairment associated with DOMS, its effectiveness at the applied densities has not been established.

Future research should focus on evaluation of the appropriateness of DOMS as an experimental model of pain and muscle damage. Validation of this model would enhance the ability to study various modalities for their potential effects on pain and muscle injuries. Besides, the mechanisms of LED action are not known; thus, further fundamental investigations need to address the underlying mechanism and physiological basis of pain modulation, utilizing LED treatment.

Once LED irradiation has finally proven its treatment value in an experimental model, the most important prospect considers establishing the effectiveness of LED to reduce pain in clinical settings.

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