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Delayed-Onset Muscle Soreness: Lack of Effect of Combined Phototherapy/Low-Intensity Laser Therapy at Low Pulse Repetition Rates

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ABSTRACT

A double-blind, placebo-controlled study using male subjects ($n = 60$), was conducted to investigate the efficacy of three different frequencies of combined phototherapy/low-intensity laser therapy (CLILT) in alleviating the signs and symptoms of delayed-onset muscle soreness (DOMS). The study was approved by the University's ethical committee. After screening for relevant pathologies, recent analgesic or steroid drug usage, current pain, diabetes, or current involvement in regular weight-training activities, subjects were randomly allocated to one of five experimental groups: Control, Placebo, or 2.5-Hz, 5-Hz, or 20-Hz CLILT groups (660–950 nm; 31.7 J/cm^2; pulsed at the given frequencies for a duration of 12 min; $n = 12$ all groups). Once baseline measurements were obtained, DOMS was induced in the nondominant arm, which was exercised in a standardized fashion until exhaustion, using repeated eccentric contractions of the elbow flexors. The procedure was repeated twice more to ensure exhaustion was achieved, after which subjects were treated according to group allocation. In the CLILT/placebo groups, the treatment head was applied directly to the affected arm at the level of the musculotendinous junction. Subjects returned on two consecutive days for further treatment and assessment. The range of variables used to assess DOMS included range of movement (universal goniometer), mechanical pain threshold/tenderness (algometer) and pain (visual analogue scale and McGill Pain Questionnaire). Measurements were taken before and after treatment on each day, except for the McGill Pain questionnaire, which was completed at the end of the study. Analysis of results using repeated measures and one-factor analysis of variance with relevant post hoc tests showed significant changes in ranges of movement accompanied by increases in subjective pain and tenderness for all groups over time ($p = 0.0001$); however, such analysis failed to show any significant differences between groups on any of the days. These results thus provide no convincing evidence for any putative hypoalgesic effect of CLILT upon DOMS at the parameters used here.

INTRODUCTION

Delayed-onset muscle soreness (DOMS) is a relatively common phenomenon that usually occurs after unaccustomed or, in particular, eccentric exercise; it is defined as the sensation of pain experienced approximately 8–24 hr postexercise, peaking between 24–72 hr and lasting for between 5–7 days.[1] Sufferers commonly complain of "tender" or "stiff" muscles, accompanied by an inability to achieve full range of movement in the affected limb. Although a range of studies have been undertaken to examine the causes and pathogenesis of DOMS, few have considered this condition from the perspective of an experimental model of myogenic pain for the assessment of putative analgesic modalities.

Many mechanisms have been proposed as the cause of DOMS; however, none have been universally accepted. Friden et al.[2] suggested disruption of the Z-bands, resulting in the release of protein-bound ions in turn causing edema and a subse-

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quent activation of nociceptors. Armstrong[3] proposed edema formation as the main mechanism of action, again with pain as the end result. Alternatively Abraham[4] and previously Asmussen[5] suggested that damage of the connective tissues between the fibers of the affected muscles eventually resulted in DOMS. However, it is interesting to note that lactic acid, so often blamed for myogenic pain, has been shown to have limited relevance to the production of DOMS.[6,7]

Newham et al.[8] have established that muscle fiber damage occurs as a result of mechanical stress, with the fibers, their membranes, and even mononuclear cell filtration affected. Armstrong[3] speculated that those cellular mechanisms and neural pathways involved in other muscle pathologies may be similar to those affected by DOMS; however, the period of delay between exercise and pain onset distinguishes DOMS from other myogenic conditions.

Although a clearer understanding of the mechanism of DOMS should provide greater insights as to potential management strategies, some studies have already been carried out to investigate the therapeutic effects of a range of agents (including electrotherapeutic modalities) with typically variable results. For example, Denegar et al.[9] found a decrease in DOMS pain with transcutaneous electrical nerve stimulation (TENS), with an associated increase in range of movement at the elbow; in contrast, a more recent controlled study at this center failed to show any such effects.[10]

Low-intensity laser therapy (LILT), typically based upon the use of (single) laser diodes, and combined (monochromatic) phototherapy/LILT (CLILT) using multisource arrays (comprising both laser and so-called superluminous diodes) have been promoted as useful therapies for the treatment of a number of conditions, principally being used for the acceleration of wound healing and (more controversially) for the relief of pain.[11] However, despite such popular advocacy, the underlying mechanism(s) of action of these modalities remains unclear, and their clinical efficacy for any clinical condition is yet to be definitively established.[11]

This notwithstanding, recent laboratory studies at this and other centers have shown direct biological and physiological effects of laser irradiation at intensities relevant to therapeutic applications. Nerve conduction studies have demonstrated significant decreases in conduction velocity after the application of laser radiation over the course of the nerve;[12,13] laser-mediated changes in blood flow have also been reported.[14] Biomodulatory effects of such irradiation on a range of cells including macrophage- and fibroblast-like cell lines as well as mitochondria have also been demonstrated under controlled conditions in the laboratory.[15–18] In assessing the putative pain relief of these modalities in pain experiments on healthy human volunteers, this and other groups have demonstrated (some) hypoalgesic effects of LILT[19] and CLILT.[20] Thus, despite skepticism from some quarters, these modalities would seem to have measurable pain-relieving effects (at least in the laboratory) that may be based upon mechanisms such as direct neurological effects as outlined above,[21] triggering of the release of natural opiates,[21] or through direct effects upon local blood flow.[14,22]

Given these findings at the biological and physiological levels, coupled with the reported hypoalgesic effects upon experimentally induced pain under controlled laboratory conditions, it would appear that the use of these modalities may be beneficial in the management of DOMS, which as a laboratory model combines both pain and muscle damage. Therefore, the aim of the current study was to assess the efficacy of CLILT upon experimentally induced DOMS.

METHODS

General

For the purposes of the current study, DOMS was induced in a standardized fashion in 60 male subjects, who were randomly assigned to one of five treatment groups: Control, Placebo, 2.5-Hz, 5-Hz, and 20-Hz CLILT groups. During three attendances over a 48-h period, treatment was applied according to group allocation and a series of measurements performed to assess the extent of DOMS, as well as the effect of the various treatments.

An outline of the procedure can be seen in Figure 1. During the first attendance initial baseline values for range of movement (ROM) and mechanical pain threshold (MPT) were measured prior to pain induction (see below). Immediately following pain induction, an assessment of subjective pain was completed using a computerized visual analogue scale (VAS), treatment was applied according to group allocation under strictly controlled double-blind conditions, and remeasurement

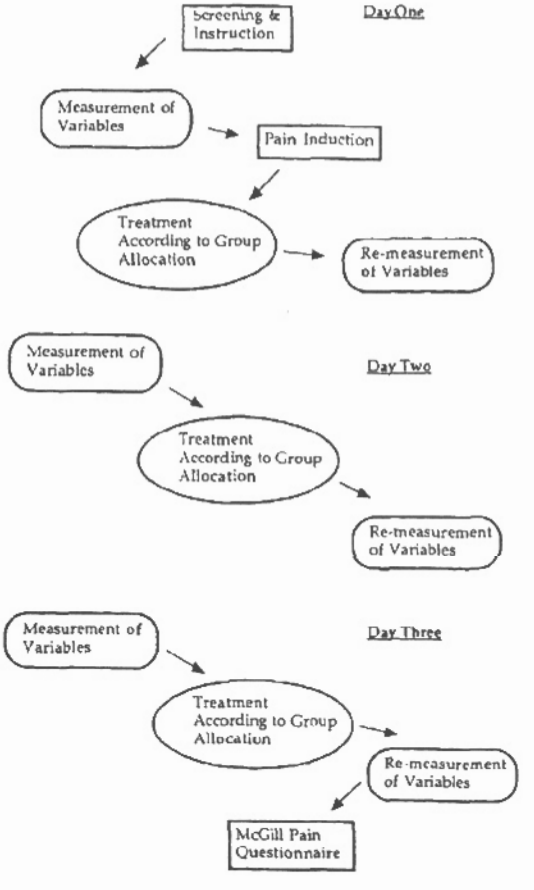

FIG. 1. Overview of procedure.

of all variables (ROM, MPT, VAS) were performed. Days 2 and 3 followed the same regime as day 1 with the exception of pain induction (i.e., measurement of variables followed by treatment and remeasurement of variables). On day 3, at the end of the trial, subjects also completed a short-form McGill Pain Questionnaire (MPQ).

Subjects

Male volunteers ($n = 60$, age range 19–25 years) participated in the study, for which ethical approval was granted by the university's ethical committee. Each subject was screened for relevant pathology, current arm pain, and current use of medication (analgesics or steroids); diabetics and subjects who participated in regular weight-training programs were excluded.

All subjects were briefed on the experimental procedure and signed a consent form prior to the commencement of the study. Subjects were encouraged to refrain from any form of exercise during their participation in the experiment, and were free to withdraw at any time.

Pain induction

For the purposes of the experiment the elbow flexors of the nondominant arm were used. The subject was seated in a chair and determination of the subject's concentric "one repetition maximum" (1RM) was performed with free weights (i.e., a loaded dumbbell), after which the subject was allowed to rest for 30 sec. After this period, an experimenter lifted the weight to the point of maximum elbow flexion for the subject, who lowered the weight in a slow and controlled fashion, for as many times as possible. Exhaustion was taken as the point at which the weight was no longer lowered under control. The subject was given another 30 sec rest, and the procedure repeated a further two times, again until exhaustion, in exactly the same manner.

Measurements

Range of movement. It has been generally accepted, and shown in other studies, that DOMS affects the ROM of the joint associated with the affected muscles.[23,24] Taking this into consideration, elbow ROM measurements were included in the design of this study, as an index of the extent of DOMS and of the efficacy of treatment. The ranges of movement measured in this study were as follows:

1. Extension angle (EANG): The maximum available range as the elbow was fully straightened
2. Flexion angle (FANG): The maximum available angle of flexion when the hand was brought to the shoulder
3. Resting angle (RANG): The angle of flexion of the elbow as the arm hung loosely by the side

All the above values were measured with a universal goniometer, using the lines of the humerus and the radius for standardization of the procedure.[10] For all measurements, 180° of extension (i.e., with the elbow perfectly straight) was taken as "zero," with flexion measures expressed as positive values and hyperextension measures expressed as negative values. Each range was measured prior to exercise and after treatment on the first day, and prior to and after treatment for the remaining two days.

Mechanical pain threshold/tenderness. MPT was taken as a correlate of tenderness and measured at eight points along the median line of the biceps brachii. Points were marked, with semipermanent ink, at 4-cm intervals, from the radial insertion to the bicipital groove. A handheld pressure algometer, capable of exerting forces up to 100N, through a 1-cm diameter head, was used to measure MPT (Electronic Force Gauge, Salter, West Bromwich, England). Measurements were taken before and after treatment in order to establish the presence of treatment effect upon tenderness, and values recorded as the pressure needed to elicit (mechanical) pain in the subject. For the purpose of analysis, only the lower four points were used because subjects reported their pain originated primarily from the distal part of the elbow flexors.

Pain assessment. Pain was assessed by a computerized VAS and a short-form MPQ. After the exercise, and prior to treatment, each subject was asked to rate their pain. During each assessment period, a 10-cm line with "No Pain" marked at one end and "Worst Pain" marked at the other appeared on the computer screen four times at 30-sec intervals. Each subject marked a point on the line, indicating their present pain, with a mouse-controlled cursor.

After treatment according to group allocation, the VAS procedure was repeated giving a total of eight scores; four pretreatment and four posttreatment. At the completion of the experiment, the mean score for pre- and posttreatment at each attendance was calculated and used for statistical analysis. At the end of the third day, in addition to the aforementioned procedure, each subject completed an MPQ, describing the "worst pain experienced" during the 48 hr of the experiment.

Treatment

After DOMS induction, each subject was allocated to one of the five treatment groups under double-blind conditions and remained in that group for the duration of the trial. *CLILT* was applied using a multidiode array (31 diodes; 660–950 nm) powered by a standard base unit (200 ML Unit, Omega Laser Systems, London); over 12 min this unit delivered a total average radiant exposure of 31.7 J/cm^2. The area irradiated was standardized as the area covering the distal half of the lower portion of the biceps brachii muscle (12 cm^2), corresponding to the musculoskeletal junction of the affected muscles. During the treatment, subjects rested supine on a plinth with their nondominant arm exposed and supported on a small pillow and with their eyes shielded by a towel. The treatment head and base unit were also shielded by towels to enhance blinding. The groups and the treatment each subject received in those groups is outlined below:

1. Control group: 12 min of rest in supine lying, no treatment given
2. Placebo group: 12 min of sham irradiation using a dummy unit
3. CLILT groups: Subjects received active irradiation as already indicated pulsed at 2.5, 5, or 20 Hz. As this was a modulated output unit, irradiation time was fixed at 12 min.

Statistics

Repeated measures and one-factor analysis of variance (ANOVA), with relevant post hoc tests, as appropriate, were employed to analyze the results obtained during the experimental procedure, using Statview™ 512+ statistical software (Abacus Concepts, Inc., Berkeley, CA). Significance was set at a level of 95%. Analysis was performed on the raw data, pre- and postdifferences for each day (i.e., "daily difference scores" to show any direct treatment effect), and using preday one values as a baseline (i.e., "difference scores" to eliminate prestudy differences between groups).

RESULTS

All subjects experienced a loss of normal range of movement and an associated increase in pain and tenderness during the days following the pain-induced procedure. Figures 2 and 3 present difference scores with Post-1, Pre-2, etc., corresponding to the time point at which measurements were taken (i.e., pre- or posttreatment on each day). In these figures, negative values represent a worsening of DOMS and positive values an improvement in the condition.

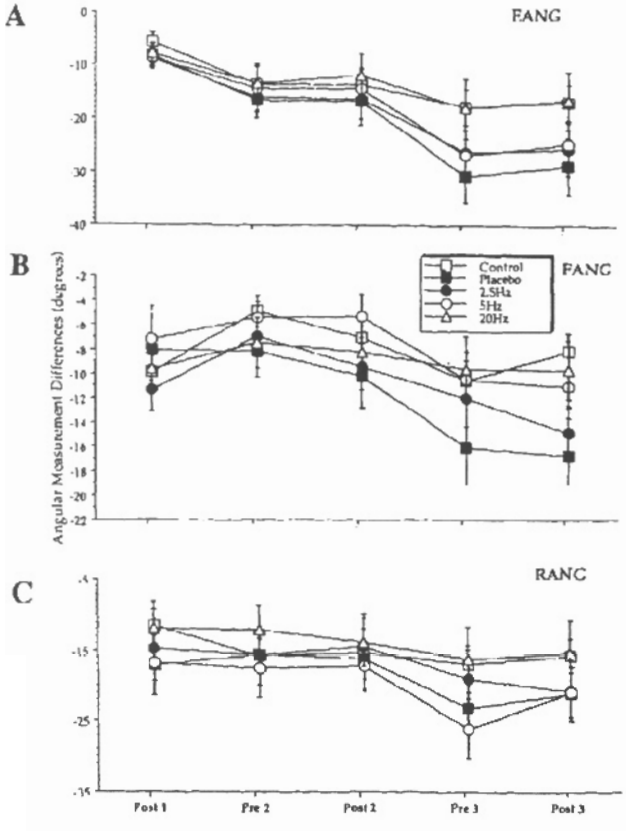

FIG. 2. Summary of results: Range of movement. In all cases negative values represent a loss of available range of movement in degrees. (Points represent mean ± S.E.M.; $n = 12$ all groups.) (A) Values for elbow extension angle (EANG) difference scores. (B) Values for elbow flexion angle (FANG) differences scores. (C) Values for elbow angle at rest (RANG) differences scores.

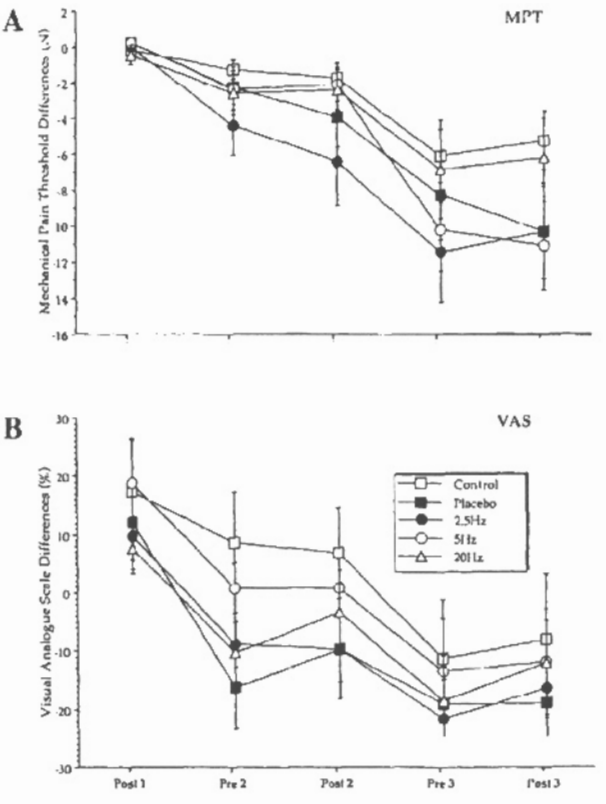

FIG. 3. Summary of results: Mechanical pain threshold (MPT) and visual analogue scale. (A) Values for MPT/tenderness differences scores. Negative values represent a decrease in MPT or an increase in the degree of tenderness. (Points represent means ± S.E.M., $n = 12$ all groups.) (B) Values of visual analogue scale (VAS) difference scores. Negative values represent an increase in subjective pain compared to scores obtained immediately post-DOMS induction. (Points represent mean ± S.E.M., $n = 12$ all groups).

Range of movement

All subjects experienced a loss of normal movement as a result of the exercise protocol; this effect was more pronounced in extension than flexion. Results are considered below for each measurement of ROM.

Elbow extension angle (EANG). Results for EANG are summarized in Figure 2A. As can be clearly seen from the figure, all subjects experienced significant reduction of their maximum angle of elbow extension. Repeated measures ANOVA showed no significant differences between groups; in contrast, there was a significant difference over time ($p = 0.0001$) during the 3 days of the trial.

Elbow flexion angle (FANG). Results for FANG are summarized in Figure 2B. Immediately after exercise and treatment, all the subjects experienced a reduction of range of elbow flexion. Repeated measures ANOVA showed no significant differences between groups, however, there was a significant difference over time ($p = 0.0001$) over the three days of the trial.

Elbow resting angle (RANG). Results for RANG are summarized in Figure 2C. Repeated measures ANOVA again showed no significant differences between groups, but a significant difference over time ($p = 0.0001$).

Mechanical pain threshold/tenderness

Results for mechanical pain threshold, summarized in Figure 3A, show a marked reduction of the mechanical pain threshold for the majority of subjects, reflecting an increase in tenderness in the affected muscles. This was found to be significant ($p = 0.0001$) over time, but not between treatment groups.

Visual analogue scale

Results from VAS are summarized in Figure 3C, and as can be seen, all subjects showed a significant ($p = 0.0002$) and uniform increase in their pain levels over time. Analysis of results showed no significant differences between groups.

McGill pain questionnaire

Results for the cumulative Pain Rating Index scores obtained from the MPQ data are summarized in Figure 4. Although the placebo and 20-Hz treatment groups demonstrated the lowest pain scores, one-factor ANOVA failed to find any significant differences between groups.

Summary

All of the variables examined demonstrated the expected changes as a consequence of the exercise protocol; there was a significant decrease in all ROMs and an increase in both tenderness and subjective pain over time. Despite such consistent and significant effects of the induction procedure, which provided measurable symptoms of DOMS, no statistically significant differences were found between groups for any of the variables assessed here.

DISCUSSION

The design of this study aimed to investigate the putative hypoalgesic and photobiostimulatory [sic] effects of CLILT. The selection of irradiation parameters was based upon previous (positive) findings using an experimental ischemic pain model. In contrast, the current results showed no significant therapeutic effect on any of the variables measured. Indeed, the data for mechanical pain threshold show a weak trend towards increases in tenderness in the 2.5-Hz and 5-Hz treatment groups, as well as in the Placebo group when compared to the Control and 20-Hz treatment groups; however, significance was never achieved.

Another trend that can be observed from the current results is an apparent decrease in tenderness, VAS scores, and MPQ scores in the 20-Hz CLILT treatment group. Although again not significant, results from this group for these three variables consistently followed a trend towards hypoalgesia. If further work in this area is to be undertaken, it would seem that the effects of this particular pulsing frequency would be worthy of further investigation.

The treatment unit used for this study was chosen because of its clinical popularity[11] and because of previous work that showed significant effects upon blood flow[25] as well as (and particularly) experimental ischemic pain.[12] In light of the results from the current study, it may be that the parameters chosen here were inappropriate for this model of pain and muscle damage and (consequently) that more favorable results may be found at different pulse repetition rates or different energy densities. However, without appropriate data this remains nothing more than speculation.

The clinical efficacy and precise mechanism of action of LILT and CLILT remains unclear and a matter of some debate.[21,26] However, this modality has previously demonstrated that it may assist in accelerating wound healing in damaged tissues[11,12] and has direct cellular effects.[15–17] Although the precise pathophysiology of DOMS remains unclear, it is generally assumed that there is a degree of muscle fiber and connective tissue damage that produces the commonly observed pain and tenderness. Incorporating both myogenic pain and tissue damage, DOMS should therefore have provided an ideal model for investigating the putative beneficial effects of CLILT. However, the current results have provided no evidence to support the claims made for this modality, at least at the parameters specified. In planning any future work in this area, investigators might therefore usefully consider manipulation of the irradiation parameters used (particularly total dosage/radiant exposure) to assess whether the lack of effect observed here is "real" or merely the consequence of using inappropriate irradiation parameters. Extending the duration of the assessment period might also prove useful in assessing any longer term effects of treatment, particularly as DOMS may last for up to 10 min or more when induced in the manner described here.

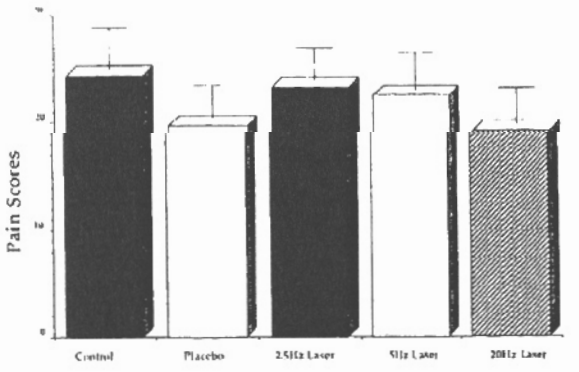

FIG. 4. Summary of results: McGill Pain Questionnaire (MPQ). Graph shows Pain Rating Index (P.R.I.) scores. (Columns represent means ± S.E.M.; $n = 12$ all groups.)

CONCLUSION

The results presented in this paper apparently contradict the previously proposed hypoalgesic effects of CLILT; however, these results cannot be considered as substantial evidence to oppose previous work. To more fully understand the apparent laser-mediated increase in tenderness suggested by the results here, further study is necessary. Further work in this area should investigate the effects of alternative LILT parameters,

alternative pain-induction procedures, as well as alternative measurement procedures.

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