Effect of Transcutaneous Electrical Nerve Stimulation, Cold, and a Combination Treatment on Pain, Decreased Range of Motion, and Strength Loss Associated with Delayed Onset Muscle Soreness

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ABSTRACT: Athletic trainers have a variety of therapeutic agents at their disposal to treat musculoskeletal pain, but little objective evidence exists of the efficacy of the modalities they use. In this study, delayed onset muscle soreness (DOMS) served as a model for musculoskeletal injury in order to: (1) compare the changes in perceived pain, elbow extension range of motion, and strength loss in subjects experiencing DOMS in the elbow flexor muscle group following a single treatment with either transcutaneous electrical nerve stimulation (TENS), cold, a combination of TENS and cold, sham TENS, or 20 minutes of rest; (2) compare the effects of combining static stretching with these treatments; and (3) determine if decreased pain is accompanied by a restoration of strength. DOMS was induced in the non-dominant elbow flexor muscle group in 40 females (age = 22.0 ± 4.3 yr) with repeated eccentric contractions. Forty-eight hours following exercise, all subjects presented with pain, decreased elbow extension range of motion, and decreased strength consistent with DOMS. Subjects were randomly assigned to 20-minute treatments followed by static stretching. Cold, TENS, and the combined treatment resulted in significant decreases in perceived pain. Treatments with cold resulted in a significant increase in elbow extension range of motion. Static stretching also significantly reduced perceived pain. Only small, nonsignificant changes in muscle strength were observed following treatment or stretching, regardless of the treatment group. These results suggest that the muscle weakness associated with DOMS is not the result of inhibition caused by pain. The results suggest that these modalities are effective in treating the pain and muscle spasm associated with DOMS, and that decreased pain may not be an accurate indicator of the recovery of muscle strength.

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Athletic trainers and physical therapists have a variety of therapeutic agents available for treating musculoskeletal pain. However, there is limited evidence to substantiate the efficacy of some modalities and little research has been performed to compare the effects of various treatment protocols.

One of the problems facing those who investigate the analgesic response to treatment with therapeutic modalities is the difficulty of assembling a pool of subjects with similar conditions. Delayed onset muscle soreness (DOMS) has been used as a model of musculoskeletal injury (3,4) because it is a self-limiting condition characterized by symptoms similar to many athletic injuries.

Delayed onset muscle soreness is commonly experienced following novel physical exercise, especially when the exercise involves repeated eccentric muscle contractions. The soreness generally increases for the first 24 to 48 hours (26) and is associated with decreased range of motion (ROM) (3,4) and muscular weakness (7,15,16,20,26,27). Several authors (8,9, 15,16,26) have attributed the weakness associated with DOMS, at least in part, to inhibition caused by pain. Komi and Buskirk (15), after studying subjects performing either concentric or eccentric work, stated that "those in the eccentric group experienced soreness in their exercised muscles. This caused a concomitant drop in muscle strength." However, more recently, Newham et al (20) suggested that pain and strength loss result from tissue damage and that decreased pain would not result in a restoration of muscle strength.

This study was conducted in order to: (1) compare the changes in perceived pain, elbow extension range of motion, and muscle strength in subjects experiencing DOMS immediately following a single treatment with either transcutaneous electrical nerve stimulation (TENS), cold, a combination of cold and TENS, sham TENS, or 20 minutes of rest; (2) compare the effects of combining static stretching with the above mentioned treatments; and (3) determine if decreased perceived pain would be accompanied by a restoration in muscle strength.

Methods

Forty female volunteers (age =22.0 ± 4.3 yr, ht = 167.1 ± 5.5 cm, wt = 62.3 ± 8.6 kg) were advised of the purposes of the study and the method of inducing DOMS. All subjects provided informed consent in compliance with University Human Investigation Committee guidelines. The subjects had not been involved in upper body weight training within 6 months prior to beginning the study, denied a history of recent upper extremity injury, and were free from soreness in the nondominant upper extremity.

Pretest and Exercise

Subjects were required to report to the laboratory twice during the study. During the first session, we reviewed the investigational procedures, oriented them to TENS and the Kin-Com isokinetic dynamometer (Chattecx Corp., Chattanooga, TN), and recorded descriptive data. Normal elbow extension range of motion (ROM) was measured with a standard goniometer. Average concentric and average eccentric torque generated by the elbow flexor muscle group of the non-dominant arm were measured from 90° to 45° flexion at 30°/sec on the dynamometer. Subjects were seated with the shoulder flexed approximately 75° and the elbow aligned with the axis of the dynamometer. A limited ROM was selected for the testing, because previous research indicated that some subjects would lose up to 45° of elbow extension (3,4). The angular velocity of the dynamometer was selected, because we believed that higher velocities would increase the risk of additional muscle injury during eccentric contractions.

Each subject performed three near-maximal concentric and eccentric contractions (each concentric contraction was followed by an eccentric contraction) that were averaged by the computer software. The Kin-Com system samples at a rate of 100 times per second. The movement from 90° to 45° flexion at an angular velocity of 30°/sec required 1.5 seconds, permitting 150 samples. Thus, a mean of each sampling point from the three contractions was used to form a composite torque curve. The average torque value for the concentric and eccentric contractions was then generated from the means of each of the 150 data points. In a conversation with E. Dunlay of Chattecx Corporation (September 1991), it was confirmed that, in the method used by Chattecx to calculate average torque values, the average torque does not equal the sum of the peak torques divided by the number of contractions.

Then, each subject was assigned randomly to one of the five treatment groups: cold, TENS, a combination of cold and TENS, sham TENS, or control (no treatment). At the conclusion of the first session, subjects completed a series of eccentric exercises with the elbow flexor muscle group of the nondominant arm. The exercise protocol has been used previously to induce DOMS (3,4). Prior to returning for assigned treatments, the subjects were asked to refrain from using analgesic or anti-inflammatory medications, receiving physical therapy, or engaging in vigorous upper extremity physical activity.

Treatment and Retests

Forty-eight hours after the exercise bouts, subjects returned to the laboratory. Elbow extension ROM was measured at the point where volitional extension became limited because of pain. Average concentric and eccentric torque generated by the elbow flexor muscle group were measured as described above. Subjects were assessed for perceived pain in the exercised muscles with a graphic pain rating scale (Fig 1).

The graphic pain rating scale developed for this study was based on the verbal descriptive scale used by Talag (26) to assess DOMS. Graphic rating scales are similar to visual analog scales, but have descriptors spread across the scale in addition to those at the extremes. Verbal descriptive scales have been criticized for being insensitive to small changes, while visual analog scales are a robust, sensitive, and reproducible means of expressing pain severity (12). Jensen et al (13) suggested that graphic rating scales are easier to use and improve consistency for each respondent and between respondents. We believe that this adaptation of the Talag scale is a more sensitive measure of the pain associated with DOMS.

Perceived pain was quantified by measuring the distance (to the nearest ½ cm) from the extreme left of the graphic pain rating scale to the mark made on the 12 cm line to describe the pain. The measured distance was multiplied by 2 to yield perceived pain scores from 0 to 24. This procedure eliminated fractional scores. The subjects reported pain in the exercised muscles and demonstrated decreases in elbow extension range of motion, concentric average torque, and eccentric average torque consistent with DOMS (Tables 1, 2, 3, and 4).

Each subject then received her assigned treatment, which lasted 20 minutes. We applied cold treatments by securing

Graphic Pain Rating Scale

Name ______________________ Test Session ____________

Dull Ache	A feeling of discomfort during activity
Slight Pain	An awareness of pain without distress
More Slight Pain	Pain distracts attention during physical exertion
Painful	Pain distracts attention from routine occupation such as writing and reading
Very Painful	Pain fills the field of consciousness to the exclusion of other events
Unbearable Pain	Comparable to the worst pain you can imagine

No Pain ______________________________________ Unbearable Pain

Dull Ache   Slight Pain   More Slight Pain   Painful   Very Painful

Fig 1.—Graphic pain rating scale with a 12 cm line between no pain and unbearable pain. Pain was quantified by measuring the distance (to the nearest ½ cm) from the extreme left to the mark made by subjects to describe their perception of pain. The length was multiplied by two, yielding scores from 0 = no pain to 24 = unbearable pain.

Table 1.—Perceived Pain Score (no pain = 0) (worst pain = 24) (Mean ± SD)

Group	Measurement Time: Before Exercise	Before Treatment	After Treatment	After Stretching
Cold	0 ± 0	13.1 ± 4.1	9.9 ± 5.2	6.6 ± 4.3
TENS	0 ± 0	13.3 ± 5.3	9.3 ± 5.8	6.4 ± 4.6
Cold & TENS	0 ± 0	14.6 ± 5.7	10.3 ± 6.2	7.5 ± 5.7
Sham	0 ± 0	12.5 ± 5.2	11.8 ± 4.3	8.5 ± 5.3
Control	0 ± 0	14.0 ± 4.5	14.3 ± 4.3	12.1 ± 4.9
Average	0 ± 0	13.5 ± 4.8	11.1 ± 5.3	8.2 ± 5.2

Table 2.—Elbow Extension Range of Motion (Degrees Extension, Mean ± SD)

Group	Measurement Time: Before Exercise	Before Treatment	After Treatment	After Stretching
Cold	8.3 ± 4.4	-21.5 ± 12.7	-15.3 ± 10.6	-7.0 ± 9.4
TENS	6.0 ± 3.5	-19.8 ± 12.8	-15.6 ± 14.2	-7.5 ± 12.1
Cold & TENS	7.1 ± 5.1	-18.8 ± 15.0	-11.9 ± 13.3	-5.4 ± 9.7
Sham	8.3 ± 2.7	-12.8 ± 12.0	-12.5 ± 11.3	-5.1 ± 8.9
Control	6.8 ± 5.3	-19.6 ± 12.1	-19.1 ± 11.0	-13.4 ± 9.6
Average	7.3 ± 4.2	-18.5 ± 12.7	-14.9 ± 11.8	-7.7 ± 9.9

Table 3.—Concentric Average Torque (Newton•Meter, Mean ± SD)

Group	Measurement Time: Before Exercise	Before Treatment	After Treatment	After Stretching
Cold	26.9 ± 3.2	16.5 ± 7.7	15.5 ± 6.7	17.0 ± 7.2
TENS	23.9 ± 6.4	12.9 ± 3.7	12.0 ± 3.2	11.9 ± 3.3
Cold & TENS	22.9 ± 3.6	11.9 ± 4.9	9.9 ± 3.2	11.1 ± 4.6
Sham	22.6 ± 6.9	14.6 ± 5.8	14.4 ± 5.6	14.1 ± 4.3
Control	23.4 ± 6.0	12.4 ± 3.5	11.1 ± 2.7	11.9 ± 3.3
Average	23.9 ± 5.4	13.7 ± 5.3	12.8 ± 4.8	13.2 ± 5.0

Table 4.—Eccentric Average Torque (Newton•Meter, Mean ± SD)

Group	Measurement Time: Before Exercise	Before Treatment	After Treatment	After Stretching
Cold	33.4 ± 7.5	20.9 ± 7.7	21.0 ± 6.9	21.1 ± 4.9
TENS	33.6 ± 7.4	17.5 ± 4.6	16.6 ± 4.5	16.6 ± 4.1
Cold & TENS	31.1 ± 4.3	15.6 ± 5.7	15.1 ± 4.9	15.0 ± 5.6
Sham	31.9 ± 8.5	19.8 ± 7.4	18.4 ± 7.4	19.1 ± 6.2
Control	32.6 ± 5.6	17.3 ± 6.8	15.3 ± 5.4	17.5 ± 6.5
Average	32.5 ± 6.6	18.2 ± 6.5	17.3 ± 6.0	17.9 ± 5.7

plastic produce bags filled with crushed ice over the elbow flexor muscle group. The bags were secured with an elastic bandage.

TENS was applied with a Neurotech NT-16 stimulator (Neurotech, North Andover, MA). A bipolar placement of two round, carbon, 50 mm diameter electrodes, which were treated with electrode gel and secured with elastic wraps, was used. One electrode was placed over the musculotendinous junction of the biceps brachii and the second over the area of greatest soreness, which was usually over the belly of the brachialis. The parameters of the TENS were: pulse rate = 90 pps, phase duration = 90 u sec, continuous duty cycle and intensity adjusted to provide a tingling sensation without visible muscle twitch.

The combination treatment consisted of a TENS treatment identical to the one described above with an ice bag secured over the electrodes.

Sham TENS was delivered with the NT-16 using the electrode placement described above. The parameters were set as follows: pulse rate = 2 pps, phase duration = 20 u sec, intensity adjusted to approximately 110 ma, and the duty cycle set for an "off" time of 99 sec and an "on" time of 1 sec. The control panel appeared similar for all TENS treatments.

Following the treatments, subjects were again assessed for perceived pain, elbow extension ROM, and concentric and eccentric average torque. Finally, all subjects completed a series of four 30-second static stretches with a 30-second rest between stretches. Following stretching, perceived pain, elbow extension ROM, and concentric and eccentric average torque were reassessed.

Statistical Procedures

We first analyzed the before exercise and before treatment data with a multivariate analysis of variance (MANOVA). Perceived pain, elbow extension ROM, concentric average torque, and eccentric average torque data were analyzed with separate 3*5 ANOVAs (three measurement times [before treatment, after treatment, after stretching] by five treatment groups) with repeated measures on one factor (measurement time). To control for inflated alpha levels resulting from repeated F tests, we interpreted the tests against a level of significance of .0125 (.05/4). An additional 2*5 ANOVA (2 measurement times [after treatment and after stretching] by 5 treatment groups) was conducted on the perceived pain and elbow extension ROM data. Tukey post hoc tests were used to carry out pairwise comparisons and a Scheffé post hoc test was used to determine if subjects who received cold, TENS, or the combined treatment had greater decreases in perceived pain than subjects who received sham TENS or no treatment prior to stretching.

Results

The cell means and standard deviations for the perceived pain, elbow extension range of motion, concentric average torque, and eccentric average torque are located in Tables 1 through 4 respectively.

Forty-eight hours after the exercise bout, subjects reported pain in the exercised muscles, and demonstrated decreased elbow extension range of motion, concentric average torque, and eccentric average torque (Wilks lambda = .086, $p < .01$).

Perceived pain decreased following treatment with cold, TENS, the combined treatment, and the sham treatment, as well as following stretching ($F(2,70)=96.75$, $p<.001$). However, not all groups experienced an identical response to treatment ($F(8,70)=4.45$, $p<.05$). Groups that received cold, TENS, or the combined treatment experienced greater decreases in perceived pain than those who received sham TENS or no treatment (Tukey post-hoc, $p<.05$).

Static stretching resulted in decreased perceived pain in all groups ($F(1,35)=76.7$, $p<.001$). However, subjects who received cold, TENS, or the combined treatment plus stretching had greater decreases in perceived pain than those who received sham TENS or no treatment prior to stretching (Scheffé post-hoc, $p < .05$).

Similarly, increases in elbow extension ROM were greater in some groups than in others ($F(8,70=3.06$, $p=.007$). Subjects receiving cold as part of the treatment demonstrated greater increases in elbow extension ROM following treatment (Tukey post-hoc $p<.05$). As expected, stretching resulted in increased elbow extension range of motion in all groups ($F(1,35)=123.1$, $p<.001$).

Concentric and eccentric average torque generated by the elbow flexor muscle group was decreased 43% and 44%, respectively, 48 hours following the eccentric bout. Measurement time means found in Tables 3 and 4 demonstrate that concentric and eccentric average torque did not increase following treatment or stretching. Additionally, there were no differences between groups with regard to change in concentric ($F(8,70)=0.66$, $p=.723$) or eccentric ($F(8,70)=1.36$, $p=.211$) average torque following treatment or stretching.

Discussion

It is difficult to assess and quantify pain and the analgesic response to therapeutic intervention. However, the descriptive data and significant differences between treatment groups and the sham TENS and control groups indicate that the treatments had real (not placebo) analgesic effects. Interestingly, the sham TENS resulted in a greater decrease in perceived pain than no treatment, suggesting a small placebo response to TENS.

These data also indicate that static stretching resulted in decreased perceived pain and that static stretching combined with cold and/or TENS was more effective than static stretching alone. While these findings are consistent with what many clinicians observe when treating musculoskeletal pain, the results of this study provide additional objective data to assist the athletic trainer in establishing a rationale and demonstrating efficacy for these treatment approaches.

Significant increases in elbow extension ROM following treatments with cold and following stretching also suggest interruption of a pain-spasm cycle as proposed by deVries (5). Pain originating in the sensory motor chain leads to reflex muscular spasm (17). The elimination of pain has been associated with muscular relaxation (17,24). Stimulation of the Golgi tendon organ results in motor inhibition and decreased muscular tension (19). Harris (10) stated that "a slow stretch is the best stimulus for obtaining relaxation of a given muscle group." There is wide variation in the length of the hold phase used in clinical practice. The stretching protocol for this study was selected because it is sufficient to stimulate the Golgi tendon organ and approximates the length of stretch used by the authors in clinical practice.

The descriptive data suggests that treatments including cold have a greater effect on spasm than TENS alone, even though cold did not result in a greater analgesic response. This finding may be explained by a cold-induced decrease in muscle spindle activity (6,23). We did not measure intramuscular temperature. However, others have reported decreases in intramuscular temperatures following 15 minutes (18) and 22 minutes (11) of cold application, suggesting that superficial cold can reduce muscle spasm.

The weakness associated with DOMS was not ameliorated by the treatments, even though there were significant decreases in perceived pain. While the subjects were not rendered pain-free, our results suggest that the weaknesses associated with DOMS may not be caused primarily by inhibition resulting from pain. Several investigators have reported damage to contractile tissue in muscles suffering DOMS (1,2,7,14,15,21,22). If the weakness is not caused by pain, it seems reasonable that these symptoms occur in response to the tissue damage (20). While additional work is needed to substantiate this cause and effect relationship, our findings can be applied to clinical practice. Our results suggest that pain is not an accurate marker of recovery from the strength loss associated with DOMS. While physical activity tends to relieve DOMS, clinicians must realize that freedom from pain may not be accompanied by a complete return of strength. Although the pain associated with DOMS usually disappears within 1 week, isometric strength has been reported to return to only about 80% of normal 2 weeks following intense eccentric exercise, with recovery delayed by a second bout of eccentric work (20). The impact of maximum efforts on athletes experiencing DOMS has not, to our knowledge, been addressed.

DOMS may represent an end of a spectrum of muscle strain (25). If this is the case, it would seem prudent to assess the return of strength, in addition to pain and other symptoms, prior to permitting an athlete to return to unrestricted activity following muscle strains and bouts of DOMS that have clearly impaired performance.

The results of our study suggest that cold, TENS, and a combination of cold and TENS had a significant analgesic effect in subjects experiencing DOMS. The results suggest that cold is useful in treating the muscle spasm associated with DOMS.

Furthermore, our results suggest that the muscular weakness associated with DOMS may not be caused primarily by inhibition resulting from pain. Our results support the contention of Newham et al (20) that these symptoms occur in response to tissue damage. Additional investigation is needed to determine if the strength loss associated with DOMS poses a risk of increased injury to athletes. Our results also suggest that pain may not be a valid indicator of recovery from DOMS and, quite possibly, from traumatic muscle strain. If this is the case, clinicians need to be aware that analgesic therapeutic interventions probably do not influence the return of strength following injury. The strength of injured muscle should be assessed prior to returning an athlete to unrestricted activity and competition.

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