

Effect of Whirlpool Therapy on the Signs and Symptoms of Delayed-Onset Muscle Soreness

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Objective: To determine the efficacy of warm whirlpool, cold whirlpool, and contrast therapy in the treatment of delayed-onset muscle soreness.

Design and Setting: Subjects performed eccentric contractions of the elbow flexors and received 4 treatments: immediately postexercise and 24, 48, and 72 hours postexercise. Treatments consisted of 24-minute treatments with warm whirlpool, cold whirlpool, contrast therapy, or no treatment.

Subjects: Fifty-six sex-matched volunteers from the University of Pittsburgh.

Measurements: Measurements were taken at 5 assessment times: pre-exercise (0 hours); prior to treatment at 24, 48, and 72 hours postexercise; and at 96 hours postexercise. Dependent variables were degrees of resting elbow flexion, active elbow flexion, and extension; perceived soreness values on a Graphic Pain Rating Scale; and maximal voluntary isometric

contraction. A repeated-measures analysis of variance (group by time) and Tukey post hoc analysis were used to determine which treatment groups differed significantly in returning subjects to pre-exercise values.

Results: Cold whirlpool and contrast therapy were found to return subjects to baseline values of resting elbow flexion and perceived soreness significantly more than warm whirlpool or no treatment ($P < .01$). Additionally, warm whirlpool was found to be more effective than no treatment in the return of resting elbow flexion ($P < .01$).

Conclusions: These results suggest that cold whirlpool and contrast therapy are more effective than warm whirlpool or no treatment in alleviating delayed-onset muscle soreness in the elbow flexors.

Key Words: eccentric exercise, hydrotherapy, contrast therapy

Muscle soreness resulting from physical activity may be classified as acute or delayed in onset. Acute-onset muscle soreness occurs during the activity and dissipates immediately at the end of activity, or within a few hours.^{1,2} Delayed-onset muscle soreness (DOMS) is the sensation of pain or discomfort that intensifies during the initial 24 hours postexercise, peaking between 24 and 72 hours, and subsiding during the following 5 to 7 days.¹⁻³ The signs and symptoms of DOMS include muscle soreness during palpation or movement of the involved muscles and decreases in range of motion and muscle strength.^{1,2,4-7} DOMS may have a detrimental impact on athletic performance by reducing endurance performance, reducing strength and power, and increasing the risk of additional injury.³

DOMS can occur with any unaccustomed activity; however, unaccustomed eccentric contractions have been found to result in the highest incidence of DOMS.^{1-3,6,8,9} It is theorized that fewer numbers of motor units are recruited during eccentric exercise, as compared with concentric contractions.^{1,8,10} Thus, a higher degree of stress is applied, thereby causing injury to these fibers.^{1,8,10} Although there have been various theories regarding the etiology of DOMS, mechanical disruption of the contractile elements and/or connective tissue is best supported

by current literature.^{1,4,7,8,10,11} This tissue injury leads to inflammatory processes, as evidenced by pain, swelling, and loss of muscle function, as well as cellular infiltration and biochemical markers of inflammation.^{1,2,5,7,11-14}

Clinicians in sports medicine often use superficial heat and cold in the treatment of musculoskeletal injury. The extent to which these modalities reach subcutaneous tissues is related to the rate and magnitude of tissue temperature change.¹⁵ Furthermore, the duration of application, size of the area being treated, limb circumference, and amount of subcutaneous adipose tissue have also been suggested as factors influencing tissue temperature change.¹⁵⁻¹⁹

Hydrotherapy, the external application of water to the body for therapeutic purposes,²⁰ is an example of superficial heating or cooling. During whirlpool therapy, heating and cooling of tissues occurs through conduction.^{15,16} Warm and cold whirlpools, administered at temperatures between 35.0°C and 43.3°C and 12.8°C and 18.3°C, respectively, for 20 to 30 minutes have been believed to be especially useful to decrease swelling, muscle spasm, and pain.^{15-18,20} Additionally, contrast therapy, the cyclical alternation of hot and cold whirlpool immersions, has been cited as decreasing symptoms of the inflammatory process.¹⁷⁻²⁰ Contrast therapy protocols are in-

consistent, usually including cycle ratios of 4 to 1 minutes of warm to cold whirlpool immersions, with a total treatment time of 20 to 30 minutes.^{15,17,19,20}

Although various researchers have attempted to prevent and treat the signs and symptoms of DOMS, results have been varied and inconsistent.²¹⁻³⁰ The use of superficial heat and cold application in the treatment of DOMS has been minimally investigated,^{9,31-34} and a superior treatment has yet to be determined. Specifically, a comparison of warm, cold, and contrast whirlpool therapies has yet to be investigated.

The purpose of our investigation was to measure the effects of warm whirlpool, cold whirlpool, and contrast therapy on the elbow flexors of subjects experiencing DOMS, as defined by the dependent variables of resting elbow flexion, active elbow flexion, active elbow extension, perceived soreness, and maximal voluntary isometric contraction. Our independent variable, the water temperature, was manipulated to form the treatment groups.

METHODS

Subjects

Fifty-six volunteer male ($n = 28$, age = 21.1 ± 3.1 years; ht = 179.4 ± 7.2 cm; wt = 83.0 ± 13.4 kg) and female ($n = 28$, age = 20.1 ± 2.1 years; ht = 165.7 ± 6.1 cm; wt = 62.0 ± 10.7 kg) subjects from the University of Pittsburgh participated in this investigation. Subjects were healthy, with no history of upper extremity musculoskeletal pathology or known contraindications to either heat or cold exposure. Additionally, subjects had not participated in an upper extremity weight-training program for the previous 9 weeks and were pain free in their upper extremity at the start of the investigation. We informed all subjects of the possible side effects of participating in the study, and subjects signed an informed consent as approved by the University of Pittsburgh Institutional Review Board for Biomedical Research. We instructed subjects not to use therapeutic modalities (such as ice or heat), massage, or stretching or to ingest any medications during the course of the study. Also, we asked subjects to refrain from strenuous activity for the duration of their participation in this study.

Measurements

We performed 5 measurements on the subject's nondominant arm at five assessment times: pre-exercise (0 hours), prior to administration of treatment at 24, 48, and 72 hours postexercise, and at 96 hours postexercise.

Range of Motion

We measured elbow range of motion (ROM) with a plastic international standard goniometer. Goniometry has been shown to be both reliable and valid for determining ROM.³⁵ When evaluating the effects of a treatment, other researchers have found that it is necessary to use the same investigator

when measuring ROM, so as to increase reliability.^{35,36} A previous study indicated that intratester reliability for assessing elbow ROM was $r = 0.94$.³⁶ Additionally, standardization of procedures has been suggested to further improve reliability.³⁵

For this investigation, we marked anatomic landmarks for all ROM positions with permanent marker to maximize accuracy and reproducibility across measurement assessment times. One researcher (L.A.K.) performed all measurements on all subjects for the course of their participation in our investigation. We measured all ROM positions 3 times during each session and calculated the average of the 3 values.

Resting elbow flexion. We measured passive resting elbow flexion (REF) with the subject standing with the arm relaxed at the side of the body (palm facing the lateral aspect of the quadriceps). We positioned the goniometer with the fulcrum centered over the olecranon, the stationary arm aligned with the long axis of the humerus, and the movable arm aligned with the long axis of the ulna.

Active elbow flexion and active elbow extension. While the subject stood in the anatomic position, we positioned the goniometer with the fulcrum centered over the lateral epicondyle of the humerus. We aligned the stationary arm with the lateral midline of the humerus and the movable arm with the lateral midline of the radius. We recorded ROM during both active elbow flexion (AEF) and active elbow extension (AEE).

Perceived Soreness

We used a Graphic Pain Rating Scale (GPRS), as developed by Denegar and Perrin,³¹ to assess the subject's perceived level of pain (PAIN). Graphic rating scales have been shown to be the best available method to measure pain and pain relief.³⁷ This type of pain scale has been shown to be more sensitive than other scales and is easily used by subjects, even if previous experience with the scale is lacking.³⁷

The subject rated soreness on the scale while performing AEF and AEE. The scale we used in this investigation consisted of a 12-cm line with written descriptors placed both at the extremes and along the continuum. Beginning at the extreme left and proceeding to the right, the descriptors read "no pain, dull ache, slight pain, more slight pain, painful, very painful, unbearable pain" (Figure 1). We gave the subjects standard instructions on how to complete the scale before each measurement. The subjects placed an "X" at the point on the

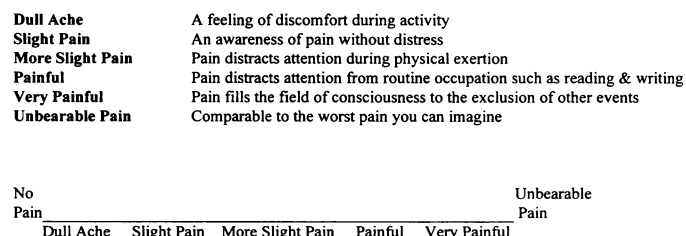


Figure 1. Graphic Pain Rating Scale (GPRS). Subjects marked an "X" at any point on the 12-cm line that best described the soreness in their elbow flexors at that particular assessment time.

line that best described their pain. We measured the intersecting center point of the "X" to the nearest 0.5 cm, and, therefore, a total of 24 values could be obtained.

Maximal Voluntary Isometric Contraction

We assessed maximal voluntary isometric contraction (MVIC) strength on the Kinetic Communicator Exercise System (KINCOM, Chattecx Corp, Chattanooga, TN). The KINCOM has been shown to be a reliable instrument for the measurement of muscular force generation, as determined by examination of its main functions: lever arm position ($r = 0.999$), lever arm speed ($r = 0.990$), and strain gauge measurement ($r = 0.948$).³⁸

We placed the subject's elbow in 90° of flexion and set the lever arm speed at 0° · s⁻¹. We instructed the subject to maximally flex the elbow and to hold the contraction for 5 seconds. We then gave the subject a 30-second rest period. We repeated this cycle 3 times and recorded the greatest force value as the MVIC.

Induction of DOMS

We induced DOMS in the forearm flexors of the nondominant arm of the subject, using a protocol designed by Weber et al.²⁹ We determined a 1-repetition maximum (1RM) value by having the subject lift dumbbells in increasing 2.27-kg (5-lb) increments. We calculated the starting weight for the exercise as 1RM + 2.27 kg. We positioned the subject standing behind a bench supporting the upper arm so as to prevent hyperextension of the elbow joint. The starting position for the exercise was full elbow flexion with forearm supination.

The subject eccentrically lowered the weight to a count of five. We then returned the dumbbell and the subject's arm to the starting position. The subject continued this cycle until fatigue or until 10 repetitions were completed. If the subject fatigued before the completion of 10 repetitions, we removed 2.27 kg (5 lb) from the weight, and the set of 10 repetitions was completed. After a set of 10 repetitions, we gave the subject a 1-minute rest period. After the rest period, the subject resumed the exercise cycle with the previous ending weight. The subject continued the exercise cycle until 50 repetitions were completed.

Treatment Protocol

We randomly assigned subjects to 1 of 4 groups. The 3 treatment groups consisted of warm whirlpool (WW) ($n = 14$), cold whirlpool (CW) ($n = 14$), or contrast therapy (CT) ($n = 14$). The fourth group received no treatment (CON) ($n = 14$). Subjects receiving treatment placed their affected arms in a whirlpool for 24 minutes with the water temperature as follows: WW = 38.9°C, CW = 12.8°C, and CT = 38.9°C and 12.8°C at a ratio of 3 to 1 minutes, respectively.

Our whirlpool treatment protocol consisted of submersing the affected arm in the water to mid-deltoid level. Each subject sat on an adjustable stool placed beside the whirlpool, and we then adjusted the level of the stool so that the subject's axilla

rested on the rim of the whirlpool. We instructed the subject to allow the arm to hang in a relaxed position in the water. We then turned on the agitator; however, we directed the flow of water away from the subject's arm.

We administered a total of 4 treatments to each subject over the course of the study. The subject received the first treatment immediately after the exercise was stopped. We administered additional treatments after measurements of the dependent variables at 24, 48, and 72 hours postexercise.

Statistical Analysis

We performed a repeated-measures analysis of variance (group by time) on the delta (Δ) scores for each dependent variable (REF, AEF, AEE, PAIN, MVIC). We calculated delta scores as the difference between assessment time values at 0 (pre-exercise) and 24 hours postexercise, 0 and 48 hours postexercise, 0 and 72 hours postexercise, and 0 and 96 hours postexercise. This analysis allowed comparisons of the dependent variables at pre-exercise (baseline values) to be compared with subsequent values at 24, 48, 72, and 96 hours. We used dependent variable delta scores because we were attempting to determine which treatment would aid subjects in returning to their pre-exercise values. We used a Tukey post hoc analysis set at an alpha level of 0.05 to detect significant pairwise differences between treatment groups.

RESULTS

The group means and standard deviations for dependent variable measurements of REF, AEF, AEE, PAIN, and MVIC are presented in Tables 1 through 5, respectively. Included in the tables are the means and standard deviations of the group scores, both actual and delta scores.

A group-by-day interaction was found for the dependent variable PAIN (Figure 2). Significant differences were found between CW and WW groups, CT and WW groups, CW and CON groups, and CT and CON groups ($F_{3,156} = 3.30, P = .001$). No significant difference was found between WW and CON groups or CW and CT treatment groups.

A group-by-day interaction was also found for the dependent variable REF (Figure 3). Analysis revealed significant differences between CW and WW groups, CT and WW groups, WW and CON groups, CW and CON groups, and CT and CON groups ($F_{3,156} = 2.72, P = .006$). No significant difference was found between CW and CT treatment groups.

No significant group-by-day differences occurred between treatment groups for AEF delta scores ($F_{3,156} = 1.04, P = .410$), AEE delta scores ($F_{3,156} = 1.73, P = .086$), or MVIC delta scores ($F_{3,156} = 1.21, P = .290$).

DISCUSSION

Results of our investigation indicate that both cold whirlpool and contrast therapy were effective in treating DOMS across

Table 1. Resting Elbow Flexion (REF) Range of Motion (°; mean ± SD) Between Assessment Times Within Treatment Groups

Group	0 Hours	24 Hours	Δ 24 Hours	48 Hours	Δ 48 Hours	72 Hours	Δ 72 Hours	96 Hours	Δ 96 Hours
Warm	12.19	20.81	8.62	20.86	8.67	23.48	11.29	19.14	6.95
Whirlpool (WW)	± 2.38	± 8.37	± 7.56	± 6.80	± 6.40	± 1.14	± 0.71	± 8.21	± 7.40
Cold	10.81	17.14	6.33	20.14	9.33	17.05	6.24	15.17	4.36
Whirlpool (CW)	± 2.98	± 6.04	± 4.40	± 7.54	± 6.45	± 6.56	± 5.35	± 5.04	± 3.75
Contrast	11.74	19.17	7.43	21.60	9.86	19.29	7.55	15.00	3.26
Therapy (CT)	± 2.29	± 5.61	± 5.24	± 6.61	± 7.22	± 6.32	± 7.09	± 3.86	± 4.44
No Treatment (CON)	11.86 ± 2.23	19.72 ± 5.15	7.86 ± 4.21	23.76 ± 7.70	11.90 ± 6.58	25.07 ± 13.53	13.21 ± 13.24	25.26 ± 13.96	13.40 ± 13.76

Table 2. Active Elbow Flexion (AEF) Range of Motion (°; mean ± SD) Between Assessment Times Within Treatment Groups

Group	0 Hours	24 Hours	Δ 24 Hours	48 Hours	Δ 48 Hours	72 Hours	Δ 72 Hours	96 Hours	Δ 96 Hours
Warm	142.57	131.26	-11.31	131.76	-10.81	133.60	-8.98	136.52	-6.05
Whirlpool (WW)	± 3.72	± 9.77	± 8.99	± 8.69	± 8.00	± 8.89	± 7.88	± 6.88	± 5.61
Cold	141.19	132.05	-9.14	131.19	-10.00	133.36	-7.83	135.90	-5.29
Whirlpool (CW)	± 1.86	± 4.35	± 5.02	± 4.94	± 5.23	± 5.04	± 5.20	± 3.47	± 3.92
Contrast	142.64	134.14	-8.50	133.45	-9.19	136.60	-6.05	139.64	-3.00
Therapy (CT)	± 3.32	± 9.10	± 8.78	± 10.18	± 9.23	± 7.83	± 7.22	± 6.36	± 5.76
No Treatment (CON)	142.38 ± 2.98	131.12 ± 7.66	-11.26 ± 7.00	128.17 ± 6.57	-14.22 ± 6.11	129.36 ± 7.06	-13.02 ± 5.77	131.81 ± 5.89	-10.57 ± 4.41

Table 3. Active Elbow Extension (AEE) Range of Motion (°; mean ± SD) Between Assessment Times Within Treatment Groups

Group	0 Hours	24 Hours	Δ 24 Hours	48 Hours	Δ 48 Hours	72 Hours	Δ 72 Hours	96 Hours	Δ 96 Hours
Warm	+3.69*	5.41	9.10	8.81	12.50	11.83	15.52	10.24	13.93
Whirlpool (WW)	± 3.76	± 9.46	± 10.02	± 9.44	± 9.44	± 13.64	± 13.60	± 13.10	± 13.01
Cold	+2.86	4.36	7.22	10.95	13.81	11.33	14.19	6.60	9.45
Whirlpool (CW)	± 3.22	± 9.13	± 7.44	± 12.85	± 12.03	± 13.73	± 12.38	± 10.39	± 9.28
Contrast	+2.17	5.36	7.53	9.52	11.69	7.41	9.57	4.83	7.00
Therapy (CT)	± 3.60	± 9.94	± 7.56	± 13.13	± 10.87	± 11.37	± 9.08	± 9.58	± 7.35
No Treatment (CON)	+3.02 ± 3.26	5.40 ± 6.85	8.43 ± 5.40	10.52 ± 7.57	13.55 ± 7.00	14.33 ± 14.72	17.36 ± 14.19	13.57 ± 14.30	16.60 ± 13.57

* (+) values indicate hyperextension.

Table 4. Perceived Soreness (PAIN) GPRS scores (mean ± SD) Between Assessment Times Within Treatment Groups

Group	0 Hours	24 Hours	Δ 24 Hours	48 Hours	Δ 48 Hours	72 Hours	Δ 72 Hours	96 Hours	Δ 96 Hours
Warm	0.00	8.71	8.71	8.71	8.71	8.93	8.93	6.71	6.71
Whirlpool (WW)	± 0.00	± 6.68	± 6.68	± 6.26	± 6.26	± 5.37	± 5.37	± 5.24	± 5.24
Cold	0.00	8.57	8.57	11.00	11.00	6.21	6.21	2.07	2.07
Whirlpool (CW)	± 0.00	± 6.58	± 6.58	± 5.46	± 5.46	± 5.98	± 5.98	± 2.65	± 2.65
Contrast	0.00	5.57	5.57	8.79	8.79	5.79	5.79	2.43	2.43
Therapy (CT)	± 0.00	± 4.13	± 4.13	± 5.59	± 5.59	± 5.04	± 5.04	± 3.03	± 3.03
No Treatment (CON)	0.00 ± 0.00	7.14 ± 4.45	7.14 ± 4.45	10.29 ± 4.94	10.29 ± 4.94	9.79 ± 5.45	9.79 ± 5.45	8.00 ± 5.55	8.00 ± 5.55

time for the dependent variables of REF and PAIN. “Effectiveness,” as defined by our investigation, implies that these variables demonstrated decreases in absolute delta scores, indicating that the group means were closer to pre-exercise values (baseline).

Elbow Range of Motion

We found that cold whirlpool and contrast therapy returned REF values closer to pre-exercise values than warm whirlpool or no treatment. Additionally, warm whirlpool was found to

Table 5. Maximal Voluntary Isometric Contraction (MVIC) Force Values (kg; mean \pm SD) Between Assessment Times Within Treatment Groups

Group	0 Hours	24 Hours	Δ 24 Hours	48 Hours	Δ 48 Hours	72 Hours	Δ 72 Hours	96 Hours	Δ 96 Hours
Warm	17.46	9.96	-7.50	11.62	-5.84	12.10	-5.36	14.00	-3.46
Whirlpool (WW)	\pm 8.11	\pm 7.47	\pm 4.28	\pm 7.70	\pm 2.90	\pm 6.87	\pm 4.57	\pm 8.16	\pm 4.31
Cold	16.89	10.60	-6.29	10.86	-6.03	11.86	-5.03	12.87	-4.02
Whirlpool (CW)	\pm 6.86	\pm 4.40	\pm 5.13	\pm 4.39	\pm 4.29	\pm 5.64	\pm 4.78	\pm 5.32	\pm 4.43
Contrast	16.32	13.70	-2.62	13.31	-3.00	14.49	-1.82	15.41	-0.91
Therapy (CT)	\pm 5.88	\pm 6.23	\pm 2.35	\pm 5.91	\pm 2.06	\pm 5.97	\pm 1.70	\pm 6.01	\pm 1.36
No	19.65	12.41	-7.25	12.46	-7.19	12.72	-6.93	13.04	-6.62
Treatment (CON)	\pm 8.92	\pm 7.70	\pm 4.29	\pm 6.96	\pm 4.10	\pm 6.56	\pm 4.66	\pm 4.13	\pm 5.51

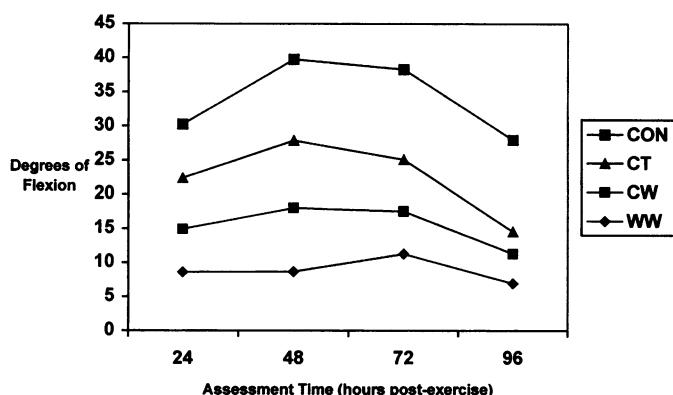


Figure 2. Resting Elbow Flexion (REF) values (range of motion) for treatment groups across all assessment times. The smaller the value of REF, the farther the value is from pre-exercise values (baseline).

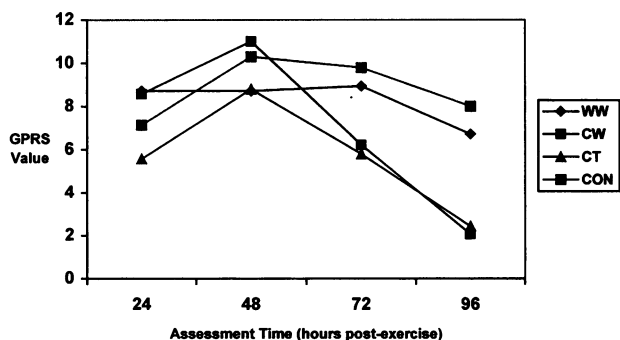


Figure 3. Perceived soreness (PAIN) values for treatment groups across all assessment times. The greater the value of PAIN, the farther the value is from pre-exercise values (baseline).

significantly return REF values to pre-exercise values over no treatment. AEF and AEE, however, were not significantly affected by any of our treatments.

In a previous study by Denegar and Perrin,³¹ treatment involving immediate application of an ice bag resulted in greater active elbow extension of subjects experiencing DOMS. Although they noted increased active ROM, because superficial cold application and subsequent measurements of dependent variables were immediate, their findings address

only short-term effects. It has been documented that the application of superficial cold immediately relieves muscle spasm through neural effects, such as decreasing the excitability and conduction velocities of free nerve endings.^{17,18,34} Additionally, decreased response of muscle spindles to stretch and increased firing rates of Golgi tendon organs have been shown to allow for muscle relaxation.^{15-18,20,34} Thus, it can be expected that superficial applications of ice may decrease muscle spasm in the short term.

We took postexercise measurements beginning the day after the first treatment, since our objective was to evaluate the long-term effect of our treatments in returning the subjects to baseline levels. Gulick et al³² found that subjects who received ice massage of the wrist extensors were the only group to return to pre-exercise values by 72 hours postexercise. The positive effect of cold whirlpool therapy on REF in our study was most likely due to the ability of superficial cold to counteract the acute inflammatory process, specifically the accumulation of edema.¹⁵⁻¹⁷ Swelling occurs as a result of increased permeability in blood vessels, which allows exudate to escape into surrounding damaged tissues.¹¹ Cold whirlpool therapy, applied between the temperature ranges of 12.8°C to 18.3°C and lasting 20 to 30 minutes, has been shown to cause vasoconstriction, thereby reducing edema accumulation.^{16,18,20} A reduction in swelling results in greater elbow joint mobility due to less edema accumulation in the biceps brachii muscle fibers and joint space.^{2,5,8,10,32}

The rationale for using contrast therapy in the inflammatory process is based upon a theory that alternative cycles of warm and cold whirlpool immersions cause vasoconstriction and vasodilation, commonly referred to as a "pumping" action.^{15,17} Current literature promotes the effectiveness of contrast therapy for increasing ROM;^{15,17} however, scientific evidence is lacking.¹⁹ For example, in a study conducted by Myrer et al,¹⁹ no significant deep tissue temperature changes were observed when performing contrast therapy on the gastrocnemius muscles of subjects. The authors' treatment protocol consisted of a ratio of 4 minutes at 40.6°C to 1 minute at 15.6°C for 4 cycles.

Due to the lack of previous research, it is difficult to determine the reasons for the effect of contrast therapy on REF in our investigation. Because debate exists regarding the claim of vasoconstriction/vasodilation occurring, and since we did

not measure serum markers for the inflammatory process, we cannot determine an exact cause-effect relationship. However, since it has been proposed that contrast therapy reduces residual swelling,¹⁷ and because REF improved in our investigation, we believe that the protocol of contrast therapy employed in our investigation mediated the swelling associated with the inflammatory process. The treatment protocol we used was cooler (38.9°C and 12.8°C, respectively) than that of Myrer et al¹⁹ and lasted 6 cycles, with the subject remaining only 3 minutes in the warm whirlpool. Although not measured, a tissue temperature decrease may have occurred with our protocol, due both to the lower water temperature employed and the longer treatment duration. This change in tissue temperature would then have facilitated resolution of the inflammatory process.

Perceived Pain

Smith³ stated that pain in athletes experiencing DOMS may cause further injuries as a result of unsound biomechanical compensations. Pain occurs through the stimulation of nociceptors in the body, with the soreness of DOMS being transmitted along C-afferent fibers, which originate in both the skin and deeper tissues such as muscle and ligament.¹ We found lower pain perception scores in subjects receiving cold whirlpool and contrast therapy. Warm whirlpool and no treatment were not found to be effective in decreasing subjective pain scores.

Denegar and Perrin³¹ found that cold application, either alone or in conjunction with transcutaneous electrical nerve stimulation, decreased perceived pain immediately after treatment. Again, their investigation supported the short-term effect of cold-induced analgesia resulting from cold application and its effect on decreasing nociceptor nerve conduction velocity and excitability.^{17,18}

Yackzan et al⁹ and Isabell et al³³ stated that ice application may not be effective in decreasing the pain associated with DOMS and further suggested that it may be contraindicated. These opinions were based upon nonsignificant statistical findings involving treatments of the elbow flexors with ice massage. Our findings refute both studies; contrast therapy and cold whirlpool therapy decreased perceived pain levels significantly more than warm whirlpool or no treatment.

Our study supports the contention that superficial cold application, either in the form of cold whirlpool or contrast therapy, may decrease aspects of the inflammatory process. Smith¹¹ proposes that macrophages, which are involved in the inflammatory response, synthesize prostaglandins, which may sensitize nociceptors. Theoretically, decreasing the inflammatory response would decrease this sensitization, resulting in less perceived soreness. Furthermore, if contrast therapy reduces residual swelling,¹⁷ this effect may have been achieved by our treatments, thereby reducing pressure on nociceptors.^{14,32}

Muscle Performance

Smith³ stated that DOMS may adversely affect athletic performance due to decreases in muscular strength and power. The loss of muscle performance associated with DOMS is thought to be related to both decreased effort on the part of the individual due to pain and a decrease in the actual force-producing capacity of the muscle itself.^{4,7} Numerous theories exist regarding the precise etiology of DOMS. It is, therefore, difficult to determine what causes the observed decrements in muscular strength.^{1,7,11-13} Mechanical disruption of the muscle fibers and/or connective tissue is currently best supported by the literature.^{1,4,5,7,8,10,11} Injury to muscle fibers is likely due to increased tension placed on fewer muscle fibrils during eccentric contractions, which causes more mechanical strain and therefore injury.^{1,6,8} Furthermore, Asmussen's¹⁰ theory states that connective tissue fibers are stiffer than muscle fiber tissue; thus, connective tissue is at a higher risk of injury. Since the area most commonly affected by DOMS is at the tenomuscular junction,^{1,10} it is probable that both theories are applicable and that damage occurs to both contractile elements and the connective tissue. Additionally, it is probable that swelling between muscle fibers may mechanically inhibit muscle function.¹¹

Denegar and Perrin³¹ pointed out that the soreness associated with DOMS is usually alleviated within 1 week of onset. However, muscle strength has been reported to be only 80% of normal at 2 weeks postexercise. Newham et al⁷ reported that subjects experiencing DOMS were not aware of strength decrements due to less perceived pain. In their investigation, subjective ratings of soreness decreased, although objective testing revealed muscle weakness. Similarly, our subjects who received cold whirlpool and contrast therapy treatments reported significant decreases in perceived pain, although their strength was not significantly improved.

Pain may not be an accurate determinant of healing in the injured tissues; thus, strength may be a more accurate factor when assessing if an athlete is able to return to pre-DOMS participation levels.^{3,31} Additionally, the motto of "working through" pain may cause more damage to already weakened muscle and/or connective tissues.^{3,8} Professionals in the sports medicine setting should be aware of the false sense of security that athletes may experience when recovering from the perceived pain of DOMS. Lastly, these individuals should take into consideration the effects of any treatment administered for DOMS.

CONCLUSIONS

When selecting a treatment strategy for DOMS, both the goals of treatment and the physiologic effects of treatment application are critical. In attempting to determine which treatment is superior, we discovered that both cold whirlpool and contrast therapy improved the dependent variables of REF and PAIN, as compared with warm whirlpool and no treatment. Cold whirlpool and contrast therapy were not significantly

different in alleviating the signs and symptoms of DOMS. Finally, the application of heat through the use of warm whirlpools was more effective than no treatment in returning subjects to pre-exercise values for REF.

Based on the results of this study, we conclude that the application of cold through the use of cold whirlpool or contrast therapy is the best treatment for DOMS. We also recommend that muscular strength, not perceived pain, be the deciding factor when determining when an athlete with DOMS should return to previous participation levels, especially in activities requiring excessive force production. Lastly, we recommend research and clinical application into the physiologic effects of contrast therapy. Exploring different ratios of warm to cold whirlpool, as well as different temperature ranges, may help to delineate the separate and combined effects of the whirlpools.

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