Intramuscular Temperature Changes During and After 2 Different Cryotherapy Interventions in Healthy Individuals

Cryotherapy is a commonly used treatment modality in acute musculoskeletal trauma and pain. Physiological changes occur both during and after cryotherapy treatment. Some of these changes are well reported in the literature, such as control of secondary hypoxic injury and edema, decreased skin and muscle temperature, decreased nerve conduction velocity, increased pain threshold and tolerance, and reduced pain.

Cryotherapy can be applied in various forms, but crushed-ice bags (CIB) and cold-water immersion (CWI) are frequently used in sports medicine. These 2 modalities have different levels of efficacy in inducing physiologic changes. When compared to CIB, CWI has been shown to be more effective in reducing nerve conduction parameters after a 15-minute cooling treatment and maintaining the reductions in sensory nerve conduction parameters during rewarming. In a study by Myrer et al., both CIB and CWI decreased intramuscular temperature after a 20-minute treatment, and there was no difference in immediate posttreatment temperature between the modalities. But in the same study, during the 30-minute posttreatment monitoring period, intramuscular temperature increased 2°C after the ice bag was removed, whereas intramuscular temperature continued to decrease nearly 2°C after CWI was removed.

In clinical practice, the same cryotherapy modalities can be applied in multiple ways. Ice bags can be applied with flexible plastic wrap, elastic wrap, or without compression. CWI can be applied at various depths and temperatures, with typical immersion
just proximal to the injured area, and at temperatures ranging from 10°C to 15°C. Previous authors have made treatment time recommendations based on subcutaneous adipose tissue thickness. Their studies reported that cooling time was affected by thickness of adipose tissue at the treatment site, and that longer treatments were necessary for greater thicknesses. Treatment time is another consideration. Intramuscular temperature 1 to 2 cm below adipose tissue has been reported to decrease 7°C to 8°C using CIB but only 5°C using CWI, after conventional treatment times of 20 to 30 minutes. Additionally, a recent study examining blood flow during cryotherapy treatments concluded that the previously recommended treatment times to achieve a 7°C change in intramuscular temperature may not be sufficient to reduce blood flow and achieve desired physiological effects.

Although clinicians and researchers often assume that it is better to have a lower temperature for a longer duration after treatment, a consensus on optimal treatment parameters has not been reached. The purpose of this study was to compare the length of time required to decrease intramuscular temperature 8°C below baseline temperature after treatment with CIB and CWI. Secondary aims were to examine intramuscular temperature between the modalities 90 minutes postintervention, the relationship between cooling time and adipose tissue thickness, and the perceived thermal discomfort during each cryotherapy modality. Based on the study by Myrer et al., we hypothesized that CIB and CWI would result in similar rates of intramuscular temperature decrease, and that CWI would result in a colder intramuscular temperature after a rewarming period. We also hypothesized that the time required to decrease intramuscular temperature 8°C would be positively correlated with adipose thickness, and that during treatment CIB would result in less perceived thermal discomfort than CWI.

**METHODS**

**Design**

We used a crossover study design, in which each subject underwent separate randomly allocated treatments of CIB or CWI, with at least 72 hours between treatment sessions.

**Participants**

Eighteen healthy subjects, 7 men (mean ± SD age, 22.9 ± 2.0 years; height, 180.3 ± 8.2 cm; mass, 84.9 ± 17.9 kg; medial calf adipose thickness, 1.4 ± 0.58 cm; calf girth, 39.6 ± 4.5 cm) and 11 women (mean ± SD age, 21.8 ± 1.3 years; height, 163.0 ± 4.9 cm; mass, 57.3 ± 5.7 kg; medial calf adipose thickness, 1.8 ± 0.39 cm; calf girth, 34.3 ± 1.6 cm), were recruited from a university setting and volunteered to participate in this study. No participant had a history of allergy to lidocaine or cold (including cold hypersensitivity or Raynaud syndrome), known circulatory compromise in the lower extremity, or open wound on the lower leg of the test extremity at the time of testing. All participants were instructed in study procedures and gave written, informed consent. The Institutional Review Board at the University of Virginia approved this study.

**Procedures**

Prior to the treatment sessions, subjects completed a screening session to determine the thickness of subcutaneous adipose tissue on the medial calf. Initially, calf girth was measured and marked at the largest circumference of the limb opposite the limb preferred to kick a ball. This mark at the medial calf served as the measurement site for subcutaneous adipose tissue, as well as the thermocouple insertion site. Ultrasound images (LOGIQ Book XP; GE Healthcare, Waukesha, WI) were recorded at the same site in B-mode, using an 8-MHz linear-array transducer to capture a still image. Images were measured using ImageJ Version 1.43u software (National Institutes of Health, Bethesda, MD) at a resolution of 46 pixels per centimeter for each image. Adipose tissue thickness was determined as the depth from the cutaneous boundary to the inferior aspect of the fascia surrounding the gastrocnemius. The mean thickness of 3 images was recorded and used to determine the thermocouple insertion depth for each subject. Ultrasound imaging is comparable to magnetic resonance imaging, the criterion standard, in image clarity and is a valid tool for measuring both abdominal and visceral adipose tissue. We have found this measurement technique to be highly reliable in our laboratory.

We measured intramuscular temperature using an 18-gauge, type T (copper-constantan thermocouple), special flexible microprobe (TT-18; Physitemp Instruments, Inc, Clifton, NJ), interfaced with a Thermes USB temperature data-acquisition system (Physitemp Instruments, Inc), with a manufacturer-reported accuracy of ±0.2°C. Intramuscular temperature was measured at 1 Hz to the nearest 10th of a degree throughout the study, using the same thermocouple, a procedure that we have found to be reliable in our laboratory. For each subject, the thermocouple was marked at 1 cm plus adipose tissue thickness, as determined by ultrasound imaging. The thermocouple was sterilized using CIDEPLUS 28-Day Solution (Johnson & Johnson, Irvine, CA), per manufacturer guidelines.

Subjects were positioned prone on a treatment table, and the area of largest girth was marked on the medial calf, using a 2.5 × 2.5-cm right-angle template to delineate the thermocouple insertion area. A disposable underpad was placed under the lower limb of the test leg. The insertion area was shaved, if needed, and cleansed with a 10% povidone-iodine solution. A physician anesthetized the surface area with an injection of 3 cc of 1% lidocaine hydrochloride (10 mg/mL) (Hospira, Inc, Lake Forest, IL), using a 21-gauge hypodermic needle. The same physician then inserted the marked ther-
mocouple into the medial calf using an 18-gauge hypodermic needle, and verified correct insertion depth through visual examination after withdrawal of the hypodermic needle. At the appropriate insertion depth, the ink marking was visible and level with the skin. A transparent sterile film dressing (Tegaderm; 3M, St Paul, MN) was then placed over the insertion site.

After a 5-minute baseline temperature recording, each subject received a randomly allocated treatment condition of CIB or CWI. Each ice bag was made by placing 1500 mL of crushed ice into a 38 × 51-cm plastic bag and evacuating the bag of excess air before closing it. Ice bags were secured with consistent compression, using an elastic wrap. The bladder of a manometer was placed over the ice bag and under the elastic wrap. Pressure was adjusted and monitored to maintain a reading of 40 to 50 mmHg throughout each ice-bag session. Cold-water immersion was completed in a 10-gallon (37.85-L) tub, filled with crushed ice and cold water to maintain a temperature of 8°C and stirred frequently. Subjects were instructed to avoid unnecessary ankle dorsiflexion and planter flexion to minimize thermocouple movement or migration. Each cryotherapy treatment (CIB or CWI) was applied until intramuscular temperature decreased 8°C from baseline. At this point, the intervention was removed and, if necessary, the subject’s lower leg was lightly patted dry and the toecap removed. Immediately posttreatment, subjects were asked to rate perceived thermal discomfort at the most intense point of treatment using a 10-cm visual analog scale, with a left anchor of “very comfortable” and a right anchor of “very uncomfortable.” Rewarming of the muscle was monitored for 90 minutes posttreatment, while the participant lay prone. After the rewarming period, the thermocouple was removed and replaced in CIDEXPLUS 28-Day Solution, and the insertion site was cleansed with a 70% isopropyl alcohol swab and covered with a bandage. The subject was then dismissed and asked to return 3 to 7 days later to complete the other randomly allocated treatment.

**Statistical Analysis**

Data were analyzed using SPSS Version 17.0 (SPSS Inc, Chicago, IL). Data were normally distributed, so paired t tests were used to examine (1) baseline intramuscular temperature before each intervention, (2) length of time to decrease 8°C during intervention, (3) intramuscular temperature after rewarming, and (4) thermal comfort at the most intense sensation during cryotherapy treatment. A Kaplan-Meier survival analysis was also performed to assess the length of time necessary to decrease 8°C between interventions. Survival was defined as a subject not yet reaching the 8°C decrease. Pearson r correlations were used to examine the relationship between CIB and adipose thickness, and CWI and adipose thickness. The level of significance was set at P <.05 for all analyses.

**RESULTS**

**Baseline Intramuscular Temperature**

Baseline intramuscular temperature was not significantly different between interventions (mean difference, –0.05°C; 95% confidence interval [CI]: –0.41°C, 0.31°C) (**TABLE**). Adipose tissue thickness was greater in females than males (mean difference, 0.42 cm; 95% CI: 0.19, 0.64).

The amount of time needed to cause a decrease of 8°C in intramuscular temperature was not significantly different between interventions (mean difference, 2.60 minutes; 95% CI: –3.10, 8.30) (**TABLE**). Likewise, the survival analysis showed no significant difference in the length of time necessary to decrease intramuscular temperature by 8°C between interventions (**FIGURE 1**). Intramuscular temperature was significantly colder 90 minutes postintervention after CWI compared to CIB (mean difference, 2.80°C; 95% CI: 2.08°C, 3.52°C) (**TABLE, FIGURE 2**). Compared to baseline temperature, intramuscular temperature 90 minutes postintervention remained lower in both conditions (CWI mean difference, 7.95°C; 95% CI: 7.23°C, 8.66°C; CIB mean difference, 5.10°C; 95% CI: 4.29°C, 5.91°C).

There was no correlation between time required to decrease intramuscular temperature 8°C and adipose tissue thickness in CWI (r = 0.04, P = .874) (**FIGURE 3**) and CIB (r = –0.25, P = .320) (**FIGURE 4**). Perceived ratings of thermal discomfort were not significantly different between interventions (mean deffer-

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**TABLE**

**Descriptive Values and Between-Group Differences for Primary and Secondary Outcome Measures**

<table>
<thead>
<tr>
<th>Description</th>
<th>Crushed-Ice Bag*</th>
<th>Cold-Water Immersion*</th>
<th>Between-Group Difference¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline intramuscular temperature</td>
<td>38.59 ± 1.26</td>
<td>38.64 ± 0.92</td>
<td>-0.05 (–0.41, 0.31)</td>
</tr>
<tr>
<td>Time to decrease intramuscular</td>
<td>42.51 ± 20.4</td>
<td>39.91 ± 14.5</td>
<td>2.60 (–3.10, 8.30)</td>
</tr>
<tr>
<td>temperature 8°C, min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90 min postintervention</td>
<td>33.49 ± 2.26</td>
<td>30.69 ± 2.17</td>
<td>2.80 (2.08, 3.52)</td>
</tr>
<tr>
<td>temperature, °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal discomfort, cm</td>
<td>3.92 ± 2.25</td>
<td>5.24 ± 2.61</td>
<td>-2.15 (–2.14, –0.49)</td>
</tr>
</tbody>
</table>

*Values are mean ± SD.

†Values are mean (95% confidence interval).

Indicates that the postintervention intramuscular temperature was significantly lower following cold-water immersion compared to crushed-ice bag (P < .001).
DISCUSSION

The main finding of this study was that the time required to decrease intramuscular temperature by 8°C was not significantly different between the different cryotherapy interventions. However, after 90 minutes of rewarming while lying prone, intramuscular temperature was significantly colder after treatment with CWI compared to CIB. Additionally, there were no correlations between time needed to decrease intramuscular temperature 8°C and adipose tissue thickness or significant difference in perceived thermal discomfort between the 2 different interventions.

Previous research has reported that intramuscular temperatures decrease from 7°C after a 20-minute treatment to 8°C after a 30-minute treatment with ice bags, and 5°C after a 20-minute treatment with CWI. Although the optimal magnitude of temperature change with cryotherapy is unknown, we chose an 8°C change as the target temperature, because most therapeutic treatments are similar in time and methodology to those in the range of 7°C to 8°C temperature change. We monitored temperature change in a mechanism similar to clinical cryotherapy applications to compare both time to cooling and temperature after a lengthy rewarming period.

To our knowledge, this is the first study to use a survival analysis to examine the time required to reduce intramuscular temperature to a specific threshold (FIGURE 1). The survival analysis represented the percentage of subjects who did not reach the 8°C temperature-reduction threshold at each 1-minute time interval. As each subject reached the 8°C threshold, the subject was removed from the remaining intervals of the analysis, until the last subject reached the threshold, at which point the analysis was complete. Such a survival analysis enables clinicians to examine the time required to decrease intramuscular temperature. As shown in FIGURE 1, the majority of subjects required more than 30 minutes of cryotherapy application to decrease intramuscular temperature, which brings into question the ability of general clinical practice techniques to adequately cool the muscle.

We hypothesized that required cooling time and adipose tissue thickness would be positively correlated. Our results found no correlation between cooling time and adipose tissue thickness with either intervention (FIGURES 3 and 4). This may be due to the body composition of our subjects, of whom the majority had adipose tissue thicknesses between 11 and 20 mm and only a few had extremely thin or thick levels of adipose tissue. Otte et al(19) concluded that a standard 20-minute treatment was inadequate to produce standard intramuscular temperatures in patients with different body compositions and made treatment-time recommendations based on subcutaneous adipose tissue thickness over the treatment area. These treatment times, to achieve a 7°C decrease in intramuscular temperature, were 12 minutes for patients with 0- to 10-mm adipose tissue, 30 minutes for patients with 11- to 20-mm adipose tissue, 40 minutes for patients with 21- to 30-mm adipose tissue, and 60 minutes for patients with 31- to 40-mm adipose tissue. Recently, Sellkow et al(20) examined microvascular blood flow with ice-bag treatments using these treatment-time recommendations, and reported that intramuscular blood flow did not decrease below baseline levels immediately after ice-bag treatment, despite an intramuscular temperature decrease of 7°C.

In our study, previous treatment-time recommendations would not have resulted in the desired decreases in intramuscular temperature 1 cm below adipose tissue. The majority of our subjects had adipose tissue thicknesses of 11 to 20 mm, as measured with real-time ultrasound imaging. To achieve the desired decrease in intramuscular temperature, these subjects would have required a 30-minute treatment, based on the above recommendations. Our results, using real-time ultrasound, indicated a treatment time of closer to 40 minutes for this subgroup, regardless of the cryotherapy method used. The treatment-time difference in the present study may be due
to a target intramuscular temperature change that was slightly greater than that of the previous study. It is also possible that intramuscular tissue temperatures were measured at a more accurate tissue depth than those of the previous study, which used skinfold calipers to measure skin and adipose tissue and to determine thermocouple placement. We believe that using real-time ultrasound imaging is superior as a research method compared to skinfold calipers, because this method enabled us to visualize the fascial lines separating adipose tissue from the gastrocnemius and to objectively measure the thickness of adipose tissue.23

Although both groups remained cooler than they were at baseline, intramuscular temperature was significantly colder after a 90-minute rewarming period following CWI compared to CIB. These results are similar to those of previous studies measuring intramuscular temperature 30 minutes posttreatment17 and sensory nerve conduction velocity 30 minutes posttreatment.7 In each of those studies, CWI cryotherapy was more effective at creating longer-lasting effects and may therefore be a more effective treatment. Both CIB and CWI remove heat from treated tissues via conduction, which involves direct contact of the intervention with the treatment area. It may be that CWI is more effective at creating longer-lasting effects due to the ability of moving water to remove additional heat from treated tissues through convection. Merrick et al23 explained that the addition of a second mode of heat transfer, in our case convection, might produce different treatment effects from those from conduction alone. In our study, CIB and CWI intramuscular temperatures were similar from the end of the treatment period to 73 minutes, but differed significantly during the final 17 minutes of rewarming. After 90 minutes, subjects treated with CWI had a 2.8°C ± 0.72°C lower intramuscular temperature than those treated with CIB. This significant difference is depicted in Figure 2 where the 95% CIs do not overlap, showing a difference in muscle temperature during rewarming. In our study, the rewarming period was completed with the subject lying prone for 90 minutes. Recently, a study examined muscle temperature changes during exercise combined with cryotherapy and reported that optimal muscle temperature occurs at rest.6 The authors of that

![Figure 2](image-url)
study recommended that patients walk the shortest amount of time possible and increase the length of cryotherapy treatment once they stop walking.4

Subject ratings of perceived comfort during each treatment were not significantly different between CIB and CWI, but the P value and moderate effect size of this measure indicate that CWI might have caused greater discomfort than CIB. This is supported by anecdotal reports from patients who find CWI more uncomfortable than CIB. In this instance, unless the treatment goals are specifically aimed at a longer-lasting decrease in muscle temperature to achieve physiologic changes, as opposed to achieving cold-induced analgesia, using CIB is an acceptable alternative to CWI to minimize patient discomfort.

Regarding our tissue-temperature-change parameters, we chose a threshold of an 8°C decrease from baseline, which is representative of the best available current information.14,17,22 Similarly, our intervention parameters were chosen based on common previously reported parameters.10,37 Water temperature during immersion was monitored and kept consistently at 12°C, but ice-bag temperature was not monitored throughout treatment. Though we are confident that the ice-bag temperature remained constant, due to cryotherapy thermodynamics and the concept of phase change (ice changing from solid form to liquid form), the concept of fusion, or melting, is important to consider.15 The melting point of ice is 0°C. Fusion occurs without a temperature change, so that solid ice immediately before melting and liquid water immediately after melting are both 0°C.15 As long as there was still solid ice in the ice bag at the end of treatment (because there wasn’t enough heat absorbed by the ice to cause melting), we know that the temperature of the intervention remained constant at 0°C.

We are unable to generalize these results to all cryotherapy interventions, because the magnitude and duration of cooling are likely different when using different parameters. Also, it is important to consider that cryotherapy applied over a joint or superficial bony prominence may produce different physiological effects with respect to the extent and rate of cooling.9,20,21 The population in this study was recruited from a university setting and consisted of healthy young adults who did not have a history of lower extremity injury in the 6 weeks prior to enrollment. Due to this limitation, the study results could not be generalized to an injured population and only provide information regarding uninjured adults. Additionally, our sample size of 18 subjects in a crossover design may be considered relatively small.

CONCLUSION

This study provides additional insight on applications of cryotherapy. Though we chose specific and justified modality application parameters, many clinicians and researchers may choose different parameters. The lack of standard and proven parameters to achieve a clinical goal may be part of the reason that research on the clinical benefits of cryotherapy is inconsistent and inconclusive.2,3 Future research should aim to determine a specific target tissue temperature that helps optimize healing after injury. A comparison of different applications of the same modality may also be useful, in that the ability to recommend standard treatment protocols based on body composition and injury type may enable patients to recover faster and experience less discomfort during recovery. Currently, treatment decisions should be directed by treatment goals. Both CIB and CWI cool muscle tissue in similar time durations, but CWI leaves tissue cooler longer after a rewarming period. This study supports consideration of the posttreatment activity of each patient. To maximize cooler temperatures after cryotherapy, subjects may need longer treatment times, combined with a period of passive rest, before continuing activities of daily living.

**KEY POINTS**

**FINDINGS:** The time required to reduce intramuscular temperature 8°C was not significantly different between CIB and CWI, although average times were

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**FIGURE 4.** Crushed-ice bag correlation analysis. Time to reach 8°C decrease in intramuscular temperature (minutes) and adipose tissue thickness over the medial gastrocnemius (millimeters). No significant correlation was found between cooling time with crushed-ice bag and adipose tissue thickness ($r = -0.25$, $P = .320$).
longer than those typically used clinically. After 90 minutes of rewarming, Intramuscular temperature was significantly colder after treatment with CWI compared to CIB.

**IMPLICATIONS:** CWI and CIB both cool muscle tissue in similar time durations, but CWI leaves tissue cooler longer after a rewarming period. To maximize cooler temperatures after cryotherapy, subjects may need longer treatment times combined with a period of passive rest before continuing activities of daily living.

**CAUTION:** We do not currently know if there is a specific target tissue temperature that would optimize healing after injury. It is possible that important physiological changes occur in the skin or muscle before or after an 8°C intramuscular temperature decrease.

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### REFERENCES


