Journal of Athletic Training 2019;54(12):1304–1307
doi: 10.4085/1062-6050-550-18

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Cooling of Lower Extremity Muscles According to Subcutaneous Tissue Thickness

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Context: When using an ice bag, previous researchers recommended cooling times based on the amount of subcutaneous tissue. Unfortunately, many clinicians are unaware of these recommendations or whether they can be applied to other muscles.

Objective: To examine if muscles of the lower extremity cool similarly based on recommended cooling times.

Design: Crossover study.

Setting: Athletic training laboratory.

Patients or Other Participants: Fourteen healthy participants volunteered (8 men, 6 women; age = 21.1 ± 2.2 years, height = 174.2 ± 4.5 cm, weight = 74.0 ± 7.5 kg).

Intervention(s): Subcutaneous tissue thickness was measured at the largest girth of the thigh, medial gastrocnemius, and medial hamstring. Participants were randomized to have either the rectus femoris or medial gastrocnemius and medial hamstring tested first. Using sterile techniques, the examiner inserted a thermocouple 1 cm into the muscle after accounting for subcutaneous tissue thickness. After the temperature stabilized, a 750-g ice bag was applied for 10 to 60 minutes to the area(s) for the recommended length of time based on subcutaneous adipose thickness (0 to 5 mm [10 minutes]; 5.5 to 10 mm (25 minutes]; 10.5 to 15 mm [40 minutes]; 15.5 to 20 mm [60 minutes)]. After the ice bag was removed, temperature was monitored for 30 minutes. At least 1 week later, each participant returned to complete testing of the other muscle(s).

Main Outcome Measure(s): Intramuscular temperature (°C) at baseline, end of treatment time (0 minutes), and posttreatment recovery (10, 20, and 30 minutes postintervention).

Results: At the end of treatment, temperature did not differ by subcutaneous tissue thickness (10 minutes = 29.0°C ± 3.8°C, 25 minutes = 28.7°C ± 3.2°C, 40 minutes = 28.7°C ± 6.0°C, 60 minutes = 30.0°C ± 2.9°C) or muscle (rectus femoris = 30.1°C ± 3.8°C, gastrocnemius = 28.6°C ± 5.4°C, hamstrings = 28.1°C ± 2.5°C). No significant interaction was present for subcutaneous tissue thickness or muscle ($P \geq .126$).

Conclusions: Lower extremity muscles seemed to cool similarly based on the recommended cooling times for subcutaneous tissue thickness. Clinicians should move away from standardized treatment times and adjust the amount of cooling time by ice-bag application based on subcutaneous tissue thickness.

Key Words: adipose, cryotherapy, ice bag, intramuscular temperature

Key Points

- The rectus femoris, hamstrings, and gastrocnemius cooled to similar temperatures during ice-bag application when subcutaneous tissue thickness was used as a guide for intervention length.
- Timing guidelines based on subcutaneous tissue thickness should be followed for cooling the lower extremity muscles using an ice bag.
- Standardized treatment times should be avoided during ice-bag application to the lower extremity muscles.

In 2002, Otte et al[1] recommended that clinicians consider moving away from standardized treatment times and take subcutaneous adipose tissue thickness into consideration for ice-bag application. This study was pivotal because the authors recommended a specific treatment time based on subcutaneous tissue thickness to produce a *typical cooling effect* defined as a decrease in muscle temperature by 7°C. They suggested that 25 minutes of a bagged-ice treatment may be enough for patients with a skinfold of 20 mm or less. In addition, they proposed that a 40-minute treatment would be needed to see similar results in patients with skinfolds between 21 and 30 mm and a 60-minute treatment for those with skinfolds between 31 and 40 mm.[1] Seventeen years is the typical amount of time required for clinical practice to change based on published evidence.[2–5] As the 17-year mark since Otte et al was released approaches, I would argue that although clinicians know adipose tissue affects cooling time, adipose tissue is not being measured or estimated before ice-bag application. I was also interested in expanding on Otte et al[1] to determine if the results they found by cooling the thigh could be reproduced in other lower extremity muscles.

In the most recent editions of common therapeutic modalities textbooks,[6–12] the Otte et al[1] article is referenced in the context of adipose tissue affecting cooling and more adipose tissue requiring a longer treatment time. One text[11] even went so far as to recommend treatment times. A number of researchers[13–24] have incorporated cooling recommendations based on subcutaneous tissue thickness into their study designs or accounted for subcutaneous tissue thickness in different results across patients. Textbooks and scholarly articles suggested translating these recommendations to patient care, but many clinicians were complacent and relied on a "cookbook approach" to patient care. In today's climate where clinicians are encouraged to practice evidence-based medicine, such an approach violates the 3 core principles of this philosophy: research evidence, patient values, and clinical expertise.[25]

The purpose of this study was to retest the findings of Otte et al[1] and match the suggested treatment times to subcutaneous tissue thickness in 3 lower extremity muscles. I was interested in measuring the outcome of the treatment and posttreatment benchmarks as indicated by intramuscular temperature change. I hypothesized that the subcutaneous tissue thickness and time pairings would be proven correct and that temperature would decrease equally in each muscle. This would further support the need for clinicians to implement appropriate treatment guidelines for ice-bag application.

Table 1. Intervention Time and Subcutaneous Tissue Thickness by Muscle

Muscle(s)	Intervention Time, min	No. of Participants	Mean Subcutaneous Tissue Thickness, mm (Mean ± SD)
Rectus femoris	10	2	5.0 ± 0.1
	25	4	5.9 ± 1.0
	40	4	12.7 ± 1.6
	60	3	17.7 ± 2.1
Gastrocnemius	10	8	4.1 ± 0.8
	25	2	6.4 ± 0.4
	40	2	12.0 ± 2.1
	60	0	
Hamstrings	10	3	4.8 ± 0.3
	25	7	7.7 ± 1.5
	40	1	13.3
	60	1	20

METHODS

Design

The study had a mixed-model randomized crossover design with group and time as factors. Each participant's intramuscular temperature was measured in the thickest portion of the rectus femoris or medial gastrocnemius and medial hamstrings to determine the length of time the ice bag would be applied. Participants were arranged in groups based on the amount of subcutaneous adipose tissue thickness: 0 to 5 mm, 5.5 to 10 mm, 10.5 to 15 mm, and 15.5 to 20 mm for treatment lengths of 10, 25, 40, and 60 minutes, respectively.[13,14] After the intervention, temperature was monitored and recorded at 10, 20, and 30 minutes.

Participants

Fourteen healthy participants between the ages of 18 and 30 years volunteered for this study (8 men, 6 women; age = 21.1 ± 2.2 years, height = 174.2 ± 4.5 cm, weight = 74.0 ± 7.5 kg). Two participants did not complete the intervention, 1 for the rectus femoris and 1 for the gastrocnemius and hamstrings. Exclusion criteria were an injury to the lower extremity in the past 6 months, any surgery to the lower extremity, an allergy or sensitivity to ice, an allergy to povidone-iodine or latex, a known bleeding condition, a wound over the treatment area, or any condition that would make the participant prone to infection. Subcutaneous tissue thickness (mm) and intervention times are presented in Table 1. A power analysis indicated that 17 participants were needed. I calculated preliminary statistics after 14 participants, which supported my hypothesis, so data collection was stopped. Recruiting participants for the longer treatment times (more subcutaneous tissue) was difficult, as body type did not always correlate with subcutaneous tissue thickness.

Instruments

A universal serial bus (USB) temperature data logger and thermocouples (THERMES-USB Temperature Data Acquisition system and IT-18 flexible implantable microprobe; Physitemp Instruments LLC, Clifton, NJ) were used for all intramuscular temperature measurements. The thermocouples were immersed in Cidex OPA (Johnson and Johnson, Markham, ON, Canada) for 24 hours before insertion and wiped clean with a high-level disinfectant. They were marked to the appropriate depth and inserted into the muscle using an 18-gauge × 1.25-in (3.2-cm) sterile hypodermic needle (model 3055; Jelco ProtectIV Safety IV Catheters, Smiths Medical ASD, Inc, Norwell, MA) by a trained clinician.

Diagnostic ultrasound (model T3000; Terason, Boston, MA) was used to measure subcutaneous adipose tissue thickness in order to determine the proper depth of the intramuscular thermocouple for measuring temperature. Previous researchers[26] found this method to be superior to pinch calipers. Subcutaneous tissue depth was measured from the superior fascial line to the inferior fascial line. To this measurement, 1 cm was added for proper thermocouple insertion.[1]

Procedures

Participants reported to an athletic training facility and wore loose-fitting shorts. The beginning position (lying supine or prone) was randomized. If supine was selected, the rectus femoris was measured in session 1. If prone was selected, the medial gastrocnemius and medial hamstrings were measured first, and treatment was applied simultaneously. The testing leg was randomized, but the hamstrings and gastrocnemius were always tested in opposite legs. Diagnostic ultrasound was used to measure subcutaneous adipose tissue thickness and determine the treatment length. A catheter needle was marked to indicate the proper depth of the thermocouple in the muscle. Next, the area was cleaned with 10% povidone-iodine using 2 swab sticks (Povidone-Iodine PVP; Medline Industries, Inc, Northfield, IL), each for 30 seconds. The catheter was inserted into the muscle, and the thermocouple was threaded through it until tissue resistance was felt. The catheter was removed from the muscle, leaving the thermocouple, which was secured to the skin using a clear, occlusive dressing (Tegaderm Transparent Film 6 × 7 cm; 3M Health Care, DeKalb, IL). The participant rested for 10 minutes to allow the temperature to stabilize.

Once the temperature stabilized, a 750-g bag of crushed ice and clear wrap were applied to the area by the same investigator for consistency. After the designated treatment time was completed, the ice bag was removed and the participant continued to lie quietly for 30 minutes. After the rewarming period was over, the thermocouple was removed, the skin was cleaned, and an antibiotic ointment

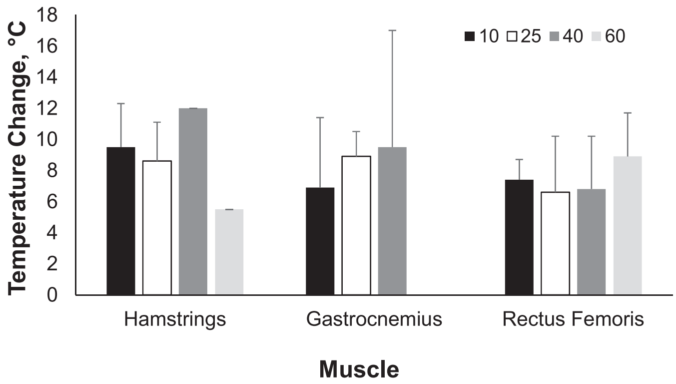

Figure. Temperature change by intervention time (min) for each muscle.

and plastic bandage were applied. The participant was instructed to keep the area clean for the next 24 hours. At least 1 week later, the participant returned to the athletic training facility to complete the study of the remaining muscle(s).

Statistical Analysis

Temperatures at 5 time points were collected: baseline, ice removal (0 minutes), and 10, 20, and 30 minutes after ice removal. Separate repeated-measures analyses of variance were used to assess differences in cooling of each muscle. Post hoc tests were conducted on significant findings. Alpha was set a priori at .05.

RESULTS

At the end of treatment, temperatures did not differ by subcutaneous tissue thickness (10 minutes = 29.0°C ± 3.8°C, 25 minutes = 28.7°C ± 3.2°C, 40 minutes = 28.7°C ± 6.0°C, 60 minutes = 30.0°C ± 2.9°C) or muscle (rectus femoris = 30.1°C ± 3.8°C, gastrocnemius = 28.6°C ± 5.4°C, hamstrings = 28.1°C ± 2.5°C). No significant interaction occurred for subcutaneous tissue thickness or muscle ($P \geq .126$; Figure).

DISCUSSION

Based on these findings, lower extremity muscles appeared to exhibit similar cooling properties, all reaching a change of 7°C after the recommended treatment time for each subcutaneous adipose tissue thickness. I wanted to expand on the work of Otte et al[1] to examine if the suggested cooling times based on subcutaneous adipose tissue would be appropriate for lower extremity muscles other than the thigh. As moving away from standardized cooling times is supported by more evidence, clinicians need guidelines for ice-bag application.

Subcutaneous adipose tissue thickness seems to be a good guideline for achieving similar amounts of lower extremity cooling across patients. A pinch caliper or diagnostic ultrasound could be used to assist clinicians in this task, although the treatment time would need to be adjusted for the amount of adipose tissue measured by each instrument (Table 2).

It should be noted that subcutaneous tissue thickness varies by sex, activity level, and treatment site,[15] providing further evidence that standard treatment times are not ideal and would not provide the same physiological effects. Myrer et al[16] found that an ice-bag application for 20 minutes to the anterior talofibular ligament resulted in 3 times more cooling than the same treatment to the thigh. A contributing factor was the difference in subcutaneous adipose tissue over the area. The anterior talofibular ligament averaged about 2.5 mm, whereas the thigh averaged 25.7 mm. Also, the thermodynamic properties of adipose tissue are low compared with other tissues of the body (eg, skin and muscle).[27] Heat does not transfer well through adipose tissue, making it a good insulator. In relation to ice-bag application, the thicker the adipose tissue, the greater the distance needed for heat conductance, resulting in more time to achieve cooling.[1]

Table 2. Treatment Time Recommendations Based on Mode of Measuring Subcutaneous Tissue Thickness

Treatment Time, min	Measurement Mode, mm	
	Pinch Caliper	Diagnostic Ultrasound
10	0–10	0–5
25	11–20	5.5–10
40	21–30	10.5–15
60	31–40	15.5–20

As clinicians, it is important for us to understand the clinical goal of an intervention. When applying cryotherapy in the form of an ice bag, adipose tissue over the target tissue needs to be taken into consideration if the goal is to reach the muscle. This concept may be difficult for clinicians to convey to patients, especially those with body-image or weight concerns. However, ice only works when used correctly. A suggestion would be to implement protocols for ice application across all patients, such as the use of diagnostic ultrasound to measure subcutaneous tissue. If this technology is not available, the clinician must communicate with the patient that for ice to be effective, the treatment area needs to be assessed using calipers to determine the location of the muscle. I would suggest avoiding using the terms *adipose* or *fat*. As mentioned earlier and from my experience assessing patients, assumptions based on visual inspection are not accurate.

In addition, the clinician should know that the type of cryotherapy and method of application will influence cooling. In this study, a standard clear ice bag was filled with crushed ice and secured directly to the skin with clear wrap. Dykstra et al[20] observed that wetted and cubed ice was more effective in lowering intramuscular temperature than crushed ice. However, this was determined using an ice bag not wrapped around the gastrocnemius and temperature measured 2 cm into the muscle. In other research,[22] a salted ice bag with elastic wrap, GameReady ice bag, and PowerPlay ice bag decreased intramuscular temperatures similarly over a 30-minute intervention. Even though subcutaneous tissue thickness was measured in both studies, treatment times were not altered.

In conclusion, one of the most commonly used modalities in sports medicine still has many unknown application parameters. Future investigators should attempt to identify proper treatment times, potentially related to subcutaneous adipose tissue thickness, and other physiological responses, such as nerve conduction velocity, secondary cell death, and pain. In the lower extremity, it seems that muscle cooling is related to the amount of subcutaneous adipose tissue. Clinicians should move away from standardized treatment times and assess subcutaneous adipose tissue thickness before ice-bag application.

ACKNOWLEDGMENTS

This project could not have been completed without the help of Devin Shannon, MS, ATC, and Rebecca M. Green, MEd, ATC, who conducted all data collection.

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