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The Magnitude of Tissue Cooling During Cryotherapy With Varied Types of Compression

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Context: Certified athletic trainers can choose different types of external compression (none, Flex-i-Wrap, and elastic wrap) when applying an ice bag to the body. However, which type facilitates the greatest magnitude of tissue cooling is unclear.

Objective: To compare the effects of 2 common types of external compression on the magnitude of surface and intramuscular cooling during an ice-bag treatment.

Design: Randomized controlled trial.

Setting: University research laboratory.

Patients or Other Participants: Fourteen college students (10 women, 4 men; age = 22.4 ± 1.8 years, height = 169.1 ± 8.2 cm, mass = 73.3 ± 18.5 kg, skinfold = 13.14 ± 1.61 mm) with previous cryotherapy experience and a posterior lower leg skinfold equal to or less than 15 mm.

Intervention(s): On 3 different days separated by 24 to 48 hours, an ice bag was applied to the posterior lower leg surface of each participant for 30 minutes with no compression, with elastic wrap, or with Flex-i-Wrap.

Main Outcome Measure(s): Posterior lower leg surface and intramuscular (2 cm) temperatures were recorded for 95 minutes.

Results: At 15 minutes, the elastic wrap produced greater surface temperature reduction than no compression ($P = .03$); this difference remained throughout the protocol (P range, .03 to .04). At 30 minutes, surface temperatures were 14.95°C, 11.55°C, and 9.49°C when an ice bag was applied with no external compression, Flex-i-Wrap, and elastic wrap, respectively. Surface temperatures between Flex-i-Wrap and elastic wrap and between Flex-i-Wrap and no compression were never different. At 10 minutes, Flex-i-Wrap ($P = .006$) and elastic wrap ($P < .001$) produced greater intramuscular temperature reduction than no compression produced; these differences remained throughout the protocol. At 10 minutes, no compression, Flex-i-Wrap, and elastic wrap decreased intramuscular temperature by 1.34°C, 2.46°C, and 2.73°C, respectively. At 25 minutes, elastic wrap (8.03°C) produced greater temperature reduction than Flex-i-Wrap (6.65°C) ($P = .03$) or no compression (4.63°C) ($P < .001$). These differences remained throughout ice application and until 50 minutes after ice-bag removal.

Conclusions: During an ice-bag application, external compression with elastic wrap was more effective than Flex-i-Wrap at reducing intramuscular tissue temperature. Elastic wraps should be used for acute injury care.

Key Words: intramuscular temperatures, surface temperatures, insulation

Key Points

- External compression of an ice bag with an elastic wrap provided greater temperature reduction after a 30-minute treatment than did compression with Flex-i-Wrap.
- Intramuscular temperature decreases were different but surface temperature decreases were not different between Flex-i-Wrap and elastic wrap compression.
- Intramuscular temperature was lower with compression than with no compression at 10 minutes and was lower with elastic wrap than with Flex-i-Wrap at 25 minutes.
- Compression with elastic wrap demonstrated a higher average atmosphere-interface temperature than the other conditions.
- Certified athletic trainers should use elastic wrap compression during ice-bag treatments to create a greater magnitude of tissue cooling.

Cryotherapy, which is the application of cold to an injured area, is a treatment protocol used to manage the magnitude of the inflammatory process,[1–9] blood flow,[10–14] initial swelling,[1–6,9,15] secondary injury,[1,3–9,16,17] and pain.[1–3,5–9] Researchers have demonstrated that the application of external compression with cryotherapy greatly decreases both surface and intramuscular temperatures when compared with no compression.[17,18]

Historically, elastic wrap has been the most commonly used type of external compression,[1] but Flex-i-Wrap (Cramer Products Inc, Gardner, KS) has become a popular mode of external compression during the past decade. This disposable plastic wrap is more convenient than elastic wrap for an athlete who leaves the treatment area after application of the ice bag. The ice bag can be removed, and the wrap can be discarded without returning it to the treatment facility. However, it is unknown if compressing an ice bag with Flex-i-Wrap is as effective as compressing it with an elastic wrap. To our knowledge, no investigators have directly compared the magnitude of tissue cooling among different types of external compression. Therefore, the purpose of our study was to compare 2 common methods of external compression on surface and intramuscular temperatures during and after a 30-minute ice-bag application to the posterior lower leg. We wanted to determine the most effective method for reducing tissue temperature.

METHODS

Design

Our study consisted of a 2 (depth) × 3 (compression type) × 13 (time) within-subjects, repeated-measures design. The independent variable compression type consisted of no compression, Flex-i-Wrap, and elastic wrap, and the independent variable time consisted of 0, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, and 90 minutes. The dependent measures of interest were surface temperature and intramuscular temperature 2 cm below the surface.

Participants

Fourteen college students (10 women, 4 men; age = 22.4 ± 1.8 years, height = 169.1 ± 8.2 cm, mass = 73.3 ± 18.5 kg, skinfold = 13.14 ± 1.61 mm) volunteered to participate. At the time of data collection, each participant was healthy; had no history of heart disease, cardiovascular disorder, neurologic disease or injury, or latex or iodine allergy; had no current injury to the lower extremity; and was not under the care of a physician for any illness or injury. Each participant had used cryotherapy with no complications and had no fear of needles. Skinfold thickness of the right posterior calf was measured with a Lange skinfold caliper (Beta Technology Inc, Cambridge, MD). Participants with a skinfold thickness greater than 15 mm were excluded from the study to minimize the effects of adipose thickness among participants.[8,9]

All participants provided written informed consent, and the study was approved by the Institutional Review Board of the University of Nevada, Las Vegas.

Instrumentation

Atmospheric temperature was measured using 1 PT-6 nonimplantable thermocouple (Physitemp Instruments Inc, Clifton, NJ) secured to the cart beside the participant. Surface temperature was measured using 2 PT-6 thermocouples. The mean of these 2 measurements was used for analysis. Before each use, the nonimplantable thermocouples were washed with soap and water.

Intramuscular temperature was measured using a sterile 23-gauge thermocouple (model TX-23-21; Columbus Instruments, Columbus, OH), which was implanted with a 21-gauge disposable needle. All needles were sterile and were disposed of in accordance with Occupational Safety and Health Administration standards. Before the first use, the intramuscular thermocouple was sterilized and sealed in a package. After each subsequent use, the intramuscular thermocouple underwent high-level disinfection by being placed in 10% povidone-iodine for 10 minutes, then bathed in CIDEXPLUS (Advanced Sterilization Products, Irvine, CA) for 40 minutes; immediately before implantation, the intramuscular thermocouple was rinsed with sterile water.[8,9,19,20]

The nonimplantable and intramuscular thermocouples were secured to the skin using Transpore transparent surgical tape (3M Health Care, St Paul, MN). We used an Iso-Thermex electrothermometer (model 256; Columbus Instruments) to sample atmospheric, surface, and intramuscular temperatures at a rate of 60 Hz. The data were collected on a laptop computer.

We attempted to minimize variability by using the same thermocouple in the same channel on the Iso-Thermex. Recently, Jutte et al[21] demonstrated that the Iso-Thermex electrothermometer has a validity and reliability of ±0.03°C. Our Iso-Thermex was calibrated in a range of −50°C to 50°C before our study, which was similar to the calibration reported by Jutte et al.[21] They reported that the error in the PT-6 thermocouples was ±0.1°C. Previously, we measured the reliability and validity of the PT-6 and TX-23-21 thermocouples by comparing the readings recorded on the BAT 10 thermometer (Physitemp Instruments Inc) and the Iso-Thermex thermometer and determined that the variance within the PT-6 and TX-23-21 thermocouples was 0.26°C ± 0.042°C and 0.49°C ± 0.05°C, respectively.[22] In addition, previously reported values for reliability and validity of thermocouples measuring water bath temperature at 5°C, 10°C, 15°C, 20°C, 25°C, and 30°C before and after autoclave sterilization of TX-23-21 thermocouples demonstrated variability between ±0.18°C and ±0.03°C.[21,23]

Treatment

Three treatments were applied to each participant; 1 treatment per day was applied, with treatments separated by 24 to 48 hours. The treatment groups were randomized with a balanced Latin square. Treatments included 30-minute ice-bag application to the right posterior lower leg muscle (1) with no additional compression, (2) compressed with Flex-i-Wrap, and (3) compressed with an elastic wrap.

Procedures

Given that local muscle temperature may be elevated by previous activity,[20,24,25] participants were instructed to limit physical activity 2 hours before their appointments.[19] Because the walk to the laboratory also could elevate local muscle temperature, participants began the experiment each day by lying prone on the padded treatment table for 15 minutes before instrument application to allow local tissue temperature to return to baseline.[10,17] For added comfort, a Pron Pillo (Chattanooga Group, Hixson, TN) was available. Participants could read, watch digital video discs, and perform other tasks involving minimal movement of the lower extremities during the protocol; however, during the experiment, each participant was required to remain prone.

Before the first application, a 10- × 10-cm area of skin over the midportion of the right gastrocnemius belly was shaved and thoroughly cleansed using 10% povidone-iodine followed by a 70% isopropyl alcohol preparation pad.[8,9,17,19,20,26,27] The center of the shaved area served as the site for intramuscular thermocouple implantation and the reference point for surface temperature measurement.

Before the intramuscular thermocouple was disinfected, a black mark was placed at 2 cm on the thermocouple, representing the implantation depth. We also secured a strip of Transpore tape around the needle at 2 cm to represent implantation depth. To decrease the time the needle was in the body, the intramuscular thermocouple was fed through the needle before being implanted in the posterior lower leg. The intramuscular thermocouple was implanted with the marked needle from the posterior aspect of the right gastrocnemius, perpendicular to the treatment table, to the predetermined depth of 2 cm.[9,17,20,26–29] After the needle was inserted to 2 cm, it was removed from the gastrocnemius, exposing the intramuscular thermocouple to the muscle tissue. At this time, the black mark on the intramuscular thermocouple was examined to ensure the proper depth of the intramuscular thermocouple implantation was achieved. To decrease the risk of infection, the second implantation site was 1 cm medial to the initial site, and the third site was 1 cm lateral to the initial site (J. M. Tarno, DO, written communication, September 2004).

Next, the needle was wrapped in a sterile gauze pad and secured distal to the treatment site with a piece of Transpore tape. The nonimplantable thermocouples were then applied 1 cm superiorly and inferiorly to the intramuscular implantation site and were secured with strips of Transpore tape. The thermocouples then were connected to the Iso-Thermex electrothermometer. Five minutes after the thermocouples were in place, intramuscular and surface temperatures were measured every 30 seconds before and during the 30-minute treatment and every 30 seconds during the 60-minute posttreatment.[7–9,17,29] However, the data were analyzed at 0, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, and 90 minutes, with 0 minutes representing the time of ice application and 30 minutes representing the time of ice-bag removal.

A 30- × 41-cm ice bag with the air evacuated and containing 1.58 kg of crushed ice was placed directly over the thermocouples and covered approximately the entire muscle belly of the triceps surae.[19,20,26] The ice bag was not compressed, was compressed with Flex-i-Wrap, or was compressed with an elastic wrap (15.24 cm [6 in] wide, 9.9 m [11 yd] long; Hartmann-Conco Inc, Rock Hill, SC). The same individual (D.T.) applied both Flex-i-Wrap and elastic wrap. Each wrap was applied circumferentially, from distal to proximal, to the limb so 2 layers of the wrap completely covered the ice.

The ice bag remained in place for 30 minutes.[8,9,17,19,20,26] At the conclusion of the 30-minute treatment, the ice bag and wrap (when applied) were removed, and the posterior lower leg was allowed to rewarm. The participant remained in the prone position on the treatment table, preventing excess muscular activity, for 60 additional minutes.[8,9,17,20] At the conclusion of the 90-minute protocol, the surface and intramuscular thermocouples were removed. The limb was dried, the treatment site was swabbed with a 70% isopropyl alcohol preparation pad, and the implantation site was covered with a Band-Aid (Johnson & Johnson, New Brunswick, NJ).[8,9,19,26–28] The participants were scheduled to return 24 to 48 hours later for the second treatment condition and 24 to 48 hours after the second treatment for the third treatment condition.[25] On the subsequent days of the experiment, the same preparation and treatment protocols were followed.

Interface Temperatures

Although it was not part of the study design, we placed 2 additional PT-6 surface probes on the outside of the compressive wraps or on the ice bag with the no-compression treatment on 4 of the 14 participants during all 3 cryotherapy applications. We analyzed the interface temperature between the top of the wrap and the atmosphere during 25 minutes of ice-bag application so we could determine how the ice bag interacted with the atmosphere.

Data Analysis

Mean data were analyzed using 2 separate 3 (compression type) × 13 (time) analysis of variance (ANOVA) procedures with repeated measures. The independent variables of interest were compression type (ice bag with no external compression, ice bag compressed with Flex-i-Wrap, ice bag compressed with elastic wrap) and time (0, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, and 90 minutes). The dependent measure of interest was temperature (surface, intramuscular). When we found an interaction, we used a simple main-effects analysis. We also used a 1-way ANOVA with post hoc Bonferroni correction to test for treatment differences at each level of time. The data were analyzed using SPSS (version 16 for Windows; SPSS Inc, Chicago, IL).

RESULTS

The surface temperature data analysis revealed main effects for compression type ($F_{2,39}$ = 5.92, P = .006) and for time ($F_{12,468}$ = 403.45, P < .001). Most important, we found a compression type-by-time interaction ($F_{24,468}$ = 2.825, P < .001). Before ice-bag application, no difference was found among compression types on surface temperature ($F_{2,39}$ = 0.146, P = .86). At 5 and 10 minutes of ice-bag application, surface temperatures were not different between Flex-i-Wrap and no compression or between elastic wrap and no compression (P > .05) (Figure 1). We found differences between elastic wrap and no compression from 15 minutes through 80 minutes (P range, .03 to .04) (Table 1). No differences in surface temperature were found at any time between no compression and Flex-i-Wrap or between compression with Flex-i-Wrap and elastic wrap (P > .05). At the conclusion of the 30-minute treatment, no compression decreased surface temperature by 15.58°C (51.64%); Flex-i-Wrap, by 18.52°C (61.59%); and elastic wrap, by 20.79°C (68.66%).

The intramuscular temperature data analysis revealed main effects for compression type ($F_{2,39}$ = 21.7, P < .001) and for time ($F_{12,468}$ = 629.33, P < .001). Again, the analysis revealed a compression type-by-time interaction ($F_{24,468}$ = 7.936, P < .001). Before ice-bag application, no difference was recorded among compression types on intramuscular temperature ($F_{2,39}$ = 0.341, P = .732). At 10 minutes of ice-bag application, both Flex-i-Wrap (P = .006) and elastic wrap (P < .001) produced greater intramuscular temperature reductions than no compression

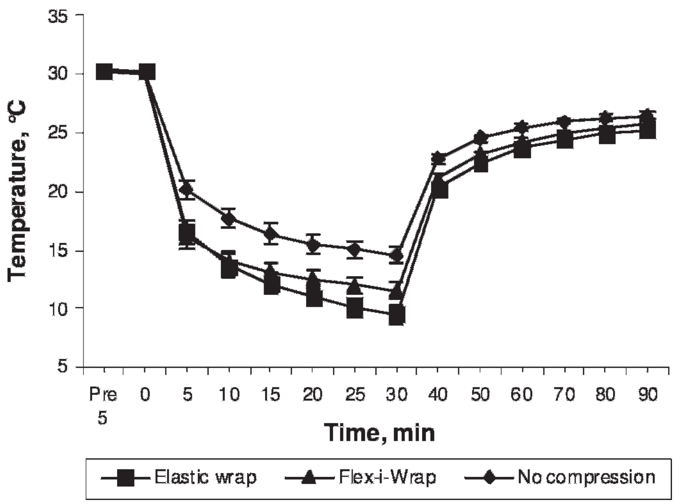

Figure 1. Surface temperature over time (mean ± standard error). The ice bag was applied at 0 minutes and removed at 30 minutes.

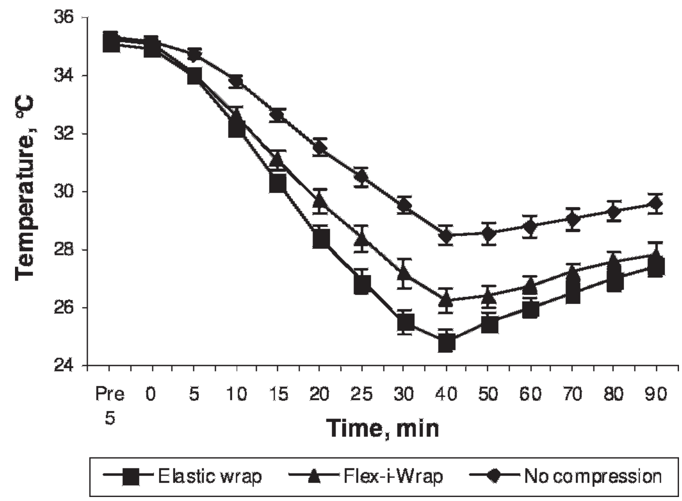

Figure 2. Intramuscular temperature over time (mean ± standard error). The ice bag was applied at 0 minutes and removed at 30 minutes.

(Figure 2). At this time, no compression decreased intramuscular temperature by 1.34°C (3.82%); Flex-i-Wrap, by 2.46°C (7.03%), and elastic wrap, by 2.73°C (7.82%) (Table 2). These differences remained throughout the duration of the protocol. At 25 minutes of ice-bag application, elastic wrap produced lower intramuscular temperature than Flex-i-Wrap produced ($P = .03$). At this time, intramuscular temperature decreased by 6.65°C (18.98%) with Flex-i-Wrap and by 8.03°C (22.99%) with elastic wrap. This difference persisted throughout the remaining 5 minutes of the ice-bag application and until 50 minutes after ice-bag removal. After 30 minutes of ice-bag application, intramuscular temperature decreased by 5.60°C (15.95%) with no compression, 7.87°C (22.47%) with Flex-i-wrap, and 9.40°C (26.91%) with elastic wrap. No compression (6.64°C [18.91%]), Flex-i-Wrap (8.78°C [25.03%]), and elastic wrap (10.06°C [28.8%]) each generated their largest intramuscular temperature decreases 10 minutes after ice-bag removal.

Interface Temperatures

Table 3 presents our findings from our analysis of the interface temperatures between the top of the wrap and the atmosphere during 25 minutes of ice-bag application for the 4 participants. The average interface temperature between the atmosphere and the surface of the elastic wrap was 11.99°C, whereas the same measurements with Flex-i-Wrap and no compression were 9.66°C and 9.32°C, respectively (Figure 3).

DISCUSSION

Our most interesting finding was that ice-bag application with Flex-i-Wrap was not different from ice-bag application with no compression or with an elastic wrap with respect to surface temperature. However, compression with an elastic wrap produced lower surface temperatures than no compression. These differences in surface temperatures

Table 1. Surface Temperature With 3 Compression Types (Mean ± SD)

	Ice-Application Technique								
	Ice Only			Flex-i-Wrap[a]			Elastic Wrap		
Time, min	Temperature, °C	Decrease, °C	Decrease, %	Temperature, °C	Decrease, °C	Decrease, %	Temperature, °C	Decrease, °C	Decrease, %
0	30.17 ± 1.25			30.07 ± 1.19			30.28 ± 1.28		
5	20.16 ± 4.39	10.01	33.17	16.09 ± 5.12	13.98	46.49	16.53 ± 5.50	13.75	45.41
10	17.73 ± 4.54	12.44	41.23	14.04 ± 4.81	16.03	53.30	13.67 ± 5.27	16.61	54.85
15	16.42 ± 4.50[b]	13.75	45.58	13.13 ± 4.41	16.94	56.34	12.12 ± 4.83	18.16	59.97
20	15.51 ± 4.34[b]	14.66	48.59	12.52 ± 4.12	17.55	58.36	11.02 ± 4.39	19.26	63.61
25	15.03 ± 4.14[b]	15.14	51.18	12.01 ± 3.92	18.06	60.06	10.16 ± 4.13	20.12	66.45
30	14.59 ± 3.98[b]	15.58	51.64	11.55 ± 3.77	18.52	61.59	9.49 ± 3.95	20.79	68.66
40	22.86 ± 2.02[b]	7.31	24.43	21.09 ± 2.20	8.98	29.86	20.27 ± 2.08	10.01	33.06
50	24.58 ± 1.63[b]	5.59	18.53	23.18 ± 1.61	6.89	22.91	22.45 ± 1.56	7.83	25.86
60	25.45 ± 1.40[b]	4.72	15.64	24.25 ± 1.42	5.82	19.35	23.69 ± 1.55	6.59	21.76
70	25.96 ± 1.31[b]	4.21	13.95	24.95 ± 1.39	5.12	17.03	24.41 ± 1.50	5.87	19.39
80	26.28 ± 1.24[b]	3.89	12.89	25.40 ± 1.40	4.67	15.53	24.92 ± 1.50	5.36	17.70
90	26.50 ± 1.23	3.67	12.16	25.81 ± 1.47	4.26	14.17	25.30 ± 1.37	4.98	16.45

[a] Cramer Products Inc, Gardner, KS.
[b] Indicates a difference in surface temperature between elastic wrap and ice only ($P < .05$).

Table 2. Intramuscular Temperature With 3 Compression Types (Mean ± SD)

	Ice-Application Technique								
	Ice Only			Flex-i-Wrap[a]			Elastic Wrap		
Time, min	Temperature, °C	Decrease, °C	Decrease, %	Temperature, °C	Decrease, °C	Decrease, %	Temperature, °C	Decrease, °C	Decrease, %
0	35.12 ± 0.63			35.04 ± 0.58			34.93 ± 0.65		
5	34.72 ± 0.71	0.40	1.14	34.05 ± 0.81	0.99	2.84	33.99 ± 0.68	0.94	2.70
10	33.78 ± 0.77[b]	1.34	3.82	32.58 ± 1.20	2.46	7.03	32.20 ± 0.86	2.73	7.82
15	32.61 ± 0.92[b]	2.51	7.15	31.07 ± 1.34	3.97	11.33	30.28 ± 1.15	4.65	13.31
20	31.52 ± 1.05[b]	3.60	10.26	29.67 ± 1.52	5.37	15.33	28.45 ± 1.42	6.48	18.55
25	30.49 ± 1.11[b]	4.63	13.19	28.39 ± 1.67	6.65	18.98	26.90 ± 1.52[c]	8.03	22.99
30	29.52 ± 1.18[b]	5.60	15.95	27.17 ± 1.77	7.87	22.47	25.53 ± 1.56[c]	9.40	26.91
40	28.48 ± 1.28[b]	6.64	18.91	26.26 ± 1.61	8.78	25.03	24.87 ± 1.47[c]	10.06	28.80
50	28.55 ± 1.33[b]	6.57	18.71	26.39 ± 1.34	8.65	24.69	25.46 ± 1.26[c]	9.47	27.12
60	28.80 ± 1.33[b]	6.32	18.00	26.77 ± 1.13	8.27	23.61	26.00 ± 1.23[c]	8.93	25.57
70	29.04 ± 1.31[b]	6.08	17.32	27.21 ± 1.16	7.83	22.35	26.51 ± 1.31[c]	8.42	24.11
80	29.31 ± 1.31[b]	5.81	16.55	27.59 ± 1.24	7.45	21.27	26.98 ± 1.36[c]	7.95	22.76
90	29.57 ± 1.32[b]	5.55	15.81	27.82 ± 1.50	7.22	20.61	27.41 ± 1.37	7.52	21.53

[a] Cramer Products Inc, Gardner, KS.
[b] Indicates intramuscular temperature was lower with Flex-i-Wrap and with elastic wrap than with no compression ($P < .05$).
[c] Indicates intramuscular temperature was lower with elastic wrap than with Flex-i-Wrap ($P < .05$)

when using elastic wrap compression occurred after 15 minutes of ice-bag application and remained throughout the protocol until 80 minutes. Surface temperature reduction under a variety of treatment conditions has been widely reported.[2,9,16,17,24,25,30,31] Typically, surface temperatures decrease between 20°C and 25°C after 30 minutes of ice-bag application. The final surface temperatures that we reported were higher than most reported surface temperatures.[2,9,17,24,25,31,32] Surface temperature decrease and recovery over time are similar to those previously reported (Figure 1).[2,9,17,24,25,31,32]

During our study, intramuscular tissue temperature decreased 5.60°C with no external compression, 7.87°C with Flex-i-Wrap, and 9.40° with an elastic wrap at the conclusion of a 30-minute ice-bag application (Table 2). However, lowest temperatures were recorded 10 minutes posttreatment (40 minutes): 28.48°C for no compression, 26.26°C for Flex-i-Wrap, and 24.87°C for elastic wrap. At 10 minutes, we found a difference in intramuscular temperature between compression and no compression, which remained for the duration of the protocol. By 25 minutes of ice-bag application, the intramuscular temperature under the elastic wrap was lower than it was when under the Flex-i-wrap. An additional 1.49°C intramuscular temperature decrease occurred when an elastic wrap was used instead of Flex-i-Wrap as external compression.

Table 3. Interface Temperature Between the Compressive Wrap and the Atmosphere With 3 Compression Types

	Ice-Application Technique		
Time, min	Ice Only	Flex-i-Wrap[a]	Elastic Wrap
4	9.00°C	8.17°C	11.82°C
9	8.96°C	8.80°C	11.54°C
14	9.13°C	9.36°C	11.92°C
19	9.31°C	10.09°C	12.06°C
24	9.62°C	10.55°C	12.21°C
29	9.90°C	10.97°C	12.39°C
25-min average	9.32°C	9.66°C	11.99°C

[a] Cramer Products Inc, Gardner, KS.

To explain these differences, we examined the insulation effects of the different types of external compression. Compression with the elastic wrap demonstrated a higher average atmosphere-interface temperature than either other condition. Flex-i-Wrap and no compression had similar atmosphere-interface temperatures. The primary factor in reduced tissue temperature with elastic wrap possibly is an increased insulation effect. This is substantiated by the 2.33°C difference between the average Flex-i-Wrap (9.66°C) and the elastic wrap (11.99°C) atmosphere-interface temperatures. We believe a higher atmosphere-interface temperature assisted in generating the additional temperature decrease after a 30-minute ice-bag application with an elastic wrap compared with Flex-i-Wrap and no compression. Because Flex-i-Wrap and no compression had similar interface temperatures, we believe that the primary factor in a reduced tissue temperature between compression and no compression may be improved contact between the tissue and the ice bag during a compression application. We believe the primary factor in a reduced intramuscular tissue

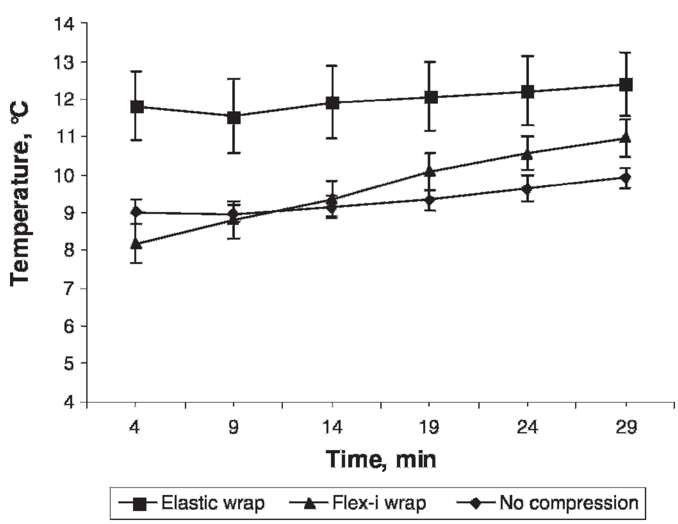

Figure 3. Atmosphere-interface temperature over time during ice-bag application (mean ± standard error).

temperature between types of compression is the amount of insulation present in the compressive wrap. This may explain the differences between our findings and those previously reported.[17,19,20,26,27,31]

During the Flex-i-Wrap condition, the intramuscular temperature at the conclusion of the ice-bag application was 27.17°C (a decrease of 7.87°C). This is a smaller decrease than decreases reported in most previous studies at the fat-plus 1-cm depth.[17,19,20,26,27,31] Our intramuscular temperature with an elastic wrap was 25.53°C (a decrease of 9.40°C) after the 30-minute ice-bag application. This temperature decrease was smaller than decreases reported in all previous studies using compression except that of Merrick et al[17] at the fat-plus 1-cm depth (23.54°C).[9,17,20,26,27,31] Of note, we found a smaller temperature decrease than Myrer et al,[19] who reported an intramuscular temperature decrease of 14.43°C without compression in the less-than-8-mm fat-plus 1-cm group and of 10.62°C in the 10- to 18-mm fat group[19] at the conclusion of a 20-minute ice-bag application. It is unclear why a shorter duration of ice application (20 versus 30 minutes) without compression resulted in the colder treatment; however, some differences appear to exist in the magnitude of cooling measured when using similar, yet varied, methods of temperature measurement.

Because we chose to use an absolute depth of measurement in a homogeneous group, we may have actually cooled less tissue, resulting in less tissue cooling than we reported. When we applied cryotherapy, intramuscular temperature decreased gradually between 5°C and 8°C after 30 minutes. When cryotherapy was removed, the intramuscular temperature continued to decrease another 2°C to 3°C during the next 10 minutes before it gradually increased toward baseline. After 60 minutes of rewarming, the intramuscular temperature was still depressed between 5°C and 8°C when compared with baseline temperatures across all conditions. Comparisons of the data from the intramuscular temperatures revealed a similar pattern of temperature decreases between our study and previous studies.[17,19,20,26,27,31]

Merrick et al[17] examined the effect of external compression during cryotherapy on surface and intramuscular temperatures. The authors standardized the amount of external compression between 42 and 48 mm Hg, then they applied an ice bag to the anterior thigh for 30 minutes, measuring surface, fat-plus 1-cm, and fat-plus 2-cm temperatures. Surface temperatures decreased by 7.24°C to 25.26°C with no compression and by 4.94° to 27.56°C with compression. Intramuscular temperatures at 1 cm subadipose decreased by 9.7°C to 26.58° when no external compression was applied and by 12.7°C to 23.54°C when an elastic wrap was applied. Intramuscular temperatures at the fat-plus 2-cm depth decreased by 8.38°C to 28.21°C without external compression and by 10.13°C to 26.46°C with external compression.

There are several possible explanations, such as intramuscular depth, instrumentation, and amount of compression applied, for why our final intramuscular temperatures were warmer than those reported by Merrick et al.[17] We believe the most likely reason is the depth of measurement. Examining intramuscular temperature at the specific and constant depth of 2 cm on every participant is a measurement method not previously reported. Previous authors have used an equation, (skinfold/2) + desired implantation depth, to measure intramuscular temperature at a constant depth below adipose, where the actual implantation depth varied based on the amount of skinfold in the individual.[8,9,17,19,20,26,27,31] We chose to control adipose tissue depth by using a homogeneous group of participants (skinfold ≤15 mm), based on the research of Myrer et al[19] and Jutte et al,[9] who suggested that adipose thickness alters the rate of intramuscular tissue cooling.

Merrick et al[17] reported a mean anterior thigh skinfold of 15.8 ± 3.7 mm, and they used the equation (skinfold/2) + 1 cm to determine the intramuscular thermocouple implantation depth. Their procedure possibly would put their intramuscular thermocouple at an average depth of 17.9 mm, with an average adipose of 7.9 mm overlying the intramuscular thermocouple. If we had used the same formula, our average implantation depth would have been 16.57 mm, with an average adipose of 6.57 mm overlying the intramuscular thermocouple.

After 20 minutes of ice application, Myrer et al[19] found a 14.4°C intramuscular temperature decrease in individuals with less than 8-mm skinfold overlying the treatment site, a 9.1°C decrease in individuals with a 10- to 18-mm skinfold, and a 5°C decrease in individuals with equal to or greater than 20-mm skinfold. The authors did not state whether their ice bag was compressed; we presumed it was not. In our study, intramuscular temperature decreased 6.48°C after 20 minutes with elastic wrap compression, whereas it decreased only 3.60°C with no compression. Myrer et al[19] reported a 14.4°C decrease at 1 cm deep after 20 minutes of ice application when an average adipose of 3.25 mm overlay the treatment area. We used an implantation depth of 200 mm, which was almost twice as deep as they reported (103.25 mm) and was underlying a greater amount of adipose (6.57 mm versus 3.25 mm); therefore, the resultant temperature decreases we found should have been less than those reported by Myrer et al.[19]

Another explanation for the difference between the intramuscular temperatures seen in our study and in others is the amount of compression applied during each treatment. Serwa et al[33] showed that an extremely tight application of external compression (50 to 60 mm Hg) did not produce an intramuscular temperature decrease when compared with an average compressive force (30 to 40 mm Hg). Although no statistical differences in temperature were observed among compression amounts, forces, or tightness, actual differences existed. Some authors[17,24,33,34] have used a manometer to quantify the amount of external compression. Merrick et al[17] quantified their compressive wraps between 42 and 48 mm Hg. We were unable to quantify the amount of external compression applied during the experimental conditions. Our inability to quantify and standardize the amount of compression applied during each treatment is a limitation of our experimental protocol.

We determined that compression of any kind results in a greater magnitude of tissue cooling compared with not compressing the ice bag. Compressing an ice bag to the body may reduce the amount of space between the ice bag and the tissue, allowing more ice to interact with the tissue. We did not apply a compression-only trial or measure blood flow, so we could not determine if one type of compression (elastic wrap or Flex-i-Wrap) would alter surface or intramuscular temperature more than the other when no ice bag was placed under the compressive wrap or if one type of compression would decrease blood flow more than the other.

We created an intramuscular temperature decrease of 5.60°C, 7.87°C, and 9.40°C when an ice bag was applied to the posterior lower leg for 30 minutes with no compression, with Flex-i-Wrap, and with elastic wrap, respectively. Each of our intramuscular temperatures was measured at the constant depth of 2 cm; however, as stated, we controlled adipose tissue by excluding individuals who had a skinfold measurement of more than 15 mm over the posterior lower leg.

Our results further demonstrated that intramuscular temperature values cannot be accurately predicted from surface temperature, as presented by Jutte et al,[9] and that target tissue temperature is a more important determining factor for adequate intramuscular temperature decrease than surface temperature. We are the first to describe a difference in intramuscular temperature decrease between cryotherapy applications (an ice bag compressed with Flex-i-Wrap or elastic wrap) without observing a difference in surface temperature decrease between the same 2 cryotherapy applications. This observation was unexpected, but it is interesting that the 2 types of external compression resulted in surface temperature decreases that were not different but in intramuscular temperatures that were different.

We found a temperature difference between types of external compression when intramuscular temperature was examined. When cryotherapy is used in conjunction with an elastic wrap, the intramuscular temperature will be lower than when an ice bag is compressed with Flex-i-Wrap after only 25 minutes of application, which is a standard ice-application time. This difference in intramuscular cooling will continue for at least another 10 minutes if the patient remains at rest.

After an acute injury, the protocol of rest, ice, compression, elevation, and stabilization should be used to treat the area, and an elastic wrap should be used as external compression instead of Flex-i-Wrap. If a lower intramuscular temperature is created, the cryotherapy treatment may reduce secondary injury, edema formation, and blood flow. This protocol might allow the athlete to return to participation sooner.

CONCLUSIONS

External compression with an elastic wrap provided a greater magnitude of tissue cooling after a 30-minute ice-bag treatment compared with the ice bag compressed with Flex-i-Wrap. This can be explained by the greater insulation provided by the elastic wrap. We believe that certified athletic trainers should use elastic wraps during ice-bag treatments to create greater magnitude of tissue cooling. This greater magnitude of tissue cooling may result in quicker recovery from athletic injuries, presuming that a treatment that causes greater cooling is of greater benefit. The ideal temperature reduction with cryotherapy for the management of injury has yet to be determined.

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