Received: 29 November 2018 | Revised: 4 March 2019 | Accepted: 2 April 2019
DOI: 10.1111/sms.13430

ORIGINAL ARTICLE

WILEY

The effect of varying degrees of compression from elastic vs plastic wrap on quadriceps intramuscular temperature during wetted ice application

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The aim of this study was to evaluate and compare the effectiveness of wetted ice bag, applied with high compression elastic wrap or held in place with low compression plastic wrap, on reducing vastus lateralis intramuscular temperature and skin surface temperature. Ten healthy male participants had wetted ice packs applied to a standardized area on the anterior aspect of the quadriceps simultaneously to both legs for 30 minutes. The ice pack was secured with high compression (elastic wrap) to the left anterior thigh (60.6 ± 8.1 mm Hg) and low compression (plastic wrap) to the right anterior thigh (15.5 ± 4.0 mm Hg). Intramuscular temperature (1 and 3 cm) and skin temperature of the vastus lateralis were measured continuously during a 10-minute baseline period, 30-minute treatment period, and a 60-minute recovery period. No difference was observed between treatments in terms of the magnitude of reduction in intramuscular temperature at both 1 and 3 cm and skin temperature regardless of compression pressure ($P > 0.05$). Temperature upon conclusion of elastic wrap treatment was as follows: 17.8 ± 5.2°C at 1 cm and 23.1 ± 4.9°C at 3 cm; plastic wrap treatment: 17.9 ± 4.4°C at 1 cm and 24.5 ± 6.7°C at 3 cm. Plastic wraps may offer a practical alternative to elastic wraps for clinicians as they may be disposed of by the patient or athlete without having to stay at the treatment facility.

KEYWORDS
cryotherapy, ice bag, muscle recovery, thermocouple

1 | INTRODUCTION

Cryotherapy is the mainstay of clinical practice for the acute management of soft tissue injuries such as muscle tears and contusions.[1-5] In these conditions, the goal is to reduce tissue temperatures to limit blood flow and metabolic rate at the site of injury[6-8] in order to limit the secondary injury response that occurs after the acute trauma.[9] Early application of ice, often with added water to facilitate contact with the skin as well as to improve heat transfer between the treatment and the skin, immediately following soft tissue injury may lead to improved outcomes.[5] Unfortunately, to date, research examining the effects of ice application following contusion is limited to studies in animal models. Investigations have found that cryotherapy can attenuate inflammatory cell infiltration, oxidative stress markers, and modulate edema.[10,11] Immediate application of ice after experimentally induced muscle injury in animal models has been shown to modulate the impairment in mitochondrial function and skeletal muscle morphology,[11] reduce the size of the hematoma,[12] and reduce the subsequent tissue edema.[13] Thus, there is a good scientific rationale for the application of ice treatment immediately after muscle injury.

In clinical practice, ice treatments are typically applied in conjunction with compression, often with either elastic wrap[14-16] or more recently plastic wrap.[17] It is well understood that cryotherapy combined with compression decreases both surface and intramuscular temperatures when compared with no compression,[14-18] which may enhance recovery following acute muscle injury. However, the ideal magnitude of compression has not been established and there are no clear, evidence-based guidelines on how best to use compression in conjunction with ice application. Furthermore, the degree of compression applied by practitioners varies greatly.[19] The rationale for minimal compression is simply to hold the ice bag in place and to ensure uniform contact to the skin. Alternatively, increased compression is thought to control the formation of edema[20] and to enhance the effectiveness in reducing tissue temperature.[14-18]

Studies that have examined the role of compression in conjunction with ice treatment are limited because the control condition, defined as no compression, involved either placing an ice bag on top of the muscle[14,15,17] or the limb on top of the ice bag;[16] both of which result in some degree of compression that was unaccounted for. The benefit of compression, in terms of magnitude of cooling the skin, can be achieved from compression as low as 14 ± 2 mm Hg using elastic wrap.[21] However, it is not known if the weight of either the limb or the ice bag itself is sufficient to provide compression in this range. Practitioners continue to believe that securing ice in place with elastic wrap to facilitate increased compression will reduce tissue temperature more than simply placing an ice bag over a treatment area. Alternatively, plastic wrap used to secure the ice bag in place may provide sufficient compression to optimize tissue cooling.

The important clinical question is whether or not the magnitude of compression from elastic wraps, 41-55 mm Hg,[19] does in fact lead to temperature reductions greater than from plastic wrap applied simply to hold the treatment in place. Therefore, the aim of this study is to compare reductions of intramuscular temperature between ice bags applied with high compression elastic wrap vs with low compression plastic wrap.

2 | MATERIALS AND METHODS

2.1 | Design

Vastus lateralis intramuscular temperature at 1 and 3 cm and skin temperature were compared between ice bag treatments. Treatments were applied simultaneously with high compression (elastic wrap) to the left anterior thigh and low compression (plastic wrap) to the right anterior thigh for all subjects.

2.2 | Participants

Ten men (mean ± SD; age, 35 ± 8 years; height, 178.8 ± 6.2 cm; body mass, 80.5 ± 4.8 kg) volunteered to participate in this study. Prior to participation, volunteers were informed of the procedures and provided written, informed consent. All participants were free from lower extremity injury within 1 month of the study, vascular disease in the lower leg, compromised circulation in the lower leg, allergy to cold or ice, as detailed in a medical screening questionnaire. The institutional research ethics committee approved all procedures in accordance with the Declaration of Helsinki and participants gave written informed consent.

2.3 | Instrumentation

To account for subcutaneous fat layers, skinfold at the site of thermocouple insertion on the quadriceps was measured using calipers (Harpenden, Baty International, West Sussex, UK). Thermocouple insertion depth was verified by subtracting the total insertion depth (1 cm or 3 cm plus half the skinfold) from the corresponding length of the needle used. The difference (length of needle minus calculated insertion depth) was verified with a sterile ruler. One 45 and one 32 mm sterile intravenous 20 gauge needle catheter was used for the 3 and 1 cm insertion, respectively.

The vastus lateralis was marked approximately 6 cm lateral to the mid-point between the superior pole of the patella and the anterior-superior iliac crest using a sterile felt-tip pen. An additional marking was placed 1 cm inferior to and 1 cm superior to the mid-point to represent the thermocouple insertion sites. The marked area was cleaned with a povidone-iodine surgical scrub solution for 30 s in preparation for insertion of intramuscular temperature probes. The 3 cm thermocouple was always inserted first, at 1 cm proximal to the previously marked midpoint. Once at the correct insertion depth, the needle was removed and the flexible catheter remained inserted. A sterile flexible intramuscular thermocouple probe (Type T, IT-21; Physitemp Instruments, Clifton, NJ) was threaded through the barrel of the catheter to the pre-calculated depth. The catheter was removed from the muscle, and threaded and taped using surgical tape to the head of the thermocouple cable to secure it away from the insertion site, while the thermocouple remained inserted. This procedure was then repeated for the 1 cm deep thermocouple inserted 1 cm distal to the marked midpoint. The thermocouple insertion sites were secured in place with one patch of sterile Tegaderm by bending the thermocouples at the insertion flush with the skin. A superficial thermocouple was secured with a 1 cm x 2 cm long piece of transopore tape directly next to the Tegaderm at the insertion site on each leg to measure skin temperature. The three thermocouples per leg were then connected to a digital monitor (Bailey Instruments BAT-12, Physitemp Instruments, Inc) for continuous recording.

Actual insertion depth was verified at the conclusion of data collection by measuring the length of the thermocouple from the point exiting the skin to the tip of the probe using a sterile ruler. The superficial thermocouple and manometer were removed. A topical antiseptic solution (bacitracin) was applied to the insertion sites and covered with sterile adhesive bandages. Subjects reported no adverse events or infections. Intramuscular thermocouples were cleaned and disinfected for repeated applications using CidexPlus solution.[22]

2.4 | Compression measurement

To ensure consistency of the applied pressure between the treatment conditions, a manometer (Kikuhime, TT Medi Trade) was placed between the thigh and the ice bag to quantify the compression. The bladder of the manometer was placed at the center of the distal margin of the cleaned area and secured with transpore tape so that it would not act as a thermal insulator for any thermocouple. The wraps were adjusted until the high compression treatment reached at least 50 mm Hg (elastic wrap), while the low compression treatment was no more than 20 mm Hg (plastic wrap). The level of compression was set at the start of the experiment and no further pressure adjustment was made, replicating clinical conditions where treatment is rarely adjusted once applied. To ensure consistency, the same individual was responsible for wrapping the ice bags.

2.5 | Cryotherapy treatments

Once the thermocouples were inserted to the respective depths, instantaneous temperature measurements were taken at 1-second intervals for the duration of the experiment. Subjects remained in a seated position throughout the duration of the experiment. A 10-min baseline recording preceded application of the ice treatments. Then 30- x 41-cm wetted ice bags (Cramer Products Inc), weighing 1.2 kg with 236.6 mL of water added, were placed over the muscle belly of the vastus lateralis. On the left leg, the ice bag was secured with a 1.34 m × 15 cm (6-in single) elastic wrap (Chattanooga, DJO llc) applied circumferentially from distal to proximal around the treated limb while on the right leg the ice bag was secured with plastic wrap (Flexi-Wrap, Cramer Products Inc, Gardner, KS; see Figure 1). The plastic wrap was applied with sufficient pressure to hold the ice bag in place without it slipping laterally. This replicated the routine clinical application of ice to the thigh for the treatment of a quadriceps contusion. The elastic wrap was applied with as much pressure as could be comfortably tolerated by the subject. Care was taken to remove air from the ice bags before strapping them to the thigh. After 30 minutes, the ice and compression wraps were removed and recovery of skin and muscle temperature was recorded for an additional 60 minutes.

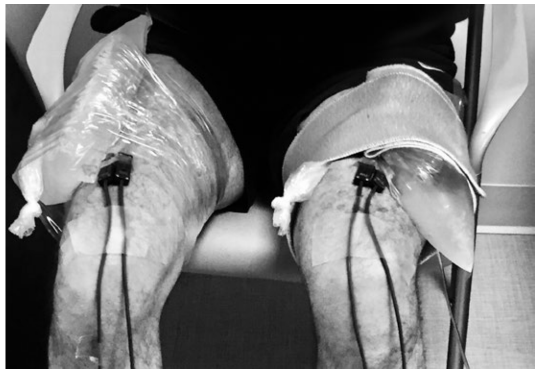

FIGURE 1 Participant during cryotherapy treatment. Ice bag secured with a high compression pressure (avg: 60.6 ± 8.1 mm Hg) elastic wrap on the left leg and ice bag secured with low compression (avg: 15.5 ± 4.0 mm Hg) plastic wrap on the right leg

2.6 | Statistical analysis

Statistical analyses were performed using SPSS v.21 (IBM). The comparison of treatments over time was assessed using a 2 × 19, treatment by time, repeated measures analyses of variance (ANOVA) for intramuscular temperature at each depth and for skin temperature. The levels for the treatment factor were (low vs high compression) and time (baseline, 5 minutes through to 90 minutes in 5 minutes increments (30-minute treatment and 60-minute post-treatment). Where necessary, pairwise comparisons of temperatures between the two treatments were performed using Fisher's LSD test. Within each treatment, the changes in dependent variables over time were assessed by a one factor ANOVA with differences vs baseline assessed using Bonferroni corrections for planned pairwise comparisons based on the number of time intervals in the particular ANOVA. Additionally, Pearson product-moment correlations were used to assess the relationship between thigh skinfold thickness and intramuscular temperature. Data are presented as mean ± standard deviation. Statistical significance was set at $P < 0.05$ for all comparisons. All statistical analyses were performed using SPSS v.21 (IBM).

3 | RESULTS

3.1 | Pressure data

Actual compression pressures were 60.6 ± 8.1 mm Hg for the high compression elastic wrap leg, and 15.5 ± 4.0 mm Hg for the low compression plastic wrap leg. The lowest applied pressure for the compression elastic wrap leg was 51.4 mm Hg, while the highest was 73.1 mm Hg. The lowest applied pressure for the plastic wrap leg was 8 mm Hg, while the highest was 20 mm Hg. The mean difference between treatments was 45.1 ± 8.3 mm Hg ($P = 0.0001$).

3.2 | Intramuscular temperature

Actual thermocouple insertion depths, corrected for skinfold measurements (skinfold: low compression, 14.9 ± 5.6 mm; high compression, 15.3 ± 5.3 mm) were 2.8 ± 0.3 cm and 1.4 ± 0.4 cm for high compression elastic wrap and 2.8 ± 0.4 cm and 1.0 ± 0.4 cm for low compression plastic wrap. Insertion depths were not different between treatments (difference between treatments: 3 cm, 0.02 ± 3.2 mm, $P = 0.85$; 1 cm, 0.35 ± 7.0 mm, $P = 0.15$).

The peak temperature effect for each treatment condition is reported in Table 1. During both treatments, intramuscular temperature at 3 cm declined progressively and showed a gradual recovery toward baseline when the treatment was removed, with no difference between treatments (treatment effect $P = 0.421$; time effect $P < 0.001$; treatment by time $P = 0.522$; Figure 2). Intramuscular temperature at 1 cm declined progressively during both treatments, with initially a slower recovery toward baseline in the low compression treatment (treatment effect $P = 0.475$; time effect $P < 0.001$; treatment by time $P = 0.004$). Ten min into recovery, intramuscular temperature at 1 cm was 1.9 ± 2.2°C lower from low compression plastic wrap vs high compression elastic wrap ($P = 0.023$). This difference was still significant 5 min later (1.5 ± 1.7°C; $P = 0.021$), but there were no differences between treatments at any other time interval (Figure 2).

Intramuscular temperatures decreased from baselines of 35.1 ± 1.1°C at 3 cm and 34.4 ± 1.3°C at 1 cm, to 23.1 ± 4.9°C at 3 cm and 17.8 ± 5.2°C at 1 cm by the end of the high compression elastic wrap treatment. Intramuscular temperatures decreased from baselines of 35.4 ± 0.9°C at 3 cm and 34.4 ± 0.9°C at 1 cm, to 24.5 ± 6.7°C at 3 cm and 17.9 ± 4.4°C at 1 cm by the end of the low compression plastic wrap treatment (Figure 2). After 1 h of recovery, intramuscular temperature remained significantly below baseline in the high compression (28.6 ± 1.8°C at 3 cm, $P < 0.001$; 27.6 ± 1.7°C at 1 cm, $P < 0.001$) and low compression conditions (29.3 ± 2.3°C at 3 cm, $P < 0.001$; 27.4 ± 1.4°C at 1 cm, $P < 0.001$). Decreases in intramuscular temperature were inversely related with skinfold thickness at 1 cm ($r = -0.67$, $P < 0.001$) and at 3 cm ($r = -0.57$, $P < 0.001$).

3.3 | Skin temperature

Skin temperatures during treatments were slightly lower for the high compression elastic wrap vs the low compression plastic wrap treatment, but early in recovery skin temperatures were slightly higher for the elastic wrap vs the plastic wrap conditions (treatment by time $P = 0.026$; Figure 3). However, at no time point during treatment or recovery was there a difference in skin temperature between treatments based on pairwise comparisons.

4 | DISCUSSION

The main finding in this study was that cooling the anterior thigh utilizing a wetted ice bag secured to the leg with plastic wraps applying low compression was comparable to using elastic wraps applying substantial compression in terms of the magnitude of reduction in intramuscular temperature of the vastus lateralis at both 3 and 1 cm (Figure 2) and skin temperature of the anterior thigh (Figure 3). Our data reached a nadir of 18°C from both treatments at 1 cm while at 3 cm intramuscular temperature reached a nadir of 23°C from elastic wrap and 25°C from plastic wrap. Our values are comparatively lower than previously reported effects in both the anterior thigh (24 and 26°C,[14] and 28 and 32°C,[15] at 1 and 2 cm, respectively, subadipose) and medial calf (20°C[16] and 25°C,[17] at 1 cm subadipose and 2 cm absolute depth, respectively) applying compression using elastic wrap. Importantly, marginally lower skin and intramuscular temperatures have been reported when applying wetted as opposed to dry ice bags with[15] and without[23] added compression, because a wet interface may allow for greater thermal conduction than a dry interface. Since we added one cup of water to each ice bag, the wet ice in the present study may have enhanced thermal conduction regardless of the degree of compression. This may help explain why our intramuscular temperatures were lower than those previously reported in studies that used dry ice bags.[14-17]

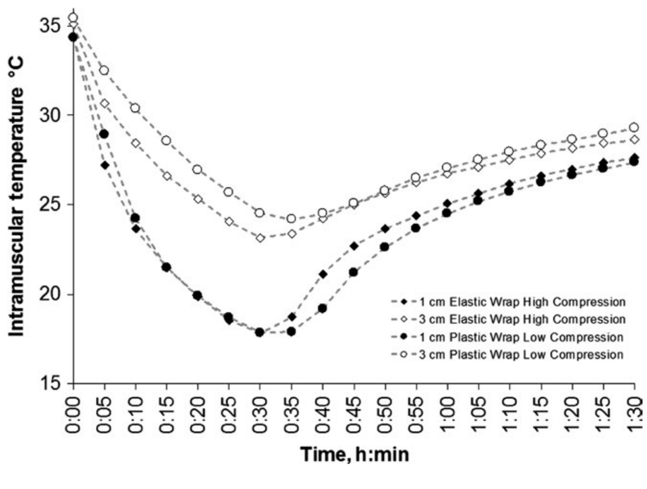

FIGURE 2 Vastus lateralis intramuscular temperature (°C). Intramuscular temperature at both depths declined progressively during both 30-min treatments and remained below baseline after 1 hour of recovery at both depths

Treatment	Skin surface	1 cm	3 cm
High compression elastic wrap	7.43 ± 4.02	17.85 ± 5.25	23.15 ± 4.86
Low compression plastic wrap	8.11 ± 5.37	17.86 ± 4.41	24.19 ± 6.42

TABLE 1 Average skin and intramuscular temperatures at time of greatest treatment effect (°C [±SD])

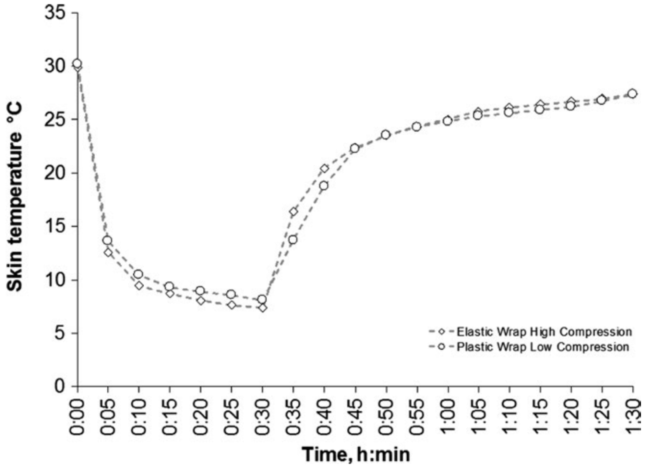

FIGURE 3 Mean skin temperature (°C) over time. Skin temperature declined during both treatments with no difference between treatments

In the present study, the nadir in vastus lateralis muscle temperature occurred immediately upon the conclusion of elastic wrap compression treatment at both intramuscular temperature depths (17.8°C at 1 cm and 23.1°C at 3 cm). By contrast, vastus lateralis muscle temperature continued to decrease for 5 minutes following the removal of the ice bag (35 minutes absolute time) in the minimal compression plastic wrap treatment at both intramuscular temperature depths (17.9°C at 1 cm and 24.2°C at 3 cm) with a gradual increase in temperature thereafter. Clinically, the rationale for using compression in addition to cryotherapy in the treatment of acute muscle injuries is that compression itself is purported to reduce blood flow,[24] attenuate changes in osmotic pressure, and reduce the space available for swelling and hematoma to occur.[25] By reducing blood flow, the inflow of heat from other parts of the body is also reduced[14] and the effects of cryotherapy treatment alone may be augmented. Although blood flow is decreased during compression, immediately upon release of the elastic wrap, subcutaneous vasodilation enhances the blood flow from the non-cooled areas of the body to penetrate the cooled region. This may explain why intramuscular and skin temperatures began to increase immediately following the termination of the high compression treatment but not immediately after minimal compression. It is important to note that blood flow was not directly investigated in this study and this effect may not be the same for the two wraps utilized in this study. Following an hour of recovery from treatment, intramuscular temperature had not returned to baseline in either condition. This agrees with the findings of others[14,17] and was expected because studies have established that intramuscular temperatures do not return to pre-application temperatures for up to 4 hours after ice application,[26] with deep temperatures not returning to baseline for up to 6 hours.[27]

Previously, Tomchuk (2010) compared ice-bag application with no additional compression (placed on the calf muscle), compression with elastic wrap, and compression with plastic wrap. After a 30-min treatment, the nadir in intramuscular temperature at 2 cm was 28°C in the no compression condition, 25°C with elastic wrap and 26°C with plastic wrap. The authors concluded that elastic wrap was more effective than plastic wrap at reducing intramuscular tissue temperature. However, the aforementioned study did not account for subadipose tissue at the gastrocnemius therefore the reported intramuscular temperatures are at <2 cm. Additionally, the actual magnitude of compression applied during the experimental conditions was not reported. In the present study, intramuscular temperatures reached a nadir of 18°C from both treatments at 1 cm while at 3 cm intramuscular temperature reached a nadir of 23°C from elastic wrap and 25°C from plastic wrap. The intramuscular cooling effect observed in the present study during both compression treatments was superior to that reported by Tomchuk (2010) due to: (a) the use of wetted ice bags and (b) a greater magnitude of compression applied in the present study. The present data indicate that 16 mm Hg applied with plastic wrap is sufficient to optimize intramuscular cooling.

A limitation of this study was that only healthy male participants were included. Since the proposed effects of cryotherapy and compression are to decrease blood flow,[24] swelling, and/or edema formation[25] following acute muscle injury it would be helpful if this study were repeated in participants of both genders, with injury. Further, since decreases in intramuscular temperature were correlated with skinfold thickness due to the insulating effect of adiposity,[28,29] the study should be repeated specifically in a female population because women generally have greater subcutaneous body fat compared to men. The results from this study may further differ in a female population due to the added confounding effects of sex hormone-related fluctuations in body temperature and thermoregulatory processes during the menstrual cycle.[30] Consequently, the results of this study should be extrapolated with a degree of caution to the effect of applying an ice bag with or without compression on intramuscular temperature in healthy females and in those with muscle injury. Future studies should also aim to establish the optimal decrease in intramuscular temperature necessary to maximally lower tissue metabolism, in humans.

In conclusion, the magnitude of temperature reduction was comparable using either elastic wrap with high compression or plastic wrap with minimal compression. The reductions in intramuscular and skin temperature may help explain, on a physiological basis, the previously reported benefits of cooling in conjunction with compression.

5 | PERSPECTIVES

Reducing blood flow and tissue metabolism in the immediate post-injury period may be beneficial for limiting the exacerbation of the injury that typically occurs within the first 24 hours after a muscle injury. This study highlights the importance of wetted ice bag treatment applied with either high compression elastic wrap (61 mm Hg) or low compression plastic wrap (16 mm Hg) for maximizing the reduction in intramuscular temperature, the result of which are the lowest reported to date during a cryotherapy treatment. This study supports the use of ice bag with plastic wrap as an alternative to elastic wrap for treatment of acute muscle injuries because plastic wraps may offer clinicians a practical and disposable alternative allowing the patient or athlete to leave the treatment facility.

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How to cite this article: Kwiecien SY, Mathew S, Howatson G, McHugh MP. The effect of varying degrees of compression from elastic vs plastic wrap on quadriceps intramuscular temperature during wetted ice application. *Scand J Med Sci Sports*. 2019;00:1–6. https://doi.org/10.1111/sms.13430