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Cold pack/skin interface temperature during ice treatment with various levels of compression

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Abstract

Objective To compare cold pack/skin interface temperature during a 20-minute ice application with various levels of compression.
Design Repeated measures.
Setting Laboratory setting in an educational institution.
Participants Forty healthy females aged between 20 and 23 years.
Interventions An ice pack was applied to the right thigh with compression using an elastic bandage. Five different levels of compression were used: 0 (no compression), 14, 24, 34 and 44 mmHg.
Main outcome measure Cold pack/skin interface temperature was monitored every minute during the 20-minute ice application.
Results Ice application with compression led to significantly lower cold pack/skin interface temperatures than ice application without compression during the 20-minute application (with compression: mean 6.1 °C, 95% confidence interval 5.9–6.3 °C; without compression: mean 8.1 °C, 95% confidence interval 7.7–8.5 °C) ($P < 0.05$). The level of compression did not significantly affect the magnitude of the cooling temperature (14 mmHg: mean 6.4 °C, 95% confidence interval 6.0–6.8 °C; 24 mmHg and 34 mmHg: mean 6.1 °C, 95% confidence interval 5.7–6.5 °C; 44 mmHg: mean 5.9 °C, 95% confidence interval 5.5–6.3 °C) ($P > 0.05$). The minimum temperature reached with ice application with compression of 0, 14, 24, 34 and 44 mmHg was achieved after 9, 7, 6, 6 and 5 minutes of application, respectively (0 mmHg: mean 5.0 °C, 95% confidence interval 4.9–5.1 °C; 14 mmHg: mean 4.2 °C, 95% confidence interval 4.1–4.3 °C; 24 mmHg: mean 4.0 °C, 95% confidence interval 3.9–4.1 °C; 34 mmHg: mean 3.9 °C, 95% confidence interval 3.7–4.0 °C; 44 mmHg: mean 3.7 °C, 95% confidence interval 3.6–3.9 °C) ($P < 0.05$).
Conclusion Ice application with adjunctive compression leads to a greater magnitude and rate of cooling compared with ice application without compression. The higher the level of compression, the shorter the time to the minimum recorded temperature. Further research is required to demonstrate the effect of various levels of compression applied over an ice pack in a clinical population.

Keywords: Compression; Cryotherapy; Rehabilitation

Introduction

Basic immediate care for acute musculoskeletal injuries includes protection, rest, ice, compression and elevation [1]. Compression is usually achieved with an elastic wrap applied over an ice pack or another cold modality, or directly to the body part [2]. Compression is thought to control the formation of oedema [3,4] and to enhance the effectiveness of a cold pack in reducing tissue temperature [5,6]. However, there are no universally accepted guidelines specifying the optimum magnitude of the compressive force that should be applied [7]. The general recommendation is to apply compression firmly but not so tightly as to cause pain [8], or to apply compression at a level that will accommodate oedema immediately following injury [1]. However, the relationship between the magnitude of the compressive force and the temperature of the underlying tissues during cryotherapy has yet to be established.

Previous studies have measured the interface temperature between the skin and the cold pack (or other method of cold application) to examine the efficacy of cryotherapy

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in reducing tissue temperature. The interface temperature is calculated as the average value of the temperature of the skin, the cold pack and the surrounding environment [6,9–13]. Although cold pack/skin interface temperature is not a direct measure of the underlying subcutaneous and deep tissue temperature, the two have been found to correlate during cryotherapy [10,11,14]. Thus, the non-invasive measurement of cold pack/skin interface temperature can be used to indicate the efficacy of cryotherapy. The aim of this study was to compare cold pack/skin interface temperatures during ice treatment for 20 minutes, in common clinical use [7,15,16], with various levels of compression applied over the ice pack using an elastic wrap.

Methods

Study design

The study followed a repeated-measures design. Five levels of compression were used with an application time of 20 minutes: 0 (no compression), 14 ± 2 mmHg, 24 ± 2 mmHg, 34 ± 2 mmHg and 44 ± 2 mmHg. Cold pack/skin interface temperature was measured at 1-minute intervals.

Subjects

Forty female subjects participated in the study. A questionnaire was used to screen subjects for contraindications to cryotherapy. Subjects were excluded if they had cardiovascular or peripheral vascular disorders, known neurological or musculoskeletal disorders, a history of smoking, diabetes or trauma, or had undergone surgery or an open wound on the right lower limb, a history of allergy to cold, a current injury, or abnormal skin sensation. All subjects were given information about the study and provided informed consent. The study was approved by Chulalongkorn University Human Ethics Committee.

Procedure

Each subject wore shorts and lay supine on the couch for 10 minutes in a room with a constant temperature of 25.0 ± 1.0 °C to stabilise skin temperature. A line was drawn between the anterior superior iliac spine and the midpoint of the superior border of the patella on each subject's right thigh. A mark was made halfway along this line. The sensor area of a FWK/H5 type K thermocouple probe which connected to a DK-101 digital thermometer (Denki Electronic Corp., Saitama 367-0206, Japan) was placed over the mark to measure the cold pack/skin interface temperature. The digital display of the thermometer indicates temperature (°C) to a resolution of 0.1 °C with an accuracy of ±1 °C. A 13 cm × 15 cm plastic bag containing 0.6 kg of chipped ice and the bladder of a manometer (STABILIZER Pressure Bio-feedback, Chattanooga Group, TN 37343, USA), used to quantify the level of compression, was applied centrally over the mark. Both were secured to the thigh using a 10 cm × 2 m elastic bandage at the following levels of compression: 14 ± 2 mmHg, 24 ± 2 mmHg, 34 ± 2 mmHg, and 44 ± 2 mmHg. A no-compression condition served as a control (Fig. 1). To minimise displacement of the probe, the subject was asked to relax and avoid any unnecessary movement of their legs. Cold pack/skin interface temperature was recorded during ice application for 20 minutes at 1-minute intervals. Each subject underwent all five conditions with at least 24 hours for recovery in between each condition. The sequence of conditions was randomised using a Latin square. The subject was instructed to refrain from vigorous activities, alcohol, caffeine or food ingestion for at least 2 hours before the experiment to stabilise the central circulatory system.

Fig. 1. Ice pack, thermocouple probe and manometer positions.

Reliability study

Before data collection, intra-observer reliability of cold pack/skin interface temperature was assessed on 10 subjects during a 20-minute ice application with compression of 34 ± 2 mmHg. Each subject was tested twice on two separate days with at least a 24-hour lapse between the measurements. Intra-observer reliability was evaluated using Bland and Altman's 95% limits of agreement [17].

Data analysis

A two-way analysis of variance (ANOVA) for repeated measures was employed to determine the effects of level of compression, application time and their interaction on cold pack/skin interface temperature. When a significant interaction between level of compression and application time was detected, the effect of each variable was examined separately using one-way ANOVA [18]. The Newman–Keuls post hoc comparison was employed to determine whether two selected means were significantly different from each other. The statistical analyses were performed using SPSS Version 10.0.

The level of significance was set at 0.05 for all statistical analyses.

Results

Reliability study

There was no significant systematic bias between test days, as shown by the 95% confidence interval for the mean bias encompassing zero except at 20 minutes where zero was outside the 95% confidence interval (Table 1). The 95% limits of agreement for intra-observer reliability of cold pack/skin interface temperature during the 20-minute ice application ranged from ±1.3 to ±6.6 °C.

Main study

The mean age, height, weight and body mass index of participants are shown in Table 2. Fig. 2 shows the mean cold pack/skin interface temperature immediately before and during the 20-minute ice pack application with various levels of compression. The two-way ANOVA indicated significant effects for level of compression ($F_{4,156} = 17.12$, $P < 0.001$), application time ($F_{20,780} = 1971.7$, $P < 0.001$) and their interaction ($F_{80,3120} = 9.0$, $P < 0.001$). Thus, follow-up analyses were performed using one-way ANOVA to investigate the effect of level of compression at each time point (immediately before and during the 20-minute application), and the effect of time for each level of compression.

Investigation of the effect of level of compression at each time point revealed that the cold pack/skin interface temperature immediately before application (0 minutes) and 1 minute after application did not differ between the conditions ($F_{4,195} = 0.45$, $P = 0.776$ for 0 minutes; $F_{4,195} = 2.34$, $P = 0.057$ for 1 minute). From 2 to 20 minutes after application, cold pack/skin interface temperature was affected significantly by the level of compression ($P < 0.01$). Post hoc Newman–Keuls tests showed that temperatures during ice application with compression were significantly lower than temperatures during ice application without compression (control) (with compression: mean 6.1 °C, 95% confidence interval 5.9–6.3 °C; control: mean 8.1 °C, 95% confidence interval 7.7–8.5 °C) ($P < 0.05$). However, no significant difference in temperature was found during ice application with different levels of compression (14 ± 2 mmHg: mean 6.4 °C, 95% confidence interval 6.0–6.8 °C; 24 ± 2 mmHg and 34 ± 2 mmHg: mean 6.1 °C, 95% confidence interval 5.7–6.5 °C; 44 ± 2 mmHg: mean 5.9 °C, 95% confidence interval 5.5–6.3 °C) ($P > 0.05$).

Investigation of the effect of time for each level of compression revealed that cold pack/skin interface temperature was significantly affected by application time for all conditions ($F_{20,819} = 322.5$, $P < 0.001$ for 14 ± 2 mmHg; $F_{20,819} = 362.9$, $P < 0.001$ for 24 ± 2 mmHg; $F_{20,819} = 282.2$,

Table 2
Means, standard deviations (S.D.) and ranges for age, height, weight and body mass index

	Mean	S.D.	Range
Age (years)	21	0.9	20 to 23
Height (m)	1.6	0.1	1.5 to 1.7
Weight (kg)	51.2	5.5	43 to 66
Body mass index (kg/m^2)	19.9	1.9	18 to 25

Table 1
Intra-observer bias and limits of agreement (°C) between days 1 and 2 of cold pack/skin interface temperature during ice application with compression of 34 ± 2 mmHg ($n = 10$)

Application time (minutes)	Mean bias	95% confidence interval for bias	95% limits of agreement	Accuracy ±
0	0.3	−1.1 to 1.7	−3.6 to 4.2	3.9
1	−0.6	−3.0 to 1.8	−7.2 to 6.0	6.6
2	−1.4	−3.4 to 0.6	−6.8 to 4.0	5.4
3	−1.4	−3.0 to 0.2	−5.8 to 3.0	4.4
4	0.2	−0.9 to 1.3	−2.7 to 3.1	2.9
5	0	−1.1 to 1.1	−2.9 to 2.9	2.9
6	−0.1	−1.1 to 0.9	−2.8 to 2.6	2.7
7	0	−0.8 to 0.8	−2.3 to 2.3	2.3
8	0.2	−0.5 to 0.9	−1.8 to 2.2	2.0
9	0.1	−0.8 to 1.0	−2.2 to 2.4	2.3
10	−0.2	−1.2 to 0.8	−2.9 to 2.5	2.7
11	−0.1	−1.1 to 0.9	−2.8 to 2.6	2.7
12	0.1	−0.8 to 1.0	−2.4 to 2.6	2.5
13	0.2	−0.5 to 0.9	−1.8 to 2.2	2.0
14	0.1	−0.8 to 1.0	−2.4 to 2.6	2.5
15	0.3	−0.3 to 0.9	−1.3 to 1.9	1.6
16	0.3	−0.3 to 0.9	−1.3 to 1.9	1.6
17	0.1	−0.5 to 0.7	−1.6 to 1.8	1.7
18	0.4	−0.2 to 1.0	−1.3 to 2.1	1.7
19	0.5	0 to 1.0	−0.9 to 1.9	1.4
20	0.7	0.2 to 1.2	−0.6 to 2.0	1.3

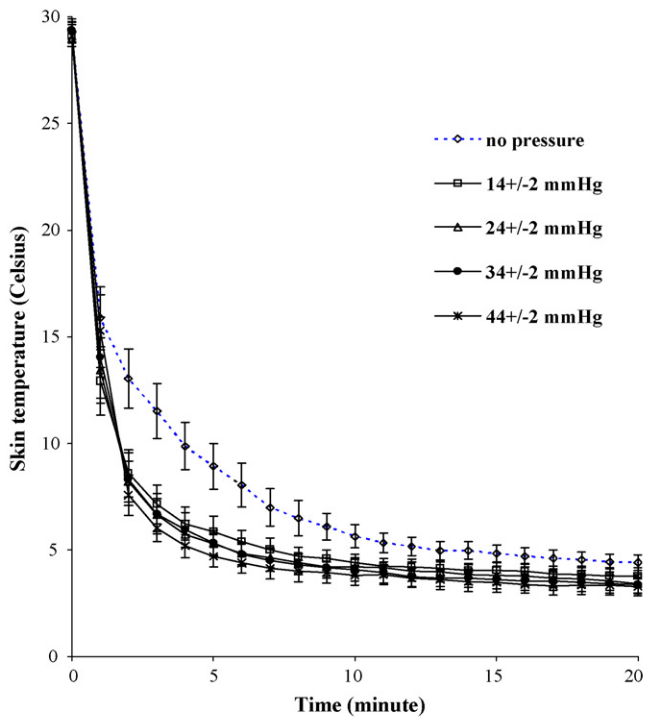

Fig. 2. Mean cold pack/skin interface temperature (±95% confidence interval of mean) before and during the 20-minute application of an ice pack with five levels of compression.

$P < 0.001$ for 34 ± 2 mmHg; $F_{20,819} = 378.6$, $P < 0.001$ for 44 ± 2 mmHg; $F_{20,819} = 220.9$, $P < 0.001$ for control). Post hoc Newman–Keuls tests indicated that the temperature after ice application without compression (control) reduced progressively and significantly from 0 to 9 minutes ($P < 0.05$), and did not alter significantly from 9 to 20 minutes (mean 5.0 °C, 95% confidence interval 4.9–5.1 °C) ($P > 0.05$). The temperature after ice application with compression of 14 ± 2 mmHg, 24 ± 2 mmHg, 34 ± 2 mmHg and 44 ± 2 mmHg dropped significantly and became stable after 7, 6, 6 and 5 minutes of application, respectively (14 ± 2 mmHg: mean 4.2 °C, 95% confidence interval 4.1–4.3 °C; 24 ± 2 mmHg: mean 4.0 °C, 95% confidence interval 3.9–4.1 °C; 34 ± 2 mmHg: mean 3.9 °C, 95% confidence interval 3.7–4.0 °C; 44 ± 2 mmHg: mean 3.7 °C, 95% confidence interval 3.6–3.9 °C) ($P < 0.05$).

Discussion

The results indicated that the amount of compression applied over an ice pack had no effect on the magnitude of the cooling temperature, although the reduction of cold pack/skin interface temperature was significantly quicker for ice application with compression compared with that without compression. The temperature during ice application without compression reached a minimum (5 °C) in 9 minutes, whilst ice application with various levels of compression reached a minimum temperature (3.7–4.2 °C) after 5–7 minutes. Note that the higher the level of compression, the shorter the time to the minimum temperature.

In this study, the cold pack/skin interface temperature was measured by placing the thermocouple probe between an ice pack and skin underneath an ice pack. The sensor portion of the probe was not protected from direct contact with the ice pack. This set-up has been used in previous studies investigating the effect of cryotherapy [6,9–13]. However, Chesterton et al. [19] attempted to measure true skin temperature instead of cold pack/skin interface temperature using a thermocouple probe. They applied a layer of self-adhesive felt, 0.3-cm thick, to the sensor portion of the probe in order to protect the measuring tip from direct contact with the cold pack. By using the protected probe, Chesterton et al. [19] recorded a mean temperature of 14.4 °C after a 20-minute application of a frozen gel pack (23 cm × 11 cm, weight 335 g) wrapped in a damp towel. Recently, Kanlayanaphotporn and Janwantanakul [12] employed a similar methodology to that of Chesterton et al. [19], but using a thermocouple probe with an unprotected measuring tip, to measure mean temperature during the application of a frozen gel pack (24 cm × 11 cm, weight 310 g) wrapped in a damp towel. The authors reported a mean temperature of 13.6 °C after 20 minutes of cold application. From these data, it appears that there is little difference in the temperature recorded using protected and unprotected probes. Thus, it is questionable whether the method of insulation employed by Chesterton et al. [19] would allow true skin temperature to be measured. In the current study, the temperature recorded reflected the interface temperature between the skin and the ice pack, which is affected by the temperature of the skin, the ice pack and the surrounding environment.

The findings of the present study agree with those of Merrick et al. [6] who reported a greater cooling temperature and cooling rate of skin and deep tissues during ice application with compression of 42–48 mmHg compared with ice application without compression. Merrick et al. [6] suggested that ice application with compression leads to significantly greater tissue temperature reduction than ice application without compression, because compression improves contact between the skin and the ice pack and reduces blood flow at the treatment site. Also, they suggested that an elastic wrap may serve as an insulator, minimising heat transfer from the surrounding environment to the ice pack.

In the present study, the magnitude of the cooling temperature during ice application with compression did not alter with various levels of compression. Under all conditions, the cold pack/skin interface temperature dropped to a similar level of 3–4 °C. Subjects did not experience any adverse reactions, such as allergic reactions, burns or frostbite. From a thermodynamic viewpoint, the temperature of melting ice is no less than 0 °C. During application, ice absorbs heat from the body by conduction, thereby raising the temperature of the melting ice [20,21] until the temperatures equalise. Cells are destroyed when the tissue temper-

ature drops below −10 °C [22]. Thus, although markedly different to the 14.4 °C recorded by Chesterton et al. [19], a cold pack/skin interface temperature of 3–4 °C is unlikely to cause cell damage. The use of different compressive forces is unlikely to have a great effect on the insulating effect of an elastic wrap, but may alter cold pack/skin contact and local blood flow. As no further cooling effect was noticed beyond a cold pack/skin interface temperature of 3–4 °C, it is possible that the minimum temperature possible with this method of cold application was reached. The results of this study suggest that the benefit of compression in terms of magnitude of cooling is achieved with compressive forces as small as 14 ± 2 mmHg.

Although higher compressive forces did not affect the temperature reached, they did result in an increased rate of cooling. Research has shown that compression impairs local blood flow [23,24]. It is conceivable that the increased rate of cooling is due to a progressive reduction of blood flow in the subcutaneous tissues.

Generalisation of the results from this study to a clinical population is limited by several factors. Firstly, only young, healthy individuals were examined in this study. Trauma or pathological conditions cause physiological changes in injured tissues that may affect blood flow, enzyme level, metabolic rate and capillary permeability. Thus, extrapolation of these results to people with traumatised tissue or pathologic conditions should be undertaken with caution. Further research on the effect of compression on tissue temperature during cryotherapy in clinical populations is recommended. Secondly, many variables were controlled in the study including the size of the cold pack and the ambient temperature. Similarly, a reasonably homogenous population, with respect to body mass index, was recruited. Therefore, it is possible that variation in any of these parameters may affect the results; for example, the tissues of subjects with higher body mass indices are likely to show different heating and cooling properties due to differences in tissue composition. Lastly, a manometer was used to quantify the level of compression applied. Although it is a relatively simple method, it may not be adopted for use in the clinical setting, and other methods of monitoring compressive forces need exploration.

Cryotherapy is commonly applied to skin. However, it is often the injured structures underneath the treatment site that require the therapeutic effect of cold. Evidence indicates that cryotherapy can reduce the temperature of subcutaneous tissues including muscles and intra-articular structures [15,25]. Previous research in which the temperature of the skin and the deep tissues were recorded simultaneously during 20 minutes of cooling demonstrated a close relationship between the temperatures of the two structures [10,11,14,25]. One possible mechanism of deep tissue cooling after cryotherapy application is that underlying deep tissue loses heat in order to rewarm cooled superficial tissue [10]. Cooler superficial tissue will lead to greater temperature reduction in deep tissue [15,25], resulting in greater physiological and biological effects such as a decrease in oedema, pain, metabolism, muscle spasm and inflammation [2]. Thus, it seems reasonable to suggest that ice application with compression may provide a greater cooling effect, both in magnitude and rate of cooling. The results of this study suggest that a moderate compressive force may be of benefit in conditions where a rapid rate of cooling is required, potentially in the treatment of acute musculoskeletal injuries where cooling is reported to decrease cellular metabolism and, thus, minimise the extent of secondary ischaemic injury [21].

Key messages

- Ice application with compression is an effective means to reduce the cold pack/skin interface temperature compared with ice application without compression.
- The higher the level of compression applied over an ice pack, the shorter the time until the minimum recorded interface temperature is achieved.

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Conflicts of interest: None.

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