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The effect of quantity of ice and size of contact area on ice pack/skin interface temperature

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Abstract

Objective To determine the effect of quantity of ice and contact area on ice pack/skin interface temperature during a 20-minute cooling period.
Design Repeated measures.
Setting Laboratory setting in an educational institution.
Participants Twenty healthy males aged between 18 and 22 years.
Interventions An ice pack was applied to the right thigh with compression using an elastic bandage. The effects of three packs measuring 18 cm × 23 cm containing 0.3, 0.6 and 0.8 kg of ice, and one pack measuring 20 cm × 25 cm containing 0.6 kg of ice were compared.
Main outcome measure The reduction in temperature at the ice pack/skin interface during 20-minute ice applications was monitored at 1-minute intervals.
Results The application of 0.8-kg and 0.6-kg ice packs led to a significantly greater decrease in the interface temperature compared with the 0.3-kg ice pack [0.8 kg vs. 0.3 kg: −2.35 °C, 95% confidence interval (CI) of the difference −3.36 to −1.34 °C; 0.6 kg vs. 0.3 kg: −2.95 °C, 95% CI −4.07 to −1.83 °C]. No significant difference in temperature was found between the 0.6-kg and 0.8-kg ice packs (0.8 kg vs. 0.6 kg: 0.6 °C, 95% CI −0.12 to 1.32 °C, $P > 0.05$). The size of the contact area did not alter the degree of cooling significantly (difference between smaller and larger pack: 0.05 °C, 95% CI −0.93 to 1.03 °C, $P > 0.05$). The lowest temperature during ice application was reached after 8–9 minutes of cooling.
Conclusion Application of an ice pack containing at least 0.6 kg of ice leads to a greater magnitude of cooling compared with application of a 0.3-kg ice pack, regardless of the size of the contact area. Thus, clinicians should consider using ice packs weighing at least 0.6 kg for cold treatment.

Keywords: Cryotherapy; Rehabilitation; Quantity; Skin temperature

Introduction

Cryotherapy is often used to treat acute musculoskeletal injuries and for postsurgical rehabilitation [1–3]. One of the most commonly used cryotherapy modalities is the ice pack [4,5]. One method used to apply ice involves placing chipped or crushed ice into a plastic bag, taking into consideration the amount of ice as well as the size of the bag and contact area, which affects cooling efficiency [6]. In the PRICE guidelines for the management of soft tissue injury, endorsed by the Chartered Society of Physiotherapy, there are no specific recommendations on the amount of ice or size of contact area that should be used for any specific body region; it is only stated that cold application should cover the entire area affected by the injury [4]. In previous studies on the efficacy of ice packs in the reduction of tissue temperature, the amount of ice used varied from 0.3 to 1.8 kg [6–12]; however, no rationale has been offered for the choice of these quantities. There is a similar dearth of evidence for the size of the contact area between the skin and the ice pack. Previous studies which have used ice packs have reported contact areas ranging from 195 to 750 cm^2 [11–13], but others have omitted these details altogether [6,7,14,15].

To date, there has been a lack of information on the minimum amount of ice and size of contact area that should be used during cryotherapy to achieve the desired physiological response, such as local analgesia, reduced blood circulation,

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slowed nerve conduction velocity and reduction of muscle spasm. As a result, further research is required to measure the effects of varying the amount of ice and size of contact area on tissue temperature reduction.

The aims of this study were to compare ice pack/skin interface temperature after application of: (i) three weights of ice; and (ii) two contact areas. Whilst interface temperature cannot be used to measure the exact temperature of the underlying tissues, it is recognised to provide a fair indication of underlying subcutaneous and deep tissue temperature [7,8,16,17]. It is an indirect measure of the efficiency of cryotherapy and has the advantage of being non-invasive [6,9,13,18].

Methods

Study design

A repeated measures design was used to compare ice pack/skin interface temperature during ice application with three weights of ice (0.3, 0.6 and 0.8 kg) and two pack sizes (18 cm × 23 cm and 20 cm × 25 cm). Ice pack/skin interface temperature was recorded at 1-minute intervals during ice application for a period of 20 minutes; one of the most common durations of treatment used [15,18,19]. Previous studies have demonstrated that application of a cold modality leads to a rapid reduction in tissue temperature, and the maximum cooling effect occurs between 5 and 9 minutes after application [11,20,21]. The 1-minute time period was chosen to provide an understanding of the rate of cooling and to determine the time period at which the maximum cooling effect occurred.

Subjects

A convenience sample of 20 males participated in the study. Evidence indicates that skin blood flow varies significantly during the menstrual cycle [22]. Thus, to increase participant homogeneity, only males were included. A questionnaire was used to screen participants for contraindications to cryotherapy. Participants were excluded if they had cardiovascular or peripheral vascular disorders, known neurological or musculoskeletal disorders, a history of smoking, diabetes or trauma, a history of allergy to cold, a current injury or abnormal skin sensation, or had undergone surgery or had an open wound on the right lower limb. 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 °C (±1 °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 half-way along this line. The sensor area of a FWK/H5 type K thermocouple probe connected to a DK-101 digital thermometer (Denki Electronic Corp., Saitama, Japan) was placed over the mark to measure the ice pack/skin interface temperature. The digital display of the thermometer indicates temperature to a resolution of 0.1 °C with an accuracy of ± 1 °C. A plastic bag containing crushed ice and the bladder of a manometer (Stabilizer Pressure Bio-feedback, Chattanooga Group, USA), which was used to quantify the level of compression, were applied centrally over the mark. Both were secured to the thigh using a 0.1-m × 2-m elastic bandage at a level of compression of 44 mmHg (±2 mmHg) (Fig. 1).

Fig. 1. Ice pack and thermoprobe in position.

This level has been shown to be effective in reducing ice pack/skin interface temperature, possibly due to improved contact between the skin and the cold pack, as well as a reduction in blood flow at the treatment site [21]. The level of compression was set at the start of the experiment and no further pressure adjustment was made, replicating clinical conditions where bandaging is rarely adjusted during sessions of ice treatment. Four methods of applying crushed ice were used (Table 1).

The smallest amount of ice reported in a previous study was 0.3 kg and this was therefore used in this study [10]. The dimensions of the packs were based on their commercial availability and conformity to the size of the treatment area. Additionally, there was a reasonable difference in contact area between the two pack sizes (86 cm^2).

Table 1
Dimensions of ice packs.

Weight of crushed ice (kg)	Pack size (cm)	Contact area (cm^2)
0.3	18 × 23	414
0.6	18 × 23	414
0.8	18 × 23	414
0.6	20 × 25	500

Table 2
Intra-observer bias and limits of agreement (°C) between Days 1 and 2 of ice pack/skin interface temperature during the 20-minute ice application with a 0.6-kg ice pack with dimensions of 18 cm × 23 cm (n = 10).

Application time (minutes)	Mean bias	95% confidence interval for bias	95% limits of agreement	Accuracy ±
0	0.1	−0.4 to 0.6	−1.3 to 1.5	1.4
1	−0.4	−1.1 to 0.3	−2.3 to 1.5	1.9
2	0.1	−2.0 to 2.2	−5.6 to 5.8	5.7
3	0.3	−0.9 to 1.5	−3.0 to 3.6	3.3
4	0.5	−0.5 to 1.5	−2.3 to 3.3	2.8
5	0.4	−0.3 to 1.1	−1.5 to 2.3	1.9
6	0	−0.8 to 0.8	−2.3 to 2.3	2.3
7	0.1	−0.8 to 1.0	−2.2 to 2.4	2.3
8	0.1	−0.5 to 0.7	−1.6 to 1.8	1.7
9	0.1	−0.8 to 1.0	−2.2 to 2.4	2.3
10	0.2	−0.5 to 0.9	−1.6 to 2.0	1.8
11	0.1	−0.4 to 0.6	−1.3 to 1.5	1.4
12	0.3	−0.2 to 0.8	−1.0 to 1.6	1.3
13	0.3	−0.2 to 0.8	−1.0 to 1.6	1.3
14	0.2	−0.3 to 0.7	−1.0 to 1.4	1.2
15	0.2	−0.3 to 0.7	−1.0 to 1.4	1.2
16	0.2	−0.3 to 0.7	−1.0 to 1.4	1.2
17	0.2	−0.3 to 0.7	−1.0 to 1.4	1.2
18	0.1	−0.3 to 0.5	−1.0 to 1.2	1.1
19	0	−0.5 to 0.5	−1.3 to 1.3	1.3
20	−0.1	−0.6 to 0.4	−1.5 to 1.3	1.4

Subjects were asked to relax and avoid any unnecessary movement of their legs in order to reduce the risk of probe displacement. Each subject underwent all four experimental conditions, with at least 24 hours for recovery between each condition. The sequence in which the ice packs were applied was randomised using a Latin square. Participants were instructed to refrain from vigorous activities and ingestion of alcohol, caffeine or food for at least 2 hours before the experiment.

Reliability study

Before data collection, intra-observer reliability of ice pack/skin interface temperature measurement was assessed on 10 subjects during a 20-minute ice application with a 0.6-kg ice pack measuring 18 cm × 23 cm. 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 [23].

Data analysis

The differences in minimum temperature between each pair of conditions were calculated for each subject. The mean and confidence interval (CI) of the differences was then calculated. A two-way analysis of variance (ANOVA) for repeated measures was employed to determine the effects of the amount of ice, size of contact area, application time and their interaction on ice pack/skin interface temperature. When a significant interaction between the amount of ice/size of contact area and application time was detected, the effect of each variable was examined separately using one-way ANOVA [24]. The Newman–Keuls post hoc comparison was employed to determine whether two selected means were significantly different from each other. Statistical analyses were performed using Statistical Package for the Social Sciences Version 10.0 (SPSS Inc., Chicago, IL, USA). 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% CI for the mean bias encompassing zero (Table 2). The 95% limits of agreement for intra-observer reliability of ice pack/skin interface temperature during the 20-minute ice application ranged from ± 1.1 to ±5.7 °C.

Main study

The mean age, height, weight and body mass index of participants are shown in Table 3. Fig. 2 illustrates mean ice pack/skin interface temperature immediately before and during each 20-minute period of ice application. The

Table 3
Participant characteristics.

	Mean	SD	Range
Age (years)	21	1.1	18 to 22
Height (m)	1.7	3.4	1.7 to 1.8
Weight (kg)	61.6	6.7	53 to 78
Body mass index (kg/m^2)	20.7	1.8	19 to 25

Table 4
Mean and minimum temperature during the 20-minute application of the four ice packs.

Weight of crushed ice (kg)	Pack size (cm)	Mean temperature (°C)	Minimum temperature (°C)
0.3	18 × 23	9.6	7.7
0.6	18 × 23	6.0	4.4
0.8	18 × 23	6.6	5.1
0.6	20 × 25	6.3	4.6

difference in the cooling effect between the ice packs weighing 0.8 and 0.6 kg was 0.6 °C (95% CI of the difference −0.12 to 1.32 °C). The difference in the cooling effect between the ice packs weighing 0.8 kg and 0.3 kg was −2.35 °C (95% CI −3.36 to −1.34 °C), and the difference in the cooling effect between the ice packs weighing 0.6 kg and 0.3 kg was −2.95 °C (95% CI −4.07 to −1.83 °C). The two-way ANOVA indicated significant effects of experimental condition ($F_{3,57} = 26.46$, $P < 0.001$), application time ($F_{20,380} = 1969.7$, $P < 0.001$) and their interaction ($F_{60,1140} = 4.4$, $P < 0.001$). Thus, follow-up analyses were performed.

Effect of quantity of ice

Statistical analysis revealed that skin temperature immediately before application of 0.3 kg of ice (33.2 °C) was significantly lower than that for 0.8 kg of ice (33.9 °C) ($F_{3,76} = 3.14$, $P = 0.03$). Mean interface temperatures during 20-minute applications of 0.3, 0.6 and 0.8 kg of ice are shown in Table 4. Post hoc Newman–Keuls tests showed that the interface temperature during application of 0.3 kg of ice was significantly higher than that during application of 0.6 and 0.8 kg of ice ($P < 0.05$). However, no significant difference in interface temperature was found between application of 0.6 and 0.8 kg of ice ($P > 0.05$).

Investigation of the effect of time of application of 0.3, 0.6 and 0.8 kg of ice revealed that the interface temperature after application of 0.3 kg of ice reduced progressively and significantly from 0 to 8 minutes ($P < 0.05$), and did not alter significantly from 8 to 20 minutes. The interface temperature after application of 0.6 and 0.8 kg of ice dropped progressively and significantly ($P < 0.05$), and did not change significantly after 9 and 8 minutes of ice application, respectively. Minimum interface temperatures during the application of 0.3, 0.6 and 0.8 kg of ice are shown in Table 4.

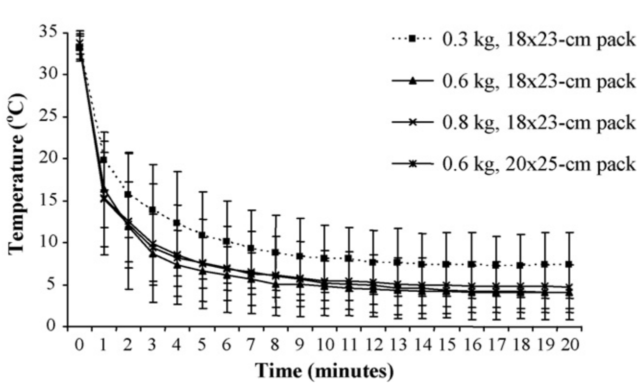

Fig. 2. Mean ice pack/skin interface temperature (±2SD) before and during the 20-minute application of ice under the four experimental conditions.

Effect of the size of contact area between the skin and ice pack

Statistical analysis revealed no significant difference in temperature immediately before or during 20-minute ice applications using 18-cm × 23-cm and 20-cm × 25-cm packs ($P > 0.05$). The difference in the cooling effect between the smaller and larger ice pack was 0.05 °C (95% CI of the difference −0.93 to 1.03 °C). Investigation of the effect of time demonstrated that interface temperature after ice application in the 18-cm × 23-cm pack and the 20-cm × 25-cm pack decreased significantly ($P < 0.05$), and became stable after 9 and 8 minutes of application, respectively.

Discussion

This study examined the effect of three weights of ice on interface temperature. The results suggest that the amount of ice used influenced the degree but not the rate of cooling. Application of 0.6 or 0.8 kg of ice (6.0 to 6.6 °C) was significantly more efficient in reduction of interface temperature than 0.3 kg of ice (9.6 °C). The temperature during application dropped to a minimum of 4.4 to 7.7 °C in 8 to 9 minutes. The results also suggest that the degree and rate of cooling are not affected by the size of the contact area (414 and 500 cm^2).

Skin temperature was measured before the application of each ice pack to check for differences in the starting skin temperature between conditions. Data analysis revealed that skin temperature immediately before application of 0.3 kg of ice was significantly lower than that before application of 0.8 kg of ice, with a difference of 0.7 °C. Although the clinical significance of this difference in initial temperature is unknown, the discrepancy is unlikely to alter the response pattern of tissue temperature reduction during cold application. Previous research has shown that changes in local blood volume during cryotherapy are comparable in non-traumatised and traumatised tissues, despite a probable increase in tissue temperature due to inflammation in the traumatised tissues [3,18].

Ice pack/skin interface temperature was measured by placing the thermocouple probe between the ice pack and the skin. The sensor portion of the probe was not protected from direct contact with the ice pack. Although not ideal, this technique has been used in previous studies investigating the effect of cryotherapy [7,10,13,16,25,26]. It should be noted that the temperatures recorded in the current study, which reflect the interface temperature between the skin and the ice pack, are affected by the temperature of the skin, the ice pack and the surrounding environment.

Cryotherapy reduces tissue temperature by heat extraction from the skin to the cold agent. The extent of tissue temperature reduction depends on several factors including the physical properties of the cold modality (e.g. size, specific heat and latent heat of fusion) [6,20]. For an ice pack, size refers to the amount of ice and the size of the pack, which both influence the size of the contact area.

In this study, the magnitude of the temperature reduction during application of 0.3 kg of ice was lower than that for 0.6 and 0.8 kg of ice. By increasing the size of the contact area, no further cooling effect was noted. It may be that the interface reached the lowest temperature possible with this method of cold application. Under all conditions, the time to reach the minimum temperature measured was similar (8 to 9 minutes after ice application). The results of this study suggest that 0.6 kg of ice in a pack measuring 18 cm × 23 cm is sufficient to achieve the maximum cooling effect under the conditions tested.

Subjects did not experience any adverse reactions, such as allergic reaction, burn 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 increasing the temperature of the melting ice [6,27] until the temperatures equalise. Cells are destroyed when tissue temperature drops below −10 °C. [28]. Thus, an ice pack/skin interface temperature of 4 to 5 °C is unlikely to cause cell damage. In fact, this level of interface temperature will result in several desirable physiological responses for acute musculoskeletal injuries and postsurgical rehabilitation [20]. For example, a skin surface temperature of 13.6 °C would lead to local analgesia [12,29]. A tissue temperature of 12.5 °C would result in a reduction in nerve conduction velocity [30,31].

To minimise the cellular metabolic rate, tissue temperature should be maintained at approximately 10 °C [32]. According to this study, the methods of ice application used appear to reduce tissue temperature sufficiently to induce local analgesia and reduce nerve conduction velocity and cellular metabolic rate. However, application of 0.6 or 0.8 kg of ice, regardless of pack size, would induce such therapeutic effects more quickly compared with application of 0.3 kg of ice.

Generalisation of the results of this study to a clinical population is limited by several factors. First, the use of a small ($n = 20$) convenience sample of young healthy subjects, who provided a reasonably homogeneous population with respect to gender and body mass index, restricts the external validity of this study. Second, changes in temperature were monitored during a single episode of cryotherapy. Repeated application at frequent intervals over a period of time is common practice for the treatment of acute injuries. The authorities provide varied recommendations about the frequency of application [19]. Palmer and Knight [26] investigated change in thigh skin surface temperature during repeated ice application. They reported that the temperature after a 20-minute ice application was no different from that following a further application 60 minutes later. However, further study is needed to explore the extent of temperature change with several repetitions of ice pack application or shorter time intervals between applications. Third, ambient temperature was controlled. Caution should be exercised when using ice packs in different ambient temperatures or populations. Fourth, no blinding of the subjects or examiner was undertaken in the study. However, the effect of lack of blinding on the outcome of this study was minimised as the subjects were unlikely to have control over their body response during ice application, and the use of a standardised protocol and a digital thermometer would reduce the effect of any potential bias. The clinical significance of the differences in temperature found during cryotherapy in various conditions is uncertain, and warrants further study.

Cryotherapy is commonly applied to the 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 [15,17,33]. Previous research in which the temperatures of the skin and deep tissues were recorded simultaneously during 20 minutes of cooling demonstrated a close relationship between the temperatures of the two structures [3,7,16,17,33]. One possible mechanism of deep tissue cooling after cryotherapy application is that the underlying deep tissue loses heat in order to rewarm the cooled superficial tissue [16]. Cooler superficial tissue leads to a greater temperature reduction in deep tissue [15,17,33], resulting in greater physiological effects [34]. Moreover, a cryotherapy technique that has a rapid rate of cooling would be advantageous, particularly when treating acute musculoskeletal injuries, because it is suggested that the extent of secondary injury is minimised by the rapid decrease in cellular metabolism [27]. From the results of this study, it is recommended that at least 0.6 kg of ice should be used in the preparation of ice packs for cryotherapy, giving the greatest reduction in tissue temperature and fastest cooling rate. These, in turn, will affect oedema, pain, muscle spasm and inflammation, without fear of adverse reactions from cold. No further benefit is apparent when the size of the contact area is increased.

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