An investigation into the effect on skin surface temperature of three cryotherapy modalities.

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ABSTRACT

OBJECTIVE: To investigate the comparative cooling effect at the knee, of Crushed Ice and two commonly used commercial cryotherapy modalities, following a clinically relevant application of 20 minutes.

DESIGN: Within subjects, randomised cross over design.

SETTING: University Laboratory

PARTICIPANTS: Eleven healthy male participants

MAIN OUTCOME Measures: Skin temperature over the anterior knee measured by thermal imaging camera.

RESULTS: Mean absolute baseline skin surface temperature (Tsk) was 28.4ºC (±1.2 ºC). The greatest reduction in Tsk was produced by Crushed Ice Δ14.6 ºC (±3.7 ºC) resulting in an absolute Tsk of 13.8 ºC; followed by Ice Man Δ12.3 ºC (±2.4 ºC) resulting in an absolute Tsk of 16.1ºC and then Arctic Flow Δ4.9 ºC (±1.3 ºC) resulting in an absolute Tsk of 23.5ºC. One-way ANOVA revealed significant differences ($p<.05$) between modalities for change in Tsk.

CONCLUSIONS: Crushed Ice and Ice Man produced very similar results following a 20 minute application to healthy adult male knees, however only Crushed Ice resulted in a skin temperature in the desired 10-15°C therapeutic range, results for Ice Man were just above this range. The resultant skin temperature following a similar application of Arctic Flow was well above the therapeutic range.

KEY WORDS: Cryotherapy, Skin Temperature, Thermal Imaging, Knee

EINE UNTERSUCHUNG ÜBER DIE BEEINFLUSSUNG DER HAUTTEMPERATUR DURCH DREI MODALITÄTEN DER KRYOTHERAPIE

ZIEL DER STUDIE: Vergleich des Kühleffektes von zerstosssenem Eis und zweier kommerziell verfügbarer Formen der Kältebehandlung am Kniegelenk bei ein klinisch relevanten Anwendungsdauer von 20 Minuten.

DESIGN: randomisierte Cross-over innerhalb derr Teilnehmer.

SETTING: Universitäts-Labor

TEILNEHMER: 11 gesunde Männer

HAUPTERGEBNISPARAMETER: Die mit einer Infrarotkmera bestimmte Hauttemperatur an der Knievorderseite.

ERGEBNISSE: Der Durchschnittwerte der mittleren Ausgangswertes der Hauttemperatur (T_h) betrug 28.4ºC (±1.2 ºC). Die größte Verminderung der Hauttemperatur wurde durch zerstossenes Eis im Ausmaß von Δ14.6 ºC (±3.7 ºC) erzielt, was zu einer absoluten T_h von13.8 ºC; geführt hatte. Es folgten "Ice Man" mit einer Temperaturdifferenz von Δ12.3 ºC (±2.4 ºC) und einer absolute T_h von 16.1ºC und "Arctic Flow" mit einer Δ4.9 ºC (±1.3 ºC) und einer resultierenden T_h von 23.5ºC. Hinsichtlich der Änderung der T_h fand eine einfache ANOVA signifikant Unterschiede ($p<0.05$) zwischen den Modalitäten.

SCHLUSSFOLGERUNG: Zerstossenes Eis und "Ice Man" führten nach 20 Minuten Anwendung an den Kniegelenken gesunder Männer zu ähnlichen Ergebnssen, obwohl nur zerstossenes Eis die gewünschte Hautemperatur im therapeutischen Bereich zwischen 10-15°C erzeilet, während die Werte nach "Ice Man" knapp über diesen Bereich lagen Die erzielte Hauttemperatur nach der Anwendung von "Arctic Flow" lag deutlich über den gewünschten Bereich.

KEY WORDS Kryotherapie, Hautemperatur, Thermographie, Knie

Thermology international 2009, 19(4) 121-126

Introduction

Cryotherapy is a popular treatment modality for the immediate care of soft tissue injury, despite occasional reports of the complication of ice burn [1,2,3,4,5,6]. Although these reports are relatively infrequent and small in number relative to the frequency of application of cryotherapy they do continue to occur periodically over time. This indicates that clinicians need to remain vigilant for any adverse reactions when applying cryotherapy modalities; underpinning this is the requirement for a good understanding of the effects of the particular modality utilised. In particular in scenarios where clinicians have a choice between a number of modalities it is important to know what different cooling effects may occur.

Although the skin is rarely the target tissue for cryotherapy, the superficial nature of application dictates that it is unavoidably the tissue that will be cooled first due to its immediate proximity to the cooling modality. Therefore an understanding of the effect of cryotherapy on skin temperature (Tsk) is important. On a practical level in most clinical scenarios it is also the only tissue where temperature can actually be monitored and recorded. The optimum Tsk needed to gain beneficial therapeutic physiological changes, within deeper target tissues has been reported as being in the range of 10-15°C [7,8]. There is some debate over how much cooling takes place in the subcutaneous tissues during and following cryotherapy applications; MacAuley [7] and Merrick [9] provide comprehensive reviews of the evidence that supports that superficially applied cryotherapy modalities have beneficial physiological effects in deeper subcutaneous effects. Recently Hardaker et al [10] were able to demonstrate a strong relationship between Tsk and intramuscular temperature at 3cm sub-adipose depth in the quadriceps in adult male subjects during and after cryotherapy.

According to Von Nieda & Michlovitz [11] the magnitude of tissue temperature change and the physiological response to cryotherapy depend on the interplay of four factors

- "Temperature difference between cryotherapy and target tissue (Fourier's Law)
- "Length of exposure
- "Thermal conductivity and specific heat capacity of the area being cooled
- "Thermodynamic properties of the cooling agent

Table 1 presents Tsk data from a number of cryotherapy studies, in order to assist comparability lower limb studies only have been included.

Table 1.
Studies comparing different cryotherapy modalities applied to the lower limb
* indicates where T*sk* lies within desired therapeutic range of 10-15°C

Authors, length of application, body part	**Cryotherapy Modality**	**Resultant absolute T*sk***
Belitsky, Odam, & Hubley-Kozey [23] 15 minutes: Gastrocnemius	Wet ice Dry ice Gel pack	17.9°C 20.1°C 22.1°C
Oosterveld, Rasker, Jacobs, & Overmars [24] 30 minutes: Knee	Ice chips Nitrogen-cold air	11.5°C * 13.8 °C *
Merrick, Knight, Ingersoll, & Potteiger [25] 30 minutes: Quadriceps	Compression & Crushed ice Crushed ice	4.94°C 7.24°C
Chesterton, Foster, & Ross [13] 20 minutes: Quadriceps	Gel pack Frozen peas	14.4°C * 10.8°C *
Kim, Baek, Choi, Lee, & Park [12] 5 minutes: Knee	Cold air	9.7°C
Merrick, Jutte, & Smith [26] 30 minutes: Quadriceps	Ice bag Wet ice Gel Pack	6.47°C 6.24°C 9.86°C
Warren, McCarty, Richardson, Michener, & Spindler [27] 30 minutes: Knee	Ice Cryo/Cuff	8°C 14.8°C *
Kanlaynaphotporn & Janwantanakul [28] 20 minutes: Quadriceps	Ice pack Gel pack Frozen peas Water and Alcohol	10.2°C * 13.9°C * 14.4°C * 10.0°C *
Hardaker, Moss, Richards, Jarvis, McEwan, & Selfe [10] 15 minutes: Quadriceps	Crushed ice	13.9°C *
Kennet, Hardaker, Hobbs, & Selfe [29] 20 minutes: Ankle	Crushed Ice Water Immersion Frozen Peas Gel Pack	11.2°C * 13.2°C * 15.0°C * 17.4°C

A brief review of table 1 shows that no clear picture emerges as to the optimum cryotherapy modality for reducing lower limb Tsk to the therapeutic target range of 10-15ºC. Despite only lower limb studies being selected there are a number of confounding factors which make interpretation of the data in Table 1 difficult from a clinical perspective; these are related to the four factors highlighted earlier [11]. The first factor is related to Fourier's law which states that; "per unit area the transfer of heat in a given direction is proportional to the temperature gradient", this suggests that a cryotherapy modality with a lower temperature offers greater opportunity for heat energy transfer, which should then result in a lower Tsk. In the study by Kim, Baek, Choi, Lee, & Park [12] cold air at a temperature of -30ºC was used resulting in a temperature gradient of 61.8ºC whereas Chesterton, Foster, & Ross [13] used frozen peas at 0.31ºC resulting in a temperature gradient of approximately 30.2ºC. Despite the large difference in magnitude of the temperature gradients the resultant Tsk are not actually very different from each other, in the Kim, Baek, Choi, Lee, & Park [12] study absolute Tsk was 9.7ºC and in the Chesterton, Foster, & Ross [13] study the absolute Tsk was 10.8ºC;. The reason for this lack of difference despite the very large differences in temperature gradients relate to the length of exposure to the modality. Kim, Baek, Choi, Lee, & Park [12] used 5 minutes whereas Chesterton, Foster, & Ross [13] applied the modality for 20 minutes. The differences in the anatomy and physiology of the target body parts under the skin i.e. joint or muscle, in terms of their thermal conductivity and their specific heat capacity are also important even though all the studies presented are in the lower limb. The specific heat capacity of muscle is 3.75 j/g/ºC compared to that of 1.59 j/g/ºC for bone [14]. Tissue with a higher specific heat capacity will retain more heat than tissue with a lower specific heat capacity when the same cryotherapy modality at the same temperature is applied. There are also striking differences in the thermodynamic properties of the modalities studies. For example ice will undergo phase change, absorbing a large amount of heat energy as it changes physical state melting from ice to water, whereas a gel pack or a Cryo/Cuff will not undergo phase change so will therefore not absorb as much heat energy. The studies in Table 1 that compared crushed ice with other modalities consistently report lower Tsk following crushed ice compared to the other modalities studied, highlighting the importance of the effect of phase change in cryotherapy.

Commercial cryotherapy products are widely available and are popular, yet their comparative efficacy and their efficiency remain under investigated. Reviewing Table 1 supports the view of Merrick [9] who states that there are few data indicating which form of cryotherapy is most effective. The aim of this study was to investigate the comparative cooling effect at the knee, by measuring Tsk, following a clinically relevant application of 20 minutes of Crushed Ice and two commonly used commercial cryotherapy modalities Ice Man and Arctic Flow.

Methods

Participants

The study received ethical approval from the Faculty of Health Research Ethics Committee, University of Central Lancashire (UCLan), Preston, England, it also conformed to the World Medical Association Declaration of Helsinki [15]. Written informed consent was gained from all participants prior to participating in the study. Eleven healthy male participants mean age 29.6 (±9.3) years were recruited from staff and student populations at UCLan, Preston, England. Male participants only were selected due to the gender differences found in females in response to local cooling [16]. A within subjects randomised cross over design [17] was used where all participants were required to attend 3 separate testing sessions, at the same time of day, one for each of the modalities, at least 24 hours apart from each other.

Prior to testing participants were screened for eligibility for participation in the study, exclusion criteria were; referred pain to the knee from any other lower limb or spinal joint, increased temperature of the knee joint, sensory deficit, cold intolerance/hypersensitivity and any skin lesions. Pre- testing participants were requested to adhere to the following standardised thermal imaging data collection protocol; no caffeine consumption, cigarettes or exercise 2 hours before and no alcohol for 24 hours before testing [18, 19, 20]. Ambient room temperature was recorded using a thermometer, throughout each test session to ensure a thermally stable environment; mean ambient room temperature was 23.3ºC ±1.9ºC.

Equipment

Exposed lower limbs were given a 15 minute acclimatisation period, away from heat sunlight and draughts to allow stabilisation to room temperature [18, 19, 20]. Participants were seated comfortably in a chair with knees at an angle of 45°. A ThermoVision, A40M, Thermal Imaging camera (Flir systems, Danderyd, Sweden) was positioned 0.91m from the right knee, on a tripod, at an angle of 45° in parallel with the anterior surface of the knee.

Cryotherapy Application

An Anatomical Marker System was applied to the skin surface of the anterior knee to facilitate defining a region of interest (ROI) in subsequent thermal data analysis. This consisted of small thermally inert anatomical markers placed in 4 positions; tibial tubercle, medial and lateral border of patella tendon at the level of the tibiofemoral joint line and centre of the base of the patella [21]. A baseline thermal image of the knee was taken prior to cryotherapy application. Each cryotherapy modality was applied to the right knee in all participants for 20 minutes in accordance with the PRICE guidelines which suggest an application time of 20-30 minutes for ice [22].

The order of application of the 3 different cryotherapy modalities was randomised using a computer generated randomisation schedule, the modalities were;

1. One litre of Crushed Ice (Scotsman Ice Machines, Milan), contained within a plastic bag, and placed over a damp towel.

2. Arctic Flow (DJO, Guildford, Surrey, England), consists of a flask containing crushed ice mixed with water connected to a knee sleeve. The flask is raised above the level of the knee sleeve to allow gravity to feed the cold water to the knee sleeve.

3. Ice Man (DJO, Guildford, Surrey, England), consists of a reservoir for crushed ice mixed with water connected to a knee sleeve. An electric pump circulates the cold water continuously through the knee sleeve.

A thermal image to record the temperature of each treatment modality was taken immediately pre and post application. Immediately following the removal of the cryotherapy application a second thermal image of the knee was taken.

Thermal data analysis

Quantification of thermal images was facilitated by computer linked to the thermal camera and was carried out using Thermacam Researcher 2.8 (Flir systems, Danderyd, Sweden) software, and then processed in Microsoft Excel. The ROI was the anterior knee as defined by the anatomical markers; mean temperature for the ROI was taken from each thermal image. The ROI was drawn using the polygon tool within the computer software.

Statistical analysis

One way repeated measures analyses of variance (ANOVA) at a 95% confidence interval was used to determine differences between modalities for temperature change, the mean absolute Tsk immediately following cryotherapy application and the effect of the modality on change in mean Tsk pre to post application. Pairwise comparisons with Bonferroni adjustment were used to highlight specific significant differences between the modalities.

Results

Modality temperature

Crushed Ice had the lowest absolute pre-application modality temperature 3.9°C (±0.9°C), followed by Ice Man 7.6°C (±3.5°C) and Arctic Flow 8.3°C (±4.5°C). All modalities demonstrated an increase in temperature post application.The greatest temperature increase post appli- cation was demonstrated by Arctic Flow Δ10.6°C (±3.6°C); Ice Man increased the least Δ0.7°C (±1.2°C); Crushed Ice increased by Δ1.08°C (±1.2°C). One-way ANOVA revealed significant differences ($p<0.05$) between modalities for temperature change. Post-hoc testing with Bonferroni correction highlighted that the rise in temperature in the Arctic Flow was significantly more than that of Crushed Ice ($p <0.01$) and Ice Man ($p <0.01$). However, no signi- ficant differences were found between Crushed Ice and Ice Man.

Skin surface temperature

Mean absolute baseline skin surface temperature was 28.4ºC (±1.2 ºC). The greatest reduction in Tsk was produced by Crushed Ice Δ14.6 ºC (±3.7 ºC) resulting in an absolute Tsk of 13.8 ºC. This was followed by Ice Man Δ12.3 ºC (±2.4 ºC) resulting in an absolute Tsk of 16.1ºC and then Arctic Flow Δ4.9 ºC (±1.3 ºC) resulting in an absolute Tsk of 23.5ºC. One-way ANOVA revealed significant differences ($p<0.05$) between modalities for change in Tsk. Post-hoc testing with Bonferroni correction highlighted that the differences were between; Crushed Ice and Arctic Flow ($p<0.01$), and between; Ice Man and Arctic Flow ($p<0.01$); there was no significant difference between Crushed Ice and Ice Man ($p>0.05$).

Discussion

All three modalities were applied according to the manufacturer's instructions for a clinically relevant period of time [22], as predicted the temperature of each of the modalities increased and the Tsk decreased in all experimental conditions, as the modalities and the skin moved towards a state of thermal equilibrium during the period of application. However the results for the Arctic Flow were significantly different to Crushed Ice and Ice Man which produced very similar results to each other.

Modality temperature

Ice Man and Arctic Flow both had very similar baseline temperatures 7.6°C and 8.3°C respectively which would have produced similar temperature gradients with the skin. These two modalities would therefore be predicted to have similar effects; however the results from these two modalities were significantly different to each other, Ice man absolute Tsk 16.1ºC: Arctic flow absolute Tsk 23.5ºC. The baseline temperatures were similar as both modalities consist of iced water systems however it is their mode of operation that produced the significant difference in Tsk, as the pump system in Ice Man ensures a constant circulation of cold water to the knee sleeve therefore increasing the cooling effect. In the Arctic Flow no circulation of the water takes place and the temperature of the skin and the water in the knee sleeve move towards a state of thermal equilibrium, this is highlighted by the large ?10.6 ºC rise in temperature of the Arctic Flow during the experiment.

In contrast the temperature of Ice Man and Crushed Ice increased very little Δ0.7°C and Δ1.08°C respectively and results reveal no significant difference in temperature between these two modalities. As stated previously Crushed Ice will have undergone phase change, as the ice closest to the skin melted, fresh ice will have replaced it promoting further phase change. A similar mechanism will have occurred in the Ice Man due to the pump circulating the cold water through the reservoir of iced water.

Skin surface temperature

Following application the resultant absolute Tsk for each modality was Crushed Ice 13.8°C, Ice Man 16.1°C and Arctic Flow 23.5?C, this is consistent with the data from the studies presented in Table 1 where the application of Crushed Ice consistently produces the lowest skin temperatures when compared to other cryotherapy modalities. As previously stated the desired temperature range of the skin temperature is reported as 10-15°C in order to produce beneficial physiological effects within sub-cutaneous tissues [7, 8]. The results of this study suggest that when applied for 20 minutes, only Crushed Ice would be capable of producing a positive therapeutic effect. However, although the mean absolute Tsk of 16.1°C for Ice Man falls just above, the therapeutic range, when considering the standard deviation of ±2.4 °C it becomes apparent that this modality is capable of reducing Tsk to fall within the desired range. Further studies may wish to investigate if a longer application time for this modality would result in a skin temperature within the therapeutic range.

Application of Arctic Flow resulted in an absolute Tsk of 23.5°C which falls well outside the therapeutic range, the reasons for this have been discussed above. However, this modality should not be discounted as it could still have a useful role in those patients that are unduly sensitive to cold and who would benefit from a mild cooling effect. Alternatively clinicians who require stronger cooling effects when using this modality should ensure that periodically the knee sleeve is drained and then refilled with fresh cold water from the flask in order to maintain the desired temperature in the knee sleeve, further work would be required to define the optimal time interval between draining and refilling.

Conclusion

Crushed Ice and Ice Man produced very similar results following a 20 minute application to healthy adult male knees, however only Crushed Ice resulted in a skin temperature in the 10-15°C therapeutic range, results for Ice Man were just above this range. The results demonstrated that the resultant skin temperature following a similar application of Arctic Flow was well above the therapeutic range, reasons for this and the clinical implications have been discussed.

This study adds to the body of knowledge that provides a scientific underpinning of clinical practice. When there is a choice the physical characteristics and performance capability of different cryotherapy modalities should be understood and used to inform clinical reasoning processes. Additionally it is also important to remember that applying the same cooling stimulus to different anatomical regions will provoke a different cooling response dependent on the local anatomy and physiology. Although the physiological responses to cryotherapy modalities requires further investigation, it is useful to remember that a skin temperature range of 10-15°C should be aimed for when applying cryotherapy modalities.

Acknowledgements

The authors would like to thank Dominic Thewlis and Professor Jim Richards for their technical assistance in producing this work and all the participants who gave their time freely.

Conflict of Interest

The authors would also like to thank DJO who supplied the Arctic Flow and Ice Man, however DJO had no role in the design, analysis or interpretation of the study or its findings.

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(Manuscript received on 30.07.2009, accepted on 3.10.2009)