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Mapping knee skin surface sensitivity and temperature following cryotherapy

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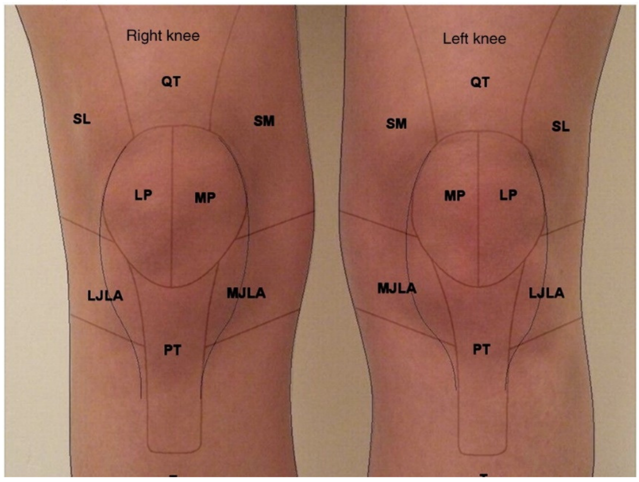
Abstract
Objectives
To investigate the effects of cryotherapy on knee skin surface sensitivity and temperature using monofilaments and thermal imaging.
Methods
Following a 20-minute cryotherapy exposure (crushed ice), knee skin surface sensitivity and temperature was mapped in 19 healthy participants using infrared camera and tactile sensory evaluation. The data were collected before and up to 20 minutes after cryotherapy exposure.
Results
Comparing to baseline, in women, significant decrease in skin surface sensitivity in the upper medial section of photographic knee pain map was observed up to 20-minutes after cryotherapy exposure. In men, the respective difference was observed only immediately after the exposure.
Conclusions
Crushed ice application may reduce skin surface sensitivity around a knee medial aspect and result in impeding return to play due to affected joint position sense following cryotherapy.
Keywords:
cryotherapy; cooling; knee; thermal imaging; skin sensation

INTRODUCTION

Cryotherapy decreases superficial tissue temperature via the removal of heat from the body (1). The pathophysiologic effects of topical modalities such as local cryotherapy include reductions in metabolism (2), pain, spasm, blood flow, inflammation, edema and tissue extensibility (1). It has been widely reported that nerve conduction velocity (NVC) is also decreased by local cooling (2,3). There has been conflicting evidence on the effects of local cooling on joint position sense (JPS) and the multifaceted stimuli of cutaneous receptor feedback in joint and soft tissue structures (4-6). The application of cryotherapy techniques is common in clinical practice and sport injury management (7,8). The therapeutic range for cooling has often been defined as skin surface temperature (T_{sk}) from 10°C to 15°C measured using non-invasive infrared thermal imaging (9). That temperature can be achieved by using crushed ice, wetted ice, gel pack, and cold-water immersion (10). The thermal properties of modalities vary in their cooling abilities and efficiency.

Afferent information feedback from skin receptors via tactile stimulation plays an important role in proprioceptive responses (11). Cutaneous receptors regulating a response to thermal and pressure changes include nociceptors, mechanoreceptors, and thermoreceptors (1). Tactile sensitivity has been reported to vary across different parts of the body (12). Cooling may penetrate to a depth of 2 to 4 cm decreasing the activation threshold of nociceptors and

Figure 1. Photographic Knee Pain Map developed and kindly agreed to be utilized in the study by Elson et al (2011) (21) for original use in collecting knee pain data.
Nine anterior zones: lateral joint line area (LJLA), medial joint line areas (MJLA), superior lateral (SL), superior medial (SM), quadriceps tendon (QT), lateral patella (LP) medial patella (MP), patella tendon (PT), and tibia (T).



subsequently reducing painful stimuli (1). Cooling might affect the response from mechanoreceptors as well (1). Slowed impulse conduction and cutaneous sensation has been considered to reduce pressure stimuli following cooling (13). Although cutaneous receptors may play a lesser role in proprioceptive feedback than muscle spindles

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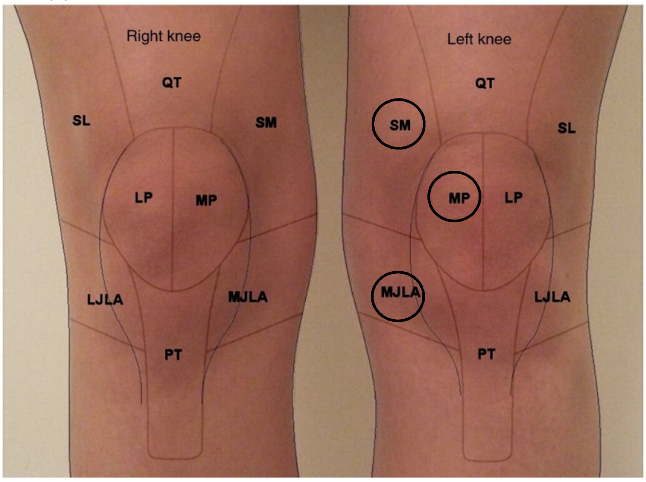
or joint receptors, Costello et al. highlighted that any alteration of tissue temperature following cryotherapy needs to be fully elucidated (14,15). Recently, Alexander et al. proposed that the accuracy of knee joint control might be reduced following a 20-minute crushed ice application (6). That suggests that cooling may affect skin stretch receptors playing an important role in joint position sense and proprioceptive acuity (14,16,17). Subsequently, deficits in proprioception may be accountable for increasing risk of knee injury (15,18). Relationship between skin surface sensitivity (SSS) patterns and JPS response before and after cryotherapy has not been reported so far.

The knee pain map has previously been suggested as a reliable method of recording the location of knee pain (20). Subsequently, it has evolved into a photographic knee pain map (PKPM) used for diagnostic communication and research purposes (21). The PKPM was used in the current study to define specific areas of the knee to explore the effect of cryotherapy on SSS. The aim of the study was to investigate the effects of cryotherapy on knee skin surface sensitivity and temperature using monofilaments and thermal imaging

Figure 2. Post-cryotherapy photographic knee pain map (PKPM) highlighting areas of decreased SSS highlighted by section for the entire sample (MJLA, SM), female (SM), and male (MP) data.
Nine anterior zones: lateral joint line area (LJLA), medial joint line areas (MJLA), superior lateral (SL), superior medial (SM), quadriceps tendon (QT), lateral patella (LP) medial patella (MP), patella tendon (PT), and tibia (T).



METHODS

Participants
Nineteen healthy volunteers who have regularly participated in land-based team sports and aged between 18 to 40 years. The participants did not have history of neurological disease, knee pain, visual or vestibular disturbance, lower limb injuries within the last six months, history of lower limb surgery, or common contraindications to cryotherapy like diabetic hypersensitivity to cold. All the participants provided written consent. The study adhered to the Declaration of Helsinki (22) and approved by the University of Central Lancashire ethics committee (STEMH).

Protocol
The study was set in a movement analysis laboratory. Room temperature was measured hourly during each day of data collection. The average ambient temperature was 21.7°C (0.4°C). This was a single-group pre-/post-test study. The data were collected before applying crushed ice to the anterior aspect of knee and every five minutes up to 20-minutes after that. Prior to the baseline data collection, a 15-minute acclimatization period ensured that steady state temperature had been reached. According to previous reports, a non-dominant limb is more prone to injuries during weight-bearing sporting tasks (23,24). As proposed by Surenkok et al., a dominant lower limb was defined as one that the participants naturally kicked a ball with (25).

To quantify SSS over the anterior aspect of the knee, Aesthesio®, Precise Tactile Sensory Evaluator (DanMic Global, LLC, USA) made of nylon monofilaments of different lengths and diameters was used. A linear scale of perceived tactile intensity ranged from 0.008 g up to 300 g divided in 20 levels. Initially, the participants were in comfortable supine position with their eyes open. The sensory evaluator was demonstrated to them applying 0.60 g pressure at the back of a participant's hand. After the demonstration, to reduce any sensory cues to gain vestibular or visual information, the participants were blindfolded during the testing (26). Before the intervention, T_{sk} was measured three times at two sites of interest – center of patella and tibialis anterior region (10 cm inferiorly and 2 cm laterally from the tibial tuberosity). The T_{sk} was measured using a non-contact infrared camera (FLIR Systems ThermoVision™ A40M, Sweden) following a previously published clinical protocol with emissivity set at 0.97 to 0.98 (6,19).

The PKPM (21) was used to define nine anterior zones of the knee (Figure 1). During sensory testing, the participants were laying in a supine sitting position with bolster support under both lower limbs. Monofilaments were pushed perpendicularly to the site of testing until bent. Starting with 0.008 g, the sensory evaluator was applied five times in each zone in random order following standardized testing protocols (27). If a participant felt the sensory evaluator touching his knee, he informed a researcher by saying "Yes" and pointing by hand at the area of sensation. If a participant did not feel any sensation after five repetitions in any of zones, a researcher applied the next levels of sensory evaluator until each zone on a knee map had five sets of recordings.

After SSS and T_{sk} baseline recordings, cryotherapy was applied over an anterior knee. To achieve a therapeutic T_{sk} between 10°C and 15°C (10), 800 g of crushed ice was applied to the anterior aspect of a participant's non-dominant knee for 20 minutes (8,10,28). Crushed ice in a clear plastic bag was covered by a damp single microfiber towel and held in place by a cling film wrap (6). Immediately after the intervention, T_{sk} measurements and SSS data were collected in exactly the same manner as at the baseline and the data were subsequently collected at 5-minute intervals up to 20 minutes. For consistency, the same researcher collected all the SSS data for all the participants. No adverse events occurred during the procedure. During the rewarming period, a participant remained in the same supine position without movement in a lower limb.

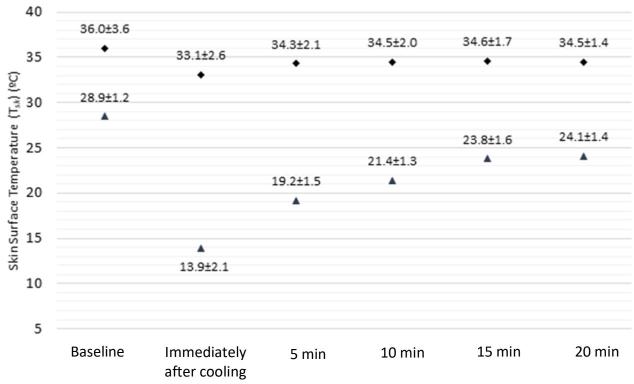
Statistical Analysis

The data were distributed normally. The T_{sk} estimates from patella and tibialis anterior were pooled. The repeated measures ANOVA and paired t-test (on gender) were performed using SPSS version 24 (SPSS, Inc., Chicago, USA) and setting significance at p=<0.05.

RESULTS

Figure 3. Skin surface temperature (T_{sk}) (°C) over the anterior knee after cooling (entire sample)

▲ Patella center ♦ Tibialis anterior



Of the 19 healthy volunteers, 11 were men and 8 were women. Their average age was 20.2 (1.6) years and body mass index (BMI) was 24.4 kg/m^2.

Mean T_{sk} at the center of patella significantly decreased (p=<0.05) achieving a therapeutic range of 10°C to 15°C (Figure 3 and Table 1). Respective decrease for tibialis anterior region did not achieve a therapeutic range. After 20 minutes, in both regions, the T_{sk} remained lower than at the baseline. The results were similar for the entire sample and for each gender. The SSS significantly decreased in superior medial area immediately and in medial joint line areas up to 10 minutes after the intervention (Table 1). Significant differences in SSS were also observed between genders (Table 1 and Figure 2).

DISCUSSION

Although frequently used in the management of injuries and recovery periods in sport, evidence is lacking as to the response in SSS following local cooling at the knee and the effect this may have on somatosensory mechanisms in consideration of proprioceptive feedback. The current study aimed to minimize the gap in knowledge as to the effect on crushed ice application to the anterior aspect of the knee on SSS. This information may be beneficial to further understanding of the impact of cryotherapy applications on neuromuscular feedback responses that can affect proprioceptive acuity and movement control.

Mapping of SSS as a baseline and monitored over a rewarming period of 20 minutes noted significant differences, presenting as a decrease in SSS for the SM section of the knee for whole group data (males and females) when comparing pre-intervention to immediately post intervention data (p=0.04) and 20-minutes post intervention (p=0.04). This concurs with data published in a recent study, whereby participants presented with decreased sensitivity following cooling application, with a lack of tactile sensitivity up to five minutes after the end of cryotherapy (28). Comparison directly between studies however is extremely limited due to location differences of cooling protocols between studies, (28) being assessed in the forearm not the lower limb. SSS in the current study did not return to baseline measurements for whole-group data after 20-minutes. The male only group reported significant reductions in SSS thresholds (p=0.02) for the MP section of the PKPM when comparing pre vs. immediately-post data; female only group recorded reductions in SM section of the PKPM (p=0.02) comparing immediately post to 5-minutes post intervention. An increase in SSS (p=0.02) occurred however between immediately post to 5 minutes post data but SSS did not return to baseline measures even after 20-minute rewarming period. Tsk fell to within therapeutic range recorded at immediately post intervention removal, supporting previous literature (10). Current findings warrant consideration when athletes are immediately returning to functional activity or competitive play following crushed ice cryotherapy applications as reductions in SSS may impair neuromuscular feedback mechanisms that heighten risk of injury.

The findings suggest that compared to lateral sections of the knee, as depicted by the PKPM, the medial regions respond differently through a significant reduction in SSS in comparison. This is reported in whole group data (p=<0.04), male (p=0.02) and female (p=0.02) data at different sections of the PKPM. An explanation of these results may consider the known anatomical structures of the knee, and attention to the neural pathways when comparing lateral to medial regions of the knee. The superficial saphenous nerve branches at the knee into the large infrapatellar nerve distributing over the medial to anterior region of the patella. Local cryotherapy applications report influential neurological changes including the increase in pain tolerance and threshold (3). Conduction velocity is reported to decrease following local cooling due to maintenance of action potential and increased refractory periods (3). A reduction subsequently in sensory perception results in changes in sensitivity due to modifications in neural pathways. In consideration therefore, of the superficial innervation of the saphenous and infrapatellar nerves on the medial aspect of the knee compared to the common fibular (peroneal) nerve on the lateral side positioned deeper and less anteriorly, receptor feedback over the region of the knee may differ in response to cold stimuli and pressure from the crushed ice pack. The difference in levels of reduced cutaneous sensitivity over the various sections as depicted by the PKPM may translate into proprioceptive deficiencies detrimental to knee JPS during functional activity. This however was not quantified in the current study. It may be postulated that deeper joint receptors would compensate for the reductions in skin cutaneous feedback in light of suggestions in current literature (15).

When comparing combined PKPM sections for the whole knee area, average male and female data appears to indicate that female participants had a lower threshold of SSS as a baseline measurement (VFH 5n) compared to males (VFH 1n). In consideration of the somatosensory system, hair and hair follicles play a significant role in

Table 1. Skin surface temperature (T_{sk}) (°C) and surface sensitivity (SSS)

Time point → / Area ↓	Baseline	Immediately after cooling	5 min	10 min	15 min	20 min
Section of PKPM / Monofilament level recorded (Mn)						
QT	2.403	2.983	3.227	2.903	3.045	2.716
SM	3.057[2]	3.682[1]	3.074	3.233	2.949	2.983
SL	2.824	3.449	2.903	2.716	3.403	3.324
LP	3.227	3.676	3.756	3.676	3.557	3.244
MP	2.949[3]	3.534	3.864	3.148	3.318	3.136
LJLA	3.295	3.585	3.091	3.045	3.045	3.545
MJLA	3.028	3.727[1]	3.415[1]	3.619[1]	3.574	3.261
PT	3.852	3.790	3.761	3.977	3.699	3.636
T	3.511	3.699	3.716	3.608	3.932	3.716
Skin Surface Temperature (T_{sk}) (°C)						
Patella center	28.9 (1.2)	13.9 (2.1)[1]	19.2 (1.5)[1]	21.4. (1.3)[1]	23.8 (1.6)[1]	24.1 (1.4)[1]
Tibialis anterior	36.0 (3.6)	33.1 (2.6)[1]	34.3 (2.2)[1]	34.5 (2.0)[1]	34.6 (1.7)[1]	34.5 (1.3)[1]

[1] Significant pre-/post difference for the entire sample; [2] Significant pre-/post difference for women; [3] Significant pre-/post difference for men

sensory feedback triggered by tactile stimuli (30). Generally, female participants presented with less hair on the knee, (over the area covered by the PKPM). Although not glabrous in presentation as the palmar region of the hand is, the reduction of hair over the knee region may have influenced the response from the tactile stimuli of the VFH on the skin surface. It is therefore difficult to compare male and female groups and a limitation in need of consideration in future studies when considering participant populations.

The current study followed a cooling exposure duration of 20-minutes in line with common clinical cryotherapy application recommendations (8). In sporting situations however, it may be unlikely a player is able to ice for a full 20 minutes before returning to play, due to common exposures during competitive play, half-time, pitch-side (8). Future research should consider shorter intervention durations to determine if differences still occur in SSS. Although minimal evidence are available for their use in the assessment of cooling and patterns of SSS at the knee using VFH, literature is accessible in the use of monofilament. Monofilaments have traditionally been used is the assessment of peripheral neuropathy (31), in particular diabetic patients (32). Literature recognizes their use in assessing SSS for peripheral neuropathy assessment some considered to be reliable in the measurement of SSS change (32). The use of VFH to measure SSS at the knee is supported by the current study; however, the encouragement of further research in this remit may develop data on the sensitivity and specificity of this tool for its application in clinical studies of cryotherapy.

Proprioceptive acuity is recognized to be more significantly affected by reductions in afferent muscle spindle feedback compared to cutaneous (14,17,33). Therefore, future investigations may want to consider the combined investigation of the effects of local cooling on SSS and functional joint position sense to note any potential correlation between levels of reduced cutaneous peripheral signals on proprioceptive feedback mechanisms. Further consideration of the assessment of force discrimination post local cooling of distal joints may also provide clarity on the effects of cooling on proprioceptive acuity in consideration of the multiple mechanisms that contribute to its maintenance. This would further the current evidence base on the effects of cryotherapy and whether and when it may be safe to return to functional weight bearing activities following cold exposure.

In consideration of the changes in SSS in different sections of the PKPM it may have been useful to map T_{sk} to individual sections to note any potential correlations between T_{sk} and SSS per section. The development of multiple regions of interest to measure T_{sk} for each segment of the PKMP would need to be established from baseline thermal imaging data capture.

CONCLUSION

Crushed ice application at the knee significantly reduces skin surface sensitivity around the medial aspect immediately post removal. Noted differences in skin surface sensitivity following cooling between males and females occurred. Skin surface sensitivity over the medial aspect of the knee in mixed sex group does not return to baseline after a 20-minute rewarming period following an application of crushed ice for a 20-minute duration over the knee. It is uncertain as to the extent reductions in SSS may have on proprioceptive acuity and further investigations are advised, although therapists should be conscious of changes in skin surface sensitivity that may impede return to play following pitch-side cooling exposures due to the effect on feedback mechanisms controlling joint position sense at the knee.

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