Ice-water immersion and delayed-onset muscle soreness: a randomised controlled trial

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ORIGINAL ARTICLE

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Objective: To determine if ice-water immersion after eccentric quadriceps exercise minimises the symptoms of delayed-onset muscle soreness (DOMS).
Design: A prospective randomised double-blind controlled trial was undertaken. 40 untrained volunteers performed an eccentric loading protocol with their non-dominant leg.
Interventions: Participants were randomised to three 1-min immersions in either ice water (5±1˚C) or tepid water (24˚C).
Main outcome measures: Pain and tenderness (visual analogue scale), swelling (thigh circumference), function (one-legged hop for distance), maximal isometric strength and serum creatine kinase (CK) recorded at baseline, 24, 48 and 72 h after exercise. Changes in outcome measures over time were compared to determine the effect of group allocation using independent t tests or Mann–Whitney U tests.
Results: No significant differences were observed between groups with regard to changes in most pain parameters, tenderness, isometric strength, swelling, hop-for-distance or serum CK over time. There was a significant difference in pain on sit-to-stand at 24 h, with the intervention group demonstrating a greater increase in pain than the control group (median change 8.0 vs 2.0 mm, respectively, p=0.009).
Conclusions: The protocol of ice-water immersion used in this study was ineffectual in minimising markers of DOMS in untrained individuals. This study challenges the wide use of this intervention as a recovery strategy by athletes.

Delayed-onset muscle soreness (DOMS) is pain or discomfort that typically occurs 1–2 days after unaccustomed eccentric loading of skeletal muscle,[1–3] and generally resolves within a week of the inciting activity.[4] Recreational and elite athletes experience DOMS after unaccustomed exercise involving an eccentric muscle-loading component, and this occurs often after introduction of a new phase or type of training. It is well documented that eccentric contraction produces greater muscle damage and strength deficits than concentric or isometric contractions.[5 6] This damage is evident as disruption of the normal banding patterns (alignment) of skeletal muscle and broadening or complete disruption of sarcomere Z lines.[7–9] Muscle cell damage allows release of enzymes including creatine kinase (CK), with serum CK consistently increased within 1–3 days of eccentric exercise,[5 10 11] and contributes to strength deficits seen in DOMS.[9 12 13] Oedema or swelling, as a result of production of prostaglandin E2, has been observed in eccentrically exercised muscle at 24, 48 and 72 h.[14–17] Prostaglandin E2 also sensitises the group IV afferent fibres of muscle connective tissue, responsible for transmitting dull aching pain to the central nervous system.[18] This sensitisation in DOMS may result in allodynia.[4 9 19–22]

Owing to a wide range of clinical features associated with DOMS, such as strength deficits and stiffness of adjacent joints, as well as the lack of understanding of the underlying pathophysiology, many recovery strategies have been used by athletes, coaching staff and health professionals alike, in an attempt to minimise the symptoms and signs of this syndrome. Such strategies include massage,[23 24] stretching[2 25] and anti-inflammatory medications.[26 27] Studies to date have demonstrated mixed results of these treatments on DOMS, mostly with minimal analgesic effects, and inconsistent effects on strength, joint range and CK levels.

Cryotherapy has long been used to treat musculoskeletal soreness with the expectation that decreased tissue temperature will result in constriction of local blood vessels, thus diminishing inflammatory response and oedema associated with musculoskeletal trauma.[3] Complete ice-water immersion of the affected muscle theoretically maximises the therapeutic effect of the reduced temperature. Accordingly, ice-water immersion is frequently used in sports medicine, particularly among high-level athletes, in an effort to minimise DOMS.[22 31] Anecdotal reports suggest that ice-water immersion may have a positive effect on muscle soreness after an intense or unaccustomed training session, allowing athletes to continue to train at peak intensity over subsequent days. Several studies have investigated cold-water immersion in the prevention of DOMS,[28 29] and results regarding the benefit of this practice are inconclusive. These studies have methodological limitations in their use of small sample sizes, inadequate blinding, resistance-trained subjects and variable eccentric exercise protocols, making it difficult to evaluate the effectiveness of this treatment. Furthermore, the ice-water immersion studies to date have used treatment protocols that are of limited clinical relevance owing their use of repeated immersions over several days after exercise.[28–30] Current practice among high-level sports in Australia is to use 1 min immersion in ice water, followed by 1 min out for a total of three cycles immediately after exercise. Despite its widespread use, this ice-water immersion protocol has not been evaluated, and evidence attesting to its efficacy is lacking.

The aim of this study was to evaluate the efficacy of a commonly used protocol for ice-water immersion for the prevention of DOMS, using the rigour of a randomised

Abbreviations: CK, creatine kinase; DOMS, delayed-onset muscle soreness; VAS, visual analogue scale

Table 1 Characteristics of participants in the study

	Control (n = 20)	Intervention (n = 20)	t Value	p Value
Age (years)	21.0 (3.1)	21.4 (4.3)	0.63*	
Height (m)	1.67 (0.08)	1.68 (0.08)	−0.176	0.85
Weight (kg)	64 (9)	63 (11)	0.330	0.35
BMI (kg/m^2)	23 (2)	22 (3)	0.731	0.14
Male:female	4:16	7:13		0.29†

BMI, body mass index.
*Values are mean (SD).
Mann–Whitney U test.
†Pearson's χ^2.

controlled trial. It was hypothesised that, compared with tepid water, ice-water immersion would minimise pain, swelling, functional and strength deficits, and muscle damage after eccentric quadriceps exercise.

METHODS

Study design

A randomised controlled trial was performed to compare the effects of ice-water (5°±1℃) and tepid-water (24℃) immersion on markers of DOMS after a bout of unaccustomed eccentric quadriceps exercise.

Participants

Participants responded to poster advertisements distributed throughout the Schools of Physiotherapy and Medicine, University of Melbourne, Melbourne, Victoria, Australia. Adults aged >18 years were eligible for inclusion. Exclusion criteria included a history of eccentric quadriceps exercise in the past 3 months, a history of quadriceps muscle tear, neurological disease involving the lower limbs, current lower-limb musculoskeletal injury and inability to understand English. Participants with potential vascular problems for which ice-water immersion is contraindicated (eg, diagnoses of diabetes or Raynaud's disease) were also excluded.

The University of Melbourne Human Research Ethics Committee approved the study and all participants provided written informed consent. All outcome assessments were performed at The Centre for Health Exercise and Sports Medicine. The non-dominant quadriceps only was used to maximise the likelihood of DOMS occuring.

Randomisation and masking

The randomisation sequence was generated using a random numbers table and allocation was concealed using sequentially numbered opaque envelopes held at a central location. The investigator responsible for the outcome assessments was blinded to group allocation, and participants were advised not to reveal their group allocation to the investigator. Participants were blinded as to which intervention was considered therapeutic.

Eccentric exercise protocol

The exercise protocol was carried out on a seated leg extension machine using the test leg only. The one-repetition maximum weight lifted concentrically was determined for each participant. In all, 120% of the one-repetition maximum was calculated and used as the weight to be lowered eccentrically using the test leg. Each participant completed 5 sets of 10 repetitions in total, with a 1 min rest allowed in between each set.

Interventions

Water immersion was carried out immediately after the eccentric exercise protocol. Participants stood submerged to the level of the anterior superior iliac spines. Participants randomised into the treatment group were immersed in melting iced water at 5±1℃. Those in the control group were immersed in tepid water at 24℃. Participants remained in the bath for 1 min, followed by 1 min out of the bath. This cycle was repeated three times.

Outcome measures

All outcome measures were recorded at baseline, and 24, 48 and 72 h after the eccentric exercise protocol.

Pain and tenderness in the test leg quadriceps muscle using the visual analogue scale

The visual analogue scale (VAS) was an unmarked horizontal 100 mm line with the terminal descriptors "no pain" and "worst pain possible". Pain was rated with a single vertical line on the scale for the activities of sit to stand, passive quadriceps

Table 2 Results of Mann–Whitney U test for baseline comparisons of outcome measures between control and intervention groups

	Control (n = 20)	Intervention (n = 20)	p Value
Pain (mm)			
Sit-to-stand	0.0 (0.0–0.8)	0.0 (0.0–0.0)	0.24
Passive stretch	1.0 (0.0–5.0)	2.0 (0.0–9.5)	0.42
Hopping	0.5 (0.0–3.0)	0.0 (0.0–2.0)	0.69
Running	0.0 (0.0–1.0)	0.0 (0.0–0.0)	0.43
Isometric strength	8.0 (0.0–22.5)	4.5 (1.3–17.5)	0.84
Tenderness (mm)			
Mid-belly	5.5 (0.0–15.3)	3.0 (0.0–9.0)	0.43
Musculotendinous	1.0 (0.0–7.8)	1.0 (0.0–4.5)	0.88
Circumference (mm)			
Mid-belly	555 (531–569)	540 (489–570)	0.21
Musculotendinous	407 (391–426)	394 (369–415)	0.28*
Serum CK (IU/l)	119.5 (64.0–133.0)	106.0 (71.8–186.5)	0.47
Hop (m)	1.9 (1.7–2.1)	1.8 (1.6–2.3)	0.94
Torque (N.m)	145.2 (113.3–162.3)	132.6 (120.2–158.0)	0.71

CK, creatine kinase.
Data reported as median (interquartile range).
*Independent t test.

Table 3 Within group comparisons of pain scores over time, reported as median (interquartile range)

Pain (mm)	Baseline	24 h	z Score	p Value
Passive stretch				
Control (n = 20)	1.0 (0.0–5.0)	6.0 (2.3–16.0)	−1.995	0.046
Intervention (n = 20)	2.0 (0.0–9.5)	16.5 (4.0–56.0)	−3.827	<0.001
Maximal isometric contraction				
Control (n = 20)	8.0 (0.0–22.5)	26.5 (8.3–41.8)	−2.919	0.004
Intervention (n = 20)	4.5 (1.3–17.5)	38.0 (13.8–55.0)	−3.679	<0.001
Serum CK (IU/l)				
Control (n = 20)	120 (64–133)	150 (117–221)	−3.584	<0.001
Intervention (n = 20)	106 (72–187)	180 (89–306)	−3.361	0.001
Mean (SD) maximal isometric strength (N.m)				
Control (n = 20)	147 (40)	129 (30)	−3.173	0.002
Intervention (n = 20)	148 (52)	136 (40)	−2.240	0.025

CK, creatine kinase.

stretch, one-legged hop-for-distance test, running and maximal isometric contraction.

Tenderness was assessed using a pressure algometer (Pain Diagnostics and Thermography, Italy) exerting a standard force of 6 lb/cm^2, at two reference points marked on the thigh along a line drawn from the anterior superior iliac spines to the superior pole of the patella. One point was at the mid-point of this line (representing the mid-belly of the rectus femoris), and the other at 5 cm above the superior pole of the patella (representing the musculotendinous junction). Participants were asked to rate their tenderness at each point on a VAS.

Swelling

Measures of thigh circumference were used to indicate swelling of the quadriceps muscle at each of the two reference points marked as above. The mean of three measures was determined at each point.

Table 4 Changes in pain and tenderness ratings (on 0–100 mm visual analogue scale) over time at 24, 48 and 72 h after exercise, by group

Pain (mm)	Control (n = 20)	Intervention (n = 20)	z Score	p Value
Sit-to-stand				
24 h	2.0 (0.0–8.8)	8.0 (2.5–34.0)	−2.61	0.009*
48 h	2.5 (0.3–10.5)	11.5 (1.5–26.0)	−1.97	0.05
72 h	0.0 (0.0–2.0)	1.0 (0.0–10.5)	−1.57	0.12
Passive stretch				
24 h	4.5 (−0.8–8.5)	12.5 (3.5–37.3)	−2.59	0.010
48 h	4.0 (0.0–10.0)	10.5 (6.3–24.5)	−2.04	0.041
72 h	0.5 (−3.5–3.8)	4.5 (0.0–7.8)	−1.68	0.093
Hopping				
24 h	7.0 (2.0–9.5)	13.5 (5.5–26.5)	−1.32	0.19
48 h	5.5 (1.0–10.5)	11.5 (3.3–25.0)	−1.69	0.093
72 h	1.0 (−0.8–6.3)	3.5 (0.0–7.8)	−1.23	0.22
Running				
24 h	4.0 (0.0–12.8)	17.5 (3.5–26.0)	−2.08	0.038
48 h	6.5 (1.0–15.8)	17.0 (3.8–29.8)	−1.71	0.088
72 h	1.0 (0.0–4.0)	1.0 (0.0–11.8)	−0.99	0.32
Isometric contraction				
24 h	9.0 (1.5–20.8)	25.0 (8.5–40.5)	−1.83	0.068
48 h	1.0 (−5.8–19.5)	16 (1.0–44.0)	−1.92	0.054
72 h	−4.5 (−13.8–10.8)	4.0 (−3.8–17.8)	−1.69	0.091
Tenderness mid-belly (mm)				
24 h	4.5 (0.0–11.5)	7.5 (0.3–19.8)	−0.96	0.34
48 h	4.0 (0.0–11.8)	8.0 (3.0–20.3)	−1.27	0.20
72 h	0.0 (−2.8–8.5)	5.5 (0.0–16.5)	−1.57	0.12
Tenderness musculotendinous (mm)				
24 h	1.0 (−1.5–7.5)	4.5 (0.5–13.3)	−1.88	0.061
48 h	3.5 (−0.8–10.8)	3.0 (0.0–10.8)	−0.42	0.67
72 h	0.0 (−3.8–3.0)	0.0 (−0.8–8.5)	−1.02	0.31

CK, creatine kinase.
Values are median (interquartile range).
*p<0.01.

Functional performance

The one-legged hop-for-distance test[31 32] was used to assess quadriceps function. The maximum distance obtained from three hopping attempts was recorded. Maximal isometric quadriceps strength was also evaluated using a KinCom isokinetic dynamometer (Chattecx Corporation, Chattanooga, Tennessee, USA). Isometric testing was performed at 60° knee flexion. The peak force obtained from three attempts was recorded in newtons (N), and multiplied by the lever arm length in metres (m) to obtain the peak torque in N.m.

Serum CK

Serum CK samples were obtained as a marker of muscle damage. Samples were analysed using an Olympus2 vial CK reagent (Integrated Sciences, New South Wales, Australia; Catalogue Number OSR6179; 4×24 ml R1, 4×6 ml R2).

Sample size

We aimed to detect a 25% reduction in pain at 48 h with ice-water immersion. A previous study reported a mean increase in pain of 69 mm on the VAS at 48 h in individuals receiving no intervention after eccentric exercise.[25] Assuming a mean(SD) increase in pain of only 52(16) mm in the intervention group, 30 participants in all were required to demonstrate a significant difference between groups using an independent t test (significance level of 0.05 and 80% power). The sample size was increased to 40 to allow for any dropouts or missing data.

Data analysis

Data were analysed using SPSS software version 14 on an intention-to-treat basis. Data were checked for normality before analysis. Groups were compared at baseline with regard to participants' characteristics and outcome measures using Mann–Whitney U tests, χ^2 tests, and independent t tests. The last observation carried forward was used to impute data missing at reassessment. To assess whether DOMS had occurred, Wilcoxon's signed ranks tests were used to determine significant changes in variables within groups from baseline to 24 h using an α level of 0.05. To evaluate the effects of the intervention, changes in scores for each outcome were determined between baseline and the subsequent three reassessments. Changes in outcome measures over time were compared between groups using independent t tests or Mann–Whitney U tests. A more conservative α level of 0.01 was used to protect against type 1 error, given the multiple comparisons performed on the dataset.

RESULTS

Table 1 summarises the characteristics of participants in the study. No significant difference was noted between the participants in the two treatment groups at baseline with regard to age, height, weight or body mass index. Participants in both groups reported similar scores on all outcome measures at baseline and there were no significant differences between groups (table 2).

Exercise protocol and DOMS

The eccentric exercise protocol was successful in producing DOMS as indicated by the significant changes from baseline to 24 h in pain with passive stretch, pain with maximal isometric contraction, serum CK and muscle strength (table 3). Pain with passive stretch was significantly increased in both groups at 24 h after eccentric exercise compared with baseline ($p = 0.046$ for controls and $p<0.001$ for the intervention group), as was pain with maximum isometric contraction ($p = 0.004$ and $p<0.001$, respectively). Both groups showed a significant increase in serum CK at 24 h ($p<0.001$ and $p = 0.001$, respectively), and a significant decrease in maximum isometric strength ($p = 0.002$ and 0.025, respectively).

Effect of ice-water immersion on outcome measures

Table 4 shows that participants in the intervention group demonstrated a greater increase at 24 h in pain on sit-to-stand than those in the control group (median change 8.0 vs 2.0 mm respectively, $p = 0.009$). No significant differences were evident between control and intervention groups at any time point with

Table 5 Comparison of changes in other outcome measures across time (24, 48 and 72 h after exercise)

	Control (n = 20)	Intervention (n = 20)	z Score	p Value
Serum CK (IU/l)				
24 h	42.0 (10.3–97.0)	38.0 (13.8–78.3)	−0.24	0.81
48 h	24.0 (−14.0–71.3)	11.0 (−4.5–23.5)	−1.25	0.21
72 h	17.0 (−4.5–58.3)	8.5 (−31.5–33.8)	−1.07	0.29
Thigh circumference mid-belly (mm)				
24 h	1.7 (6.5)	2.4 (7.2)	−0.322	0.75
48 h	1.1 (7.0)	4.0 (5.7)	−1.436	0.16
72 h	2.1 (5.9)	2.2 (6.1)	−0.053	0.96
Thigh circumference musculotendinous (mm)				
24 h	2.0 (5.1)	1.3 (5.4)	0.420	0.68
48 h	1.7 (6.1)	1.0 (5.9)	0.368	0.72
72 h	2.8 (5.5)	1.0 (5.1)	1.076	0.29
One-legged hop for distance (m)				
24 h	−0.08 (0.08)	−0.07 (0.11)	−0.492	0.63
48 h	−0.08 (0.09)	−0.05 (0.13)	−0.996	0.33
72 h	−0.08 (0.11)	−0.03 (0.12)	−1.366	0.18
Maximal isometric strength (N.m)				
24 h	−17.4 (20.5)	−11.5 (22.5)	−0.858	0.40
48 h	−5.5 (22.1)	−4.4 (19.5)	−0.159	0.88
72 h	1.8 (22.1)	−0.3 (28.3)	0.267	0.79

$p<0.01$.
Values are either median (interquartile range) or mean (SD).

regard to all other pain measures. No significant differences were evident between control and intervention groups at any time point with regard to serum CK, thigh circumference, one-legged hop for distance or isometric strength (table 5).

DISCUSSION

Despite the lack of scientific evidence supporting the use of ice-water immersion to prevent DOMS in the sporting environment, it remains widely used in clinical practice as a recovery technique.[22 33] Although treatment protocols vary with regard to the duration and frequency of immersions and the temporal relationship with exercise, anecdotal evidence suggests that the most commonly used protocol in Australia involves 1 min ice-water immersion followed by 1 min out of water for a total of three cycles, applied immediately after a bout of exercise. We aimed to test the efficacy of this common clinical protocol. Our double-blind randomised controlled trial demonstrated that in a group of untrained healthy volunteers, ice-water immersion produced no significant change in most markers of DOMS. The only exception to this was pain on concentric quadriceps contraction at 24 h, which was actually increased in the intervention group compared with controls, contrary to the hypothesis at the study outset. However, the small magnitude of this difference in pain between groups is of questionable clinical significance.

Serum CK is accepted widely as a marker of muscle damage.[11 34–36] In the current study, a peak median CK increase of 170% from baseline occurred at 24 h. This suggests that the eccentric exercise protocol used was successful in eliciting muscle damage, although peak increases up to 600% have been reported in other studies with more aggressive eccentric quadriceps loads.[2 5 6 37 38] Increases in pain and reductions in quadriceps strength at 24 h in both groups further attest to the success of the exercise protocol in inducing DOMS.

Pain was the only parameter significantly influenced by the treatment in our study, and contrary to expectation, ice-water immersion actually increased the severity of pain after 24 h of eccentric exercise. It is unclear why pain increased in participants subjected to ice-water immersion. A noxious cold stimulus such as ice-water immersion is known to evoke varied sensory experiences in humans including cold, pain, ache and prickling, which are mediated by thermoreceptors and nociceptors.[39] Temperatures <15℃ are associated with additional perceptions of pain and ache as well as cold, and peak pain sensation occurs at a temperature of approximately 3℃ for at least 10 s.[39] Application of noxious cold stimulus for >1 min may also stimulate vascular and muscle nociceptors. The ice-water immersion group in the current study may have therefore experienced a significant painful stimulus at the time of immersion. The experience of pain is determined by both physiological and psychological influences, and the meaning or context that a subject attaches to a particular stimulus can influence the subjective interpretation of the pain they experience.[40 41] Thus, the ice-water immersion group may have had a heightened subjective interpretation of discomfort on performing the sit-to-stand activity (which was the first outcome reassessed at 24 h) secondary to both their expectation of being sore as a result of the exercise on the previous day and the significant additional pain experienced during immersion.

Contrary to the research hypothesis, the ice-water immersion protocol used in the current study did not influence CK levels. It is likely that a bout of immersion immediately after exercise as used in the current study would not have had a sustained effect on vessel permeability and was therefore unlikely to influence CK efflux from the damaged muscle on subsequent days. This may also explain why there was no effect on swelling over subsequent days.

What is already known on this topic

- Ice-water immersion is a commonly used treatment in sporting populations, believed to limit the inflammatory response after muscle damage mainly through a vasoconstrictive effect.
- Previous literature evaluating the effect of ice-water immersion on eccentrically induced muscle damage contains conflicting results involving poorly justified protocols of immersion that are also impractical to apply.

What this study adds

- This study challenges the use of ice-water immersion in athletes, given that for eccentric exercise-induced muscle damage, ice-water immersion offers no benefit for pain, swelling, isometric strength and function, and in fact may make athletes more sore the following day.

The lack of a treatment effect for other outcomes may be due to the eccentric exercise protocol inducing only low levels of muscle damage. This is reflected by relatively low pain scores, small percentage strength deficits and small CK increases after exercise (tables 4 and 5). In comparison with other studies, which have demonstrated mean VAS scores of up to 71 mm after exercise with 10 sets of 10 maximal hamstring contractions,[25] for example, the control group in the current study achieved only a maximum of 27 mm of pain (on isometric contraction at 24 h), and the intervention group a maximum of 38 mm (again on isometric contraction at 24 h). The strength deficits observed in this study were also small compared with other studies of DOMS which demonstrated 25–40% strength reduction at 24 h and increases in mean CK of 278–600% above baseline [2 5 6 30]. Thus, because of the small strength deficits induced, there was limited capacity for the treatment to be effective, which is likely to have contributed to the non-significant findings.

With all physical activity there is a psychological component that can enhance performance,[42] particularly in elite athletes who use many different types of recovery strategies that have little evidence behind them. What may be considered beneficial by one athlete as a recovery technique is not necessarily of any perceived benefit to another. Over time, athletes develop their own rituals of preparation and recovery that they use before and after every competition performance or training bout. The perceived psychological benefit of using a familiar recovery technique may have a greater influence on performance than perhaps the actual physiological benefit of that technique. Although the present study used a control intervention in tepid water to account for these potential placebo effects of ice-water immersion, the study sample did not include athletes, so it is possible that different results would be obtained in a group of elite athletes.

The main strength of this study was the use of a rigorous double-blind randomised control design, which included a control intervention (tepid water bath) to assess the effects of temperature alone with few confounders. Another strength of this study is that it evaluated a clinically feasible treatment regimen that is commonly used in Australia.

Future research may involve repeating the current study with a more damaging eccentric exercise protocol to be able to determine significant differences between treatment and placebo interventions for all outcome measures.

Future research may focus on specific groups of elite athletes who regularly use ice-water immersion and develop reliable functional measures for each group that may demonstrate more subtle objective deficits resulting from muscle soreness. It would be valuable to assess athletes in their chosen sport to determine the specific muscle symptoms that result from an intense competition performance as it may be possible to identify a reliable model of sports-induced muscle damage, and reliable outcome measures that are affected by muscle soreness. From this, the effects of various interventions such as ice-water immersion could be properly assessed in sports-induced muscle soreness.

In conclusion, this study challenges the use of this intervention as a recovery strategy by athletes given that ice-water immersion to minimise or prevent symptoms of muscle damage after eccentric exercise is ineffectual in young, relatively untrained individuals. Given that trained athletes are relatively well protected against DOMS, ice-water immersion is likely to offer them even less benefit for the minimal soreness they may experience after eccentric exercise.

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