



Original article

Effectiveness of air pulsed cryotherapy on delayed onset muscle soreness of elbow flexors following eccentric exercise

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ABSTRACT

Introduction: Cryotherapy is widely used in sports to facilitate recovery from exercise-induced muscle damage that often results from strenuous training and/or competition. However, a paucity of evidence exists on the therapeutic values of repeated air pulsed cryotherapy (CRYO) application to suggest its usefulness to clinicians, coaches, sports scientists and athletes in the field of sports and rehabilitation.

Aim: This study investigates the effectiveness of CRYO on the recovery from delayed onset of muscle soreness (DOMS) induced by eccentric exercise.

Material and methods: Thirty-two participants (21.31 ± 1.03 years, height 1.72 ± 0.05 m, BMI 22.15 ± 1.69 kg/cm²) were equally randomized into CRYO group and control group (CONT). DOMS was induced by eccentric contractions of elbow flexors. Visual analogue scale score (VAS), mid arm circumference (MAC), pressure pain threshold (PPT), range of motion of active elbow flexion (ROM-AF), passive elbow flexion (ROM-PF), active elbow extension (ROM-AE), passive elbow extension (ROM-PE) and isometric peak torque of elbow flexors (IPT) were measured at pre-exercise (PRE), immediately, 1, 2, 3, 4, and 7 days post exercise.

Results and discussion: There were significant interactions effect (group X time) with ($P < 0.05$) for VAS, MAC, PPT, ROM-PF, ROM-AE, and ROM-PE. Additionally, all outcome measures (except for ROM-AF and IPT) demonstrated a significant improvement ($P < 0.05$) in DOMS recovery in the CRYO group compared to CONT group.

Conclusions: A 20 minutes (4 session \times 5 minutes) session for 5 consecutive days of repeated air pulsed cryotherapy has beneficial effects on the recovery of DOMS on elbow flexors from eccentric exercise.

1. INTRODUCTION

Delayed onset muscle soreness (DOMS) due to exercise induced muscle damage (EIMD) is a common problem among elite and novice athletes as a result of excessive or unaccustomed training.¹ The mechanism underlying DOMS remains inconclusive, as the physiological events that cause exercise-induced micro-tears in the muscle fibres and resultant damage involves a combination of mechanical or biochemical factors.^{1,2} Researchers have identified several causative factors of DOMS that include lactic acid accumulation in muscle, muscle spasm, connective tissue damage, inflammation, enzyme efflux, and free radicals.^{3,4} DOMS describes the inflammatory response and oxidative stress in a muscle which trigger the release of several chemical mediators that are responsible for pain, and local elevation of inflammatory substances like histamine, prostaglandin and leukotriene.¹ These inflammatory substances stimulate directly the sensation of pain by sensitizing type III and IV pain afferents free nerve ending.⁵

DOMS is commonly characterized by muscle pain, swelling, loss of muscle function that includes decreased range of motion (ROM) and strength deficits.⁶ Symptoms are usually first evident within 24 h post exercise, reaching the peak occurrence between 24 h and 72 h, and gradually dissipating between 7 and 10 days.⁷ Furthermore, the muscle pain may be associated with decreased muscle performance in the form of decreased rapid force capacity and maximal muscle strength.⁶ DOMS is usually cited by coaches and athletes as being detrimental to recovery and performance, the rapid reversion of DOMS in athletes is essential for both function restoration and regain of sports performance.^{6,7} Therefore, several modalities of recovery have been used to hasten the recovery period from DOMS which include warm-up and cool-down,⁸ soft tissue massage,³ stretching exercise,⁹ electrotherapy,¹⁰ thermotherapy¹¹ and cryotherapy.^{7,12} However, the efficacy of such interventions on exercise induced muscle damage remains equivocal.¹³

Cryotherapy is one of a standard care for acute inflammation.¹⁴ Cryotherapy is proposed to decrease skin-tissue temperature, reduce secondary hypoxic injury, and reduce inflammation consequently decreases edema.^{14,16} However, the effect of cryotherapy on recovery of DOMS remains inconclusive.^{12,14} There is still controversy over what constitutes the optimal modality, frequency and duration of cryotherapy application for DOMS.¹² Available scientific evidences from a meta-analysis and systematic review suggest that no standard guidelines for a target temperature for optimal therapeutic effects have been established.^{17,18} However, the current practice based treatment guidelines for acute tissue injury recommend intermittent cryotherapy application several times a day for approximately 15–20 minutes throughout 72 h retrieval period after injury or until the tendency for swelling has resolved.¹⁵ Previous studies which investigates the effect of cooling on symptoms associated with DOMS conclude that cryotherapy has been

shown to reduce the signs and symptoms of DOMS.^{19–22} On the other hand, evidences from studies do not support any effect on muscle recovery after cryotherapy.^{7,12,23–25} Such discrepancies in the effect may originate due to differences in exercise protocol to induce DOMS, different cooling applications, small sample size and lack of consistency in dosage and frequency for the cryotherapy, which generally consists of a single application, inadequate duration,¹³ all of which may have contributed to lack of uncertain findings for effectiveness.

A novel modality of cryotherapy is the air-pulsed cryotherapy, a treatment involving very short exposures to extreme cold (-30°C) to treatment area, and it is getting popular among athletes and coaches.²⁶ Air-pulsed cryotherapy involves repeatedly exposing very cold air on skin and the sub-epidermal tissues to withdraw heat energy by convection from treatment area.²³ The very cold air exposure is reported to cause a greater decrease in skin temperature than other cryotherapy technique.²⁷ To our knowledge, there is no study that evaluated the effect of repeated air pulsed cryotherapy on DOMS as per the clinical recommendations made by standard guidelines for cryotherapy application.¹⁵ Therefore, the current study attempts to answer the question about clinical effectiveness of the repeated air pulsed cryotherapy treatment for DOMS. Such information is useful for the clinicians in the field of sports medicine, and rehabilitation as well as to the sports scientists, athletes and coaches towards managing and training any individuals with DOMS.

2. AIM

The main aim of the current study is to investigate the effect of 20 minutes per day (4 session \times 5 minutes) of air pulsed cryotherapy application on DOMS induced on elbow flexor muscle (biceps brachii) by eccentric exercise.

3. MATERIAL AND METHODS

3.1. Participants

A total of 32 volunteers (32 males), aged 18 to 25 years (21.31 ± 1.03 years, height 1.72 ± 0.05 m, BMI 22.15 ± 1.69 kg/cm²) participated in the study. All participants were healthy volunteers who were recruited from campus and community settings around the university. Any volunteer with history of alcohol consumption and with reported contraindications to cryotherapy treatment were excluded from the study. The inclusion criteria required the participants with no history of musculoskeletal and neurological disorders of upper limb, no recent injuries to upper limb over the last 12 months and with no history of any form of resistance training to upper limb over the last 3 months of time period. The participants were randomly assigned into one of the two groups namely repeated air pulsed cryotherapy intervention (CRYO group, $n = 16$) and control group (CONT, $n = 16$). The ethical approval of

the study was granted by an institutional ethics committee and all the participants signed a written informed consent form prior to the start of the study.

3.2. Eccentric exercise induction protocol

The eccentric exercise of elbow flexor muscle was performed using isokinetic dynamometer (Con-Trex CMV AG, Dubendorf, Switzerland). Prior to the exercise performance, the machine was calibrated as per the recommendations of the manufacturer. Each participants performed a bout of 3 sets of 20 maximal eccentric contractions of elbow flexors of the nondominant arm. For each eccentric contraction, the elbow joint was forcibly extended from a flexed (60°) to a fully extended position (180°) in 1 s at an angular velocity of $120^\circ/\text{s}$ in a supinated arm position and the arm was passively repositioned at 60° (at rate of 30° deg/s). The subjects were verbally encouraged to generate maximal force against resistance from flexed position towards extension during the elbow extending action throughout range of motion, with a 3 minutes rest allowed in between each set.²³

3.3. Intervention protocol

Air pulsed cryotherapy was administered to all the participants in the CRYO group by a trained research assistant, who used a Cryo⁶ skin cooling system (Zimmer Medizin Systems, Neu-Ulm, Germany). All the participants in the CRYO group received 4 repeated applications of cryotherapy each session lasting for a duration of 5 minutes. A rest period of 1 minute was given between each sessions to avoid any cold burns due to extreme cold.²³ The cold pulsed air was applied 2 cm above the distal tendon of biceps brachii to the nondominant arm with a maximal available air flow intensity of 9 over a $4 \times 10 \text{ cm}$ area. The scanning of the cold air was performed through vertical and horizontal motions with a 5-cm distance kept between the tube nozzle and skin. An infrared thermometer (DT -480, China) was used to confirm skin temperature during cryotherapy treatments for a sufficient effect of cold therapy (5°C – 15°C).²⁸ The CONT group participants were rested in supine position without cryotherapy treatment and were given general advice to take rest and not to carry any heavy weight. All of the participants were requested to avoid any kind of vigorous physical activity.

3.4. Data collection

A total of eight separate outcome measures which include visual analogue scale score (VAS), mid arm circumference (MAC), pressure pain threshold (PPT), range of motion of active elbow flexion (ROM-AF), passive elbow flexion (ROM-PF), active elbow extension (ROM-AE), passive elbow extension (ROM-PE) and isometric peak torque (IPT) of elbow flexors were measured in random order. All the outcome measures were evaluated repeatedly over 7 different points at baseline (PRE) taken prior to the eccentric exercise induction of DOMS, immediately (Imm), and on 1, 2, 3, 4, and 7 day (1D, 2D, 3D, 4D, and 7D) respectively.

3.5. Visual analogue scale

The pain intensity perceived by the participants was assessed using a VAS score. The VAS consists of a 10-cm line labelled with 0 at the left endpoint representing no pain and 10 at the right endpoint representing unbearable pain. The subjects were asked to mark the level of perceived pain on VAS as the participants stood in an upright position, flexed their forearm slowly to a 90° angle and returned to the initial position of full elbow extension.²³

3.6. Pressure pain threshold

PPT was assessed to measure peripheral sensitization using a digital pressure algometer (Somedic AB, Sollentuna, Sweden) with a probe size of 1.0 cm^2 . After calibration with a 100 kPa calibrating weight, the probe was placed perpendicularly over the mid-belly of the biceps muscle and force was gradually applied at a rate of 40 kPa/s. The participants pressed a button when they started to feel pain as a result of applied pressure. This protocol was performed three times with 30 s interval between measurements and an average value (in kPa) of the three measures was used for further analysis.^{29,30} The point of measurement at the skin was marked with a semipermanent marker for the consistency of the subsequent measurements.

3.7. Mid arm circumference

An anthropometric tape measure was used to measure the elbow flexors circumference at the level of mid-belly of the biceps brachii muscle.²¹ The skin was marked with a semipermanent marker to maintain consistency of measurement for the subsequent days. The measurements were taken while the participant was in the sitting position with arm relaxed and hanging by the side. An average of the three measures was recorded in centimetres for further analysis with a 30 s of interval between each measurement.

3.8. Range of motion

A standard goniometer was used to measure the total ROM for the elbow joint with active ROM (AROM) assessed before passive ROM (PROM) and flexion measured before extension. All measurements were taken in the supine position. The measurement procedure was standardized for both measurements with the fulcrum of the goniometer centred over the lateral epicondyle of the humerus and the stationary arm was placed parallel to the humerus pointing towards the acromion process. The moving arm was parallel to the radius pointing to the styloid process of the radius. The active flexion angle was defined as the angle at the elbow when participant performed flexion movement at the elbow joint to touch the shoulder with the palm and the active extension angle was the angle when participants extended the elbow joint as much as possible. The pain-free AROM was determined by instructing participant to stop at the position where the initial pain was perceived. For the PROM, the participant was then instructed to relax the arm and the movement was performed by the investigator.³¹ The participant notified the investigator when he first perceived pain. Three measurements

were taken for each angle with a 30 s of interval between each measures. The average of the three measures was recorded in degree for further analysis

3.9. Isometric peak torque

IPT measurement of the elbow flexors was carried out at a joint angle of 90° using an isokinetic dynamometer (Con-Trex CMV AG, Dubendorf, Switzerland). The participants were instructed to pull the forearm towards the shoulder to induce elbow flexion and to sustain the maximal effort for 5 s at a fixed elbow angle. A total of three measurements were taken with 30 s of interval between each measures.²³ An average value of torque from the three measures was recorded in Newton meters (Nm) for further analysis.

3.10. Statistical analysis

A sample size calculation was estimated from a previous study with DOMS as the primary clinical outcome at a power at 0.80 and an effect size of 0.46. Data were analysed using the

SPSS 22.0 for Windows Statistical Package (SPSS Inc, Chicago, IL). All variables were tested for normality using the Shapiro–Wilk test. Changes in variables over time were compared between groups using a mixed model repeated measures ANOVA (group × time) on normalized data. Bonferroni test analysis was followed up to detect differences in the main effect. The Greenhouse–Geisser epsilon was used to adjust the degrees of freedom to increase the critical value of the *F* ratio. Level of significance was set at *P* < 0.05 for all analyses.

4. RESULTS

There was no significant difference in the mean age, weight and BMI between groups, except height. The changes in absolute values (mean ± SD) for the outcome measures at pre-exercise (Pre), immediately (Imm) and days 1 to 7 (1D–7D) post exercise for the groups (CRYO, *n* = 16) and control (CONT, *n* = 16) are presented in Table 1.

Table 1. Changes in outcome measures from pre exercise (Baseline), immediately (Imm) and days 1 to 7 (1D–7D) for the cryotherapy (CRYO, *n* = 16) and control (CONT, *n* = 16) groups.

Measures	Pre	Imm	1D	2D	3D	4D	7D
VAS, cm							
CONT	0	0.012 ± 0.05	3.47 ± 0.74 ^a	4.47 ± 0.96 ^a	4.51 ± 1.42 ^a	2.91 ± 1.14 ^a	0.51 ± 0.46 ^a
CRYO	0	0.018 ± 0.07	2.57 ± 0.35 ^{ab}	3.20 ± 0.76 ^{ab}	2.26 ± 0.93 ^{ab}	0.41 ± 0.40 ^b	0.06 ± 0.12 ^b
Mean diff (95%CI)	0	0 (−0.05–0.04)	0.9 (−0.48–1.32)	1.27(−0.64–1.90)	2.25(−1.38–3.11)	2.50(−1.9–3.08)	0.45(−0.64–0.2)
PPT, kPa							
CONT	339.19 ± 56.8	287.69 ± 52.99 ^a	243.02 ± 46.17 ^a	251.48 ± 57.07 ^a	279.09 ± 55.49 ^a	304.38 ± 48.81 ^a	336.00 ± 59.42
CRYO	330.7 ± 39.52	282.56 ± 49.25 ^a	258.92 ± 35.27 ^a	278.52 ± 41.98 ^{ab}	310.0 ± 45.68 ^{ab}	330.25 ± 41.35 ^b	338.19 ± 40.40
Mean diff (95%CI)	8.48	5.13	15.90	27.04	30.85	25.87	2.18
	(−27.04–44.00)	(−31.81–42.07)	(−45.65–13.85)	(−63.35–9.27)	(−67.57–5.90)	(−58.57–6.83)	(−39.08–34.70)
MAC, cm							
CONT	29.21 ± 3.55 ^a	29.41(3.56)	29.64 ± 3.64 ^a	29.81 ± 3.77 ^a	29.84 ± 3.79 ^a	29.48 ± 3.63 ^a	29.25 ± 3.58
CRYO	28.26 ± 2.40	28.38(2.37)	28.50 ± 2.41 ^{ab}	28.49 ± 2.44 ^{ab}	28.36 ± 2.41 ^b	28.29 ± 2.41 ^b	28.27 ± 2.39
Mean diff (95%CI)	0.95(−1.2–3.1)	1.02(−1.1–3.2)	1.1(−1.1–3.3)	1.3(−0.9–3.6)	1.49(−0.8–3.7)	1.18(−1.0–3.4)	0.98(−1.2–3.2)
ROM-AE, °							
CONT	145.94 ± 3.05	143.27 ± 3.75 ^a	134.0 ± 4.48 ^a	131.71 ± 6.51 ^a	134.19 ± 5.59 ^a	139.08 ± 3.80 ^a	145.92 ± 2.73
CRYO	146.79 ± 3.44	143.79 ± 4.26 ^a	135.41 ± 5.12 ^a	134.64 ± 5.34 ^a	138.17 ± 4.95 ^a	141.19 ± 3.53 ^a	147.15 ± 3.30
Mean diff (95%CI)	0.8 (−3.2–1.5)	0.52(−3.4–2.4)	−1.42(−4.9–2.0)	−2.93(−7.2–1.4)	−3.9(−7.8–0.16)	−2.1(−4.7–0.54)	−1.2(−3.4–0.96)
ROM-AE, °							
CONT	−2.08 ± 4.53	9.75 ± 6.81 ^a	32.39 ± 8.00 ^a	51.35 ± 7.44 ^a	35.44 ± 10.38 ^a	18.21 ± 7.77 ^a	1.814 ± .36
CRYO	−2.66 ± 5.20	8.00 ± 9.14 ^a	23.13 ± 8.30 ^{ab}	28.95 ± 9.03 ^{ab}	15.40 ± 6.10 ^{ab}	2.41 ± 6.78 ^{ab}	−2.44 ± 4.97
Mean diff (95%CI)	0.6(−2.9–4.1)	1.75(−4.1–7.6)	9.3(3.4–15.1)	22.39(16.4–28.4)	20.04(13.8–26.2)	15.8(10.5–21.1)	4.25 (−0.8–7.6)
ROM-PE, °							
CONT	147.90 ± 3.12	144.46 ± 4.06 ^a	136.57 ± 4.01 ^a	133.56 ± 4.12 ^a	135.55 ± 4.37 ^a	141.81 ± 2.85 ^a	147.91 ± 2.91
CRYO	148.62 ± 2.80	145.42 ± 3.21 ^a	142.81 ± 3.47 ^{ab}	142.39 ± 3.08 ^{ab}	145.79 ± 3.50 ^b	147.71 ± 3.35 ^b	148.79 ± 3.20
Mean diff (95%CI)	0.7(−2.8–1.4)	0.96(−3.6–1.7)	6.24 (−8.9–3.5)	8.83(−11.4–6.2)	10.25(−13.1–7.4)	5.90(−8.1–3.6)	0.88(−3.1–1.3)
ROM-PE, °							
CONT	−2.96 ± 4.97	4.39 ± 6.19 ^a	17.71 ± 6.81 ^a	27.13 ± 8.77 ^a	25.73 ± 11.73 ^a	8.94 ± 7.03 ^a	−2.64(4.99)
CRYO	−3.60 ± 3.92	3.42 ± 8.20 ^a	9.51 ± 9.64 ^{ab}	13.84 ± 11.33 ^{ab}	6.73 ± 7.04 ^{ab}	−3.25 ± 4.29 ^b	−3.64(3.89)
Mean diff (95%CI)	0.6(−2.6–3.9)	0.9(−4.3–6.2)	8.2(2.14–14.2)	13.3(5.9–20.6)	19(11.9–26.0)	12.2(7.9–16.4)	1(−2.2–4.2)
IPT, Nm							
CONT	42.82 ± 9.77	33.02 ± 5.86 ^a	29.63 ± 5.44 ^a	30.97 ± 5.21 ^a	32.74 ± 5.82 ^a	35.42 ± 6.18 ^a	38.12 ± 8.32 ^a
CRYO	39.78 ± 6.58	30.875 ± .60 ^a	28.72 ± 5.39 ^a	30.66 ± 5.34 ^a	32.44 ± 5.81 ^a	35.11 ± 5.74 ^a	36.75 ± 6.12 ^a
Mean diff (95%CI)	3.0 (−3–9)	2.1(−1.9–6.3)	3.0(−3–9)	0.9(−1.9–6.2)	0.64(−2.9–4.8)	0.87(−3.5–4.1)	0.88(−3.9–4.6)

Comments: No significant differences between groups at the baseline; values are mean ± SD, ^a Significant compared with PRE, ^b Significant compared with CONT.

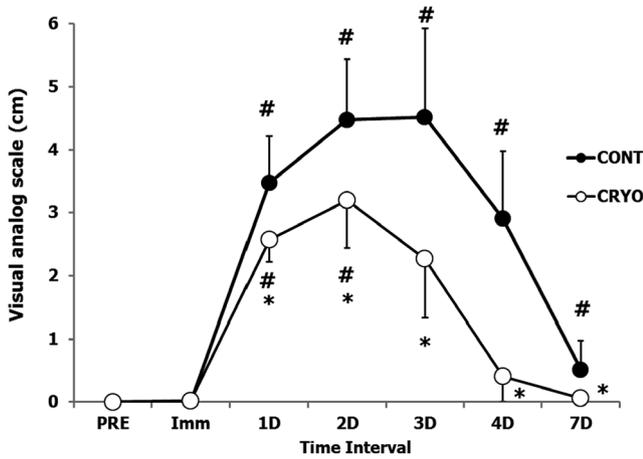


Figure 1a. Changes of VAS: PRE, Imm, and 1D–7D post exercise for the CRYO and CONT groups. Comments: Values are the mean ± SD. * Significant compared with PRE ($P < 0.05$), # Significant between groups ($P < 0.05$).

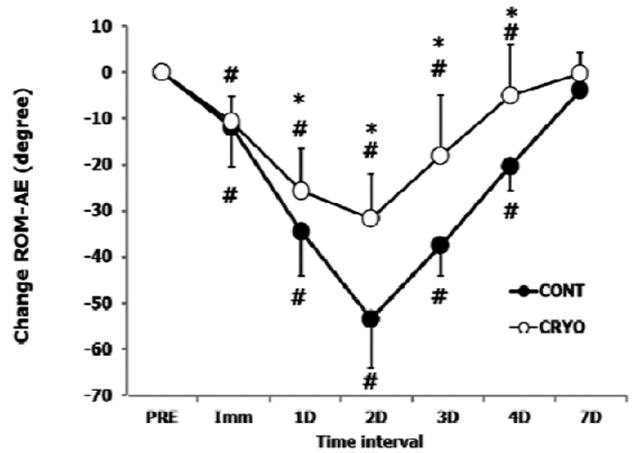


Figure 2a. Changes in ROM-AE: PRE, Imm, and 1D–7D post exercise for the CRYO and CONT groups. Comments: * Significant compared with PRE ($P < 0.05$), # Significant between groups ($P < 0.05$).

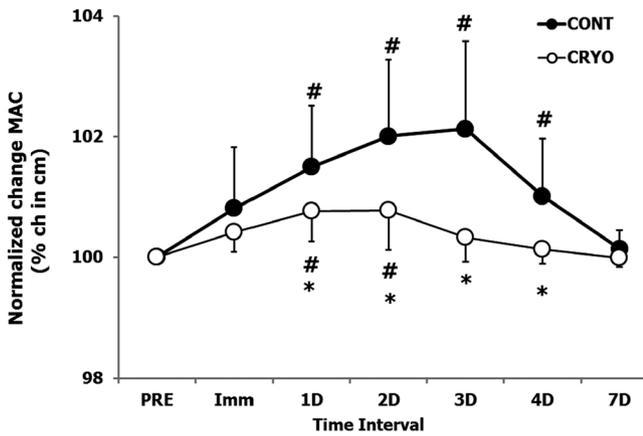


Figure 1b. Normalized changes in MAC: PRE, Imm, and 1D–7D post exercise for the CRYO and CONT groups. Comments: * Significant compared with PRE ($P < 0.05$), # Significant between groups ($P < 0.05$).

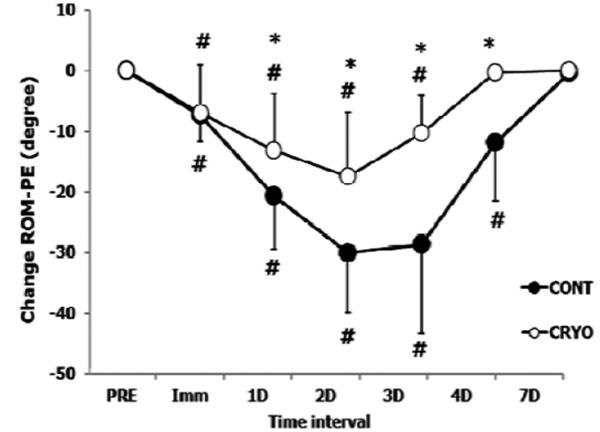


Figure 2b. Changes in ROM-PE: PRE, Imm, and 1D–7D post exercise for the CRYO and CONT groups. Comments: * Significant compared with PRE ($P < 0.05$), # Significant between groups ($P < 0.05$).

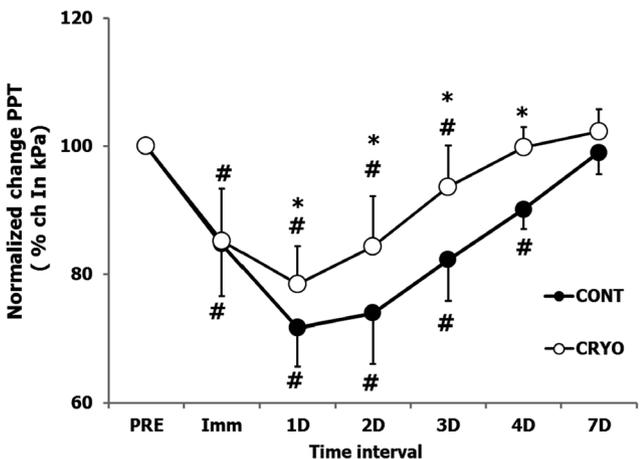


Figure 1c. Normalized changes in PPT: PPRE, Imm, and 1D–7D post exercise for the CRYO and CONT groups. Comments: * Significant compared with PRE ($P < 0.05$), # Significant between groups ($P < 0.05$).

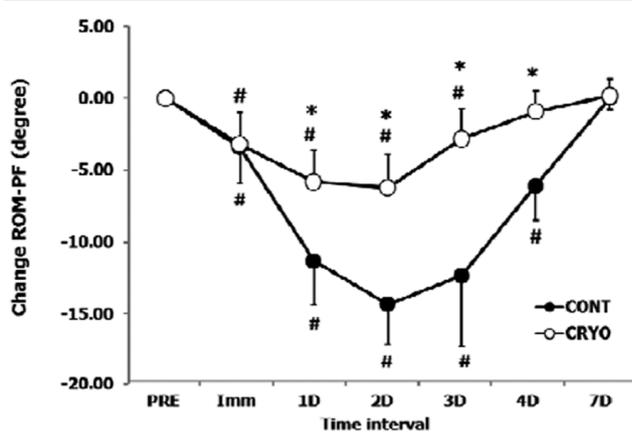


Figure 2c. Changes in ROM-PF: PRE, Imm, and 1D–7D post exercise for the CRYO and CONT groups. Comments: * Significant compared with PRE ($P < 0.05$), # Significant between groups ($P < 0.05$).

4.1 Pain intensity

The results showed a significant main effect of time for VAS (changes within the participants between baseline and repeated measures) with ($F_{1,99,59.76} = 332.62, P = 0.001, \eta^2 = 0.91$) and significant main effect of condition (changes between CRYO and CONT group) with ($F_{1,30} = 38.18, P = 0.001, \eta^2 = 0.56$). A significant main effect on interaction between time and conditions (within and between differences across the time of measures between the groups) was also observed with ($F_{1,99,59.76} = 29.62, P = 0.001, \eta^2 = 0.49$). DOMS peaked 4.51+1.42 for CONT group at 3D and 3.20+0.76 for CRYO group at 2D (Figure 1b) The effect size was larger for all the significant effects which ranged $\eta^2 = 0.49$ –0.91).

4.2. Pain pressure threshold

A significant main effect of time on PPT was observed in both groups ($F_{3,18,95.56} = 113.91, P = 0.001, \eta^2 = 0.80$). Similarly, the main group effect was also significant between groups ($F_{1,30} = 23.43, P = 0.002, \eta^2 = 0.43$) on 1D ($P = 0.007$), 2D ($P = 0.002$), 3D ($P = 0.001$), and 4D ($P = 0.001$) respectively. PPT returned to PRE for CRYO group at 4D compared with 7D for CONT return to PRE levels (Figure 1b). ANOVA revealed a significant group \times time interaction ($F_{3,18,95.56} = 6.40, P < 0.003, \eta^2 = 0.18$) with a larger effect size.

4.3. Mid arm circumference

The results showed a significant main effect of time in both groups ($F_{3,08,92.60} = 32.23, P = 0.001, \eta^2 = 0.52$) and a significant main effect between groups ($F_{1,30} = 18.48, P = 0.001, \eta^2 = 0.38$). The main effect of interaction (group \times time) was also significant ($F_{3,08,92.60} = 10.59, P = 0.001, \eta^2 = 0.26$). All the observed changes are clinically significant with large effect size ($\eta^2 = 0.26$ –0.52). Figure 1c shows the main effect of interaction where MAC return to PRE values for the CRYO group at 3D compared with CONT at 7D.

4.4. Active range of motion

There was a significant main effect of time on ROM-AF in both groups ($F_{2,14,64.35} = 204.62, P = 0.001, \eta^2 = 0.87$), however no significant effect was established between groups and interaction of group \times time ($P > 0.05$). For ROM-AE, there was a significant main effect of time ($F_{3,53,106.03} = 202.48, P < 0.001, \eta^2 = 0.87$) and group ($F_{1,30} = 24.47, P = 0.001, \eta^2 = 0.48$) with a significant interaction effect of group \times time ($F_{3,53,106.03} = 16.16, P = 0.001, \eta^2 = 0.35$). CRYO group demonstrated significant lower deficit in ROM-AE than CONT group at 2D ($P = 0.015$), 3D ($P = 0.001$), 4D ($P = 0.001$), and 5D ($P = 0.001$) as indicated in Figure 2a.

4.5. Passive range of motion

For ROM-PF, a significant effect of time ($F_{3,24,97.31} = 134.20, P = 0.001, \eta^2 = 0.82$), group ($F_{1,30} = 66.24, P = 0.001, \eta^2 = 0.48$) and main interaction of group \times time ($F_{3,24,97.31} = 31.29, P = 0.001, \eta^2 = 0.51$) was observed respectively with larger effect size. The CRYO group demonstrated a significantly lower deficit in ROM-PF than CONT group on 1D to 4D post-exercise ($P = 0.001$) (Figure 2b). Similar results

of significance were obtained for ROM-PE on time effect ($F_{2,77,83.11} = 78.66, P < 0.001, \eta^2 = 0.72$), group effect ($F_{1,30} = 16.43, P = 0.001, \eta^2 = 0.35$) and interaction of group \times time ($F_{2,77,83.11} = 11.49, P < 0.001, \eta^2 = 0.27$). CRYO group demonstrated a significantly lower deficit in ROM-PE than CONT group on 1D ($P = 0.026$), 2D ($P = 0.001$), 3D ($P = 0.001$) and 4D post-exercise ($P = 0.001$) (Figure 2b).

4.6. Isometric peak torque

The results showed a significant main effect of time in both groups ($F_{4,26,156.66} = 282.19, P = 0.001, \eta^2 = 0.90$), and a significant time \times group interaction effect ($F_{4,26,127.88} = 2.79, P = 0.026$). However, there was no significant effect observed between groups ($P = 0.084, \eta^2 = 0.09$). Table 1 shows that the IPT remained lower than the PRE value after 7D.

5. DISCUSSION

The study results demonstrated that repeated air pulse cryotherapy significantly enhanced the recovery process of DOMS following eccentric exercise to a greater extent than the CONT group. Past studies suggested that the muscle needs to be eccentrically engaged to optimal and adequate intensity of muscle work in order to create a DOMS phenomenon before any effect on DOMS to be investigated.^{23,32} In current study, an eccentric exercise protocol successfully induced DOMS which had been confirmed by significant changes in all dependent variables over time (Table 1). The pattern of changes observed in dependent variables after DOMS by eccentric exercise were similar to the trend reported in previous studies.^{23,32}

In current study, muscle soreness peaked at 2D–3D post exercise which is consistent with previous studies.^{21,23,24,33} The CRYO group had significantly reduced VAS rating than CONT groups at 1D to 7D ($P < 0.001$). While the change in VAS rating in CRYO group from 4D to 5D (2.26+0.93 cm to 0.41+0.40 cm) was superior to minimally clinical important difference (1.7 to 2.0 cm),³⁴ the muscle soreness returned to PRE level for the CRYO group at 4D compared with 7D for the CONT (Table 1, Figure 1a). Therefore, it can be suggested that air pulsed cryotherapy might effectively relieves pain after 24 h of application. Our result was similar to Ingram et al.²⁰ who reported a significant reduction in soreness of quadriceps muscle among participants at 24 h with two 5-minutes immersions in 10°C water. Similarly, Oakley et al.¹⁹ also found a significant pain reduction of hamstring muscle with 20 minutes of cold application three times a day throughout 72 h post exercise. In contrast, numerous cryotherapy studies had no significant change in muscle soreness.^{23,24,35–37}

The CRYO group had a significant increase of PPT value at 2D, 3D and 4D and return to PRE level at 4D (Table 1, Figure 1c) suggested that air pulsed cryotherapy was more effective than CONT group in mechanical pain reduction. The course of change in PPT observed over time was similar to previous studies^{32,38} where PPT showed a largest decline 24 h

after DOMS following eccentric exercise. These results suggested that air pulsed cryotherapy reduced pain and increased PPT contributed by rapid reduction in skin temperature. As low skin temperature is shown to induce a local analgesic effect ($<13.6^{\circ}\text{C}$) and reduced nerve conduction velocity ($<12.5^{\circ}\text{C}$),³⁹ it might explain the mechanism on how repeated air pulsed cryotherapy reduced pain and increased PPT. In current study, 5 minutes air pulsed cryotherapy (-30°C) reduced the skin temperature to $7.44 \pm 1.32^{\circ}\text{C}$ which was more cooler than a previous study²³ ($9. \pm 0.8^{\circ}\text{C}$) during 20 minutes application and the temperature remained lower than 18°C among the participants for at least for 10 minutes even after cooling application.

The CRYO group had a significant relief in swelling as measured by MAC after 1D–4D compared to the CONT group and MAC returned to PRE level at 3D (Table 1, Figure 1b). The findings were similar to Eston and Peter who reported that cold water immersion (every 12 h for a total of 7 sessions) following eccentric biceps exercise showed a significant reduction in stiffness and swelling.²¹ In contrast, few other studies^{23,26} demonstrated that cryotherapy did not significantly affect swelling which could be explained due to differences in protocols such as modality of cryotherapy, duration of treatment and lack of continuation of treatment associated with DOMS. Therefore, the repeated air pulsed cryotherapy protocol used in current study carefully considered the above differences together with clinical recommendations by increasing the treatment time to 20 minutes with increased frequency of treatment application.

The decreases in ROM-AF, ROM-PF, ROM-AE and ROM-PE following DOMS induced by eccentric exercise might be as a result of muscle stiffness. The stiffness might occur due to connective tissue damage, tissue edema which increased mechanical sensitivity of muscle receptors to discomfort as activated by pressure or stretching.^{1,21} As a result of DOMS, ROM-AE and ROM-PE might cause more pain particularly due to eccentric action of the damaged elbow flexor muscle which might lead to reduced movements. Nevertheless, ROM-AE and ROM-PE in CRYO group showed significantly lesser reduction than CONT group which could be attributed to positive effect of repeated air pulsed cryotherapy application. The significant reduction of ROM-PF in CRYO group was lesser than the CONT group. Therefore, it was possible that air pulsed cryotherapy could accelerate the recovery in ROM-PF, ROM-AE and ROM-PE by reducing pain, inflammatory process and muscle tightness. However, no significant change in ROM-AF between groups was observed. Past study suggested that cold application might increase local blood viscosity and tissue stiffness interrupting active exercise¹⁵ which might explain why no change in the ROM-AF occurred.

The current study showed a large decline (approximately 31%) in strength of elbow flexors in 1D post exercise DOMS and the strength remained below the baseline even at day 7. The possible explanations for loss of muscle strength may include rupture of the myofibril, sarcolemma, t-tubules and consequent failure of action potential conduc-

tion and excitation-contraction coupling, which may have resulted to an inability to generate force.⁴⁰ In our study, IPT had no significant difference between groups. The pattern of strength loss and recovery observed in current study is similar to Guilhem et al.²³ who reported that maximal isometric torque of elbow flexors strength decreased by 33% in 24 h after exercise and the eccentric exercise protocol used were similar to the present study (3×20 eccentric contractions). Therefore, it might be argued that repeated air pressured cryotherapy did not have any effect on the muscle strength. To our knowledge, no studies showed significant improvement in strength of elbow flexors after eccentric exercise from cryotherapy.^{23,36,41}

There are few limitations present in the study. The study considered only healthy male participants and hence, the external validity of the study findings may not be applicable to other groups of population (e.g., females, elderly individuals, clinical population). As gender is reported to affect the pain outcome measures, the researchers recruited only the male participants. No measurement of subcutaneous fat tissue was considered which could be another limitation as presence of sub cutaneous fat might act as an insulator and inhibit effects on tissue cooling. Nevertheless, BMI data showed that the participants did not have obesity which might minimize the effects of sub cutaneous tissue to cooling effects. Further research should focus on testing the study findings in other populations involving different muscle groups before applying the positive effects of the study to day to day clinical practice. Applications of cold for short period (<10 minutes) are reported to be ineffective in DOMS recovery⁴² and hence, a duration of 20 minutes was considered as optimal duration for repeated air pulsed cryotherapy application.

6. CONCLUSIONS

A 20 minutes (4 session \times 5 minutes) session for 5 consecutive days of repeated air pulsed cryotherapy has beneficial effects on the recovery of DOMS on elbow flexors following eccentric exercise. Future studies are required to investigate the effects of repeated air pulsed cryotherapy in multiple muscle groups among athletes.

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Conflict of interest

None declared.

References

- 1 Cheung K, Hume P, Maxwell L. Delayed onset muscle soreness: treatment strategies and performance factors. *Sports Med.* 2003;33(2):145–164. <https://doi.org/10.2165/00007256-200333020-00005>.
- 2 Tee JC, Bosch AN, Lambert MI. Metabolic consequences of exercise-induced muscle damage. *Sports Med.* 2007;37(10):827–836. <https://doi.org/10.2165/00007256-200737100-00001>.
- 3 Andersen LL, Jay K, Andersen CH, et al. Acute effects of massage or active exercise in relieving muscle soreness: randomized controlled trial. *J Strength Cond Res.* 2013;27(12):3352–3359. <https://doi.org/10.1519/JSC.0b013e3182908610>.
- 4 Close GL, Ashton T, McArdle A, Maclaren DP. The emerging role of free radicals in delayed onset muscle soreness and contraction-induced muscle injury. *Comp Biochem Physiol A Mol Integr Physiol.* 2005;142(3):257–266. <https://doi.org/10.1016/j.cbpa.2005.08.005>.
- 5 Nosaka K, Newton M, Sacco P. Delayed-onset muscle soreness does not reflect the magnitude of eccentric exercise-induced muscle damage. *Scand J Med Sci Sports.* 2002;12(6):337–346. <https://doi.org/10.1034/j.1600-0838.2002.10178.x>.
- 6 Clarkson PM, Hubal MJ. Exercise-induced muscle damage in humans. *Am J Phys Med Rehabil.* 2002;81(11 Suppl):S52–S69. <https://doi.org/10.1097/00002060-200211001-00007>.
- 7 Glasgow PD, Ferris R, Bleakley CM. Cold water immersion in the management of delayed-onset muscle soreness: is dose important? A randomised controlled trial. *Phys Ther Sport.* 2014;15(4):228–233. <https://doi.org/10.1016/j.ptsp.2014.01.002>.
- 8 Olsen O, Sjøhaug M, van Beekvelt M, Mork PJ. The effect of warm-up and cool-down exercise on delayed onset muscle soreness in the quadriceps muscle: a randomized controlled trial. *J Hum Kinet.* 2012;35:59–68. <https://doi.org/10.2478/v10078-012-0079-4>.
- 9 Khamwong P, Pirunsan U, Paungmali A. A prophylactic effect of proprioceptive neuromuscular facilitation (PNF) stretching on symptoms of muscle damage induced by eccentric exercise of the wrist extensors. *J Bodyw Mov Ther.* 2011;15(4):507–516.
- 10 Curtis D, Fallows S, Morris M, McMakin C. The efficacy of frequency specific microcurrent therapy on delayed onset muscle soreness. *J Bodyw Mov Ther.* 2010;14(3):272–279. <https://doi.org/10.1016/j.jbmt.2010.01.009>.
- 11 Khamwong P, Pirunsan U, Nosaka K, Paungmali A. Prophylactic effect of hot pack on symptoms of eccentric exercise-induced muscle damage of the wrist extensors. *Eur J Appl Physiol.* 2012;12(5):443–453. <https://doi.org/10.1080/17461391.2011.566359>.
- 12 Jakeman JR, Macrae R, Eston R. A single 10-min bout of cold-water immersion therapy after strenuous plyometric exercise has no beneficial effect on recovery from the symptoms of exercise-induced muscle damage. *Ergonomics.* 2009;52(4):456–460. <https://doi.org/10.1080/00140130802707733>.
- 13 Torres R, Ribeiro F, Alberto Duarte J, Cabri JM. Evidence of the physiotherapeutic interventions used currently after exercise-induced muscle damage: systematic review and meta-analysis. *Phys Ther Sport.* 2012;13(2):101–114. <https://doi.org/10.1016/j.ptsp.2011.07.005>.
- 14 Bleakley C, McDonough S, MacAuley D. The use of ice in the treatment of acute soft-tissue injury: a systematic review of randomized controlled trials. *Am J Sports Med.* 2004;32(1):251–261. <https://doi.org/10.1177/0363546503260757>.
- 15 Cameron MH. *Physical Agents in Rehabilitation: From research to practice.* 4 ed. Philadelphia, Pennsylvania: W.B. Saunders company; 2013.
- 16 Gregson W, Black MA, Jones H, et al. Influence of cold water immersion on limb and cutaneous blood flow at rest. *Am J Sports Med.* 2011;39(6):1316–1323. <https://doi.org/10.1177/0363546510395497>.
- 17 Leeder J, Gissane C, van Someren K, Gregson W, Howatson G. Cold water immersion and recovery from strenuous exercise: a meta-analysis. *Br J Sports Med.* 2012;46(4):233–240. <https://doi.org/10.1136/bjsports-2011-090061>.
- 18 Bleakley C, McDonough S, Gardner E, Baxter GD, Hopkins JT, Davison GW. Cold-water immersion (cryotherapy) for preventing and treating muscle soreness after exercise. *Cochrane Database Syst Rev.* 2012;(2):CD008262.
- 19 Oakley ET, Pardeiro RB, Powell JW, Millar AL. The effects of multiple daily applications of ice to the hamstrings on biochemical measures, signs, and symptoms associated with exercise-induced muscle damage. *J Strength Cond Res.* 2013;27(10):2743–2751. <https://doi.org/10.1519/JSC.0b013e31828830df>.
- 20 Ingram J, Dawson B, Goodman C, Wallman K, Beilby J. Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. *J Sci Med Sport.* 2009;12(3):417–421. <https://doi.org/10.1016/j.jsams.2007.12.011>.
- 21 Eston R, Peters D. Effects of cold water immersion on the symptoms of exercise-induced muscle damage. *J Sports Sci.* 1999;17(3):231–238.
- 22 Bailey DM, Erith SJ, Griffin PJ, et al. Influence of cold-water immersion on indices of muscle damage following prolonged intermittent shuttle running. *J Sports Sci.* 2007;25(11):1163–1170. <https://doi.org/10.1080/02640410600982659>.
- 23 Guilhem G, Hug F, Couturier A, et al. Effects of air-pulsed cryotherapy on neuromuscular recovery subsequent to exercise-induced muscle damage. *Am J Sports Med.* 2013;41(8):1942–1951. <https://doi.org/10.1177/0363546513490648>.
- 24 Goodall S, Howatson G. The effects of multiple cold water immersions on indices of muscle damage. *J Sports Sci Med.* 2008;7(2):235–241.
- 25 Howatson G, Goodall S, van Someren KA. The influence of cold water immersions on adaptation following a single bout of damaging exercise. *Eur J Appl Physiol.* 2009;105(4):615–621. <https://doi.org/10.1007/s00421-008-0941-1>.

- ²⁶ Hausswirth C, Louis J, Bieuzen F, et al. Effects of whole-body cryotherapy vs. far-infrared vs. passive modalities on recovery from exercise-induced muscle damage in highly-trained runners. *PLoS One*. 2011;6(12):e27749. <https://doi.org/10.1371/journal.pone.0027749>.
- ²⁷ Knight KL, Han KM, Rubley MA, Brucker JB. Comparison of tissue cooling and numbness during application of cryo5 air cooling, crushed ice packs, ice massage, and ice water immersion. *J Athletic Train*. 2002;36:S103.
- ²⁸ Bleakley CM, Hopkins JT. Is it possible to achieve optimal levels of tissue cooling in cryotherapy? *Phys Ther Rev*. 2010;15(4):344–350. <https://doi.org/10.1179/174328810X12786297204873>.
- ²⁹ Paungmali A, Joseph LH, Sitalertpisan P, Pirunsan U, Uthaikhup S. Lumbopelvic Core Stabilization Exercise and Pain Modulation among Individuals with Chronic Nonspecific Low Back Pain. *Pain Pract*. 2017;17(8):1008–1014. <https://doi.org/10.1111/papr.12552>.
- ³⁰ Khamwong P, Paungmali A, Pirunsan U, Joseph L. Prophylactic Effects of Sauna on Delayed-Onset Muscle Soreness of the Wrist Extensors. *Asian J Sports Med*. 2015;6(2) e25549. [https://doi.org/10.5812/asjms.6\(2\)2015.25549](https://doi.org/10.5812/asjms.6(2)2015.25549).
- ³¹ Zainuddin Z, Newton M, Sacco P, Nosaka K. Effects of massage on delayed-onset muscle soreness, swelling, and recovery of muscle function. *J Athl Train*. 2005;40(3):174–180.
- ³² Lau WY, Blazevich AJ, Newton MJ, Wu SS, Nosaka K. Assessment of Muscle Pain Induced by Elbow-Flexor Eccentric Exercise. *J Athl Train*. 2015;50(11):1140–1148. <https://doi.org/10.4085/1062-6050-50.11.05>.
- ³³ Nosaka K, Newton M, Sacco P. Muscle damage and soreness after endurance exercise of the elbow flexors. *Med Sci Sports Exerc*. 2002;34(6):920–927. <https://doi.org/10.1097/00005768-200206000-00003>.
- ³⁴ Vickers AJ. Comparison of an ordinal and a continuous outcome measure of muscle soreness. *Int J Technol Assess Health Care*. 1999;15(14):709–716.
- ³⁵ Sellwood KL, Brukner P, Williams D, Nicol A, Hinman R. Ice-water immersion and delayed-onset muscle soreness:a randomised controlled trial. *Br J Sports Med*. 2007;41(6):392–397. <https://doi.org/10.1136/bjms.2006.033985>.
- ³⁶ Howatson G, Gaze D, van Someren KA. The efficacy of ice massage in the treatment of exercise-induced muscle damage. *Scand J Med Sci Sports*. 2005;15(6):416–422. <https://doi.org/10.1111/j.1600-0838.2005.00437.x>.
- ³⁷ Paddon-Jones DJ, Quigley BM. Effect of cryotherapy on muscle soreness and strength following eccentric exercise. *Int J Sports Med*. 1997;18(8):588–593. <https://doi.org/10.1055/s-2007-972686>.
- ³⁸ Lau WY, Nosaka K. Effect of vibration treatment on symptoms associated with eccentric exercise-induced muscle damage. *Am J Phys Med Rehabil*. 2011;90(8):648–657. <https://doi.org/10.1097/PHM.0b013e3182063ac8>.
- ³⁹ Algafly AA, George KP. The effect of cryotherapy on nerve conduction velocity, pain threshold and pain tolerance. *Br J Sports Med*. 2007;41(6):365–369. <https://doi.org/10.1136/bjms.2006.031237>.
- ⁴⁰ Clarkson PM, Sayers SP. Etiology of exercise-induced muscle damage. *Can J Appl Physiol*. 1999;24(3):234–248. <https://doi.org/10.1139/h99-020>.
- ⁴¹ Howatson G, Van Someren KA. Ice massage. Effects on exercise-induced muscle damage. *J Sports Med Phys Fitness*. 2003;43(4):500–505.
- ⁴² Hohenauer E, Taeymans J, Baeyens JP, Clarys P, Clijsen R. The Effect of Post-Exercise Cryotherapy on Recovery Characteristics: A Systematic Review and Meta-Analysis. *PloS One*. 2015;10(9):e0139028. <https://doi.org/10.1371/journal.pone.0139028>.