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The effect of Liquid ice after high-intensity exercise on muscle function compared to Block ice

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A B S T R A C T

Background/Objectives: Cryotherapy is used to recover muscle damage after exercise and to treat acute sports injuries. Liquid ice (LI) can keep cold for a long time, and is assumed more effective than block ice (BI). From this, the aim of this study was to investigate the effects of LI on the change of passive stiffness (PS) as muscle function and to validate the effectiveness of LI compared to BI.
Methods: We performed the experiment as part of a case series of verification of the effects of cryotherapy. 22 healthy men (target area: right leg) were randomized to two groups: LI group and BI group. PS was measured three times during experiment protocol, pre: before exercise; post; after treating each cryotherapy after exercise; 48h: 48 hours after pre. Statistical analysis compared the PS, the amount of change in PS, and the rate of change in PS between the two groups.
Results: The rate of change between pre and 48h in LI was significantly lower compared to that in BI ($p = 0.03$). There was no significant difference regarding other results between groups. It revealed that the difference of effect between LI and BI for PS of muscles after high-intensity exercises.
Conclusion: These results could be helpful for the choice of intervention for reducing muscle stiffness after exercise and at sports field.

1. Introduction

High-intensity exercises, especially those with eccentric contractions cause muscle damage[1–3] which leads to injuries, such as decreased muscle strength and decline in range of motion (ROM). Since these muscle injuries affect sports performance, it is important to repair muscle damage after exercise.[4]

The main functions of skeletal muscles are to generate force and power, maintain posture, and produce movement.[5] Among them, muscle flexibility is important for movements such as walking and sports performance.[6] ROM is commonly used as an objective indicator of muscle flexibility as a part of muscle function.[6] Passive stiffness (PS) can also be used to objectively and quantitatively assess muscle flexibility.[7]

Several cryotherapy methods have been used to repair muscle damage[8–10] and treat acute sports injuries.[11,12] The popular method of cryotherapy involves an ice bag. As it is easy and multipurpose, it is commonly used in the outside, such as in sports. However, maintaining the temperature of ice bag is difficult as it depends on prevailing weather and temperature condition. Liquid ice (LI), a new cryotherapy material, is gel ice made from saline water (Fig. 1). Cryotherapy using LI may be more effective than using block ice (BI) as LI can be kept cold for a longer time and has higher contact with body surfaces. In addition to cryotherapy using BI, there have been previous studies on cryotherapy using materials such as BI and cold water or examining multiple outcomes for a single intervention,[9,13–18] however, no study has been conducted on the effects of different types of ice using the same material.

This study aimed to investigate the effects of LI on changes in muscle flexibility and to validate its effectiveness.[19,20] We focused

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Fig. 1. Liquid ice can be seen on the left side and block ice on the right.

on PS and used it as an index of flexibility as it can objectively and quantitatively assess muscle flexibility. We hypothesized that cryotherapy using LI would have a lower PS compared to that of BI after high-intensity exercise. Moreover, we performed a case series to verify of the effects of cryotherapy.

2. Methods

2.1. Participants

The participants of this study were 22 healthy men, and their right legs were used. Some participants had prior experience with cryotherapy. We confirmed that the participants did not undergo cryotherapy during the study period. They had not been diagnosed with muscle strain in their right hamstrings in the past six months and did not have diseases which prohibited cryotherapy such as Raynaud's disease. The participants were explained the experimental procedures and risks before they provided informed consent to participate in the study. The study was approved by the ethics committee and complied with the principles of the Helsinki Declaration.

2.2. Procedures

2.2.1. Experimental protocol

The subjects were randomized into two groups, depending on the intervention method, using the permuted block method: LI group (n = 11) and BI group (n = 11). The study was conducted for two days to measure the PS three times (Fig. 2). On the first day, we measured the PS of each participant (pre). Then, each participant exercised, received cryotherapy by LI or BI for 20 minutes,[21] rested for 30 minutes, and PS was measured again (post). The PS was measured for the third time after 48 hours from the two initial tests (48h).[21] We focus on the changes in muscle flexibility under general body temperature. Therefore, we chose these three time points.

2.2.2. Exercise protocol

The participants performed efferent exercises using a dynamometer (Biodex System 4.0, Biodex Medical System, Inc. Shirley, New York, USA). They were positioned on a chair, and the angle of the right knee was set from 90° to 40°.[21] They performed eight sets of 10 right maximum knee efferent flexion and the speed of knee flexion was 60°/s.[22] The first set was submaximal in order to familiarize them with the machine. The rest time was 60 seconds.

2.2.3. Cryotherapy intervention

The ice bags contained approximately 300 g of LI (Nippon Electric Heat Co.) or BI. After exercise, participants were provided with a cold application for 20 minutes[21] with either LI or BI and placed at the center of the right posterior thigh. The time period of the cold application has been described in a previous study.[21]

2.2.4. Measurements

The PS of all participants was measured as muscle function[7] and it was assessed using the same dynamometer. The subjects lay on a bed, and their waist was held in position using belts. The right leg was tightly secured to the dynamometer leg plate, and the starting position of the right knee and hip joints was at 90° flexion. For passive testing, the subject's right knee joint was extended at a speed of 5°/s.[23] Participants were instructed to push a stop button just before they felt pain in their hamstrings. When the button was pushed, the passive knee flexion torque (Nm) and knee extension angle (°) were measured. The PS was calculated as the slope of the passive knee flexion torque-angle curve. In the curve, the values of knee flexion torque were obtained at two points: the maximum knee extension angle and its half angle. Based on this, the value obtained by dividing the torque change in the torque angle curve by the angle change during that period was calculated as passive stiffness (Nm/deg).[19,24] Along with the values at each time point (pre, post, and 48h), the amount and the rate of change between pre and post, pre and 48h, as well as post and 48h were calculated. We measured the PS three times at each point and used the average values of the second and third measurements.

Table 1
Characteristics of 22 participants. Each data showed mean ± SD.

	Block ice (BI)	Liquid ice (LI)
Height (cm)	172.89 ± 4.18	173.64 ± 7.43
Weight (kg)	74.32 ± 11.69	76.15 ± 10.55
BMI (kg/m^2)	24.82 ± 3.44	25.26 ± 3.11
Age (years old)	23.45 ± 1.29	23.36 ± 0.92

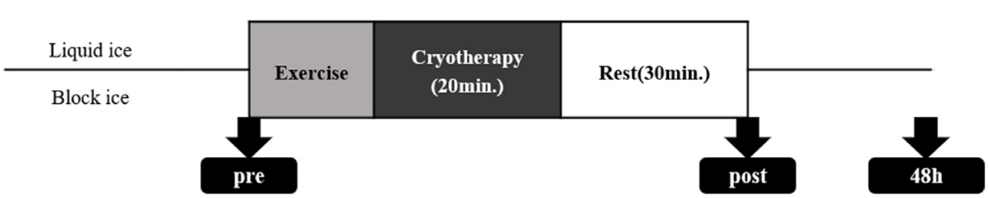

Fig. 2. Experimental protocol and measurement time points.

Table 2
The value of passive stiffness (PS), the amount of change of PS, and the rate of change of PS.

		BI group	LI group	p value
PS (Nm/deg)	pre	0.28 ± 0.10	0.39 ± 0.20	0.13
	post	0.33 ± 0.01	0.38 ± 0.18	0.36
	48h	0.36 ± 0.13	0.40 ± 0.22	0.64
The amount of change of PS (Nm/deg)	pre and post	0.04 ± 0.10	−0.00 ± 0.12	0.36
	pre and 48h	0.08 ± 0.05	0.01 ± 0.15	0.17
	post and 48h	0.04 ± 0.13	0.01 ± 0.09	0.65
The rate of change of PS (%)	pre and post	0.21 ± 0.41	0.04 ± 0.24	0.23
	pre and 48h	0.32 ± 0.30	0.05 ± 0.39	0.03*
	post and 48h	0.20 ± 0.44	0.02 ± 0.28	0.27

Each data showed mean ± SD. The results of *t*-test or Mann-Whitney U tests between LI group and BI group. *$p < 0.05$.

2.3. Statistical analyses

The LI and BI groups were compared in terms of PS using the amount and the rate of PS. The Shapiro-Wilk test was used to determine whether the data were normally distributed. Unpaired t-tests were used for the normal distribution. Mann-Whitney U tests were used for the non-normal distribution. The statistical significance level was less than 5%. The data was analyzed with JMP Pro 14 statistical software package (SAS Institute Inc., Cary, NC, USA).

3. Results

The participants' data regarding age, height and weight are shown in Table 1, and they revealed no significant differences (mean ± SD: age, 23.4 ± 1.0 years; height, 173.2 ± 5.9 cm; weight, 75.3 ± 1.1 kg). The rate of pre and 48h LI was significantly lower than that of BI ($p = 0.030$), and other results did not differ significantly between LI and BI (Table 2).

4. Discussion

This study focused on the effectiveness of LI compared to BI for the muscle function. The results showed that cryotherapy using LI tended to reduce muscle stiffness 48 hours after high-intensity exercises; it was more effective than that the BI.

Muscle damage caused by high-intensity exercises causes inflammation and pain, leading to increased muscle stiffness. Damaged muscle during and immediately after exercise becomes stiff over time with further exercise.[25,26] Early and rapid cryotherapy after exercises is helpful in controlling acute inflammation; as a result, the inflamed area and deterioration of muscle stiffness are suppressed.[13] Cryotherapy tends to slow the oxygen demand of mitochondria, thereby decreasing the metabolic demand and inflammation of the muscle.[27] Therefore, it is useful for controlling aggravating secondary hypoxia and stiffening muscles. Furthermore, a study on cryotherapy reported that decreasing the tissue temperature by 10°−15°maximizes its effect.[11] It is speculation that it can effectively decrease the temperature of muscle surfaces and muscles and help muscles recover faster compared to BI via the wide range of contact and coolness due to the gel constitution of the LI and a temperature lower than that of BI.[17] The current study showed that LI tended to reduce muscle stiffness 48 hours after high-intensity exercises more quickly than that the BI. This suggests that acute cooling controls the further occurrence of muscle damage, and, as a result, repairs the damage faster, compared to BI, by decreasing metabolic and metabolic demands and controlling stiffening muscles.

The rate of change between pre and 48h was considered as an index of whether the muscle returned to the pre state. LI showed a significantly lower value for this rate of change. In other words, LI contributes to faster muscle recovery than BI. There was no significant difference in the rate of change between pre and post, and post and 48h. This means that there is no difference in the immediate and long-term effects between LI and BI. Some reports have shown that muscle damage is repaired 48h after exercise and cryotherapy.[14,28] However, there was no change in muscle function due to differences in the ice itself. These results show that there is a difference in the recovery speed of the muscles but no difference in the immediate or long-term effects. This revealed a difference in the effect of LI and BI on the PS of muscles after high-intensity exercises. These results could be helpful for reducing muscle stiffness in sportsperson.

This study had several limitations. First, we did not set a non-treatment group; therefore, we cannot ascertain whether cryotherapy using ice bags is better than no treatment. Second, the relationship between muscle stiffness and symptoms is unclear. Third, it is necessary to consider the reliability of PS before starting our study. However, since PS measurement was used in the previous research,[29,30] it was used in our research without validation. Fourth, we cannot refer to the physiological and performance aspects of the intervention, since we did not measure the differences in muscle temperature, blood indicators or exercise performance indicators by differences in LI and BI. Future studies should verify the physiological effects of LI and the effects of cryotherapy as a case series.

5. Conclusion

The present study showed that cryotherapy using LI after high-intensity exercise has a positive effect on muscle flexibility and can be useful in sports.

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Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

References

1. Algazwi DAR, Teng VSY, Aldriweesh AS, Hallinan JTPD. Exercise-Induced bilateral rectus femoris injury. *Am J Phys Med Rehab*. 2019;98(11):e138–e139. https://doi.org/10.1097/PHM.0000000000001168.
2. Clarkson PM, Nosaka K, Braun B. Muscle function after exercise-induced muscle damage and rapid adaptation. *Med Sci Sports Exerc*. 1992;24(5):512–520. https://doi.org/10.1249/00005768-199205000-00004.
3. Twist C, Eston R. The effects of exercise-induced muscle damage on maximal intensity intermittent exercise performance. *Eur J Appl Physiol*. 2005;94(5-6):652–658. https://doi.org/10.1007/s00421-005-1357-9.
4. Fatouros IG, Chatzinikolaou A, Douroudos II , et al. Time-course of changes in oxidative stress and antioxidant status responses following a soccer game. *J Strength Condit Res*. 2010;24(12):3278–3286. https://doi.org/10.1519/

JSC.0b013e3181b60444.

5. Frontera WR, Ochala J. Skeletal muscle: a brief review of structure and function, 2014 96:3 *Calcif Tissue Int*. 2014;96(3):183−195. https://doi.org/10.1007/S00223-014-9915-Y.
6. Gleim GW, Mchugh MP. Flexibility and its effects on sports injury and performance. *Sports Med*. 1997;2(5):289−299.
7. Le Sant G, Ates F, Brasseur J-L, Nordez A. Elastography study of hamstring behaviors during passive stretching, 9Pérez MA, ed. *PLOS ONE*. 2015;vol. 10, e0139272. https://doi.org/10.1371/journal.pone.0139272.
8. Hohenauer E, Costello JT, Deliens Tom, Clarys Peter, Stoop R, Clijsen R. Partial-body cryotherapy (−135°C) and cold-water immersion (10°C) after muscle damage in females. *J Med Sci Sports*. 2020;30:485−495. https://doi.org/10.1111/sms.13593.
9. Fonseca LB, Brito CJ, Silva RJS, Silva-Grigoletto ME, da Silva Junior WM, Franchini E. Use of cold-water immersion to reduce muscle damage and delayed-onset muscle soreness and preserve muscle power in Jiu-Jitsu athletes. *J Athl Train*. 2016;51(7):540−549. https://doi.org/10.4085/1062-6050-51.9.01.
10. Yeung SS, Ting KH, Hon M, et al. Effects of cold water immersion on muscle oxygenation during repeated bouts of fatiguing exercise a randomized controlled study. *Medicine (United States)*. 2016;95(1). https://doi.org/10.1097/MD.0000000000002455.
11. 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.
12. Hawkins SW, Hawkins JR. Clinical applications OF cryotherapy among sports physical therapists. *Int J Sports Phys Ther*. 2016;11(1):141−148.
13. 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.
14. Abaïdia AE, Lamblin J, Delecroix B, et al. Recovery from exercise-induced muscle damage: cold-water immersion versus whole-body cryotherapy. *Int J Sports Physiol Perform*. 2017;12(3):402−409. https://doi.org/10.1123/ijspp.2016-0186.
15. 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.
16. Akehi K, Long BC, Warren AJ, Goad CL. Ankle joint angle and lower leg musculotendinous unit responses to cryotherapy. *J Strength Condit Res*. 2016;30(9):2482−2492. https://doi.org/10.1519/JSC.0000000000001357.
17. Dykstra JH, Hill HM, Miller MG, Cheatham CC, Michael TJ, Baker RJ. Comparisons of cubed ice, crushed ice, and wetted ice on intramuscular and surface temperature changes. *J Athl Train*. 2009;44(2):136−141. https://doi.org/10.4085/1062-6050-44.2.136.
18. Ascensão A, Leite M, Rebelo AN, et al. Effects of cold water immersion on the recovery of physical performance and muscle damage following a one-off soccer match. *J Sports sci*. 2011;29(3):217−225. https://doi.org/10.1080/02640414.2010.526132.
19. Matsuo S, Suzuki S, Iwata M, et al. Acute effects of different stretching durations on passive torque, mobility, and isometric muscle force. *J Strength Condit Res*. 2013;27(12):3367−3376. https://doi.org/10.1519/JSC.0B013E318290C26F.
20. Effects of Ankle Position during Static Stretching for the Hamstrings on the Decrease in Passive Stiffness | Enhanced Reader.
21. 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 Exerciseinduced muscle damage. *J Strength Condit Res*. 2013;27(10):2743−2751. https://doi.org/10.1519/JSC.0b013e31828830df.
22. Rocha CS, Lanferdini FJ, Kolberg C, et al. Interferential therapy effect on mechanical pain threshold and isometric torque after delayed onset muscle soreness induction in human hamstrings. *J Sports Sci*. 2012;30(8):733−742. https://doi.org/10.1080/02640414.2012.672025.
23. Nordez A, Casari P, Cornu C. Effects of stretching velocity on passive resistance developed by the knee musculo-articular complex: contributions of frictional and viscoelastic behaviours, 2008 103:2 *Eur J Appl Physiol*. 2008;103(2):243−250. https://doi.org/10.1007/S00421-008-0695-9.
24. Kubo K, Morimoto M, Komuro T, Tsunoda N, Kanehisa H, Fukunaga T. Influences of tendon stiffness, joint stiffness, and electromyographic activity on jump performances using single joint, 2006 99:3 *Eur J Appl Physiol*. 2006;99(3):235−243. https://doi.org/10.1007/S00421-006-0338-Y.
25. Dankel SJ, Razzano BM. The impact of acute and chronic resistance exercise on muscle stiffness: a systematic review and meta-analysis. *J Ultrasound*. 2020;23(4):473−480. https://doi.org/10.1007/S40477-020-00486-3.
26. Santos R, Valamatos MJ, Mil-Homens P, Armada-da-Silva P. The effect of strength training on vastus lateralis' stiffness: an ultrasound quasi-static elastography study, 2020, Vol 17, Page 4381 *Int J Environ Res Publ Health*. 2020;17(12):4381. https://doi.org/10.3390/IJERPH17124381.
27. Selkow NM, Herman DC, Liu Z, Hertel J, Hart JM, Saliba SA. Blood flow after exercise-induced muscle damage. *J Athl Train*. 2015;50(4):400−406. https://doi.org/10.4085/1062-6050-49.6.01.
28. 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 Exerciseinduced muscle damage. *J Strength Condit Res*. 2013;27(10):2743−2751. https://doi.org/10.1519/JSC.0b013e31828830df.
29. Magnusson SP, Simonsen EB, Aagaard P, Kjaer M. *Biomechanical Responses to Repeated Stretches in Human Hamstring Muscle in Vivo*. vol. 24. 2016:622−628. https://doi.org/10.1177/036354659602400510.
30. Magnusson SP, Simonsen EB, Aagaard P, Boesen J, Johannsen F, Kjaer M. Determinants of musculoskeletal flexibility: viscoelastic properties, cross-sectional area, EMG and stretch tolerance. *Scand J Med Sci Sports*. 1997;7(4):195−202. https://doi.org/10.1111/J.1600-0838.1997.TB00139.X.