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Original Article

Effect of timing of citrate drink ingestion on blood lactate removal

Satomi Okano, RPT, PhD[1)], Honoka Nakayama, RPT[2)], Hitomi Nishizawa, RPT, PhD[3)*]

[1)] *Department of Physical Therapy, Faculty of Health Sciences, Iryo Sosei University, Japan*
[2)] *Chiba Tokushūkai Hospital, Japan*
[3)] *School of Health Sciences, Faculty of Medicine, Shinshu University: 3-1-1 Asahi, Matsumoto, Nagano 390-8621, Japan*

Abstract. [Purpose] Citrate drinks are readily available and effectively remove lactate from blood, improving performance. However, whether they are more beneficial when consumed before or after exercise is unclear. We aimed to examine the effect of citrate drink intake timing on blood lactate removal. [Participants and Methods] We randomly assigned 41 healthy male students to four conditions: citric acid intake before exercise, citric acid intake after, water intake after, and no intake. The participants performed a 5-min ergometer cycle, and we measured the blood lactate levels before and at 0, 5, 10, 20, and 30 min after exercise. We calculated the reduction rate of blood lactate levels by subtracting the respective blood lactate values from those at 0 min and then dividing by the blood lactate value at 0 min (Ex-5, Ex-10, Ex-20, and Ex-30). [Results] The measured blood lactate values or their reduction rates were not significantly different between the four conditions. Significant differences were observed between the pre- and post-citric acid conditions for Ex-5, Ex-10, Ex-20, and Ex-30. [Conclusion] The effects of different timings of citric acid intake on blood lactate removal were not significantly different, and the reduction rate of blood lactate values continued to increase with citric acid intake, regardless of timing.

Key words: Citrate, Blood lactate, Lactate removal

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INTRODUCTION

Effective methods for early recovery from sustained and repetitive physical function training, activities of daily living (ADL) training in rehabilitation, and physical performance loss caused by high-intensity training and competition in sports settings are desired worldwide. Previous studies showed that active recovery[1, 2)], dynamic stretching[3)], and citrate drink ingestion[4, 5)] are beneficial for lactate removal and performance recovery. In particular, citrated drinks can be easily consumed by a single person without requiring a large stomach space. Citrate is a familiar substance found in lemons (60 mg/g) and pickled plums (60 mg/g). Citrate drink intake before exercise was reported to significantly improve performance in tennis[4)] and 5-km treadmill running[5)]. Similarly, citrate drinks promote blood lactate (BLA) removal when consumed after exercise on a bicycle ergometer drive[6)].

Lactate, a metabolite of the glycolytic system and a substrate used for mitochondrial respiration, plays an important role in linking these pathways[7)]. Furthermore, it induces angiogenesis as a signaling molecule[8)]. Lactate itself does not cause fatigue. Rather, the combined effects of acidosis, phosphate ion accumulation, and low Ca^{2+} levels inhibit muscle contraction, resulting in poor performance[9, 10)]. Therefore, lactate accumulation is more or less related to acidosis *in vivo*, and rapid lactate removal may contribute to improved performance; thus, BLA is a useful indicator that can be immediately assessed in clinical practice. The increase in hydrogen ions and lactate produced by muscles during exercise causes acidosis; however,

*Corresponding author. Hitomi Nishizawa (E-mail: hitnishi@shinshu-u.ac.jp)

citrate intake induces alkalosis, which suppresses the decrease in pH[4]. It was also reported that when citrate in the plasma increases, intracellular citrate also increases[11]. However, no study to date has examined whether citrate drink ingestion is more effective before or after exercise. We aimed to determine the effect of the timing of citrate drink consumption on BLA removal after exercise.

PARTICIPANTS AND METHODS

In total, 41 healthy male students participated in the study. We obtained participant consent through written and verbal explanations. The exclusion criteria were the presence of orthopedic disease, neurological disease with paralysis or pain, respiratory or circulatory system disorders during exercise, alcohol allergy, and daily intake of supplements containing vitamin C or high amounts of citric acid (CA). This study was approved by the University Medical Ethics Committee (Approval No. 4289) of our institution.

We used a randomized crossover design, randomly assigning the participants to four conditions: CA intake before exercise (pre-CA, n=41), CA intake after exercise (post-CA, n=41), water intake after exercise (post-W, n=20), and no intake (nothing, n=21). Participants performed both pre-CA and post-CA. For post-W and nothing, they were randomly assigned to one or the other. The CA drink was prepared by dissolving 4 g CA (Kenei Pharmaceutical Co., Ltd., Osaka, Japan) in 100 mL of water. In the pre-CA condition, the participants drank 100 mL of the CA drink 30 min before exercise, and in the post-CA condition, the participants drank 100 mL immediately after exercise. In the post-W condition, the participants drank 100 mL of water immediately after exercise.

Each condition was performed in random order, with at least 1 week between experiments. The participants were instructed not to eat anything except water within 1 h and not to perform intense physical activity within 24 h before the experiment.

An exercise task was performed using a cycle ergometer (STB-3400; Nihon Kohden Co., Ltd., Tokyo, Japan). Prior to the main experiments, the anaerobic threshold (AT) was determined from expiratory gas data measured using the breath-by-breath method with a gas analyzer (AT-1100, Anima, Co., Tokyo, Japan) during a cardiopulmonary exercise test. The participants rested in a seated position on a cycle ergometer for 3 min to ensure that their heart rate and respiratory quotient were stable before they performed a 3-min warm-up. Subsequently, a ramp-loading test was performed at 20 W/min and was terminated when the heart rate reached 85% of the predicted maximal heart rate or when the symptomatic limit was observed; this was followed by a 3-min cool-down period. The pedaling speed was 50 rpm, and warm-up and cool-down were performed at a 20-W loading rate. Two experienced physiotherapists evaluated the AT scores. Based on the results of the pilot study, the exercise load on the cycle ergometer was determined as 150% AT at 70 rpm for 5 min.

BLA was measured before exercise (pre), immediately after (0 min), 5 min after (5 min), 10 min after (10 min), 20 min after (20 min), and 30 min after exercise (30 min) using Lactate Pro 2 (ARKRAY, Inc., Kyoto, Japan), a simplified device. The measurement site was the fingertip on the dominant hand. After the puncture site was disinfected with alcohol and thoroughly dried, the participants themselves used a blood collection puncture device (Naturalette Petit; ARKRAY, Inc.) to collect a small amount of blood. Blood was aspirated using a Lactate Pro 2 sensor (ARKRAY, Inc.) to measure the BLA.

The measured values of BLA (mmol/L) at pre-, 0 min, 5 min, 10 min, 20 min, and 30 min and the reduction rate were used for data analysis. The reduction rate was calculated by subtracting the BLA values at 5, 10, 20, and 30 min from that at 0 min before dividing by that at 0 min (Ex-5, Ex-10, Ex-20, and Ex-30). The Shapiro–Wilk test was used to examine normality. No normality was detected in any of the data; the Kruskal–Wallis test was applied for between-condition comparisons, and the Friedman test, for within-condition comparisons. The significance level was set at $p<0.05$. The statistical analyses were performed using the PASW Statistics software (version 25.0; SPSS Inc., Chicago, IL, USA).

RESULTS

In total, 41 healthy men consented to participate in this study through public recruitment, and the data from all 41 participants were used in the analysis (Table 1). The BLA levels measured at each measurement point under the four conditions are listed in Table 2. No significant differences in the absolute BLA values were observed between the four conditions: pre, $p=0.242$; 0 min, $p=0.633$; 5 min, $p=0.435$; 10 min, $p=0.299$; 20 min, $p=0.530$; and 30 min, $p=0.609$. Within-condition comparisons showed a significant increase in the BLA at 0 min compared to pre in all the conditions: pre-CA, $p<0.001$; post-CA, $p<0.001$; post-W, $p<0.001$; and nothing, $p<0.001$. The BLA reduction rates are listed in Table 3. There was no significant difference in the BLA reduction rates between the four conditions: Ex-5 ($p=0.804$), Ex-10 ($p=0.613$), Ex-20 ($p=0.965$), and Ex-30 ($p=0.993$). Regarding the CA intake condition, significant differences were found between Ex-5 and Ex-10 (pre-CA, $p=0.022$; post-CA, $p=0.009$) and between Ex-20 and Ex-30 (pre-CA, $p=0.029$; post-CA, $p=0.004$). Ex-10 and Ex-20 showed significant differences among the three conditions: pre-CA, $p=0.001$; post-CA, $p=0.019$; and nothing, $p=0.017$.

DISCUSSION

In this study, we measured the BLA with each condition, including water intake and no intake as controls to verify whether the timing of citrate drink intake was more effective before or after exercise. In all four conditions, the exercise load was

Table 1. Physical characteristics of participants

Participants (male)	Age (years)	Height (cm)	Body weight (kg)
41	20.9 ± 2.5	171.8 ± 5.7	63.3 ± 8.0

Data are expressed as the mean ± standard deviation.

Table 2. BLA values before and after the exercise

	Pre-CA	Post-CA	Post-W	Nothing
Pre (mmol/L)	1.41*	1.39*	1.44*	1.53*
0 min (mmol/L)	4.79*	4.56*	4.37*	5.19*
5 min (mmol/L)	3.77	3.51	3.18	3.98
10 min (mmol/L)	3.01	2.67	2.61	3.18
20 min (mmol/L)	2.16	2.00	2.10	2.29
30 min (mmol/L)	1.62	1.56	1.61	1.69

Data are expressed as the mean. *$p<0.001$.
BLA: blood lactate; CA: citric acid; W: water.

Table 3. Reduction rate of BLA immediately after exercise

	Pre-CA	Post-CA	Post-W	Nothing
Ex-5	0.22 ± 0.18	0.23 ± 0.14	0.27 ± 0.16	0.23 ± 0.16
Ex-10	0.37 ± 0.16	0.41 ± 0.12	0.41 ± 0.14	0.38 ± 0.15
Ex-20	0.53 ± 0.12	0.54 ± 0.12	0.52 ± 0.17	0.55 ± 0.10
Ex-30	0.64 ± 0.09	0.63 ± 0.11	0.61 ± 0.13	0.65 ± 0.10
Comparison between Ex-5 and Ex-10	a	b		
Comparison between Ex-10 and Ex-20	b	a		a
Comparison between Ex-20 and Ex-30	a	b		

Data are expressed as the mean ± standard deviation. a: $p<0.05$, b: $p<0.01$.
BLA: blood lactate; CA: citric acid; W: water.

appropriate because significant differences in the BLA were observed at rest (pre-exercise) and immediately after exercise (0 min) (Table 2). There was no significant difference in BLA values and BLA reduction rates after 5 min of cycle ergometry at 150% AT, regardless of the timing of citrate drink intake or when compared to the condition without citrate drink intake. We established a feasible intake volume and CA concentration for clinical rehabilitation and sports settings; however, we need to consider the time and amount of CA absorbed by the body. Urwin et al.[12] demonstrated that alkalosis reaches its peak 3 h after ingestion of 500 mg/kg CA, whereas the CA intake used in this study was 4 g or 63.2 mg/kg. Insufficient CA intake may prevent the induction of adequate alkalosis. We set the volume of water in which CA was dissolved at 100 mL as the amount that could be orally administered on-site and adopted 4 g/100 mL as the upper limit concentration, as no mouth or throat pain was observed in the pilot study. Therefore, it was necessary to consume larger amounts of CA over a longer period. However, the side effects of consuming high CA concentrations should be considered. Oöpik et al.[5] reported that 17 college runners who ingested 500 mg/kg body mass of sodium citrate dissolved in 1 L of mineral water developed symptoms of diarrhea or an urge to defecate. Cunha et al.[4] also revealed that 10 athletes ingested 500 mg/kg body mass of sodium citrate in capsules with a liter of water, and 5 athletes developed mild abdominal pain, headaches, and other discomforts. Establishing the optimal amount of CA and the method of intake will be a challenge in the future.

Intra-condition comparisons of BLA reduction rates showed significant differences between Ex-5 and Ex-10, Ex-10 and Ex-20, and Ex-20 and Ex-30 in the pre-CA and post-CA conditions (Table 3). This indicated that the rate of lactate reduction continued to increase with CA intake. However, no significant differences were detected between the pre-CA and post-CA conditions. Although the CA intake was timed 30 min apart under the two conditions, it is possible that more time was needed for the internal environment of the body to change sufficiently.

In conclusion, we aimed to determine the effects of different citrate drink intake timings on BLA removal. We found that temporal differences in CA intake, specifically before and after exercise, did not significantly affect BLA removal. In contrast, the BLA reduction rates continued to increase with CA intake, regardless of the timing. This suggests that CA may be effective for BLA removal, even after exercise and muscle fatigue. Based on the results of this study, it is expected that the

intake of CA in rehabilitation or sports settings in amounts at least equal to the present study will help in the early recovery of physical performance after high-intensity exercise. Further studies are warranted to determine the appropriate amount and timing of CA intake.

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Conflict of interest

None.

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