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Acute effects of sodium citrate supplementation on competitive performance and lactate level of elite fitness challenge athletes: A crossover, placebo-controlled, double-blind study

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ABSTRACT

Purpose: The performance of sodium citrate has been investigated in high-intensity exercises, but fewer studies have addressed the role of citrate in weight-bearing exercises.

Methods: Twenty fitness challenge athletes, aged 24–32 years, volunteered to participate in this crossover, placebo-controlled, double-blind study. Initially, ten athletes were given a placebo and asked to complete a fitness challenge (i.e., chin-ups, squat jumps, dips, walking lunges, sit-ups, and burpees-devil press). Another ten athletes were supplemented with sodium citrate 0.5 g/kg body mass supplements 3 h prior to performing the fitness challenges. The same procedures were completed two days later with the supplement and placebo dextrose groups switched in a cross-over design. Athletes and assessors were blinded for the experimental condition (placebo vs. verum). Lactate levels were measured 5 min after exercise. The athletes' performance on each item of the fitness challenge as well as their lactate levels, were compared. Differences between the means of the measured variables were contrasted using a dependent *t*-test.

Results: Supplementing sodium citrate substantially improved athletes' performance in all six fitness challenge items ($p < 0.05$, $0.69 <$ Cohen's $d < 2.52$, moderate to large). In addition, lactate levels registered after the fitness challenge were lower in the citrate sodium supplementation vs. placebo condition ($p = 0.001$, Cohen's $d = 0.63$, moderate).

Conclusion: Acute sodium citrate supplementation may help fitness challengers postpone muscular fatigue and increase performance, potentially via the prevention of lactate accumulation.

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1. Introduction

Over the past decades, many dietary techniques[1,2] and exercise interventions,[3] have been investigated to postpone the onset of muscular fatigue, which is a critical limiting factor in sports performance. In particular, an emphasis has been placed on approved foods and/or supplements[1,4] according to the World Anti-Doping Agency (WADA). Despite the multifactorial reasons for muscle fatigue, the abundance of hydrogen ions (H^+) within the muscle cell, as well as the reduced release of calcium, potassium, and chloride from the sarcoplasmic reticulum, are proposed as primary causes of fatigue and muscle damage during high-intensity short-term training.[5] As a result, dietary techniques targeting enhancing intracellular beta-alanine and extracellular buffering capacity, as well as sodium bicarbonate supplementation, have been widely explored to alleviate muscle fatigue during exercise.[6] By taking sodium bicarbonate, the acidity in the muscles decreased, which in turn reduced fatigue.[7] Furthermore, the consumption of sodium citrate resulted in an elevated plasma volume through an increase in sodium ion levels in the serum, consequently suppressing aldosterone activity.[8] Sodium citrate is preferable to sodium bicarbonate because it does not have adverse effects on the gastrointestinal system, unlike sodium bicarbonate loading. The gastrointestinal side effects may include headaches, stomachaches, and diarrhea.[8]

Although its ergogenic potential was first discovered over 30 years ago, a dietary technique that has received less attention is sodium citrate.[9] Preliminary research suggests that an ergogenic adjuvant supplement is ineffective, thus sodium citrate has garnered less attention than beta-alanine or sodium bicarbonate.[6] However, participants in most studies were instructed to consume sodium citrate 90 min before exercise. While this appears to be a suitable time for sodium bicarbonate ingestion since the highest concentration of $HCO3^-$ occurs at this time,[10] it can take up to 3 h for sodium citrate to reach maximum levels after consumption.[11,12] Finally, Urwin et al.[12] claimed that sodium citrate supplement, is useful for minor digestive issues. Existing research.[12] supports these statements since the peak concentration of HCO_3^- for sodium bicarbonate was substantially higher and occurs after around 170 min.[12] To date, the ergogenic capacity of sodium citrate has not been studied as much as sodium bicarbonate, so the comparative effect of optimal intake protocols for the respective supplements is still unclear. On the other hand, no previous research has directly compared the effect of sodium citrate supplementation in different exercise modes, and the importance of exercise mode for these results is unclear, given that different exercise modes (i.e., running, cycling, and rowing) have already been reported.[13]

Citrate supplementation can help avoid impaired function due to dehydration and enhance dehydration prevention, in addition to the common side effects of sodium citrate compared to other buffering agents.[14] $NaHCO3$ also decreases stress at the cellular level, as well as lower heat shock protein responses to exercise, according to more recent research.[15] Supplementing sodium citrate appears to be a better option than sodium bicarbonate in terms of performance and adverse effects.[16]

The International Bodybuilding Federation (IFBB)[17] announced the Fitness Challenge as a new discipline in late 2021. The course consists of six tasks (i.e., chin-ups, squat jumps, dips, walking lunges, sit-ups, and burpees-devil press), each of which the athlete does for 2 min before resting for 2 min prior to performing the next item for 2 min, and so on until all six items have been completed. As a result, this sport might be considered among the most demanding for the pathways affected by citrate supplementation. The main difference between this field and other sports is that the emphasis on technique is less important, and the athlete's performance depends more on his physical condition. Therefore, it can be used as a test for the performance of sodium citrate buffer.

Anaerobic glycolysis provides the majority of energy utilized during strenuous activity, followed by lactate metabolism.[18] This conversion to lactate metabolism results in a decrease in muscle pH from around 7.1 (resting) to ~6.5 following high-intensity exercise until fatigue sets in due to the increased acidification levels.[19] During this period of decreased pH, the activity of various glycolytic enzymes is reduced, and ATP synthesis rate falls.[19] Furthermore, excess H^+ (byproduct of lactate metabolism) impacts oxidative phosphorylation and phosphocreatine production by competing with calcium ions for the troponin junction,[20] directly engaging in muscle contraction.[21] The existence of intracellular buffers (phosphates, proteins, and dipeptides in the cytosol), extracellular buffers, and dynamic buffer systems, including renal and respiratory processes, keeps the pH balance in the physiological range under essential circumstances.[22] The previous studies did not explicitly evaluate the effects of sodium citrate supplementation on various forms of exercise, and the significance of exercise in these circumstances is unknown.

In recent research,[23] the supplementation of sodium citrate helped ten young tennis players perform better in a simulated tennis game compared to a placebo condition. Since a positive association ($r = 0.70$) between pH level and winning games was recorded, the primary findings of that study support the notion that the alkaline state of sodium citrate (0.5 g/kg body mass) may improve physical performance in similar situations. Due to the paucity of information regarding the effects of sodium citrate on intense physical performance, further study is warranted. The goal of the current study was to determine how sodium citrate supplementation affects the performance of a group of athletes during the IFBB fitness challenge. Based on a previous study,[23] it was hypothesized that sodium citrate supplementation would improve the records of fitness challenge athletes.

2. Methods

The current research project was a double-blind, placebo-controlled, randomized, crossover study. Prior to the trial, all participants were informed about the risks and benefits of the fitness challenges test. They were told about the purpose of the study and signed an informed consent document. All tests were done in the afternoon at approximately 17:00 h. The temperature, humidity, and environmental conditions were similar across sessions (temperature: 22–25 °C; humidity: 59–66%). The research procedure was approved by the local University Research Ethics Committee of Imam Khomeini International (reference number 17629) and the study was registered on the Open Science Framework (OSF: https://doi.org/10.17605/OSF.IO/9KEAB) and was carried out in accordance with relevant guidelines and regulations of the 168 Declaration of Helsinki.

2.1. Participants

The study population included 20 male elite athletes, who were competing in the Iranian Fitness Challenge Championship and volunteered to participate in this study. To be eligible to compete in the national championship, all athletes had to be placed first in their respective provincial competitions. Participants ranged in age from 24 to 32 years and had a mean BMI of 22.3 kg/m^2. Participants practiced between 14 and 18 h of weekly training.

2.2. Experimental protocol

In the first trial, 10 athletes received a placebo and were asked to complete the fitness challenge tests. Another 10 athletes were supplemented with sodium citrate and completed the same fitness challenge test. Similar capsules were used to keep the contents inside the capsule secret. The same protocol (Fitness Challenge Items) was administered again two days later in a randomized cross-over, but the supplement and placebo conditions were switched across the participating individuals this time (Fig. 1). Participants were instructed to refrain from exercising for two days before testing. Before each fitness challenge, all individuals received an adequate night's sleep and were under observation. Their diets were standardized for two days before each test to avoid

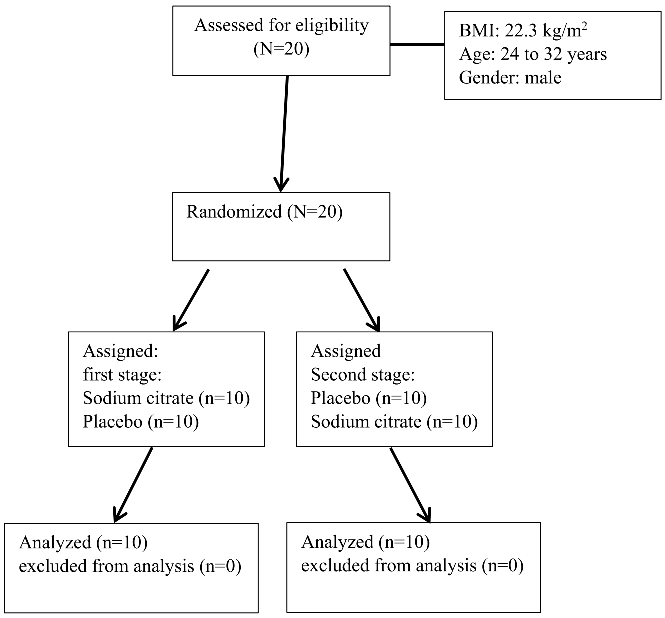

Fig. 1. Flowchart of the study.

consumption of alkaline foods or spices. In fact, they had a controlled diet and were asked not to eat anything other than the recommended diet.

2.3. Fitness challenge test

The fitness challenge contest consists of six exercises, each of which is performed at maximal intensity for 2 min during which the athlete attempts to complete as many repetitions as possible using their maximum force and effort. Each exercise was separated by a 2-min rest.

International fitness challenge judges determined each athlete's performance score according to IFBB guidelines.[17] Guidelines allowed athletes to consume water between events (https://ifbb.com/wp-content/uploads/2023/01/Fitness-Challenge-2023-rules.pdf2023).[17] Coaches were also allowed to encourage participants throughout the performance. Competition judges recorded participants' records during each of the two trials.

2.4. Supplementation method

Three hours before the test, participants ingested either a sodium citrate supplement (0.5 g/kg body mass) or a placebo (dextrose) in 500 mg capsules with 1 liter of water. Participants and assessors were blinded for the experimental condition (placebo versus verum).[8] A pharmacist produced all capsules and distributed them to the participants. Participants were given 3 h to relax after consuming sodium citrate or the placebo.

2.5. Blood lactate levels

Blood samples were obtained from the index finger of the participants' right hand 5 min after completion of the fitness challenge to determine their blood lactate levels. A lactometer (model 0483 CE, Germany) was used to measure blood lactate levels. The index finger of the participant's right hand was cleaned and dried, followed sanitation of the blood collection site using a cotton swab soaked in alcohol prior to blood sampling. The analyzer displayed the amount of lactate in millimoles per liter on the device screen.

2.6. Statistical analyses

To identify and characterize the data, descriptive statistics (means ± standard deviations) were employed. The Shapiro-Wilk test was used to test and confirm the normality of the data. To identify differences between means of each fitness performance variable, a paired *t*-test was utilized. The effect size (Cohen's d) was calculated to determine the magnitude of the change in score and interpreted using the following criteria: $0.2 \leq d < 0.5$: small, $0.5 \leq d < 0.8$: moderate, and $d \geq 0.8$: large. SPSS software (version 27, IBM, Chicago, IL) was applied to compute all statistical calculations and all statistical analyses were performed at a significance level of $p < 0.05$.

3. Results

No injuries occurred during fitness testing and no participants reported discomfort state after ingestion of verum or placebo.

Performance during each component of the fitness challenge was increased significantly in the sodium citrate trial compared to the placebo trial (Table 1). Effect sizes were large for all tests except dips. The average percent improvement across all items was 2.9% (SD = 1.4%). The greatest improvement was registered in the walking lunges test (4.9%) followed by chin-ups (3.7%) and burpee tests (3.6%). The least improvement was noted in the dips tests (1.2%). Blood lactate levels were not significantly different between resting conditions for the sodium citrate trial versus the placebo trial (Table 2). However, post-exercise lactate levels were significantly lower in the sodium citrate trial compared to the placebo trial. The effect size for the difference between the sodium citrate trial and the placebo trial was considered large.

4. Discussion

The present study was designed to determine the effect of acute sodium citrate supplementation versus placebo on the performance of fitness challenge athletes. Study findings revealed that supplementing with sodium citrate significantly improved performance in each fitness challenge item. As the participants neared the completion of each item, fatigue was delayed, thus resulting in increased performance. Among the six items, the best effectiveness was observed in the walking lunges movement and the least effectiveness in the deep parallel movement. It seems that the involvement of the large muscles of the lower body and the production of more lactic acid in this movement can be one of the reasons for the greater effectiveness of the sodium citrate supplement. Therefore, we were able to confirm our research hypothesis. To the best of our knowledge, only one study has determined the effects of sodium citrate supplementation in participants performing weight-bearing exercises (i.e., prolonged isometric contractions).[24] Ingestion of sodium citrate (0.4 g/kg body mass) during the prolonged contraction of the knee at 35% of maximal voluntary contraction (MVC) in healthy active male volunteers (25–35 years) resulted in pain reduction. Recent additional research has shown sodium citrate to enhance tennis players' performance.[23] Since a positive association ($r = 0.70$) was recorded between pH level and winning games, the primary findings of that study support the notion that the alkaline state of sodium citrate (0.5 g/kg) resulted in improved performance.[12] The authors claimed supplementing training sessions with sodium citrate may increase training volume, allowing for more time to practice high-quality skills.[12]However, it must be noticed that technical and tactical aspects of the game may have impacted winning sets, but the facilitation of anaerobic endurance cannot be discounted as a determining factor in match outcome.

Sodium citrate is, in fact, a fundamental substrate for cellular metabolism in a variety of energy processes. It is a mediator in the Krebs cycle, which transports acetyl-CoA from the mitochondria to the cristae and inhibits glycolysis by inhibiting phosphofructokinase (PFK).[25] The inhibitory impact on glycolysis has been observed in several studies[26] to

Table 1
The mean and standard deviations of fitness challenge items with and without sodium citrate supplementation with differences between experimental conditions (placebo vs verum).

Item	Condition	Mean	SD	t	p-value	Effect size	Delta (%) Percent increase for SC vs. P
Chin-ups (prone & strict)	Sodium citrate	45.7	3.7	4.41	0.001	0.91 (0.44–1.51)	3.72%
	Placebo	44.0	4.6				
Squat jump (up to 20″-24″ box)	Sodium citrate	44.0	4.6	4.41	0.001	0.91 (0.44–1.15)	2.05%
	Placebo	43.1	4.8				
Dips (feet forward)	Sodium citrate	72.3	4.8	2.28	0.034	1.69 (0.03–0.97)	1.11%
	Placebo	71.5	5.2				
Walking lunges (with a barbell)	Sodium citrate	39.5	6.7	3.45	0.003	2.52 (0.26–1.26)	5.06%
	Placebo	37.5	7.4				
Sit-ups (weighted)	Sodium citrate	46.9	2.6	5.14	0.001	0.69 (0.57–1.71)	1.71%
	Placebo	46.1	2.7				
Burpees & "Devil Press"	Sodium citrate	37.3	3.8	6.89	0.001	0.85 (0.87–2.18)	3.75%
	Placebo	35.9	3.7				

Legend: SD: standard deviation.

Table 2
Comparison of lactate levels between sodium citrate supplementation and placebo trials.

Blood lactate level (mmol/L)	Sodium citrate	Placebo	t	p-value	Effect size
Resting lactate	1.8 ± 0.2	1.7 ± 0.1	1.00	0.33	0.02 (−0.22 to 0.66)
Post-exercise lactate	15.5 ± 0.7	16.1 ± 0.6	4.24	0.001	0.63 (−1.47 to −0.41)

impair short-term performance (greater than 180 s), but fades with sustained exercise resulting in increased lactate buildup.[25] On the other hand, alkalosis found after sodium citrate ingestion decreases the interstitial buildup of K^+ generated by muscle during strenuous activity.[15] The accumulation of K^+ lowers muscular irritability[27] and adds to tiredness.[28]

In the current study, sodium citrate supplementation prevented lactate buildup compared to a placebo. This ability to postpone the onset of muscle acidosis (i.e., a fall in muscle pH) during exercise is typically attributed to ergogenic potential as a result of improved blood buffering capacity.[29] Furthermore, the ergogenic benefits of this supplement are primarily due to its ability to raise extracellular buffering capacity, which allows the passage of hydrogen ions (H^+) from muscle cell during contractions,[30] thus lowering the pH inside the cell to promote glycogenolytic activity.[31] The intake of sodium[32] and citrate[33] via the small intestine wall are followed by the appearance and elimination (mainly by the kidneys) of these compounds from the circulation,[34] resulting in a significant ionic difference.[35] With the exception that intense ions are counteracted, this difference of strong ions is followed by increasing the rate of H^+ excretion, lowering the rate of HCO_3^- excretion[36] restoring electrical balance (reducing the difference of strong ions) and producing blood alkalosis.[37]

Although the present study provides a novel addition to the literature concerning the effects of sodium citrate supplementation on fitness athletes' performance, the present results pertained only to male athletes. Future studies on female athletes are warranted as it is well known that sex may impact the lactate responses to high intensity exercising. In addition, the effectiveness of sodium citrate supplementation on performance in other sporting activities should be investigated.

5. Conclusions

Because the formation of lactate is significant during the fitness challenges, sodium citrate supplementation may help prevent excessive accumulation of lactate, and as a result, enhance overall performance in these weight-bearing exercises. Further research is needed on the effects of sodium citrate supplementation in different sports, physical activities, and cohorts (e.g., females).

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Declaration of competing interest

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Abbreviations

HCO3	bicarbonate
IFBB	The International Bodybuilding Federation
MVC	maximal voluntary contraction
WADA	World Anti-Doping Agency

Section I

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Section II

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