ABSTRACT

Introduction: Although sodium bicarbonate (NaHCO3) supplementation has been shown to decrease fatigue and improve high-intensity exercise performance, the effects on maintenance of isometric contractions are not clear. Objective: To investigate the effect of NaHCO3 on the performance of individuals subjected to a fatigue protocol in an isometric exercise on the isokinetic dynamometer. Methods: Participants were 12 men in a randomized, double-blind, crossover, placebo-controlled trial. Sixteen minutes after the intake of 0.3 g/kg of body mass of NaHCO3 or placebo, the participants performed an isometric fatigue protocol of right knee extension exercises during eight minutes at 70% of maximum voluntary isometric contraction. The fatigue indicator was the time point at which torque was reduced to 50% of the initial value. The length of resistance was assessed by maintaining the task over 50% of the initial torque. Results: Blood pH was higher in pre-protocol and in the fatigue indicator after NaHCO3 intake, as were the blood lactate concentrations in the fatigue indicator and at the end of the protocol (p < 0.001). NaHCO3 supplementation increased the time to fatigue and lessened the rate of decline of isometric peak torque at the end of the protocol (p < 0.001). RPE and RPP were smaller at the end of the protocol in the NaHCO3 condition, and the RPE of the session was diminished (p < 0.001). Conclusion: NaHCO3 supplementation enhances steady isometric contraction performance and reduces the internal load. Level of Evidence II; Diagnostic studies - Investigation of an examination for diagnosis.

Keywords: Muscle fatigue; Sodium bicarbonate; Alkalosis; Exercise.

RESUMEN

Introducción: La suplementación de bicarbonato de sodio (NaHCO3) ha demostrado atenuar la fatiga y mejorar el desempeño del ejercicio de alta intensidad, pero los efectos sobre el mantenimiento de contracciones isométricas son poco claros. Objetivo: Investigar el efecto del NaHCO3 en el desempeño de individuos sometidos al protocolo de fatiga en ejercicio isométrico en el dinamómetro isocinético. Métodos: Doce hombres participaron del estudio aleatorizado, doble ciego, cruzado y controlado por placebo. Sesenta minutos después de la ingestión de 0.3 g/kg de masa corporal de NaHCO3 o placebo, los participantes realizaron un protocolo isométrico de fatiga de los extensores del joelho. Resultados: La PSE y la RPP fueron menores al final del protocolo con NaHCO3, así como las concentraciones de lactato y pH del sangue, así como los índices de percepción subjetiva de esfuerzo (PSE) y dolor (PSD) fueron analizados. La PSE de la sesión fue mejorada al 30 minutos después del test. Conclusion: La suplementación de NaHCO3 mejora el desempeño de contracciones isométricas sustentadas y atenua la carga interna. Nivel de Evidencia II; Estudios diagnósticos – Investigación de un examen para diagnóstico.

Descritores: Fatiga muscular; Bicarbonato de sodio; Alcalose; Ejercicio.
INTRODUCTION

Muscular fatigue (MF) is a complex, multifactorial phenomenon and, depending upon the task done, with various mechanisms that could impact on the strength reduction magnitude. Specifically, in the high-intensity exercises with the predominance of the glycolytic system, the high hydrolysis of ATP results in the increasing of hydrogen ions concentrations ([H⁺]) followed by a pH decreasing. This condition is named metabolic acidosis and could lead to a series of mechanisms affecting the contraction-relaxation muscle’s process and, consequently, could be considered as an important MF indicator. Although MF is understood as a decrement in the ability to yield strength and muscular strength, when the task involves supporting a maximum contraction, the performance decrease is parallel to MF increase. Nevertheless, when the exercise asks for submaximal contractions, it is possible that the emergence of MF will not be associated with the effort interruption. As many activities in daily life and many exercise modalities involve submaximal contractions, the arising of MF could not be a limitation to the ability of an individual to perform the exercise, which means that submaximal contractions could be kept after the beginning of MF.

In this sense, the use of alkaline substances has been widely employed in various sports modalities and high-intensity exercise protocols, trying to improve the performance by decreasing MF. The sodium bicarbonate (NaHCO₃) intake increases the blood concentration of sodium bicarbonate, which favors the H⁺ and lactate efflux of the muscle cell and, in this way, decelerate the acidification process. A series of studies have shown that the intake of NaHCO₃ improve the performance in high-intensity exercises, mainly the ones of intermittent nature, although other researchers have found divergent results. Amongst these factors, the use of ergogenic substances in isometric exercises has been poorly evaluated. Assessing the effects of alkalosis induced by NaHCO₃ intake in the exercise performance in healthy people, found a significantly increase in performance on the strength reduction magnitude. Specifically, in the high-intensity exercises with the predominance of the glycolytic system, the high hydrolysis of ATP results in the increasing of hydrogen ions concentrations ([H⁺]) followed by a pH decreasing. This condition is named metabolic acidosis and could lead to a series of mechanisms affecting the contraction-relaxation muscle’s process and, consequently, could be considered as an important MF indicator.

Amongst these factors, the use of ergogenic substances in isometric exercises has been poorly evaluated. Assessing the effects of alkalosis induced by NaHCO₃ intake in the exercise performance in healthy people, found a significantly increase in performance on the strength reduction magnitude. Specifically, in the high-intensity exercises with the predominance of the glycolytic system, the high hydrolysis of ATP results in the increasing of hydrogen ions concentrations ([H⁺]) followed by a pH decreasing. This condition is named metabolic acidosis and could lead to a series of mechanisms affecting the contraction-relaxation muscle’s process and, consequently, could be considered as an important MF indicator.
The internal training load for each session was evaluated by multiplication of the exercise session duration in minutes by the training intensity, indicated by the RPE through the scale according to the previous studies.20 The subjects were told to choose a describer and a number from 0 to 10. To guarantee that the RPE mean data obtained refers to the total training, the subjects were asked to answer the following question 20 to 30 minutes after the end of the session: “How was your training today?”

The D’Agostino-Pearson test was applied to the Gaussian distribution analysis. The paired Student’s t-test and One-way ANOVA followed by Bonferroni’s post hoc test were performed to compare differences in fatigue protocol. Comparison analysis between inactive and active groups was performed by a repeated-measures ANOVA, followed by Bonferroni’s post hoc test. Cohen’s effect sizes were calculated, and evaluated based on the following criteria proposed by Rhea:21 <0.50 trivial, 0.50 to 1.25 small, 1.25 to 1.9 moderate and >2 large. An alpha of 0.05 was used to determine statistical significance. All data values were expressed as mean ± standard deviation. All analyses were performed using SPSS software (v 15.0; IBM, Armonk, NY, USA).

RESULTS

Mean values and standard deviation of the anthropometric parameters can be seen in Table 1.

The analysis of the effects of NaHCO₃ supplementation did not show significantly differences between placebo and NaHCO₃ in the variables isometric peak of torque (PT) (Placebo: 321 ± 15; NaHCO₃: 321 ± 18Nm) and torque development rate (Placebo: 73 ± 3; NaHCO₃: 76 ± 4 Nm/s) as described on Figure 1A and 1B respectively.

Significantly difference were not found on isometric PT corresponding to 50% of the maximum peak among the interventions (Figure 2A). However, in the end effort, the NaHCO₃ (Fatigue: 160 ± 23 Nm; End of protocol: 55 ± 23 Nm) supplementation induced an improvement in the isometric PT maintenance when compared to the placebo intervention (Fatigue: 160 ± 20 Nm; End effort: 16 ± 8 Nm). A great effect size was found in both interventions (Placebo: 7.20; NaHCO₃: 4.56), although the NaHCO₃ supplementation induced a smaller effect when compared to the placebo. The NaHCO₃ supplementation promoted greater maintenance of isometric PT (Figure 2B), delaying (p<0.001) the time (Placebo: 42 ± 5 sec; NaHCO₃: 95 ± 5 sec) to reach fatigue with great effect size (10.6).

In figure 3B it is shown that significantly differences (p<0.001) in [La–] were found in the Placebo intervention (Rest: 1.08 ± 0.37; Fatigue: 4.47 ± 1.51; end effort: 6.92 ± 1.13) as well with NaHCO₃ (Rest: 0.95 ± 0.24; Before: 5.42 ± 1.63; After: 7.71 ± 0.74) and great effect size in both interventions (Placebo: 15.78; NaHCO₃: 28.16). However, the NaHCO₃ induced hyperlactecemia both in fatigue and in the end of protocol when compared to the placebo.

Table 1. Mean and standard deviation (SD) of the biometrics parameters.

<table>
<thead>
<tr>
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<th>Mean ± SD</th>
<th>95% CI</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>32 ± 8</td>
<td>24.96 – 39.04</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>81 ± 4</td>
<td>77.44 – 83.99</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.74 ± 0.1</td>
<td>1.69 – 1.79</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>27 ± 2</td>
<td>25.14 – 28.29</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>21 ± 7</td>
<td>14.94 – 27.06</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>17 ± 6</td>
<td>11.74 – 22.83</td>
</tr>
<tr>
<td>Lean mass (kg)</td>
<td>63 ± 5</td>
<td>59.00 – 67.86</td>
</tr>
</tbody>
</table>

BMI: body mass index; IC: confidence interval.

Figure 1. Mean and standard error of isometric peak of torque (Panel A) and torque development rate (Panel B).

Figure 2. Mean and standard error of the peak of isometric torque at 50% of the isometric peak of torque (fatigue) and at the end of protocol (Panel A) and the time of sustaining strength till reach 50% of isometric peak of torque (Panel B).
Significantly differences (p<0.001) found in the intervention with placebo in RPE (Fatigue: 6.14 ± 1.77; End effort: 9.28 ± 1.89) as well as RPP (Fatigue: 7.28 ± 9.85; End effort: 9.85 ± 0.37) and great effect size was found in both parameters (1.77 and 1.40) respectively. Similar results were found in RPE after the NaHCO3 intake (Fatigue: 5.71 ± 1.88 < End effort: 7.85 ± 1.95) and the great effect size was found in both parameters (1.13 and 0.32). In addition, the NaHCO3 supplementation induced lower (p<0,001) RPE (Figure 4A) and RPP (Figure 4B) when compared to placebo.

It was found significantly difference (p<0.001) among the internal load in the both interventions (Placebo: 74.29 ± 6.04; NaHCO3: 56.0 ± 6.53 arbitrary units), considering the parameters more commonly used in the training prescription (Figure 5).

**DISCUSSION**

The main findings of this study correspond to the significantly increase in the time to reach fatigue (50% of initial PT) and a smaller reduction of isometric PT at the end of protocol after the NaHCO3 supplementation. This result shows the ergogenic effect in the maintenance of the isometric strength assessed in the isokinetic dynamometer. The improvement in the exercise performance observed in this study follows other studies with improvement in the performance after alkalosis induction. It is known that the fatigue process is a multifactorial phenomenon, however in high-intensity exercises, MF is associated with the increase of [H+] with a simultaneous decrease in the intramuscular pH. The best performance found after the NaHCO3 intake probably is linked to the increase of the H+ efflux of the muscle in exercise, which decreases the intramuscular acidosis and thus delays the fatigue.

The efflux of H+ from the cell into the extra cell is influenced by the pH gradient and occurs together with the lactate efflux, undertaken through the monocarboxylate transporter protein linked to the plasma membrane. Thus, the higher extracellular pH values pre-exercise and in the bout of fatigue observed after the NaHCO3 intake suggest that the H+ speed of transportation was increased as a consequence of the higher pH gradient resulting from the alkaline substance intake.

Although increase in the blood [La-] has been observed during the implementation of the protocol both after NaHCO3 and placebo when compared to the pre-exercise a higher efflux of lactate was observed in the bout of fatigue and at the end of protocol, when the participants were supplemented with NaHCO3. In turn, the increased lactate efflux contributes to the intramuscular pH maintenance and, thus, to the...
intensity of the exercise. As suggested by Coombes and McNaughton, the higher values of blood [La−] could reflect on a higher anaerobic contribution during the exercise and a higher dependence of anaerobic glycolysis to complete the protocol in the NaHCO3 essay. 

Consistently, has been demonstrated that the intake of 0.3 g/kg body mass of NaHCO3 increases both the pre-exercise extracellular pH and the blood [La−] during the test. In connection with the initial PT and the torque development rate conducted in the MVIC test (pre-protocol, eight minutes), statistical differences were not observed between the two conditions, pointing out that the maximum strength was not affected by the NaHCO3. One possible explanation for this is that, due to the short duration of the effort (three contractions of five seconds), a significant production of H+ did not occur, since in this type of effort the primary transfer channel is ATP-CP and not the glycolytic one. In this sense, the NaHCO3 action is unable to affect the performance. 

The alkalosis effect in the effort perception has been investigated in research of various modalities of exercise, but the results are conflicting. Krustup et al. found smaller values for only after 440 m in an intermittent test of high intensity, but not after 160 and 280 m, and in the moment of exhaustion after NaHCO3 supplementation when compared to the control. Nevertheless, when the participants ingested the alkaline substance, there was an improvement of 14% in the performance. In turn, Duncan et al. did not find differences in the RPE between NaHCO3 and control of trained men in resistance exercise, although there was a higher number of repetitions in the first exercise after the use of NaHCO3. In our study, we did not find alterations in the effort perception in the bout of fatigue. However, a lesser degree of RPE was established after the eight minutes of protocol. In theory, we can suggest that centrally mediated mechanisms could be affected. Among these mechanisms, has been proposed that the metabolic alterations in the muscle in exercise result in inhibitory neural feedback through different fibers from groups III and IV, which are responsive to a range of chemical stimuli. Thus, the smaller RPE and the higher performance with NaHCO3, could reflect a smaller metabolic alteration (including H+) due to the action of this substance and, consequently, a less negative muscular feedback and a smaller effect on the descending central command for the motor neurons. However, it is interesting to note that at the end of protocol (when the RPE was smaller in NaHCO3) pH values were not different between NaHCO3 and placebo. The investigation of other metabolic variables could help to understand this phenomenon.

Concerning the RPE’s session performed after 30 minutes after the end of the protocol, smaller values were observed when the participants were supplemented with NaHCO3. The session’s RPE has been proposed as a valid method to monitor the exercise’s intensity and allows the individual to give a general assessment about how difficult the session was. As per our knowledge, till now there is not a research investigating the influence of NaHCO3 in the answers of RPE’s session. Again, it is possible that smaller metabolic alterations have occurred during the exercise in function of the higher extracellular buffered after the NaHCO3 intake, which could be contributed for a full recovery and as maller perception of effort after 30 minutes of recovery.

CONCLUSION

The results suggest that the NaHCO3 intake could improve the performance of sustained isometric contractions of knee extensors with decrease in the RPE e RPP and a smaller load. However, it is needed to conduct more research to investigate the NaHCO3 effect in the internal load parameters, as, in the RPE’s session, which can give information related to the recovery and help in the exercise of dynamic characteristics prescription. 

All authors declare no potential conflict of interest related to this article.