Sodium Bicarbonate ingestion increases pH in blood but does not attenuate Exercise Induced Arterial Hypoxemia or enhance performance

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Abstract

Introduction: The exact causes of Exercise Induced Arterial Hypoxemia (EIAH) are not yet known. Earlier studies on the ergogenic effects of NaHCO3 have neglected to investigate the occurrence of EIAH among their subject, something that could explain the conflicting results. EIAH cannot be over looked since reportedly 50% of well trained athletes experience EIAH. One possible ergogenic effect of NaHCO3 would be to attenuate EIAH through an increase in blood pH in a subject. This has been shown previously by means of intravenous infusion during maximal rowing.

Aim: The aim of the study was to examine the effect of oral intake of NaHCO3 on EIAH and performance in trained cyclists.

Method: Seven male cyclists (age 23.7 (22-27) years, VO2peak 64 (60-72) ml min⁻¹ (kg body mass)⁻¹ volunteered for the study. The subjects performed two maximal exercise tests to exhaustion 48 hours apart in a counter balanced cross over double blind fashion. Subjects received 0.3 g kg BW⁻¹ CaCO3 and 0.3 g kg BW⁻¹ NaHCO3 in the placebo and bicarbonate trial respectively.

Free flowing arterialized capillary blood was sampled at rest and exhaustion and analyzed for pH, O₂ Saturation, pO₂, pCO₂, and blood lactate. Ventilatory variables were measured continuously throughout the test V′O₂, V′CO₂, V′E, V′E/VO₂, RER and HR. In addition pulse oximetry was used to evaluate O₂ saturation.

Results/Discussion: At rest pH and PCO₂ was elevated (p<0.05) in the bicarbonate trial compared to the placebo trial. At exhaustion in the bicarbonate trial pH, blood lactate, RER, was significantly elevated (p<0.05) when compared to the placebo trial. O₂ saturation from blood samples at exhaustion in the bicarbonate trial showed a trend towards improving (p=0.061). No difference was seen between the two trials in PO₂, VO₂peak, V'Emax, HRmax or performance. During exercise, bicarbonate ingestion increased blood pH but did not improve arterial saturation or performance. The increase in blood pH achieved by ingestion of bicarbonate was not as large as the increase achieved by intravenous infusion in another study. Even with the larger increase in blood pH in those studies, there was only a small improvement in performance. One possible explanation for the performance improvement with bicarbonate infusion in that study was a reduced ventilation that could effect respiratory muscle work and thereby work capacity. The bicarbonate ingestion in the present study did not reduce ventilation. This could possible be achieved with higher doses of NaHCO3, which would most likely result in increased frequency of gastrointestinal distress among subjects.
Key words: EIAH, SaO2, Sodium Bicarbonate

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Abbreviations

VO2max  Maximal Oxygen Consumption
RER      Respiratory Exchange Ratio (VCO2/V'O2)
EIAH     Exercise Induced Arterial Hypoxemia, a lowering of the oxyhaemoglobin saturation induced by exercise
V'O2     Oxygen Consumption
VCO2     Carbon Dioxide production
V'E      Minute Ventilation
V'E max  Maximal Minute Ventilation
HR       Heart Rate
HR max   Maximal Heart Rate
pO2      Partial Pressure of Oxygen
pCO2     Partial Pressure of Carbon Dioxide
NaHCO3   Sodium Bicarbonate
SaO2     Arterial Oxygen Saturation
INTRODUCTION

*Exercise Induced Arterial Hypoxemia (EIAH)*

Traditionally, arterial haemoglobin O\(_2\) saturation was thought to remain unchanged during intense exercise, thereby suggesting that the pulmonary system was not a limiting factor in determining maximum oxygen uptake in healthy individuals (25). However, more recent research has shown that exercise-induced arterial hypoxemia (EIAH) is possible and that it is present in approximately half of well-trained endurance athletes but not in moderate or untrained subjects during intense exercise (24). It has been showed that blood viscosity increased to a greater extent in EIAH subjects during exercise, possible leading to vascular shear stress (3). Whether this could impair the blood gas barrier required further study, a six-week polyunsaturated fatty acid diet improved EIAH in master athletes strengthening high blood viscosity as a factor (23). Moderate hyperoxia has been shown to increase VO\(_2\) max and aerobic power to a greater degree in EIAH subject than in non-EIAH subjects (11). Triathletes show no difference in the magnitude of EIAH between running and cycling modes of testing (15). Sildenafil has been shown to decrease the reduction in VO\(_2\) max during a six-day exposure to a altitude of 4350 m (27). Legrand et al. showed that increased O\(_2\) arterial desaturation increased muscle deoxygenation (17)(16). Acute hypervolaemia improved arterial oxygen pressure in subjects experiencing EIAH (29). Athletes who display reduced arterial O\(_2\) saturation during intense exercise in normoxia are more susceptible to reduced VO\(_2\) max in mild hypoxia (5). Lately, the existence of intrapulmonary arteriovenous shunts have been put forward as a probably cause of EIAH (8).

It has been concluded that EIAH is now recognised to occur in a significant number of fit and healthy individuals of both sexes and of varying ages, but the cause has yet to be determined, even what organ system, directly or indirectly is responsible for this limitation (7). The definitions of EIAH vary between researchers, but the most common definition is a reduction of SaO\(_2\) by 4% from resting values. An arterial saturation below 90% is considered severe exercise-induced arterial hypoxemia. (16). There are some excellent review articles that examine EIAH in depth (7, 21, 26).
**Sodium Bicarbonate supplementation**

The ergogenic effects of Sodium Bicarbonate (NaHCO₃) are somewhat uncertain, since it has only been proved ergogenic over shorter periods of intense exercise (1, 2, 10, 18, 19). Unfortunately earlier studies on the ergogenic effects of NaHCO₃ have neglected to investigate the occurrence of EIAH among their subject, something that could explain the conflicting results. EIAH cannot be over looked since reportedly 50% of well trained athletes experience EIAH. One possible ergogenic effect of NaHCO₃ would be to attenuate EIAH through an increase in blood pH. This has been shown previously by means of intravenous infusion during maximal rowing (22). A possible reason for the conflicting results regarding ergogenic effects of NaHCO₃ could be because of subjects experiencing different severity of arterial desaturation during maximal exercise.

**Aim of the study**

The aim of the study was to test the hypothesis that an oral intake of NaHCO₃ would attenuate EIAH and improve performance in trained male cyclists.

**MATERIALS AND METHODS**

**Subjects**

Seven male competitive cyclists [mean age 23.7 yr (range 22-27 yr), body weight 71.4 kg (range 63-79 kg), height 181.3 cm (range 175-190 cm), maximal oxygen uptake (VO₂max) 64 ml·kg⁻¹·min⁻¹ (range 60-72 ml·kg⁻¹·min⁻¹] were recruited from the local collegiate cycling team and volunteered for the study. Male subjects were recruited because of their generally higher aerobic capacity. Subjects were informed in detail of the experimental procedure and gave their written informed consent. In the three weeks preceding the experiments all subjects were healthy, injury free and none were taking any medication. The study was approved by the Ethics Committee of Högskolan Dalarna University College and performed according to the Declaration of Helsinki.
**Experimental protocol**

All subjects performed three trials, with the first being a screening trial, although identical to the two following intervention trials. The two intervention trials were administered in a counter-balanced, cross-over double-blinded fashion. All trials were separated by exactly 48 hours. The subjects performed a graded exercise test on a friction braked cycle ergometer (Monark 839 E, Monark Exercise AB, Vansbro Sweden) starting at 100 w, with workloads increasing by 50 w every four minutes until volatile exhaustion or when the subjects were unable to keep cadence above 70 rpm. No verbal encouragement was given to the subjects, except constant information of workload and time checks. A rest period of 1 minute intercepted each four minute work period, to allow for blood sampling without disturbing the subject. Maximal power output (Wmax) of each trial was calculated as follows (12).

\[ W_{\text{max}} = W_f + \left( \frac{x}{240} \right) \times 50 \]

Where \( W_f \) is the workload of the last completed increment and \( x \) is the number of seconds completed during the last attempted increment. During every trial, a powerful fan was used to cool the subject.

**Drug Administration**

Either 0.30 g·kg\(^{-1}\) bw of Sodium Bicarbonate pills (NaHCO\(_3\)) or 0.33 g·kg\(^{-1}\) bw Calcium Carbonate pills (CaCO\(_3\)) was ingested prior to the second and third trial. The drugs(29) divided into five servings, with one serving ingested every 20 minutes together with 0.2 litres of water. The first serving was ingested 90 minutes prior to each exercise trial. The dosage of 0.3 g·kg\(^{-1}\) bw, the five servings and the total intake of 1 litre of water has been demonstrated in earlier studies on NaHCO\(_3\) supplementation to be sufficient to provide ergogenic benefits without causing severe side effects (1). The possible side effects from NaHCO\(_3\) are gastrointestinal distress and nausea, but the risks for these side effects are minimised with the current intake regimen.

**Blood Sampling**

Blood samples for the measurement of bicarbonate, O\(_2\) pressure, CO\(_2\) pressure, pH, and base excess in arterialized capillary blood was obtained from a free flowing puncture(13, 28) of a preheated fingertip on the non-dominant hand and collected in a 100 microlitre heparized tube (Clinitubes D957G-70-100-100 µL, Radiometer, Copenhagen, Denmark). All blood samples were stored horizontally and analysed within one minute of sampling (ABL 825 Flex, Radiometer, Copenhagen, Denmark). In addition a 25 microlitre sodium heparinized tube (
Plastic capillaries 20 µL, EKF Diagnostics, Barleben, Germany) was used to collect a blood sample for a separate analysis of lactate (Biosen 5140, EKF Diagnostics, Barleben, Germany (6).

Blood samples were obtained after 15 minutes of supine resting, at the end of each workload, directly after termination of exercise and after five and ten minutes of recovery. During the resting period prior to testing the subjects hand was placed in a warm water bath (~42°C), during ergometer cycling the lower arm and hand was covered by a heated pad. The fan used to cool the subject also cooled the dominant hand with the pulsoximeter fingertip sensor, this cooling was not desired since it could effect periphal circulation of the hand, and therefore SaO2 measurement. To combat this the dominant hand was covered by a towel.

**Gas measurement**

A computerized metabolic system with a mixing chamber (Oxycon Pro, Erich Jaeger GmbH, Hoechberg, Germany) (4, 9) was used to measure VO2, VCO2, V'E, RER and heart rate (HR). HR was also measured with a portable heart rate monitor (Polar S810i, Kempele, Finland). VO2, VCO2 and RER was sampled every ten seconds and averaged over the last minute of every workload. HR was average over the last five seconds of each workload. The Oxycon Pro was calibrated according to the instruction manual post and prior to all trials.

**Pulse oximetry**

Pulse oximetry (Datex-Ohmeda 3900, Louisville, USA) was monitored continuously throughout both the 15 minute rest and the entire exercise test. The index finger of the dominant hand was cleaned with alcohol and let to air dry before placing the sensor according to the user manual. SaO2 data and signal strength data was averaged and stored in the device every six seconds and later downloaded to a laptop computer. For resting values, the values of the entire 15 minute period were averaged and for exercise values, the 10 lowest consecutive values (representing 1 minute) of each workload were averaged, in the majority of cases these values were also the final readings of each work load. Pulse oximetry to measure arterial oxyhemoglobin saturation during exercise have previously been validated, fingertip sensor placement being prefered to earlobe sensor placement (17) (20).
**Statistical Analysis**

Data are presented as Mean ± SD. Differences between means were tested for statistical significance by using two-tail Student’s t-test. Statistical significance was set at the 95% confidence limit (P<0.05).

**RESULTS**

**Exercise performance**

The performance measure of Wmax was 367± 26 W for the placebo trial and 368± 23 W for the bicarbonate trial, with no significant difference between the trials. See figure 1.

![Graph](image)

**Fig. 1. Relative performance Wmax·kg bw-1 of each subject in each of the two trials.**

**Ventilation and heart rate**

The maximal ventilation for the placebo trial was 187± 22 l·min-1 and for the bicarbonate trial 191±18 l·min-1, with no significant difference between the trials. Maximal heart rate was 195 ±9 bpm for the placebo trial and 194±10 bpm for the bicarbonate trial. Maximal oxygen uptake was 4.7±0.4 and 4.7±0.3 l·min-1 for the placebo and bicarbonate trial respectively. However RER at maximal exercise increased significantly from 1.21±0.02 to 1.24±0.03 (P<0.05).
**Blood-gas variables**

SaO₂ as measured from blood samples decreased from 96.5± 0.8% at rest to 94.1± 1.8 % at maximal exercise in the placebo trial and from 96.4± 1.3 % to 95.2± 1.6 % in the bicarbonate trial, with no significant difference between trials. CO₂ pressure at rest was higher in the bicarbonate trial 5.71± 0.26 compared to 5.33± 0.16 kPa in the placebo trial to  (P<0.05), but there was no significant difference at maximal exercise with 4.11± 0.46 kPa in the placebo trial and 4.25± 0.32 kPa in the bicarbonate trial. Oxygen pressure increased from 9.63±0.54 kPa at rest to 11.54± 0.59 kPa at maximal exercise in the placebo trial and from 9.12± 1.96 kPa to 11.56± 0.85 in the bicarbonate trial, with no significant difference between trials. One potential source of error in the measurement of O₂ and CO₂ pressure could be the heating of the hand, during rest this was achieved using a warm water bath, and during exercise a heating pad was used. Every ten minutes the heating pad was replaced with new one, freshly heated in a microwave oven. This could induce differences in temperature of the hand thus effecting peripheral circulation and pressure of O₂ and CO₂. The best solution to this problem would be to use anaerobic arterial sampling of the radial artery, unfortunatley this procedure involves greater risks for the subject and was therefore beyond the scope of the present study. Another aspect of the preheated hand is that both the warm water bath and the heating pad possibly exaberated the core temperature increase experienced during exercise.

**Lactate and pH**

Resting blood lactate values were 1.04±.28 and 1.14± 0.13 mmol/l for the placebo and bicarbonate trial respectively. Maximal lactate values increased significantly from 15.25±2.73 to 18.05± 2.48 mmol/l for the placebo and bicarbonate trial respectively (P<0.05). Blood pH was significantly elevated at both resting 7.489± 0.021 vs. 7.396± 0.045 and maximal exercise 7.217± 0.074 vs. 7.143± 0.064 in the bicarbonate trial when compared with the placebo trial (P<0.05).
Fig. 2. Mean blood lactate values at rest, at every workload and at five and ten minute recovery for NaHCO₃ and CaCO₃ trials.

Fig. 3. Mean blood pH values at rest, at every workload and at five and ten minute recovery for NaHCO₃ and CaCO₃ trials.

**Pulse Oximetry**

Resting arterial saturation as measured by pulse oximetry was 98.3± 1.3 and 98±1.6 % and decreased significantly (P<0.05) to 90± 1.7 and 90.7±2.7 % at maximal exercise for the placebo and bicarbonate trial respectively, but with no significant difference between the trials. All subjects in the present study experienced a greater than 4% reduction in arterial saturation and does thereby qualify as EIAH subjects.
DISCUSSION

Exercise performance

Since there was no difference in Wmax between the two trials this study does not suggest sodium bicarbonate to be an ergogenic aid potent enough to increase performance during incremental ergometer cycling exercise. The reason for this could be dependent on the dosage of the bicarbonate supplementation, with earlier studies showing small improvements in performance through intravenous infusion of bicarbonate (22). However, because of the possible side effects of bicarbonate loading, a higher dosage could prove problematic (1). The fact that neither heart rate nor ventilation was different between the trials, helps to explain the absence of performance improvement in the NaHCO₃ trial, since one of the possible ergogenic mechanisms of NaHCO₃ would be to induce hypoventilation and a lowering of the metabolic cost of breathing.

Ventilation and heart rate

Conflicting with earlier studies, in the present study, hypoventilation was not induced by NaHCO₃ intake (22). The possible reason for this was probably the relatively small dose of sodium bicarbonate. Nielsen et al, showed that by an intravenous infusion of ~50-60 ml·min⁻¹ NaHCO₃, the usual decrease of blood pH during maximal exercise was almost avoided and arterial desaturation was only slightly attenuated (22). In the present study NaHCO₃ ingestion elevated pH when compared to the placebo trial, but to a much smaller degree than, this would also explain the even smaller (~ 1%) and non significant increase of arterial saturation in the present study.

Blood-gas variables and pulse oximetry

According to the arterial saturation measured from arterialized capillary blood only two subjects experienced mild EIAH. This is problematic since the data from the pulse oximeter suggests that all subjects experience mild to severe EIAH. In the case of the pulse oximeter data the results are surprising since we would only expect roughly 50% of the subjects to experience EIAH (24). This finding could possibly challenge the general notion that 50% of well trained athletes suffer from EIAH, and suggest that in the sub group tested in the present study the prevalence of EIAH is higher than previously reported. Because of the one litre of water ingested together with the drugs, all subjects showed a one kilogram increase in body weight in both intervention trials, one could argue that the extra intake of water caused the
possible side effect of hypervolemia and thus open the possibility of improved arterial oxygen pressure (29). However since this was equally present in both intervention trials, it should represent no problem. Another issue when measuring blood-gases is that measurement is sensitive to temperature. However, in the present study blood-gases were measured by an ABL 825 Flex analyzer, were measurements are not affected by small changes in temperature due to the 37º C measuring chamber. One possible reason for the low SaO2 values could be that the towel covering the dominant hand with the pulseoximeter sensor was not sufficient to offset the cooling effects of the fan. However, since the signal values of the pulseoximeter were acceptable, this is not a likely possibility.

Lactate and pH

Blood pH increased as a result of bicarbonate ingestion, both at rest and during maximal exercise when compared to the placebo trial. Blood lactate values also increased in the bicarbonate trial and both these results are supported by earlier findings. However the increase in maximal lactate values of ~ 2.5 mmol·L-1 is of a much smaller magnitude than the ~ 10 mmol·L-1 achieved by means of NaHCO3 intravenous infusion (22). There are several mechanisms that can explain the elevated blood lactate values, a higher lactate output caused by a higher efflux of protons due to an increase in extracellular bicarbonate, diffusion via bicarbonate-chloride exchange and via sodium-hydrogen exchange (14).

CONCLUSION

The results of this study did not show any ergogenic effect of sodium bicarbonate ingestion, however, further research on the topic is warranted to investigate if any ergogenic effect could be dose related.

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