Effect of Sodium Bicarbonate on $[\text{HCO}_3^-]$,$\text{pH}$, and Gastrointestinal Symptoms

Amelia J. Carr, Gary J. Slater, Christopher J. Gore, Brian Dawson, and Louise M. Burke

**Context:** Sodium bicarbonate (NaHCO$_3$) is often ingested at a dose of 0.3 g/kg body mass (BM), but ingestion protocols are inconsistent in terms of using solution or capsules, ingestion period, combining NaHCO$_3$ with sodium citrate (Na$_3$C$_6$H$_5$O$_7$), and coingested food and fluid. **Purpose:** To quantify the effect of ingesting 0.3 g/kg NaHCO$_3$ on blood pH, $[\text{HCO}_3^-]$, and gastrointestinal (GI) symptoms over the subsequent 3 hr using a range of ingestion protocols and, thus, to determine an optimal protocol. **Methods:** In a crossover design, 13 physically active subjects undertook 8 NaHCO$_3$ experimental ingestion protocols and 1 placebo protocol. Capillary blood was taken every 30 min and analyzed for pH and $[\text{HCO}_3^-]$. GI symptoms were quantified every 30 min via questionnaire. Statistics used were pairwise comparisons between protocols; differences were interpreted in relation to smallest worthwhile changes for each variable. A likelihood of >75% was a substantial change. **Results:** $[\text{HCO}_3^-]$ and pH were substantially greater than in placebo for all other ingestion protocols at almost all time points. When NaHCO$_3$ was coingested with food, the greatest $[\text{HCO}_3^-]$ (30.9 mmol/kg) and pH (7.49) and lowest incidence of GI symptoms were observed. The greatest incidence of GI side effects was observed 90 min after ingestion of 0.3 g/kg NaHCO$_3$ solution. **Conclusions:** The changes in pH and $[\text{HCO}_3^-]$ for the 8 NaHCO$_3$-ingestion protocols were similar, so an optimal protocol cannot be recommended. However, the results suggest that NaHCO$_3$ coingested with a high-carbohydrate meal should be taken 120–150 min before exercise to induce substantial blood alkalosis and reduce GI symptoms. **Keywords:** ergogenic aid, buffering, induced alkalosis

Sodium bicarbonate (NaHCO$_3$) has been used as an ergogenic aid for events that depend on the generation of energy via anaerobic glycolysis (McNaughton, Strange, & Backx, 2000). Its ingestion has been reported to improve competitive and laboratory-based protocols of sustained exercise lasting 1–7 min involving swimming (Gao, Costill, Horswill, & Park, 1988; Zajac, Cholewa, Poprzecki, Wasikiewicz, & Langfort, 2009), middle-distance running (Goldfinch, McNaughton, & Davies, 1988; Van Montfoort, Van Dieren, Hopkins, & Shearman, 2004; Wilkes, Gledhill, & Smyth, 1983), and rowing (McNaughton & Cedaro, 1991). Similar findings have also been reported for high-intensity performance at the end of 30- to 60-min protocols (McNaughton, Dalton, & Palmer, 1999) and repeated-sprint performance typical of team sports (Lavender & Bird, 1989; McKenzie, Coutts, Stirling, Hoeben, & Kuzara, 1986).

NaHCO$_3$ ingestion has been proposed to enhance performance by increasing extracellular buffering capacity (Burke & Pyne, 2007; McNaughton, Siegler, & Midgley, 2008), but there appears to be a threshold elevation in blood bicarbonate concentration ($[\text{HCO}_3^-]$) or pH required (6 mmol/L and 0.05, respectively) before ergogenic potential is evident (Bishop & Claudius, 2005; McNaughton & Cedaro, 1991; Van Montfoort et al., 2004; Wilkes et al., 1983). Postexercise blood lactate values can be 1–2 mmol/L higher after NaHCO$_3$ ingestion than in placebo or control trials (McNaughton et al., 1999; Wilkes et al., 1983).

A disadvantage of NaHCO$_3$ supplementation is the possibility of gastrointestinal (GI) upset, resulting in symptoms such as nausea, stomach pain, diarrhea, and vomiting (Burke & Pyne, 2007). This is a serious practical consideration for athletes in a competition setting. In fact, each of the current authors has observed that, across a range of sports, NaHCO$_3$ loading is infrequently practiced by athletes who could potentially benefit from enhanced buffering capacity. Fear or personal experience of GI upset could contribute to the avoidance of NaHCO$_3$ use. Although particular symptoms have been recorded and quantified in some studies (Stephens, McKenna, Canny, Snow, & McConnell, 2002; Van Montfoort et al., 2004), a limitation of many NaHCO$_3$ supplementation trials is the lack of documentation of side effects with particular protocols of ingestion (Matson & Tran, 1993). Knowledge of protocols less likely to induce GI distress may increase athletes’ use of and benefit from NaHCO$_3$ supplementation.

Carr and Gore are with the Physiology Dept., and Slater and Burke, the Sports Nutrition Dept., Australian Institute of Sport, Canberra, Australia. Dawson is with the School of Sport Science, Exercise and Health, The University of Western Australia, Perth, Australia.
The dose of NaHCO₃ used most commonly is 0.3 g/kg body mass (BM; Burke & Pyne, 2007; Matson & Tran, 1993); this has been derived from several dose-response studies (Douroudos et al., 2006; Horswill et al., 1988; McNaughton, 1992), but there remain inconsistencies in several other aspects of the administration protocol of NaHCO₃, including the form (capsules or solution), ingestion period (from the beginning to conclusion of ingestion), and the volume of coingested fluid (Burke & Pyne, 2007; Matson & Tran, 1993; McNaughton et al., 2008). The manipulation of these three factors, even with a consistent 0.3-g/kg BM dosage, could result in multiple administration protocols, each of which could elicit subtle differences in performance and, particularly, in GI side effects (Matson & Tran, 1993). Although the time course of acid-base change after specific NaHCO₃-ingestion protocols has been investigated previously (Potteiger, Webster, Nickel, Haub, & Palmer, 1996; Price & Singh, 2008; Renfree, 2007), and results suggest that peak acid-base disturbances occur at some point 60–90 min from ingestion, a more comprehensive investigation of the effect of different administration protocols on blood [HCO₃⁻], pH, and blood lactate concentration, as well as GI disturbances, has yet to be performed.

Therefore, this study aimed to quantify the effect of oral ingestion of NaHCO₃ (0.3 g/kg BM) on blood pH, [HCO₃⁻], and GI symptoms over a 3-hr period, using nine different administration protocols, to determine an optimal administration protocol. Our goal was to systematically evaluate a range of NaHCO₃-ingestion protocols, derived from the existing variation in supplementation strategies, to develop an ingestion protocol that would elicit substantial elevations in blood [HCO₃⁻] and pH and minimal GI side effects, to potentially enhance the ergogenic effect of NaHCO₃.

Methods

Subjects

Thirteen participants (8 women and 5 men) completed this study (M ± SD: age 29.8 ± 5.0 years, height 177.9 ± 9.4 cm, mass 74.43 ± 11.70, sum of seven skinfolds 76.0 ± 25.0 mm). All were recreationally physically active. Written consent was obtained from each participant, and the protocol was approved by the ethics committee of the Australian Institute of Sport.

Experimental Overview

In a crossover design, each participant completed a total of nine testing sessions, comprising one placebo and eight experimental trials conducted in a semicounterbalanced order. Consecutive sessions were separated by at least 48 hr and commenced at the same time of day (6–6:30 a.m.) in controlled laboratory conditions. Participants reported after an overnight fast. After a baseline fingertip capillary blood sample, participants began ingesting NaHCO₃ according to one of the nine protocols. Capillary blood samples were also taken 30 min after the beginning of ingestion and every 30 min thereafter, for 180 min after the complete ingestion of the NaHCO₃. Participants remained seated for the duration of the testing session. Their dietary intake was standardized by recording all food and fluids ingested in the 24-hr period before the first trial, detailing mass (g) and volume (ml), and replicating this intake for all subsequent testing sessions. This was done in an attempt to standardize baseline capillary blood values, because it has been reported (Greenhaff, Gleeson, & Maughan, 1988) that large fluctuations in dietary intake in the days before a test can influence acid-base status. Participants were issued their food record before each testing session and replicated this ingestion pattern for the 24 hr before the test.

NaHCO₃ Ingestion

A summary of the protocols used is shown in Table 1. Participants ingested NaHCO₃ at a dose of 0.3 g/kg BM (McKenzie Pty. Ltd., Altona, Australia), a sodium chloride placebo (Salpak Pty. Ltd., Seven Hills, Australia) with an equimolar amount of sodium, or a commercially available combination of NaHCO₃ and Na₃C₆H₅O₇ called Ural (Sigma, Croydon, Australia). When Ural was ingested, it was prescribed to achieve an equivalent dose of NaHCO₃ (0.3 g/kg BM), resulting in the coingestion of 0.1 g/kg BM Na₃C₆H₅O₇. Powdered supplements to be dissolved in fluid were weighed using a biochemistry

<table>
<thead>
<tr>
<th>Protocol</th>
<th>NaHCO₃ or placebo</th>
<th>Solution or capsules</th>
<th>Fluid volume (7 or 14 ml/kg BM)</th>
<th>Ingestion period (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NaHCO₃</td>
<td>solution</td>
<td>7</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>NaHCO₃</td>
<td>solution</td>
<td>14</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>NaHCO₃</td>
<td>solution</td>
<td>14</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>NaHCO₃</td>
<td>capsules</td>
<td>14</td>
<td>60</td>
</tr>
<tr>
<td>5</td>
<td>NaHCO₃</td>
<td>capsules</td>
<td>14</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>NaHCO₃</td>
<td>capsules</td>
<td>7</td>
<td>30</td>
</tr>
<tr>
<td>7</td>
<td>placebo</td>
<td>solution</td>
<td>14</td>
<td>30</td>
</tr>
<tr>
<td>8</td>
<td>NaHCO₃ + meal</td>
<td>capsules</td>
<td>7</td>
<td>30</td>
</tr>
<tr>
<td>9</td>
<td>NaHCO₃ + citrate</td>
<td>solution</td>
<td>14</td>
<td>30</td>
</tr>
</tbody>
</table>

Note. BM = body mass. Protocols 1–6 and 8 used sodium bicarbonate (NaHCO₃) at a dose of 0.3 g/kg BM. Protocol 7 used NaCl with equimolar amount of sodium, and Protocol 9 used NaHCO₃ at a dose of 0.3 g/kg BM combined with 0.1 g/kg BM sodium citrate.
balance (±0.0001 g; A&D, San Jose, CA). Protocols were designed so that the total administration period (from commencement to completion of ingestion) was either 30 or 60 min; the coingested volume of fluid was either 7 or 14 ml/kg BM of low-kilojoule flavored cordial (Steric Trading, Villawood, Australia), and the NaHCO₃ was ingested as either NaHCO₃ powder dissolved in fluid or as capsules (Aspen Pharmacare, St. Leonards, Australia). Solutions and fluids were prepared the day before the testing session and refrigerated overnight.

The total volume of fluid and number of capsules for each protocol was divided into three equal amounts. Capsules and fluid (at a temperature of ~4 °C for fluids) were ingested at 15-min intervals for the 30-min protocols and at 30-min intervals for the 60-min protocols. Participants were instructed to ingest each dose in as little time as possible, typically over 2–3 min. When they coingested the supplement with a meal, they were provided with food (toasted bread with fruit spread and cereal bars; Kellogg, Melbourne, Australia) that included 1.5 g carbohydrate per kilogram BM. The energy intake for the meal was 2,275 ± 470 kJ. Participants ingested the meal over the total ingestion period (30 min) for this protocol.

Capillary Blood Sampling and Analysis

Before capillary blood sampling, participants immersed one hand in warm water (~45 °C) for ~1 min. The hand was then dried and one finger was pierced with a sterile 2.0-mm retractable lancet (Medlance, Ozorkow, Poland). The first drop of blood was removed and then 100 μl blood was collected in a glass capillary tube (Radiometer, Copenhagen, Denmark). Blood samples were immediately analyzed using a blood-gas analyzer (Radiometer ABL 725, Radiometer, Copenhagen, Denmark) for pH and bicarbonate concentration.

GI Side Effects

Participants were provided with a validated questionnaire (adapted with permission from Jeukendrup et al., 2000) at the same time that each blood sample was taken to quantify side effects. There were 16 items describing possible GI side effects, plus heartburn, dizziness, headache, and muscle cramp, and a 10-point Likert scale, ranging from 1 = no problem at all to 10 = the worst it has ever been, to indicate the severity of that side effect at that point in time.

Statistical Analysis

We used a contemporary analytical approach, calculating the probability of clinical or practical significance, rather than using a p value less than .05 to determine statistical significance (Hopkins, Marshall, Batterham, & Hanin, 2009). The smallest worthwhile change in performance is 0.3 of the typical within-athlete random variation (Hopkins, Hawley, & Burke, 1999), wherein the typical random variation in performance (within an athlete) between one race and another is ~1.5% (Hopkins & Hewson, 2001). Therefore, the smallest worthwhile change in performance for an athlete is ~0.5% (1.5% × 0.3). The improvement in performance reported previously after NaHCO₃ supplementation is ~1.5%, and the corresponding increases in blood [HCO₃⁻] and pH are ~6 mmol/L and 0.05 (McNaughton et al., 1999; Parry-Billings & MacLaren, 1986; Wilkes et al., 1983), respectively. By inference, the smallest worthwhile changes in absolute blood [HCO₃⁻] and pH that are likely to be associated with improved performance are 2 mmol/L and 0.02, respectively. The smallest worthwhile change in GI symptoms was set at 1 unit on the scale provided in the questionnaire.

Change scores from baseline were calculated from individual raw blood [HCO₃⁻], pH, and GI symptoms for each protocol. For each postingestion time point (30, 60, 90, 120, 150, 180, 210, and 240 min), change scores were entered into a spreadsheet (http://www.sportsci.org/resource/stats/xPostOnlyCrossover.xls). Pairwise comparisons of change scores for each postingestion time point were made between protocols, to determine whether the probability of the difference between protocols at each time point was greater than the smallest worthwhile change for blood bicarbonate concentration after NaHCO₃ supplementation. The likelihoods were set as <1%, almost certainly not; <5%, very unlikely; <25%, unlikely, probably not; 25–75%, possibly, possibly not; >75%, likely, probably; >95%, very likely; and >99%, almost certainly and were interpreted relative to the smallest worthwhile effect for the respective bicarbonate concentration, pH, and GI-symptoms data. A >75% probability that differences between protocols were above the smallest worthwhile change threshold was interpreted as a substantial difference.

Results

Figure 1 shows the time course of [HCO₃⁻], pH, and GI symptoms at preingestion and all postingestion time points for all protocols.

Bicarbonate Concentration

Blood [HCO₃⁻] for all experimental ingestion protocols was likely to be substantially greater than that recorded in the placebo trial at almost all time points. The peak blood [HCO₃⁻] (30.9 mmol/L) and the greatest change in [HCO₃⁻] from baseline (6.6 mmol/L) were recorded 150 min after ingestion commenced, with ingestion Protocol 8. Protocol 9 was the least effective protocol, and at each postsupplementation time point there were substantial differences in [HCO₃⁻] between this protocol and the protocol that elicited the peak [HCO₃⁻] at that time point (Figure 1[a]).

pH

The pH for all ingestion protocols was likely to be substantially greater than that recorded in the placebo trial at almost all time points. The peak pH value (7.49) was recorded 120 min postingestion for Protocol 6, and the greatest change in pH from baseline (0.08) was recorded
GI Symptoms

The greatest incidence of GI side effects was recorded 90 min postingestion with Protocol 1. At four of the eight time points, the lowest incidence of GI symptoms was recorded with Protocol 8; substantial improvements were likely comparable to Protocol 1 at 90 min and Protocol 3 at 180 min postingestion, when 1.5 g/kg BM carbohydrate was coingested with the NaHCO₃ dose (Figure 1[c]).

Discussion

The main findings of our study were that peak blood alkalosis can be expected ~120–150 min after commencing ingestion of various protocols involving NaHCO₃ at 0.3 g/kg BM. Among eight different supplement protocols, the lowest incidence of GI distress occurred after the ingestion of NaHCO₃ capsules coingested with 7 ml/kg of fluid and a standardized meal (1.5 g carbohydrate/kg BM), suggesting that the coingestion of a standardized meal is a more important consideration for NaHCO₃ supplementation than fluid volumes or the capsule or solution form of NaHCO₃ used. The highest incidence of GI side effects occurred 90 min after the commencement of ingestion of a NaHCO₃ solution in a small volume of fluid. Our results provide a practical model for ingesting NaHCO₃ before exercise to optimize blood alkalosis and reduce the occurrence of GI symptoms; specifically, the ingestion of the dose should commence 120–150 min before the start of exercise and, if practical, the dose should be coingested with a small meal of carbohydrate-rich food.

The mean peak value for blood [HCO₃⁻] measured in the current investigation was 30.9 mmol/L. This value is similar to the 29.4 mmol/L reported by McNaughton and Cedaro (1991) and the mean 31.5-mmol/L value reported by Brien and McKenzie (1989) after 0.3 g/kg BM NaHCO₃ ingestion. The mean peak change in [HCO₃⁻] above baseline (6.6 mmol/L) was slightly greater than the range (3.2–5.9 mmol/L) given in Matson and Tran’s (1993) meta-analysis of bicarbonate-supplementation studies using a 0.3-g/kg BM dose but similar to values reported by Wilkes et al. (1983; 7.3 mmol/L) and Brien and McKenzie (1989; 6.6 mmol/L) and slightly greater than that found by Potteiger et al. (1996). These peak absolute and change values were found 120–150 min after NaHCO₃ ingestion began.

The peak pH value recorded in this investigation was 7.49, occurring 120 min after the commencement of ingestion of NaHCO₃ capsules with Protocol 6 (capsules ingested over 30 min with the smaller volume of fluid). Wilkes et al. (1983) also reported a preexercise, postinges-
tion value of 7.49, and other studies have found values of 7.40 (Brien & McKenzie, 1989) and 7.48 (McNaughton & Cedaro, 1991; Potteiger et al., 1996) in their experimental (alkalotic) conditions. At the 120-min time point, the greatest change score for pH (0.08) recorded in the current investigation fell in the 0.03–0.09 range given by Matson and Tran (1993) for the typical change in capillary blood pH after supplementation with 0.03 g/kg BM NaHCO₃. The change value recorded in this investigation was also consistent with the 0.09 reported by Wilkes et al. and 0.06 reported by Brien and McKenzie (1989).

It is difficult to compare our current observations for the time course of changes in capillary blood values of [HCO₃⁻] and pH values with the results from other studies in which values are typically provided for pre-ingestion, preexercise, and postexercise rather than at regular intervals. Furthermore, it is often problematic to determine the time from the beginning of ingestion, because the period allowed for participants to ingest the NaHCO₃ is often not reported. However, another investigation in which capillary blood characteristics were monitored every 30 min after ingestion of NaHCO₃ (0.3 g/kg BM) found that that lowest values for hydrogen-ion concentrations were found at 60 and 90 min after the completion of the ingestion protocol, and the greatest acid-base disturbance occurred between 90 and 120 min (Renfree, 2007). There are some similarities between the protocols used in Renfree’s study and our current Protocol 8, which produced the greatest alkalosis but at a later time point. These include the time allowed for bicarbonate ingestion and the volume of coingested fluid. However, differences in our Protocol 8 that may explain a delayed rate of bicarbonate ingestion include the ingestion of a meal and the use of bicarbonate capsules rather than a solution. Potteiger et al. (1996) also reported a comprehensive time course of [HCO₃⁻] and pH after NaHCO₃ ingestion, with blood samples taken at 10-min intervals for 120 min. They found peak pH and [HCO₃⁻] to occur at earlier time points (120 and 100 min, respectively) than in the current investigation (150 and 120 min), and this may also be linked to the food ingestion included in our protocol and not that of Potteiger et al.

Relatively few studies have quantified GI symptoms associated with bicarbonate loading with the use of a validated scale as we did in this investigation. We found that the greatest incidence of GI symptoms for a single protocol was recorded 90 min after the commencement of ingestion of NaHCO₃, yet the lowest incidence of symptoms was 120 min after the commencement of ingestion when NaHCO₃ was coingested with a meal. Van Montfoort et al. (2004) compared Na₃C₆H₅O₇, sodium lactate, and a sodium chloride placebo, using a 10-point scale to describe the severity of two possible symptoms (feeling sick and stomach ache), measured at 30-min intervals from the start of ingestion until 120 min after a performance test. The greatest score for feeling sick was recorded 90 min after the commencement of ingestion, in the sodium chloride condition. Those results are similar to those of the current investigation for nausea (conceptually similar to feeling sick) and for the timing of peak GI side effects, although these were present for several of the NaHCO₃ protocols, as well as for the (sodium chloride) placebo condition. Van Montfoort et al. also reported the greatest incidence of stomach ache 90 min after the completion of performance testing in the Na₃C₆H₅O₇ condition. In our investigation, high ratings of upper abdominal pain, left abdominal pain, and right abdominal pain were recorded for the ingestion protocol using the Na₃C₆H₅O₇–NaHCO₃ combination. Stephens et al. (2002) used a scale on which participants reported their stomach comfort level and bowel-urgency rating on a scale of 1–5; however, details of the frequency of measurement of symptoms or the results of the scale were not given. McNaughton (1992) also gave subjective information on the observation of GI symptoms when doses greater than 0.3 g/kg BM were given in a dose-response investigation. This information is difficult to compare with the results obtained in the current study, because of the lack of detail provided about the timing, type, and severity of any GI distress. Having an appreciation of the time frame for GI-symptom development could help refine ingestion protocols. Ideally a supplementation protocol should be prescribed so that exercise performance coincides with the greatest elevation in [HCO₃⁻] and pH with concurrent lowest incidence of GI symptoms. Based on the results of the current study for ingestion Protocol 8, the balance between optimal blood alkalosis and minimized GI disturbance will be achieved if exercise commences 150 min after ingesting 0.3-g/kg BM NaHCO₃ capsules over 30 min. Although a performance test was not employed in this study, the results can be used to identify supplementation protocols that are practical to use in future studies or in preparation for sporting events. The high incidence of GI symptoms after the NaHCO₃–Na₃C₆H₅O₇ protocol suggests that this protocol was not beneficial. Subjects preferred the use of capsules to the ingestion of a bicarbonate solution. We found few differences between the seven experimental protocols of pure NaHCO₃ ingestion in terms of absolute blood [HCO₃⁻] and pH values and the changes recorded from baseline values. There was also little influence of the manipulation of variables such as coingested fluid volume, the use of capsules or solution, or the ingestion period. However, the ingestion of a meal (1.5 g carbohydrate/kg BM) over the 30-min bicarbonate-ingestion period in Protocol 8 resulted in the greatest bicarbonate value and one of the highest absolute pH values. The lowest incidence of GI side effects was also recorded at four of the eight time points after this protocol.

In conclusion, from the measurement of blood [HCO₃⁻], pH, and GI symptoms in this investigation, we suggest that the best protocol for bicarbonate loading involves the dose 0.3 g/kg BM of pure NaHCO₃ rather than a combination of sodium bicarbonate and citrate, which should be taken 120–150 min before the start of exercise. The supplement should be coingested with a small high-carbohydrate meal to optimize blood alkalosis and reduce the occurrence of GI symptoms.
Acknowledgments

The authors would like to acknowledge the time and efforts of all participants in this study. This project was funded by the University of Western Australia School of Sport Science, Exercise and Health and Sports Nutrition at the Australian Institute of Sport. The authors declare that they have no conflict of interest.

References


