Chapter

Sodium Bicarbonate Ingestion and Exercise: Dosage Revisited

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Abstract

High intensity exercise results in an excess of hydrogen ions and acute, transient reductions in blood and muscle pH. Sodium bicarbonate ingestion is a strategy employed by many athletes to increase the buffering capacity for such hydrogen ions in an attempt to offset acidosis and improve or maintain performance. However, the acute doses used in such scenarios can result in gastrointestinal discomfort. More recent work has considered lower doses and determination of individual peaks in alkalosis. This commentary will overview conventional ingestion strategies and consider a complimentary approach to ingestion dosage in relation to a range of body masses.

Keywords: Alkalosis, performance, high intensity exercise, body mass, gastrointestinal distress

Introduction

This commentary focusses upon factors relating to the dosage of sodium bicarbonate commonly utilized within studies examining its ergogenic potential. The aim is to consider these factors from a different perspective, not only to potentially reduce side effects and inter-individual differences in blood buffer responses but also to stimulate future research approaches. The clinical use of sodium bicarbonate and associated doses of are initially considered and contrasted to those used within the field of sports performance, specifically focusing upon recommended ergogenic doses and recent considerations to maximize buffer capacity with minimal adverse effects.

Clinical background / context

Sodium bicarbonate has been used as a treatment for a number of conditions including; relief of discomfort in mild urinary infections, maintenance of alkaline urine, chronic acidotic states (National Institute for Clinical Health Care Excellence; NICE, 2018), dyspepsia (Thomas and Stone, 1994) and cardiac arrythmias from flecainide toxicity (Goldman et al., 1997) and tricyclic antidepressant overdoses (Bruccoleri and Burns, 2017; Clark and Vance, 1992; Calkins et al., 2003). The typical doses used for a urinary infections range from approximately 5 to 10 grams daily. For example, the NICE (2018) notes an adult dose for; relief of discomfort in mild urinary infections of 3g every two hours until pH exceeds 7.0, daily dose of 5-10g for maintenance of alkaline urine and 4.8g daily for chronic acidotic states. Contraindications for the use of sodium bicarbonate though should be considered including salt-restricted diets and renal impairment along with caution for the prolonged use in a number of conditions eliciting specific side effects. Although little documented toxicity has occurred when ingesting sodium bicarbonate there are reports of sodium bicarbonate overdose in relation to its ingestion for dyspepsia (Thomas and Stone, 1994) and subsequent sources relating to treatment of sodium bicarbonate overdose (DoveMed, nd). However, as discussed in the following section, the use of sodium bicarbonate by *healthy* individuals for its ergogenic potential involves considerably greater acute doses with greater potential for side effects. It may therefore not be surprising that some general medical concerns regarding the use of sodium bicarbonate by athletes and coaches have been noted (National Library of Medicine, nd).

EXERCISE PHYSIOLOGY BACKGROUND / CONTEXT

During all-out high intensity exercise pH typically drops to approximately 6.75 and 7.10 in muscle and blood, respectively (Mendez-Villaneuva et al., 2012, Gaitanos et al., 1991). As the bicarbonate ion (HCO_3^-) is the predominant buffer of hydrogen ions (H^+) in the body (Silverthorn, 1996) it is particularly suited to offsetting the acute and transient acidosis as a result of the accumulation of 'fatiguing' by-products from anaerobic metabolism (i.e. glycolysis). Enhancing the body's buffering capacity to attenuate such metabolic acidosis and the onset of fatigue is therefore an attractive proposal for those individuals undertaking short duration high intensity exercise.

Since the early study of Denning et al (1931) investigating 'the effect of acidosis and alkalosis on the capacity for work' there has been considerable interest in the ergogenic effects of sodium bicarbonate ingestion prior to high intensity exercise. In Denning et al.'s study a participant undertook two treadmill runs at 9.3 $km.hour^{-1}$ (oxygen consumption of 1.96 and 2.52 $l.min^{-1}$, respectively) following sodium bicarbonate ingestion. Resultant blood pH values were 7.46 and 7.47 for each trial representing increases in pH of 0.07 and 0.06 units when compared to 'normal' resting trials (i.e. 7.39 and 7.41), respectively. Although the dose of sodium bicarbonate was not explicitly stated for these alkalosis trials the increases in blood pH are consistent with those expected from a meta-analysis of sodium bicarbonates ergogenic potential over 60s year's later (Motsan and Tran, 1996).

Within the literature pertaining to sodium bicarbonate ingestion and exercise performance the dosages used have ranged between 0.1 and 0.5g.kg body mass (Price et al., 2003, McNaughton et al., 1992; Gaitanos et al., 1991, George and MacLaren, 1988; Horswill et al., 1988). The conventional dose of sodium bicarbonate required for an ergogenic effect in high intensity exercise (0.3g sodium bicarbonate per kg body mass) is based on the data of McNaughton (1992). This study compared sodium bicarbonate doses of between 0.1 and 0.5g per kg body mass on 60 seconds all-out cycle sprint test. The $0.3 g.kg^{-1}$ dose was considered optimal, as no further improvements were observed with larger doses, and minimal gastrointestinal discomfort following ingestion, which increased with larger doses.

As well as optimal dosing of sodium bicarbonate, the optimal time for absorption following ingestion has also been considered (Renfrew, 2008; Price and Singh, 2008). Within the literature absorption periods following ingestion of sodium bicarbonate of between 60 min to three hours have been reported (Price et al., 2003, McNaughton et al., 1992; Gaitano et al., 1991; George and MacLaren, 1988; Sutton et al., 1981). However, following the 0.3 g.kg body $mass^{-1}$ dose of sodium bicarbonate peak blood pH and HCO_3^- concentration and the nadir in H^+ concentration have been reported to range between 60-90 minutes, but remaining elevated above pre-ingestion values for considerable durations (i.e. until the end of measurement duration at 180 minutes). These data suggest individual variation in peak responses exists. Although specific reasons are unknown, it is potentially a result of individual differences in the initial neutralisaton of HCO_3^- by stomach acids and the absorption of HCO_3^- across the small intestine. Indeed, recent data has considered an individualized approach to sodium bicarbonate ingestion by determining individual specific peaks in blood HCO_3^- and pH (Sparkes et al., 2016) and repeating this prior to performance to potentiate maximal performance effects (Gough et al., 2018a; 2018b). Such an individualized approach does indeed appear to be robust with respect to repeatability (Sparkes et al., 2016; Gough et al., 2017).

A potentially important factor in optimizing alkalosis and offsetting gastrointestinal distress, which, to the author's knowledge has not been considered, is the ensuing concentration of each the sodium bicarbonate solution. The conventional dose of sodium bicarbonate has often been administered in a fixed volume of fluid (e.g. 400 ml). In this instance, although the absolute sodium bicarbonate solute is proportional to body mass, the resultant concentration of the solution will differ considerably between individuals. For example, Table 1 shows that for participants ingesting the conventional dose of 0.3 g per kg body mass the concentration of the solution changes markedly with body mass. Such wide ranging drink concentrations may contribute to the inter-individual variation in the magnitude of alkalosis achieved and gastrointestinal side effects, particularly in participants of greater body mass and subsequently larger absolute intakes of bicarbonate. Conversely, participants of lower body mass may not have a sufficient dose for alkalosis to be elicited. However, the effects of such differing concentrations has not yet been reported.

Table 1. Resultant concentration of sodium bicarbonate solutions for a range of body masses using the conventional dose of 0.3 g per kg body mass and 400 ml solution volume. NB molecular weight of sodium bicarbonate taken as 84g.

Body mass (kg)	$NaHCO_3$ mass (g)	Concentration (Moles)
55	16.5	0.491

65	19.5	0.571
75	22.5	0.670
85	25.5	0.759
95	28.5	0.848

Based on our previous research in the area of sodium bicarbonate and performance we took the opportunity to assess the effects of body mass (i.e. absolute dosage of sodium bicarbonate) in relation to changes in blood pH. Data from three studies utilizing the 0.3 g,kg body mass^{-1} dose in a 400 ml solution (Price et al, 2003, Price et al., this volume; Price and Simons, 2010) and unpublished observations were combined for analysis (n=38). All participants were male. In all studies blood pH was measured using an ABL5 Radiometer (Copenhagen, Denmark) from fingertip capillary samples prior to ingestion of sodium bicarbonate and at 30 and 60 min post ingestion. The change in blood pH (delta pH) from pre-ingestion to 30 and 60 min was determined.

Figure 1 shows a significant relationship between body mass and delta pH 60 min following ingestion of sodium bicarbonate. It can be seen that approximately two thirds of participants demonstrated increases of 0.05 pH units or below, and are potentially not ergogenic. Conversely, one third of participants demonstrated increases in blood pH above this level, and thus were potentially ergogenic. Interestingly, for those participants over 85 kg no increases in pH were above the level of 0.05 delta pH after 60 min. To this end, participants were grouped according to body mass (i.e. 55 to 65 kg, 65.1 to 75 kg, 75.1 to 85 kg and >85kg) and the mean delta pH at 60 min considered (Figure 2). Here, a linear increase in delta pH with body mass up to 75 kg was observed (ANOVA, P=0.076). Interestingly, the heaviest group elicited the same increase in pH as the lightest group ($P<0.05$). It is possible that both groups were limited in their bicarbonate absorption but for different reasons. The heavier group may been limited due to sub-optimal conditions for absorption of HCO_3^- in the gut whereas the lighter group may not have had a large enough dose to elicit effective alkalosis. Indeed many participants in the lighter group demonstrated a delta pH of under 0.03. It is also quite possible that both groups may also have peaked prior to or after the 60 min time period measured. To examine the latter point, values for delta pH at 30 and 60 min for each group are shown in Figure 3. With the exception of the >85kg group, all groups blood pH increased from 30 min to 60 min post ingestion. This figure shows that the heavier group (with the greatest absolute dose of sodium bicarbonate) peaked at 30 minutes with values then decreasing. Indeed this was true for 4/6 participants (67%) whereas for the 55.0-65.0 kg, 65.1-75.0 kg, and 75.1-85.0 kg groups this response occurred in only 1/8 (12.5%), 4/11 (36%) and 0/11 (0%), respectively. Furthermore, within the >85kg group, all but two participants achieved increases in pH of over 0.06 at 30 min, likely due to larger dose ingested. In contrast the lightest group (55.0-65.0 kg) demonstrated the lowest increases at 30 min post ingestion.

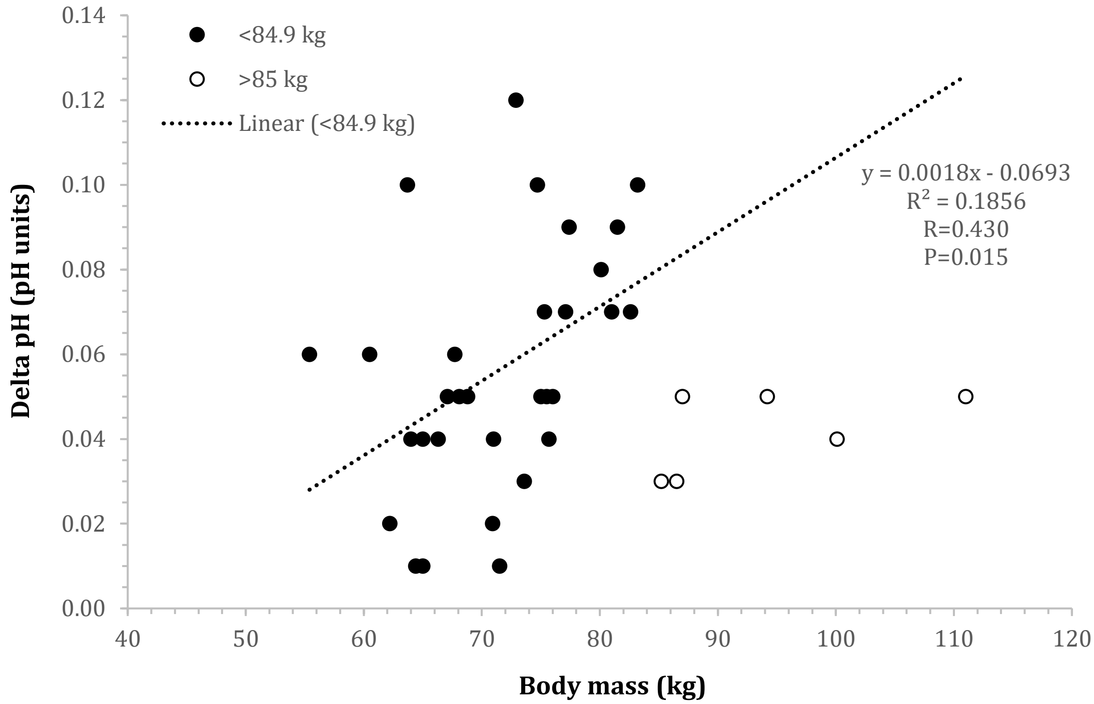

Figure 1. Change in blood pH (delta pH) over 60 min following ingestion of 0.3g.kg body mass^{-1} sodium bicarbonate in 400ml of fluid. Regression line represents relationship between delta pH and body mass in those participants under 85 kg body mass.

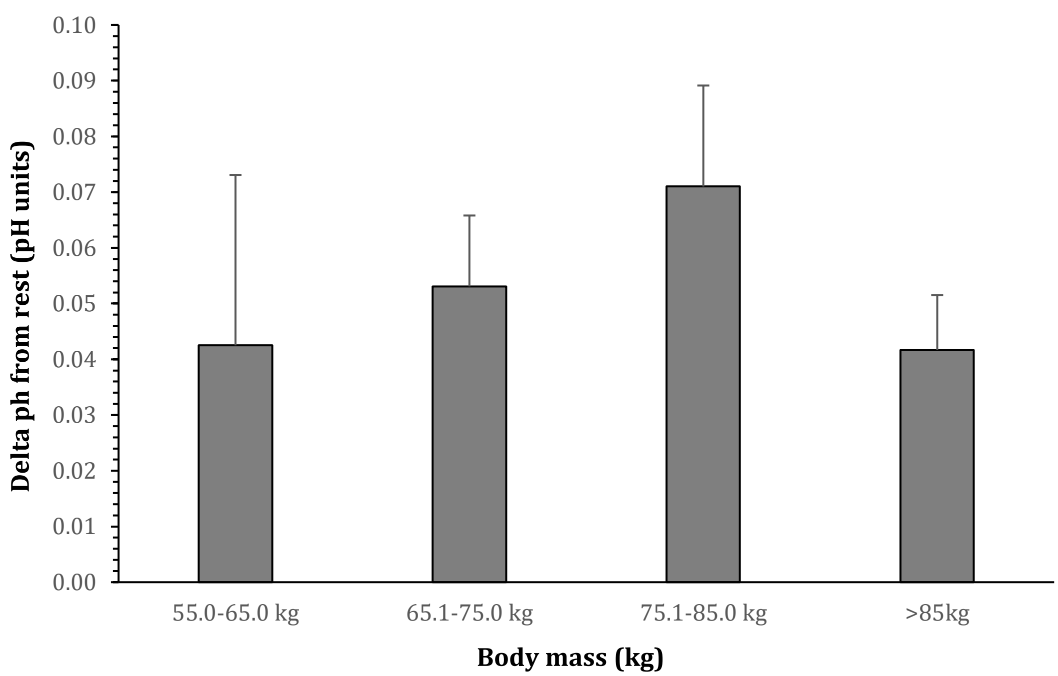

Figure 2. Change in blood pH (delta pH) 60 min following ingestion of 0.3g.kg body mass^{-1} sodium bicarbonate for the four body mass groups.

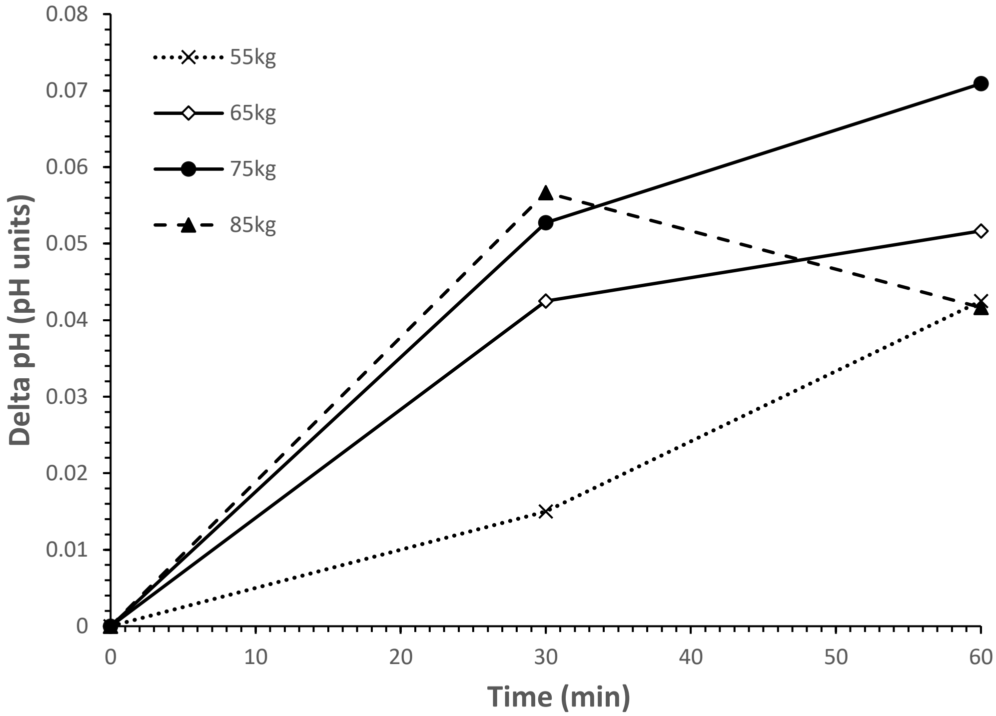

Figure 3. Change in blood pH (delta pH) 30 and 60 min following ingestion of 0.3g.kg body mass^{-1} sodium bicarbonate for the four body mass groups. NB: Standard deviation bars omitted for clarity.

When considering the accepted optimal dose of 0.3 g.kg body mass^{-1} our retrospective analysis supports this for the 75.1 to 85.0 kg group due to the greatest delta pH achieved and most consistent responses across participants from baseline to 30 min and subsequently 60 min values. Based on this finding where a fixed fluid volume of 400 ml is used it is possible that the most optimal solution concentration is represented by that of the 75.1 to 85.0 kg group of 0.714 M (using an average body mass of 80kg for that group). This mass is similar to that of the participants in the study of McNaughton (1992) and many subsequent studies. Therefore, for groups of heavier and lighter body mass outside of the original optimization study, lower and greater doses of sodium bicarbonate may be required, respectively. Although this adjustment in dose may help to reduce gastrointestinal distress in heavier participants there is the caveat of increasing the potential for discomfort in lighter participants. Lighter groups could consider longer absorption times for individual peaks to be achieved when using smaller absolute amounts of sodium bicarbonate or ingest repeated smaller aliquots of solution. Where the effects of sodium bicarbonate have been investigate in females body masses typically relate to the 55 to 65 kg group (Bishop and Claudius, 2005; McNaughton t al., 1997; Tiryaki et al., 1991). Therefore, future research should consider ingestion strategies for sodium bicarbonate for different body masses. For larger body masses, the potential for a maximal upper limit of ingestion (e.g. 24 g) may be considered.

CONCLUSIONS AND RECOMENDATIONS FOR FUTURE RESEARCH

In conclusion, both traditional and more recent approaches to optimizing alkalosis through sodium bicarbonate ingestion doses may be enhanced by considering the total mass of sodium bicarbonate ingested in relation to the concentration of the solution consumed. Although this has been partially addressed by using both fluid volumes and sodium bicarbonate doses proportional to body mass (Price and Cripps, 2007; Higgins et al., 2013) future work should directly compare these approaches. Gastrointestinal distress should also be considered to more fully assess efficacy. Being able to standardize the increase in pH and timing of sodium bicarbonate ingestion with such practices would be extremely beneficial to the athletic population.

REFERENCES