Practical Considerations for Bicarbonate Loading and Sports Performance

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Abstract
Consumption of sodium bicarbonate (300 mg/kg 1–2 h before exercise) can temporarily increase blood bicarbonate concentrations, enhancing extracellular buffering of hydrogen ions which accumulate and efflux from the working muscle. Such ‘bicarbonate loading’ provides an ergogenic strategy for sporting events involving high rates of anaerobic glycolysis which are otherwise limited by the body’s capacity to manage the progressive increase in intracellular acidity. Studies show that bicarbonate loading strategies have a moderate positive effect on the performance of sports involving 1–7 min of sustained strenuous exercise, and may also be useful for prolonged sports involving intermittent or sustained periods of high-intensity work rates. This potential to enhance sports performance requires further investigation using appropriate research design, but may be limited by practical considerations such as gut discomfort or the logistics of the event. The effect of chronic use of bicarbonate supplementation prior to high-intensity workouts to promote better training performance and adaptations is worthy of further investigation. While this relatively simple dietary strategy has been studied and used by sports people for over 80 years, it is likely that there are still ways in which further benefits from bicarbonate supplementation can be developed and individualized for specific athletes or specific events.

Introduction
Bicarbonate is an extracellular anion with important roles in maintaining pH and electrolyte gradients between intra- and extracellular environments. Consumption of large amounts of bicarbonate can temporarily increase blood bicarbonate concentrations and pH, enhancing extracellular capacity to dispose
of hydrogen ions which accumulate and efflux from the working muscle [1]. Such ‘bicarbonate loading’ provides an ergogenic strategy for sporting events involving high rates of anaerobic glycolysis which are otherwise limited by the body’s capacity to manage the progressive increase in intracellular acidity. Although the direct role of hydrogen ion accumulation in muscle fatigue is unclear [2], there is evidence dating back to the 1930s that dietary strategies that decrease blood pH (e.g. intake of acid salts) impair the capacity for high-intensity exercise, while alkalotic therapies such as the intake of bicarbonate improve such performance [3]. This review provides an update on the practical issues involved in bicarbonate loading for sports performance and raises questions that are as yet unanswered.

**Acute Loading Protocols**

The most common bicarbonate loading technique is to ingest an acute dose in the hours before the targeted exercise session. Ideally, sufficient bicarbonate is consumed at the optimal time to create a meaningful increase in blood bicarbonate concentrations and buffering capacity. A cheap and widely available form of bicarbonate is the common household/cooking product, sodium bicarbonate, with the typical dose being 300 mg per kg of the athlete’s body mass (BM; i.e. ∼20 g for a 70-kg athlete) consumed 1–2 h prior to exercise. Many athletes find, however, that a mixture of 4–5 tsp of sodium bicarbonate in water or other fluids is unpalatably salty. Alternative options include pharmaceutical alkalizer products: powders, capsules or tablets which have been developed to relieve the discomfort associated with urinary tract infections. Citrate has also been used as a buffering agent. However, since it appears to be less effective in enhancing performance and is associated with a greater risk of side effects [4], it will not be discussed further in this review.

The major side effect of bicarbonate supplementation is gastrointestinal (GI) distress including nausea, stomach pain, diarrhea and vomiting [1]. Indeed, sports scientists often observe that bicarbonate loading is not practiced by athletes who could potentially benefit from an enhanced buffering capacity in a competitive setting due to the fear or personal experience of such GI upsets. Previous advice to athletes to overcome this issue was to consume the bicarbonate dose with plenty of fluids to reduce the risk of hyperosmotic diarrhea. A recent study systematically investigated bicarbonate supplementation protocols, varying the time taken to consume the load (spreading it over 30–60 min), the form of the bicarbonate (flavored powder or capsules) and the coingestion of various amounts of fluid or food with the bicarbonate [5]. The strategy that
optimized blood alkalosis and reduced the occurrence of GI symptoms was to consume bicarbonate capsules in a spread-out protocol, commencing 120–150 min before the start of exercise and, if practical, at the same time as consuming a meal composed of carbohydrate-rich food choices and some fluid. Athletes should practice with such strategies to fine-tune a successful protocol for their situation [5].

Even if gut issues can be overcome, athletes should consider the potential for other practical problems associated with bicarbonate loading. Loading with sodium bicarbonate involves the intake of a large amount of sodium, which when consumed with fluid can lead to a temporary fluid retention or hyperhydration. This may be useful in some sports in which high rates of sweat loss will otherwise lead to a significant fluid deficit. On the other hand, the gain in BM may be unwelcome to athletes in weight-bearing sports or weight-category sports. Another potential disadvantage of bicarbonate loading is when the athlete is selected for a post-event doping test. Although bicarbonate loading is a legal strategy in competitive sport, it can produce urine with a pH that falls outside the range that is acceptable for laboratory testing. The athlete may be required to wait several hours before he/she can produce a urine sample with pH levels that are acceptable to drug testing authorities. This may cause some disruption to the athlete’s recovery routines.

Benefits for Sports Performance

Theoretically, bicarbonate loading could be ergogenic for sporting events which are limited by high rates of generation of energy via anaerobic glycolysis. The obvious candidates are events involving sustained high-intensity exercise lasting 1–7 min (‘sustained power’ sports), such as middle-distance swimming, middle-distance running and rowing events. However, bicarbonate loading may also benefit the performance of longer events (e.g. 30–60 min) involving sustained exercise just below the so-called anaerobic threshold if it can support the athlete for periods in which the pace is increased (i.e. surges during the event, the final sprint to the end). Similarly, the repeated-sprint performance typical of team and racquet sports, and even combative sports, may also be enhanced by improved buffering.

Over the past 40 years, sports scientists have investigated this potential in a large number of studies with various levels of application to real-life sport. Ideally, research that is of interest to athletes would involve highly trained competitors, exercise protocols with high reliability and ecological validity, and implementation of competition nutrition strategies that simulate real-world
practices [6]. Although few studies achieve all these characteristics, table 1 summarizes the results of some relevant investigations of bicarbonate supplementation and sports performance published in the last decade. This summary shows that there is reasonable but not unanimous support for the benefits of bicarbonate loading for each of the sporting scenarios previously mentioned.

Nevertheless, reviews of the larger body of literature have concluded in different ways that bicarbonate loading can be of benefit to some athletes, particularly the so-called power events. An early meta-analysis [7] concluded that the ingestion of sodium bicarbonate has a moderate positive effect on exercise of 30 s to 7 min, with the mean performance of the bicarbonate trial being 0.44 standard deviations better than the placebo trial. Ergogenic effects were related to the level of metabolic acidosis achieved during the exercise, showing the importance of attaining a threshold pH gradient across the cell membrane from the combination of the accumulation of intracellular H+ and the extracellular alkalosis. Requena et al. [8] undertook a narrative review which concluded that athletes competing in high-intensity sports involving fast motor unit activity and large muscle mass recruitment (athletics events, cycling, rowing, swimming and many team sports) could benefit from bicarbonate loading.

Finally, a recent comprehensive meta-analysis [4] of 38 studies and 137 estimates of the effect of blinded sodium bicarbonate supplementation on exercise outcomes quantified the mean effects of performance. It found a possibly moderate performance enhancement of 1.7% (90% confidence limit ± 2.0%) with a typical dose of ~0.3 g/kg BM) in a single 1-min sprint in male athletes. Study and subject characteristics had the following modifying small effects: an increase of 0.5% (±0.6%) with a 0.1 mg/kg BM increase in dose; an increase of 0.6% (±0.4%) with five extra sprint bouts; a reduction of 0.6% (±0.9%) for each 10-fold increase in test duration (e.g. 1–10 min); reductions of 1.1% (±1.1%) with non-athletes and 0.7% (±1.4%) with females. The only noteworthy effects involving physiological variables were a small correlation between performance and pre-exercise increase in blood bicarbonate [4].

**Alternative Ways to Use Bicarbonate in Sport**

A variation of the acute loading regime is to ‘serially’ load bicarbonate in small doses over consecutive days prior to a competitive event or race. Initial studies demonstrated that several days of such dosing (500 mg/kg BM spread into 3–4 separate doses over the day) builds up blood buffer levels that persist for at least 24 h after the last dose and with fewer gut symptoms [9]. Theoretically, this protocol could be used to achieve a loading preparation for multiple events over the
Table 1. Crossover studies of acute bicarbonate supplementation prior to sports-specific performance test in trained individuals (2002–2012)

<table>
<thead>
<tr>
<th>Subjects and study</th>
<th>Dose of sodium bicarbonate</th>
<th>Sports performance</th>
<th>Enhancement</th>
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</tr>
</thead>
<tbody>
<tr>
<td>8 highly trained male swimmers [11]</td>
<td>300 mg/kg per day 105–90 min before trial</td>
<td>Swimming 200-meter TT followed by a further TT 24 h later</td>
<td>Immediate TT – no TT 24 h later – no</td>
<td>No enhancement of TT performance compared with placebo (1:59.57 ± 0:06.21 vs. 1:59.02 ± 0:05.82) and no difference in further TT after 24 h suggested that highly trained athletes may already have enhanced muscle buffering capacity and benefit less from bicarbonate loading.</td>
</tr>
<tr>
<td>10 elite moto-cross (BMX) cyclists [12]</td>
<td>300 mg/kg 90 min before trial</td>
<td>BMX simulation 3 × 30-second cycling Wingate tests with 15-min recovery Counter movement jump</td>
<td>No</td>
<td>Authors concluded that test protocol may not have produced sufficient H⁺ efflux to benefit from additional buffering.</td>
</tr>
<tr>
<td>8 well-trained rowers [13]</td>
<td>300 mg/kg and/or 6 mg/kg caffeine before trial</td>
<td>Rowing 2,000-meter ergometer TT</td>
<td>No</td>
<td>Performance was enhanced by ~2% with caffeine, but GI symptoms associated with bicarbonate counteracted this leading to unclear performance outcome.</td>
</tr>
<tr>
<td>20 male cyclists [14] Parallel group design for β-alanine with crossover for bicarbonate</td>
<td>300 mg/kg before trial and/or 4 weeks at 6.4 g/day β-alanine</td>
<td>Cycling TTE at 110% power max</td>
<td>Perhaps</td>
<td>β-Alanine enhanced cycling capacity. Addition of bicarbonate increased TTE by 6 s (4% increase), which did not reach statistical significance, but according to magnitude-based inferences has a 70% probability of being a meaningful improvement.</td>
</tr>
<tr>
<td>25 male rugby players [15]</td>
<td>300 mg/kg 65 min before warm-up</td>
<td>Rugby Union Rugby-specific repeated sprint test after 25-min warm-up + 9-min rugby-specific play</td>
<td>No</td>
<td>No difference in performance of rugby-specific test between trials. High risk of gut side effects reported that may impair performance.</td>
</tr>
<tr>
<td>9 collegiate male tennis players [16]</td>
<td>300 mg/kg before and 100 mg/kg during exercise</td>
<td>Tennis Simulated tennis match with Loughborough Tennis skill test performed before and after</td>
<td>Yes</td>
<td>Consistency scores for a number of strokes declined significantly after match with placebo, but were maintained in the bicarbonate trial.</td>
</tr>
<tr>
<td>12 elite female water polo players [17]</td>
<td>300 mg/kg before exercise</td>
<td>Water polo 59-min match simulation with 56 × 10-meter sprint swims</td>
<td>No</td>
<td>Percentage difference in mean sprint times with bicarbonate vs. placebo was not substantial (0.4 ± 1.0, p = 0.51).</td>
</tr>
<tr>
<td>10 male amateur boxers [18]</td>
<td>300 mg/kg before exercise</td>
<td>Boxing Sparring: 4 × 3-min rounds with 1-min recovery</td>
<td>Yes</td>
<td>Significant increase in punches successfully landed in bicarbonate trial.</td>
</tr>
<tr>
<td>6 male and 8 female competitive swimmers [19]</td>
<td>300 mg/kg before exercise</td>
<td>Swimming 8 × 25 m with 5-second recovery (simulation of 200-meter race controlled for variability in turns)</td>
<td>Yes</td>
<td>Total swim time was 2% faster in the bicarbonate trial (159.4 ± 25.4 vs. 163.2 ± 25.6 s; p &lt; 0.04).</td>
</tr>
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<tr>
<td>6 elite male swimmers [20]</td>
<td>300 mg/kg spread 120–30 min before trial 6 mg/kg caffeine 45 min before trial</td>
<td>Swimming 2 × 200-meter TT on 30-min recovery</td>
<td>No, for a one-off 200-meter TT Yes, for repeat 200-meter TTs</td>
<td>Bicarbonate enhanced performance, with and without caffeine on repeat performance. Effect was less evident for a single effort.</td>
</tr>
<tr>
<td>9 elite male BMX riders [21]</td>
<td>300 mg/kg 90 min before trial</td>
<td>BMX simulation 3 × 30-second cycling Wingate tests with 30-min recovery</td>
<td>No</td>
<td>Authors concluded that test protocol may have been too short and recovery period too long to sufficiently challenge buffering capacity.</td>
</tr>
<tr>
<td>9 elite male swimmers [22]</td>
<td>300 mg/kg spread 90–60 min before trial</td>
<td>Swimming 200-meter TT</td>
<td>Yes</td>
<td>Swimming TT with bicarbonate trial was 1.6% faster than placebo trial in internationally competitive swimmers.</td>
</tr>
<tr>
<td>4 female and 12 male national level endurance runners [23]</td>
<td>300 mg/kg 120–90 min before trial</td>
<td>Running 1,000-meter track run</td>
<td>Perhaps – but due to belief effect?</td>
<td>Fastest run when told and received bicarbonate (184.7 ± 24.1 s) with next best time when told they had received active agent but did not receive it (185.1 ± 22.1 s). Times when told no active agent were similar despite receiving bicarbonate (188.5 ± 24.4 s) or not (187.9 ± 22.4 s). Overall, the only statistically significant effect was a main effect of being told they had received an active agent.</td>
</tr>
<tr>
<td>9 national level judo athletes [24]</td>
<td>300 mg/kg 120 min before trial</td>
<td>Judo Three judo-specific throwing fitness tests on 5-min recovery</td>
<td>Yes</td>
<td>Bicarbonate supplementation increased total throws completed, primarily in bouts two and three. Greater mean power with bicarbonate supplementation in bouts three and four and greater PPO in bout four.</td>
</tr>
<tr>
<td>14 national level judo athletes</td>
<td>300 mg/kg 120 min before trial</td>
<td>Four Wingate anaerobic upper body tests on 3-min recovery</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>7 female team sports players [25]</td>
<td>2 × 200 mg/kg 90 and 20 min before exercise</td>
<td>Team sport simulation Intermittent cycling protocol of 2 × 36-min ‘halves’ involving repeated 2-min blocks (all out 4-second sprint, 100-second active recovery at 35% VO2peak and 20 s of rest)</td>
<td>Yes</td>
<td>Bicarbonate supplementation failed to produce any effect on performance in first half, but caused trend towards improved total work in the second half (p = 0.08). In particular, subjects completed significantly more work in 7 of 18 4-second sprints in second half in the bicarbonate trial.</td>
</tr>
<tr>
<td>15 competitive male distance runners [26]</td>
<td>300 mg/kg 90–180 min before race</td>
<td>Running Treadmill run to exhaustion at speed designed to last 1–2 min</td>
<td>Yes</td>
<td>Analysis estimated likelihood of treatments increasing endurance compared to placebo by at least 0.5% (smallest worthwhile improvement). Bicarbonate produced 2.7% enhancement of endurance (96% chance of improvement)</td>
</tr>
</tbody>
</table>
same/successive days or to time doses to avoid high-risk periods for gut upsets (i.e. acutely before, or even day of, exercise). Unfortunately, there are few studies of the effectiveness of this protocol on sports performance, and investigations in trained individuals are welcomed.

Another line of investigation is the chronic use of bicarbonate to support the training process rather than competition performance. Edge et al. [10] studied the effects of chronically loading with bicarbonate (400 mg/kg BM) prior to interval training sessions (3/week) over an 8-week training block in moderately trained female athletes. The bicarbonate-supplemented group showed substantially greater improvements in both lactate threshold (26 vs. 15%) and time to exhaustion (164 vs. 123%) than a placebo group. The authors speculated that

Table 1. Continued

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<tr>
<td>8 male + 8 female national level swimmers (27) (30-day washout)</td>
<td>300 mg/kg, 120 min before exercise (6 days at 20 g/day creatine also taken prior to bicarbonate trial)</td>
<td>Swimming 2 × 100-meter swims with 10-meter passive recovery</td>
<td>Yes (?)</td>
<td>Faster time for second swim with creatine/bicarbonate trial than with placebo: 1-second reduction in performance from first swim in placebo compared with 0.1-second drop-off in supplement trial (p &lt; 0.05). Study unable to indicate individual effect of bicarbonate.</td>
</tr>
<tr>
<td>8 active male runners (28)</td>
<td>300 mg/kg 1 h before exercise</td>
<td>Team sport simulation: Intermittent cycling protocol of 30 min involving repeated 3-minute blocks (90 s at 40%, 60 s at 60% VO2_max and 14 s at maximal sprint)</td>
<td>Yes</td>
<td>Significant main effect with greater PPO achieved in 14-second sprints across protocol in bicarbonate trial, whereas placebo trial showed gradual decline in PPO across time. Blood lactate levels higher than is generally reported in team sports; thus, movement patterns may not reflect the true workloads or physiological limitations of team sports.</td>
</tr>
<tr>
<td>7 female and 3 male collegiate swimmers (29) Dose-response design</td>
<td>100, 200 or 300 mg/kg 60 min before TT (45 min before warm-up)</td>
<td>Swimming 100- to 400-meter TT depending on main event, short course pool</td>
<td>Yes at all doses</td>
<td>Swimmers improved TT performances at all doses: compared with control, times were 97.0 ± 1.27% for 0.1 g/kg, 98.19 ± 1.75% for 0.2 g/kg and 99.10 ± 1.02% for 0.3 g/kg, all p &lt; 0.05. Side effects increased with increasing dose.</td>
</tr>
<tr>
<td>6 well-trained male cyclists/ triathletes and 1 cross-country skier (30)</td>
<td>300 mg/kg 2 h before exercise</td>
<td>Cycling 30 min at 77% VO2_max + TT (∼30 min)</td>
<td>No</td>
<td>Increase in blood lactate but no difference in TT performance time, muscle glycogen utilization or lactate.</td>
</tr>
</tbody>
</table>

Adapted from Burke et al. [6] with studies listed in reverse chronological order of date of publication. LT = Lactate threshold; PO = power output; PPO = peak power output; TT = time trial.
training intensity rather than accumulation of hydrogen ions is important in increasing endogenous muscle buffering capacity, and that buffering protocols may reduce damage to muscle proteins [11]. This also warrants further investigation.

Conclusions

Although there is a large body of literature spanning nearly 80 years which shows general support for the use of bicarbonate loading to aid performance of sustained high-intensity sports, there are still many questions or issues that require clarification and further investigation:

1. Best protocols for acute (or serial) bicarbonate loading to enhance blood buffering capacity and minimize the risk of GI upsets.
2. Individual variability in the response to bicarbonate loading in trained individuals: effect of caliber of athlete, training history, sex, practice to develop gut tolerance.
3. Protocols to accommodate warm-up involving high-intensity pieces or longer event interspersed with high-intensity periods and repeated sprints.
4. Protocols to accommodate events with several bouts in a short period, for example several races on the same program or heats/semis/finals within 6–24 h.
5. Combination with other evidence-based supplements – e.g. caffeine, nitrate, creatine, β-alanine. Are the benefits additive, counteractive or synergistic?
6. Chronic application of bicarbonate loading to enhance training adaptations to interval training.

Disclosure Statement

The author has no conflicts of interest.
References

Questions and Answers

**Question 1:** So Dr. Burke, what side effects can be expected from using bicarbonate prior to competition?

**Answer:** Well, many athletes have unfortunate side effects in the form of gut problems that can range from burping and feeling a little bit squeamish in the stomach right through to vomiting and diarrhea. This is not a good look and may also be performance impairing.

**Question 2:** Is there a benefit to using sodium bicarbonate as a training aid?

**Answer:** It could be useful to try and support the training session to allow the athlete to train harder, but also to reduce some of the negative side effects of having a high acidity in the muscle so you may get less damage to the muscle and a better training outcome in the long-term.

**Question 3:** So what is your practical recommendation for athletes to use this substance?

**Answer:** It’s tricky as we have changed our mind over the last 5–10 years. We think there is probably room for doing it in competition as long as the athlete can practice with it and learn to tolerate the gastric side effects. The training side of things has good hypothetical support, but it is a bit messy and logistically difficult for an athlete to bicarb load before many individual training sessions, so maybe looking for a more chronically applied buffer for the training support is a better way to go.

**Question 4:** A lot of athletes are now using β-alanine. What do you think about this?

**Answer:** That’s the chronically applied buffer I was talking about. It’s a supplement that can improve the muscle’s internal buffering capacity by chronically increasing muscle stores of the cellular buffer carnosine. Once loading has been achieved it could assist each training session. On competition day, you could also...
consider adding bicarbonate loading. This could result in both the internal and external buffering system being improved, and the combined outcome could be beneficial.

**Question 5:** Is there a specific amount which you recommend for athletes if they use the sodium bicarbonate and β-alanine?

**Answer:** When we are working with bicarbonate, the typical dose is around 300 mg or 0.3 g for every kg of body weight; for me it would be something like 15 g of bicarbonate, for a 70-kg athlete about 20 g, which is quite a large dose. But we certainly play around with that because there are different ways in which athletes might need to use it, particularly if you are in a sport in which you might need to compete more than once. So, if you’ve got heats and finals of an event, you might use one dose for the first application, and then you might need to alter the dose for the second application. It’s one of those things that are important to work through with a sports scientist in training, so that you can get the protocol that works right for you in competition.

**Question 6:** What about β-alanine?

**Answer:** β-Alanine is a chronically consumed supplement; something that you take every day and our initially used doses were about 3–4 g per day, for 10 weeks. We now think you can achieve a faster loading with 6–8 g per day for 4 weeks, then perhaps reduce it to 2 or 3 g per day. Ideally, spread you should those doses out over the day and use sustained-release formulations, so that you’d get the minimization of the prickly sensation that can happen when you take a β-alanine, supplement.

**Question 7:** Is β-alanine of relevance for athletes like weightlifters, or just for endurance sports?

**Answer:** It’s important for athletes doing high-intensity work, where there’s an accumulation of the hydrogen ions, and the acidity builds up in the muscle. That could be for people doing intermittent high intensity work or doing single sessions at sustained high intensities for 2–8 min. For many athletes, training will incorporate those sort of session; so, it could be a training aid for a whole range of sports as well as for those athletes that deal with the very high intensity work as their sporting performance outcome.

**Question 8:** What is the difference between creatine and β-alanine because a lot of studies are now using both supplements? What’s the benefit or why do they combine both supplements?

**Answer:** When you take creatine as a supplement, you build up the phosphocreatine stores in the muscle which provide a fuel source for exercise. β-alanine supplementation is trying to build up muscle carnosine, which may help your ability to exercise for longer before the muscle starts to fatigue. Thus,
in one case you’ve got a fuel, and in the other case you’ve got the environment that allows muscle fuel to be used at high intensities for a longer period. Of course we are also beginning to lean that muscle carnosine has other important activities that could also enhance exercise performance. Future studies may identify new benefits.