Exercise Physiology Corner:

Blood buffering

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Ingestion of alkalizing buffering agents (primarily NaHCO₃) has become a popular strategy for improving exercise endurance, despite the fact that a great deal of confusion exists over what effects these buffering agents have on metabolism, fatigue and exercise performance. In addition, it is possible that dietary factors other than NaHCO₃ may affect acid-base balance of the blood. The objective of this article is fourfold: (1) Discuss factors that may affect acid-base balance of the blood and cell; (2) Discuss the effects acid-base balance may have on metabolism during exercise; (3) Discuss what effect acid-base balance has on exercise performance; and (4) Discuss any possible contraindications to sodium bicarbonate ingestion.

Factors that Affect Acid-Base Balance

The body’s primary defense against disturbances in acid-base balance are the blood buffers. Blood protein, hemoglobin and bicarbonate play, quantitatively, the largest role. Training does not affect the buffering capacity of the blood (27). The most important buffers within skeletal muscle are protein-bound histidyl residues, histidine-containing dipeptides and free histidine (24). Carnosine may be another important buffer within the muscle. Both carnosine levels and total buffering capacity of skeletal muscle are higher in sprint-trained athletes than in endurance trained athletes and untrained controls indicating high-intensity training may affect muscle carnosine and total muscle buffering capacity (24).

The first clinical observations of acid-base abnormalities occurred during the 1831 cholera epidemic in London (4). Excessive losses of carbonate of soda were found in the diarrhea of the cholera victims. Since then a large number of factors have been identified that will upset acid-base balance in the body.

As was suggested from the cholera observation, extended diarrhea causes large losses of base and leads to acidosis. The reverse can also occur. When severe vomiting occurs, large amounts of acid are lost from the stomach and alkalosis can result. Chronic renal insufficiency can also lead to acidotic states (4).

The disrupted carbohydrate metabolism found in uncontrolled diabetes leads to an acidosis caused by an accumulation of ketone bodies (1). A similar situation occurs in starvation; acidosis occurs due to an accumulation of ketones following a caloric deficit (4).

Both ingestion and parenteral administration of NaHCO₃ has long been used clinically to successfully treat many of these acidotic conditions. In addition, a number of investigators have used NaHCO₃ to induce alkalosis in normal subjects (5, 6, 8, 14, 15, 16, 17, 18, 20, 22, 25, 28, 30). Some used a set amount of NaHCO₃; as little as 0.75 gram in one study (28), and as much as 20 grams in another study (30). Most, however, based the dosage on body weight, varying...
from 0.065 to 0.5 gram NaHCO₃ per kilogram body weight (5, 8, 14, 15, 17, 20, 22, 25, 28). One study was concerned with observing what effects manipulation of the dose and the time span in which NaHCO₃ was administered has on acid-base balance of the blood (14). First it was found that the greatest change in acid-base balance of the blood occurred two to four hours after administration of an oral dose of NaHCO₃. After four hours, the blood gradually became less alkaline and, after 24 hours, only 40 percent of the increase seen at four hours was still present in the blood. It was also found that when the NaHCO₃ dosage was divided into two equal administrations, one 12 hours after the initial administration, a greater increase in alkalinity was seen. Second, three doses of NaHCO₃ were compared (0.065, 0.13, and 0.26 gram NaHCO₃ per kilogram body weight). The most alkaline blood was seen in the highest NaHCO₃ administration (base excess 4.4 and pH 7.47), but the low NaHCO₃ dose (base excess 3.5 and pH 7.45) demonstrated only slightly less alkaline blood.

Diet also plays a role in acid-base balance of the blood. It has long been known that a carnivorous diet causes the urine to be acidic. Foods high in acidic ash, such as meats, and low in alkaline ash, such as most vegetables, could at least partially be responsible for an increase in acid in the urine. In addition, it appears that endogenous acid production from metabolism is a function of sulfate-containing amino acids and organic anions (4). This endogenous acid production has been shown to affect the acid-base balance of the blood (4). Therefore, a diet high in acidic sulfur-containing amino acids should cause the blood to be more acidic. Observations of the chronic acid-base balance of vegetarians and meat eaters revealed that the vegetarians' blood was more alkaline than the meat eaters (14). Experiments comparing the effects of high protein-fat diets with high carbohydrate diets demonstrate clearly that individuals consuming a diet high in carbohydrate and low in fat (60 percent carbohydrate, 24 percent fat and 16 percent protein) have more alkaline blood than those individuals consuming a diet high in protein-fat and low in carbohydrate (20 percent carbohydrate, 49 percent fat and 31 percent protein) (14). It is impossible to determine whether the differences in acid-base balance were due to alterations in dietary fat or protein or both fat and protein. However, the effects that sulfur-containing amino acids have on endogenous acid production indicate that the protein intake may be at least partially responsible.

Acid-base Balance and Metabolism

It is well documented that changes in acid-base balance do not affect submaximal oxygen uptake (7, 9, 16, 20, 29, 30). Thus the amount of energy needed to perform a task would neither be increased nor decreased by increasing the buffering capacity of the blood. Maximal oxygen uptake also does not seem to be changed by NaHCO₃ ingestion (13, 20), but does seem to be decreased after NH₄Cl ingestion during incremental exercise tests (7, 9, 16, 20, 30). The decrease in maximal oxygen uptake seen in acidosis is thought to be caused by the decrease in peak power output during the incremental exercise. Subjects became fatigued and discontinued the test prior to reaching work levels that would elicit VO₂ max. Presumably no increase in maximal oxygen uptake was seen in the alkalotic versus control conditions, because the subjects were able to reach maximal oxygen uptake prior to stopping the test because of fatigue during the control condition. It appears that acid-base balance of the blood has little effect on maximal metabolic rate as long as the subjects are not forced to stop the test prior to reaching maximal capacity because of fatiguing preliminary work.

Blood lactate levels are very closely related to the acid-base balance of the blood, with lower pH associated with higher lactate. This will occur during rest, during exercise and following both submaximal and maximal exercise. It is unclear whether blood alkalosis directly affects muscle cell acid-base balance, thus increasing the cell's potential for anaerobic glycolysis, or whether efflux of lactate from the muscle cell is increased in more alkalotic conditions. Some controversy exists over whether bicarbonate can readily cross the muscle cell membranes. In order for ingestion of NaHCO₃ to have a direct effect on cell metabolism, the bicarbonate would obviously have to enter the cell. Some investigators have proposed that increasing the bicarbonate will have little or no effect on the acid-base balance of the muscle cell (3, 10), while others have estimated substantial changes in pH of the muscle cell when the acid-base balance of the blood is altered (2, 11). If bicarbonate is able to enter the muscle cell and increase buffer within the cell, the potential for production and use of energy should be maintained longer during high-intensity H⁺-producing exercise. Even if significant amounts of bicarbonate are not able to enter the muscle cell, an increased rate of flux of lactate from the muscle cell should facilitate a greater decrease in intracellular H⁺, forestalling muscle cell acidosis during H⁺-producing exercise. Though it has been found that there is not a direct relationship between lactate flux and


H+ flux from the muscle cell during non-steady-state exercise (20), it is evident that a more alkaline blood will increase the efflux of lactate and H+ (12, 21). In either case, increases in blood bicarbonate could affect H+ content within the exercising and recovering muscle cell.

Blood lactate levels are the result of both efflux from cells and uptake into cells. Therefore, increases in blood lactate could be caused by either an increase in the efflux, a reduction in uptake, or a combination of efflux and uptake. Increases in blood lactate due to increased efflux would be associated with increased energy production from anaerobic glycolysis, while a decreased uptake would not be associated with anaerobic glycolysis. Acidosis has not been found to be associated with a reduction of lactate uptake in liver, whereas lactate removal from the blood is increased during acidosis in the kidney. Little is known about the effects of acidosis on the muscle cell’s ability to remove lactate. Since liver quantitatively has a large role in removal of lactate from the blood, it can be surmised that increased lactate found in more alkaline blood is caused, at least in part, by increased efflux of lactate from cells (20).

Several potential mechanisms exist for reducing force production during acidosis. These were discussed in “Acid-Base balance in the body,” NSCA Journal, 13(1):66-67.

Fuel availability may also have some effect on muscle cell metabolism. There is some evidence that alkalosis may have an effect on free fatty acid oxidation (16). Although peak aerobic capacity may not be affected, an increase in the use of fat as a fuel may insure that sufficient amounts of glycogen are available later in the exercise session. This may particularly play a part during interval type exercise where the likelihood of localized glycogen depletion is increased.

Performance
In studies in which the blood acid-base balance is manipulated prior to exercise, conflicting performance results are found. When subjects ingest NH4Cl and are acidic prior to exercise, consistent significant decrements in performance are found (16, 20, 22, 23, 30). However, when blood alkalosis is induced with NaHCO3 prior to exercise, significant improvements in performance are not always found. Some studies have found significant improvements in performance (6, 16, 25, 26, 28, 30), while others have found non-significant improvements (5, 13, 17, 19, 22), and still others have found no change in performance at all (15, 18, 22). It should be pointed out that the studies failing to find significant improvements in performance contained small sample sizes, and probably demonstrated low statistical power. In other words, the null hypothesis, no improvement in performance, should be viewed with scrutiny. Still, it is not possible to conclude with any conviction that starting exercise in an alkalotic state will affect performance in a single bout of exercise.

It may be possible that alkalosis may improve performance on subsequent exercise bouts. If the cell membrane is relatively impermeable to NaHCO3, the buffering capacity of the muscle cell would be relatively unaffected by NaHCO3 ingestion. However, diffusion of H+ out of the cell should be facilitated, causing a delay in muscle cell acidosis. Since the diffusion of H+ out of the cell probably does not occur instantaneously, it is possible that extracellular alkalosis will have greater effects on exercise performance during exercise that both develops acidosis within the muscle cell and allows time for H+ to diffuse out of the cell. Several studies that demonstrated significant improvements in exercise performance did so subsequent to several exercise bouts (5, 8, 25). Consistent with this, two buffering studies that demonstrated the greatest improvements in performance performed the exhaustive exercise following 20 minutes of exercise at 70 percent VO2 max (16, 30). All of these studies included preliminary exercise that presumably produced a surplus of lactate and H+. All five studies demonstrated marked improvements in performance.

Contraindications
Sodium bicarbonate is considered a medicine and must be treated accordingly. Its use should be absolutely contraindicated, unless prescribed by a physician, under the following conditions (31):

1. If you are allergic to sodium bicarbonate;
2. If you are allergic to any substance, such as foods, sulfites or other preservatives, or dyes;
3. If you are on a low-salt, low-sugar or any other special diet;
4. If you are breast feeding;
5. If you have any signs of appendicitis or intestinal or rectal bleeding;
6. If you have edema, heart disease, high blood pressure, kidney disease, liver disease, problems with urination, toxemia of pregnancy;
7. If you are taking any medication.
Ingestion of sodium bicarbonate should always be in accordance with the physician’s instructions, if the medicine is prescribed, or with the manufacturer’s package directions in case of self-treatment (31). Harmful side effects are rare if sodium bicarbonate is taken properly; however, they do occur. The incidence of dangerous side effects are of course increased if sodium bicarbonate is taken for long periods of time, in large doses and/or by individuals with kidney disease (31). Discontinue use of sodium bicarbonate and see a physician if any of the following side effects occur (31):

1. Frequent urge to urinate;
2. Continuing headache;
3. Continuing loss of appetite;
4. Mood or mental swings;
5. Muscle pain or twitching;
6. Nausea or vomiting;
7. Nervousness or restlessness;
8. Swelling of feet or lower legs;
9. Unpleasant taste;
10. Unusually slow breathing;
11. Unusual tiredness or weakness;
12. Stomach cramps;
13. Unusual increase in thirst;
14. Any other side effect.

Conclusions
Manipulations of the acid-base balance of the blood by NaHCO₃ ingestion may or may not affect metabolism and exercise performance during one bout of exercise. It is more probable, but not certain, that metabolism and exercise performance may be affected by manipulation of the acid-base balance of the blood during repeated bouts of exercise. Acid-base balance of the blood can be affected by sodium bicarbonate ingestion, as well as by controlling the diet. In addition, research indicates that training improves the buffering capacity of the muscle, but not the blood. A judicious diet and training program can go far in maintaining good acid-base balance of muscle and blood. Although it cannot be stated that a small amount of sodium bicarbonate occasionally ingested is harmful for healthy individuals, chronic sodium bicarbonate ingestion may be associated with harmful side effects.

References
of Applied Physiology. 37:197-204.

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