Invited Editorial
Sodium Bicarbonate Revisited

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Sodium bicarbonate is essential for human life, used by physicians and perfusionists on a daily basis, and generally viewed as a fairly benign clinical tool. However there is a body of published evidence that should suggest to perfusionists that bicarbonate is not necessarily the innocuous salt water that it is commonly viewed as, but has inherent risks associated with its use. From this authors perspective there has also been a paucity of education provided to perfusionists regarding sodium bicarbonate therapy. It is these two points; evidence of potential pitfalls and the lack of education that has prompted writing of this editorial, with the added hope that perfusionists will begin to question how sodium bicarbonate is used in their practices and perhaps stimulate discussion and clinical investigation.

There are at least 13 synonyms that have been used for sodium bicarbonate over the millennia including sodium hydrogen carbonate, sodium acid carbonate, saleratus (salerates – aerated salt), nahcolite, thermokalite, carbonic acid monosodium salt, carbonic acid sodium, monosodium hydrogen carbonate, meylon, and vichy salt. The ancient Egyptians found it as a mixture of sodium carbonate and sodium bicarbonate (natron) in ancient lake beds and used it as soap for cleaning. I imagine that for most of us, our first exposure to sodium bicarbonate was the orange, red, and blue box of Arm & Hammer baking soda that sat in the kitchen cabinet or refrigerator where we grew up.

Today sodium bicarbonate is used in many applications including: soda blasting to remove paint, rust, oil, etc. from surfaces that would be harmed by sand blasting, tooth cleanser, silver tarnish remover, odor eliminator, leavening agent, fire suppression agent, oral anti acid, in the manufacture of effervescent tablets, as a buffer for many fluids including pharmaceuticals, and as we all know an injectable solution to correct metabolic acidosis.

The majority of the sodium bicarbonate produced per year is manufactured by the Solvay process, which involves bubbling carbon dioxide through a concentrated sodium chloride and ammonia solution. The Solvay Corporation, the world’s largest producer, manufactures over 800,000 tons each year, while over 300,000 tons is mined each year in Wyoming and Colorado.

Though not supported by hard data, I would surmise that most perfusionists use sodium bicarbonate in the vast majority of their clinical cases. I also would guess that “bicarb” is generally viewed as a useful and generally benign tool in the perfusionist’s belt. It certainly has a low toxicity, with the oral lethal dose 50% estimated to be greater than 4000 mg/kg in the rat (1). Lastly I believe that sodium bicarbonate is overused by the majority of perfusionists, and the following is a long winded explanation.

In contradiction to its perceived docile nature, sodium bicarbonate is absolutely essential for human existence. Serving as a major buffer throughout the body, bicarbonate comprises over 50% of the buffering capacity of blood. As all perfusionists have been taught, the kidneys and lungs work in concert to maintain a bicarbonate concentration close to 22–26 mEq/liter. It has been calculated that the average human body produces approximately 13,000 mEq of carbon dioxide as a metabolic byproduct each day, the majority of which is converted to bicarbonate for transport to the lungs, then converted back to CO2 and exhaled. Without these mechanisms in place the pH of our bodies would fall to levels incompatible with life within minutes.

The use of bicarbonate as a pharmacological agent in modern medicine began during a particularly nasty cholera epidemic in Europe in 1831 and 1832. In those days
Cholera was known as the “blue epidemic” which described the appearance of the infected victim shortly before their demise (2). Cholera kills its victims through acute dehydration brought about by torrential diarrhea and vomiting. The severe dehydration leads to hypovolemia and collapse of the circulatory system. The practice of medicine in those days was very primitive by our standards, and the common treatment for cholera involved venesection and other assorted quackery, which more often than not, served to hasten the death of the patient rather than impart a cure.

An Irish physician named William Brooke O’Shaughnessy, who is most famous for introducing cannabis sativa as a therapeutic agent to western medicine, performed a detailed analysis of the blood of cholera victims in London. O’Shaughnessy authored two papers during the epidemic addressing cholera. The first paper was presented at the Westminster Medical Society of London. In that lecture he suggested that a possible treatment for cholera would involve the injection of nitrates or chlorates of potash in solution to restore the red color to the blood (2). His second paper, which was published in 1832, suggested that the blood be treated to bring back its normal electrolyte balance and specific gravity (3).

As luck would have it there was another physician, Dr. Thomas Latta in Leith, Scotland (4), who was treating cholera patients using traditional methods with very little success. Having read the article by O’Shaughnessy, Latta injected six pints of a hypotonic solution of sodium chloride and sodium bicarbonate (166 mOsm) into the basilic vein of a woman who was in the final stages of cholera with no hope for recovery. Dr. Latta reported that after 30 minutes of injection the woman stated that she was “free from all uneasiness.” Latta reported his experiences with fluid resuscitation in a letter to the Lancet and as such is identified as the father of intravenous infusion therapy. Unfortunately it was another 50 years before intravenous infusion became a common practice for hypovolemic resuscitation.

The early 1960s saw exponential growth in cardiac interventions heralded by the increased use of the heart lung machine for cardiopulmonary bypass (CPB), and the development and formal establishment of cardiopulmonary resuscitation (CPR) involving rescue breathing, cardiac compression, and fluid resuscitation. Studies showed that heart muscle function and the catecholamine response are depressed by acidosis. It had been recognized for some time that cardiac arrest quickly resulted in a profound acidosis for the victim, and clinicians also observed that patients placed on cardiopulmonary bypass often developed some degree of acidosis as well. Because of previous experiences with volume resuscitation including bicarbonate in the fluid, and the knowledge that sodium bicarbonate functions to raise the pH in an acidosis, bicarbonate was added to priming solutions for CPB and administered to patients during CPR to correct any acidosis. It is important to realize that there had been no studies performed to investigate any benefit for the administration of bicarbonate. The benefit was assumed for physiological reasons and logically due to the success of both CPR and CPB.

A paper by Usher, published in 1963 in the journal Pediatrics, gave credence to the inclusion of NaHCO₃ during fluid resuscitation to infants. Prior to this time fluid resuscitation in infants was not commonly used. Infants in respiratory distress were infused with a 10% glucose solution and 5–15 mEq of sodium bicarbonate solution at a rate of 65 mL/kg/day, which demonstrated an improvement in survival for these patients (5). It was assumed that the bicarbonate played a beneficial role in the resuscitation fluid; however this hypothesis was not tested for 14 years, when Corbet et al. conducted a randomized clinical trial in 1977 that showed the inclusion of bicarbonate had no effect on the outcome (6). There were however clues immersing that sodium bicarbonate infusion was not without risk.

In 1967 Usher followed his 1963 paper with another study, which showed that when the patient’s acidosis was corrected rapidly there was an increase in infant mortality caused by intraventricular cerebral hemorrhage (7). Several papers published over the next three decades have implicated sodium bicarbonate administration as a causative agent for intracranial bleed and subsequent death (8–10). Particular risk seems to occur when the bicarbonate is administered quickly and the negative effect may be attenuated by slow infusion (11,12). There has been one randomized prospective trial showing an increase in death and intracranial hemorrhage in premature infants given a rapid infusion of albumin and sodium bicarbonate (13).

Bicarbonate administration may cause an increase in the serum osmolality (14,15), a decrease in cerebral blood flow (16), an increase in cerebral blood volume (17), a decrease in cardiac output (18,19), and a decrease in intracellular pH due to CO₂ diffusing into cells. Bicarbonate combines with calcium chloride to form calcium carbonate, it drives potassium intracellular, and it increases the plasma sodium concentration and plasma volume. It also causes systemic vasodilation when administered quickly, and it shifts the oxyhemoglobin dissociation curve to the left. Sodium bicarbonate is anything but benign.

There have been at least three review articles written in the past 11 years that looked at the available literature for evidence of a benefit to bicarbonate administration for cardiopulmonary resuscitation (20), lactic acidosis (21), and infant respiratory distress syndrome (22). All three reviews came to the same conclusions that up to the date of their publication there had been no studies confirming that the administration of sodium bicarbonate was of any benefit. In fact, since the year 2000, the Advanced Cardiac Life Support guidelines no longer recommend that bicarbonate be administered routinely during cardiopulmonary resuscitation in adults or pediatrics.
In perfusion school we were taught that the act of putting someone on cardiopulmonary bypass placed the patient in a state of controlled shock with the catecholamine response, shutting down of peripheral vascular beds, resulting in varying degrees of lactic acidosis requiring the administration of sodium bicarbonate. As well, we were taught how to calculate a dose based on the results from an arterial blood gas, the patient's size, and circuit volume. However a cursory sampling of the perfusion text books from the last 25 years reveal very little guidance as to the proper administration of sodium bicarbonate.

The following are examples of the full extent of the discussion on bicarbonate usage from a sampling of perfusion text books.

From Reed and Stafford (p. 207) “During cardiopulmonary bypass, metabolic acidosis is always a result of inadequate perfusion. Although the acid-base status may be immediately corrected by the administration of bicarbonate, the normal process leading to the metabolic acidosis is not corrected until perfusion becomes adequate.” (p 252) “Normal Dosage: By the intravenous route, with doses calculated by the degree of imbalance.” (23) From Austin & Harner (p. 18) “In low flow perfusion, acid blood levels tend to increase (metabolic acidosis). Administration of sodium bicarbonate may be required to buffer the blood (raise the pH—lower the acid)” (24) From Cardio-Pulmonary Bypass Principles and Techniques of Extracorporeal Circulation by Mora (p. 26) “For proper adjustment of pH in a cardioplegic solution with a bicarbonate buffer, some carbon dioxide must be equilibrated with the bicarbonate.” (p 283) “Severe metabolic acidosis depresses myocardium and should be treated with NaHCO₃ or tromethamine (THAM).” (25) Finally from Cardiopulmonary Bypass Principles and Practice, Third Edition (p. 615) “Hyperkalemia can be treated with insulin, calcium, and bicarbonate.” (26) This is the only reference to the use of sodium bicarbonate I have found in this volume.

Aside from the apparent lack of formal education for perfusionists regarding the use of sodium bicarbonate, there is the omnipresent controversy surrounding cardiopulmonary bypass and metabolic acidosis. Recent studies in the adult and pediatric populations have shown that the majority of the metabolic acidosis observed in patients undergoing cardiopulmonary bypass seems to be caused by electrolyte changes induced by dilution with crystalloid priming solutions (27–30). These acid base disturbances are typically hyperchloremic acidosis or decreased strong ion difference acidosis. One study has suggested that sodium bicarbonate may be useful in some circumstances, not because of its buffering ability, but because the sodium would reduce the chloride to sodium ratio and it would help to increase the strong ion difference (29). The previously mentioned studies did not implicate lactic acidosis or hypo perfusion as common causes of metabolic acidosis, which have already been deemed inappropriate for sodium bicarbonate therapy.

In summary, sodium bicarbonate is not a benign molecule; potential risks and side effects are associated with its use. Though used almost universally by perfusionists, there is a historical lack of education about indications, contraindications, and dosage. A conservative approach that would seem foreign to the majority of perfusionists was advocated by Adrogue and Madias in the New England Journal of Medicine, discussing the treatment of acute metabolic acidosis in patients undergoing cardiopulmonary resuscitation, where they wrote; “Because the administration of sodium bicarbonate entails certain risks, it should be given judiciously in amounts that will return blood pH to a safer level of about 7.20. To accomplish this goal, plasma bicarbonate must be increased to 8 to 10 mmol per liter.” (31) I suspect that the majority of perfusionists, surgeons and anesthesiologists would consider the previous suggestion to be wholly inappropriate for treating our patients in the operating room. However there is very little evidence to the contrary.

The following is suggested as a minimum set of guidelines; administer the smallest dose of bicarbonate necessary to achieve the desired response. Slow, dilute administration accompanied with arterial and venous pCO₂ monitoring is preferable. Strictly avoid bicarbonate administration into ports that are used for CaCl₂ to avoid the precipitation of calcium carbonate out of solution (32). Avoid administration immediately prior to weaning from bypass to allow for dilution of the hyperosmotic solution, and correction of the concomitant acute respiratory acidosis. Along with monitoring of all electrolytes and osmotic pressure, use techniques and circuits that reduce the dilutional volume in the extracorporeal circuit. Not only will the hematocrit and protein concentrations be preserved but it will help minimize any electrolyte imbalances resulting in strong ion acidosis.

Though I realize that this discussion cannot be considered to be exhaustive, and I have not conducted a survey of bicarbonate use among perfusionists, there does seem to be a disconnect between the use of sodium bicarbonate and the education of perfusionists through the available literature with evidence for its efficacy and indication. There is an obvious need for clinical investigations to determine the efficacy, conditions, and dosages that provide the safest therapeutic modalities for treating our patients on cardiopulmonary bypass.

REFERENCES


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