series of studies has shown that renal blood flow and glomerular filtration rate are regulated by plasma chloride. Hyperchloremia induces renal vasoconstriction by inhibiting the intrarenal release of renin and angiotensin II, leading to a decreased urine output.[5,6] The cellular mechanism is unclear but may be related to adenosine, PGE_2, or thromboxane mediator release. Renal blood flow decreased by 36%, and GFR decreased by 29% with hyperchloremia.[7]

I submit that one should aim to not disturb electrolyte and acid-base physiology in the perioperative patient. This means not administering large volumes (*e.g.*, 20 l) of normal saline. To replace 1 l of blood loss, one could administer 3 l of normal saline, representing an excess chloride load of 165 mmol, or 3 l of Ringer's lactate, an excess of 27 mmol of chloride, or 1 l of normal serum albumen, an excess of 25 mmol of chloride. These latter two fluids with their lesser excess chloride load would be unlikely to produce hyperchloremic acidosis.

Management of a normal saline-induced acidemia should involve switching to Ringer's lactate and aiming for a pH above 7.2 where arrhythmias, myocardial depression, and decreased responsiveness to catecholamines are much reduced. This can be achieved by allowing the bicarbonate buffering system to be maximally effective by lowering the PCO_2 appropriately. This will minimize the titration of intracellular protein buffers.[8] Giving the chloruretic aciduretic agent furosemide will also be of use with functioning kidneys.[9] If fresh frozen plasma is indicated on transfusion criteria, then its administration may also be helpful because it has excellent buffering capabilities.[10,11]

Marc A. Russo, M.B.B.S., D.A.(UK)
John Hunter Hospital
Newcastle, NSW, Australia

References

1. Veech RL: The toxic impact of parental solutions on the metabolism of cells: A hypothesis for physiological parental therapy. Am J Clin Nutrit 1986; 44:519-51
2. Black DAK: Body fluid depletion. Lancet 1953; 1:305-12
3. Traverso LW, Lee BVS, Lanford MJ: Fluid resuscitation after an otherwise fatal hemorrhage: I. Crystalloid solutions. J Trauma 1986; 26:168-75
4. McFarlane C, Lee A: A comparison of Plasmalyte 148 and 0.9% saline for intra-operative fluid replacement. Anaesthesia 1994; 49:779-81
5. Wilcox CS: Regulation of renal blood flow by plasma chloride. J Clin Invest 1983; 71:726-35
6. Wilcox CS: Release of renin and angiotensin II into plasma and lymph during hyperchloremia. Am J Physiol 1987; 253:F734-41
7. Wilcox CS: Renal haemodynamics during hyperchloremia in the anaesthetized dog: Effects of captopril. J Physiol Lond 1988; 406:27-34
8. Vasuvattakul S, Warner LC, Halperin ML: Quantitative role of the intracellular bicarbonate buffer system in response to an acute acid load. Am J Physiol 1992; 262:R305-9
9. Sebastian A, Schambelan M, Sutton JM: Amelioration of hyperchloremic acidosis with furosemide therapy in patients with chronic renal insufficiency and type 4 renal tubular acidosis. Am J Nephrol 1984; 4:287-300
10. Traverso LW, Medina F, Bolin RB: The buffering capacity of crystalloid and colloid resuscitation solutions. Resuscitation 1985; 12:265-70
11. Traverso LW, Hollenbach SJ, Bolin RB: Fluid resuscitation after an otherwise fatal hemorrhage: II. Colloid solutions. J Trauma 1986; 26:176-82

(Accepted for publication May 21, 1997.)

Anesthesiology
1997; 87:1011-2

Dilutional Acidosis or Altered Strong Ion Difference

To the Editor:—Dilutional acidosis is an interesting concept but has not been clearly defined clinically. Mathes' *et al.*[1] and previous case reports[2,3] of metabolic acidosis secondary to the administration of large amount of normal saline have an additional feature in common, namely hyperchloremia. As a general rule, hyperchloremia is associated with metabolic acidosis and hypochloremia with metabolic alkalosis. In all these case reports, hyperchloremia may have caused the metabolic acidosis rather than by the dilution of serum bicarbonate. High chloride load as the cause of hyperchloremic metabolic acidosis has recently been suggested in anesthetic literature.[4]

How does a change in chloride concentration bring about such profound alteration in acid-base equilibrium? The answer to this question is not obvious when analyzed using the Henderson-Hasselbalch equation. However, it can be explained by Stewart's method of analysis of quantitative acid-base chemistry.[5] To understand and apply Stewart's approach to acid-base analysis and management requires a shift in the way we think and understand acid-base problems. Fencl and Leith[6] recently reviewed Stewart's quantitative approach to acid-base chemistry and summarized that "Stewart's approach shows the way to understanding and mathematical modeling of biological fluids as physico-chemical systems. It provides a basis for quantitative analysis and rational manipulation of acid-base state, *in vivo* and *in vitro*, and it challenges current interpretations of compartmentalized acid-base exchanges across biological membranes."

According to Stewart, in a solution containing strong electrolytes, the difference in the sum of the positive charges and that of the negative charges carried by the strong ions, referred to as strong ion difference (SID), is one of the major determinants of hydrogen ion concentration. It is the net unbalanced positive charge on the strong

ions present in the solution that is balanced by the net charge on all other weak ions. In normal plasma, SID has a numerical value of about 40. Lower values of SID lead to metabolic acidosis, and higher values lead to metabolic alkalosis. In Mathes' case report, the high chloride load may have caused a reduction in the SID, which resulted in the metabolic acidosis.

One of the interesting questions resulting from Stewart's approach relates to how sodium bicarbonate corrects the metabolic acidosis. The metabolic acidosis may be corrected not so much by its bicarbonate content but by its sodium content. The increased sodium concentration resulting from bicarbonate therapy corrects the reduced SID toward normal, thereby correcting the acidosis. According to Stewart, bicarbonate is a dependent variable and therefore cannot bring about a change in another dependent variable like hydrogen ion concentration.

In conclusion, we believe that hyperchloremia caused the metabolic acidosis by altering the SID, and we do not believe that dilution of bicarbonate is a likely cause.

Pema Dorje, M.D.
Assistant Professor
Gaury Adhikary, M.D.
Lecturer
Ian D. McLaren, M.D.
Assistant Professor
Stephen Bogush, M.D.
Resident
Department of Anesthesiology
University of Michigan Medical Center
Ann Arbor, Michigan

References

1. Mathes DD, Morell RC, Rohr MS: Dilutional acidosis: Is it a real clinical entity? ANESTHESIOLOGY 1997; 86:501–3
2. Goodkin Da, Raja RM, Saven A: Dilutional acidosis. South Med J, 1990; 83:354–5
3. Azzam FJ, Steinhardt GF, Tracy TF, et al: Transient perioperative metabolic acidosis in a patient with ileal bladder augmentation. ANESTHESIOLOGY 1995; 83:198–200
4. Miller LR, Waters JH, Provost C: Mechanism of Hyperchloremic Metabolic Acidosis. ANESTHESIOLOGY 1996; 84:482–3
5. Stewart PA: Modern quantitative acid-base chemistry. Can J Physiol Pharmacol 1983; 61:1444–61
6. Fencl V, Leith DE: Stewart's quantitative acid-base chemistry: Applications in biology and medicine. Resp Physiol 1993;91:1–16.

(Accepted for publication May 21, 1997.)

Anesthesiology
1997; 87:1012–3

Decrease in the Total Amount of Extracellular Bicarbonate Is Not Dilution

To the Editor:—Mathes *et al.*,[1] in their case report titled "Dilutional Acidosis: Is it a Real Clinical Entity?" have reported a case of metabolic acidosis that they believe is due to dilutional acidosis developing as a direct result of infusion of a large volume of isotonic saline. Although we agree that dilutional acidosis can occur when the plasma bicarbonate concentration is decreased by extracellular fluid expansion, we disagree with the authors on the following issues:

1. This case report is not a true example of "dilutional acidosis." Dilutional acidosis occurs when the plasma bicarbonate concentration decreases as a result of volume expansion with solutions that contain neither acid nor alkali.[2] The intraoperative metabolic acidosis that occurred in this case may not be the direct result of giving a large volume of isotonic saline. Instead, the following factors may have significantly contributed to the generation of this metabolic acidosis:

- Bicarbonate loss in conjunction with 3.5-l blood loss
- Bicarbonate loss due to electrolyte exchange from the normal saline that was used to moisten laparotomy sponges and to irrigate the surgical field
- Decreased "buffer power" of blood due to blood loss
- Accumulation of fixed acids

Fixed acids are responsible for the formation of 50–100 mmol of hydrogen ions per day. In the acute setting, the magnitude of contribution of the kidney to the pH homeostasis may be insignificant. In this case, however, the operative procedure lasted longer than 8 h, and this length of time cannot be regarded as an acute situation. Accumulation of fixed acids during this extended period of time can contribute significantly to this metabolic acidosis. To rule out the possibility of fixed acids playing a role in the metabolic acidosis, the authors emphasized the presence of nonanion gap metabolic acidosis in this patient. Although increased anion gap may be used as a criterion to differentiate the various causes of metabolic acidosis, the possibility of nonanion gap or even decreased anion gap (as compared with baseline anion gap) exists in the presence of organic acid acidosis in conjunction with extreme hyperchloremia. In this patient, the chloride increased from 90 to 128 mEq/l.

2. Discrepancy in the proposed treatment of metabolic acidosis: The treatment of acidosis depends on its severity, any associated electrolyte/hemodynamic disturbance, and the judgment of the clinician. Although the authors state that there is no need to manage dilutional metabolic acidosis with bicarbonate, yet their patient