Comparison of the effects of intravenous administration of isotonic and hypertonic sodium bicarbonate solutions on venous acid-base status in dehydrated calves with strong ion acidosis

Alparslan Coskun, Dr vet Med, PhD; Ismail Sen, Dr vet Med, PhD; Hasan Guzelbektes, Dr vet Med, PhD; Mahmut Ok, Dr vet Med, PhD; Kursat Turgut, Dr vet Med, PhD; Sebnem Canikli, Dr vet Med

Objective—To compare the effects of IV administration of isotonic (1.3%) and hypertonic (8.4%) sodium bicarbonate ($NaHCO_3$) solutions on acid-base status in dehydrated calves with strong ion (metabolic) acidosis.

Design—Randomized controlled clinical trial.

Animals—50 calves with diarrhea and severe dehydration.

Procedures—Calves were randomly assigned to receive isotonic $NaHCO_3$ solution (65 mL/kg [29.5 mL/lb], IV) over 3 hours (n = 30) or hypertonic $NaHCO_3$ solution (10 mL/kg [4.5 mL/lb], IV) over 20 minutes (20). Blood samples were collected at 0 hours (immediately prior to solution administration) and at 0.5, 1, 2, and 4 hours after administration began. Samples were submitted for blood gas analysis, serum biochemical analysis, and determination of blood Na^+, K^+, and Cl^- concentrations and percentage change in plasma volume.

Results—Calves that received isotonic $NaHCO_3$ solution had an increase in venous blood pH, HCO_3 concentration, and base excess; a small, transient increase in P_{O_2}; and no change in P_{CO_2} within 4 hours after administration began. Calves that received hypertonic $NaHCO_3$ solution had an immediate increase in venous blood pH, HCO_3 concentration, and base excess; a small, transient increase P_{CO_2}; and no change in P_{O_2} within 0.5 hours after treatment began. Plasma volume increased to a greater extent following administration of isotonic solution than after administration of hypertonic solution.

Conclusions and Clinical Relevance—IV administration of 8.4% $NaHCO_3$ solution in small volumes provided fast and effective improvement of severe acid-base abnormalities in calves with severe strong ion acidosis but did not improve hydration status as well as administration of a larger volume of isotonic $NaHCO_3$ solution. (*J Am Vet Med Assoc* 2010;236:1098–1103)

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Neonatal calf diarrhea is a multifactorial disease that, despite the decades of research on the topic, remains the most common cause of death in young calves.[1] It develops predominantly during the first 4 weeks of life[2] and can lead to dehydration, acidemia, hyperkalemia, and impaired cardiovascular and renal function.[3,4] Acidemia in diarrheic calves results from strong ion acidosis in response to hyponatremia, normochloremia to hyperchloremia, and hyper D-lactatemia and from nonvolatile buffer ion acidosis in response to increased plasma protein concentration.[4,5] L-lactic acidosis is believed to arise from poor tissue perfusion caused by dehydration or endotoxemia, with subsequent anaerobic glycolysis and a decrease in hepatic clearance of L-lactate.[6] D-lactate is the most important factor responsible for the clinical signs of weakness and depression in calves with diarrhea.[7,8] According to quantitative acid-base theory, the strong ion (metabolic) acidosis that develops in severely diarrheic, dehydrated calves is due primarily to increased fecal loss of sodium and bicarbonate and accumulation of strong anions (D- or L-lactate or uremic strong anions) resulting in a decrease in blood SID[9] together with changes in total weak nonvolatile acids (increases in serum total protein and albumin concentrations). The SID is defined as the difference in concentration between plasma strong cations (Na and K) and strong anions (Cl and D- or L-lactate). A simplified strong ion model[10,11] that makes use of measurements of albumin, globulin, and phosphate is claimed to be a simpler means of determining total weak nonvolatile acids and K_a (the dissociation constant of plasma weak acids) and more accurate means than the classic model proposed by Stewart.

Fecal fluid loss in profuse watery diarrhea can reach up to about 13% to 18% of body weight/d and is probably

Abbreviations

HSBS	Hypertonic sodium bicarbonate solution
ISBS	Isotonic sodium bicarbonate solution
SID	Strong ion difference
SID_3	Strong ion difference calculated from blood Na^+, K^+, and Cl^- concentrations
SIG	Strong ion gap

From the Department of Internal Medicine, Faculty of Veterinary Medicine, University of Selcuk, 42070, Konya, Turkey.
Supported by a grant from SU Scientific Research Office.
Address correspondence to Dr. Sen (ismailsen@selcuk.edu.tr).

underestimated in most situations.[12] Calves with severe diarrhea become dehydrated and develop strong ion acidosis attributable to loss of water, electrolytes, and bicarbonate. One of the most important factors for decreasing mortality rates associated with diarrhea in calves is parenteral and oral administration of appropriately formulated electrolyte solutions,[13] which can correct the dehydration, strong ion acidosis, and electrolyte imbalances. Inclusion of an alkalinizing agent is required to correct systemic strong ion acidosis.[13,14] Sodium bicarbonate solutions are particularly effective for treating acute, severe strong ion acidosis because they have a rapid effect when administered IV.[13] Isotonic (1.3% or 1.4%) sodium bicarbonate solutions (13 to 14 g of $NaHCO_3$/L) are often recommended for treatment of acidemia in calves with and without dehydration.[4,15,16]

Hypertonic (8.4%) $NaHCO_3$ solution should be administered with caution, particularly in dehydrated calves that are unable to suckle.[7] Potential adverse effects of HSBS administration include hyperosmolarity of extracellular fluid, hypernatremia, hypokalemia, hypocalcemia, and paradoxical intracellular and CSF acidosis.[17–19] Such solutions should not be used in calves with diarrhea that have concurrent respiratory disease because the calves may not be able to effectively exhale the excess carbon dioxide generated in buffer reactions.[7,20] Rapid IV administration or overdose with 7.0% HSBS has been associated with development of intracranial hemorrhage in some species, in addition to the other adverse effects.[18,21] In contrast, rapid IV administration of HSBS is reportedly an effective and safe method for treating strong ion acidosis in normovolemic halothane-anesthetized calves with experimentally induced respiratory and strong ion acidosis.[7] In addition, IV administration of HSBS to acidotic neonatal calves does not appear to have any adverse effects on plasma concentrations of several commonly measured electrolytes or enzyme activities.[22] Consequently, controversy continues regarding the use of HSBS in treatment of calves with acid-base abnormalities.

The purpose of the study reported here was to compare the effects of IV administration of isotonic (1.3%) and hypertonic (8.4%) sodium bicarbonate ($NaHCO_3$) solutions on acid-base status in dehydrated calves with strong ion (metabolic) acidosis. A second objective was to determine and compare the changes in plasma volume following fluid administration.

Materials and Methods

Calves—Calves with strong ion acidosis admitted for treatment at the Veterinary Clinic of the University of Selcuk between 2006 and 2008 were eligible for inclusion in the study. Routine physical examination findings including extent of eyeball recession into the orbit, inability to stand, lack of or weak suckling reflex, and decrease in cervical skin elasticity were recorded. A jugular venous blood sample was obtained from each calf and submitted for blood gas analysis, serum biochemical analysis, and determination of blood Na^+, K^+, and Cl^- concentrations. In all, 50 calves deemed severely dehydrated (eyeball recession into the orbit ≥ 6 mm[23]) and markedly acidemic (ie, jugular venous pH ≤ 7.20)[23] were included in the study. Most were Swiss-Brown calves; all were < 45 days of age, with a mean body weight of 34 kg (74.8 lb; range, 20 to 40 kg [44 to 88 lb]) at admission. Afterward, a jugular venous catheter was placed aseptically and secured to the neck to permit collection of blood samples. The study protocol complied with the requirements of the University Research Fund for Animal Care and Welfare.

Experimental protocol—Calves were randomly assigned by use of random number generator to receive ISBS (1.3% $NaHCO_3$ [13 mg of $NaHCO_3$/mL]; n = 30) or HSBS (8.4% $NaHCO_3$ [84 mg of $NaHCO_3$/mL]; 20). Those in the ISBS group received 65 mL of ISBS/kg (29.5 mL/lb; IV) over 3 hours such that all 30 calves received 1 L (13 g) of sodium bicarbonate over 1 hour, and the remaining required amount was administered over the next 2 hours. This required amount (mEq) was calculated as follows: negative base deficit (mmol/L) × 0.6 (factor for calves for extracellular fluid space) × body weight (kg). The resulting value was converted from millimoles of sodium bicarbonate per liter to grams of sodium bicarbonate per liter by dividing by 12.[13,19] Calves in the HSBS group received 10 mL of HSBS/kg (4.5 mL/lb; IV) over 20 minutes. In addition, cefazolin sodium[a] (30 mg/kg [13.6 mg/lb], IV) and flunixin meglumine[b] (2.2 mg/kg [1 mg/lb], IV) were administered daily for 3 days to all calves.

Blood sample collection—Venous blood samples were obtained at 0 hours (immediately prior to administration of sodium bicarbonate solution; baseline) and at 0.5, 1, 2, and 4 hours after administration began. Blood samples were collected anaerobically from the jugular venous catheter into sodium heparin–containing plastic syringes for blood gas analysis, which was performed within 10 minutes after collection. Blood samples for serum biochemical analyses were collected into untreated tubes, allowed to clot at room temperature (approx 20°C [68°F]), and centrifuged. The serum was harvested and stored at –20°C (–4°F) until analyzed.

Calves were monitored closely by a supervising veterinarian for the first 4 hours after IV administration of ISBS or HSBS. After the 4-hour study period ended, additional supportive treatment (0.9% NaCl solution, IV; or alkalinizing electrolyte solutions, PO) was administered as needed until the calves were discharged from the veterinary hospital.

Laboratory analysis—Blood gas analysis was performed with a blood gas analyzer.[c] Values were corrected for rectal temperature, and the blood HCO_3^- concentration, anion gap, and extracellular base excess values were calculated. Blood Na^+, K^+, and Cl^- concentrations were measured with ion-selective electrodes. Serum albumin, urea, glucose, and total protein concentrations were measured with a commercial kit[d] and an automatic analyzer.[e]

Determination of percentage change in plasma volume—Change in plasma volume at time *i* was calculated from the serum protein concentration at 0 hours (SP_0) and the serum protein concentration at time *i* (SP_i) by use of the following formula: $(SP_0 - SP_i) \times 100/SP_i$.[24]

Calculation of SID and SIG—Blood lactate and Ca^{++} concentrations in the study were not measured. Therefore, measured SID was calculated from 3 strong ions as SID_3 as the sum of Na^+ and K^+ concentrations minus the Cl^- concentration.[9]

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The SIG is based on the electroneutrality equation of watery biologic solutions. It is calculated from the anion gap as the sum of the Na^+ and K^+ concentrations minus the sum of the Cl^- and HCO_3^- concentrations and from the net negative charge of nonvolatile buffers (A^-), which approximates the net protein charge. As such, the SIG equals A^- minus the anion gap, convention being that a negative value for SIG indicates the presence of unmeasured strong anions (usually D- or L-lactate in calves with diarrhea). The formula to calculate SIG (mEq/L) was as follows:

$$SIG = \frac{(\text{total protein concentration} \times 3.43)}{(1 + 10^{[7.08 - pH]}) - \text{anion gap}}$$ [4]

Statistical analysis—Data were expressed as least squares mean ± SE. A statistical software program[f] was used for all statistical analyses. To evaluate differences between ISBS and HSBS calves and within-group differences over time with respect to variables measured, ANOVA and Tukey multiple range tests were performed. A Student *t* test was used to compare baseline values between treatment groups. The Fisher exact test was used to compare proportions of surviving calves between the groups. A value of $P < 0.05$ was considered significant.

Results

Calves—Most study calves had usually yellow and watery diarrhea. According to histories obtained from the owners, the calves were affected by diarrhea for about 1 to 2 days. All 50 calves also had marked acidemia and were ≥ 10% dehydrated. Most had signs of mental depression.

All calves were hospitalized during the treatment period. Calves in the ISBS group received between 1,625 and 2,600 mL of 1.3% sodium bicarbonate solution. Those in the HSBS group received between 200 and 400 mL of 8.4% sodium bicarbonate solution. Eight of the 50 (16%) calves died during the experiment. Those calves (5 calves in the ISBS group and 3 in the HSBS group) had signs of severe depression, became laterally recumbent, and had a markedly low venous blood pH (pH, < 6.9; n = 5), a low base excess (≥ –25 mmol/L; 5), hypoglycemia (≤ 40.5 mg/dL; 8), a low rectal temperature (range, 36.5° to 40.7°C; 8), and large negative SIG values

Table 1—Mean ± SE venous blood gas values, blood electrolyte concentrations, and serum biochemical values before (0 hours) and 0.5, 1, 2, and 4 hours after beginning IV administration of ISBS (65 mL/kg [29 mL/lb]; n = 30 calves) over 3 hours or HSBS (10 mL/kg [4.5 mL/lb]; 20 calves) over 20 minutes in severely dehydrated, diarrheic calves.

	Baseline	After administration began (h)				
Variable	0	0.5	1	2	4	Reference limits
pH						
ISBS	7.06 ± 0.03[a]	7.25 ± 0.02[b]	7.27 ± 0.02[b]	7.29 ± 0.02[b]	7.31 ± 0.01[b]	7.35 to 7.45
HSBS	7.06 ± 0.04[a]	7.32 ± 0.03[b]	7.31 ± 0.04[b]	7.27 ± 0.04[b]	7.27 ± 0.04[b]	
P_{CO_2} (mm Hg)						
ISBS	43.22 ± 2.21[a]	40.25 ± 1.69[a]	43.64 ± 1.81[a]	43.08 ± 1.64[a]	44.50 ± 1.57[a]	35 to 45
HSBS	43.46 ± 2.96[a]	48.32 ± 2.79[a]	48.14 ± 3.24[a]	47.58 ± 3.00[a]	45.37 ± 2.01[a]	
P_{O_2} (mm Hg)						
ISBS	28.29 ± 1.58[a]	36.21 ± 1.61[b]	34.25 ± 1.33[b]	32.73 ± 1.38[b]	30.90 ± 1.19[b,c]	75 to 100
HSBS	27.31 ± 2.32[a]	31.72 ± 1.91[a]	32.69 ± 2.36[a]	31.98 ± 1.82[a]	28.59 ± 1.86[a]	
Na^+ (mmol/L)						
ISBS	137.3 ± 1.7[a]	143.6 ± 1.8[b]	145.3 ± 1.9[b]	146.8±1.9[b]	146.7 ± 1.8[b]	136 to 148
HSBS	136.6 ± 3.0[a]	146.1 ± 3.6[b]	147.4 ± 3.3[b]	146.5 ± 3.0[b]	146.2 ± 3.4[b]	
K^+ (mmol/L)						
ISBS	4.86 ± 0.22[a]	4.11 ± 0.20[b]	4.02 ± 0.20[b]	3.92 ± 0.19[b]	3.76 ± 0.19[b]	3.4 to 4.8
HSBS	5.18 ± 0.35[a]	4.31 ± 0.34[a,b]	4.36 ± 0.43[a,b]	3.93 ± 0.33[b]	3.86 ± 0.37[b]	
Cl^- (mmol/L)						
ISBS	101.7 ± 2.3[a]	105.8 ± 2.2[a]	104.5 ± 2.0[a]	106.3 ± 2.2[a]	105.5 ± 2.0[a]	90 to 102
HSBS	97.3 ± 3.7[a]	97.7 ± 4.2[a]	99.7 ± 4.1[a]	100.8 ± 4.2[a]	99.8 ± 4.3[a]	
Anion gap (mmol/L)						
ISBS	27.52 ± 1.56[a]	24.41 ± 1.61[a]	24.18±2.17[a]	24.11 ± 1.71[a]	25.03 ± 1.60[a]	14 to 20
HSBS	32.10 ± 2.12[a,b]	27.32 ± 2.50[a,b]	27.52±2.99[a,b]	26.05 ± 2.02[b]	27.09 ± 2.14[a,b]	
Oxygen saturation (%)						
ISBS	32.27 ± 2.76[a]	58.07 ± 2.65[b]	56.35 ± 2.16[b]	54.08 ± 2.60[b]	51.69 ± 2.58[b]	70 to 100
HSBS	31.82 ± 4.24[a]	53.15 ± 3.05[b]	54.46 ± 5.18[b]	51.58 ± 4.15[b]	44.33 ± 3.92[a,b]	
Glucose (mg/dL)						
ISBS	57.38 ± 6.80[a]	55.50 ± 6.69[a]	60.76 ± 6.15[a]	61.04 ± 5.55[a]	67.77 ± 6.57[a]	45 to 75
HSBS	45.47 ± 8.22[a]	39.75 ± 9.31[a]	45.64 ± 9.16[a]	50.46 ± 8.00[a]	56.67 ± 10.38[a]	
Urea (mg/dL)						
ISBS	50.82 ± 6.24[a]	44.86 ± 5.80[a]	42.05 ± 5.23[a]	43.40 ± 5.28[a]	44.11 ± 44.11[a]	20 to 30
HSBS	56.93 ± 6.89[a]	50.58 ± 5.98[a]	56.08 ± 6.5[a]	53.62 ± 7.18[a]	52.22 ± 6.98[a]	
Total protein (g/dL)						
ISBS	6.27 ± 0.25[a]	4.70 ± 0.30[b]	4.32 ± 0.21[b]	4.39 ± 0.28[b]	4.38 ± 0.24[b]	6.7 to 7.5
HSBS	6.23 ± 0.37[a]	4.86 ± 0.31[b]	4.81 ± 0.39[b]	4.56 ± 0.24[b]	4.73 ± 0.26[b]	
Albumin (g/dL)						
ISBS	2.88 ± 0.12[a]	2.09 ± 0.15[b]	1.91 ± 0.09[b]	1.93 ± 0.12[b]	1.90 ± 0.10[b]	3 to 3.6
HSBS	2.75 ± 0.20[a]	2.22 ± 0.11[a,b]	2.16 ± 0.16[a,b]	2.07 ± 0.10[b]	2.02 ± 0.16[b]	
SID_3 (mEq/L)						
ISBS	40.87 ± 1.64	41.57 ± 1.49	44.10 ± 1.95	44.42 ± 1.45	46.25 ± 1.62	38 to 46
HSBS	42.30 ± 1.63	50.80 ± 3.14	49.86 ± 2.40	45.87 ± 2.00	49.45 ± 1.94	
SIG (mEq/L)						
ISBS	–16.27 ± 1.63	–14.32 ± 1.81	–16.55 ± 2.20	–14.56 ± 1.76	–16.06 ± 1.74	–2 to 6
HSBS	–19.37 ± 2.17	–15.39 ± 2.34	–12.50 ± 2.80	–12.58 ± 1.90	–13.31 ± 2.62	

[a–c]Within the same row, values with different superscripts are significantly ($P < 0.05$) different.

(≥–24.17 mEq/L; 8). Baseline values for blood pH ($P = 0.003$), base excess ($P < 0.001$), and serum glucose concentration ($P = 0.034$) differed significantly between survivors and nonsurvivors. Mental status, suckling reflex, rectal temperature, and standing-up effort improved somewhat in both groups at 1 to 2 hours after solution administration began.

Acid-base analysis—All the calves had a severe strong ion acidosis when admitted to the hospital, with a jugular venous blood pH ranging from 6.80 to 7.20, P_{CO_2} ranging from 28 to 60 mm Hg, blood HCO_3^- concentration ranging from 4.4 to 16 mmol/L, base excess ranging from –10.2 to –28 mEq/L, P_{O_2} ranging from 20.0 to 44.9 mm Hg, and anion gap ranging from 14.9 to 45 mEq/L (**Table 1**). There were no significant differences in baseline blood gas values between treatment groups.

The 30 calves that received ISBS had increases in venous blood pH, HCO_3^- concentration (**Figure 1**), and base excess (**Figure 2**); a small transient increase in P_{O_2} (Table 1); and no change in P_{CO_2} within 4 hours after IV administration began. There were significant differences in pH, base excess, and HCO_3^- between baseline and all subsequently measured values. Twenty-five of the 30 (83%) calves recovered and were discharged from the hospital in a healthy state.

The 20 calves that received HSBS had an immediate increase in venous blood pH, HCO_3^- concentration, and base excess; a small transient increase in P_{CO_2}; and no change in P_{O_2} within 0.5 hours after IV administration began. However, venous blood pH and blood HCO_3^- concentrations in those calves decreased gradually after the 0.5-hour point. There were significant ($P < 0.05$) differences between baseline and subsequent measurements with respect to pH, base excess, and HCO_3^-. Seventeen (85%) calves recovered and were discharged from the hospital in a healthy condition. This proportion was similar ($P = 0.60$) to that for ISBS-treated calves.

The rate of systemic alkalinization was similar between the 2 treatment groups within 2 hours after IV sodium bicarbonate solution began, as indicated by values for jugular venous blood pH, HCO_3^- concentration, base excess, and anion gap.

Blood SID and SIG—Low measured SID was detected in all calves, indicating the presence of marked strong ion acidosis. Although small changes in SID_3 were evident in ISBS-treated calves, SID_3 in HSBS-treated calves was higher than the upper reference limit at 0.5 hours after administration began and remained high for the duration of the study. A large, negative blood SIG was evident in both calf groups before treatment, indicating the presence of a quantitatively important amount of strong anions. The large, negative SIG decreased during the first 30 minutes after administration of sodium bicarbonate solution began but remained stable during the study (Table 1).

Serum biochemical analysis—Biochemical concentrations did not differ significantly between ISBS- and HSBS-treated calves at baseline. Furthermore, there were no significant differences between groups in blood Cl^- and serum glucose concentrations and urea at any point during the experiment, except that total protein and albumin concentrations were significantly lower than baseline values. Blood Na^+ concentration increased during sodium bicarbonate treatment, whereas blood potassium concentration decreased (Table 1).

Plasma volume—Plasma volume increased in calves treated with ISBS and HSBS (**Figure 3**). However, there were

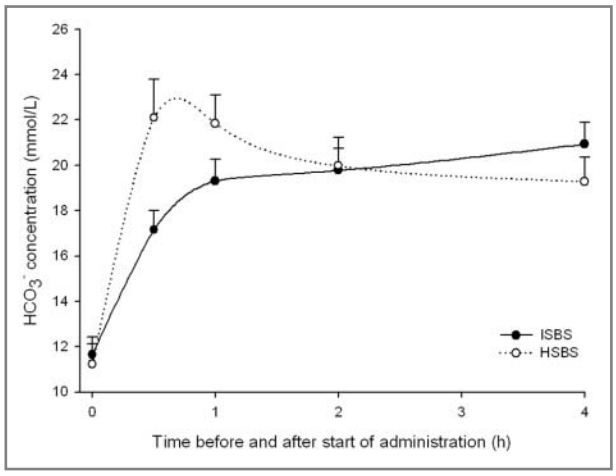

Figure 1—Mean ± SE blood HCO_3^- concentration before (0 hours) and 0.5, 1, 2, and 4 hours after IV administration of ISBS (65 mL/kg [29 mL/lb]; n = 30 calves) over 3 hours or HSBS (10 mL/kg [4.5 mL/lb]; 20 calves) over 20 minutes in severely dehydrated, diarrheic calves.

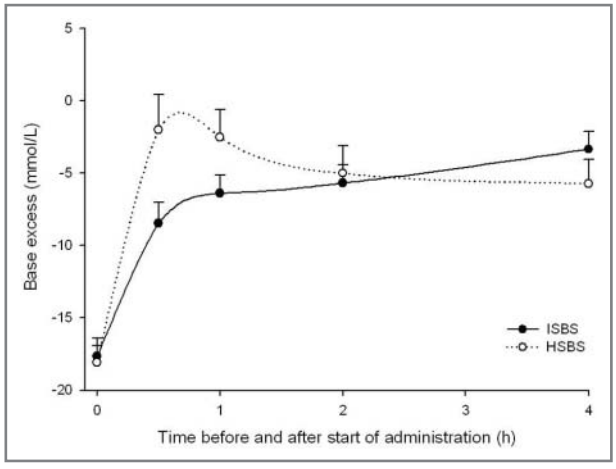

Figure 2—Mean ± SE jugular venous base excess before (0 hours) and 0.5, 1, 2, and 4 hours after IV administration of ISBS (65 mL/kg; n = 30 calves) over 3 hours or HSBS (10 mL/kg; 20 calves) over 20 minutes in severely dehydrated, diarrheic calves.

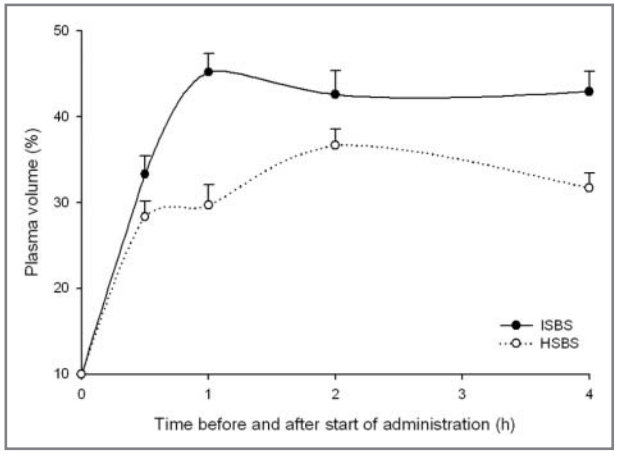

Figure 3—Mean ± SE plasma volume in venous blood obtained before (0 hours) and 0.5, 1, 2, and 4 hours after IV administration of ISBS (65 mL/kg; n = 30 calves) over 3 hours or HSBS (10 mL/kg; 20 calves) over 20 minutes in severely dehydrated, diarrheic calves.

no significant differences in the changes in plasma volumes for calves in either group during the experiment.

Discussion

The results of the present study suggested that IV administrations of 1.3% and 8.4% sodium bicarbonate solutions were similarly effective in treating acid-base abnormalities in calves with marked strong ion acidosis. Administration of HSBS led to a more rapid improvement of venous acid base abnormalities than did administration of ISBS.

Acidemia and strong ion acidosis are common in sick calves.[25] To correct strong ion acidosis, sodium bicarbonate is particularly effective because it has a high effective SID when administered IV.[13,25,26] Systemic sodium bicarbonate administration more rapidly alkalinizes the blood, compared with metabolizable bases such as sodium L-lactate and sodium acetate.[27] In the present study, IV infusion of 8.4% sodium bicarbonate solution resulted in increases in blood HCO_3^- concentration, base excess, and venous blood pH faster than IV infusion of 1.3% sodium bicarbonate solution within 0.5 hours after administration began. Administration of HSBS led to an immediate correction of the strong ion acidosis. The more rapid increase in blood HCO_3^- concentration following administration of HSBS versus ISBS was accompanied by a more rapid increase in blood pH. Infusion of HSBS resulted in a transient increase in venous P_{CO_2}, from 43 to 48 mm Hg within 0.5 hours after the beginning of the infusion, but this increase in P_{CO_2} was not significant.

Gram-negative bacterial infections are common in calves from birth to the first few days of age,[13] and endotoxemia is an important cause of illness and death in neonatal calves.[28] In the present study, 8 (16%) calves died. Death in these calves was attributed to preexisting septicemia and hypoglycemia, and the mortality rate was similar for both treatment groups. Venous blood pH was lower in nonsurviving versus surviving calves. However, P_{CO_2} and SIG values of nonsurvivors were higher than those of survivors. Endotoxemia can result in lactic acidemia and both hyperglycemic and hypoglycemic responses. Hypoglycemia develops early and transiently in endotoxic shock, is accompanied by an increase in glucose production rate, and depends on mobilization of hepatic glycogen stores.[13] In the present study, the serum glucose concentration of nonsurviving calves was lower than that of surviving calves.

When serum total protein, albumin, and phosphate concentrations are highly abnormal, it is suggested that acid-base status should be evaluated by use of the simplified strong ion approach.[11] In our study, baseline values of serum total protein concentration were higher than the upper reference limit in both groups. On the other hand, small changes in values for blood Cl^- concentrations in treated sick calves were also detected. Correction of the acid-base abnormalities after IV administration of ISBS or HSBS led to an increase in blood Na^+ and blood Cl^- concentration and a decrease in serum total protein concentration. A large, negative SIG in both treatment groups was indicative of the presence of unmeasured strong ions, which were most likely D- or L-lactate. The SIG values remained markedly high and blood pH moderately low at 4 hours after administration of sodium bicarbonate solution began, indicating that calves still had a strong ion acidosis. A decrease in plasma SID directly causes a strong ion acidosis and acidemia.[9] In the present study, measured SID (SID_3) was 40.9 mEq/L for ISBS-treated calves and 42.3 mEq/L for HSBS-treated calves. Although SID values in the ISBS group increased slightly but nonsignificantly, SID values in the HSBS group indicated an immediate increase 0.5 hours after infusion began. These SID values remained high during the remainder of the study period.

The higher effective blood SID in HSBS versus ISBS calves suggested acid-base abnormalities improved more rapidly after HSBS administration than after ISBS administration.[26] Administration of HSBS in calves with strong ion acidosis did not cause a deterioration in general condition of the calves. This finding is in agreement with the findings of other researchers, who reported that rapid IV administration of HSBS did not cause a clinically important or statistically significant increase in P_{CO_2}.[27] Another research group reported that IV administration of HSBS is appropriate in calves without respiratory problems with more severe metabolic acidosis (base excess ≤ –20mM).[29] A 5% hypertonic sodium bicarbonate formulation was used for the treatment of newborn calves with asphyxia and mixed (respiratory and metabolic) acidosis, and clinically relevant adverse effects reportedly did not develop.[30] There was also no increase in blood P_{CO_2} to indicate the development of a paradoxical acidosis in blood.

Intravenous administration of ISBS has become a widely accepted treatment option for diarrheic calves on the basis of results of randomized, controlled clinical trials[26,31] because ISBS rapidly corrects metabolic acidosis and dehydration to restore normal cellular function.[12] In the present study, IV administration of ISBS resulted in gradual increases in blood pH and base excess values and blood HCO_3^- concentration during the first 4 hours after administration began. This treatment also did not alter blood P_{CO_2} values. A dose of 1 to 4 L of ISBS is recommended for IV treatment of calves with diarrhea.[7,32] Our findings were similar to those of other studies that found IV infusion of ISBS is beneficial in calves with metabolic acidosis. Taken together, these findings might suggest that IV infusion of HSBS would also be beneficial in the treatment of calves with strong ion acidosis. However, HSBS should be used with caution in calves with strong ion acidosis that have concurrent respiratory disease.

Intravenous fluid therapy is necessary in severely dehydrated, clinically depressed calves with diarrhea.[14,32] In the present study, all calves had a degree of dehydration > 10%, and blood Na^+ concentration was increased by infusion of ISBS and HSBS, whereas blood K^+ concentration significantly decreased. Total body K^+ concentration decreases in diarrheic calves; however, hyperkalemia is often present in diarrheic calves with severe acidosis.[33,34] Administration of HSBS was unable to achieve the effect of correcting dehydration in diarrheic calves during the study period. This failure was most likely attributable to insufficient IV fluid therapy.

Assuming 10% dehydration in a calf with a euhydrated body weight of approximately 20 to 40 kg, 2 to 4 L of free water was required to correct the dehydration of the calves. Although serum total protein and albumin concentrations were significantly reduced after infusion of ISBS or HSBS, no apparent clinical improvement in degree of dehydration of HSBS-treated calves was observed. The HSBS-treated calves received approximately 200 to 400 mL of HSBS, whereas ISBS-treated calves received 1,625 to 2,600 mL of ISBS. Many calves in both groups were still mildly acidemic and moderately dehydrated within 4 hours after administration began, requiring follow-up parenteral or oral fluid supplementation. The beneficial restoring effects of hypertonic solutions are primarily attributable to rapid plasma volume expansion.[13] However, increases in plasma volume over time were nonsignificant in both treatment groups in our study.

The results of the study reported here suggested that IV administrations of 1.3% and 8.4% sodium bicarbonate solutions are similarly effective in the correction of strong ion acidosis in severely dehydrated, diarrheic calves. Plasma volume in ISBS- and HSBS-treated calves increased slightly but insignificantly during the experiment. Intravenous administration of HSBS in small volumes provided a quick, practical, and effective improvement of severe acid-base abnormalities. The persistent high SIG is probably the strongest argument to correct acid-base imbalances with sodium bicarbonate initially and to advocate immediate volume expansion in severely dehydrated calves with strong ion acidosis attributed to D- or L-lactate.

a. Sefazol, Mustafa Nevzat ilaç Sanayi AŞ, İstanbul, Turkey.
b. Flumed, Alke, Pendik, Istanbul, Turkey.
c. GEM Premier Plus, Instrumentation Laboratory, Lexington, Mass.
d. Spinreact, Spinreact SA, Olot, Spain.
e. Automatic analyzer, Abbott Laboratories, Abbott Park, Ill.
f. SPSS, version 10.0 for Windows, SPSS Inc, Chicago, Ill.

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