Acid Base Balance and Electrolyte Therapy

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The laboratory evaluation of acid base and electrolyte status in cattle has two purposes. The data are useful to identify pathogenic mechanisms and hence, diagnosis, and secondly, the data are a prerequisite to effective fluid therapy. The serum measurements required are Na+, K+, Cl– and HCO_3- concentrations. The latter is commonly measured as "total CO_2 content" (TCO_2). These anions and cations are routinely measured by flame photometry, ion-specific analyzer or other instrumentation common to all medical or veterinary laboratories. The TCO_2 can be accurately measured in the practitioner's laboratory without expensive equipment using a commercial kit.[a] From a practical standpoint, reference values for electrolytes in cattle, listed in Table 1, are interchangeable between laboratories. Ion-specific analyzers yield values for Cl- and Na+ that are slightly higher than other methods. The sample required for Na+, K+, Cl- and TCO_2(HCO_3-) concentrations is nonhemolyzed serum. Each electrolyte is stable for extended periods at 4°C. Clots should be removed soon after sample collection, and hemolysis should be avoided because falsely high serum K+ concentration occurs with lysis of erythrocytes in bovine samples.

Whereas Na+, K+, Cl- and TCO_2 (HCO_3-) are routinely measured in the laboratory, serum contains numerous other anions and cations which are usually not routinely measured. The so-called unmeasured cations are Ca++ and mg++, but these are occasionally measured to evaluate certain bovine diseases; we will not discuss these cations further in this paper.[b] The unmeasured anions are HPO_4- SO_4-, protein, and the organic acids, ketoacids and lactic acid. The former three remain quite constant in health and disease, but the latter two, ketoacids and lactic acid are variable in metabolic disorders of cattle. In health and disease, serum concentrations of anions always equal that of cations. A useful value is the calculated amount of unmeasured anions derived by the following formula:

$$[\text{UNMEASURED ANION}] = [\text{Na+} + \text{K+}] - [\text{CL-} + TCO_2]$$

The concentration of unmeasured anions derived by this formula is unfortunately referred to in medical and veterinary literature as the "anion gap". It isn't a gap at all, but it represents real anions, two of which change in concentration during metabolic disease. By applying the formula to the routinely measured electrolytes, Na+, K+, cl- and TCO_2 (HCO_3-), a fifth useful value, the anion gap, can be derived. Reference values for the unmeasured anion concentration (anion gap) are in Table 1.

TABLE 1. Reference values for serum electrolyte concentrations in cattle.

mEq/l			
Cations		Anions	
Na^+	132-152	HCO_3^-	20-30
K^+	3.9-5.8	Cl^-	97-111
		Unmeasured Anions	14-21

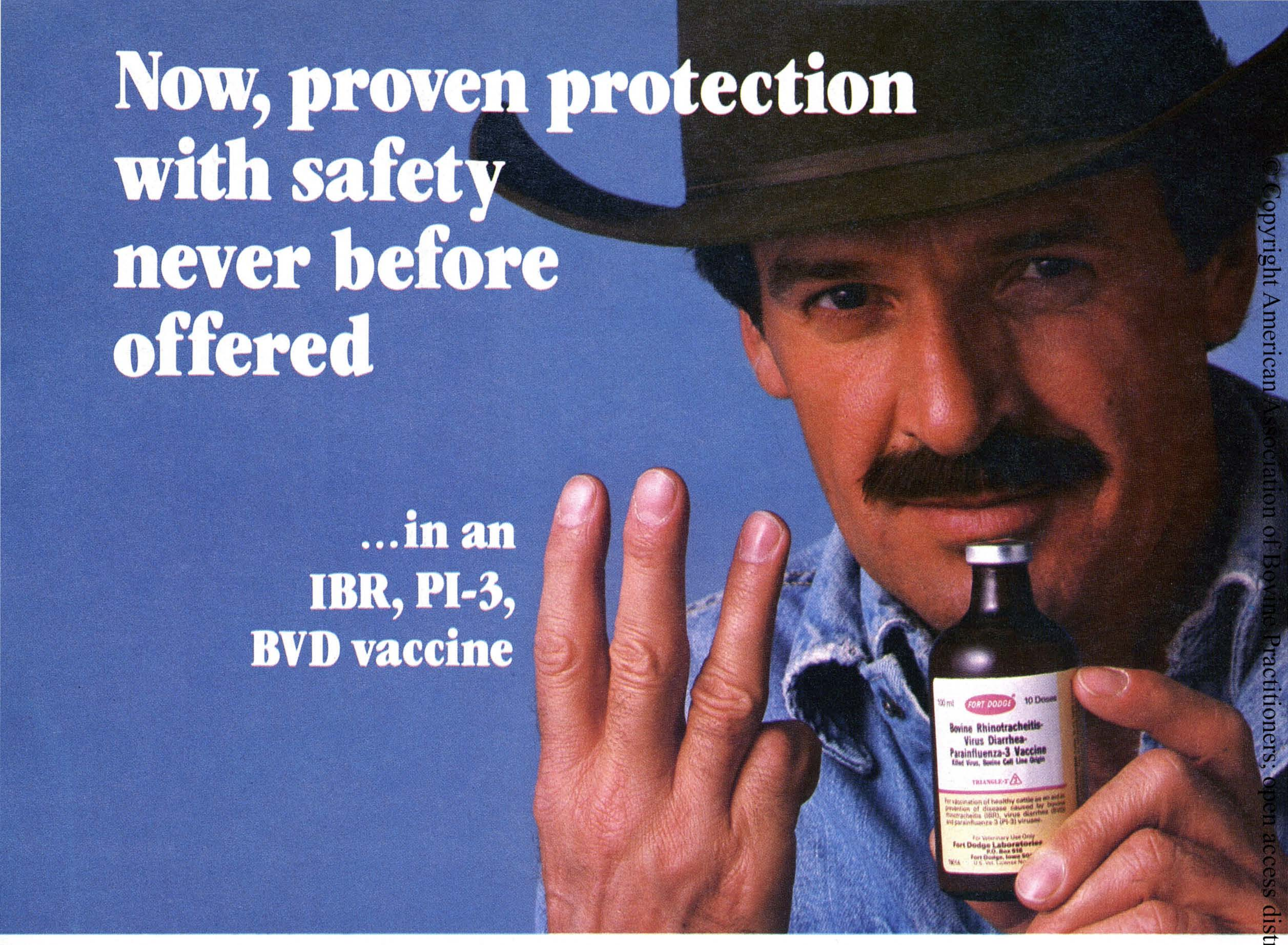
Differentiation of Mechanisms of Acid Base and Electrolyte Imbalance and Disease Diagnosis

Disorders of acid base balance are separated into respiratory disturbances and metabolic disturbances. Respiratory acid base imbalance is characterized by shift in pH due to altered concentration of CO_2 gas. Metabolic acid base imbalance is characterized by shift in pH due to altered HCO_3- (TCO_2) concentration. Since the clinical differential diagnosis of respiratory disease is not dependent on laboratory assessment of acid base balance, and since treatment of respiratory diseases rarely requires electrolyte fluids, this type of acid base disturbance will not be discussed

a. Harleco CO_2 Apparatus, Harleco, 480 Democrat Road, Gibbstown, New Jersey.

b. Ca++ and Mg++ are usually reported in mg/dl. Consequently their concentrations can not be used in the equation for anion gap.

Acknowledgement: Drs. Douglas Kemp and Douglas Byars, University of Georgia Veterinary Medical Teaching Hospital, are gratefully acknowledged for their advice and help in preparation of this paper.



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Fort Dodge Laboratories, Fort Dodge, Iowa 50501 in this paper. Differential diagnosis of diseases that cause metabolic acid base imbalance is aided by laboratory assessment, and treatment of these diseases often includes electrolyte fluids.

Metabolic acid base imbalance can be separated into two types, metabolic acidosis and metabolic alkalosis. In the former, HCO_3^- (TCO_2) concentration is low, and in the latter, it is high.

Two pathogenic mechanisms cause metabolic acidosis, low HCO_3^- (TCO_2) concentration: (1) loss of HCO_3^- rich secretions; and (2) endogenous production of excess organic acids such as ketoacids, lactic acid or uremic acids. Bovine diseases causing metabolic acidosis by loss of HCO_3^- rich secretions are diarrheal diseases and diseases characterized by excessive salivation, rabies, actinobacillosis, upper digestive system foreign body or organophosphate toxicity. Duodenal, pancreatic and salivary secretions rich in HCO_3^- are produced with a net bodily gain in H^+ and net loss in HCO_3^-. Normally, HCO_3^- in these secretions is reabsorbed so that acid base balance is maintained. Bovine diseases causing metabolic acidosis by endogenous production of excess organic acids are ketosis (ketoacidosis), shock, grain overload and septic metritis/mastitis (lactic acidosis) and uremic acidosis of renal failure. (A paradoxical imbalance occurs in renal failure, and it will be explained later in this paper.) The organic acids dissociate yielding a H^+ ion and an anion. The H^+ ion is titrated by the bicarbonate buffer system, and hence HCO_3^- (TCO_2) concentration is low.

If HCO_3^- (TCO_2) concentration is low, the animal most likely has metabolic acidosis. If the unmeasured anion concentration (anion gap) is normal, the metabolic acidosis is probably caused by excessive loss of HCO_3^- rich secretions. If the unmeasured anion concentration (anion gap) is high, the metabolic acidosis is probably caused by endogenous production of organic acids.

Metabolic alkalosis in cattle is generally caused by one pathogenic mechanism, abomasal acid trapping and net HCO_3^- gain. Cattle with metabolic alkalosis are almost always hypochloremic. The abomasal secretion of HCl results in the loss of the H^+ ion to the gut lumen and retention of the HCO_3^- anion in extracellular fluid. A Cl^- ion is also lost into the gut lumen. Normally these ions, H^+ and Cl^- are reabsorbed as abomasal contents progress down the tract, and acid base and electrolyte balance are maintained. When abomasal emptying is impaired, alkalosis and hypochloridemia develop.

Bovine diseases causing metabolic alkalosis and hypochloridemia are left or right abomasal displacement, abomasal torsion, small intestinal obstruction, omasal obstruction (less severe), cecal volvulus, vagal indigestion (abomasal atony) and protracted hypocalcemia. Two other diseases may cause abomasal atony or impaired abomasal emptying, ketosis and renal failure. In these two diseases, the production of ketoacids or uremic acids may have milk offsetting effects on the degree of alkalosis, but hypochloridemia is unaffected, and the concentration of unmeasured anions increases. If the disease causing metabolic alkalosis is a type in which shock may occur, lactic acid production may have a similar effect to that of ketoacids or uremic acids, i.e. tempered alkalosis and increased concentration of unmeasured anions.

Consequently, bovine metabolic alkalosis may be separated into two types: (1) abomasal acid trapping with net HCO_3^- gain and normal unmeasured anion concentration (normal anion gap); and (2) abomasal acid trapping with net HCO_3^- gain and concomitant lactic acidosis, ketoacidosis or uremic acidosis. Most cattle with renal failure and uremia are characterized by metabolic alkalosis, hypochloridemia and high unmeasured anion concentration.

Disturbances of acid base and electrolyte balance in animals are usually characterized by normonatremia, because water and Na^+ depletion are usually proportional. However, in cattle with large losses of intestinal fluid in diarrheal diseases, dietary salt deficiency and renal disease hyponatremia may be observed. Hyperkalemia, a potentially life threatening circumstance, occurs in association with acidosis in some cases, and it is marked in cattle with massive skeletal muscle necrosis. Falsely high serum K^+ due to hemolysed serum must always be considered in the interpretation of hyperkalemia. Hypokalemia is very common in unhealthy cattle, and it is generally attributed to lack of dietary intake as a consequence of anorexia.

Several cases with acid base, electrolyte and other pertinent data are listed in Table 2. These cases illustrate the changes discussed in this paper.

Treatment of Bovine Acid Base and Electrolyte Imbalance

Treatment of cattle for acid base and electrolyte imbalance can be accomplished in an economical and practical manner. The first consideration is the volume of fluid required by the patient in question:

ESTIMATED % DEHYDRATION × Kg BODY WT
= LITERS OF FLUID REQUIRED
(Based on Clinical Assessment)

Ten liter *polypropylene* carboys[c] (polyethylene carboys melt if autoclaved) can be adapted to accept a bell IV set.[d]

The second consideration is the selection of fluid. Isotonic, so-called "normal", electrolyte solutions can be used for fluid replacement, *but they do not correct acid base*

c. Nalge #2319-0020, Nalge Company, Rochester, New York.

d. The spigots may not withstand repeated autoclaving. For alternatives, consult Dr. Douglas Kemp, Clinical Pharmacist, University of Georgia Teaching Hospital.

TABLE 2. Bovine Cases with Acid Base and Electrolyte Imbalance.

	Calf, 3 Da. Diarrhea	Lactating Cow, 5 Yr. Anorexia Off Milk Production	Bull, 4 Yr. Distended Abdomen Scant Feces	Heifer, 3 mo. Anorexia Weight Loss Polyuria
PCV %	47	ND	37	37
Plasma Protein, g/dl	8.6	ND	9.3	8.5
BUN, mg/dl	60	63	9	295
Creatinine, mg/dl	ND	ND	3.8	21
Urine Sp. G.	ND	1.024	1.035	1.014
Na^+, mEq/l	138	134	146	123
K^+, mEq/l	7.6	2.9	2.9	1.6
Cl^-, mEq/l	121	72	60	56
TCO_2, mEq/l	4.7	45.4	51.4	45
Unmeasured Anions, mEq/l (Anion Gap)	19.9	19.5	37.5	23.6

Interpretations:

Calf: Metabolic acidosis, normal anion gap, bicarbonate loss. Dx = Colibacilosis. The calf was estimated to weigh 70 kg and to be 7% dehydrated. The amount of fluid replacement needed = 70 kg x .07 = 4.9 liters. The bicarbonate deficit = 70 kg x .30 x (25 mEq-4.7 mEq)=405 mEq; 405 mEq÷12.5 mEq/gm = 32.4 grams $NaHCO_3$. The calf was given the bicarbonate in a liter of 5% dextrose IV over 1 hour, and the remaining volume, 3.9 liters, was replaced with lactated Ringers IV. Serum glucose and K^+ were rechecked to correct hypoglycemia and hypokalemia that might have occurred as a consequence of fluid therapy.

Lactating Cow: Metabolic alkalosis, normal anion gap, abomasal acid trapping. Dx = Left Displaced Abomasum

Bull: Metabolic alkalosis, high anion gap, abomasal acid trapping, secondary organic acidosis. Dx = Abomasal Torsion

Heifer: Metabolic alkalosis, high anion gap, abomasal acid trapping, uremic acidosis. Dx = Acorn Poisoning

or electrolyte imbalance. Therefore, it may be necessary to provide acidifying fluid to correct alkalosis or alkalinizing fluid to correct acidosis. Bovine metabolic acidosis must be corrected by addition of bicarbonate to the replacement fluid. The formula to determine how much HCO_3^- to give is as follows:

(1) Kg BODY WT × 30% × [BOVINE HCO_3^- REFERENCE VALUE (25) - PATIENT'S HCO_3^- (TCO_2)] = mEq HCO_3^- REQUIRED

(2) mEq HCO_3^- REQUIRED ÷ 12.5 mEq/GRAM = GRAMS $NaHCO_3$ REQUIRED

This amount of $NaHCO_3$ can be added to: (1) isotonic Na Cl solution;

(2) 5% dextrose in water; or (3) up to 25 grams $NaHCO_3$/500 ml water can be directly given IV slowly. $NaHCO_3$ should not be added to lactated Ringers or Ringers solution, because a precipitate will form. The practical dilemma at this point is that $NaHCO_3$ solutions can not be autoclaved. At the University of Georgia, these solutions are filtered prior to use.[e]

Bovine metabolic alkalosis is most often corrected by treatment of the disease entity causing the imbalance. Establishing normal abomasal function rapidly reverses the alkalotic state. On rare occasions with critical patients, acidifying solutions must be administered. Unfortunately no easy formulas are in common use to determine the acid equivalent to be given. One cocktail recommended by the University of Georgia Veterinary Medical Teaching Hospital is as follows: NH_4Cl 54 grams plus KCl 40 grams mixed with distilled H_20 qsad 500 ml. This 500 ml **concentrate** is diluted with 10 liters of sterile isotonic saline

e. 0.2 Micron Pharmacy Filter, Cat. #PF2000, Burron Medical Inst., 824 Twelfth Ave., Bethlehem, Pennsylvania. (800-523-9695).

and given IV. The amount of fluid given is determined by the formula given above in this report.

The last consideration in fluid selection concerns potassium. If the patient is hyperkalemic, K+ containing solutions should be avoided. However if the patient is hypokalemic, KCl should be added to the replacement fluid. The same formula for calculating HCO_3^- required can be used to calculate the mEq of K+ required. The mEq K+ required divided by 14 mEq/gram equals grams KCl required. This amount of K+ should be added to the replacement fluid volume. Serum K+ should be reevaluated during the course of fluid therapy.

An example of how the therapy considerations are applied is given for one case listed in Table 2.

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