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Influence of different oral rehydration solutions on abomasal conditions and the acid-base status of suckling calves

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ABSTRACT

The aim of the study was to investigate the influence of oral rehydration solutions (ORS) on milk clotting, abomasal pH, electrolyte concentrations, and osmolality, as well as on the acid-base status in blood of suckling calves, as treatment with ORS is the most common therapy of diarrhea in calves to correct dehydration and metabolic acidosis. Oral rehydration solutions are suspected to inhibit abomasal clotting of milk; however, it is recommended to continue feeding cow's milk or milk replacer (MR) to diarrheic calves to prevent body weight losses. Three calves with abomasal cannulas were fed MR, MR-ORS mixtures, or water-ORS mixtures, respectively. Samples of abomasal fluid were taken before and after feeding at various time points, and pH, electrolyte concentrations, and osmolality were measured. The interference of ORS with milk clotting was examined in vivo and in vitro. To evaluate the effects of ORS on systemic acid-base status, the Stewart variables strong ion difference ([SID]), acid total ($[A_{tot}]$), and partial pressure of CO_2 (pCO_2) were quantified in venous blood samples drawn before and after feeding. Calves reached higher abomasal pH values when fed with MR-ORS mixtures than when fed MR. Preprandial pH values were re-established after 4 to 6 h. Oral rehydration solutions prepared in water increased the abomasal fluid pH only for 1 to 2 h. Oral rehydration solutions with high $[SID_3]$ ($[Na^+] + [K^+] - [Cl^-]$) values produced significantly higher abomasal pH values and area under the curve data of the pH time course. Caseinomacropeptide, an indicator of successful enzymatic milk clotting, could be identified in every sample of abomasal fluid after feeding MR-ORS mixtures. The MR-ORS mixtures with $[SID_3]$ values $\geq$92 mmol/L increased serum $[SID_3]$ but did not change venous blood pH. Oral rehydration solutions do not interfere with milk clotting in the abomasum and can, therefore, be administered with milk. In this study, MR-ORS mixtures with high $[SID_3]$ values caused an increase of serum $[SID_3]$ in healthy suckling calves and may be an effective treatment for metabolic acidosis in calves suffering from diarrhea.
Key words: calf, milk clotting, oral rehydration solution, strong ion difference

INTRODUCTION

Acidemia and metabolic acidosis are important disorders of acid-base status in diarrheic calves (Hartmann et al., 1997). Neonatal diarrhea is the most common cause of death of calves in their first weeks of life (USDA, 2007) and is accompanied by a decrease of blood pH (Lorenz et al., 2005). Mortality, deprivation of calves, and treatment costs of neonatal diarrhea cause high economic losses in the cattle industry (Weigler et al., 1990).

Treatment with oral rehydration solutions (**ORS**) is the most common therapy for diarrheic calves with a sufficient suckle reflex. It is a cheap and effective method for the correction of dehydration and metabolic acidosis (Nappert and Spennick, 2003). Because feeding low-energy ORS exclusively causes gross energy deficits, it is advisable to continue feeding milk to prevent BW losses (Heath et al., 1989; Garthwaite et al., 1994). However, ORS are also known to increase abomasal fluid pH (Constable et al., 2006), thereby possibly inhibiting abomasal clotting of milk.

Currently, the acid-base status of humans and animals is evaluated by the Henderson-Hasselbalch equation. However, because the Henderson-Hasselbalch approach can only be accurately applied to plasma at approximately normal conditions in body temperature, blood pH, serum protein, and sodium concentration, its utility is minimized for describing disturbances of acid-base status in ruminants (Constable, 1999). In the 1980s, Peter Stewart generated the strong ion model of acid-base status, offering an invaluable novel

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insight into the pathophysiology of mixed acid-base disorders (Constable, 1999). According to this model, 3 independent variables of the acid-base status exist: 1) strong ion difference (**SID**) = strong cations minus strong anions; 2) acid total ($\mathbf{A_{tot}}$) = total concentration of nonvolatile weak acids; and 3) partial pressure of carbon dioxide ($\mathbf{pCO_2}$; Stewart, 1981). According to Stewart, SID, A_{tot}, and pCO_2 are the primary variables of acid-base status, and all other variables (e.g., pH/$[H^+]$, $[HCO_3^-]$) are secondary variables derived from the primary variables.

Sodium and chloride concentrations are the major components of [SID] (i.e., concentration of SID) as they are quantitatively the most important ions in the extracellular fluid (Constable, 1999). Other strong ions are potassium, magnesium, calcium, and sulfate; however, these ions have a less dominant role in adjusting the plasma pH because of their low plasma concentrations and smaller variability. In addition, lactate and other organic acids such as BHBA or acetoacetate behave like strong ions in plasma and are completely dissociated at physiological pH. Furthermore, some plasma ions, especially anions such as sulfate, BHBA, or other organic acids, cannot be determined or are not detected routinely (Constable, 1997). Therefore, the determination of [SID] is an approximate calculation and is predominantly expressed as $[\mathbf{SID_3}] = [Na^+] + [K^+] - [Cl^-]$ (mmol/L) or $[\mathbf{SID_4}] = [Na^+] + [K^+] - [Cl^-] - [\text{lactate}^-]$ (mmol/L) (Constable et al., 2005b). An increase of [SID] leads to alkalosis, and a decrease leads to acidosis (Constable, 1999).

In contrast to the buffer ion HCO_3^- (an open buffer system affected by pCO_2), the elements of A_{tot} are nonvolatile. Acid total is particularly represented by albumin and phosphate, but bovine globulins have a net negative charge and thus are also considered to be a fraction of A_{tot} (Constable, 2002). Determination of $[A_{tot}]$ (i.e., concentration of A_{tot}) in calf serum is possible by using the method of Constable et al. (2005b): $[A_{tot}]$ (mmol/L) = 0.343 (mmol/g) × [total protein] (g/L) or 0.622 (mmol/g) × [albumin] (g/L).

Recent studies have shown that acidemia in diarrheic calves is due to strong ion acidosis ($[Na^+]\downarrow$, $[Cl^-]\uparrow$, $[\text{lactate}^-]\uparrow$) and nonvolatile buffer ion acidosis ($[A_{tot}]\uparrow$) as a result of the dehydration [L. Bachmann, J. Berchtold (veterinary practice, Obing, Germany), C. Siegling-Vlitakis (Department of Veterinary Physiology, Freie Universitaet Berlin, Berlin, Germany), A. Willing and E. Radtke (Institute of Veterinary Diagnostics, Berlin, Germany), H. Hartmann; unpublished data; Constable et al., 2005b]. Furthermore, hyper-D-lactatemia frequently occurs in diarrheic calves and produces all the clinical signs attributed to metabolic acidosis (Lorenz et al., 2005). These findings imply that ORS should contain high values for SID; however, few studies have evaluated commercially available ORS on the basis of the Stewart variables (Staempfli et al., 1996).

The purpose of this study was to investigate the influence of ORS on abomasal electrolyte concentrations, pH, and osmolality, as well as on milk clotting and the acid-base status of suckling calves according to the Stewart model.

MATERIALS AND METHODS

Animals

Three male calves (aged 11, 15, and 23 d) obtained from local farms were surgically fitted with abomasal plastic cannulas as described previously (Reinhold et al., 2006) and kept in calf boxes with rubber mats and straw bedding. Experiments were approved by federal authorities for animal research (LAGeSo, Berlin, Germany) and conducted in accordance with the principles and specific guidelines presented in the *Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching* (FASS, 1999). Before the start of experiments and between 2 experimental phases, calves were fed 4 times a day (0800, 1400, 1900, and 2230 h), with high-quality, all-milk-protein milk replacer (**MR**, 50.5% skimmed milk powder; 30% sweet whey powder; 15.5% vegetable oil, refined; 3% wheat starch; 2% additives).

Experimental Design

Experiments started 3 d after cannulation (calves at 14, 18, and 26 d; BW: 60–70 kg); the experimental period consisted of 5 d of experimental feeding, then 2 d for recovery, and then another 5 d of experimental feeding. Four ORS with different buffer ions were used: acetate (**ORS-1**; Bayer AG, Leverkusen, Germany), propionate (**ORS-2**, Chevita, Pfaffenhofen, Germany), bicarbonate (**ORS-3**, Albrecht, Aulendorf, Germany), and citrate (**ORS-4**, Pfizer, New York, NY) (Table 1). Depending on the preparation in water or MR and the amount of ORS used, different values for pH, osmolality, and $[SID_3]$ were measured or calculated for the mixtures (Table 2). During the experimental phases, calves received 2 L of MR, MR-ORS mixture (ORS-1A, ORS-1C, ORS-2A, ORS-3A, or ORS-4A), or water-ORS mixture (ORS-1B, ORS-2B, ORS-3B, or ORS-4B) at 0800 and 1400 h and were deprived of water and hay. Abomasal fluid samples were collected immediately before feeding and 30, 60, 120, and 240 min after feeding. Blood samples were taken by jugular vein puncture immediately before feeding, and 120 and 240 min after feeding. In the evenings (at 1900 and 2230 h), calves