Influence of Calcium Chloride on Systemic Acid-Base Status and Calcium Metabolism in Dairy Heifers[1]

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ABSTRACT

Twenty heifers (12 Holsteins and 8 Jerseys) ranging from 15 to 22 mo of age (SD = 2.2 mo) and weighing 271 to 486 kg (SD = 72 kg) were offered diets containing 0, .5, 1, and 1.5% $CaCl_2$ for 3 wk followed by a 1-wk readjustment period to evaluate the effect of $CaCl_2$ on acid-base status, diuresis, and Ca metabolism. These evaluations were conducted under conditions simulating changes in dietary cation-anion balance that potentially can be utilized as prophylaxis for parturient paresis during transition from dry cow period to lactation. Free proton concentration in blood increased and blood bicarbonate decreased with increasing dietary $CaCl_2$. Plasma protein and blood hematocrit were unaffected by dietary $CaCl_2$. Plasma Ca and urinary hydroxyproline excretion also were unaffected, but urinary Ca excretion rose with increasing dietary $CaCl_2$, possibly reflecting either increased bone mobilization or intestinal absorption of Ca. Elevating dietary Cl increased both plasma Cl and urinary Cl excretion. During the readjustment period, all differences caused by $CaCl_2$ disappeared. Based on the responses of acid-base status and Ca metabolism to the different dietary concentrations of $CaCl_2$, we suggest that feeding 1% $CaCl_2$ to dry cows for 3 wk prepartum could be a suitable method to prevent parturient paresis without causing detrimental acid-base disturbances.

(Key words: calcium chloride, calcium metabolism, acid-base status)

Abbreviation key: DCAB = dietary cation-anion balance, H^+ = free proton concentration, pCO_2 = partial pressure of CO_2.

INTRODUCTION

Calcium chloride is a hygroscopic Ca salt that has been administered therapeutically as a diuretic and urine acidifying agent (12). Animal science applications include castration (10), dehorning (9), regulation of feed intake (21), both i.v. therapy and peroral prophylaxis (8) for parturient paresis, and lowering the dietary cation-anion balance (DCAB) (19). Mongin (13) has defined DCAB as milliequivalents (Na + K) – Cl/100 g diet DM; $CaCl_2$ increases dietary Cl without increasing either Na or K, and so by this definition it lowers DCAB.

Reducing DCAB has been shown to lower blood pH in dairy cattle (19); therefore, it may encourage bone mobilization in order to provide systemic buffering capacity (6), with the consequential but potentially important release of bone Ca. This idea is supported by the work of Block (2), who reported that feeding a diet low in DCAB during the dry period completely prevented parturient paresis. In a similar study (5), $CaCl_2$ was utilized along with $MgCl_2$ and NH_4Cl to lower DCAB during the dry period; again, the incidence of parturient paresis during lactation was reduced. The efficacy of a low DCAB in preventing parturient paresis may be related either to a reduction in intestinal pH, yielding increased Ca absorption, or to activation of the parathyroid gland, resulting in increased mobilization of bone Ca. This response may require a positive Ca balance (11).

Calcium chloride possesses all the properties required to prevent parturient paresis. It lowers

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intestinal pH (1) and DCAB and provides supplemental Ca to increase Ca balance. In addition, it could be incorporated easily into the concentrate of the dry cow for 2 to 3 wk prepartum in practice. However, before widescale application can be recommended, the systemic effects of $CaCl_2$ on acid-base status and Ca metabolism in ruminants should be evaluated, and safe dietary concentrations should be established. Therefore, the objectives of this trial were to evaluate systemic effects of dietary $CaCl_2$ on nonlactating animals and to identify the dietary concentration of $CaCl_2$ that will yield optimal effects on Ca metabolism without eliciting adverse side effects.

MATERIALS AND METHODS

Twenty heifers (12 Holsteins and 8 Jerseys) ranging from 15 to 22 mo of age (SD = 2.2 mo) and weighing 271 to 486 kg (SD = 72 kg) were blocked according to breed, arranged in a randomized complete block design, and offered diets (Table 1) containing 0, .5, 1, and 1.5% $CaCl_2$ (DM basis) with DCAB of 20.2, 14.9, 8.1, and −11.7. Animals were housed together in free stalls, but they were individually limit-fed (approximately 95% of ad libitum intake) a mixture of corn silage and concentrate in a 64:36 ratio (DM basis) via transponder-controlled doors (American Calan Co., Northwood, NH). Animals were fed amounts of total diet designed to minimize orts; however, there was occasional feed refusal, and these orts were not weighed. Therefore, the DM and Ca intakes listed in Table 2 are presented as estimated values, and feed intake was not analyzed statistically. The trial consisted of a 1-wk adaptation period (wk 0) during which silage and a commercial heifer concentrate were fed, followed by a 3-wk experimental period (wk 1 to 3) during which heifers received one of the test

TABLE 1. Ingredient and nutrient composition of test diets.[1]

	Diets			
	0% $CaCl_2$	.5% $CaCl_2$	1.0% $CaCl_2$	1.5% $CaCl_2$
	(%)			
Ingredients				
Corn silage	64.5	64.5	64.5	64.6
Shelled corn	24.8	24.8	24.8	24.7
Soybean meal (44% CP)	8.1	8.1	8.1	8.1
Limestone	1.60	1.07	.54	0
Calcium chloride	0	.53	1.06	1.60
Dicalcium phosphate	.40	.40	.40	.40
Magnesium oxide	.20	.20	.20	.20
Dynamate[2]	.20	.20	.20	.20
Trace-mineralized salt[3]	.20	.20	.20	.20
Analyzed nutrient composition				
CP	12.1	12.1	11.5	11.8
TDN	74.2	74.3	74.2	74.0
ADF	20.6	20.5	20.6	20.8
NDF	48.0	46.8	53.8	54.4
Ca	.91	.92	.71	.92
P	.35	.36	.35	.36
Mg	.35	.39	.35	.35
Na	.08	.10	.08	.06
K	.92	.94	.92	.93
Cl	.24	.48	.67	1.35
S	.12	.12	.13	.13
meq((Na + K) − Cl)/100 g diet DM	20.2	14.9	8.1	−11.7

[1]Listed as percentage on DM basis.

[2]Double sulfate of K and Mg.

[3]Contained 3500 ppm Zn; 3400 ppm Fe; 2000 ppm Mn; 330 ppm Cu; 70 ppm I; and 50 ppm Co.

diets; it ended with a 1-wk period (wk 4) during which all heifers received the 0% $CaCl_2$ diet. The 4th wk was included to simulate the change to a diet for lactating cows (without $CaCl_2$) that would occur postpartum on a dairy farm and to evaluate the effects of removing $CaCl_2$ from the diet on several variables. Diets (Table 1) were formulated to meet established nutrient requirements of dairy heifers (14). Dietary Na concentration was slightly below recommended concentrations (14). The reason for the low Ca analysis for the 1.0% $CaCl_2$ diet is unclear, but the incremental increase in Cl concentration for this diet versus the .5% $CaCl_2$ indicates that the appropriate amount of $CaCl_2$ was added to the diet. The analysis of Cl concentration for the 1.5% $CaCl_2$ diet also was unexplainably high.

Samples of blood and urine were collected on the last day of each week at 4 h postfeeding, from the end of wk 0 to the end of wk 4. Blood was collected via jugular venipuncture with syringes, drawn into Na-heparinized, evacuated glass tubes (Beckton Dickinson Vacutainer Systems, Rutherford, NJ), placed on crushed ice and analyzed for pH, partial pressure of CO_2 (pCO_2) (Instrumentation Laboratory, Inc., Lexington, MA), and for hematocrit within 2 h. Samples then were centrifuged; the plasma was harvested into clean polystyrene tubes and frozen for subsequent analyses. A midstream urine sample was collected via manual stimulation of the vulva and analyzed for pH (Corning 150 pH/ion analyzer, Scientific Instruments, Medfield, MA), osmolality (Osmette A; Precision Systems, Inc., Sudbury, MA), creatinine (procedure number 555; Sigma Diagnostics, St. Louis, MO), and Cl. In addition, a 10-ml aliquot of urine was acidified with 300 μl of concentrated HCl and frozen for subsequent Ca analysis. Plasma and urine were analyzed for Ca via atomic absorption spectrophotometry (Perkin-Elmer, Model 560, Norwalk, CT) and for Cl via potentiometric titration (Haake Buch-

TABLE 2. Estimated intake and least squares mean response of blood and urine to dietary $CaCl_2$, averaged across wk 1, 2, and 3.

	Diets						
	0% $CaCl_2$	.5% $CaCl_2$	1.0% $CaCl_2$	1.5% $CaCl_2$	SE	Effect	*P*
Estimated DMI, kg/d	8.4	8.4	8.0	7.6			
Estimated Ca intake, g/d	76	76	56	70			
Blood H^+[1], neq/L	35.2	35.8	36.8	37.1	.5	Linear	.011
pH equivalent	7.45	7.45	7.43	7.43			
Blood HCO_3^-, meq/L	27.6	27.8	27.3	25.4	.5	Linear	.006
						Quadratic	.042
Blood pCO_2,[2] mm Hg	40.8	41.8	42.2	39.5	.9	Quadratic	.070
Hematocrit, %	34.2	33.2	34.7	34.8	.9		
Plasma protein, g/dl	6.85	6.21	6.67	6.46	.25		
Plasma Ca, meq/L	4.47	4.42	4.50	4.55	.08		
Urine Ca excretion[3]	.017	.043	.184	.295	.029	Linear	.001
Plasma Cl, meq/L	108.0	107.5	107.9	111.1	.5	Linear	.001
						Quadratic	.003
Urine Cl excretion[3]	.547	1.122	1.684	1.889	.158	Linear	.001
Urine H^+, neq/L	10	27	809	2.902	257	Linear	.001
pH equivalent	7.993	7.570	6.092	5.537		Quadratic	.002
Urine osmolality, mOsm/kg	634	639	488	693	94		
Urine OH-proline excretion, mg OH-proline/mg creatinine	.066	.071	.076	.070	.008		

[1]Free proton concentration.

[2]Partial pressure of CO_2.

[3]Expressed as urine mineral (meq/L)/urine creatinine (mg/dl).

ler Instruments, Inc., Saddlebrook, NJ). In addition, plasma was analyzed for total protein (procedure number 540; Sigma Diagnostics, St. Louis, MO), and urine OH-proline was determined according to the procedures of Parekh and Jung (15). Samples of the test concentrate mixes and corn silage were collected separately each week and analyzed for nutrient content via commercial laboratory.

Data were analyzed both by week and by average across wk 1 to 3 via SAS general linear models procedure (17); treatment, breed, and treatment by breed effects were included in the model. Residual error was the test term for all effects. When treatment effects were significant ($P < .10$), treatment sums of squares were partitioned into single degree of freedom contrasts to test for linear, quadratic, and cubic responses to increases in dietary $CaCl_2$. Blood and urine pH were converted to free proton concentration (H^+) for ANOVA; mean responses are presented both as H^+ and pH.

RESULTS AND DISCUSSION

Mean Response for Weeks 1 to 3

Blood H^+ increased linearly, whereas blood HCO_3^- decreased linearly as dietary $CaCl_2$ replaced dietary limestone (Table 2). Blood pCO_2 tended to respond quadratically with dietary $CaCl_2$ supplementation, falling as $CaCl_2$ increased from 1 to 1.5% of DM. Dietary supplementation of Cl with a relatively poorly absorbed cation (Ca) has been demonstrated to yield metabolic acidosis (19). As Cl absorption increases, blood HCO_3^- normally decreases (6), causing a reduction in blood pH. In the present study, plasma Cl was highest for the 1.5% $CaCl_2$ diet, and both plasma Cl and urinary Cl excretion (Table 2) increased linearly ($P = .001$) with increasing $CaCl_2$. Although blood H^+ was highest and HCO_3^- and pCO_2 were lowest on 1.5% $CaCl_2$, all values remained within the range of values reported as normal for cattle (3).

Calcium concentrations were formulated to be constant across all four diets, although estimated Ca intake appeared to be lower for 1% $CaCl_2$ (Table 2) because of the lower Ca content of this diet. Plasma Ca concentrations (Table 2) were similar for all diets; however, urinary Ca excretion clearly increased linearly with supplemental dietary $CaCl_2$. Similar responses were observed when lowering DCAB from 125.8 to 22.0 with cows (5) and from 45.8 to .7 with goats (4). This response to a reduction in DCAB likely is a major factor in the effectiveness of a low DCAB in preventing parturient paresis. The increased urinary Ca excretion that accompanies a low DCAB might be attributed to increased absorption of Ca (20), to increased mobilization of Ca from bone (4), to an acidosis-induced reduction in renal Ca reabsorption (16), or to a combination of these factors. Takagi and Block (18) reported that feeding low DCAB to sheep 1) increased true intestinal absorption of Ca, 2) reduced bone accretion, 3) increased urinary Ca excretion, and 4) increased the flux of Ca through the exchangeable Ca pool without changing the size of the pool. Feeding a low DCAB paradoxically increases urinary Ca excretion and provides protection against parturient paresis. The mechanism of action appears to be via an increase in Ca available to the cow for metabolic functions, which is reflected in the greater clearance of Ca via the kidneys.

Calcium chloride has been used as a diuretic agent (12). As such, it could potentially affect water balance. In this trial, hematocrit and

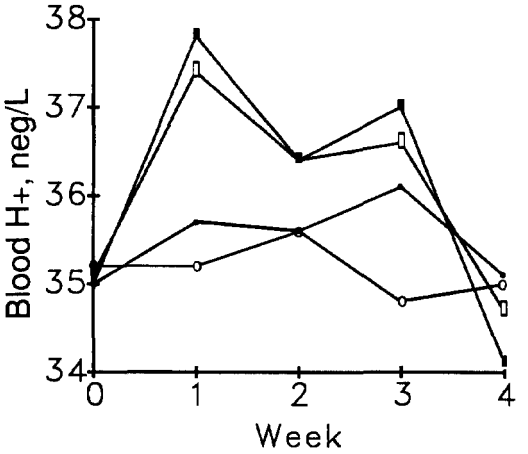

Figure 1. Blood free proton concentration (H^+) by week throughout the trial. ○ = Control; ● = .5% $CaCl_2$; ❐ = 1% $CaCl_2$; ■ = 1.5% $CaCl_2$. The SE for wk 0, 1, 2, 3, and 4 were .53, .89, .76, .44, and .56. Calcium chloride was included in diets during wk 1 to 3.

plasma protein concentration (Table 2) were utilized as indicators of extracellular fluid volume status; they were not affected by diet. Urine osmolality, monitored to evaluate urine dilution, also was unaffected.

Urine H^+ (Table 2) increased with increasing dietary $CaCl_2$, apparently in response to the acidogenic properties of $CaCl_2$. These results confirm the effectiveness of $CaCl_2$ as a urinary acidifying agent (12) and are in agreement with those of Tucker et al. (19). Urine OH-proline, utilized as an indicator of rate of Ca mobilization from bone, tended to increase with increasing dietary $CaCl_2$, but differences were not significant.

Temporal Analysis

Figure 1 presents changes in acid-base status throughout the trial. Blood H^+ increased sharply with the 1 and 1.5% $CaCl_2$ diets at wk 1. By wk 3, blood H^+ was higher than control for all diets containing $CaCl_2$. Blood H^+ decreased quickly to pretrial values when $CaCl_2$ was removed from the diets (wk 4). Blood HCO_3^- was affected most dramatically by the 1.5% $CaCl_2$ diet, a response that was evident within the first week of the study and was paralleled closely by changes in blood pCO_2 (Figure 2). Blood HCO_3^- and pCO_2 for cows

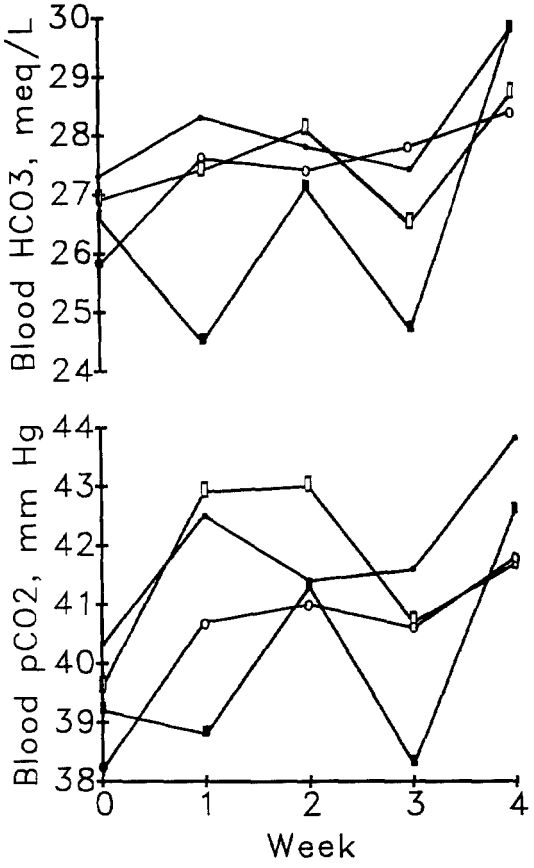

Figure 2. Blood HCO_3^- and partial pressure of CO_2 (pCO_2) by week throughout the trial. ○ = Control; ● = .5% $CaCl_2$; □ = 1% $CaCl_2$; ■ = 1.5% $CaCl_2$. The SE for blood HCO_3^- and pCO_2 for wk 0, 1, 2, 3, and 4 were .79, 1.54; .59, 1.37; .54, 1.05; .57, .81; and .55, 1.12. Calcium chloride was included in diets during wk 1 to 3.

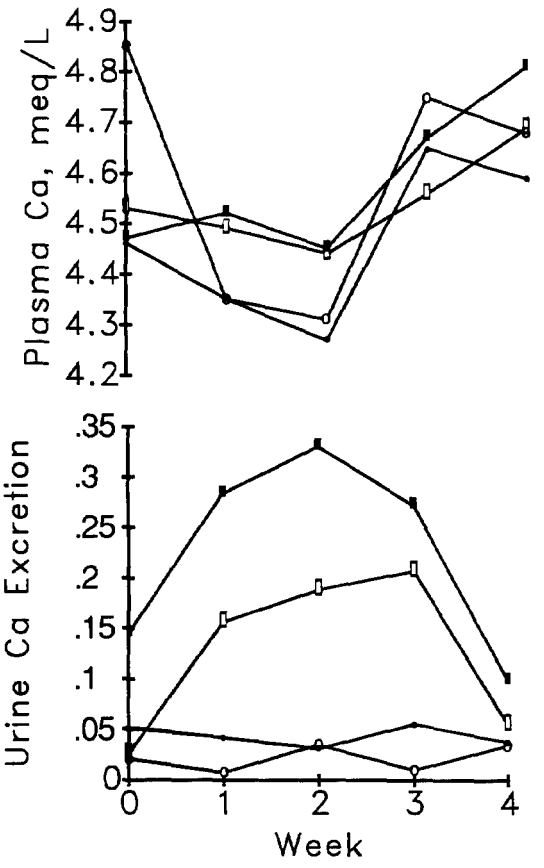

Figure 3. Plasma Ca and urine Ca excretion by week throughout the trial. ○ = Control; ● = .5% $CaCl_2$; □ = 1% $CaCl_2$; ■ = 1.5% $CaCl_2$. Ca excretion = urine Ca (meq/L)/urine creatinine (mg/dl). The SE for plasma Ca and urine Ca excretion for wk 0, 1, 2, 3, and 4 were .216, .0516; .075, .0327; .100, .0309; .119, .0372; and .055, .0309. Calcium chloride was included in diets during wk 1 to 3.

receiving $CaCl_2$ returned to means similar to control during wk 4; however, all values for wk 4 tended to be higher than initial values for the study (wk 0). The reduction in blood HCO_3^- with $CaCl_2$ supplementation likely is attributable to the acidogenic nature of Cl. The absence of sustained metabolic acidosis after $CaCl_2$ was removed from the diet indicates that the metabolic acidosis was quickly corrected and that feeding $CaCl_2$ to dry cows should have no adverse effect on systemic acid-base status once lactation begins.

Plasma Ca (Figure 3) was not affected by $CaCl_2$ during wk 1 to 3, but it was highest (NS) during wk 4 for heifers that had received 1.5% $CaCl_2$. Plasma Ca tended to increase for all diets during wk 3, but the largest increase was exhibited by heifers receiving the control diet; therefore, this increase cannot be attributed to $CaCl_2$ alone. At each week, urinary Ca excretion (Figure 3) increased linearly ($P < .001$) with $CaCl_2$ supplementation during wk 1 to 3, but this response disappeared during wk 4.

Both plasma Cl concentrations and urinary Cl excretion (Figure 4) tended to reflect the Cl concentration of the diet; plasma Cl was increased linearly ($P < .001$) by $CaCl_2$ during wk 3 only, but urinary Cl excretion increased linearly ($P < .04$) with $CaCl_2$ supplementation each week during wk 1 to 3. However, urine Cl excretion was similar for all diets during wk 4.

Previous research (19) has demonstrated that urine reflects the acidogenic nature of a low DCAB. In the present study, urine H^+ (Figure 5) responded quickly and dramatically to $CaCl_2$, increasing linearly ($P < .02$) with increasing $CaCl_2$ during wk 1 to 3. However, urine H^+ returned to pretrial values for all diets during wk 4, reflecting the decreased acidogenic diet challenge.

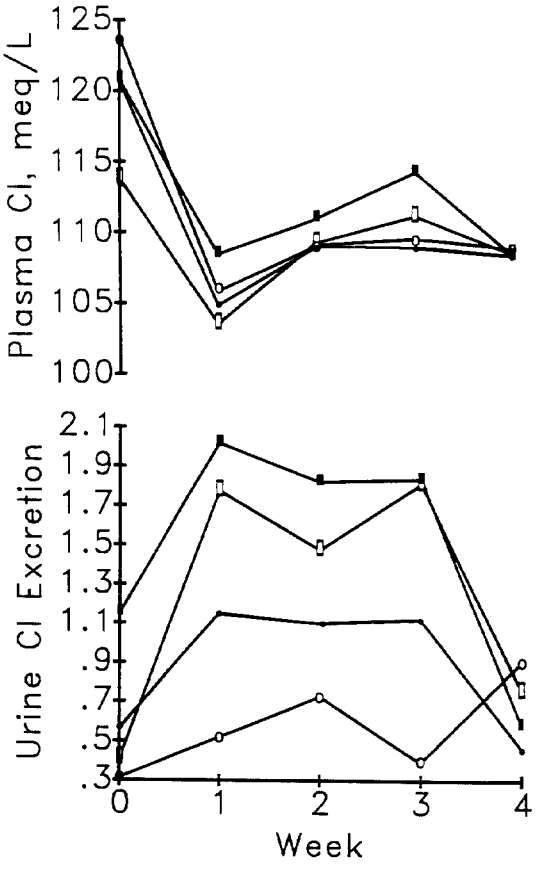

Figure 4. Plasma Cl and urine Cl excretion by week throughout the trial. o = Control; ● = .5% $CaCl_2$; ❐ = 1% $CaCl_2$; ■ = 1.5% $CaCl_2$. Cl excretion = urine Cl (meq/L)/urine creatinine (mg/dl). The SE for plasma Cl and urine Cl excretion for wk 0, 1, 2, 3, and 4 were 4.08, .3285; 1.26, .2781; .83, .3423; .86, .1432; and .94, .3163. Calcium chloride was included in diets during wk 1 to 3.

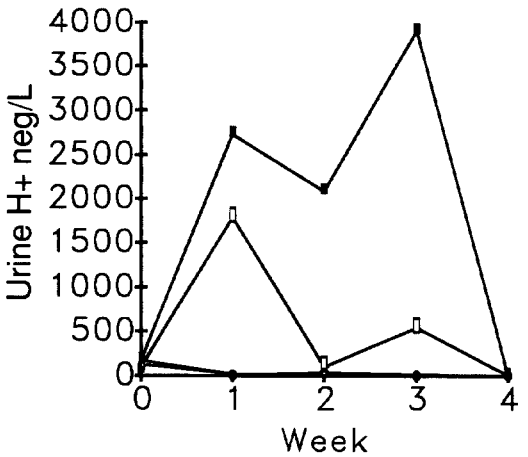

Figure 5. Urine free proton concentration (H^+) by week throughout the trial. o = Control; ● = .5% $CaCl_2$; ❐ = 1% $CaCl_2$; ■ = 1.5% $CaCl_2$. The SE for wk 0, 1, 2, 3, and 4 were 103, 748, 367, 323, and 1. Calcium chloride was included in diets during wk 1 to 3.

CONCLUSIONS

Feeding a diet with a low DCAB during the dry period presumably aids in the prevention of parturient paresis once lactation begins. Therefore, physiological changes effected by this diet are assumed to carry over into lactation. The rapid readjustment of acid-base status and mineral metabolism exhibited in this trial upon removal of $CaCl_2$ from the diets suggests that the prophylactic value of prepartum, acidogenic diets may be expressed during the first few days following parturition.

Alterations in acid-base status were most pronounced for diets with 1.0 and 1.5% $CaCl_2$. However, these diets also appeared to increase mobilization of Ca most markedly, as reflected by increased urine Ca excretion. Blood H^+ was similar for 1.0 and 1.5% $CaCl_2$, but 1.5% $CaCl_2$ caused a greater reduction in blood HCO_3^-. As evidenced by urinary Ca excretion and urine H^+, feeding 1% $CaCl_2$ apparently increased mobilization of Ca while subjecting the heifer to a less severe acid load than for 1.5% $CaCl_2$. Therefore, we suggest that feeding 1% $CaCl_2$ for 3 wk prepartum should provide prophylaxis for parturient paresis without seriously affecting systemic acid-base status.

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