The Effects of Feeding Milk to Diarrheic Calves Supplemented with Oral Electrolytes

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ABSTRACT

The effects of feeding different levels of milk to diarrheic calves (n = 19) supplemented with oral electrolytes were investigated. In the early stages of the disease the calves were fed either enough milk to maintain normal growth in a healthy calf, one half that volume or no milk. The three groups were further subdivided according to whether or not the electrolyte solution contained bicarbonate. A full milk ration allowed uninterrupted weight gains of 1% body weight/day (p = 0.003), but caused greater inappetence (p = 0.003 to 0.037) at the beginning of the trial than lower levels of milk intake. Electrolyte solutions with bicarbonate reduced growth rates in milk fed calves (p = 0.014). The density of fat stores increased with the level of milk feeding (p = 0.04 to 0.053). The mitotic index of the duodenal mucosa increased with milk feeding (p = 0.08), indicating a superior mucosal regeneration potential. Thymic atrophy was pronounced in those calves fed no milk (p = 0.001). It was concluded that the continued feeding of milk to diarrheic calves was beneficial. Electrolyte solutions containing bicarbonate should be avoided when milk is fed to diarrheic calves.

RÉSUMÉ

Cette expérience portait sur 19 veaux diarrhéiques et elle visait à déterminer les effets de leur alimentation avec une quantité variable d'un lait enrichi d'électrolytes qui contenaient ou non du bicarbonate. Au début de l'expérience, les veaux reçurent une quantité de lait égale à celle qui permet de maintenir une croissance normale chez des sujets en santé, ou seulement la moitié de cette quantité, ou pas de lait du tout. Les auteurs subdivisèrent ensuite les trois groupes de veaux, selon que la solution d'électrolytes contenait ou non du bicarbonate. Une ration complète de lait permit aux veaux de gagner constamment 1% de leur poids corporel/jour (p = 0,003); au début de l'expérience, elle causa cependant plus d'inappétence (p = 0,003 à 0,037) qu'une ration incomplète. La solution d'électrolytes qui contenait du bicarbonate réduisit le taux de croissance des veaux qui recevaient aussi du lait (p = 0,014). L'importance des réserves adipeuses se révéla proportionnelle à la quantité de lait donnée (p = 0,04 à 0,053). L'index mitotique de la muqueuse duodénale augmenta avec l'alimentation lactée (p = 0,08), indice d'un meilleur potentiel de régénération. Les veaux qui ne reçurent pas de lait affichèrent une atrophie marquée du thymus (p = 0,001). Les auteurs conclurent que leurs veaux diarrhéiques bénéficiaient d'une alimentation lactée continue et qu'il faudrait éviter de donner une solution d'électrolytes qui contient du bicarbonate, à des veaux diarrhéiques qui reçoivent du lait.

INTRODUCTION

Controversy has surrounded the feeding of the diarrheic calf since the 1940's (1). In particular, the feeding of milk, the calf's natural diet, has been debated. Surprisingly, there are few studies concerning the effects of feeding various diets during the disease (2-5). There are both clinical and physiological sides to the debate.

The first clinical recommendations were to withhold milk for one day and to refeed for the next two days with a 1:1 milk:water solution (6). However, later work favored feeding milk by documenting more rapid recovery from diarrhea, less debilitation, continued weight gain and improved circulating plasma volume in diarrheic calves fed milk(3,5). Contrary to this, others have claimed that diarrheic calves should be starved until the diarrhea has stopped (4,6,7). These claims probably have their origins in the rapid drop in fecal output seen when an animal is starved.

It is clear from physiological studies in diarrheic calves that the ability of the calf's intestine to digest and absorb in the healthy (8-10) and diarrheic (11-14) state is different. These studies have shown that lactose digestion and xylose absorption are impaired during diarrhea and led to the recommendations that milk should be withheld. This would "rest" the already compromised intestines and prevent an additional osmotic diarrhea caused by fermentation of undigested lactose in the large bowel (15). It has also been proposed that feeding milk allows for the development of intestinal bacterial overgrowth (13) which contributes to the diarrhea. In contrast the argument in favor of continuous feeding is that the intestinal mucosa feeds directly from the ingesta in its lumen (16) and has a higher requirement for energy during disease (17).

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The starving of diarrheic infants is associated with poor immediate (18,19) and long-term growth rates (20), poor demeanor (21,22), and prolonged recovery (18,21). Many of these effects are believed to be the result of protein-calorie malnutrition (20-24). In pediatric medicine the continuous feeding of milk to the diarrheic infant has been a standard recommendation since 1948 (18,22,25,26).

Most oral supplement studies in diarrheic calves have compared whole milk and milk diluted with water (27) and/or electrolyte solutions (28-30). Milk is a poor source of the major electrolytes lost in diarrhea (Na+, Cl-, HCO_3-) (31). The pathophysiology of calf diarrhea (14,32-37) suggests that treatment of affected animals should include electrolytes to combat fecal losses. Diluting bovine milk impairs clotting (27). Hence, feeding milk without electrolyte supplementation or feeding diluted milk will not provide a proper assessment of the effect of milk in the treatment of diarrheic calves.

The objectives of this study were to monitor clinical and pathological aspects of feeding milk to diarrheic calves supplemented with oral electrolyte solutions. Two different oral electrolyte solutions were used, one contained bicarbonate, the other did not.

MATERIALS AND METHODS

CALVES

Nineteen healthy Holstein bull calves were used in this study. Thirteen were purchased at a local auction mart, and six directly from local dairy farms. Their ages were estimated or known to be between five and eight days. All animals were kept in accordance with the Canadian Council on Animal Care "Guide to the Care and Use of Experimental Animals".

ACCLIMATIZATION

The calves were acclimatized for 36 h, weighed and placed into individual crates. During this time they were fed a balanced electrolyte solution (solution "+", Table I) once in the first 12 h, followed by fresh untreated cows' milk. All calves drank vigorously during the acclimatization period.

TABLE I. Analysis of Constituents of Electrolyte Solutions and Milk Used in the Experiment

Constituent	Electrolyte Solution "+"	"-"	Milk[a]
Na+	105[b]	105	18
K+	20	20	36
Cl^-	35	105	16
$Citrate^-$	10	10	9
$HCO3^-$	80	—	—
Glucose	180	180	146[d]
Osmolality[c]	420	420	300
pH, units	8.4	7.98	6.7
Energy (MJ/L)	0.5	0.5	2.6

[a]Reference 31
[b]All units are in mmol/L, except pH and energy (MJ/L)
[c]Measured by freezing point depression
[d]Lactose

INOCULUM

Each calf was fed 10-15 mL of a pooled fecal inoculum 36 h after arrival, in the evening feed. The inoculum was positive for rotavirus and coronavirus, nonhemolytic *Escherichia coli*, K99 positive *E. coli* and *Cryptosporidium* spp. No *Salmonella* or *Campylobacter* spp. were cultured from the inoculum. When a calf became diarrheic (fecal score $>$ 2.5, see below) for more than 16 h it entered the trial.

EXPERIMENTAL DESIGN

In a factorial 3 x 2 design experiment the 19 calves were randomly assigned to six groups on arrival (Table II). The six groups were: A+, A-, B+, B-, C+, C-. Day 1 of the trial normally occurred 36 to 48 h after inoculation. The experiment ended on the morning of day 11. Calves which became severely depressed and unresponsive for more than 16 h were removed from the trial. The calves were fed untreated cows' whole milk, and nonproprietary electrolyte solutions (Table I), both at room temperature. During the first four days of the trial groups A+ and A- were deprived of milk, whilst groups C+ and C- were fed an amount of milk sufficient for maintenance and growth in healthy calves (38). Groups B+ and B- were fed an intermediate amount of milk. On days 5 and 6 the milk intake in groups A and B calves was increased to match the intake in Group C; all calves were fed the same amount of milk on days 7 through 10 (Table III). The maximum amount of milk fed to a calf per day was 150% of maintenance requirement and was calculated on an individual animal basis, to allow for a weight gain of 1-1.5% bodyweight/day (38), the maximum volume of milk fed to a 45 kg calf was approximately 5.5 L/day or 12.2% body weight (Table IV).

All calves were fed electrolytes. The "+" groups were fed electrolyte solution with bicarbonate, the "-" groups were fed electrolyte solutions without bicarbonate.

The calves were fed four times daily every four hours over a 12 h period. Milk and electrolytes were fed at alternate meals. The calves either drank from buckets or nipple pails. If a calf drank less than 250 mL within 5 min, it was given the remainder by orogastric tube.

CLINICAL STUDIES

Twice daily, before the first and third feedings, the calves were exam-

TABLE II. Summary of the Experimental Design During the First Four Days of the Trial. Calves are Divided into Milk and Bicarbonate Groups. Group Sizes are Indicated

Electrolyte Groups	Milk Groups A	B	C
"+" with bicarbonate	no milk n = 3	1/2 ration milk n = 3	full ration milk n = 3
"-" without bicarbonate	no milk n = 3	1/2 ration milk n = 3	full ration milk n = 4

ined clinically by an independent assessor, and their demeanor and hydration were assessed as described by Booth *et al* (39). Fecal consistency was scored as described by Bywater (30) and, together with an estimation of the volume of feces passed, a fecal score was determined (Table V).

The calves were weighed on arrival and on trial days 2,4,6,8 and 10 using a scale with an accuracy of 500 g. Each calf was weighed four times each weigh-day before feeding. The mean of the four values was taken to be the weight for that day. Changes in body weight were expressed as percentage difference of the preinfected weight on arrival.

Calves which suffered concurrent disease, evidenced by elevation in body temperature over 40° C, coughing, nasal discharge, a painful swollen umbilicus or joint distention were treated with trimethoprim/sulphadoxine (Borgal, Hoechst) parenterally at 3 mL/45 kg twice daily, until improvement of clinical signs or the end of the experiment.

Blood gas analyses were determined on calves which were euthanized before the end of the experiment.

PATHOLOGY

All calves were euthanized with pentobarbitone 108 mg/kg (Euthanyl-Forte/MTC), intravenously, and a necropsy was performed.

The weights of the carcass, small and large intestines, liver, left quadriceps muscle (including the patella) and thymus were recorded. The weight of the small and large intestine, tied off at the pyloric sphincter and the level of the caudal mesenteric artery respectively, included their contents, mesenteric lymphatics and blood vessels. The scales used for the carcass and organs were accurate to 200 g and 0.1 g respectively.

The densities of omental, perirenal, coronary and left femoral marrow fat were assessed visually as described by Schoonderwoerd *et al* (40).

Standard sections of thymus, duodenum, jejunum and liver were examined histologically after fixation in 10% buffered formalin and staining with hematoxylin and eosin.

TABLE III. Daily Volume of Milk and Electrolytes Fed to Calves

	A+/A-		B+/B-		C+/C-	
Trial Day	Milk	Electrolytes	Milk	Electrolytes	Milk	Electrolytes
1	0[a]	1.0	0.5	0.5	1.0	0.5
2	0	1.0	0.5	0.5	1.0	0.5
3	0	1.0	0.5	0.5	1.0	0.5
4	0	1.0	0.5	0.5	1.0	0.5
5	0.5	0.5	0.75	0.5	1.0	0.5
6	0.75	0.5	0.75	0.5	1.0	0.5
7	1.0	0.33	1.0	0.33	1.0	0.33
8	1.0	0.33	1.0	0.33	1.0	0.33
9	1.0	0.33	1.0	0.33	1.0	0.33
10	1.0	0.33	1.0	0.33	1.0	0.33

[a]Values are fractions of the volume (1.0) of fresh cows' milk that supplies 150% of maintenance energy requirements (38)

STATISTICAL ANALYSIS

All analyses were carried out using a Systat microcomputer program (41). Parametric data were first assessed for normal distribution using Bartlett's test for homogeneity of variance. Changes in live body weight and pathological data were analyzed by a repeated measures multivariate analysis of variance (ANOVA) with effects for time, milk, bicarbonate and milk-bicarbonate interaction. The effects of antibiotic therapy, mean initial weight and a pathological diagnosis of concurrent disease on changes in body weight were analyzed by incorporating each of these variables separately into an ANOVA using a model that contained factors for time, milk, bicarbonate and the variable under study.

Nonparametric clinical data were coded so that the higher the score the more severe was the clinical sign. Data were compiled as values for individual variables, groups of related variables and as a total score for all variables. Each set of variables was analyzed by Kruskal-Wallis tests for each time period (daily).

Factors associated with mortality were analyzed using Fischer's exact test after grouping the calves by milk and bicarbonate feeding, concurrent disease and whether the calf was above or below the group mean weight.

RESULTS

CLINICAL STUDIES

The progression of the depression, fecal and hydration status scores were similar for all groups (Figs. 1-3). On day 5, depression scores were higher for milk fed calves ($p = 0.042$, Fig. 1). The dehydration score was highest on day 6 (Fig. 3); enophthalmia made the greatest contribution to this score. At the end of the trial the calves which survived were still mildly depressed (mean score 0.5), and moderately diarrheic (mean score 3.3) and dehydrated (mean score 1.1).

TABLE IV. Summary of Total Energy and Volume Intake in the Different Milk Groups. Calculations are Based on Requirements for a 45 kg Calf

	A+/A-		B+/B-		C+/C-	
Trial Day	Energy[a]	Volume[b]	Energy	Volume	Energy	Volume
1	0.06	12.2	0.19	12.2	0.35	19
2	0.06	12.2	0.19	12.2	0.35	19
3	0.06	12.2	0.19	12.2	0.35	19
4	0.06	12.2	0.19	12.2	0.35	19
5	0.19	12.2	0.27	15.6	0.35	19
6	0.27	15.6	0.27	15.6	0.35	19
7	0.35	16.7	0.35	16.7	0.34	16.7
8	0.35	16.7	0.35	16.7	0.34	16.7
9	0.35	16.7	0.35	16.7	0.34	16.7
10	0.35	16.7	0.35	16.7	0.34	16.7

[a]MJ/kg body weight/day
[b]% body weight/day

TABLE V. Summary of Clinical Parameters Recorded Daily (For Details See References 30,39)

Depression Score (39)		
	Suck reflex:	0 strong and coordinated
		1 weak and coordinated
		2 chewing
		3 absent
	Menace reflex:	0 instantaneous
		1 slow
		2 absent
	Tactile responses:	0 skin and head move
		1 skin only twitches
		2 no response
	Ability to stand:	0 stands voluntarily
		1 stands with assistance
		2 refuses to stand
	Maximum score:	9
Hydration Status Score (individual items each scored 0-2)(39)		
	Eye canthus separation	
	Warmth of oral cavity	
	Warmth of extremities	
	Eye skin turgor	
	Maximum score:	8
Fecal Score (30)		
	Consistency:	0 firm
		1 pasty
		2 loose
		3 watery
	Volume:	filling of tray (score 1-4)
	Maximum score:	7

Clinical diarrhea was defined as a score over 2.5.

During the first seven days, groups fed greater volumes of milk also had to be fed more often by orogastric tube (Fig. 4). Throughout the experiment calves were more likely to take their first meal of the day voluntarily.

The mean weight of the calves at the beginning of the trial was 42.9 ± 2.8 kg (SEM); the lightest calf was 32.4 kg, the heaviest 59 kg. Calves fed electrolytes which contained bicarbonate were significantly heavier (46.7 ± 1.7 kg) at the beginning of the experiment than calves fed electrolytes without bicarbonate (39.7 ± 3.7 kg).

The maximum weight gain was 20.6%, achieved by a calf in group C- (full milk, no bicarbonate) on day 10. The maximum weight loss was 8.8%, in a calf in group B+ (intermediate milk, with bicarbonate) on day 6.

Calves fed a full ration of milk (groups C+/C-) gained weight throughout the experiment (milk effect p = 0.003, time effect p = 0.001, Fig. 5). The average weight gain in this group was 1% body weight/day. Calves on a limited milk intake (A and B groups) lost weight until day 6; when energy intake increased they also gained weight (Fig. 5). These calves were approximately the same weight at the beginning and end of the experiment.

A significant milk-bicarbonate interaction effect on weight gains was observed (Figs. 6 and 7, p = 0.046). Calves fed milk and electrolyte solutions containing bicarbonate (groups B+, C+) gained less weight than those fed milk and nonbicarbonate solutions (groups B-, C-). This difference was most marked during the later stages when the calves received most milk (Figs. 5-7). There was no difference in the way body weight changed between groups A+ and A-, fed no milk at the beginning of the experiment (Fig. 7). Changes in body weight were not related to antimicrobial treatment or initial body weight.

Five calves were treated with antimicrobials and had evidence of concurrent disease at necropsy; four calves were treated, but had no evidence of concurrent disease at necropsy (these calves were killed before the end of the experiment, see

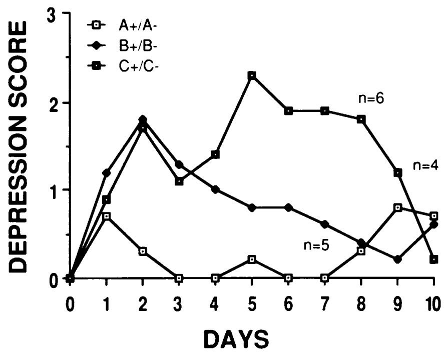

Fig. 1. Mean daily depression scores of milk groups. The scoring system is summarized in Table IV. There were six calves in each of groups A and B, and seven in group C, unless otherwise stated. There is a significant difference between groups on day 5 (p = 0.042), but not on any other days (all p-values > 0.1).

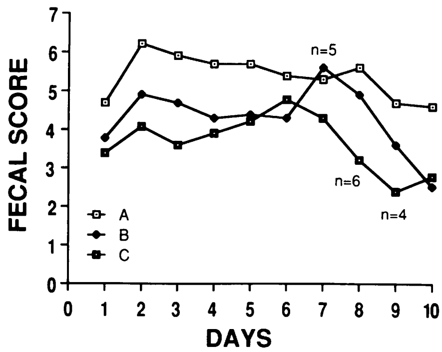

Fig. 2. Mean daily fecal scores of milk groups. The scoring system is summarized in Table IV. There were six calves in each of groups A and B, and seven in group C, unless otherwise stated. There are no significant differences between groups (all p-values > 0.1).

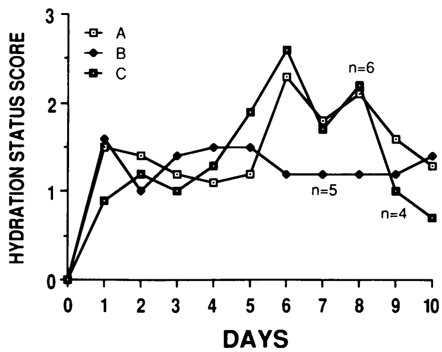

Fig. 3. Mean daily hydration status score of milk groups. The scoring system is summarized in Table IV. There were six calves in each of groups A and B, and seven in group C, unless otherwise stated. There are no significant differences between groups (all p-values > 0.1).

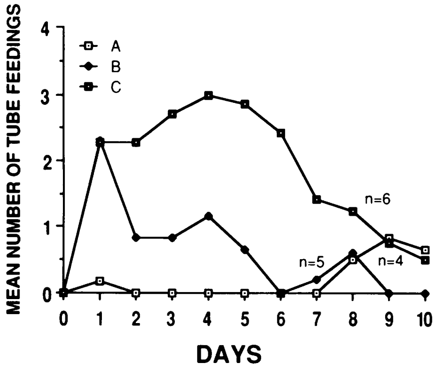

Fig. 4. Mean number of times a day calves had to be tube fed each day. There were six calves in each of groups A and B, and seven in group C, unless otherwise stated. Significant differences between groups occur on days 1-7 ($p = 0.003$ to 0.037); for days 8-10 all p-values > 0.25.

below); four other calves had evidence of concurrent disease at necropsy, but had not been treated with antimicrobials.

Significant risk factors for mortality in four calves which were euthanized before the end of the experiment could not be identified (Table VI). All calves euthanized before the end of the experiment had severe metabolic acidosis with partial respiratory compensation.

PATHOLOGY

The relative weights of the intestines, liver, quadriceps muscles and thymus did not differ among treatment groups (Table VII).

Milk feeding was associated with increased absolute liver weights ($p = 0.014$) (Table VII). The amounts of omental, coronary and perirenal fat stores were greater when more milk was fed (Table VIII, $p = 0.04$ to 0.053).

Milk deprivation resulted in thymic atrophy ($p = 0.001$), a thicker duodenal serosa ($p = 0.028$), and a lower mitotic index of the duodenal mucosa ($p = 0.083$) (Table IX). Electrolyte solutions containing bicarbonate were associated with a thicker duodenal muscularis ($p = 0.037$), longer duodenal villi ($p = 0.021$), and thinner jejunal epithelial cells ($p = 0.005$) (Table X). The effect of a milk-bicarbonate interaction was significant for the duodenal serosa ($p = 0.037$) (Table X).

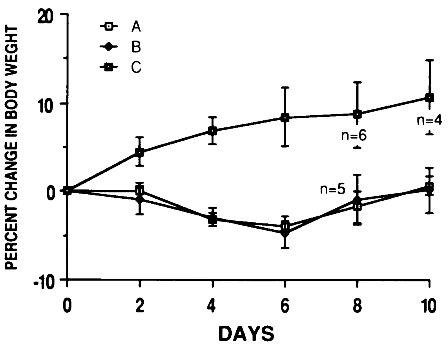

Fig. 5. Relative changes in body weight of milk groups. Changes in weight are expressed as a percentage of the initial body weight. There were six calves in each of groups A and B, and seven in group C, unless otherwise stated. Significant differences exist between groups ($p = 0.003$) and days ($p = 0.001$).

DISCUSSION

The results of this trial indicate that continued milk feeding sustained growth of diarrheic calves and was associated with the development of greater fat stores, better regeneration of the gastrointestinal mucosa and less thymic atrophy than in calves deprived of milk.

The inoculum was believed to mimic infection by oral-fecal contamination of calves (42). It induced severe diarrhea suitable for study under controlled conditions. The incubation period was similar to other experiments (2,3, 27-30); all but one calf, which was excluded from the trial, developed profuse diarrhea for over a week.

Treating calves of different weights with fixed volumes of oral electrolyte solutions as has been used in previous treatment trials (27-30), increases the variability in the data. For example if fixed volumes had been fed to the calves in this experiment, a volume of 1 L, or a change in weight by 1 kg, would have represented 3.12% of the body weight of the lightest calf, but only 1.7% of the heaviest. Hence the use of treatments and measurements relative to body weight aids interpretation of the results.

The depression score was similar for all groups except on day 5 (Fig. 1). This single significant difference does not strongly support the hypothesis that dietary differences contributed to the degree of depression in this experiment. Farmers and veterinarians often describe a period of depression in calves when they are convalescing from diarrhea and being reintroduced to milk. The data of this experiment did not indicate that this occurred.

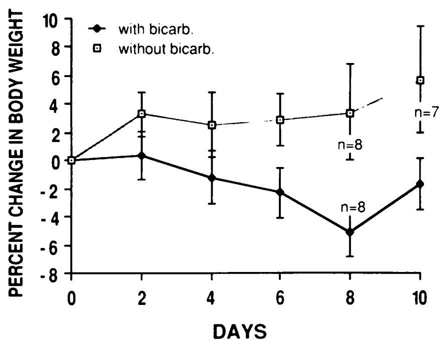

Fig. 6. Relative changes in body weight of bicarbonate groups. Changes in weight are expressed as a percentage of the initial body weight. There were nine calves in the group of calves fed bicarbonate and ten in the group not fed bicarbonate containing electrolyte solutions, unless otherwise stated. Significant differences exist between groups ($p = 0.046$)

Differences in fecal scores were minimal between groups (Fig. 2). This may indicate that even in the diarrheic state the neonatal calf's intestinal tract has sufficient reserve capacity to assimilate milk without exacerbation of the diarrhea.

The degree to which calves' eyes become recessed reflects hydration status as well as body fat stores, as the retrobulbar fat pad is in part responsible for the protuberance of the eye. Enophthalmia was the main contribution to the hydration score

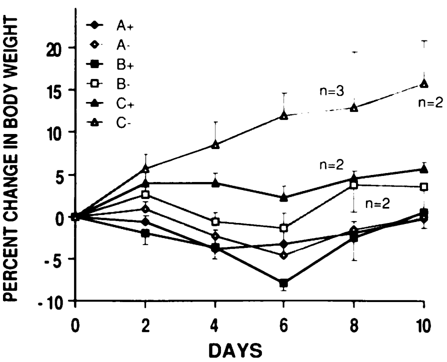

Fig. 7. Relative body weight changes for each group. Changes in weight are expressed as a percentage of the initial body weight. There were three calves in each group, but four in group C-, unless otherwise stated. Significant differences exist between groups ($p = 0.014$).

TABLE VI. Summary of the Characteristics of the Four Calves Which Were Euthanized Before the End of the Experiment

Group	B-	C+	C-	C-
Milk[a]	0.5	1.0	1.0	1.0
Bicarbonate[b]	–	+	–	–
Weight[c]	–	–	+	+
Source[d]	M	M	F	M
Clinical Assessment (Day of euthanasia)				
Depression score	4	3	5	3
Hydration status	6	7	4	2
Fecal output	7	7	6	5
Venous Blood Gas Analysis				
pH (7.400)[e]	7.030	7.019	7.026	7.127
pCO_2[f] (55 mmHg)	33.2	36.8	37.4	38.5
HCO_3 (25 ± 5 mmol/L)	8.1	8.6	8.9	11.7
BE[g] (0 ± 4 mmol/L)	-21.9	-21.6	-21.8	-15.9

[a]Amount of milk fed during the acute stage: fraction of full ration
[b]Electroltyes contained bicarbonate (+)/ or not(-)
[c]Above (+) or below (-) mean starting weight
[d]Market (M) or farm (F)
[e](Units and normal values)
[f]Partial pressure of carbon dioxide
[g]Base excess

and the high values on day 6 may reflect both dehydration (Fig. 3) and loss of body weight (Fig. 5).

The volume of electrolytes given to each calf was in excess or similar to the upper limits recommended for most proprietary products (43-45). Oral fluid therapy was started within hours of the onset of diarrhea. This vigorous oral fluid replacement therapy was effective in preventing severe dehydration in the majority of the calves (Fig. 3). This is comparable to human studies, where appropriate oral rehydration therapy has reduced the need for intravenous replacement therapy by approximately 80% (46).

Inappetence (animals requiring tube feeding) was the most sensitive indicator of the calves' overall clinical condition (Fig. 4). During the first seven days of the trial the number of times a calf had to be fed by orogastric tube each day related to the level of milk feeding (Fig. 4). Development of inappetence did not follow the same pattern as changes in depression score, hydration status or fecal output, nor was it associated with an esophagitis at necropsy. Tube feeding was usually necessary late in the day. In the milk fed groups the first feed of the day was always milk and so it is likely that something related to the milk was responsible for the inappetence. The anorexic effect of a milk meal persisted for longer than 4-8 h. Volume overload (gastric fill) is unlikely to have contributed to inappetence, as calves in groups B+/B- refused more feeds than calves in groups A+/A-, but were fed equal total daily volumes (Table IV, Fig. 4). Furthermore the total volume of fluid fed changed throughout the experiment and these changes in volume did not parallel changes in the degree of inappetance (compare Table IV and Fig. 4).

Appetite depression may have been the result of satiety resulting from a higher caloric intake (47), milk fat retarding gastric emptying and intestinal passage time (48), protein and amino acids reducing hunger (47), nausea resulting from secondary carbohydrate intolerances (49,50), endotoxemia (51) or cachectin production (52). If the inappetent calves had not been force-fed, but allowed to drink milk voluntarily, it is probable that a balance between hunger and milk-induced inappetence would have been met. This would have allowed the calves to regulate the optimal amount of milk intake themselves.

Changes in body weight were unlikely to have been due to differences in water retention, although

TABLE VII. Summary of Gross Pathological Items and Data for Milk and Electrolyte Groups

	Milk Groups A	B	C	Significance[b]
Number per group[a]	6	5	4	
Carcass weight (kg)	38.7 (4.3)[c]	42.3 (0.6)	49.8 (2.7)	0.041
Organ weights (g)				
Intestines	2878.2 (176.4)	3050.0 (297.3)	3392.7 (441.3)	0.904
Liver	922.6 (81.2)	1060.0 (41.4)	1165.9 (54.9)	0.014
Quadriceps	560.2 (69.7)	662.2 (33.4)	725.9 (56.7)	0.168
Thymus	41.9 (13.0)	74.3 (19.2)	86.9 (12.4)	0.176
Relative organ weights (% carcass weight)				
Intestines	7.44 (0.40)	7.28 (0.02)	6.81 (0.21)	0.245
Liver	3.47 (0.30)	2.52 (0.02)	2.44 (0.02)	0.907
Quadriceps	1.40 (0.03)	1.33 (0.23)	1.45 (0.07)	0.309
Thymus	0.10 (0.02)	0.13 (0.05)	0.17 (0.03)	0.137

	Electrolyte Groups "+" Bicarbonate	"–" Bicarbonate	Significance[b]
Number per group[a]	8	7	
Carcass weight (kg)	45.6 (2.9)	40.3 (2.1)	0.086
Organ weights (g)			
Intestines	3242.8 (396.0)	2856.8 (214.0)	0.341
Liver	1090.4 (58.3)	981.8 (58.4)	0.046
Quadriceps	675.4 (64.8)	595.3 (41.7)	0.063
Thymus	68.4 (14.5)	63.3 (15.2)	0.397
Relative organ weights (% carcass weight)			
Intestines	7.01 (0.16)	7.23 (0. 70)	0.772
Liver	2.37 (0.20)	2.53 (0.10)	0.982
Quadriceps	1.46 (0.17)	1.44 (0.10)	0.211
Thymus	0.15 (0.05)	0.15 (0.06)	0.696

[a]Only those calves which completed the trial were included
[b]Probability that differences between treatments are due to chance
[c]Values are means (SEM)

TABLE VIII. Summary of the Mean Scores for Fat Density in Milk Groups

	Milk Groups A	B	C	Significance[b]
Omental	3.5[a]	3.6	4.7	0.040
Coronary	3.8	3.8	4.5	0.044
Perirenal	3.0	3.6	4.3	0.053
Marrow	3.7	4.0	4.0	0.709

[a]Visual density score: transparent 1; translucent 2; depleted 3; normal 4; excessive 5
[b]Probability that differences between treatments are due to chance

only indirect evidence supports this. Weight gains due to water retention as a sequel to high sodium intake have been demonstrated in piglets and diarrheic babies (53,54). In this experiment total sodium intake did not correlate with weight gains (Tables I, III and IV). Several other lines of reasoning also suggest that weight gains were related to caloric rather than water content of the diet. The hydration status and fecal scores were the same for all groups (Figs. 2 and 3), suggesting a similar fluid balance in all calves. Changes in body weight did not occur in parallel to changes in volume fed: groups C+/C- continued to gain weight in the last four days of the experiment, although the relative volume fed became less (compare Table IV and Fig. 5). Furthermore in the B and C groups the calves fed non-bicarbonate containing electrolyte solutions gained more weight than calves fed bicarbonate containing electrolytes even though volume intake was the same (Fig. 7). Finally the deposition of fat stores correlates with increased caloric intake (Table VIII).

Diarrheic calves given a full ration of milk gained weight at a rate comparable to standards for healthy veal calves (55), indicating that the reduction in intestinal digestion and absorption reported in the diarrheic calf (11-13), are of doubtful clinical importance. These findings are comparable to reports in the human literature (18-26), where restricting dietary intake in diarrheic infants is not encouraged and support recommendations in the veterinary literature to provide high energy intakes during diarrhea (43,56).

A one-half ration of milk fed at the beginning of the experiment was not associated with a gain in weight. This is not surprising, as the amount of energy supplied to these calves was only approximately 75% of the recommended requirements for maintenance in the healthy calf.

Electrolyte solutions containing bicarbonate had a deleterious effect on body weight (Figs. 6 and 7). This effect was more marked at the higher rates of milk feeding. Alkaline and bicarbonate containing solutions are known inhibitors of milk clotting (27,56), and hence interfere with digestion (14). Thus differences in pH and bicarbonate content of the two electrolyte solutions used (Table I) may have caused differences in milk clotting and subsequent digestive properties. Bicarbonate also increases abomasal emptying (57) and it is possible that feeding electrolyte solutions containing bicarbonate reduces intestinal passage time and hence digestion. That this effect was seen even though milk and electrolytes were never fed together, indicates that therapy for the diarrheic calf should not combine milk and electrolyte solutions containing bicarbonate if growth is to be maintained.

In another study, feeding electrolyte solutions containing bicarbonate to diarrheic calves with a blood pH <7.2, decreased acidemia and improved demeanor (39). In the present experiment there was a period, early in the disease (Day 1, Fig. 4), when most calves were inappetent, independent of diet. If this phase could be associated with acidosis, then this may represent a suitable time to feed electrolyte solutions containing bicarbonate. It is also possible that the acidotic calves euthanized before the end of the trial would have benefitted from milk restriction and feeding electrolyte solutions containing bicar-

TABLE IX. Comparison of the Histopathological Data: Effect of Different Levels of Milk Feeding

	Milk Groups A+/A-	B+/B-	C+/C-	Significance[b]
Number per group[a]	6	5	4	
Duodenum				
Total thickness	50.6 (6.8)[c]	66.1 (1.2)	57.5 (3.5)	0.576
Serosa[d]	3.1 (2.3)	3.6 (0.8)	6.4 (3.3)	0.028
Muscularis	10.2 (1.1)	12.1 (5.9)	10.8 (0.9)	0.435
Submucosa	6.2 (2.2)	9.6 (0.7)	9.0 (2.6)	0.595
Villi	20.4 (4.7)	30.4 (2.7)	20.1 (2.5)	0.883
Epithelial cells	10.7 (0.1)	10.8 (3.0)	11.8 (1.6)	0.666
Villus:Crypt ratio	2.5 (0.6)	2.1 (0.2)	1.8 (0.1)	0.251
Brunners gland dilation[d]	2.0	2.0	2.5	0.895
Inflammation[d]	1.5	1.0	2.0	0.504
Mitotic index[d]	13.5 (4.5)	22.7 (1.4)	20.0 (5.7)	0.083
Jejunum				
Total thickness	44.6 (4.4)	43.0 (9.8)	37.2 (3.2)	0.780
Adventitia	3.1 (0.2)	3.3 (2.1)	2.6 (0.8)	0.608
Muscularis	6.7 (4.3)	8.2 (2.1)	5.6 (0.5)	0.396
Submucosa	1.7 (0.2)	2.7 (1.3)	1.2 (0.3)	0.272
Villi	23.9 (4.1)	21.8 (4.6)	20.4 (7.4)	0.890
Epithelial Cells[d]	9.1 (0.1)	7.0 (1.4)	8.4 (2.6)	0.017
Villus:Crypt ratio	2.2 (0.8)	2.2 (0.8)	2.3 (0.1)	0.974
Inflammation[d]	1.0	1.5	1.5	0.518
Mitotic index	18.3 (4.2)	28.3 (0.5)	26.9 (7.6)	0.663
Thymus				
Atrophy score[d]	3.0	2.0	1.0	0.001
Liver				
Atrophy score[d]	2.0	2.0	2.0	0.764

[a]Only calves were included, which completed the trial
[b]Probability that differences between treatments are due to chance
[c]Values are comparative and are measured in mean cm (SEM) on a magnified screen
[d]Scoring system for nonparametric data is: mild 1, moderate 2, severe 3

TABLE X. Comparison of Histopathological Data: Effect of Bicarbonate in the Electrolyte Solutions and Milk-Bicarbonate Interaction

	Bicarbonate Groups		Significance[b]	
	"+"	"−"		Milk-Bicarbonate
Number per Group[a]	8	7	Bicarbonate	Interaction
Duodenum				
Total thickness	56.4 (5.5)[c]	53.8 (6.5)	0.083	0.468
Serosa	4.9 (3.8)	4.1 (1.0)	0.253	0.010
Muscularis	9.4 (2.0)	12.3 (3.8)	0.037	0.020
Submucosa	8.0 (1.0	8.9 (3.4)	0.953	0.711
Villi	23.7 (1.9)	17.0 (0.1)	0.021	0.948
Epithelial cells	10.8 (2.1)	11.5 (1.3)	0.117	0.407
Villus:Crypt ratio	2.3 (0.6	2.0 (0.1)	0.699	0.309
Brunners gland dilatation[d]	2.0	2.0	0.841	0.765
Inflammation[d]	1.0	2.0	0.612	0.661
Mitotic index	21.5 (4.1)	18 (5.7)	0.110	0.731
Jejunum				
Total thickness	42.7 (3.1)	41.4 (5.7)	0.414	0.990
Adventitia	2.9 (0.5)	3.4 (1.7)	0.741	0.389
Muscularis	7.2 (2.3)	6.5 (3.0)	0.579	0.065
Submucosa	2.0 (1.2)	1.5 (0.4)	0.291	0.665
Villi	21.4 (2.6)	22.8 (3.7)	0.865	0.269
Epithelial cells	9.2 (1.1)	7.2 (1.8)	0.005	0.037
Villus:Crypt ratio	2.7 (0.2)	1.8 (0.3)	0.094	0.577
Inflammation[d]	1.0	2.0	0.077	0.735
Mitotic index	25.2 (8.8)	23.8 (4.2)	0.496	0.675
Thymus				
Atrophy score[d]	2.0	2.0	0.064	0.212
Liver				
Atrophy score[d]	2.0	2.0	0.864	0.070

[a]Only calves were included which completed the trial
[b]Probability that differences between treatments are due to chance
[c]Values are comparative and are measured in mean cm (SEM) on a magnified screen
[d]Scoring system for nonparametric data is: mild 1, moderate 2, severe 3

bonate to correct their severe metabolic problems.

In other studies, milk feeding has been reported to speed recovery (3,27); in this study the clinical rate of recovery was the same in all groups (Figs. 1-4). The majority of the calves which completed the trial would have probably made a complete recovery.

Regardless of the feeding regime, changes in body weight were partitioned equally amongst the organs investigated (Table VII) indicating that diarrhea does not alter the distribution of nutrients to the body. Omental and mesenteric fat stores are readily mobilized during periods of malnutrition (40). Increases in fat stores in this experiment related to higher caloric intakes (Table VIII). Thymic atrophy was more pronounced in milk deprived calves (Table IX). This is consistent with protein-calorie malnutrition (40) and suggests immunological compromise (58). The mitotic index of the intestinal mucosa is depressed following fasting (24), during protein-calorie malnutrition and some diarrheas (23) indicating a reduction in cell proliferation and replacement. In infants, chronic protein-calorie malnutrition has been associated with persistent diarrhea due to defective intestinal mucosal repair and maturation (20,21,24). It is not known to what extent the diarrhea may have affected mitotic activity in this trial. Reduction in the caloric intake in the early stages of the experiment was consistently associated with reduction of intestinal mitotic activity. Several authors have speculated that inappropriately long periods of starvation exacerbate diarrhea in calves (43); the reduction in mucosal regeneration seen in the starved calves of this experiment may in part explain this. It is surprising that this effect could still be detected four to six days after resumption of an adequate diet.

This paper describes the day to day progression of diarrheic calves with induced diarrhea. The degree of depression, dehydration, and a fecal score were independent of diet, whereas inappetence was induced early in the disease by feeding milk. The results of this trial also indicate that depriving diarrheic calves of milk for four days at the onset of disease induced a marked loss in body weight, a reduction in body fat stores, poor intestinal mucosal turnover and thymic atrophy. Many of these effects were still detectable after four to six days of an adequate energy intake. To avoid these effects we recommend that diarrheic calves should be supplemented with electrolytes and allowed to voluntarily drink as much milk as they like. If milk is imbibed by the diarrheic calf, body weight is best maintained if the supplemental electrolyte solutions do not contain bicarbonate.

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