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Comparison of Two Oral Electrolyte Solutions and Route of Administration on the Abomasal Emptying Rate of Holstein-Friesian Calves

Mohammad Nouri and Peter D. Constable

Dehydrated calves with diarrhea are routinely given an oral electrolyte solution (OES) by suckling or esophageal intubation. An important issue related to rehydration therapy is the rate of OES delivery to the small intestine. It is widely assumed that the glucose content of the OES does not impact the speed of resuscitation and that fluid administered by esophageal intubation provides a similar resuscitative response to that obtained by suckling. The aims of this study were to compare the abomasal emptying rate in calves suckling an OES containing a high or low glucose concentration and in calves administered a high-glucose OES by suckling or esophageal intubation. Seven male Holstein-Friesian calves were given the following treatments in random order: 2 L of a commercially available high-glucose OES ([glucose] = 405 mM) by suckling or esophageal intubation or 2 L of a commercially available low-glucose OES ([glucose] = 56 mM) by suckling. Abomasal emptying rate was determined by acetaminophen absorption, ultrasonography, and glucose absorption. High-glucose OES rapidly increased plasma glucose concentration after suckling but produced a slower rate of abomasal emptying than did low-glucose OES. Esophageal intubation of high-glucose OES produced the same initial change in abomasal volume as did suckling, but delayed the rate of OES delivery to the small intestine. Our results suggest that suckling a low-glucose OES provides the fastest rate of abomasal emptying and plasma volume expansion, whereas a high-glucose OES provides the most appropriate oral solution for treating hypoglycemic calves.

Key words: Acetaminophen; Calf diarrhea; Glucose absorption curve; Ultrasonography.

Calf diarrhea is a common disease of US dairy calves.[1] Dehydrated calves with diarrhea are routinely given an oral electrolyte solution (OES), which can be categorized as alkalinizing or nonalkalinizing and as containing a high or low glucose concentration and osmolarity. It is currently believed that the ideal OES for treating mildly to moderately dehydrated calves should contain multiple agents (eg, glucose, acetate, propionate, and glycine) that facilitate intestinal absorption of sodium and water, use acetate and propionate instead of bicarbonate as an alkalinizing agent, not inhibit milk clotting in the abomasum, be high in energy (with multiple sources of energy such as glucose, acetate, propionate, and amino acids), and have a glucose-to-sodium ratio between 3 : 1 and 1 : 1.[2]

The rate of abomasal emptying influences the rate at which the OES is delivered to the small intestine and therefore the speed of rehydration in dehydrated calves.[3] The volume of an ingested fluid meal is the most important determinant of the emptying rate in monogastric animals[4] and suckling calves.[5] Other physiologically important determinants of emptying rate are energy density (ie, caloric content) of a meal,[6–8] type of protein or fat,[9–11] and osmolarity of the solution.[12] Because an increased caloric content of an ingested meal slows gastric emptying rate,[6–8] we hypothesized that an OES containing a high-glucose concentration would be emptied more slowly in suckling calves than a low-glucose OES.

Oral electrolyte solutions are administered by suckling or esophageal intubation in calves with poor suckle response.[13] It is widely assumed that fluid administered by esophageal intubation provides a similar resuscitative response to that obtained by suckling. However, administration of fluids to neonatal calves by esophageal intubation does not induce esophageal groove closure and therefore the fluid initially is deposited in the reticulorumen.[13,14] Movement of fluid from the reticulorumen into the abomasum immediately follows,[14,15] presumably in response to a pressure gradient between the reticulorumen and the abomasum, and because the reticulum and rumen are dorsal to the abomasum in the neonatal calf.[3] The effect of esophageal intubation on the rate at which a high-glucose OES is delivered to the small intestine of the calf is unknown, but we hypothesized that the rate of delivery was lower in calves after esophageal intubation than after suckling. This hypothesis was based on the results of previous studies that indicated esophageal intubation of colostrum or a 15% lactose solution led to lower serum immunoglobulin G or glucose concentrations, respectively, compared to suckling.[16–18] In addition, esophageal intubation of a D-xylose solution resulted in a delay to the time of maximal D-xylose concentration compared to suckling,[14] suggesting that intubation leads to a decreased rate of delivery to the small intestine.

Accordingly, the aims of the study reported here were to compare the abomasal emptying rate in calves suckling commercially available oral electrolyte solutions containing either a high or low glucose concentration and in calves administered the same OES by suckling or esophageal intubation.

From the Department of Veterinary Clinical Medicine, College of Veterinary Medicine, University of Illinois, Urbana, IL. Dr Nouri is Presently affiliated with the Department of Clinical Sciences, College of Veterinary Medicine, Shahid Chamran University, Ahvaz, Iran.

Reprint requests: Peter D. Constable, BVSc, PhD, Department of Veterinary Clinical Sciences, School of Veterinary Medicine, Purdue University, Lynn Hall, West Lafayette IN 47907; e-mail: constabl@purdue.edu.

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Materials and Methods

Animals

This study was approved by the Institutional Animal Care and Use Committee of the University of Illinois at Urbana-Champaign. Seven male Holstein-Friesian colostrum-fed calves (body weight range, 39–51 kg) were obtained from the University of Illinois dairy at 2–4 days of age. Calves were kept unrestrained in individual stalls that were bedded with sawdust, and were fed twice a day (60 mL/kg body weight) with an all milk protein milk replacer[a] (crude protein minimum, 20%; crude fat minimum, 20%; crude fiber maximum, 0.15%; calcium minimum, 0.5%; calcium maximum, 1.0%; phosphorus, minimum 0.6%). Calves had access to fresh water at all times.

Instrumentation

A jugular venous catheter was placed at least 18 hours before the 1st study. Venous catheterization was performed after sedation with xylazine (0.2 mg/kg IM). The skin over the right jugular vein was clipped and aseptically prepared. One milliliter of lidocaine was injected under the skin over the jugular vein and the skin was incised (1 cm in length) with a scalpel blade to assist in catheter placement. A 16-g or 18-g catheter then was placed in the jugular vein, an extension set was attached to the catheter, and the catheter and extension set were secured to the neck. The catheter was flushed q12h with heparinized 0.9% NaCl solution (40 U heparin/mL).

Experimental Design

Between days 7 and 17 of life, each calf was placed in a moveable calf stall and given each of the following 3 treatments in random order: a high-glucose OES[b] by suckling or esophageal intubation, or a low-glucose OES[c] by suckling. At least 36 hours elapsed between each study to ensure an adequate wash-out period; during this time calves were fed milk replacer. The high-glucose OES contained the following: dextrose, 405 mM; sodium, 106 mEq/L; potassium, 26 mEq/L; chloride, 51 mEq/L; calcium, 5 mM; magnesium, 3 mM; phosphate, 5 mM; sulfate, 3 mM; bicarbonate, 80 mM; and glycine, 33 mM; calculated osmolarity, 717 mOsm/L. The low-glucose OES contained: dextrose, 56 mM; sodium, 120 mEq/L; potassium, 10 mEq/L; chloride, 70 mEq/L; calcium, 5 mM; magnesium, 2.5 mM; sulfate, 2.5 mM; bicarbonate, 40 mM; and glycine, 40 mM; calculated osmolarity, 360 mOsm/L. Glucose therefore was administered at approximately 3.2 g/kg body weight or 0.4 g/kg body weight in the high- and low-glucose OES groups, respectively. Oral electrolyte solutions were prepared immediately before administration as directed by the manufacturer by dissolving the powder in 2 quarts (1.86 L) of warm water. Four quarts of OES were prepared and 2 L was retained for administration as the test solution. Acetaminophen[d] (50 mg/kg body weight) was added to each 2-L test solution and mixed well and the resultant solution administered to the calf.

Abomasal emptying rate was determined by acetaminophen absorption and ultrasonographic measurement of abomasal dimensions. Both techniques have been validated as measures of abomasal emptying rate in suckling calves.[3,19] The glucose absorption curve was used as a 3rd measure of emptying rate.[20] Jugular venous blood samples for determination of plasma acetaminophen, glucose, and total protein concentrations were obtained at −30, 0, 10, 20, 30, 45, 60, 75, 90, 120, 150, 180, 210, 240, 300, and 360 minutes relative to the start of fluid administration (time = 0 minutes). Blood was collected into 6-mL tubes containing sodium fluoride and potassium oxalate,[e] centrifuged at 1,000 × *g* for 15 minutes, and 3 mL of plasma was harvested and stored at −20°C for <4 weeks before analysis. Ultrasonographic measurements were obtained before and immediately after administration of the test solution, and at 10, 20, 30, 45, 60, 90, 120, 150, 180, and 240 minutes after the start of administration of the test solution.

Determination of Abomasal Emptying Rate

Acetaminophen Absorption. Plasma was thawed at room temperature and analyzed spectrophotometrically by using a colorimetric nitration assay as previously described.[19] The maximum observed plasma concentration (actual C_{max}) and time of maximum observed plasma concentration (actual T_{max}) were obtained from a plot of the plasma acetaminophen concentration versus time data. The 1st derivative of Siegel's modified power exponential formula was used to model the acetaminophen time curve, as previously described.[19] The equation was derived from the fact that the acetaminophen-time curve represented as a cumulative dose curve is an inverse analog of the scintigraphic curve: $C(t) = mk\beta e^{-kt}(1 - e^{-kt})^{\beta-1}$, where C(t) is the acetaminophen concentration in plasma (μg/mL) at time t in minutes, e is an irrational number approximating 2.718, and m, k, and β are constants; m is the total cumulative recovery of acetaminophen when time is infinite, k is an estimate of the rate constant for abomasal emptying, and β provides an estimate of the duration of the lag phase before an exponential rate of emptying is reached.

Data were fit by use of nonlinear regression[f] and the adequacy of model fit evaluated by visual examination of plots of observed versus predicted concentrations and examination of residual plots. The time to calculated C_{max} (model T_{max}) was obtained as follows: model $T_{max} = \log_e(\beta)/k$, where $\log_e$ is the natural logarithm with base e. The value for model C_{max} was calculated by applying the values for m, k, and β, and *t* is model T_{max} to the 1st derivative of Siegel's modified power exponential formula.

Ultrasonography. Calves were gently restrained in standing position and a 3.5-MHz ultrasound sector probe[g] was applied to the clipped ventral abdomen in transverse and sagittal planes to determine the maximal visible abomasal dimensions (length, width, and depth), as previously described.[3] The length was defined as the maximal dimension in the axial plane, the width as the sum of the maximal dimension in the left lateral and right lateral planes, and the height as the maximal dimension in the dorsal plane. Because the abomasum of the calf attains an ellipsoid shape after suckling,[3] abomasal volume was calculated by using the formula for the volume of an ellipsoid (volume = width × length × height × π/6, where π is an irrational number approximating 3.142).

Siegel's modified power exponential formula was used to calculate the half emptying time ($t_{1/2}$) from the abomasal volume, as previously described.[3] Briefly, a volume versus time curve was generated for each experiment: $y(t) = 1 - (1 - e^{-kt})^{\beta}$, where y(t) is proportion of peak postsuckling volume at time t, time is the time interval from start of fluid administration in minutes, k is a constant defining the rate of emptying, and β is the extrapolated y-intercept for the terminal portion of the curve. Data were fit by use of nonlinear regression[f] and the adequacy of model fit evaluated by visual examination of plots of observed versus predicted concentrations and examination of residual plots. Using the values for k and β obtained from nonlinear regression, we calculated ultrasonographic $t_{1/2} = (-1/k)\log_e(1 - 2^{-1/\beta})$.

Glucose Absorption. Plasma glucose and total protein concentrations were determined using an automatic analyzer.[h] The maximum observed plasma concentration (actual C_{max}) and time of maximum observed plasma concentration (actual T_{max}) were obtained from a plot of the plasma glucose concentration versus time data. A delay in actual T_{max} implies a slower rate of abomasal

Table 1. Abomasal emptying rate indices of 7 calves suckling 2 L of a high-glucose oral electrolyte solution (OES) by suckling or esophageal intubation, or a low-glucose OES by suckling.

Factor	High-glucose OES suckled	High-glucose OES intubated	Low-glucose OES suckled	SE
Acetaminophen absorption				
Actual C_{max} (μg/mL)	40.9[a]	38.6[a]	44.4[a]	2.4
Actual T_{max} (minutes)	152[ab]	197[a]	111[b]	22
Model C_{max} (μg/mL)[b]	37.0[a]	35.5[a]	41.7[a]	2.5
Model T_{max} (minutes)[b]	143[a]	217[b]	105[c]	14
Ultrasonography				
Preprandial abomasal volume (mL)	68[a]	61[a]	66[a]	7
Maximum postprandial abomasal volume (mL)	2,030[a]	2,091[a]	2,049[a]	34
Change in abomasal volume (mL)	1,962[a]	2,030[a]	1,982[a]	34
$t_{1/2}$ (minutes)	50.9[a,b]	55.6[a]	44.6[b]	3.1
β	1.27[a]	1.36[a]	1.40[a]	0.11
Glucose Absorption				
Actual C_{max} (mg/dL)	168[a]	166[a]	104[b]	11
Actual T_{max} (minutes)	84[a]	74[a,b]	51[b]	14
Area under the curve (mg/6 h/dL)[c]	680[a]	667[a]	528[b]	32

[a] Abomasal emptying rate was assessed by acetaminophen absorption, ultrasonography, and glucose absorption. Data are least squares means and standard error (SE). Values on the same row with different superscript letters are significantly different.

[b] Model C_{max} and T_{max} for acetaminophen were obtained by fitting a nonlinear equation to the 1st derivative of Siegel's modified power exponential formula for acetaminophen (see "Materials and Methods" for details).

[c] For glucose absorption, area under the curve is the area under the plasma glucose concentration-time relationship for the 6-hour period after suckling.

Actual C_{max}, the maximal plasma acetaminophen or glucose concentration; actual T_{max}, the time at which actual C_{max} occurred; ultrasonographic $t_{1/2}$, half-time of abomasal emptying; β, an estimate of lag-phase duration before the start of exponential emptying.

emptying.[20,21] The area under the plasma glucose concentration–time curve was calculated from 0 to 6 hours by using the trapezoid method; the area provides a crude index of the amount of glucose absorbed for each treatment.

Change in Plasma Volume

The change in plasma volume at time *i* was calculated from the plasma protein concentration at time = 0 minutes (PP_0) and the plasma protein concentration at time *i* (PP_i), whereby: percent change in plasma volume = $(PP_0 - PP_i) \times 100/PP_i$.[22]

Statistical Analyses

Data were expressed as least squares mean and standard error and a value of $P < .05$ was considered significant. The primary variables of interest were acetaminophen model T_{max}, ultrasonographic $t_{1/2}$, glucose actual T_{max}, and area under the plasma glucose concentration–time curve. A repeated-measures analysis of variance (with repeated measures on treatment and time) was used to determine the main effects of treatment and time and the interaction between treatment and time. Variables with nonnormal distributions were log transformed or ranked before statistical analysis was performed. A statistical software program[i] was used for all statistical analyses.

Results

All calves remained healthy during the study period. The mean time taken to suckle the 2 L of high-glucose or low-glucose OES ranged from 1.6 to 3.0 minutes. The time required to administer 2 L of high-glucose OES by esophageal intubation was <2 minutes.

Change in Abomasal Volume

Preprandial abomasal volume was similar for all treatment groups (Table 1). Administration of 2 L of a high-glucose OES by esophageal intubation produced the same net change in abomasal volume as did suckling 2 L of a high-glucose OES or low-glucose OES (Fig 1). This result indicated that all of the fluid administered by esophageal intubation rapidly entered the abomasum.

Abomasal Emptying Rate

The high-glucose OES was emptied slightly slower after esophageal intubation than after suckling, as indicated by model T_{max} values for acetaminophen absorption (Fig 2; Table 1). The actual T_{max} for acetaminophen tended ($P = .099$) to be longer after esophageal intubation of the high-glucose OES, compared to suckling the high-glucose OES.

Suckling a high-glucose OES resulted in a slower rate of abomasal emptying than suckling a low-glucose OES, as indicated by model T_{max} values for acetaminophen absorption (Fig 2; Table 1). Ultrasonographic $t_{1/2}$ tended ($P = .079$) to be longer after suckling the high-glucose OES, compared to suckling the low-glucose OES (Fig 1).

Glucose Absorption Curve

The glucose absorption curve for calves suckling a high-glucose OES was markedly different than that of calves suckling a low-glucose OES (Fig 3). As expected,

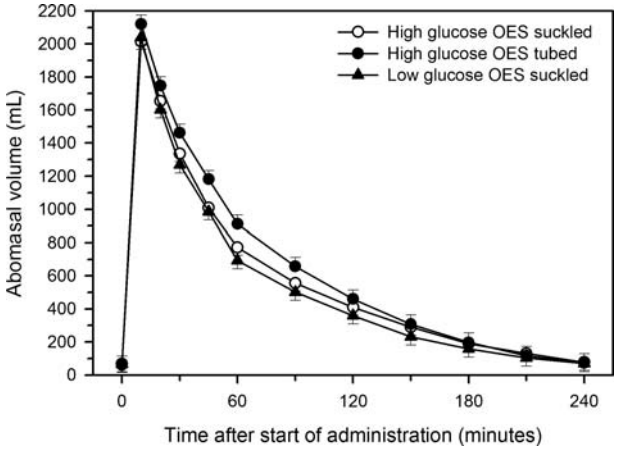

Fig 1. Change in abomasal volume (least squares mean ± standard error) in 7 calves that were administered 2 L of a high-glucose oral electrolyte solution (OES) by suckling or esophageal intubation or 2 L of a low-glucose OES by suckling, starting at time = 0 minutes.

calves suckling a high-glucose OES had a higher plasma glucose concentration and larger value for the area under the curve compared to those suckling a low-glucose OES (Table 1). However, the actual C_{max} value for glucose concentration occurred later in calves suckling a high-glucose OES compared to those suckling the low-glucose OES. This result is consistent with a slower rate of emptying in calves suckling a high-glucose OES.

The glucose absorption curves initially were similar for calves given a high-glucose OES by suckling or esophageal intubation (Fig 3). However, after 90 minutes, the plasma glucose concentration in calves administered the high-glucose OES by esophageal intubation was lower than that observed after suckling.

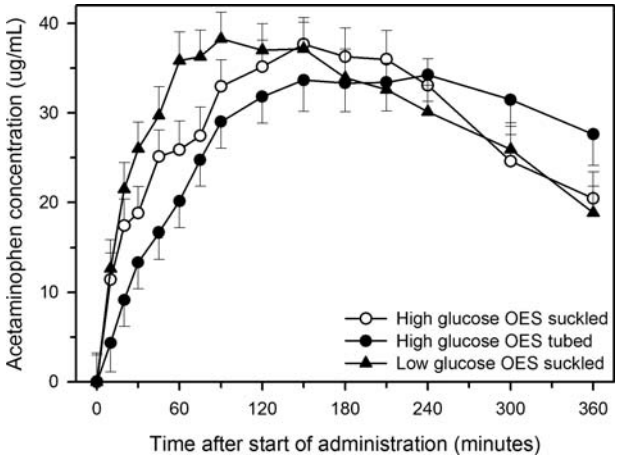

Fig 2. Change in plasma acetaminophen concentration (least squares mean ± standard error) in 7 calves that ingested acetaminophen (50 mg/kg body weight) in 2 L of a high-glucose oral electrolyte solution (OES) by suckling or esophageal intubation or by suckling 2 L of a low-glucose OES, starting at time = 0 minutes.

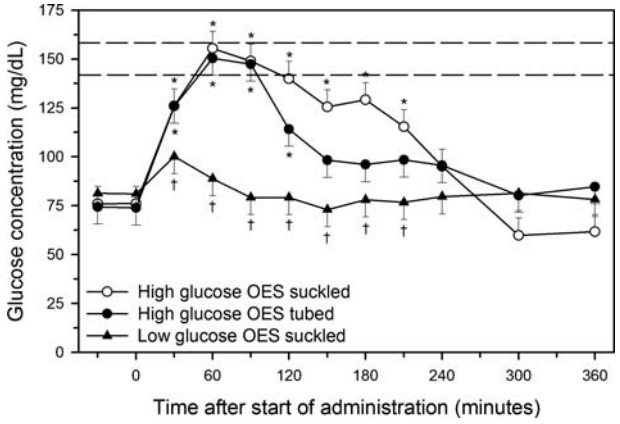

Fig 3. Change in plasma glucose concentration (least squares mean ± standard error) in 7 calves that were administered 2 L of a high-glucose oral electrolyte solution (OES) by suckling or esophageal intubation or 2 L of a low-glucose OES by suckling. An asterisk (*) indicates significantly different from time = 0 value. A dagger (†) indicates significantly different from the value for the high-glucose OES suckled group at the same time. The horizontal dashed lines indicate the range of values (140–160 mg/dL) for the renal threshold for glucose in neonatal calves.[31,32]

This result is consistent with a slower rate of emptying in calves receiving the high-glucose OES by esophageal intubation.

Change in Plasma Volume

There was no main effect of treatment on percent change in plasma volume, although there was a significant main effect of time ($P < .0001$) (Fig 4), with all 3 test solutions increasing plasma volume. Although the interaction between treatment and time (F test, $P = .16$) was not significant, the 1st significant increase in plasma volume from baseline occurred at 120 minutes when calves suckled the low-glucose OES compared to suckling

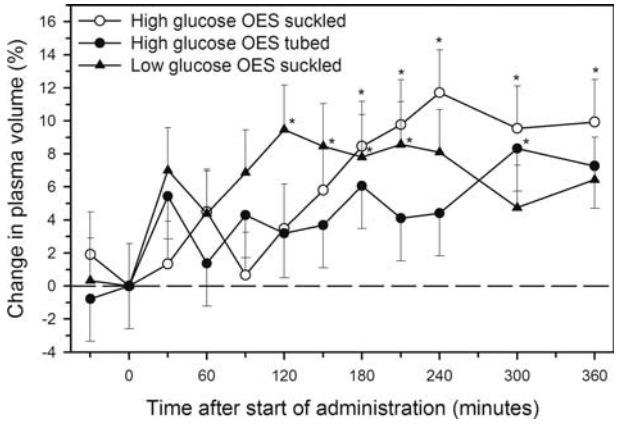

Fig 4. Percent change in plasma volume (least squares mean ± standard error) in 7 calves that were administered 2 L of a high-glucose oral electrolyte solution (OES) by suckling or esophageal intubation or 2 L of a low-glucose OES by suckling. An asterisk (*) indicates significantly different from time = 0 value.

the high-glucose OES (180 minutes) or esophageal intubation of the high-glucose OES (300 minutes). This result indicated that suckling a low-glucose OES produced the fastest rate of plasma volume expansion.

Discussion

The first major finding of the study reported here in euhydrated calves was that suckling a low-glucose OES resulted in a slightly faster rate of abomasal emptying than suckling a high-glucose OES. The second major finding was that suckling a low-glucose OES produced a faster rate of plasma volume expansion than suckling or esophageal intubation of a high-glucose OES. The third major finding was that esophageal intubation of 2 L of an OES produced the same initial change in abomasal volume as did suckling, but delayed the rate of OES delivery to the small intestine.

A high-glucose OES slows the abomasal emptying rate compared to a low-glucose OES by 3 separate but related mechanisms: increased intraduodenal glucose and total caloric load,[25] hyperglycemia,[26] and hyperinsulinemia.[27] Receptors in the duodenum currently are believed to sense the caloric density of fluid emptied from the stomach or abomasum, leading to reflex changes in emptying rate. The total glucose load rather than the osmolarity of the glucose solution is the more important determinant of emptying rate in monkeys[25] and presumably in calves. The slowing of gastric emptying during pathologic and physiologic hyperglycemia has been well documented in monogastric animals and is associated with suppression of antral waves, changes in the organization of antoduodenal motility, a reduction in proximal gastric tone, and stimulation of phasic and tonic pyloric pressure.[28–30]

Glucose was administered at approximately 3.2 g/kg body weight and 0.4 g/kg body weight in the high- and low-glucose OES, respectively. The small intestine of the healthy calf absorbs all of the suckled glucose when administered at 2.5 g/kg body weight.[21] Therefore, most or all of the glucose in the high-glucose OES was assumed to be absorbed in the calves in the study reported here. In halothane-anesthetized calves, glucose was absorbed in healthy and diarrheic calves at a similar rate of 2.4–7.2 mg/cm of small intestinal segment/h.[31] Based on a mean small intestinal length of 15.8–18.6 m in 1- to 2-week-old Holstein-Friesian calves,[32] the total glucose absorption rate in the small intestine therefore is estimated to range from 3.8 to 13.4 g/h. Assuming a 12-hour feeding interval, calves should be able to absorb 46–161 g of glucose in a given feeding. This calculation suggests that for 45-kg–body weight calves, the upper limit of glucose in an OES may be 1.0–3.6 g/kg body weight. Glucose administration rates above these calculated values run the risk of allowing unabsorbed glucose to carry over into the large intestine, where glucose may be fermented to short-chain volatile fatty acids and exacerbate fecal water loss.

We used 3 different methods for evaluating abomasal emptying rate. Acetaminophen absorption and ultrasonography produced a similar ranking of emptying rates (low-glucose OES suckled > high-glucose OES suckled > high-glucose OES intubated) with statistically significant differences depending on the precision of each technique. However, the results of our study highlight potentially important limitations of the plasma glucose–time relationship as an index of abomasal emptying rate. The plasma glucose–time relationship is dependent on the glucose concentration in the OES, the rate of abomasal emptying, the small intestinal transit time and surface area available for absorption, the rate of glucose entry into cells (which is dependent on the rate and magnitude of insulin release after glucose absorption), and the magnitude of glucose loss in the urine if plasma glucose concentration exceeds the renal threshold of 140–160 mg/dL.[23,24] Although the value for actual T_{max} derived from the glucose concentration–time relationship reflected the rate of abomasal emptying as assessed by acetaminophen absorption or ultrasonography, the increase in plasma glucose concentration to the renal threshold in calves given the high-glucose OES (Fig 3) decreases the accuracy of this index as a measure of abomasal emptying rate.

Orally administered hypertonic solutions have the potential to produce transient dehydration in diarrheic calves because of an osmotically driven movement of water from the extracellular compartment to the intestinal lumen in response to the initial osmolarity or the subsequent malabsorption of glucose in the small intestine.[21] Such a dehydrating effect would be manifest as a decrease in plasma volume, as calculated from the change in plasma total protein concentration. Results of the study reported here (Fig 4) and other studies[33,34] indicate that both high- and low-glucose OES caused expansion, and not contraction, of the plasma volume and presumably the extracellular fluid space. However, because the change in plasma volume was not measured during the first 30 minutes after administration of the high-glucose OES, it was possible that a mild and transient (<30 minutes) dehydrating effect was present in these calves.

The abomasal volume at any point in time is the sum of the preprandial volume, suckled volume, and volume of fluids secreted by the salivary glands and abomasum, minus the volume leaving the abomasum into the duodenum or reticulorumen.[3] Our finding that the calculated change in abomasal volume approximated the suckled volume in the 3 groups (Table 1; Fig 1) suggests that only a very small percentage of the intubated and suckled volume initially is present in the reticulorumen. It has been previously determined that <10% (the limit of detection) of the suckled volume is present in the reticulorumen 30 minutes after suckling,[35] and very little is present for the first 3–6 minutes after the start of suckling.[36] Taken together with the results of the study reported here, the volume present in the reticulorumen of healthy calves after suckling or intubation appears to be predominantly due to reflux from the abomasum, rather than spillage from incomplete closure of the esophageal groove.

Despite similar abomasal volumes immediately after suckling or esophageal intubation, the delivery of the

high-glucose OES to the small intestine was slower after intubation (Fig 2; Table 1). This finding was consistent with that found after intubation of colostrum,[16,17] lactose solutions,[18] or D-xylose solutions,[14] and indicates that esophageal intubation produces a different effect on coordinating motility between the reticulorumen, abomasum, and duodenum than does suckling. Although the mechanism is not clear, the effect of route of administration on abomasal emptying may be due to differences in central control of the pyloric motor profile[37] or suckling-induced changes in the concentration-time profile of insulin, gastrin, cholestokinin, and oxytocin.[38]

In conclusion, our results suggest that suckling a low-glucose OES provides the fastest rate of solution delivery to the small intestine and a slightly faster rate of plasma volume expansion than does suckling or esophageal intubation of a high-glucose OES. In contrast, our findings indicate that suckling or esophageal intubation of a high-glucose OES provides the most appropriate oral solution for treating hypoglycemic calves, because the high-glucose OES produced a larger and more sustained increase in plasma glucose concentration. Observed differences in abomasal emptying rate and plasma volume expansion between the 3 treatments were relatively small, and it remains to be determined whether a slight slowing in the rate of abomasal emptying and plasma volume expansion is clinically important in dehydrated diarrheic calves.

Footnotes

[a] Agri Master, Supreme All Milk, Blain Supply, Janesville, WI
[b] Entrolyte-HE, Pfizer Inc Animal Health Group, New York, NY
[c] Hy-Sorb, Bimeda Inc, Le Sueur, MN
[d] Acetaminophen, Sigma Aldrich, St Louis, MO
[e] Becton Dickinson Vacutainer systems, Becton Dickinson, Franklin, NJ
[f] PROC NLIN, SAS Institute Inc, Cary, NC
[g] Ultramark 4, Advanced Technology Laboratories, Tempe, AZ
[h] Hitachi 704 automatic analyzer, Hitachi, Tokyo, Japan
[i] PROC MIXED, SAS 8.2, SAS Institute Inc, Cary, NC

Acknowledgments

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