Effects of enteral and intravenous fluid therapy, magnesium sulfate, and sodium sulfate on colonic contents and feces in horses

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Objective—To assess changes in systemic hydration, concentrations of electrolytes in plasma, hydration of colonic contents and feces, and gastrointestinal transit in horses treated with IV fluid therapy or enteral administration of magnesium sulfate ($MgSO_4$), sodium sulfate ($NaSO_4$), water, or a balanced electrolyte solution.

Animals—7 horses with fistulas in the right dorsal colon (RDC).

Procedure—In a crossover design, horses alternately received 1 of 6 treatments: no treatment (control); IV fluid therapy with lactated Ringer's solution; or enteral administration of $MgSO_4$, Na_2SO_4, water, or a balanced electrolyte solution via nasogastric intubation. Physical examinations were performed and samples of blood, RDC contents, and feces were collected every 6 hours during the 48 hour-observation period. Horses were muzzled for the initial 24 hours but had access to water ad libitum. Horses had access to hay, salt, and water ad libitum for the last 24 hours.

Results—Enteral administration of a balanced electrolyte solution and Na_2SO_4 were the best treatments for promoting hydration of RDC contents, followed by water. Sodium sulfate was the best treatment for promoting fecal hydration, followed by $MgSO_4$ and the balanced electrolyte solution. Sodium sulfate caused hypocalcemia and hypernatremia, and water caused hyponatremia.

Conclusions and Clinical Relevance—Enteral administration of a balanced electrolyte solution promoted hydration of RDC contents and may be useful in horses with large colon impactions. Enteral administration of either Na_2SO_4 or water may promote hydration of RDC contents but can cause severe electrolyte imbalances. (Am J Vet Res 2004;65:695–704)

Impaction of the large colon is a common cause of colic in horses.[1-3] However, information obtained from controlled studies is scarce, and present recommendations for treatment are mostly made on the basis of anecdotal observations and tradition. The standard treatment for impaction of the large colon is administration of laxatives and analgesics. For severe cases, IV administration of large volumes of fluids is also recommended.[4-6] This treatment appears to be effective for most horses, although in certain horses surgery is necessary.[7] Results from a previous study[4] suggest that systemic overhydration caused by IV fluid therapy plus the increase in intraluminal osmolality caused by enteral administration of **magnesium sulfate ($MgSO_4$)** promote secretion of fluids into the gastrointestinal lumen, thereby hydrating colonic contents and contributing to the resolution of the impaction. However, changes in the hydration of colonic contents induced by these treatments have not been evaluated in a controlled study with horses. Absorption of $MgSO_4$ after nasogastric administration is believed to be limited, although magnesium toxicosis has been reported.[8] Renal excretion of magnesium is believed to prevent hypermagnesemia, and the recommended dose of $MgSO_4$ (1.0 g/kg, enterally) appears to be safe. A single dose of $MgSO_4$ without fluid therapy is a common treatment for horses with large colon impaction and other conditions.[7] Alternatively, another saline cathartic such as **sodium sulfate (Na_2SO_4)** can be used to avoid the risk of hypermagnesemia. Furthermore, a single dose of Na_2SO_4 (1.0 g/kg, enterally) was reportedly[9] more effective than a single dose of $MgSO_4$ (0.8 g/kg, enterally) in promoting fecal hydration in 2 horses with cecal fistulas.

Enteral fluid therapy has been used as an effective and inexpensive treatment for horses with impaction of the large colon.[10] Because fluids administered by nasogastric intubation can rapidly reach the large intestine,[11,12] it is likely that this treatment promotes hydration of the contents of the large intestine shortly after administration. Enteral administration of large volumes (10 L/h) of a balanced electrolyte solution is more effective in promoting hydration of the contents

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of the **right dorsal colon (RDC)** than IV fluid therapy (10 L/h) and enteral administration of $MgSO_4$ (1 g/kg) combined.[13] However, the effects of fluids administered enterally at a slower rate have not been investigated or compared with those of fluids administered IV or laxatives administered enterally. Furthermore, the effects of a balanced electrolyte solution administered enterally have not been compared with the effects of plain water administered enterally.

The purpose of the study reported here was to assess changes in systemic hydration, concentrations of electrolytes in plasma, hydration of colonic contents and feces, and gastrointestinal transit in horses treated with IV fluid therapy or enteral administration of $MgSO_4$, Na_2SO_4, water, or a balanced electrolyte solution. We hypothesized that enteral administration of a balanced electrolyte solution with sodium, potassium, and chloride concentrations similar to those in plasma would induce hydration of the RDC contents with minimal changes in PCV and concentrations of electrolytes and protein in plasma. We also hypothesized that IV fluid therapy and enteral administration of water and laxatives ($MgSO_4$ and Na_2SO_4) would be less effective in inducing hydration of the RDC contents and feces.

Materials and Methods

This study was approved by the Virginia-Maryland Regional College of Veterinary Medicine Animal Care Committee. Six geldings and 1 mare (5 Thoroughbreds and 2 Quarter Horses) with a fistula in the RDC were used in this study. With the exception of 1 gelding, all horses were also used in another study.[14] Horses were between 6 and 17 years old (median, 9 years) and weighed between 447 and 581 kg (median, 508 kg). The fistula in the RDC had been placed 32 to 75 days (median, 49 days) before the start of the study. The technique used to place the fistula in the RDC has been described elsewhere.[a]

For at least 5 days before each experimental period, horses were housed in stalls with free access to 2 buckets of water (each containing 12 liters), a salt block,[b] and orchard grass hay. A single batch of hay was used for the entire study. Samples of hay were submitted to a reference laboratory[c] for analysis. The nutrient content of the hay (as sample basis) was the following: dry matter, 92.1%; crude protein, 11.2%; neutral detergent fiber, 61.1%; total digestible nutrients, 42%; digestible energy, 7.75 MJ/kg; calcium, 0.49%; phosphorus, 0.33%; magnesium, 0.23%; potassium, 1.97%; and sodium, 0.004%.

Study design—The study was conducted in a 6-treatment, 6-period crossover design balanced for residual effects to compare 6 experimental treatments: no treatment (control) but nasogastric intubation[d] was performed; $MgSO_4$ $7H_2O$[e] (1 g/kg dissolved in 1 L of water) administered enterally via nasogastric intubation at time 0; Na_2SO_4 anhydrous[f] (1 g/kg dissolved in 3 L of water) administered enterally via nasogastric intubation at time 0; IV fluid therapy with lactated Ringer's solution[g] (5 L/h) administered via a catheter[h] placed in the jugular vein for the first 12 hours of the observation period; tap water (5 L/h) administered enterally via nasogastric intubation for the first 12 hours of the observation period; and a balanced electrolyte solution (5 L/h, 135 mmol of sodium/L, 5 mmol of potassium/L, 95 mmol of chloride/L, and 45 mmol of bicarbonate/L)[13] administered enterally via nasogastric intubation during the first 12 hours of the observation period. The balanced electrolyte solution consisted of 5.27 g of sodium chloride,[i,] 0.37 g of potassium chloride,[j] and 3.78 g of sodium bicarbonate[k] dissolved in 1 L of tap water.[13] The order that treatments were administered to horses was randomized. Fluid and electrolyte loads provided by all treatments were calculated (**Table 1**). For the entire study, the observation periodsinitiated at approximately noon on Monday and were stopped 48 hours later on Wednesday. Thus, there was a 5-day washout period between treatments. For all treatments, the nasogastric tube was taped to the halter and kept in place while the horses were muzzled for the initial 24 hours of the observation period; horses had no access to hay or salt but free access to water. After the initial 24 hours, the nasogastric tube and muzzle were removed and horses had access to orchard grass hay, salt,[b] and water ad libitum for the last 24 hours of the observation period.

Clinical assessment and sample collection—Horses were restrained in stocks for physical examinations and sample collections. Starting immediately before and continuing throughout each 48-hour observation period, a physical examination was performed every 6 hours to evaluate rectal temperature, heart rate, mucous membrane color, capillary refill time, pulse strength at the palmar and plantar digital arteries, hoof temperature, signs of colic, and signs of lameness. At the same times, blood from a catheter in the jugular vein was collected into 2 vacuum glass tubes[l]; 1 tube con-

Table 1—Mean total electrolyte and fluid loads administered to 6 horses receiving no treatment (control); IV fluid therapy with lactated Ringer's solution (5 L/h for 12 hours); or enteral administration of magnesium sulfate ($MgSO_4$; 1 g/kg in 1 L of water), sodium sulfate (Na_2SO_4; 1 g/kg in 1 L of water), water (5 L/h for 12 hours), or a balanced electrolyte solution (5 L/h for 12 hours) containing 135 mmol of sodium/L, 5 mmol of potassium /L, 95 mmol of chloride/L, and 45 mmol of bicarbonate/L via nasogastric intubation. All treatments were administered during a 24-hour period when food was withheld. All horses also received enteral administration of cobalt-EDTA (40 mg/kg in 1 L of water) via nasogastric intubation at the beginning of each treatment

Electrolytes ansd fluids	Control	$MgSO_4$	Na_2SO_4	IV fluid therapy	Water	Electrolyte solution
Sodium (mmol)	0	0	7,221	7800	0	8,100
Potassium (mmol)	0	0	0	240	0	300
Calcium (mmol)	0	0	0	81	0	0
Magnesium (mmol)	0	2,077	0	0	0	0
Chloride (mmol)	0	0	0	6,540	0	5,700
Sulfate (mmol)	0	2,077	3,610	0	0	0
Lactate (mmol)	0	0	0	1,680	0	0
Bicarbonate (mmol)	0	0	0	0	0	2,700
Water consumption (L)	0.60	6.70	17.92	2.20	0.33	0.25
Total fluids (L)	1.60	8.70	21.92	63.20	61.33	61.25
Total fluids/kg (mL/kg)	3.10	17.03	43.39	125.30	122.24	119.92

tained EDTA, and the other contained lithium heparin. Approximately 200 to 300 mL of colonic contents was collected from the fistula in the RDC. Approximately 200 to 300 mL of feces was collected from the rectum or the floor immediately after defecation. Immediately after the first physical examination was performed and the first set of samples (time 0) was collected, cobalt-EDTA (40 mg/kg) dissolved in 1 L of water was administered via nasogastric intubation.[d] Cobalt-EDTA was prepared as previously described.[15] During each 48-hour observation period, environmental temperature and humidity were recorded[m] every 6 hours and water consumption was estimated by measuring the volume required to refill the water buckets.

Sample processing and analyses—Blood samples collected into EDTA tubes were immediately analyzed for PCV and the concentration of protein in plasma by use of the microhematocrit technique and a refractometer,[n] respectively. Blood collected into the lithium heparin tubes was centrifuged at 1,124 X *g* for 10 miniutes, and plasma was removed. Plasma was immediately frozen at –70°C for subsequent analysis of electrolytes. Automatic analyzers with ion-specific electrodes were used to measure the concentrations of sodium, potassium, chloride, total calcium, total magnesium,[o] and ionized calcium[p] in plasma.

Samples of the RDC contents and feces were divided into 2 aliquots. Extraction of the liquid phase from 1 aliquot of RDC contents and feces was performed by straining the sample through cheesecloth and centrifuging at 1,124 X *g* for 10 minutes. The liquid-phase samples were frozen at –70°C for subsequent analysis of cobalt concentration. The other aliquot was weighed immediately after collection (wet weight), dried in an oven[q] at 90°C, and repeatedly weighed until no change in the weight was detected (dry weight). Water content of the RDC contents and feces was calculated by use of the following formula:

water content = 100 X (wet weight – dry weight)/wet weight

The cobalt concentration of the liquid phase of the RDC contents and feces was measured by use of atomic absorption spectrophotometry.[r] Sodium and magnesium concentrations of the liquid phase of the RDC contents and feces were measured by inductively coupled plasma atomic emission spectrometry.[s]

Statistical analyses—Computer software[t] was used to perform a mixed-model repeated measures ANOVA to test for effects of treatment, time of sampling, and treatment by time interaction while controlling for horse and period effects. Significant interactions were further investigated by use of computer software[u] for the simple main effect of treatment within each sampling time and post-hoc analysis by use of the Bonferroni test for multiple comparisons. Initial analyses were performed by use of a model that tested for carryover effects.[16] There were no significant carryover effects ($P > 0.100$); therefore, the carryover effect was removed from the model for all subsequent analyses. **Mean retention time (MRT)** of cobalt in the RDC contents and feces was calculated by use of the noncompartmental approach (MRT = $\Sigma t_i c_i / \Sigma c_i$, where t_i = time and c_i = cobalt concentration).[17] For the MRT of cobalt, computer software[s] was used to perform a mixed-model ANOVA to test for effects of treatment. Values of $P \leq 0.05$ were considered significant.

Results

Because of problems with the colostomy, all 6 treatments were not performed on 2 horses. Because the order of treatments was different for each horse, IV fluid therapy was administered to only 5 horses, whereas all other treatments were administered to 6 horses. Complications associated with the treatments were observed only in the heaviest horse. After enteral

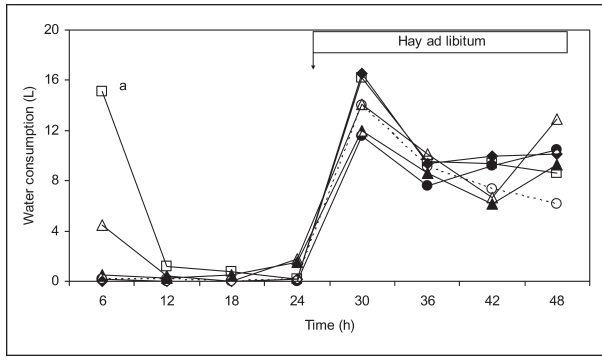

Figure 1—Mean water consumption during a 48-hour observation period in horses with fistulas in the right dorsal colon (RDC) receiving no treatment (control, open circles [n = 6]); IV fluid therapy with Lactated Ringer's solution (5 L/h for 12 hours; closed triangles [5]); or enteral administration of magnesium sulfate ($MgSO_4$; 1 g/kg in 1 L of water; open triangles [6]), sodium sulfate (Na_2SO_4; 1 g/kg in 3 L of water; open squares [6]), water (5 L/h for 12 hours; closed diamonds [6]), or a balanced electrolyte solution (5 L/h for 12 hours; closed circles [6]) containing 135 mmol of sodium/L, 5 mmol of potassium/L, 95 mmol of chloride/L, and 45 mmol of bicarbonate/L via nasogastric intubation. Food was withheld for the initial 24 hours of the observation period in all horses; all treatments were administered during this period. Within a time period, values with different letters are significantly ($P \leq 0.05$) different.

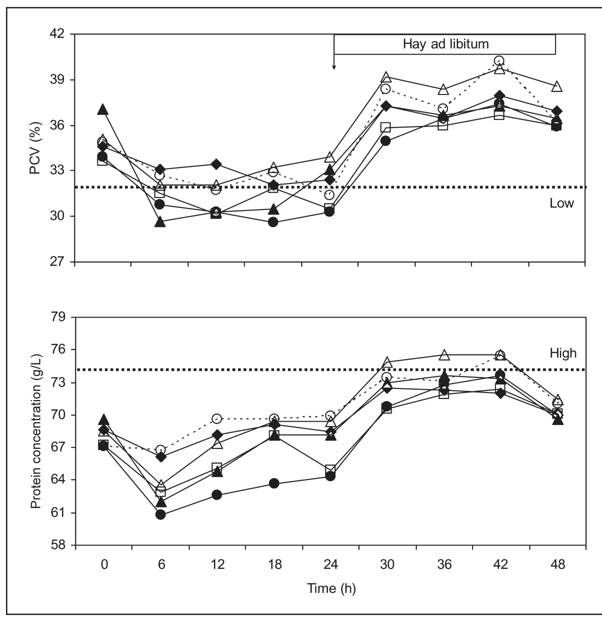

Figure 2—Mean PCV and concentration of protein in plasma obtained during a 48-hour observation period from horses with fistulas in the RDC receiving no treatment (control [n = 6]); IV fluid therapy with lactated Ringer's solution (5 L/h for 12 hours [5]); or enteral administration of magnesium sulfate ($MgSO_4$; 1 g/kg in 1 L of water [6]), sodium sulfate (Na_2SO_4; 1 g/kg in 3 L of water [6]), water (5 L/h for 12 hours [6]), or an electrolyte solution (5 L/h for 12 hours [6]) containing 135 mmol of sodium/L, 5 mmol of potassium /L, 95 mmol of chloride/L, and 45 mmol of bicarbonate/L via nasogastric intubation. Food was withheld for the initial 24 hours of the observation period in all horses; all treatments were administered during this period. Dotted lines within the graphs indicate the upper and lower reference limits for the concentration of protein in plasma and PCV, respectively.[18] *See* Figure 1 for key.

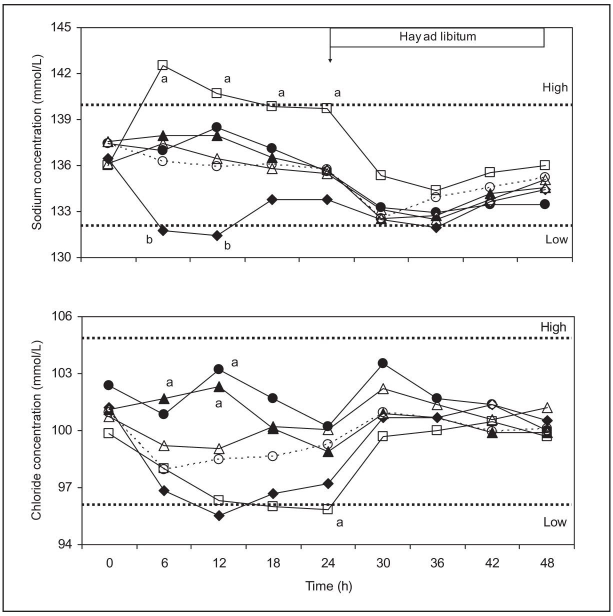

Figure 3—Mean concentrations of sodium and chloride in plasma obtained during a 48-hour observation period from horses with fistulas in the RDC receiving no treatment (control [n = 6]); IV fluid therapy with lactated Ringer's solution (5 L/h for 12 hours [5]); or enteral administration of ($MgSO_4$; 1 g/kg in 1 L of water [6]), (Na_2SO_4;1 g/kg in 3 L of water [6]), water (5 L/h for 12 hours [6]), or an electrolyte solution (5 L/h for 12 hours [6]) containing 135 mmol of sodium/L, 5 mmol of potassium /L, 95 mmol of chloride/L, and 45 mmol of bicarbonate/L via nasogastric intubation. Food was withheld for the initial 24 hours of the observation period in all horses; all treatments were administered during this period. Dotted lines within the graphs indicate the laboratory normal ranges for the concentrations of sodium and chloride in plasma. Within a time point, values with different letters are significantly ($P \leq 0.05$) different from control values and between treatments. *See* Figure 1 for key.

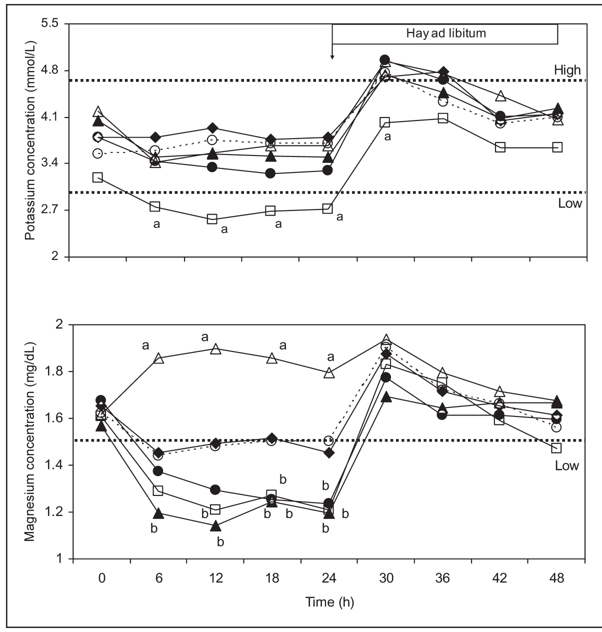

Figure 4—Mean concentrations of potassium and magnesium in plasma obtained during a 48-hour observation period from horses with fistulas in the RDC receiving no treatment (control [n = 6]); IV fluid therapy with lactated Ringer's solution (5 L/h for 12 hours [5]); or enteral administration of ($MgSO_4$; 1 g/kg in 1 L of water [6]), (Na_2SO_4; 1 g/kg in 3 L of water [6]), water (5 L/h for 12 hours [6]), or an electrolyte solution (5 L/h for 12 hours [6]) containing 135 mmol of sodium/L, 5 mmol of potassium /L, 95 mmol of chloride/L, and 45 mmol of bicarbonate/L via nasogastric intubation. Food was withheld for the initial 24 hours of the observation period in all horses; all treatments were administered during this period. Dotted lines within the graphs indicate the reference limits for the laboratory for concentrations of potassium and magnesium in plasma. Within a time point, values with different letters are significantly ($P \leq 0.05$) different from control values and between treatments. *See* Figure 1 for key.

administration of 50 L of the balanced electrolyte solution via nasogastric intubation, this horse had signs of moderate colic (pawing, recumbency, and rolling) that were managed by discontinuing fluid therapy and administering a single dose of flunixin meglumine (250 mg, IV). A few weeks later, the same horse had severe signs of colic (vigorous pawing and rolling), gastric reflux, reduced borborygmi, and synchronous diaphragmatic flutter 19 hours after enteral administration of Na_2SO_4. The horse was treated with a single dose of flunixin meglumine (500 mg, IV), a single dose of xylazine (300 mg, IV), 10 L of saline (0.9% NaCl) solution (10 L/h, IV), 60 L of lactated Ringer's solution (5 L/h, IV), and 23% calcium gluconate (240 mL, IV, added to the saline solution). Seventeen hours later, the horse appeared clinically normal, had a good appetite, and was offered access to hay ad libitum. Enteral administration of the balanced electrolyte solution and the Na_2SO_4 was repeated 1 week after the original treatment, and no complications were observed. Unlike the other horses, this horse was recumbent for most of the initial 24 hours of the observation period (while muzzled) despite the experimental treatment that was administered.

The environmental temperature and relative humidity recorded during the observation periods ranged from 10° to 32°C (median, 21°C) and 34% to 90% (median, 67%), respectively. There was time effect ($P < 0.01$) and treatment by time interaction ($P = 0.01$) but no treatment effect ($P = 0.12$) on water consumption. During the first 6 hours of the observation period when food was withheld, water consumption was higher in horses treated with Na_2SO_4, whereas there were no significant differences in water consumption among the other treatments. A marked increase in water consumption was observed in horses in all treatment groups after hay was offered ad libitum **(Fig 1)**. The PCV and concentration of protein in plasma increased after hay was offered ($P < 0.01$); however, there was no effect of treatment ($P = 0.30$ and $P = 0.11$ for PCV and plasma protein concentration, respectively) or treatment by time interaction ($P = 0.90$ and $P = 0.35$ for PCV and plasma protein concentration, respectively) on PCV and the concentration of protein in plasma **(Fig 2)**.

For concentrations of sodium and chloride in plasma, there was time effect ($P < 0.01$), treatment effect ($P < 0.01$), and treatment by time interaction ($P < 0.01$). Enteral administration of Na_2SO_4 and water via nasogastric intubation were the only treatments that affected the concentration of sodium in plasma; Na_2SO_4 induced hypernatremia, whereas water induced hyponatremia **(Fig 3)**. Enteral administration

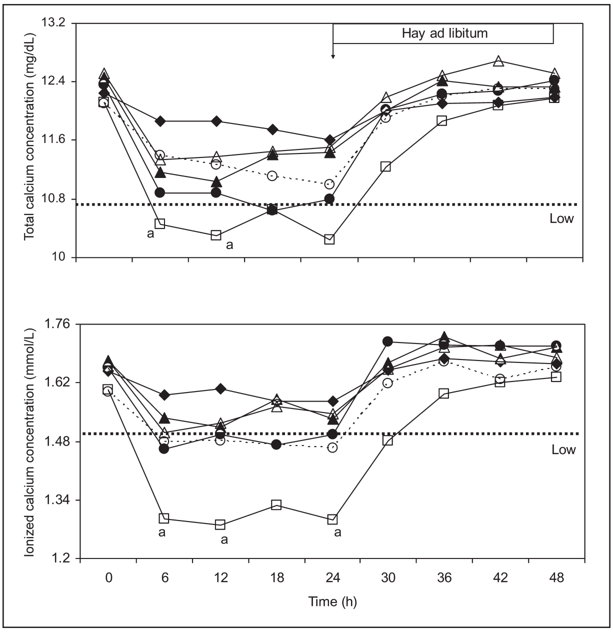

Figure 5—Mean concentrations of total and ionized calcium in plasma obtained during a 48-hour observation period from horses with fistulas in the RDC receiving no treatment (control [n = 6]); IV fluid therapy with lactated Ringer's solution (5 L/h for 12 hours [5]); or enteral administration of $MgSO_4$(1 g/kg in 1 L of water [6]), sodium sulfate (1 g/kg in 3 L of water [6]), water (5 L/h for 12 hours [6]), or an electrolyte solution (5 L/h for 12 hours [6]) containing 135 mmol of sodium/L, 5 mmol of potassium /L, 95 mmol of chloride/L, and 45 mmol of bicarbonate/L via nasogastric intubation. Food was withheld for the initial 24 hours of the observation period in all horses; all treatments were administered during this period. Dotted lines within the graphs indicate the lower reference limit for the laboratory for concentration of total calcium and the lower reference limit for the concentration of ionized calcium in plasma.[18] For ionized calcium, the reference limits for the laboratory had not been determined. Within a time point, values with different letters are significantly ($P \leq 0.05$) different from control values. *See* Figure 1 for key.

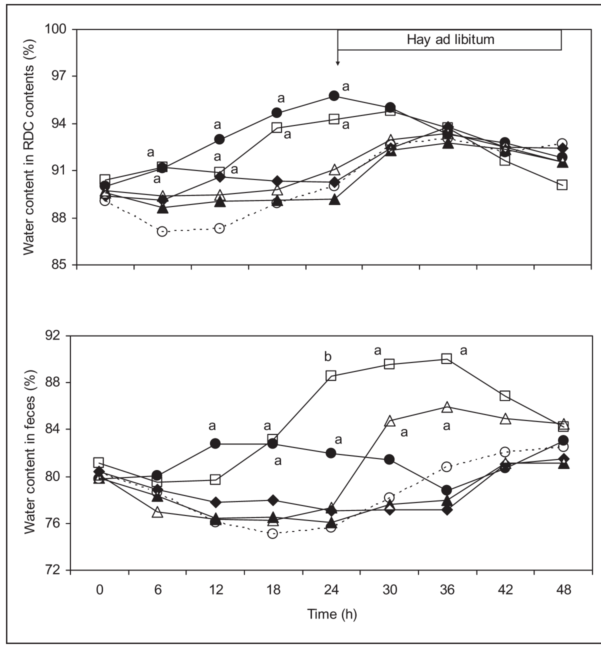

Figure 6—Mean water content in the RDC contents and feces obtained during a 48-hour observation period from horses with fistulas in the RDC receiving no treatment (control [n = 6]); IV fluid therapy with lactated Ringer's solution (5 L/h for 12 hours [5]); or enteral administration of magnesium sulfate (1 g/kg in 1 L of water [6]), sodium sulfate (1 g/kg in 3 L of water [6]), water (5 L/h for 12 hours [6]), or an electrolyte solution (5 L/h for 12 hours [6]) containing 135 mmol of sodium/L, 5 mmol of potassium /L, 95 mmol of chloride/L, and 45 mmol of bicarbonate/L via nasogastric intubation. Food was withheld for the initial 24 hours of the observation period in all horses; all treatments were administered during this period. Within a time point, values with different letters are significantly ($P \leq 0.05$) different from control values and between treatments. *See* Figure 1 for key.

of the balanced electrolyte solution and IV fluid therapy prevented a decrease in the concentration of chloride in plasma caused by fasting, whereas enteral administration of water and Na_2SO_4 induced a further decrease in the concentration of chloride in plasma. For all treatments, the concentration of chloride in plasma returned to baseline concentrations after horses were offered hay ad libitum (Fig 3).

For concentrations of potassium and magnesium in plasma, there was time effect ($P < 0.01$) and treatment effect ($P < 0.01$). For plasma concentrations of magnesium ($P < 0.01$) but not potassium ($P = 0.43$), there was treatment by time interaction. Enteral administration of Na_2SO_4 was the only treatment that affected the concentration of potassium in plasma, which was low throughout the initial 24 hours of the observation period. With all treatments, an increase in the concentration of potassium in plasma was observed after hay was offered **(Fig 4)**. All treatments except enteral administration of $MgSO_4$ induced hypomagnesemia, which resolved after hay was offered. Hypomagnesemia was more pronounced with IV fluid therapy and enteral administration of Na_2SO_4 and the balanced electrolyte solution (Fig 4).

For concentrations of total and ionized calcium in plasma, there was time effect ($P < 0.01$), treatment effect ($P = 0.02$ and $P < 0.01$ for plasma concentrations of total and ionized calcium, respectively), and treatment by time interaction ($P < 0.01$). A decrease in the total calcium concentration in plasma was seen with all treatments. However, hypocalcemia was observed only after enteral administration of Na_2SO_4 (during the entire period when food was withheld) and 6 hours after discontinuing enteral administration of the balanced electrolyte solution. Total calcium concentration in plasma returned to baseline concentrations after hay was offered **(Fig 5)**. For all treatments, the concentration of ionized calcium in plasma also decreased when food was withheld, but only enteral administration of Na_2SO_4 induced changes relative to the control. The concentration of ionized calcium in plasma returned to baseline concentrations after hay was offered (Fig 5).

For the water content of RDC contents and feces, there was time effect ($P < 0.01$), treatment effect ($P < 0.01$), and treatment by time interaction ($P < 0.01$). Only enteral administration of the balanced electrolyte solution and Na_2SO_4 induced a marked increase in the water content of RDC contents, whereas enteral administration of water induced a transient increase in the water content of RDC contents. For all treatments, the water content of RDC contents returned to baseline values after horses were offered hay **(Fig 6)**. Enteral administration of the balanced electrolyte solu-

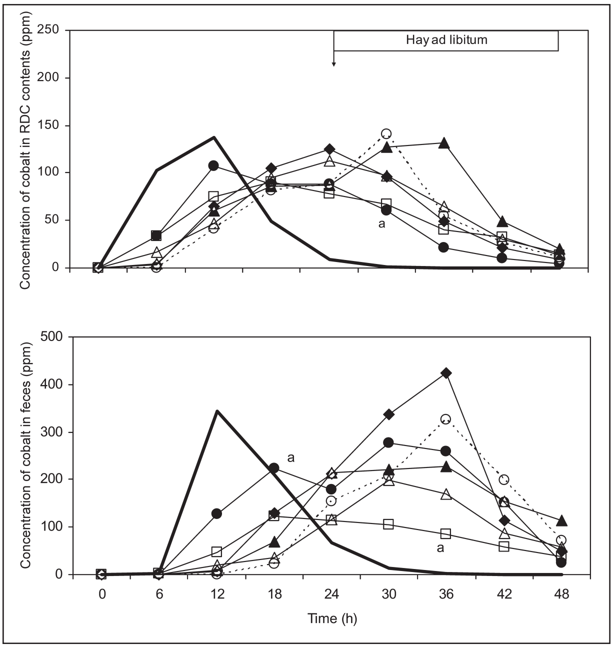

Figure 7—Mean concentrations of cobalt in the RDC contents and feces obtained during a 48-hour observation period from horses with fistulas in the RDC receiving no treatment (control [n = 6]); IV fluid therapy with lactated Ringer's solution (5 L/h for 12 hours [5]); or enteral administration of magnesium sulfate (1 g/kg in 1 L of water [6]), sodium sulfate (1 g/kg in 3 L of water [6]), water (5 L/h for 12 hours [6]), or an electrolyte solution (5 L/h for 12 hours [6]) containing 135 mmol of sodium/L, 5 mmol of potassium/L, 95 mmol of chloride/L, and 45 mmol of bicarbonate/L via nasogastric intubation. Cobalt EDTA (40 mg/kg) was administered via nasogastric intubation at time 0. Food was withheld for the initial 24 hours of the observation period in all horses; all treatments were administered during this period. The cobalt concentration curves from the same horses while fed hay ad libitum (solid line) in a previous study[14] were added for comparison. Within a time point, values with different letters are significantly ($P \leq 0.05$) different from control values. *See* Figure 1 for key.

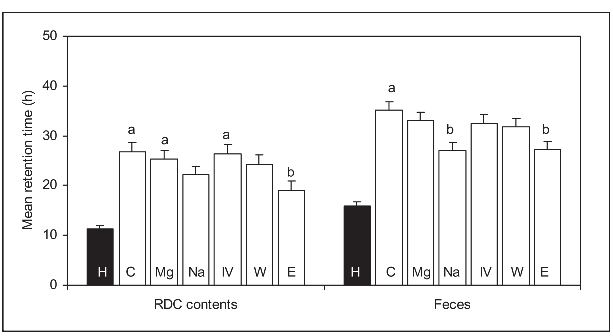

Figure 8—Mean ± SE retention time of cobalt in the RDC contents and feces obtained during a 48-hour observation period from horses with fistulas in the RDC receiving no treatment (controls, C [n = 6]); IV fluid therapy with lactated Ringer's solution (IV; 5 L/h for 12 hours [5]); or enteral administration of magnesium sulfate (Mg; 1 g/kg in 1 L of water [6]), sodium sulfate (Na; 1 g/kg in 3 L of water [6]), water (W; 5 L/h for 12 hours [6]), or an electrolyte solution (E; 5 L/h for 12 hours [6]) containing 135 mmol of sodium/L, 5 mmol of potassium/L, 95 mmol of chloride/L, and 45 mmol of bicarbonate/L via nasogastric intubation. Cobalt-EDTA (40 mg/kg) was administered via nasogastric intubation at time 0. Food was withheld for the initial 24 hours of the observation period in all horses; all treatments were administered during this period. Mean retention time of cobalt in RDC contents and feces from the same horse while fed hay (H) ad libitum in a previous study[14] was added for comparison. Values with different letters are significantly ($P \leq 0.05$) different.

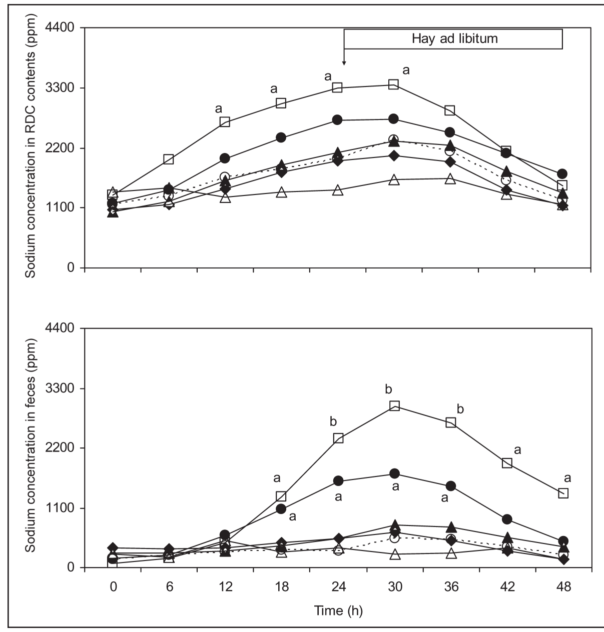

Figure 9—Mean concentration of sodium in the RDC contents and feces obtained during a 48-hour observation period from horses with fistulas in the RDC receiving no treatment (control [n = 6]); IV fluid therapy with lactated Ringer's solution (5 L/h for 12 hours [5]); or enteral administration of magnesium sulfate (1 g/kg in 1 L of water [6]), sodium sulfate (1 g/kg in 3 L of water [6]), water (5 L/h for 12 hours [6]), or an electrolyte solution (5 L/h for 12 hours [6]) containing 135 mmol of sodium/L, 5 mmol of potassium /L, 95 mmol of chloride/L, and 45 mmol of bicarbonate/L via nasogastric intubation. Food was withheld for the initial 24 hours of the observation period in all horses; all treatments were administered during this period. Within a time point, values with different letters are significantly ($P \leq 0.05$) different from control values and between treatments. *See* Figure 1 for key.

tion, Na_2SO_4, and $MgSO_4$ induced an increase in the water content of feces. This increase occurred earlier with enteral administration of the balanced electrolyte solution; however, the increase was more pronounced with enteral administration of Na_2SO_4. Changes induced by $MgSO_4$ were not detected before 30 hours. For all treatments, water content of feces returned to baseline values at the end of the 48-hour observation period (Fig 6).

For cobalt concentration in RDC contents and feces, there was time effect ($P < 0.01$) and treatment by time interaction ($P < 0.05$ and $P < 0.01$ for RDC contents and feces, respectively). There was an effect of treatment on cobalt concentration in feces ($P < 0.05$) but not on cobalt concentration in RDC contents ($P = 0.87$). There was no difference in the cobalt concentration of RDC contents between horses in the control group and those that received any treatment or among treatments during the period when food was withheld. The cobalt concentration in RDC contents was lower 6 hours after hay was offered (at the 30-hour time point) with enteral administration of the balanced electrolyte solution, compared with that of the control group. The cobalt concentration in RDC contents was higher at the 36-hour time point with IV fluid therapy, compared with the concentration after enteral administration of Na_2SO_4, balanced electrolyte solution, and water (Fig 7). The cobalt concentration in the feces

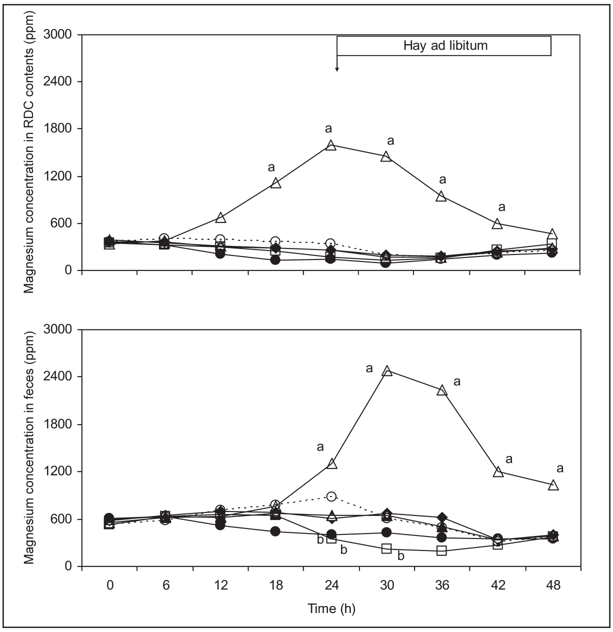

Figure 10—Mean concentrations of magnesium in the RDC contents and feces obtained during a 48-hour observation period from horses with fistulas in the RDC receiving no treatment (control [n = 6]); IV fluid therapy with lactated Ringer's solution (5 L/h for 12 hours [5]); or enteral administration of magnesium sulfate (1 g/kg in 1 L of water [6]), sodium sulfate (1 g/kg in 3 L of water [6]), water (5 L/h for 12 hours [6]), or an electrolyte solution (5 L/h for 12 hours [6]) containing 135 mmol of sodium/L, 5 mmol of potassium /L, 95 mmol of chloride/L, and 45 mmol of bicarbonate/L via nasogastric intubation. Food was withheld for the initial 24 hours of the observation period in all horses; all treatments were administered during this period. Within a time point, values with different letters are significantly ($P \leq 0.05$) different from control values and between treatments. *See* Figure 1 for key.

was higher at the 18-hour time point after enteral administration of the balanced electrolyte solution, compared with that of the control group and after enteral administration of $MgSO_4$. At the 36-hour time point, the cobalt concentration in the feces was lower after enteral administration of Na_2SO_4, compared with that of the control group and after enteral administration of water. Although at the 36-hour time point no other treatment was different from the control, the fecal cobalt concentration was lower with $MgSO_4$ and IV fluid therapy than with enteral administration of water. Withholding food shifted the concentration curves of cobalt in RDC contents and feces to the right, which indicated a delay in the transit of cobalt (Fig 7).

There was treatment effect on MRT of cobalt in RDC contents ($P < 0.01$) and feces ($P < 0.01$). With enteral administration of the balanced electrolyte solution, the MRT of cobalt in RDC contents in horses was decreased, compared with that of the control group or after enteral administration of $MgSO_4$ or IV fluid therapy **(Fig 8)**. With enteral administration of the balanced electrolyte solution and Na_2SO_4, the MRT of cobalt in feces was decreased, compared with that of the control group. No other difference in the MRT of cobalt in RDC contents or feces was detected.

For sodium concentration in RDC contents and feces, there was time effect ($P < 0.01$), treatment effect ($P < 0.01$), and treatment by time interaction ($P < 0.01$). Enteral administration of Na_2SO_4 induced sodium concentrations in the RDC contents that were higher than those in the control group **(Fig 9)**. Enteral administration of the balanced electrolyte solution and Na_2SO_4 induced sodium concentrations in the feces higher than those in the control group.

For magnesium concentration in RDC contents and feces, there was time effect ($P < 0.01$), treatment effect ($P < 0.01$), and treatment by time interaction ($P < 0.01$). Only enteral administration of $MgSO_4$ induced an increase in magnesium concentration in the RDC contents and feces, compared with that of the control group. The concentration of magnesium in feces was lower at the 24-hour time point after enteral administration of the balanced electrolyte solution, compared with that of the control group. The concentration of magnesium in feces was lower at the 24- and 30-hour time points after enteral administration of Na_2SO_4, compared with that of the control group. The concentration of magnesium in feces was lower at the 36-hour time point after enteral administration of Na_2SO_4, compared with that after enteral administration of water **(Fig 10)**.

Discussion

In the study reported here, enteral administration of an electrolyte solution containing 135 mmol of sodium, 5 mmol of potassium, and 95 mmol of chloride/L was effective in promoting hydration of the RDC contents. The rapid transit of the fluid phase of ingesta through the small intestine[11,12] may explain why enteral administration of a balanced electrolyte solution is so effective. In our study, the increased water content of RDC contents and faster transit of cobalt through the gastrointestinal tract suggested that enteral administration of the balanced electrolyte solution was, at least, as effective as enteral administration of Na_2SO_4 and more effective than all other treatments in increasing the water content of RDC contents and promoting transit of water through the gastrointestinal tract. The observation of less pronounced changes in the concentrations of electrolytes in plasma with enteral administration of the balanced electrolyte solution indicated that this treatment was more advantageous than enteral administration of Na_2SO_4.

The magnitude of change in the water content of RDC contents (mean at time 0, 90.0%; mean at 24 hours, 95.7%) induced by enteral administration of the balanced electrolyte solution would be expected to facilitate flow through the large intestine. In humans, an equivalent increase in the water content of meconium reportedly decreases meconium viscosity by half.[19]

Results of a study[20] investigating the viscosity of the contents of the large intestine in pigs found that a 5% increase in water content induced by laxatives resulted in a 3.4-fold decrease in viscosity. In rabbits and humans, viscosity of the intestinal contents is a main factor in limiting intestinal flow.[21]

In our study, although the water content of feces increased after enteral administration of the balanced electrolyte solution, diarrhea, as reported in a previous study,[v] was not consistently observed. This may have been caused by the different composition and rate of administration of fluids used in the 2 studies. In the previous study,[v] within 8 hours, horses had been treated with 1.52 times the amount of sodium (12,320 mmol) and 2.16 times the amount of chloride (12,320 mmol) that was administered during 12 hours in the study reported here. In addition, the volume (10 L) administered per hour was twice that used in this study.

Signs of abdominal pain observed in 1 horse after enteral administration of 50 L of the balanced electrolyte solution suggested intolerance to enteral fluid therapy. However, this horse received the smallest volume of fluids for its body size. Furthermore, this horse did not have signs of abdominal pain when treated twice with 60 L of fluids administered via nasogastric intubation during subsequent weeks. Because this horse became recumbent whenever the nasogastric tube was in place and the muzzle was worn (ie, during the first 24 hours of the observation period), it is possible that recumbency may have affected gastric emptying, leading to gastric dilation and abdominal pain. Alternatively, this horse's gastrointestinal tract may have simply been less tolerant to enteral fluid therapy.

In our study, the effectiveness of enteral administration of the balanced electrolyte solution in increasing the water content of RDC contents contrasts with the modest changes in the water content of RDC contents induced by enteral administration of water. The electrolyte loads that were provided by each treatment may have caused this difference. In other species, the proximal small intestine is highly permeable to water and net movement of fluids across the mucosa is determined by the osmolality of ingesta.[22] Thus, it is possible that in our study, a major portion of the tap water was rapidly absorbed from the proximal gastrointestinal tract and did not reach the large intestine. However, compared with enteral administration of the balanced electrolyte solution, differences in PCV and the concentration of protein in plasma after enteral administration of water were not detected, as would be expected with an increase in plasma volume. The fluid load may not have been sufficient to change PCV and plasma protein concentration, which are not sensitive or specific indicators of plasma volume.[23] Furthermore, PCV and plasma protein concentration were evaluated only every 6 hours, and transient increases in plasma volume may have occurred without being detected. Alternatively, rapid elimination of the absorbed water may have minimized changes in plasma volume. To better investigate these mechanisms, changes in PCV and plasma protein concentration would have to be assessed frequently, specific and sensitive methods would be required to detect changes in plasma volume (ie, indocyanine green dilution method),[24] and urine production would have to be measured. Enteral administration of water also induced hyponatremia, which suggests that large volumes of water should not be used for enteral fluid therapy. Severe hyponatremia caused by water intoxication is known to cause life-threatening neurologic dysfunction.[25,26]

The effectiveness of enteral administration of Na_2SO_4 in increasing the water content of RDC contents and feces was likely caused by the osmotic effects of the high sodium and sulfate loads provided by this treatment. Because horses in this study had free access to water, the high sodium load was followed by consumption of large volumes of water. Addition of approximately 20 L of water (3 L administered with the laxative plus the mean voluntary consumption of 17 L) likely contributed to the increased water content of RDC contents and feces observed after enteral administration of Na_2SO_4. Because plasma osmolality is a major stimulus of thirst in horses,[27] the large sodium load followed by hypernatremia may explain the increased water consumption observed in horses during the first 6 hours of the observation period. In our study, the large electrolyte load provided by Na_2SO_4 induced hypernatremia, hypocalcemia, and hypochloremia, which were followed by clinical signs characteristic of hypocalcemia in 1 horse.

Hypocalcemia in these horses may have been caused by the binding of calcium ions to sulfate, a mechanism that has been found in humans.[28] Unfortunately, the concentration of sulfate in plasma was not measured in our study. In humans, sulfate is absorbed after oral administration, leading to an increase in plasma sulfate.[29] Although acid-base status was not assessed in the study reported here, hypernatremia and hypochloremia likely caused by administration of Na_2SO_4 may have induced alkalosis,[30] which would also reduce the concentration of ionized calcium in plasma.[31] Because calcium is important for several physiologic mechanisms, including gastrointestinal motility,[32,33] and because hypocalcemia is frequently observed in horses with gastrointestinal disease,[34,35] enteral administration of 1 g/kg of anhydrous Na_2SO_4 as a laxative for horses with colic may not be appropriate. If this dose of Na_2SO_4 is administered, close monitoring of plasma electrolytes is mandatory.

In contrast to that observed after enteral administration of Na_2SO_4, treatment with $MgSO_4$ did not induce changes in the water content of RDC contents or hypocalcemia, and had less pronounced effects on the water content of feces. Because these salts are believed to function as laxatives by increasing the osmolality of gastrointestinal contents, the smaller amount of electrolytes provided by $MgSO_4$ may explain why this salt was not as effective as Na_2SO_4. The amount (in mmol) of sulfate and cations provided by 1 g of $MgSO_4$ $7H_2O$/kg was 57% and 29%, respectively, of that provided by 1 g of anhydrous Na_2SO_4/kg. In this study, the effects of $MgSO_4$ on the water content of feces were less pronounced than those reported in a previous study.[36] When compared with results of our study, these differences may be explained by the different study designs. In the other study[36] horses had continuous access to hay and received 6 L of water via nasogastric intubation, whereas in our study, horses were muzzled for 24 hours and only 2 L of water was administered as a vehicle for $MgSO_4$ and cobalt-EDTA. Furthermore, results of the study presented here indicated that the use of water content of feces as an indicator of hydration of the large colon contents and effectiveness of a laxative may be misleading. Although hypermagnesemia has been reported[w] in dehydrated horses treated with high doses of $MgSO_4$,[8] increases in the concentration of magnesium in plasma detected in the study reported here did not exceed the reference range.

The different electrolyte loads provided by each treatment may explain most of the changes in the composition of electrolytes in RDC contents and feces. However, despite the high sodium load provided by enteral administration of the balanced electrolyte solution, higher concentrations of sodium were detected in the RDC contents and feces after enteral administration of Na_2SO_4. This suggests that more sodium was absorbed after enteral administration of the balanced electrolyte solution, which is in agreement with results of a previous study[9] in which sodium absorption in the large intestine was impaired by the presence of sulfate. The large volume of water provided by enteral administration of the balanced electrolyte solution may have prevented an increase in the plasma sodium concentration due to dilution or facilitation of water excretion. The temporal coincidence of the changes in electrolyte concentration, water content, and cobalt concentration in RDC contents and feces and the ordinal manifestation of changes (first in RDC contents and later in feces) suggested that these treatments acted predominantly by direct intraluminal effects and not by reflex mechanisms (eg, gastrocolic response).

Although results of another study[4] suggest that overhydration induced by IV fluid therapy may promote water secretion into the gastrointestinal tract, in our study, IV administration of 5 L of lactated Ringer's solution every hour for 12 hours did not have any effect on hydration of the RDC contents or feces. In normally hydrated dogs, IV fluids administered at an extremely high rate (150 mL/kg/h) for 1 hour increased fluid secretion into the gastrointestinal tract.[37] To achieve this rate of infusion in horses used in the study reported here, administration of approximately 76 L of fluids every hour would have been required, which would make this treatment extremely expensive. Furthermore, life-threatening, adverse effects such as pulmonary edema may be a risk of such rapid fluid loading.[38,39]

In our study, withholding and offering food had major effects on water consumption, systemic hydration status, plasma concentrations of electrolytes, and composition of the RDC contents and feces, which may have masked certain treatment effects. The present recommendation for treatment of impaction of the large intestine is to withhold food until the impaction is completely resolved.[4-6] However, certain effects of withholding food detected in this study (ie, delay in gastrointestinal transit, dehydration of the RDC contents, and imbalances in the concentrations of electrolytes in plasma) cannot be ignored. Although withholding food is appropriate for many horses with colic, offering feed early in treatment may be beneficial in certain situations. The practice of offering feed with low fiber content to horses with large colon impaction as soon as signs of pain are no longer observed, but before complete resolution of the impaction, has been reported without problems.[10]

Several benefits of enteral fluid therapy were found in the study reported here and in other studies; however, many aspects related to the effects of enteral fluid therapy are not yet known. Therefore, it may be appropriate to recommend that enteral fluid therapy be used with caution. There is evidence[13,v] that administration of large volumes of balanced electrolyte solutions via nasogastric intubation to horses with no signs of severe compromise of the gastrointestinal transit (ie, gastric reflux) is safe and that this treatment can induce a substantial increase in the hydration of RDC contents and contribute to correcting dehydration and restoring plasma electrolytes. The benefits of saline cathartics were also observed in the study reported here; however, enteral administration of Na_2SO_4 induced imbalances in the concentrations of electrolytes in plasma, and enteral administration of $MgSO_4$ had no effect on hydration of the RDC contents. Combining enteral fluid therapy with administration of saline cathartics could maximize the effects on hydration of the RDC contents and minimize the effects on the concentrations of electrolytes in plasma. However, this hypothesis requires further investigation. Enteral administration of water induced imbalances in the concentrations of electrolytes in plasma and had a limited effect on the hydration of RDC contents; therefore, it should not be used. In normal horses, IV fluid therapy (5 L/h for 12 hours) alone cannot be recommended to induce hydration of the RDC contents.

[a]Lopes MAF, White NA II, Donaldson L, et al. Experimental fistula of the right dorsal colon in horses (abstr), in *Proceedings*. 7th Int Equine Colic Res Symp 2002;128.
[b]Rotomin, Roto Salt Co, Penn Yan, NY.
[c]DHI Forage Testing Laboratory, Ithaca, NY.
[d]18-F equine enteral feeding tube, Mila International Inc, Florence, Ky.
[e]Epsom salt, Bindley Western Industries, Indianapolis, Ind.
[f]Na_2SO_4 anhydrous 99%, Fisher Scientific, Hampton, NH.
[g]Veterinary lactated Ringer's solution, Abbott Laboratories Inc, North Chicago, Ill.
[h]14G Abocath-T, Abbott Laboratories Inc, North Chicago, Ill.
[i]Mix-N-Fine salt, Cargill Inc, Minneapolis, Minn.
[j]Potassium chloride, ICN Biomedicals Inc, Aurora, Ohio.
[k]Baking soda, Church & Dwight Co, Princeton, NJ.
[l]Vacutainer, BD, Franklin Lakes, NJ.
[m]Thermometer/humidity meter, Springfield Precision Instruments, Wood-Ridge, NJ.
[n]Hand-held refractometer, Westover Scientific, Woodenville, Wash.
[o]Olympus AU400, Olympus America Inc, Melville, NY.
[p]Rapidlab 348, Bayer Co, East Walpole, Mass.
[q]Precision mechanical convection oven, Precision Scientific, Chicago, Ill.
[r]SpectrAA 220FS, Varian Inc, Walnut Creek, Calif.
[s]SpectroFlame Modula tabletop ICP, Spectro Analytical Instruments Inc, Fitchburg, Mass.
[t]SAS MIXED, version 8, SAS Institute Inc, Cary, NC.
[u]SAS SLICE, version 8, SAS Institute Inc, Cary, NC.
[v]Lopes MAF, Johnson SR, White NA II, et al. Enteral fluid therapy for horses: slow infusion versus boluses (abstr), in *Proceedings*. Am Coll Vet Surg Vet Symp 2002;13.
[w]Scarratt WK, Swecker WS. Administration of therapeutic dosages of magnesium sulfate to clinically normal horses (abstr), in *Proceedings*. 11th Annu Res Symp Virginia-Maryland Coll Vet Med 1999;24.

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