Effects of feeding large amounts of grain on colonic contents and feces in horses

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Objective—To assess changes in systemic hydration, concentrations of plasma electrolytes, hydration and physical properties of colonic contents and feces, and gastrointestinal transit in horses with access to large amounts of grain.

Animals—6 horses with right dorsal colon (RDC) fistulas.

Procedure—In a crossover design, horses were alternately fed 1 of 3 diets: orchard grass hay ad libitum after being adapted to this diet for at least 5 days, orchard grass hay ad libitum and 4.55 kg of grain offered every 12 hours after being adapted to orchard grass hay ad libitum for at least 5 days, or orchard grass hay ad libitum and 4.55 kg of grain offered every 12 hours after being adapted to this diet for at least 5 days. Physical examinations were performed and samples of blood, colonic contents, and feces were collected every 6 hours during a 48-hour observation period.

Results—Grain ingestion had several effects, including changes in the concentrations of electrolytes in plasma; RDC contents became more homogenous, dehydrated, foamy, and less dense; RDC contents flowed spontaneously when the cannula was opened; RDC contents expanded when heated in an oven; and feces became fetid and less formed. Horses did not have any clinical signs of colic, endotoxemia, or laminitis.

Conclusions and Clinical Relevance—Changes observed in the colonic contents and feces may be explained by the large amounts of hydrolyzable carbohydrates provided by grain. Access to large amounts of grain may increase the risk of tympany and displacement of the large intestine. (*Am J Vet Res* 2004;65:687–694)

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Colic causes more deaths in horses than any other group of diseases.[1,2] In most horses, the cause of colic is unknown; however, anecdotal observations and a few epidemiologic and experimental studies[3-5] have incriminated present practices of feeding large meals and large amounts of grain as risk factors for colic. Modifications in the gastrointestinal flora and acidification of the cecal lumen have been repeatedly detected in horses with access to large amounts of grain.[6-14] Despite the potential mechanisms by which intestinal flora disturbance and acidosis could lead to colic (eg, mucosal barrier disruption, endotoxemia, or abnormal motility patterns),[15] grain ingestion may also affect gastrointestinal function by other mechanisms. In horses, experimental administration of 1 or 2 meals/d that are 1-hour in duration induces a state of transient dehydration with activation of the renin-angiotensin-aldosterone system.[16-19] On the basis of those findings, it was proposed that feeding a few large meals could cause postprandial dehydration of colonic contents and lead to impaction of the large colon, which could initiate other forms of colic such as large colon displacement and volvulus.[3] However, this theory was determined by use of artificial feeding regimens that are not used for domestic horses. Furthermore, the changes in hydration of colonic contents induced by large meals have not been determined.

The purpose of the study reported here was to assess systemic hydration, concentrations of plasma electrolytes, hydration and physical properties of colonic contents and feces, and gastrointestinal transit in horses adapted to large amounts of grain. The effect of abruptly offering large amounts of grain to horses adapted to eating only hay was also studied.

Materials and Methods

This study was approved by the Virginia-Maryland Regional College of Veterinary Medicine Animal Care Committee. Five geldings and 1 mare (4 Thoroughbreds and 2 Quarter Horses) with a fistula in the **right dorsal colon (RDC)** were used in this study and another study.[20] Horses were between 6 and 17 years old (median, 9.5 years) and weighed between 452 and 580 kg (median, 530 kg). The fistula in the RDC had been placed 11 to 34 days (median, 23 days) before the start of the study. The technique used to place the fistula in the RDC has been described elsewhere.[a]

Study design—During the entire study, 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. The study was conducted in a 3-treatment, 3-period crossover design balanced for residual effects. Horses were alternately fed 1 of 3 diets. Diet 1 consisted of orchard grass hay ad libitum after horses had been adapted to this diet for at least 5 days. Diet 2 consisted of orchard grass hay ad libitum and 4.55 kg of grain offered every 12 hours after horses had been adapted to orchard grass hay ad libitum for at least 5 days. Diet 3 consisted of orchard grass hay ad libitum and 4.55 kg of grain offered every 12 hours after horses had been adapted to this diet for at least 5 days. The order that feeding regimens were offered to horses was randomized. The 5-day diet adaptation period for each diet was also considered as a washout period between diets. For the entire study, observation periods were initiated at approximately noon on Monday and were stopped 48 hours later on Wednesday. For diets 2 and 3, grain was offered at 6.5, 18.5, 30.5, and 42.5 hours after the start of the 48-hour observation period. A single batch of orchard grass hay and a single brand of grain[c] obtained from a single source[d] were used for the entire study. A sample of grain obtained from a pool of samples from 3 different bags and a sample of hay obtained from a pool of samples from 10 different bales were collected for analysis.

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[e]; 1 tube contained 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.[f] Cobalt-EDTA was prepared as previously described.[21] During the 48-hour observation period, environmental temperature and humidity were recorded[g] every 6 hours and water consumption was estimated by measuring the volume required to refill the buckets. For diets 2 and 3, any grain that was not consumed was weighed every 6 hours and returned to the grain bucket.

Sample processing and analyses—Blood samples collected into EDTA tubes were immediately analyzed for PCV and concentration of protein in plasma by use of the microhematocrit technique and a refractometer,[h] respectively. Blood collected into the lithium heparin tubes was centrifuged at 1,124 X *g* for 10 minutes, 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,[i] and ionized calcium[j] in plasma.

Subjective assessments of certain characteristics (odor; color; viscosity; and presence of large pieces of fiber, oats, and gas bubbles) of fresh contents obtained from the RDC and feces were performed during collection and processing of samples. 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[k] 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

Table 1—Nutrient content of orchard grass hay and grain fed to 6 horses with fistulas in the right dorsal colon to assess changes in systemic dehydration, concentrations of electrolytes in plasma, hydration and physical properties of colonic contents and feces, and gastrointestinal transit.

Components (as sampled basis)	Hay	Grain
% Dry matter	92.10	87.70
% Crude protein	11.20	11.40
Soluble protein (% of crude protein)	30.00	27.00
% Acid detergent fiber	37.10	11.70
% Neutral detergent fiber	61.10	22.30
% Lignin	5.40	1.40
% Nonfiber carbohydrate	13.40	45.60
% Nonstructural carbohydrate	8.00	38.40
% Starch	1.20	30.60
% Sugar	6.80	7.80
% Crude fat	3.20	3.70
% Ash	7.56	6.97
% Total digestible nutrients	42.00	66.00
Digestible energy (MJ/kg)	7.75	12.27
Digestible energy (MCal/kg)	1.85	2.93
% Calcium	0.49	1.23
% Phosphorus	0.33	0.55
% Magnesium	0.23	0.33
% Potassium	1.97	0.74
% Sodium	0.004	0.323

The cobalt concentration of the liquid phase of RDC contents and feces was measured by use of atomic absorption spectrophotometry.[l]

The nutrient content of grain and hay samples was analyzed by a reference laboratory[m] (**Table 1**). Samples of RDC contents collected at time 0 from 2 horses on diets 1 and 3 were used to calculate the density of colonic contents by use of the following formula:

density = weight of the sample/volume of the sample.

Statistical analyses—Computer software[n] was used to perform a mixed-model repeated measures ANOVA to test for the effects of diet, time of sampling, and diet by time interaction while controlling for horse and period effects. Significant interactions were further investigated by use of computer software[o] for the simple main effect of diet 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. There were no significant ($P > 0.100$) carryover effects; therefore, the carryover effect was removed from the model for all subsequent analyses. **Mean retention time (MRT)** of cobalt in 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).[22] For MRT of cobalt, computer software[n] was used to perform a mixed-model ANOVA to test for effects of diet. Values of $P \leq 0.05$ were considered significant.

Results

The amount of grain consumed by horses fed diets 2 and 3 ranged from 1.56% to 2.00% of body weight/d (median, 1.71% of body weight/d). The amount of dry matter provided by grain ranged from 1.37% to 1.76% of body weight/d (median, 1.50% of body weight/d). The amount of nonstructural carbohydrate provided by grain ranged from 0.60% to 0.77% of body weight/d (median, 0.66% of body weight/d). The environmental temperature and relative humidity recorded during the observation periods ranged from 10° to 31°C (median, 20°C) and 23% to 95% (median, 67%), respectively. All

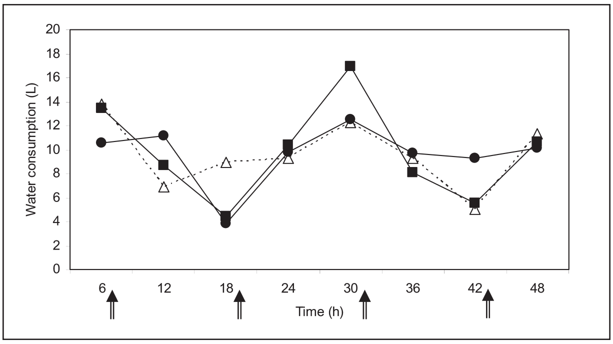

Figure 1—Mean water consumption during a 48-hour observation period in 6 horses with fistulas in the right dorsal colon (RDC) that had access to hay ad libitum (diet 1; closed squares), hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to hay only for at least 5 days (diet 2; open triangles), or hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to this diet for at least 5 days (diet 3; closed circles). Arrows indicate the times when horses had access to grain.

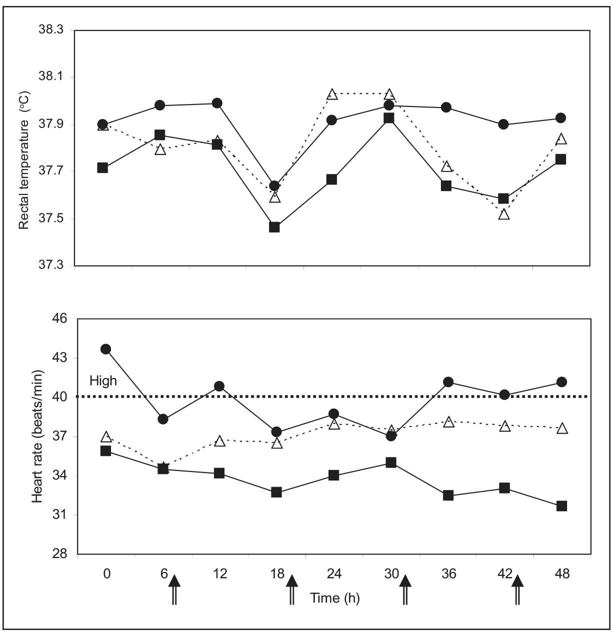

Figure 2—Mean rectal temperature and heart rate obtained during a 48-hour observation period from 6 horses with fistulas in the RDC that had access to hay ad libitum (diet 1), hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to hay only for at least 5 days (diet 2), or hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to this diet for at least 5 days (diet 3). Rectal temperature was always within the reference limits for healthy horses. The dotted line within the graph for heart rate indicates the upper reference limit.[23] *See* Figure 1 for key.

horses tolerated the diet and changes in diet. Horses did not have any clinical signs of colic, diarrhea, dehydration (no horse had prolonged skin tent, prolonged capillary refill time, or discoloration of mucous membranes), endotoxemia (no horse had prolonged capillary refill time, discoloration of mucous membranes, or fever), or laminitis (no horse had abnormal hoof temperature, abnormal pulse in the digital arteries, or lameness). Usually, horses fed diets 2 and 3 consumed the entire amount of grain that was offered within 1 or 2 hours, although small amounts (< 0.5 kg) of grain were occasionally left for > 6 hours. Horses appeared to

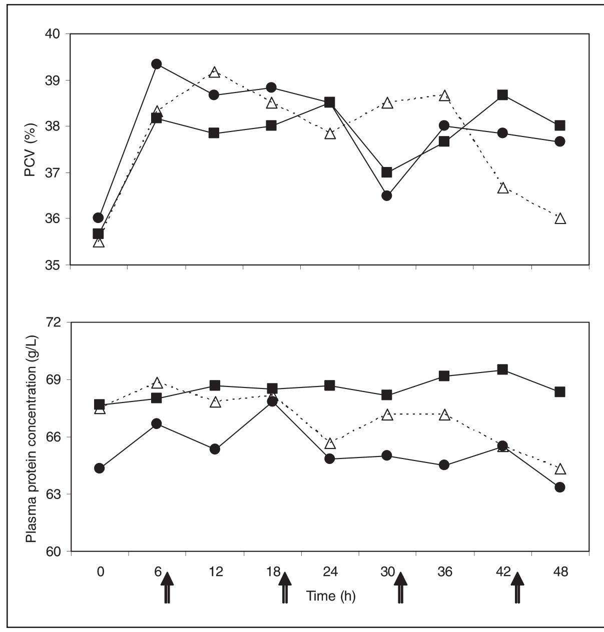

Figure 3—Mean PCV and concentration of protein in plasma obtained during a 48-hour observation period from 6 horses with fistulas in the RDC that had access to hay ad libitum (diet 1), hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to hay only for at least 5 days (diet 2), or hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to this diet for at least 5 days (diet 3). All values for PCV and the concentration of protein in plasma were within reference limits.[24] *See* Figure 1 for key.

consume less hay when grain was offered, although the amount of hay consumed was not determined.

Water consumption was affected by time ($P < 0.01$), which led to a cyclic pattern of water consumption (**Fig 1**); however, there was no effect of diet ($P = 0.97$) or diet by time interaction ($P = 0.25$). Rectal temperature was affected by time ($P < 0.01$) and diet ($P = 0.01$); however, there was no diet by time interaction ($P = 0.67$; **Fig 2**). Heart rate was affected by diet ($P < 0.01$) but not by time ($P = 0.11$), and there was no diet by time interaction ($P = 0.09$; Fig 2). For both variables, mean rectal temperature and heart rate of horses receiving only hay were significantly ($P < 0.01$) lower than when the horses were adapted to the hay and grain diet (diet 3), according to the Bonferroni test for multiple comparisons.

Mean PCV and concentrations of protein and electrolytes in plasma were within reference ranges for horses fed all 3 diets. For PCV and the concentration of protein in plasma, there was an effect of time ($P < 0.01$) but no effect of diet ($P = 0.89$ and $P = 0.19$ for PCV and the plasma concentration of protein, respectively) or diet by time interaction ($P = 0.82$ and $P = 0.22$ for PCV and plasma concentration of protein, respectively). The effect of time on PCV was limited to an increase after the initial sample collection (time 0; **Fig 3**).

The concentration of potassium in plasma was affected by time ($P = 0.04$) but not by diet ($P = 0.67$), and there was no diet by time interaction ($P = 0.12$; **Fig 4**). The concentration of sodium in plasma was affected by diet ($P = 0.04$), and there was diet by time interaction ($P = 0.01$); however, the concentration of

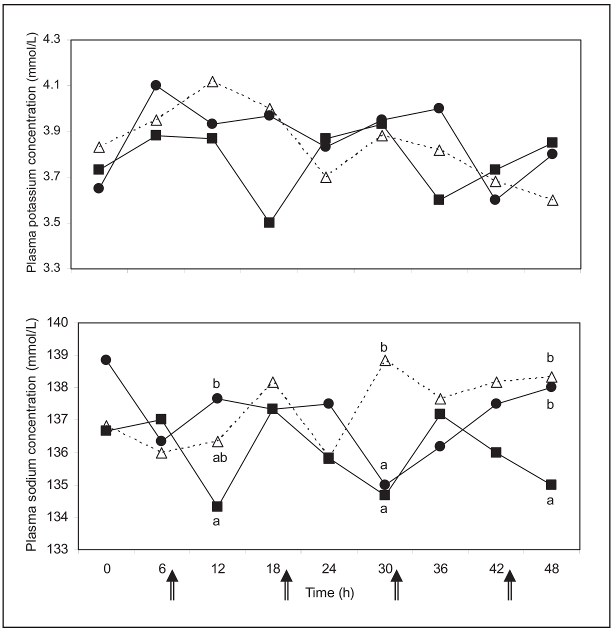

Figure 4—Mean concentrations of potassium and sodium in plasma obtained during a 48-hour observation period from 6 horses with fistulas in the RDC that had access to hay ad libitum (diet 1), hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to hay only for at least 5 days (diet 2), or hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to this diet for at least 5 days (diet 3). Within a time point, values with different letters are significantly ($P \leq 0.05$) different. All concentrations of potassium and sodium in plasma were within reference limits for the laboratory. *See* Figure 1 for key.

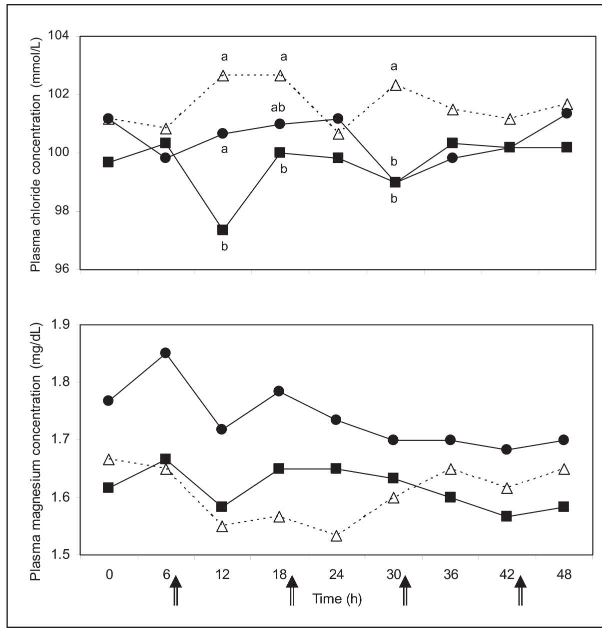

Figure 5—Mean concentrations of chloride and magnesium in plasma obtained during a 48-hour observation period from 6 horses with fistulas in the RDC that had access to hay ad libitum (diet 1), hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to hay only for at least 5 days (diet 2), or hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to this diet for at least 5 days (diet 3). Within a time point, values with different letters are significantly ($P \leq 0.05$) different. All concentrations of chloride and magnesium in plasma were within reference limits for the laboratory. *See* Figure 1 for key.

sodium in plasma was not affected by time ($P = 0.19$; Fig 4). The concentration of chloride in plasma was affected by diet ($P < 0.01$), and there was diet by time interaction ($P = 0.03$); however, the concentration of chloride in plasma was not affected by time ($P = 0.55$; **Fig 5**). The concentration of magnesium in plasma was affected by time ($P < 0.01$) and diet ($P < 0.01$); however, there was no diet by time interaction ($P = 0.61$). Mean concentration of magnesium in plasma of horses adapted to the hay and grain diet (diet 3) was significantly higher than that of horses fed only hay ($P = 0.01$) or hay and grain but adapted to only hay (diet 2; $P < 0.01$), according to the Bonferroni test for multiple comparisons (Fig 5). The total calcium concentration in plasma was not affected by time ($P = 0.43$) or diet ($P = 0.13$); however, there was diet by time interaction ($P = 0.02$). The total calcium concentration in plasma increased 18 and 30 hours after the beginning of the 48-hour observation period (**Fig 6**). The concentration of ionized calcium in plasma was affected by time ($P < 0.01$) but not by diet ($P = 0.24$), and there was diet by time interaction ($P < 0.01$; Fig 6).

Contents obtained from the RDC of horses fed diet 1 had a fetid odor; an olive green color; minimal or no visible gas bubbles; and 2 distinct phases: a liquid phase, which appeared to have low viscosity (similar to water), and a solid phase composed of pieces of plant fiber (**Fig 7**). Feces obtained from horses fed diet 1 had a characteristic sweet odor and a dark olive green color, and were well formed.

Contents obtained from the RDC of horses fed diets 2 and 3 contained less fibrous material and

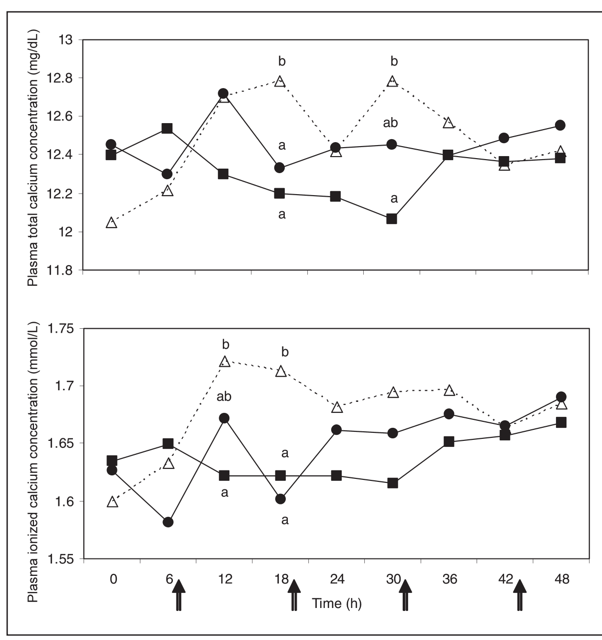

Figure 6—Mean concentrations of total and ionized calcium in plasma obtained during a 48-hour observation period from 6 horses with fistulas in the RDC that had access to hay ad libitum (diet 1), hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to hay only for at least 5 days (diet 2), or hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to this diet for at least 5 days (diet 3). Within a time point, values with different letters are significantly ($P \leq 0.05$) different. All total calcium concentrations were within reference limits for the laboratory. Reference limits of the laboratory were not determined for the concentration of ionized calcium in plasma. All ionized calcium values were within the normal reference limits.[24] *See* Figure 1 for key.

Figure 7—Appearance of RDC contents obtained during a 48-hour observation period from horses with fistulas in the RDC that had access to hay ad libitum (diet 1), hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to hay only for at least 5 days (diet 2), or hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to this diet for at least 5 days (diet 3). Notice a clear separation between the solid and liquid phases of RDC contents in horses with access to diet 1, which was not observed when horses were fed diets 2 and 3.

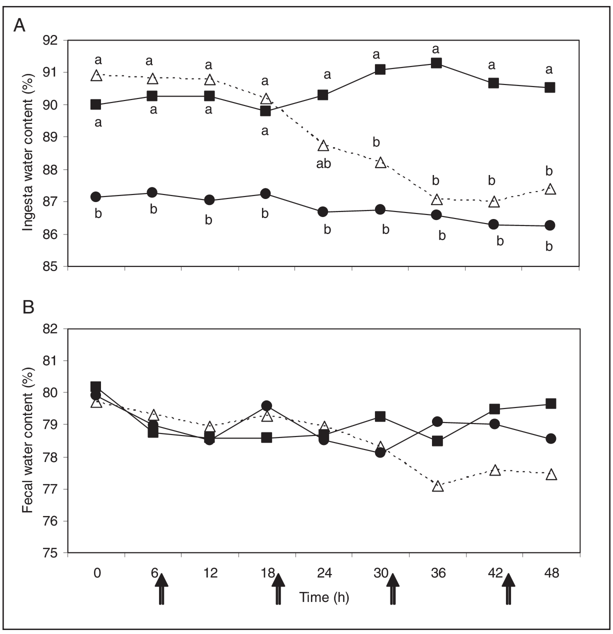

Figure 8—Mean water content of RDC contents (A) and feces (B) obtained during a 48-hour observation period from 6 horses with fistulas in the RDC that had access to hay ad libitum (diet 1), hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to hay only for at least 5 days (diet 2), or hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to this diet for at least 5 days (diet 3). Within a time point, values with different letters are significantly ($P \leq 0.05$) different. *See* Figure 1 for key.

acquired more yellow tones, compared with those from horses fed diet 1. The RDC contents had a homogenous appearance (ie, less distinct separation between the liquid and solid phases), and the liquid phase appeared to be more viscous than that from horses fed diet 1, although the overall viscosity of RDC contents did not appear to be changed. The RDC contents were foamy and flowed spontaneously when the fistula was opened. There was no detectable difference in odor among the RDC contents collected for the 3 diets. In horses with access to grain, the RDC contents expanded when heated and the water content was significantly ($P < 0.01$) lower than that of horses fed diet 1, although the water content of feces did not change ($P = 0.66$; **Fig 8**). Feces from horses fed diets 2 and 3 had

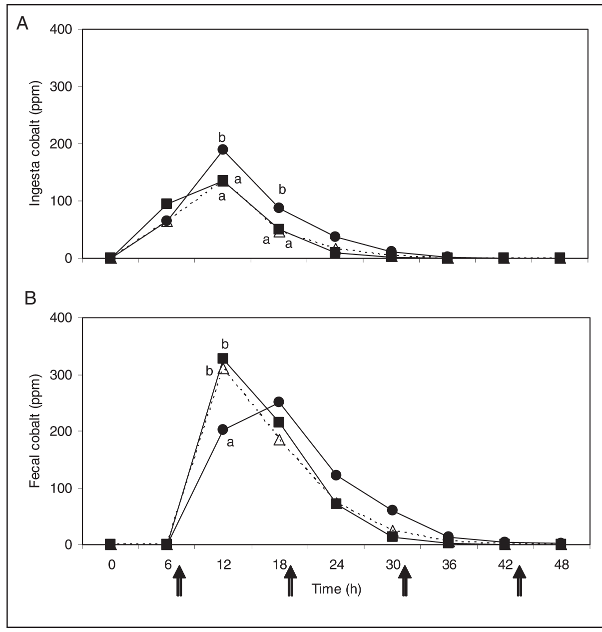

Figure 9—Mean concentrations of cobalt in RDC contents (A) and feces (B) obtained during a 48-hour observation period from 6 horses with fistulas in the RDC that had access to hay ad libitum (diet 1), hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to hay only for at least 5 days (diet 2), or hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to this diet for at least 5 days (diet 3). Cobalt-EDTA (40 mg/kg) was administered via nasogastric intubation at the beginning (time 0) of each observation period. Within a time point, values with different letters are significantly ($P \leq 0.05$) different. *See* Figure 1 for key.

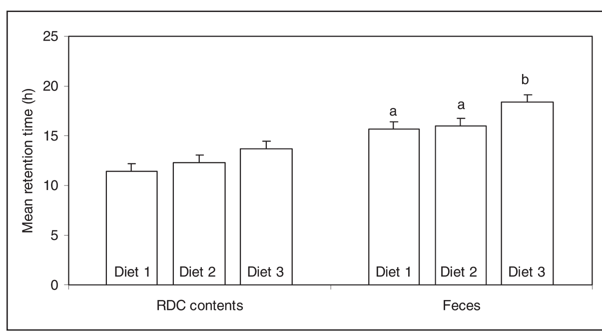

Figure 10—Mean ± SE retention time of cobalt in RDC contents and feces obtained during a 48-hour observation period from 6 horses with fistulas in the RDC that had access to hay ad libitum (diet 1), hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to hay only for at least 5 days (diet 2), or hay ad libitum and grain (4.55 kg) every 12 hours after being adapted to this diet for at least 5 days (diet 3). Cobalt-EDTA (40 mg/kg) was administered via nasogastric intubation at the beginning (time 0) of each observation period. Values with different letters are significantly ($P \leq 0.05$) different. *See* Figure 1 for key.

a fetid odor, acquired more brown tones, and were less formed than that from horses fed diet 1. Fecal liquid appeared more viscous and had gas bubbles, compared with that from horses fed diet 1. Density of the RDC contents decreased from 0.92 and 0.93 kg/L (diet 1) to 0.64 and 0.66 kg/L (diet 3), respectively, for the 2 horses in which density was determined.

Changes in the characteristics of fresh RDC contents and feces induced by grain in diet 2 were gradual. Changes in the appearance of RDC contents (including the presence of oats) were first noticed 18 to 24 hours after the beginning of the 48-hour observation period (approx 11.5 to 17.5 hours after grain was first offered), whereas changes in fecal appearance (including the presence of oats in feces) were first noticed 18 to 30 hours after the beginning of the 48-hour observation period (approx 11.5 to 23.5 hours after grain was first offered).

When horses were fed diet 3, the concentration curves of cobalt in RDC contents and feces were shifted to the right, which indicates a delay in the transit of cobalt **(Fig 9)**. For cobalt concentration in RDC contents and feces, there was an effect of time ($P < 0.01$) but no effect of diet ($P = 0.09$ and $P = 0.86$ for RDC contents and feces, respectively), although there was diet by time interaction ($P = 0.02$ and $P = 0.01$ for RDC contents and feces, respectively). Mean retention time of cobalt in feces was increased ($P = 0.03$) in horses fed diet 3, compared with horses fed diets 1 or 2 **(Fig 10)**. However, there was no effect of diet on MRT of cobalt in RDC contents ($P = 0.18$).

Discussion

Results of the study presented here indicated that horses that consumed large amounts of grain had marked changes in the RDC contents and feces. These effects were likely caused by ingestion of large amounts of hydrolyzable carbohydrate and small amounts of fiber. Reduced intake of hay in horses with access to grain was expected. In this study, the amount of dry matter provided by grain ranged from 68.5% to 118.7% of the predicted dry matter intake for nonworking, nonpregnant horses (1.5% to 2.0% of body weight).[25] Reduced intake of hay in horses with access to grain has been previously reported.[26] Although results of several studies[26-30] indicate that horses with access to grain consume less water, this was not observed in our study or in another study.[31]

In our study, the higher rectal temperature in horses that were adapted to the grain diet (diet 3) may have been caused by large amounts of rapidly fermentable carbohydrates in the gastrointestinal tract for the entire 48-hour observation period. A large portion of the hydrolyzable carbohydrates in grain may not have been digested in the small intestine and therefore became available for fermentation in the large intestine.[32] Fermentation is known to cause more heat production than hydrolysis.[33] The increased heart rate observed in horses adapted to the grain diet may have been caused by large amounts of grain that were available for digestion in the gastrointestinal tract during the 48-hour observation period. In humans, the presence of food within the gastrointestinal tract induces a significant increase in heart rate.[34] Alternatively, subclinical discomfort caused by ingestion of large amounts of grain may have contributed to the increase in heart rate observed in this study.

The increase in PCV after the initial sample collection may be explained by excitement caused by manipulation of the horse (movement between the stall and the stocks, catheter placement, nasogastric intubation, transit marker administration, and sample collection). Excitement leads to splenic contraction and increased amounts of circulating red blood cells. In the study presented here, access to large amounts of grain had no effect on PCV and plasma protein concentration, even in horses that were not adapted to grain. However, a transient increase in PCV and plasma protein concentration lasting < 3 hours after ingestion of large amounts of grain has been observed in other studies.[17-19,35-37] There may be 2 reasons why postprandial dehydration was not observed in the present study. First, blood samples were only collected 5.5 and 11.5 hours after a large amount of grain was offered, whereas in other studies,[17-19,35-37] a postprandial increase in PCV and plasma protein concentration lasted < 3 hours. Second, because horses had free access to hay, a more continuous eating pattern was induced, whereas in other studies,[17-19,35-37] horses were permitted to eat for only 1 or 2 hours 1 or 2 times/d. In the present study, although the mean concentrations of sodium, potassium, chloride, calcium, ionized calcium, and magnesium were within reference ranges, certain effects of diet were observed. These findings suggest that changes in plasma electrolyte concentrations may be important in the pathogenesis of gastrointestinal dysfunction caused by ingestion of large amounts of grain.

Changes in the physical properties of RDC contents observed in horses with access to grain were similar to that described for ruminants with frothy bloat. Frothy bloat is characterized by the formation of frothy ruminal contents and develops in ruminants fed large amounts of hydrolyzable carbohydrates, particularly after an abrupt change to a diet of large amounts of grain.[38] The availability of large amounts of rapidly fermentable carbohydrates in the rumen leads to the formation of large amounts of gases and excessive production of substances that increase the viscosity of ruminal liquid (eg, microbial mucopolysaccharides) and stabilizes the froth.[38] Although pressure in the colon was not measured in our study, the observation of spontaneous flow of RDC contents through the open fistula in horses with access to grain suggested that there was an increase in intraluminal pressure. Spontaneous flow of ingesta through a ruminal fistula and increased intraruminal pressure have been detected in ruminants with frothy bloat.[38]

Expansion of RDC contents after being heated in the oven may have been caused by the expansion of gas bubbles within the frothy material. This plus the lower density of RDC contents in horses with access to grain further indicated that there was an increased amount of gas in the RDC contents. These findings are in agreement with results of a previous study[39] of the association between ingestion of large amounts of rapidly fermentable carbohydrates and tympany. Right dorsal colon contents with low density and increased amounts of gas may favor abnormal positioning of the large intestine and predispose horses fed large amounts of grain to displacement of the large intestine and volvulus. This association has been suggested by other studies[40,41] and was supported by findings of another study.[42] in which horses fed pelleted grain had a higher proportion of large colon displacement and torsion (23.1%) than small intestine strangulated obstruction (4.5%).

It is not clear if RDC contents dehydratio produced by grain intake may be explained by the theory proposed by Clarke et al[3] that feeding large meals causes postprandial dehydration, activation of the renin-angiotensin-aldosterone system, and increased water absorption from colonic content. Cyclic postprandial activation of the renin-angiotensin-aldosterone system, as observed in horses fed a single daily meal of 1-hour duration, would probably cause cyclic changes in hydration of RDC contents.[17] In the study reported here, hydration of RDC contents did not change with time when horses were adapted to the grain meals. The reduced intake of fiber when grain was fed may have contributed to the dehydration of the colonic contents because fiber holds water within the gastrointestinal tract.[30] Another mechanism that may contribute to dehydration of RDC contents is the formation of larger amounts of volatile fatty acids when grain is fed. Results of 1 study[43] indicate that volatile fatty acid absorption by the colonic mucosa is coupled with sodium and water absorption. Thus, more volatile fatty acids available for absorption would probably result in more absorption of sodium and water. Further studies are necessary to elucidate the effect of diet on gastrointestinal secretion and water transport by the intestinal mucosa.

The assumption that dehydration of RDC contents induced by access to large amounts of grain twice daily may contribute to the formation of large intestine impaction may be misleading. Results of a study[44] in rabbits indicate that gastrointestinal flow depends on intraluminal pressure, luminal diameter, and the viscoelastic properties of intestinal contents. Coordinated intestinal contractions generate pressure gradients to overcome the resistance to flow.[44] The luminal diameter and rheologic properties of RDC contents are major factors that determine the resistance to flow.[42] Decreased intestinal diameter and increased viscosity of the contents increase resistance to flow up to a point where flow is interrupted.[44] Considering that these same principals may be valid for horses, it is likely that viscosity, not hydration, of contents is the key factor for the formation of gastrointestinal impaction. If dehydration of colonic contents was the only effect of grain ingestion, an increase in colonic content viscosity would be expected to occur.[45] However, there is also an increase in the amount of gas and a decrease in the amount of fiber in colonic contents induced by feeding grain, which is expected to decrease colonic content viscosity.[46] In our study, although viscosity of the liquid phase of RDC contents appeared to be increased in horses with access to grain, the overall viscosity of RDC contents did not appear to be changed. Unfortunately, neither the overall viscosity of the colonic contents nor the viscosity of the liquid phase of the colonic contents were measured to confirm these observations. The spontaneous flow of colonic contents through the fistula also suggested that the viscosity of RDC contents in horses with access to grain did not compromise gastrointestinal flow. Furthermore, in ruminants, a species in which substantially more information about the effects of large amounts of grain is available, formation of frothy contents is not associated with intraluminal obstruction.[38] Indeed, ruminal distension in ruminants with frothy bloat is caused by compromised rumen motility due to low ruminal pH and inhibited eructation.[38]

Because cobalt is a marker for the liquid phase of gastrointestinal contents,[21] the right shift of the cobalt concentration curves and increased MRT of cobalt in the study presented here indicated a slower transit of the liquid phase of intestinal contents in horses with access to grain, compared with horses with access to hay only. As previously described,[31,47,48] ingestion of grain may have caused an overall delay in gastrointestinal transit in horses in our study. In rats, ingestion of large amounts of hydrolyzable carbohydrates is a stimulus for the release of amylin, a hormone that inhibits gastric emptying.[49] Furthermore, in our study, the distinct separation between the liquid and solid phases of RDC contents observed in horses with access to only hay may have contributed to the difference in cobalt transit. The liquid phase may have passed separately and more rapidly than the solid phase in horses with access to only hay, whereas the liquid phase may have passed more slowly and simultaneously with the solid phase in horses with access to grain. This hypothesis is in agreement with results of other studies[50-52] in which markers of the liquid phase passed more rapidly than markers of the solid phase in horses with access to only hay.

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[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]Reliance 10, Cooperative Milling, Gettysburg, Pa.
[d]Southern States Cooperative, Richmond, Va.
[e]Vacutainer, BD, Franklin Lakes, NJ.
[f]18-F equine enteral feeding tube, Mila International Inc, Florence, Ky.
[g]Thermometer/humidity meter, Springfield Precision Instruments, Wood-Ridge, NJ.
[h]Hand-held refractometer, Westover Scientific, Woodenville, Wash.
[i]Olympus AU400, Olympus America Inc, Melville, NY.
[j]Rapidlab 348, Bayer Co, East Walpole, Mass.
[k]Precision mechanical convection oven, Precision Scientific, Chicago, Ill.
[l]SpectrAA 220FS, Varian Inc, Walnut Creek, Calif.
[m]DHI Forage Testing Laboratory, Ithaca, NY.
[n]SAS MIXED, version 8, SAS Institute Inc, Cary, NC.
[o]SAS SLICE, version 8, SAS Institute Inc, Cary, NC.

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