Meal-induced gastric relaxation and emptying in horses after ingestion of high-fat versus high-carbohydrate diets

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Objective—To evaluate the effect of ingestion of a high-carbohydrate versus a high-fat meal on relaxation of the proximal portion of the stomach and subsequent gastric emptying in horses.

Animals—6 healthy adult horses.

Procedure—The study consisted of 2 phases. In phase I, horses were offered a high-fat (8% fat) or a high-carbohydrate (8% fat) pelleted meal (0.5 g/kg) of identical volume, caloric density, and protein content. In phase II, meals consisted of a commercial sweet feed meal (0.5 g/kg) or this meal supplemented with corn oil (12.3% fat) or an isocaloric amount of glucose (2.9% fat). Proximal gastric tone was measured by variations in volume of an intragastric bag introduced through a gastric cannula and maintained with a constant internal pressure by an electronic barostat. Rate of gastric emptying was measured simultaneously with the 13C-octanoic acid breath test. Interaction between both techniques was studied in additional experiments.

Results—Meals with higher carbohydrate content induced a significantly more prolonged receptive relaxation of the proximal portion of the stomach than those with higher fat content, but the accommodation response was similar. Labeling the meals with the breath test marker influenced the accommodation response measured by the barostat. Gastric emptying rates were not significantly different between meals, although those high in carbohydrate initially emptied more slowly.

Conclusions and Clinical Relevance—In horses, in contrast to most species, dietary fat supplementation may not have a profound effect on gastric motility and emptying.

Nutritional constituents of a meal along with volume, physical structure, caloric density, and osmolality are the principal factors affecting rate of gastric emptying. It has been long recognized that presence of nutrients in the intestine is a potent stimulus for feedback regulation of gastric motor function, which can be mimicked in experimental situations by direct infusion of nutrients into the intestine. Intestinal feedback inhibition by nutrients involves relaxation of the proximal portion of the stomach, suppression of antral motility, stimulation of isolated phasic pyloric contractions, and an increase in pyloric and duodenal resistance, which work together to slow down the flow of gastric contents into the duodenum. As a result, the stomach delivers nutrients into the small intestine with rates that are compatible with maximal digestion and absorption.

Mechanisms determining the emptying rate of fat and carbohydrates are not totally understood. Both food types act on nutrient-specific receptors within the small intestinal mucosa. Although it is generally believed that fat causes a greater inhibition of gastric emptying than carbohydrate, results of some studies conducted in humans, monkeys, and pigs indicate that emptying of any of these nutrients is mainly based on delivery of a constant rate of energy into the small intestine.

Changes in tone of the proximal portion of the stomach are responsible, in part, for controlling the emptying of intragastric contents. Previous work in our laboratory has revealed the existence of a meal-induced relaxation of the proximal portion of the stomach of horses, as has been documented for other species. This relaxation facilitates the acceptance of meal within the stomach without a substantial increase in intragastric pressure. This process has 2 components that are suggested to be generated at vari-

Additional information about the study and its publication is included in the original text.
ous levels of the upper gastrointestinal tract (ie, the alimentary tract from mouth to duodenum). First, ingestion and swallowing of the meal stimulate receptors in the oropharynx and esophagus and initiate a vagovagal reflex. This first component is termed receptive relaxation because the proximal portion of the stomach relaxes in anticipation of the arrival of ingested material. Next, arrival of meal into the stomach and its passage into the small intestine trigger an additional vagovagal reflex that causes further more-sustained relaxation, termed adaptive relaxation or accommodation.

The size of the bag at this inflation pressure was set at 2 mm Hg, with a hysteresis of 0.5 mm Hg. The pressure within the bag was set at 2 mm Hg, with a hysteresis of 0.5 mm Hg. The pressure of the proximal portion of the stomach in horses. The validity of an electronic barostat and emptying with the 13C-octanoic acid breath test to establish a novel approach for the study of equine gastric physiology.

Materials and Methods

Animals—Six adult horses (3 mares, 3 geldings) were used for the experiments. An indwelling silastic cannula, described elsewhere, had been implanted in each horse between 2 and 10 years prior to this study, and none of the horses had experienced any problem related to the gastric cannula. Horses weighed between 350 and 546 kg (mean, 479 kg) and were 5 to 18 years old. They were housed in paddocks and maintained on free choice of Coastal Bermuda hay, Bahia grass pasture, and trace minerals. The Institutional Animal Care and Use Committee of the University of Florida approved all studies.

Measurement of gastric tone—A specially designed barostat was used to assess changes in volume of the proximal portion of the stomach. The validity of an electronic barostat to measure gastric motility and tone was first demonstrated in dogs by Azpiroz and Malagelada, and work in our laboratory has also proved its usefulness for the study of tone of the proximal portion of the stomach in horses. The basic principle of the barostat is to maintain a constant pressure within an air-filled intragastric bag that has infinite compliance and a volume greater than the range of volumes to be used by the barostat during the study. When the stomach contracts, the barostat removes air from the bag to maintain the intrabag pressure constant; conversely, when the stomach relaxes, air is injected into the bag. Thus, changes in bag volume are a direct indication of changes in intragastric pressure induced by variations in wall tone.

A polyester bag with a 1,600-mL total capacity and a 1.6-mm internal diameter was connected to the barostat through a 1.5-m-long plastic catheter that had a 4-mm internal diameter (inflation line). A separate catheter (pressure line) with a 1.6-mm internal diameter connected the bag to the pressure transducer, so that pressure was monitored directly within the bag. Finally, a 35.5-cm-long plastic probe was attached to the portion of the inflation line near the bag to increase the catheter rigidity inside the stomach. For the present study, pressure within the bag was set at 2 mm Hg, with a hysteresis of 0.5 mm Hg. The size of the bag at this inflation pressure did not have any influence by itself on the internal pressure. Analogue signals from the recording instruments were digitized and displayed by use of specialized software at a sample rate of 50 Hz/channel. Changes in bag volume and pressure were also recorded by use of specialized software provided by the manufacturer of the barostat.

For each test, 13C-octanoic acid (at an amount of approx 1.5 mg/kg) was added to egg yolk (1 yolk/250 mg of marker), baked in a microwave oven, and thoroughly mixed into the test meal. This dose of octanoic acid is higher than that previously used by Sutton et al (1 mg/kg). Sutton found that Bermuda grass is naturally enriched with 13C and suggested a higher dose to compensate for this source of exhaled 13CO2. Preparation of the octanoate-enriched yolk was done on the day prior to the experiment and stored in the refrigerator until use to reduce the objectionable odor and taste of octanoic acid and, thus, the risk of feed rejection. The enriched yolk was added to the test meal and thoroughly mixed 5 minutes before it was offered to horses.

Test meal compositions for study phase I and II—During phase I of the study, 2 isocaloric (1.5 kcal/kg) and nearly isovolumetric pelleted meals (16% protein) were used. The high-CHO pelleted meal was rich in starch (31%) and poor in fat (3%), whereas the high-fat pelleted meal was rich in fat (8%), had no starch, and contained more fiber (43.5% neutral detergent fiber in the high-fat meal vs 28.4% neutral detergent fiber in the high-CHO meal). Test meals were fed at 0.5 g/kg.

During phase II of the study, a control meal consisting of a commercial 10% protein sweet feed was fed at 5 g/kg and was used as the basis to prepare the 2 experimental diets. The energy content of the sweet feed was 3.2 Mcal/kg, and the amount fed provided horses with 1.5 kcal/kg. The high-fat meal (12.3% fat, 1.95 kcal/kg) and the high-CHO meal (2.9% fat; 1.95 kcal/kg) were prepared by adding corn oil and glucose at amounts of 0.05 g/kg and 0.113 g/kg, respectively, to the control meal. To account for the influence of the sweet feed on the results, the control meal was included as an additional experimental meal.

Phase I and II designs—During phase I of the study, each horse participated in 4 experiments following a 2-period randomized block design. In the first period, 3 horses received the high-fat pelleted meal and the other 3 horses received the high-CHO pelleted meal. Horses were gradually acclimated to the test diets during a 1-week period until they received 5 g/kg/d of the respective test diet, divided in 2 feedings. Thereafter, each horse was included in 2 randomly assigned studies (ie, with or without labeling the test meal with 13C-octanoic acid) to evaluate the effect of the breath test label on meal-induced relaxation of the proximal portion of the stomach. After completion of both experiments, diets were gradually switched between the 2 groups of 3 horses and the 2 experiments were repeated.

During phase II of the study, horses were maintained on sweet feed (2.5 g/kg; 10% crude protein) twice a day and free of dietary carbohydrate. The present study, pressure within the bag was set at 2 mm Hg, with a hysteresis of 0.5 mm Hg. The size of the bag at this inflation pressure did not have any influence by itself on the internal pressure.
choice Bermuda grass hay. Each horse participated in 3 experiments in a random sequence. The only difference among the 3 experiments was the meal offered (control, high-fat, or high-CHO meal). Two additional experiments were performed with only the enriched meals and either the barostat or the 13C-octanoic acid breath test to study the interaction between both techniques.

Procedure—No horse participated in > 1 experiment/wk. Food was withheld for 14 hours before each experiment. After this period, the horse was placed in the stocks and the gastric cannula opened and cleansed. Status of the squamous mucosa of the proximal portion of the stomach was evaluated with an endoscope introduced through the cannula. It was determined that all horses had normal-appearing gastric squamous mucosa. Thereafter, the previously folded barostat bag was introduced into the stomach through the cannula and inflated manually to ensure it became unfolded. Position of the barostat bag within the proximal portion of the stomach was verified by use of a nasogastrically introduced endoscope (Figure 1). Correct position was defined as being above the margo plicatus. Once verified within the proximal portion of the stomach, the bag was emptied by a syringe and connected to the barostat by the catheter. Thereafter, activity of the proximal portion of the stomach was recorded during 2 hours by changes in volume of the isobarically controlled bag. The first 30 minutes of the experiment were recorded to obtain a baseline volume. Then, the horse was offered only one of the possible meals, and recording continued for a total of 120 minutes. Duration of meal ingestion was also recorded.

Breath samples were collected by use of a modified mask fitted with a 250-mL aluminum-coated polyethylene bag. The horse was allowed to breathe once through the mask before filling the bag, which was fitted with a unidirectional valve. Duplicate samples were transferred from this bag to 10-mL red-cap tubes, conveniently sealed, and stored until ready for stable isotope analysis. Three basal breath samples were collected 60, 15, and 5 minutes before test meal ingestion and thereafter at 15-minute intervals for 3 hours, then at 30-minute intervals for a further 3 hours.

Barostat recording was entirely done with the horse in the stocks. Once this component of the study was finished at 120 minutes, the horse was moved into a stall and the rest of breath samples collected there. Because it was difficult to remove the intragastric bag after feeding the horse and to avoid loss of food through the cannula, removal of the bag was delayed until completion of the study. Following each experiment, the recording equipment was removed, the gastric cannula was plugged, and the horse was returned to the paddock.

Additional experiments involving the separate use of the electronic barostat and the 13C-octanoic acid breath test followed a similar procedure. Therefore, experiments in which only the barostat technique was used ended after 2 hours of barostat recording. On the other hand, experiments in which only the breath test technique was used consisted only of breath sample collection and were entirely performed with the horse within a stall.

Data analysis—Time of ingestion between diets was compared by use of a repeated-measures ANOVA and a Friedman 2-way ANOVA for parametric and nonparametric analysis, respectively. In determination of intragastric volume for each diet, data from the 6 horses were grouped into 2-minute blocks and averaged. The blocks comprising the first 30 minutes were used to obtain a baseline bag volume. The remaining blocks (90 minutes) corresponding to the post-feeding period were analyzed to study the relaxation response of the proximal portion of the stomach in relation to baseline volume. Accordingly, the mean value of the baseline blocks was subtracted from each postfeeding block to account for baseline differences between diets. Blocks of different diets were then compared by a repeated-measures ANOVA by use of a software program. Comparison of mean baseline volumes among various diets was also performed to measure reproducibility. Finally, mean baseline was also compared with postfeeding blocks within the same diet.

In the calculation of gastric emptying variables, all samples containing < 0.9% CO2 were rejected to minimize analytic inaccuracies. The ratio of 13C:12C of each breath sample was determined by automated continuous-flow isotope-ratio mass spectrometry and expressed relative to an international standard. This rate was converted to parts per million 13C and expressed as parts per million excess 13C, after subtraction of the mean 13C-abundance of the 3 baseline breath samples. The percentage dose recovery per hour (PDR/h) of the administered isotope in the breath was calculated and plotted against time by use of the formula elaborated by Ghos et al. The following variables of gastric emptying were calculated from this curve: the gastric emptying coefficient (GEC), which reflects the gradient of the emptying curve and is a universal index of gastric emptying rate, was calculated according to Maes; the gastric half-emptying time (t1/2); the time at which the area under the fitted cumulative 13C-excretion curve demonstrates recovery of half the administered isotopic dose; and the time to peak breath 13CO2 content (tpeak). Curve fitting and calculation of constants were performed by least squares nonlinear regression analysis by use of a software program. The modeling techniques are described in detail by Sutton et al.

Comparison of variables of gastric emptying (GEC, t1/2, and tpeak) between diets was determined by use of a paired difference t test and a 2-sample t test for paired and unpaired data, respectively. A Friedman 2-way ANOVA was performed for nonparametric analysis. All results were displayed as mean ± SEM values. Values of P < 0.05 were considered significant.

Results

Influence of the breath test label on intragastric volume—Addition of 13C-octanoic acid, which was mixed with egg yolk and used as the gastric emptying marker in the test meal, caused a significantly greater accommodation of the proximal portion of the stomach after ingestion of the high-CHO pelleted meal than after the same meal without the marker but had no significant effect on degree of receptive relaxation. In contrast, no significant difference in accommodation was found between the high-fat pelleted meal and the same meal with the marker, when mean bag volumes were compared within the same time intervals. The addition of 13C-octanoic acid to corn oil– or glucose-enriched sweet feed meals did not have any significant effect on either component of the relaxation response, compared with that recorded after ingestion of unlabeled meals. Because 13C-octanoic acid labeling influenced meal-induced accommodation after the high-CHO pelleted meal, only data obtained from unlabeled pelleted meals were used to evaluate the effect of their ingestion on intragastric volume, whereas data obtained with labeled and unlabeled sweet feed meals were included in the analyses.

Duration of meal ingestion in phase I—Time for complete meal ingestion (time to empty the food bucket) of the unlabeled high-fat pelleted meal was 228 ±
30 seconds (range, 156 to 368 seconds), whereas time for ingestion of the unlabeled high-CHO pelleted meal was 158 ± 14 seconds (range, 120 to 208 seconds). Thus, horses spent a significantly (P = 0.02) longer time ingesting the high-fat pelleted meal.

Duration of meal ingestion in phase II—Horses spent a mean of 241 ± 31 seconds (range, 180 to 376 seconds) and 267 ± 35 seconds (range, 172 to 400 seconds) to finish the unlabeled corn oil–enriched and glucose-enriched meal, respectively. For 13C-octanoic acid–labeled meals, mean time for meal ingestion was 165 ± 2 seconds (range, 160 to 172 seconds) for the control meal, 280 ± 48 seconds (range, 164 to 430 seconds) for the corn oil–enriched meal, and 310 ± 78 seconds (range, 164 to 672 seconds) for the glucose-enriched meal. Duration of meal ingestion was not significantly different between sweet feed meals.

Effect of diet on intragastric volume—Baseline air volume within the barostat bag at 2 mm Hg pressure did not differ significantly between diets in any of the studies. During phase I of the study, bag volume began to increase rapidly after initiation of ingestion of either pelleted meal (Figure 2), reached a peak volume, and then decreased sharply by the end of ingestion, eventually returning to baseline volume. This receptive relaxation episode lasted 6 minutes with ingestion of the high-fat meal and 10 minutes with ingestion of the high-CHO meal (Figure 3). A second, less profound, significant increase in bag volume, which we have designated as accommodation, was observed 1 hour after ingestion of the high-fat meal, with bag volumes remaining significantly higher than baseline throughout most of the remainder of the recording period. In
contrast, this accommodation response was not observed with the high-CHO diet, except for discrete periods in which bag volume was significantly higher than baseline. Finally, no significant difference was found between diets for any time interval.

During phase II of the study, beginning of ingestion of either unlabeled sweet feed meal was associated with a rapid increase in bag volume (Figure 4). Accordingly, a peak volume was observed soon after the end of ingestion, followed by a gradual decrease in bag volume. This receptive relaxation response was more prolonged after the glucose-enriched meal than after the corn oil–enriched meal, as evidenced by significantly higher volumes at 12 to 16 minutes after ingestion of the former, compared with the latter. Intragastric bag volume remained significantly greater than baseline volume for the entire postprandial phase of the glucose-enriched meal experiments (90 minutes), whereas it returned to baseline volume at the end of the recording period in the corn oil–enriched meal experiments. Bag volume was significantly greater than baseline for all postprandial periods, except for the corn oil–enriched meal during the first 2 postprandial minutes and the last 4 minutes of barostat recording. *Significant (P < 0.05) difference between 2-minute periods at the same postprandial time.

All aspects of the gastric relaxation response after ingestion of labeled meals were similar to those after ingestion of unlabeled meals, except that bag volume
with the corn oil–enriched meal did not return to baseline (Figure 5). In contrast to the enriched meals, bag volume only remained significantly greater than baseline during the first 40 minutes after ingestion of the control meal; during receptive relaxation, mean bag volume was significantly greater than baseline for 40 minutes after ingestion of the control meal. *Significant (P < 0.05) difference between glucose-enriched meal and control meal within the same period. †Significant (P < 0.05) difference between corn oil–enriched meal and control meal within the same period. ‡Significant (P < 0.05) difference between glucose-enriched meal and corn oil–enriched meal within the same period.

Effect of the intragastric barostat bag and diet on gastric emptying—No significant differences were found for 1/2, T_max, or GEC between the sweet feed meals when results obtained with and without the presence of an intragastric bag were compared (Table 1). In the evaluation of the effect of diet on gastric emptying during phase I of the study, results of 1 breath test for the high-fat pelleted meal were excluded from the data for suspected error in breath sample analysis. Shapes of modeled curves were similar between pelleted meals (Figure 6). However, a higher and more exponential peak for isotope recovery was found following ingestion of the high-fat meal, compared with ingestion of the high-CHO meal. This peak was underestimated by the modeling function, resulting in a slight underestimation of T_max. No significant difference was found between pelleted meals for any of the gastric emptying indices.

During phase II of the study, shapes of modeled curves were also similar between the sweet feed meals and corn oil–enriched meals.
diets, except that the initial slope for the corn oil–enriched meal was slightly steeper and the maximal rate of gastric emptying was faster, compared with the glucose-enriched meal (Figure 7). Similar to the high-fat pelleted meal, the peak of emptying of the corn oil–enriched meal was underestimated by the modeled curve but was not significantly different from that of the glucose-enriched meal. Fit of the modeled curves was better for the corn oil–enriched meal than for the other 2 diets. Overall, none of the variables were significantly different among sweet feed diets (Table 1).

**Discussion**

The main objective of our study was to compare the effect of ingestion of a high-fat meal versus a high-CHO meal on relaxation of the proximal portion of the stomach and gastric emptying in horses. Test meals had identical energy content and weight and similar volume, so that any difference observed between meals could be attributed specifically to the fat and carbohydrate components. Meal-induced changes in tone of the proximal portion of the stomach were assessed by an electronic barostat, a technique that has been previously used\(^\text{11,22}\) in horses in our laboratory.

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**Figure 6**—Mean = SEM percentage dose recovery per hour (PDR/h) versus time and respective modeled curves of \(^{13}\text{C}\) in the breath of horses following ingestion of a high-fat pelleted meal (5 horses) or a high-CHO pelleted meal (6). Gastric emptying variables did not differ between diets.

**Figure 7**—Mean PDR/h versus time and respective modeled curves of \(^{13}\text{C}\) in the breath of 6 horses following ingestion of a sweet feed meal (control) or the same meal enriched with corn oil or glucose. Experiments were done without the presence of a barostat bag. Gastric emptying variables did not differ between diets.
Ingestion of every test meal was followed by relaxation of the proximal portion of the stomach, but the pattern of relaxation (ie, the number of episodes and their time of onset and duration) differed among diets. Nonetheless, every diet induced an initial relaxation phase that was associated with time of meal ingestion. This suggests that it was induced by activation of oropharyngeal receptors and thus corresponds to what could be termed receptive relaxation.\textsuperscript{13,16} This response was significantly longer with high-CHO meals, compared with high-fat meals, but the origin of this time difference cannot be attributed to duration of meal ingestion, since horses did not take a longer time consuming high-CHO meals, compared with high-fat meals. Therefore, mechanisms other than mechanical stimulation may play a role in the control of receptive relaxation in horses. One of the possible factors may be orosensory stimulation. That is, meals varying in composition may provide different orosensory signals that may, in turn, induce various gastrointestinal responses.\textsuperscript{5} The importance of orosensory factors controlling other gastrointestinal variables, such as hunger, satiation, and gastric emptying, occurs in other species.\textsuperscript{6,24} For example, in a study\textsuperscript{6} in humans, oral administration of a high-fat soup slowed gastric emptying more than an isocaloric high-CHO soup, but gastric emptying rates were similar when the respective soups were infused into the stomach. Finally, enrichment of a control sweet feed meal, suggesting that orosensory stimulation seems to be important in the response to fat and carbohydrate.

The second component of meal-induced relaxation in the horses of our study, which was consistent with what has been described\textsuperscript{5,13,16} as accommodation, was observed following all meals, with the exception of high-CHO pellets. Because the accommodation reflex is triggered, in part, by stimulation of gastric mechanoreceptors rather than chemoreceptors,\textsuperscript{5} arrival of pelleted or sweet feed meals of similar weight and volume into the stomach should have resulted in a similar degree of mechanical stimulation and, therefore, similar time of onset of accommodation. However, accommodation after sweet feed meals occurred immediately after receptive relaxation, whereas that induced by the high-fat pelleted meal was observed long after the meal had entered the stomach. Thus, induction of accommodation in these studies likely originated within the intestine and not the stomach. One possible explanation for the absence of gastrically originated accommodation is that in horses the contribution of the stomach may not be as important as that of the intestine. The idea that time of onset and degree of accommodation depend on the site where the reflex originates has been suggested before. In particular, the duodenum is a stronger triggering site for the accommodation reflex of the proximal portion of the stomach in humans.\textsuperscript{5} Alternatively, larger meals may be needed in horses to trigger a distinctive accommodation response originating from the stomach.

Thus, the earlier onset of accommodation observed with sweet feed meals might be explained by their composition and physical characteristics. Digestion and absorption of carbohydrates and fat are required to activate intestinal chemoreceptors involved in control of gastric emptying.\textsuperscript{2,27} The glucose contained within the glucose-enriched sweet feed meal was ready for rapid absorption, whereas the carbohydrates of the high-CHO pelleted meal, which were in the form of starch, needed digestion before absorption. Similarly, fat of the corn oil–enriched sweet feed meal was possibly more readily accessible for digestion because of the physical characteristics of the meal (ie, liquid fat was mixed into sweet feed to prepare that fat-enriched meal), whereas fat was homogenized and integrated into pellets in the high-fat pelleted meal. Thus, the type of carbohydrate and fat used to enrich the respective sweet feed meals may have facilitated earlier digestion and absorption of these additives, causing earlier activation of intestinal chemoreceptors and, in turn, earlier onset of accommodation, compared with pelleted meals.

The concurrent use of the \textsuperscript{13}C-octanoic acid breath test modified the relaxation response measured by the electronic barostat. This effect was diet specific because it only increased relaxation after the high-CHO pelleted meal. One possible explanation of this interaction is that labeling with the breath test marker increased the fat content of this particular diet to an amount that surpassed a fat-specific induction threshold. For the breath test technique, a \textsuperscript{13}C-octanoic acid (medium-chain fatty acid) dose of 1.5 mg/kg was prepared in egg yolks (1 yolk/250 mg of marker) and mixed with the test meal. In a 500-kg horse, this label would consist of 3 yolks and 750 mg of octanoic acid. Therefore, labeling of the high-CHO pelleted meal resulted in a change from 3% fat to 9% fat, whereas labeling of the high-fat pelleted meal increased the amount of fat from 8% to 13.6%. That labeling of the high-fat meal had no effect on the magnitude of accommodation, despite the increase in fat content, may be explained, as suggested above, by dose independence of fat-induced relaxation in horses. That is, beyond threshold, increasing doses of fat do not cause greater relaxation. Dose independence has been reported for humans, although it is inconsistent in the literature.\textsuperscript{14,28,29} On the other hand, addition of the breath test label to the glucose-enriched sweet feed meal increased the lipid content from 2.9% to 7.7%, but the magnitude of accommodation was unaffected. Unlike the pelleted meals, bag volumes after any of the sweet feed meals remained consistently greater than baseline, and any additive effect of the breath test label may have been masked by this response. Therefore, because composition of the test meal may determine whether \textsuperscript{13}C-octanoic enrichment influences meal-induced accommodation of the proximal portion of the stomach, its possible influence should be determined a priori in any study in which it is used in conjunction with measurements of proximal gastric tone.\textsuperscript{27} In contrast, the presence of an intragastric bag within the proximal portion of the stomach to measure tone by the barostat did not influence gastric emptying rates of test meals in our study. This is consistent with results from studies in other species that revealed no effect of a barostat bag.
on gastric emptying of a liquid or a solid-liquid meal. In our study, high-fat meals and high-CHO meals emptied from the stomach at similar rates. These results were in contrast to the prevailing notion, derived from studies in other species, that fat has a more potent effect on regulation of gastric emptying than carbohydrates. Yet, our study was different from most in that all test meals had identical caloric content. Therefore, our results support the idea that meals with similar caloric content have similar emptying rates, regardless of nutrient composition. In addition, some studies in other species indicate that volume is another factor controlling gastric emptying of a meal. However, in contrast to species that are routinely used in gastric emptying studies, the horse is an herbivore whose natural nutrition depends on a constant intake of high-fiber low-energy food. Because it has a relatively small gastric capacity, control of intake rate and gastric load may be more important than control of nutrient delivery rate. In other words, in horses, volume may be more important in controlling gastric emptying than dietary composition. However, this possibility could not be evaluated in our study because test meals had similar volumes, which could be considered as small for an adult horse.

Although overall gastric emptying rate was similar between high-fat and high-CHO meals, the latter consistently emptied slower at the initial phase of emptying, which suggests that, in horses, carbohydrates may cause more profound feedback inhibition than fat on early phases of gastric emptying. A slower early phase of emptying of high-CHO meals may have been compensated by faster emptying rates at later stages to yield a half-time value similar to that of high-fat meals. The lack of significance might also be the result of a small sample size or poor fit of the modeled curves for high-CHO meals as a result of high variability in measurement. Alternatively, the variables described by Ghoos et al may not be sensitive enough to detect significant differences between meals in different phases of the gastric emptying process. Further studies, including a larger sample size or the use of alternative methods that are sensitive to different phases of emptying, are needed to resolve these issues in horses.

Our results were not consistent with those of Wyse et al, who determined that addition of soybean oil to a small meal of oats and bran caused a delay in gastric emptying in ponies, as also assessed by the 13C-octanoate breath test. It is difficult to explain this discrepancy, but a possibility is that the difference in the relative energetic contribution of fat to the meal varied between studies. That is, in the study by Wyse et al, addition of the fat component to the original meal resulted in an increment of approximately 60% of energy, whereas addition of corn oil to the control meal given to our horses increased energy content by approximately 30%. The physiologic characteristics of gastric emptying in ponies may differ from those of horses.

In conclusion, results of our study indicate that, in horses, dietary carbohydrates seem to magnify the receptive relaxation, compared with fat, whereas intestinal modulation of accommodation by fat and carbohydrates seems to be similar. Both nutrient classes, in similar caloric amounts within small meals, emptied from the stomach at similar rates, possibly because of similar intestinal feedback modulation. However, carbohydrates may be more potent modulators of gastric emptying than fat in horses at early stages of emptying. We have shown that an interaction between the electronic barostat and the 13C-octanoic acid test techniques may occur with some types of meal composition; therefore, results should be taken with caution if it appears that an interaction exists. Finally, our results were somewhat surprising because they indicate that the response of the equine stomach to dietary fat may not be profoundly different than the response to dietary carbohydrate, which is not consistent with what has been found in other species.

References


