Effect of pyloric blockade and infusion of histamine or pentagastrin on gastric secretion in horses

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Objective—To determine the origin of the nonacid (nonparietal) component of gastric secretions in horses induced by pentagastrin infusion.

Animals—6 horses.

Procedure—A Latin square design was used, involving 6 horses, 3 treatments, and 2 duodenal intubation conditions (catheter with balloon to obstruct pylorus [B] or without balloon allowing movement of contents between stomach and duodenum [NB]). Each horse had an indwelling gastric cannula and a catheter positioned in the duodenum. Gastric and duodenal contents were collected during 15-minute periods. Each experiment consisted of serial collection periods: baseline; infusion of pyrilamine maleate (1 mg/kg of body weight, IV); not treated; and IV infusion of saline (0.9% NaCl) solution alone, saline solution containing pentagastrin (6 μg/kg·h), or saline solution containing histamine (30 μg/kg·h). Volume of samples was recorded, and electrolyte concentrations were measured.

Results—Pentagastrin and histamine stimulated maximal acid output; however, during NB conditions, pentagastrin-induced concentration of hydrogen ions was significantly less than during histamine or pentagastrin infusions during B conditions. The large volume produced in response to pentagastrin during NB conditions was accompanied by increased sodium ion output that was greater than for pentagastrin during B conditions, but both values were significantly greater than values for histamine during B or NB conditions.

Conclusions and Clinical Relevance—Nonparietal secretions collected during IV infusion of pentagastrin are duodenal in origin. Reflux of duodenal contents into the stomach of horses is enhanced by pentagastrin. Flow of duodenal contents into the stomach could have implications in the pathogenesis of ulcers in horses. *(Am J Vet Res* 2000;61:1133–1139)

Gastric secretions and the composition of gastric contents of horses with various conditions have been studied by numerous investigators, using several techniques.[1-15] With the development of a technique for long-term gastric cannulation for collection of gastric contents, knowledge about function of the equine gastrointestinal tract has expanded greatly.[1,3,4,6,12,13,15] Additional understanding of the function of the small intestines of horses is possible, because this technique allows access to the proximal portion of the duodenum, including the region in which the pancreatic and bile ducts enter, as well as the stomach itself.

The composition of gastric contents collected by use of a gastric cannula during stimulation with pentagastrin has repeatedly been reported to be uncharacteristically voluminous, with a low concentration of acid and a large output of sodium.[1,3,6,13] In contrast, gastric contents collected during stimulation with histamine were more classically parietal, with high acidity and a low sodium concentration.[15] The origin of the nonparietal component of pentagastrin-stimulated gastric secretions in horses has not been specifically localized.

Reflux of duodenal contents into an empty stomach may be seen during endoscopic examination of horses even when there is a lack of evidence of underlying pathologic changes. The importance, frequency, and volume of reflux during normal conditions have not been evaluated. Similarly, composition of the duodenal contents that are refluxed have not been analyzed.

Objectives of the study reported here were to compare, in horses with empty stomachs, the composition of gastric and duodenal contents with and without pyloric obstruction and the effect of IV infusion of histamine and pentagastrin on these contents. We hypothesized that the voluminous nonparietal response to pentagastrin would be of extragastric origin, and duodenal reflux would allow this fluid to be collected via a gastric cannula.

Materials and Methods

Animals and experimental preparation—Six horses (5 Thoroughbreds, 1 Arabian; 2 mares and 4 geldings) between 3 and 20 years old were used for the study. All horses were healthy and weighed between 430 and 510 kg. They were housed on pasture that consisted of Bahia grass; additionally, they were provided coastal Bermuda hay ad libitum and fed a 12%-protein grain mixture (0.5 kg/100 kg of body weight/d). None of the horses had clinical signs of gastrointestinal tract disease. Horses were dewormed every 2 months and vaccinated against encephalomyelitis and tetanus every 6 months. An indwelling silastic gastric cannula, described elsewhere,[1] had been implanted in these horses between 1 and 24 months prior to initiation of this study. All procedures were approved by the University of Florida Institutional Animal Care and Use Committee.

Experiments were performed at intervals of ≥ 1 week. All food was withheld for 18 to 20 hours prior to an experiment, but water was available ad libitum. Horses were loose-

Received Feb 16, 1999.
Accepted Jul 26, 1999.
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Published as University of Florida College of Veterinary Medicine Journal Series No. 548.
The authors thank Drs. Martha Campbell-Thompson, James E. McGuigan, and J. B. Madison for technical assistance.

ly restrained in the laboratory. The gastric cannula was opened and allowed to drain by gravity for 15 to 20 minutes. During this period, an indwelling catheter was inserted in a jugular vein.

To accomplish duodenal intubation, a videoendoscope[a] was inserted through the gastric cannula and positioned in the duodenum approximately 30 cm distal to the pylorus and past the duodenal diverticulum, the point at which the pancreatic bile ducts enter the small intestines. A stylet (4.5 m in length) was threaded through the biopsy port of the endoscope until it was seen entering the duodenal lumen; it was held in place as the endoscope was slowly withdrawn. The distance from the pylorus to the open end of the cannula was recorded. The stylet was marked to indicate the point where the end of the cannula was located. A specially modified commercially available urethral catheter for stallions (with or without an attached balloon, depending on the experiment) was passed over the stylet, through the pylorus, and into the duodenum. In catheters with balloons, the balloon was attached 20 cm from the tip of the catheter. On catheters that did not have an attached balloon, a bold mark was made on the catheter 20 cm from the catheter tip. Additional marks were made on all catheters at 5-cm intervals, extending from the balloon or bold mark to the collection end of the catheter, which provided an accurate measure for placement of each catheter at the pylorus. Once in place, the duodenal tube extended 20 cm into the duodenum; each tube contained multiple perforations for collection of duodenal contents. For catheters with an attached balloon, the balloon was inflated and snugly fit to the pylorus (**Fig 1**). The completed preparation allowed for continuous collection, using gravity to initiate and maintain drainage, of gastric contents from the cannula and duodenal contents from the tube. Gastric and duodenal contents were collected into separate containers for subsequent analysis.

Experimental protocol—The study design was a 6 × 6 Latin square involving 6 horses, 3 treatments, and 2 duodenal intubation conditions (a catheter with an attached balloon, which was inflated to obstruct the pylorus [**blocked (B)**], or a catheter without a balloon, which allowed for movement of contents between the stomach and proximal portion of the duodenum [**not blocked (NB)**]). Gastric and duodenal contents were collected during 15-minute periods. Gastric samples were filtered through gauze prior to analysis. Volume of collected gastric and duodenal contents was measured, and, when possible, a 50-ml sample was saved for subsequent analyses. Some analyses were performed immediately, whereas other analyses subsequently were performed on samples that had been frozen after collection.

Each experiment lasted 3 hours. During the initial 45 minutes (baseline collection), treatments were not administered. Beginning 45 minutes after onset, pyrilamine maleate,[b] a histamine-1 receptor antagonist, (1 mg/kg, IV) was infused during a 15-minute period. During the subsequent 30 minutes, additional treatments were not administered. During the final 90 minutes (ie, 90 to 180 minutes after onset), each horse was given an IV infusion of saline (0.9% NaCl) solution alone, pentagastrin in saline solution (rate of 6 µg of pentagastrin/kg·h), or histamine in saline solution (rate of 30 µg of histamine/kg·h). At the conclusion of each experiment, position of the duodenal tube was assessed before it was withdrawn, and the gastric cannula subsequently was closed.

Analysis of samples—Samples of gastric and duodenal contents collected during 15-minute collection periods were measured in a graduated cylinder and immediately analyzed in duplicate to determine the **chloride ion concentration** ($[Cl^-]$), using chloridometry.[c] Aliquots of gastric contents also were immediately analyzed to determine the **hydrogen ion concentration** ($[H^+]$), using electrometric titration[d] with 0.1N NaOH to achieve a final value of pH 7.4. Aliquots of duodenal contents were stored in an ice bath until they were analyzed at the end of the experiment to determine the **bicarbonate concentration** ($[HCO_3^-]$), using electrometric back-titration to pH 8.4 in accordance with the method of Isenberg et al.[16] The remainder of the gastric and duodenal samples were frozen at –20 C for subsequent measurement of **sodium ion concentration** ($[Na^+]$) and **potassium ion concentration** ($[K^+]$) by use of flame photometry.[e] Analyses of all electrolytes were performed in triplicate except for $[H^+]$, which was performed in duplicate; the final value was expressed as a mean of these results. Gastric output of various ions per period for all horses were calculated by multiplying the volume of contents collected by the concentration of each ion during the respective period.

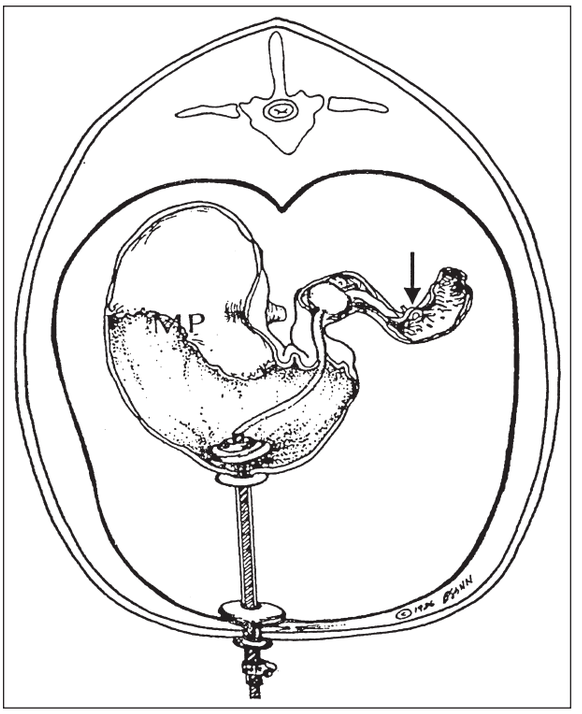

Figure 1—Illustration of a balloon catheter positioned at the pylorus to obstruct the flow of duodenal contents into the stomach of a horse. Notice that a duodenal catheter was positioned to extend beyond the duodenal diverticulum (arrow) and that it exited through the indwelling silastic gastric cannula. MP = Margo plicatus.

During selected experiments, samples of gastric and duodenal contents that had been collected between 30 and 45 minutes after onset of the experiment (ie, the last 15-minute collection period during the baseline period) were stored. Subsequently, these samples were used for measurement of concentrations of bile salts, using a commercially available assay.[f]

Statistical analyses—Volume, ion concentrations, and outputs were analyzed, using an ANOVA for repeated measures, and least-squared difference was used for pairwise comparison of means. Values of $P < 0.05$ were considered significant.

Results

Health of horses—All horses maintained or gained weight during the course of the study, and none

Table 1—Concentrations and outputs of hydrogen and sodium ions in gastric contents obtained during various experimental conditions

		Collection period				
				Infusions (maximum response)‡		
Variable	Pyloric obstruction	Basal*	Pyrilamine†	Saline	Histamine	Pentagastrin
$[H^+]$ (mEq/L)	NB	33.8 ± 6.5	27.6 ± 6.6§	28.9 ± 5.5‖	80.3 ± 4.9¶	42.4 ± 3.1
	B	47.0 ± 10.2#	32.8 ± 9.3§	38.8 ± 9.1‖	103.1 ± 3.5	84.2 ± 4.9
H^+ output (μEq/kg of body weight/15 min	NB	35.5 ± 10.2	22.5 ± 7.4§	28.6 ± 5.5‖	112.6 ± 8.3¶	80.2 ± 7.0
	B	29.5 ± 9.5#	12.8 ± 5.1§	21.8 ± 7.0‖	97.1 ± 10.8	91.2 ± 5.8
$[Na^+]$ (mEq/L)	NB	101.5 ± 8.2	107.0 ± 6.1§	108.8 ± 4.6‖	52.5 ± 5.2¶	88.2 ± 4.8
	B	89.6 ± 9.2	102.0 ± 9.1§	91.6 ± 9.5‖	31.1 ± 4.2¶	57.7 ± 6.1
Na^+ output (μEq/kg/15 min	NB	99.2 ± 12.3	82.2 ± 12.0§	108.8 ± 8.8‖	77.1 ± 12.9¶	167.4 ± 14.7**
	B	45.8 ± 7.4#	32.5 ± 5.0§	44.9 ± 7.1	30.1 ± 6.6	68.6 ± 16.2**

Values represent mean ± SEM for 6 horses.
*Basal = 3 samples obtained during a 45-minute period (no treatment administered). †Pyrilamine = 2 samples obtained during the 30-minute period following administration of pyrilamine maleate (1 mg/kg of body weight, IV, during a 15-minute period). ‡Infusions = Final 2 samples during a 90-minute period of IV infusion of saline (1 ml of 0.9% NaCl/min), histamine (30 μg/kg/h), or pentagastrin (6 μg/kg/h). Maximum response to both secretagogues was elicited by this time. §Value for pyrilamine differs significantly ($P < 0.05$) from values for other conditions. ‖Value for saline infusion differs significantly ($P < 0.05$) from values for histamine or pentagastrin infusions. ¶Value for histamine infusion differs significantly ($P < 0.05$) from values for saline or pentagastrin infusions. #Value for B condition differs significantly ($P < 0.05$) from value for NB condition. **Value for pentagastrin infusion differs significantly ($P < 0.05$) from value for histamine infusion.
B = Blocked pylorus. NB = Pylorus not blocked. $[H^+]$ = Hydrogen ion concentration. H^+ output = Hydrogen ion output. $[Na^+]$ = Sodium ion concentration. Na^+ output = Sodium ion output.

Table 2—Concentrations and outputs of potassium and chloride ions in gastric contents obtained during various experimental conditions

		Collection period				
				Infusions (maximum response)‡		
Variable	Pyloric obstruction	Basal*	Pyrilamine†	Saline	Histamine	Pentagastrin
$[K^+]$ (mEq/L)	NB	9.8 ± 0.9	8.1 ± 0.6§	9.8 ± 0.6	14.0 ± 0.9¶	10.3 ± 0.5
	B	10.3 ± 1.2#	8.0 ± 0.7§	9.4 ± 0.8‖#	17.7 ± 1.0¶#	14.2 ± 0.9**#
K^+ output (μEq/kg of body weight/15 min	NB	10.2 ± 2.1	6.4 ± 1.2§	9.8 ± 0.8‖	19.5 ± 1.3	19.5 ± 1.3
	B	5.9 ± 1.5#	2.6 ± 0.5§	4.7 ± 1.1‖	16.4 ± 1.7	15.7 ± 1.9
$[Cl^-]$ (mEq/L)	NB	143.4 ± 5.6	143.1 ± 6.3	143.2 ± 3.8	144.9 ± 3.6	144.0 ± 6.6
	B	151.1 ± 5.2#	153.3 ± 5.6	151.3 ± 5.1	156.9 ± 3.5	154.0 ± 2.6
Cl^- output (μEq/kg/15 min	NB	138.8 ± 22.7	111.1 ± 17.8§	143.3 ± 8.8‖	207.3 ± 20.5¶	272.9 ± 19.5**
	B	82.2 ± 16.9#	51.0 ± 10.4§	73.7 ± 14.1‖	149.2 ± 19.5¶	172.0 ± 19.1**

Values represent mean ± SEM for 6 horses.
**Value for pentagastrin infusion differs significantly ($P < 0.05$) from value for histamine or saline infusions.
$[K^+]$ = Potassium ion concentration. K^+ output = Potassium ion output. $[Cl^-]$ = Chloride ion concentration. Cl^- output = Chloride ion output.
See Table 1 for remainder of key.

of the horses had signs of pain or anxiety during the experimental procedures. Examination during duodenal intubation revealed that the duodenal mucosa appeared healthy prior to all experiments. Colic was not observed in these horses at any time during these experiments.

Gastric contents before infusion—Gastric contents collected when there was not an obstruction of the pylorus (ie, NB) were yellow to greenish-yellow and cloudy, similar to results in other studies.[1,3,4] When the pylorus was obstructed by the balloon (ie, B), the contents collected from the gastric cannula were clear and colorless. Pyloric obstruction significantly affected all variables, except $[Na^+]$. The output of all electrolytes was decreased, whereas $[H^+]$, $[K^+]$, and $[Cl^-]$ were increased (**Table 1 and 2**).

After pyrilamine treatment, $[H^+]$, $[K^+]$, and all electrolyte outputs significantly decreased, compared with values for the pretreatment basal condition, whereas $[Na^+]$ increased. In absolute values, these changes were not profound.

Concentration of bile acids in gastric contents of 18 samples collected when the pylorus was not blocked during the baseline collection period ranged from 21 to 77 μmol/L; these samples were all light yellow in color. In 18 samples collected when the pylorus was blocked, the concentration ranged from < 5 to 7 μmol/L, and these samples were colorless.

Gastric contents after infusion—During NB conditions, infusion of histamine or pentagastrin induced a significant increase in the volume of gastric contents flowing out of the cannula, compared with that during basal collection and during saline infusion. Furthermore, maximal volume flow during pentagas-

Table 3—Volumes of gastric contents obtained during various experimental conditions

		Collection period				
				Infusions (maximum response)‡		
Variable	Pyloric obstruction	Basal*	Pyrilamine†	Saline	Histamine	Pentagastrin
Volume (ml/15 min)	NB	466.1 ± 58.4	361.6 ± 51.1§	472.9 ± 30.5‖	664.2 ± 51.5¶	885.8 ± 39.5**
	B	251.0 ± 48.9#	153.9 ± 30.1§#	226.9 ± 42.5‖#	445.5 ± 56.0¶#	523.8 ± 52.4**#

Values represent mean ± SEM for 6 horses.
See Table 2 for key.

Table 4—Volume and concentrations of electrolyte ions in duodenal contents obtained during various experimental conditions (intraduodenal balloon inflated to prevent contamination by gastric contents)

	Collection period				
			Infusions (maximum response)‡		
Variable	Basal*	Pyrilamine†	Saline	Histamine	Pentagastrin
Volume (ml/15 min)	217.2 ± 49.5	214.6 ± 45.0	181.0 ± 49.8	155.6 ± 16.4	409.0 ± 111.5†
$[Na^+]$ (mEq/L)	143.1 ± 5.5	151.5 ± 6.7	147.8 ± 5.5	143.1 ± 2.2¶	152.6 ± 5.2
$[K^+]$ (mEq/L)	4.1 ± 0.2	4.0 ± 0.2	3.9 ± 0.1‖	3.7 ± 0.1	3.7 ± 0.3
$[Cl^-]$ (mEq/L)	99.2 ± 12.3	82.2 ± 12.0	129.2 ± 6.3‖	112.5 ± 2.7	108.5 ± 2.7
$[HCO_3^-]$ (mEq/L)	28.5 ± 2.7	28.7 ± 2.7	28.5 ± 4.7	28.3 ± 1.9	37.2 ± 2.1†

Values represent mean ± SEM for 6 horses.
$[HCO_3^-]$ = Bicarbonate ion concentration. Volumes are only relative, because the duodenum distal to the duodenal diverticulum was not blocked, and markers were not used.
See Table 2 for remainder of key.

trin infusion was significantly greater than that during histamine infusion (**Table 3**). During B conditions, histamine and pentagastrin again induced a peak volume flow from the cannula that was significantly greater than that during the basal collection period and saline infusion. Also, similar to NB conditions, maximal volume flow during pentagastrin infusion was significantly greater than that during histamine infusion, although the contrast between these 2 volumes was not as great as for the 2 volumes obtained during NB conditions.

The $[H^+]$, $[Na^+]$, $[K^+]$, and $[Cl^-]$ in the gastric contents varied considerably, depending on treatment status (Table 1 and 2). Essentially, values during saline infusion were similar to those during basal collection or after pyrilamine treatment, regardless of whether the pylorus was blocked. In contrast, histamine and pentagastrin each induced significant increases in the $[H^+]$ and $[K^+]$ and a significant decrease in the $[Na^+]$ during both B and NB conditions, but the magnitude of these changes differed noticeably, depending on the combination of treatment and B or NB condition. Most noticeable was the fact that during NB conditions, the peak $[H^+]$ during histamine infusion was twice that detected during pentagastrin infusion, whereas during B conditions, peak $[H^+]$ was not significantly different in response to either of these treatments. Furthermore, during B conditions, pentagastrin infusion caused a profound reduction of the $[Na^+]$ response that was similar to that seen in response to histamine infusion, regardless of whether it was during B or NB conditions.

With regard to the outputs of various ions, results also varied depending on pylorus blockage and treatment (Table 1 and 2). Most striking was the fact that output of hydrogen ions increased significantly in response to histamine and pentagastrin infusion, and these outputs were virtually identical during B conditions, although during NB conditions, the pentagastrin-induced maximal response was significantly less than the histamine-induced maximal response. Maximal output of sodium ions was significantly less during B conditions than during NB conditions for all infusions and during all collection periods. The maximal output of sodium ions in response to histamine infusion was significantly less than in response to pentagastrin infusion during NB and B conditions. Histamine and pentagastrin infusion each induced a virtually identical and significantly greater output of potassium ions than that detected during the basal collection period, whether during B or NB conditions. During B conditions, the outputs of potassium and chloride ions were significantly less than during NB conditions. Furthermore, histamine and pentagastrin infusion stimulated maximal output of chloride ions that was significantly greater than the output during the basal period or during saline infusion, but pentagastrin infusion induced significantly more output of chloride ions than histamine infusion, and all outputs were decreased proportionally during B conditions.

Duodenal contents before and after infusion—To avoid contamination by gastric contents, only duodenal contents collected during B conditions were analyzed (**Table 4**). The most noticeable changes in electrolyte concentrations were a significant decrease in $[Cl^-]$ induced by histamine and pentagastrin infusion, compared with concentrations for any of the other conditions, and a significant increase in $[HCO_3^-]$ induced by pentagastrin infusion, compared with concentrations for any of the other conditions. The concentration of bile acids in 6 samples collected during the last 15-minute collection period of the basal collection period ranged from 88.5 to 305.3 µmol/L (mean ± SEM, 208.3 ± 29.9 µmol/L).

On the basis of the volumes of duodenal contents collected, pentagastrin infusion, in particular, induced a profuse secretion of fluid into the proximal portion of the duodenum. Viscosity of the contents collected during pentagastrin infusion also was much more watery than that collected for other conditions.

Discussion

In the study reported here, we documented that tubing with a relatively large diameter can be easily passed through the pylorus of an adult horse, and this preparation can be used to obtain information about control of gastrointestinal secretory function of the small intestines of horses. In this study, we used this preparation to examine the hypothesis that IV infusion of pentagastrin stimulates secretion of a large volume of sodium-rich electrolyte fluid into the proximal portion of the duodenum that can reflux into the stomach and dilute gastric contents. This hypothesis was based on our finding in another study[15] that the maximal acid output in response to histamine and pentagastrin was virtually the same, but maximal acid concentration induced by histamine was almost twice that induced by pentagastrin. Testing of the hypothesis was accomplished by obstructing the pylorus with a balloon without causing discomfort to the horses. The profound decrease in concentration of bile salts in the gastric contents after inflation of the balloon provided confidence that the pylorus of each horse truly was blocked.

Treatment with pyrilamine maleate, a histamine-1 receptor antagonist, was necessary in the experiments involving histamine to prevent undesirable systemic adverse effects such as CNS abnormalities or respiratory distress. To standardize the protocol, we believed it was important to administer pyrilamine during the experiments involving pentagastrin infusion. An unexpected finding was the significant effect of pyrilamine treatment on suppression of the volume of gastric contents collected and the concentration of electrolyte constituents of those contents. Nevertheless, in a separate group of preliminary studies in which we compared the response to pentagastrin administration with and without prior treatment with pyrilamine (data not shown), we found that pyrilamine did not significantly affect the maximal secretory response. Suppression of gastric secretion by a histamine-1 antagonist has not been reported in other species when it has been given prior to histamine infusion. The reason that infusion causes this result in horses cannot be explained by analysis of results of the study reported here, although transient effects of a reduction in mucosal blood flow[17] or H_3 receptor expression[18] are possibilities.

In the preinfusion time periods, the volume of gastric collections was significantly less during B conditions than during NB conditions, suggesting that a source distal to the pylorus may be contributing to the volume (Table 3). The contents collected during B conditions also had a higher [H^+] than those collected during NB conditions, adding credence to the dilution theory. Because the [Na^+] and [K^+] of the contents did not differ greatly between B and NB conditions, the diluting fluid of presumed duodenal origin must contain these ions, similar to the duodenal contents (Table 4). The transpyloric catheter may have enhanced reflux of duodenal contents into the stomach during NB conditions, but this reflux appears to be a consistent component of gastric contents in horses from which food has been withheld, even when such a catheter is not in place.[3,8,13]

Furthermore, during NB conditions, the difference in volume of contents collected during pentagastrin infusion was much greater than that collected during histamine infusion. This suggests that pentagastrin stimulates gastric acid output and also stimulates a large secretion of NaCl-rich fluid into the lumen of the proximal duodenum, a noticeable portion of which refluxes into the stomach. Again, this is supported by the finding that the volume of contents collected during peak pentagastrin or histamine stimulation were quite similar when the pylorus was occluded (Table 3). This would explain why, when the pylorus is not occluded, the peak [H^+] in response to pentagastrin is so much less than it is in response to histamine. Nevertheless, the effect of reflux is primarily that of dilution, because the maximal acid output stimulated by either pentagastrin or histamine was virtually the same regardless of whether the pylorus was obstructed (Table 1). This lends further support to the original finding of Campbell-Thompson and Merritt[3] in which administration of pentagastrin at the rate of 6 µg/kg/h is appropriate to induce a maximal secretory response of gastric acid in horses.

On first appearance, the acid output during pentagastrin infusion without obstruction of the pylorus was surprisingly lower than acid output in response to pentagastrin infusion with obstruction or to infusion of histamine. We believe this can be explained, however, if we consider the reflux of duodenal contents as a source of dilution as well as a source of bicarbonate. Bicarbonate that refluxes into the stomach can freely interact with hydrogen ions. Our system was open to the environment of the laboratory, and, therefore, we could not measure CO_2 produced by such a reaction and released into the air. The interaction of hydrogen ions and bicarbonate ions would prevent our measurement of these ions except within a closed system. To approximate the correct acid output, we calculated the buffering capacity of the duodenal contents. The volume differences for B and NB conditions during infusion of pentagastrin were multiplied by the [HCO_3^-], and a 1:1 buffering reaction was assumed. The corrected [H^+] and acid output were 55.9 mEq/L and 103.2 mmol/kg, respectively. This corrected acid output corresponds favorably with the histamine or pentagastrin infusions during B conditions.

Whereas the lower [Cl^-] in gastric contents during NB conditions was likely attributable to the diluting effect of refluxed duodenal contents, chloride output through the cannula was greater during NB than B conditions, inferring that the refluxed fluid contained chloride ions but at a lesser concentration than that of the pure gastric secretions. The significantly greater output of chloride ions during pentagastrin infusion, compared with histamine infusion during B and NB conditions, further implied a specific pentagastrin effect unique to horses, producing large volumes of

electrolyte-rich fluid that may reflux into the stomach from the duodenum (Table 2). Apparently, pentagastrin stimulates an extragastric source of chloride ions, which are collected via the gastric cannula during NB conditions.

The finding that the maximal [H^+] of the gastric contents induced by histamine infusion was significantly greater than that induced by pentagastrin infusion during NB conditions, but not B conditions, suggests that the equine stomach responds to both these agents in a similar manner with respect to acid secretion (Table 1). We interpret the fact that the mean [H^+] during histamine infusion during NB conditions was consistently less than histamine infusion during B conditions as an indication of contamination by refluxed duodenal contents but certainly not to the degree seen during pentagastrin infusion during NB conditions.

The effects on the sodium composition of gastric contents were even more noticeable than effects on acid composition of gastric contents, although the pattern of steady [Na^+], along with the increase in sodium output during pentagastrin infusion during NB conditions, was similar to that reported elsewhere.[3,13] The [Na^+] decreased markedly during pentagastrin infusion during B conditions, resembling the pattern seen in response to histamine infusion regardless of whether the pylorus was blocked. In other words, blocking the pylorus resulted in [Na^+] and sodium ion output in response to pentagastrin that were comparable to those seen without pyloric blockage in other monogastric species.[19-21] This is consistent with our previous suggestion that the large increase in sodium ions in the gastric contents in response to pentagastrin is from extragastric, presumably duodenal, sources and is responsible for the large volume of contents collected during infusion of this secretagogue.[13]

Duodenal contents obtained by use of the intraduodenal catheter presumably were composed of a mixture of pancreatic, biliary, and duodenal secretions. We did not attempt to quantitate the volume of duodenal contents, because continuous collection of all duodenal contents was limited by the diameter of the tube and viscosity of the fluid. Furthermore, we did not provide a distal obstruction of the duodenum to prevent fluid from moving aborally during the experiments. There was a significantly greater volume of duodenal contents collected from the catheter during pentagastrin infusion, and in addition to having a significantly higher [HCO_3^-], those contents appeared to be less viscous than contents collected during either histamine or saline infusion (Table 4). These findings are consistent with the report of Alexander and Hickson[22] in which they indicated that pentagastrin is a strong stimulant of pancreatic secretion in horses. Thus, we presume that the pancreas contributed the greatest portion of this fluid. This would have been easier to determine if stimulated pancreatic secretions in horses was high in [HCO_3^-] similar to most other species.[22] Another way to verify contents as being pancreatic secretions is to measure the total protein or specific enzyme content of the fluid in question.[23] Similar to the report of Hickson and Alexander,[22] our experience has revealed that enzyme concentrations in equine pancreatic fluid are extremely small to the point of being unreliably measurable.

Anatomically, the position of the proximal portion of duodenum in relation to the stomach in horses allows gravity to enhance duodenogastric reflux. In addition, the bile and pancreatic ducts enter the duodenum relatively close to the pylorus. The fact that we found bile salts in the gastric contents further supports the likelihood that material refluxed. Relative proportions of pancreatic and hepatic secretions have not been determined, although the small number of studies on horses that have been conducted to determine daily flow rate of secretions from these 2 organs would favor the pancreas as the major source.[22,24]

Analysis of results of the study reported here clearly revealed that pentagastrin infusion stimulated the secretion of a multiple-electrolyte solution, which was extremely high in [Na^+], into the proximal portion of the small intestines, and some of this fluid refluxed into the stomach to dilute the gastric contents collected via the cannula. Separating gastric from extragastric contents by pyloric obstruction revealed that pentagastrin was capable of inducing in horses a parietal secretion with a maximal [H^+] comparable to that of other monogastric species. Although the exact origin of this extragastric fluid is unknown, the majority is probably of pancreatic origin. The importance of this reflux in normal digestive function and in pathogenesis of gastric ulcers in horses needs further investigation.

[a]Vetscope 81200, Welch Allyn, Skaneateles Falls, NY.
[b]Histavet-P, Schering-Plough Corp, Kenilworth, NJ.
[c]Digital chloridometer, Buchler Insruments Division, Nuclear Chicago, Fort Lee, NJ.
[d]PHM82 standard pH meter, TTT80 titrator, ABU80 autoburette, Radiometer America, Cleveland, Ohio.
[e]IL343 flame photometer, Instrumentation Laboratories Inc, Lexington, Mass.
[f]Enzabile, Nycomed, Uppsala, Sweden.

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