Effects of exercise on gastric volume and pH in the proximal portion of the stomach of horses

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Objective—To assess effects of exercise on a treadmill with changes in gastric volume and pH in the proximal portion of the stomach of horses.

Animals—3 healthy adult horses.

Procedure—A polyester bag of approximately 1,600 mL was placed into the proximal portion of the stomach of each horse via a nasogastric tube. Changes in bag volume, determined by an electronic barostat, were recorded before, during, and after a training session on a treadmill with and without prior withholding of food. In separate experiments, pH in the proximal portion of the stomach was continuously recorded during exercise for fed and food-withheld conditions. Finally, changes in intra-abdominal and intragastric pressure were simultaneously recorded during a training session.

Results—Bag volume rapidly decreased to nearly zero during trotting and galloping. Conversely, a return to walking resulted in a sharp increase in volume and a return to pre-exercise values. Intragastric and intra-abdominal pressures increased almost in parallel with walking, trotting, galloping, and galloping on a slope. Gastric pH decreased rapidly to < 4 at the beginning of walking, continued to decrease during trotting and galloping, and remained low until a return to walking.

Conclusions and Clinical Relevance—Increased intra-abdominal pressure during intense exercise in horses causes gastric compression, pushing acidic contents into the proximal, squamous-lined region of the stomach. Increased duration of acid exposure directly related to daily duration of exercise may be the reason that squamous lesions tend to develop or worsen when horses are in intensive training programs. (*Am J Vet Res* 2002;63:1481–1487)

Gastric squamous mucosal ulcers are a common problem in horses in training, with an incidence as high as 91% among Thoroughbreds[1] and 58% in show horses.[2] Severity of lesions can be quite variable, but common signs of serious affliction include reluctance to finish grain meals, periods of low-grade abdominal discomfort, especially after ingestion of a meal, and failure to perform up to expectations.[3,4] Training-related management programs may contribute to the prevalence of this condition. In particular, a high-concentrate diet[5,6] (which increases gastric concentrations of volatile fatty acids), grazing deprivation,[7] and alternating periods of feeding and withholding of feed[8] have been proposed as contributing factors.

It has been suggested that exercise may play an important role in formation of squamous mucosal ulcers. Delayed gastric emptying or decreased gastric motility as a result of exercise could increase exposure of the squamous mucosa to gastric contents, similar to the situation in humans with **gastroesophageal reflux disease (GERD)**,[9] in which a similarly structured mucosa (ie, mucosa of the esophagus) is damaged by direct contact with refluxed gastric contents. Gastric contents contain substances that are potentially harmful to the squamous mucosa of the proximal portion of the stomach. Hydrochloric acid seems to be the major ulcerogenic factor, because antacid treatment reduces signs and lesions in humans[10] and horses.[11] Refluxed bile salts could be an additional ulcerogenic factor.[12,13] Bile salts could play an important role in causing lesions; backflow of duodenal contents containing bile acids has been described as a normal occurrence in horses.[14] A third potential ulcerogenic factor for the squamous mucosa in horses is the volatile fatty acids produced by intragastric fermentation of carbohydrates.[15]

In addition, the pressure that abdominal muscles or respiratory movements exert on the stomach during exercise may increase intragastric pressure or favor mixing of gastric contents, thus disrupting the pH gradient that exists in the stratified contents of fed horses,[16] which would typically prevent the squamous mucosa from being exposed to high amounts of acid. The degree to which exercise is involved in squamous mucosal injury separate from the influence of other factors is still unknown, but intensity of exercise alone could play an important role.

In contrast to human medicine,[17-20] we are not aware of any published studies concerning the direct effect of exercise on gastric function in horses. Thus, the first objective of the study reported here was to investigate changes in gastric tension in the proximal portion of the stomach in fed and food-withheld states before, during, and immediately after exercise. Changes in intragastric pressure or volume of the proximal portion of the stomach were indirectly measured by use of an electronic barostat. Our second objective was to continuously record mucosal pH on the gastric side of the lower esophageal sphincter and to evaluate the effect of exercise on this region, which is representative of the squamous-lined proximal portion of the stomach.

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Materials and Methods

Animals—Three healthy Thoroughbred horses (2 mares, 1 gelding) were used in the study. Prior to the study, a gastric cannula was inserted in each horse. Horses weighed between 462 and 488 kg (mean, 472 kg) and ranged from 4 to 17 years of age (mean, 10 years). The horses were housed in paddocks and had unlimited access to hay, pasture grass, and a trace mineral mixture. Horses were provided 2 to 3 kg of grain (10% crude protein sweet feed) twice each day. Methods used for this study were approved by the Institutional Animal Care and Use Committee of the University of Florida.

Measurement of gastric volume—A specially made barostat[a] was used to assess volume in the proximal portion of the stomach of each horse. The barostat maintains a constant pressure within an air-filled intragastric bag that has infinite compliance (ie, the bag itself does not influence internal pressure).[21] When the stomach contracts, the barostat releases air from the bag to maintain a constant pressure in the bag, and conversely, when the stomach relaxes, air is injected into the bag. Thus, because the walls of the bag follow the movement of the gastric wall, changes in bag volume are an indirect measurement of changes in intragastric volume. However, changes in volume of the bag measured by the barostat may in other instances reflect passive changes in intragastric volume or pressure (eg, when external pressure is exerted on the stomach). In the study reported here, pressure in the bag was set at 4 mm Hg with a hysteresis of 0.5 mm Hg.

A polyester bag[b] with a capacity of 1,600 mL was connected to the barostat via a plastic catheter (3 m in length, internal diameter of 4 mm). Changes in bag volume and pressure were recorded by a barostat-controlled computer that used specific software provided by the manufacturer of the barostat.[a] Changes in bag volume were continuously displayed by software provided by the barostat manufacturer and a second graphics software package[c] at a sample rate of 100 Hz/channel.

Experimental protocol—Horses were not involved in training prior to inclusion in the study. At the time of inclusion in the study, horses began an exercise protocol that continued over 5 weeks until they attained a fit state. The first week of the protocol did not include any exercise and was used to obtain baseline activity of the proximal portion of the stomach in resting horses. During weeks 2 through 5, horses had 3 training sessions/wk (Monday, Wednesday, and Thursday, respectively); barostat recordings were obtained during the second and third session of each week of exercise. Each session consisted of the following sequence: 0.5 km of walking at a rate of 7 km/h, 0.8 km of trotting at a rate of 15 km/h, varying distances of galloping at a rate of 29 km/h, 0.4 km of trotting at a rate of 15 km/h, and 0.5 km of walking at a rate of 7 km/h. The distance each horse ran while galloping was increased from 1.6 km during the second week to 2.4, 3.2, and 3.2 km on a slope during the third, fourth, and fifth weeks, respectively.

Each recording session was conducted in a room that contained the treadmill. The first recording sessions of each week (second training session of each week) began 2 hours after food deprivation and were defined as the fed sessions. After moving a horse into the treadmill room, the barostat bag was inserted into the proximal portion of the stomach via a nasogastric tube. Once in place, the bag was inflated with air, and a clamp was then applied to the catheter to allow removal of the nasogastric tube. This fixed the bag snugly against the entrance of the esophagus to ensure it was correctly positioned within the proximal portion of the stomach. After gentle traction on the inflated bag, the catheter was then affixed to the horse's halter to avoid displacement during movement by the horse.

Bag volume was recorded at the rate of once per second throughout the experiments. Each recording session started with a 10-minute period with the horse standing on the treadmill during which baseline values were obtained. The horse then performed the training regimen assigned for the week. This was followed by a 10-minute recording period after completion of exercise. At the end of the session, the recording equipment was removed, and the horse was placed in a stall until the next day.

The second recording sessions (third training session of each week) began 18 hours after food deprivation and were designated as the food-withheld sessions. Instrumentation and recording protocol were the same as for the fed sessions. At the end of each food-withheld session, all the recording equipment was removed, and the horse was returned to the paddock until the next week.

Endoscopic evaluation—Endoscopy of the stomach was performed through the gastric cannula weekly in each horse at the end of the food-withheld session. Status of the squamous mucosa was evaluated and graded in accordance with the system established by the Equine Gastric Ulcer Syndrome Council.[22]

Ancillary experiments—Experiments were conducted in the 3 horses to investigate changes in intra-abdominal and intragastric pressures during exercise to enable us to better understand observed barostatic changes of the proximal portion of the stomach. For intra-abdominal pressure, the skin in the right paralumbar fossa was aseptically prepared and infiltrated with a 2% solution of lidocaine hydrochloride. A small stab incision was made midway between the last rib and the tuber coxae.[23] A teat cannula was introduced through the incision, and its outer end was connected to the pressure sensor of the barostat system. To measure changes in proximal intragastric pressure during exercise, a solid-state pressure transducer[d] was inserted via the gastric cannula. Intra-abdominal and intragastric pressures were recorded simultaneously during a training session corresponding to the second week of the barostat study.

To investigate whether the effects of exercise on bag volume could be counteracted by increasing intragastric pressure, the barostatically controlled bag was inserted into the stomach via the gastric cannula. A plastic probe (approx 35 cm in length) was attached to the portion of the catheter connected to the bag to increase rigidity of the catheter inside the stomach. To determine that it was properly placed, the catheter was introduced vertically until resistance was felt, which indicated that the top of the proximal portion of the stomach had been reached. Barostatic pressure was increased in a step-wise manner between 7 and 15 mm Hg while the horse was trotting during a training session.

Monitoring of intragastric pH—Four experiments were conducted in each horse to measure changes of pH in the most proximal portion of the stomach. Two of these experiments were conducted after 2 hours of feed deprivation (fed experiments), and 2 were conducted after 18 hours of feed deprivation (food-withheld experiments). The pH was recorded in the stomach in the area of the gastroesophageal sphincter, with continual recordings obtained by a self-referencing pH electrode.[e] The pH electrode was attached to a data collection device that measured pH every 4 seconds and stored the results.[f] Because a longer pH probe was needed for this series of experiments, we connected 2 pH probes together to make a single probe 3.8 m in length. The pH electrode and a bag connected to a catheter were introduced into the stomach via a nasogastric tube. The bag was inflated, and the nasogastric tube was removed. Thus, the position of the tip of the electrode was approximately 2 cm distal to the esophageal entrance into the stomach. The recording period included a 25-minute period during which baseline values were recorded, an entire training session (second week of the barostat study), and a 30-minute period after exercise. Recording during the first 20 minutes was performed while the horse was in the stock. Horses were then moved to the treadmill during the following 5 minutes, and the remainder of the recording session was performed, which involved a sequence of walking, trotting, and galloping. After recording was completed, the recording probe was removed, and the horse was returned to its paddock. Recorded pH data were subsequently downloaded onto a computer through the use of software provided by the manufacturer.[g]

Data analysis—Data were analyzed to evaluate intragastric volume. Also, values for intragastric pH and results of ancillary studies on intra-abdominal and intragastric pressures were analyzed.

Intragastric volume—For every exercise week, data of the experiments were grouped into 5-minute blocks, and mean value was calculated for the 3 horses. The first two blocks corresponded to the 10-minute period prior to exercise and were used as the baseline value. The subsequent 3 blocks included walking (block 3), trotting and galloping (block 4), and return to walking (block 5). The remaining blocks (6 and 7) corresponded to the 10-minute period after exercise. As the distance each horse galloped increased, the amount of data included in block 4 (trotting and galloping) also increased and was > 5 minutes (range, 8.6 to 12.0 minutes). Therefore, mean ± SE values were calculated for every block to account for differences in duration. Blocks were compared within the same week and between weeks by use of an ANOVA in a statistical software program.[h] Significance was set at $P \leq 0.05$.

Intra-abdominal and intragastric pressures—Mean values were calculated for every level of exercise, and mean values were subsequently calculated for the 3 horses. Results were expressed as mean ± SE pressures and subjected to only observational analysis.

Intragastric pH—Similar to the analysis for intragastric volume, pH data were grouped in 5-minute blocks, which resulted in the following block distribution: baseline values (blocks 1 to 5), walking (block 6), trotting and galloping (block 7), return to walking (block 8), and period after exercise (blocks 9 to 14). Mean values for experimental data of the fed and food-withheld sessions were determined separately and compared by use of an ANOVA. Blocks corresponding to trotting and galloping (block 7) were > 5 minutes (range, 7.5 to 10.0 minutes). An additional test analysis was conducted after grouping the baseline data (blocks 1 to 5) into a single block. Significance was set at $P \leq 0.05$.

Results

Intragastric volume—Baseline volumes of the intragastric bag were highly variable before exercise, ranging from 80 to 700 mL for the fed sessions to 800 to 1,300 mL for the food-withheld sessions. During fed and food-withheld training sessions, there was a marked rapid decrease in bag volume as soon as the horses moved from walking to a faster gait. This was most apparent in the food-withheld state in which baseline bag volume was large. Return to walking resulted in a sharp increase in intragastric bag volume that was equal to, or slightly greater than, the volume before exercise (**Fig 1**).

During the fed sessions, there was high variability in response among horses (**Fig 2**). Data for 1 of the fed sessions in week 2 were lost after its completion. When blocks of the same period were compared among weeks, we did not detect significant differences. When

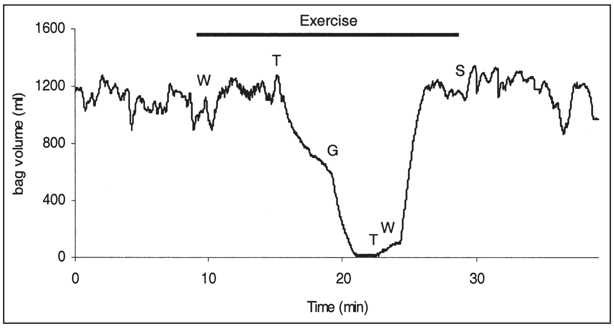

Figure 1—Representative graphs of the effect of exercise on volume of a barostatically controlled bag placed within the proximal portion of the stomach and maintained with a constant internal pressure of 4 mm Hg during an individual experiment in a horse from which food was withheld for 18 hours prior to initiation of exercise. W = Walking. T = Trotting. G = Galloping. S = Stop.

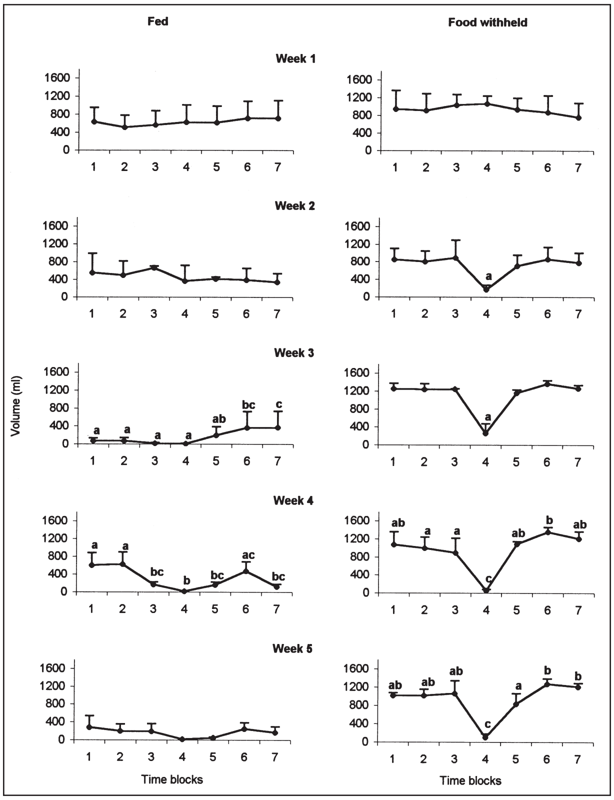

Figure 2—Effect of exercise and duration of withholding of food during a 5-week training period on volume of a bag placed within the proximal portion of the stomach with internal pressure maintained at 4 mm Hg. Volume is expressed as mean ± SE for 5-minute blocks, except for block 4, which ranged from 8.6 to 12.0 minutes for 3 horses, and except for week 2 when there were only 2 horses. Each exercise period consisted of the following blocks: blocks 1 and 2, before exercise; block 3, walking; block 4, trotting and galloping; block 5, return to walking; blocks 6 and 7, after exercise.[a,b,c]Blocks with different superscript letters are significantly ($P \leq 0.05$) different. Food was removed from fed horses 2 horses prior to initiation of exercise, whereas food was removed from food-withheld horses 18 hours prior to initiation of exercise.

blocks of different periods were compared within the same week, the only significant differences in bag volume were for weeks 3 and 4. Regardless of baseline volume, the bag remained collapsed during trotting and galloping during fed sessions for weeks 3 through 5.

During the food-withheld sessions, bag volumes during trotting and galloping (block 4) were significantly ($P = 0.03$) less than during the remainder of the training session, except for week 1, in which the horses did not exercise (Fig 2). Bag volume during trotting and galloping did not differ significantly among weeks, except for week 1 ($P = 0.02$). Walking during any of the sessions did not produce significant changes in baseline bag volumes. During week 4, mean bag volume following exercise was significantly higher than the values for the 5-minute period before walking and during walking. During week 5, bag volume after exercise was also significantly higher than during return to walking.

Intra-abdominal and intragastric pressures during exercise—Visual observation of the data indicated that changes in intragastric and intra-abdominal pressure occurred concurrently with the amount of exertion during exercise **(Fig 3)**. However, in 2 of the 3 horses, intragastric pressure increased from trotting to galloping, whereas intra-abdominal pressure decreased. Intragastric pressure increased from a mean value of 14.3 ± 8 mm Hg during walking to 34.4 ± 15, 37.8 ± 17.5, and 40.9 ± 11.3 mm Hg during trotting, galloping, and galloping on a slope, respectively. Mean intra-abdominal pressure was 2.0 ± 1.6 mm Hg during walking, 13.5 ± 2.5 during trotting, 9.7 ± 2.5 during galloping, and 9.3 ± 2.6 mm Hg during galloping on a slope.

With return to lower amounts of exertion, intragastric pressure decreased from 35.9 ± 14.6 mm Hg during galloping to 32.4 ± 13.5 and 19.1 ± 11.1 mm Hg during trotting and walking, respectively. A similar pattern of decreasing pressure was observed for intra-abdominal pressure, although the values for galloping to resting were less than the values obtained for the same amount of exertion with increasing speeds. Mean intra-abdominal pressure was 3.2 ± 1.2, –1.6 ± 3.1, –6.8 ± 2.2, and –6.5 ± 0.6 mm Hg during galloping, trotting, walking, and resting, respectively. Therefore, changes in intra-abdominal and intragastric pressures appeared visually to occur in concert with changes in amount of exertion, with the exception of the change from trotting to galloping. However, intragastric pressures were higher than intra-abdominal pressures throughout the training sessions.

Similar to results of the aforementioned experiments, intragastric bag volume decreased rapidly with initiation of trotting to the point that the bag almost totally collapsed. Pressure was then increased to 15 mm Hg. This change resulted in a counteractive effect on the bag (ie, a quick return of the bag to the baseline volume determined before exercise). Only pressures of ≥ 10 mm Hg (minimum pressures varied from 10 to 12 mm Hg among horses) completely eliminated the tendency for the bag to collapse during exercise **(Fig 4)**.

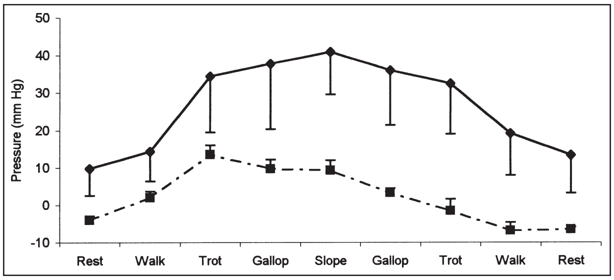

Figure 3—Changes in mean ± SE intragastric (diamond) and intra-abdominal (square) pressures during training sessions in 3 horses. Slope = Galloping on the treadmill that was sloped to increase the amount of exertion.

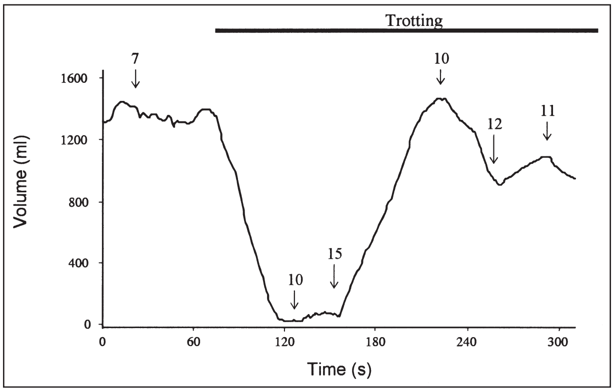

Figure 4—Representative graph of the counteracting effect of various intragastric bag pressures (values reported as number of mm Hg) on bag volume during sustained trotting in a horse. Pressures > 12 mm Hg counteracted the decrease in bag volume consistently seen at application of lower pressures.

Effect of exercise on intragastric pH—Mean pH prior to exercise (baseline) was 5.30 ± 0.97 and 5.23 ± 0.95 for fed and food-withheld sessions, respectively. With the onset of exercise, pH decreased to < 4 and continued to decrease during trotting, galloping, and return to walking. The pH remained low until horses finished the training session. After that, pH increased gradually until reaching values obtained prior to exercise **(Fig 5)**.

When the baseline period was considered as a single block and compared with the other blocks, mean pH from the beginning of walking until the first 5 minutes after exercise was significantly less than the baseline value **(Table 1)**. Moreover, pH during trotting, galloping, and return to walking also was significantly less than the value for walking in both states (fed and food-withheld) and the 5-minute period after exercise in the food-withheld state. Mean pH during trotting and galloping was lower, but not significantly so ($P = 0.069$), in horses during the food-withheld session (1.07 ± 0.46) than in the horses when they had been allowed to eat up to 2 hours prior to exercise (2.52 ± 0.82). Similarly, pH was lower, but not significantly so ($P = 0.067$), during walking for horses in the food-withheld session (0.92 ± 0.33), compared with during the fed session (2.39 ± 0.64).

Mean pH started to decrease within 5 minutes before the onset of exercise. However, this pH value was not significantly lower than the remainder of baseline values when blocks were analyzed separately.

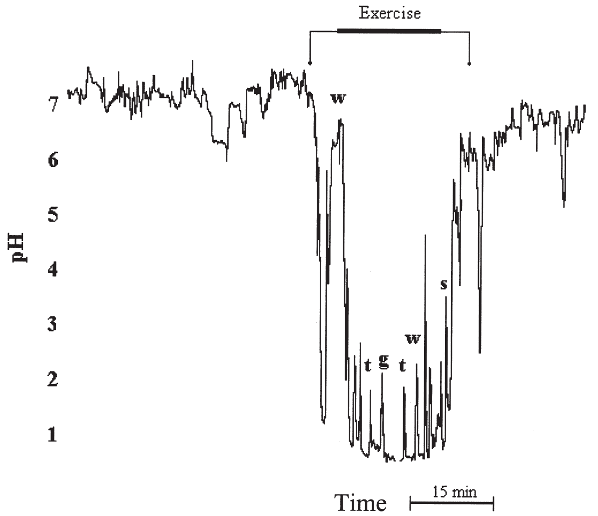

Figure 5—Changes in pH of the proximal portion of the stomach during a training session in a horse in the fed group. The exercise period is delineated (bar), and a 5-minute period (arrows) preceded and followed the exercise period. w = Walking. t = Trotting. g = Galloping. s = Stop.

Table 1—Effect of exercise on pH in the proximal portion of the stomach of 3 horses from which food was withheld for 2 hours (Fed) or 18 hours (Food withheld) prior to initiation of exercise

Period	Fed	Food withheld
Before exercise*	5.30 ± 0.97[a]	5.23 ± 0.95[a]
Walking	3.95 ± 0.70[b]	3.15 ± 0.76[b]
Trotting and galloping	2.52 ± 0.82[c]	1.07 ± 0.19[c]
Return to walking	2.39 ± 0.64[c]	0.92 ± 0.13[c]
After exercise†		
1	3.60 ± 0.61[b,c]	3.40 ± 0.57[b,d]
2	4.52 ± 0.46[a,b]	5.52 ± 0.35[a]
3	5.34 ± 0.27[a]	5.69 ± 0.27[a]
4	5.56 ± 0.29[a]	5.78 ± 0.19[a]
5	5.12 ± 0.45[a]	5.10 ± 0.47[a]
6	5.47 ± 0.29[a]	4.58 ± 0.68[a,d]

Values are expressed as mean ± SE for 5-minute periods, except for the period for trotting and galloping, which ranged from 7.5 to 10 minutes.

*To simplify analysis, data obtained for a 25-minute period before exercise were grouped and analyzed as a single 5-minute block. †Each number represents a sequential 5-minute period after the end of exercise.

[a-d]Within each column, values with different superscript letters differ significantly ($P \leq 0.05$).

Gastric endoscopy—In the 3 horses, there was development and worsening of squamous mucosal lesions during the 4-week training period. None of the horses had a lesion grade > 1 at the start of training, whereas at the end of training, lesion grades varied from 2 (small multifocal lesions along the margo plicatus) to 3 (extensive superficial lesions over the entire squamous mucosa), depending on the horse.

Discussion

An electronic barostat was used to measure tension and capacity of the proximal portion of the stomach of horses during exercise. Unlike other methods for measuring gastric motility, the barostat we used is sensitive to small variations in intragastric pressure and reflects changes in gastric volume. This system has been used to study gastrointestinal motility in dogs,[24-26] pigs,[27] rats,[28] and humans,[29-31] but to our knowledge, it has not been used in horses.

In our study, volume of the proximal portion of the stomach decreased rapidly and significantly when horses went from walking to trotting or galloping on the treadmill. The opposite effect was seen soon after horses were allowed to return to walking, reaching pre-exercise volume within 5 minutes after the end of a training session. These changes in volume, measured indirectly by changes in intragastric bag volume, were consistent regardless of whether horses were fed within 2 hours of the training session or whether they had food withheld for 18 hours prior to exercising. In contrast, gastric volume was highly variable before, during, and after exercise in horses for fed conditions. Food within the proximal portion of the stomach may have interfered with expansion of the intragastric bag, which prevented it from reaching the baseline volume observed in food-withheld conditions.

The barostat may not be a reliable method for use in conditions in which the volume of gastric contents is not controlled.[21] However, for most of the fed sessions and regardless of initial bag volume, the bag collapsed during trotting and galloping, similar to the situation observed during food-withheld sessions. The increase in bag volume over baseline value following exercise in some of the food-withheld sessions (ie, weeks 4 and 5) could indicate a short period of relaxation of the proximal portion of the stomach. We cannot at this point fully explain the meaning of this increase in volume, and additional studies are required before any conclusions can be reached.

The marked and rapid decrease in bag volume during trotting and galloping was opposite to our expectations. Rather, we expected that exercise could induce relaxation of the proximal portion of the stomach as a consequence of diversion in blood flow[32] and a resulting increase in bag volume. However, parallel increases in intragastric and intra-abdominal pressures during exercise support the idea of gastric compression by an external force, rather than increased contractile activity of the gastric wall. Further support was provided by the counteraction of changes in bag volume when barostat bag pressures were set slightly higher than the pressures recorded within the abdominal cavity during exercise.

Rapid return of intraluminal pH to the pre-exercise value substantiates the suggestion that changes in intragastric pressure and intragastric pH are causally related. Time required for clearance may explain why intragastric pH remained low in the period when horses were returning to walking and did not significantly increase until the end of the training session (Table 1). The amount of time that the squamous mucosa is exposed to acid depends on the extent of clearance, which is defined as the rate at which acid is removed from the surface of the mucosa. Decreased amounts of saliva, which normally neutralizes residual acid, may be induced by exercise and could contribute to the duration of acid exposure.[9]

Because mucosa in the proximal portion of the stomach in horses is similar to that of the esophagus in humans, squamous mucosal ulcer disease in horses and GERD in humans may share similar pathophysiologic features.[33] Gastroesophageal reflux disease involves erosions and ulcers of the stratified squamous mucosa of the distal portion of the esophagus, predominantly by excessive exposure of the mucosa to hydrochloric acid, pepsin, and perhaps bile salts.[34] In healthy humans, vigorous exercise such as running induces more symptoms of GERD and acid reflux than other strenuous activities that could involve less tensing of the abdominal muscles, such as cycling.[35] Increased body agitation or intra-abdominal pressure during exercise may overcome basal pressure of the lower esophageal sphincter and help to promote gastroesophageal reflux.[9] However, the specific events that induce reflux in humans during physical activity remain unknown. In contrast, episodes of GERD in people at rest are primarily related to physiologic dysfunction of the lower esophageal sphincter or to hiatal hernia with failure of the normal anatomic barrier to prevent reflux.[36]

Acidic gastric secretions are produced in the distal glandular portion of the stomach. In resting horses, incomplete filling of the stomach and a proximal-to-distal pH gradient created by ingested food limits exposure of most of the squamous mucosa to potentially corrosive contents.[16] However, when we exercised horses on a treadmill, intraluminal pH of the proximal portion of the stomach decreased significantly to < 4.0, which is considered to be ulcerogenic for GERD in humans.[33] This decrease was most evident during trotting and galloping, compared with during walking. Therefore, exercise in horses appears to promote increased exposure of the stratified squamous mucosa to acidic contents. Increased time of acid exposure that parallels increased training intensity may be the reason that squamous lesions tend to worsen when horses are continuously in training.[1] This would also explain the fact that horses in the study reported here developed squamous ulcers during our training program. Lower mean pH values were reached when the horses were deprived of food for 18 hours, although this difference was not significant from the fed state. We suggest that this lack of significant difference may indicate that the material pushed into the proximal portion of the stomach is the more fluid acidic component of the gastric contents, which is in close proximity to the glandular mucosa.

In general, changes in barostat bag volume paralleled changes in pH during exercise; the only notable disparity was the decrease in pH during the period of walking prior to trotting and galloping. This difference may have been attributable to episodes of abdominal muscle tension in anticipation of the events to come that were too brief to be detected by the barostat. Furthermore, as suggested previously, we wondered whether contents that are the most liquid and most acidic and are located next to the fundic glandular mucosa are most easily displaced proximally during periods of increased intra-abdominal pressure and are squeezed through or around more solid contents in the center of the stomach.

Results of the study reported here supported the hypothesis that the high incidence of gastric squamous mucosal lesions in intensively trained horses is attributable to excessive exposure of the proximal portion of the stomach to acidic gastric contents. The compressive force exerted on the stomach during exercise by contracted abdominal muscles apparently is responsible for this increased exposure. As part of their normal activities, horses do not spend much time trotting and galloping; thus, pH of most of the proximal portion of the stomach would remain > 4.0 for the majority of each day. Therefore, we propose that gastric squamous mucosal ulcers are a condition imposed by human demands on horses. Accepting this concept opens the door for consideration of novel training strategies designed to reduce the prevalence of lesions and influence the need for concurrent treatment with antacids. Control of gastric contents during exercise (ie, volume and pH) may be a plausible and more natural approach to preventing the development of ulcers in the squamous mucosa in athletic horses.

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[a]ISOBAR-3, G & J Electronics Inc, Toronto, ON, Canada.
[b]Commercial Mylar balloon, 20 cm in diameter, approximate volume of 1,600 mL, The New Garden, Gainesville, Fla.
[c]CODAS, DATAQ Instruments Inc, Akron, Ohio.
[d]Mikro-Tip pressure catheter, Millar Instruments Inc, Houston, Tex.
[e]24-hour pH catheter, Medtronic Functional Diagnostics A/S, Skovlunde, Denmark.
[f]Digitrapper, Medtronic Functional Diagnostics Inc, Shoreview, Minn.
[g]EsopHagram MD, Medtronic Functional Diagnostics Inc, Shoreview, Minn.
[h]SAS, version 8.2, SAS Institute Inc, Cary, NC.

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