Detrimental effects of postoperative ileus after laparotomy have been identified in humans and horses. Many potential etiologic agents have been investigated to determine a cause for the development of postoperative ileus. Shock, intestinal ischemia, endotoxemia, and prolonged distention and inflammation of the intestinal tract have all been implicated as contributing factors to the pathophysiology of ileus in horses. A variety of prokinetic drugs has been used to prevent development of postoperative ileus, with variable success. Prokinetic drugs that are effective in promoting motility in healthy horses often do not perform well in the presence of inflammation or ileus. The efficacy of prokinetic drugs has been assessed in prospective and retrospective clinical studies, and difficulties with performing analysis of clinical data to determine the efficacy of treatment regimens have been reported. In horses, experimentally induced ileus has been investigated. This involved implantation of electrodes and force transducers on the serosal surface of the intestine to measure intestinal myoelectrical activity; however, either 1 or 2 laparotomies were required to complete the instrumentation. Electrogestography has been used in humans and dogs to noninvasively measure myoelectrical gastric activity with surface electrodes. Recently, EGG was also introduced as electrosseiography and EIG to measure myoelectrical activity of the equine intestinal tract; the latter term, EIG, seems more appropriate than EGG when motility of the large intestine is assessed. However, in those studies, only 2 electrodes were used to measure intestinal myoelectrical activity in horses.

Use of multichannel electrointestinography for noninvasive assessment of myoelectrical activity in the cecum and large colon of horses

Judith B. Koenig, Dr med vet, DVS; Christina E. W. Martin, BSc; Stephanie G. Nykamp, DVM, MS; Martin P. Mintchev, MS, PhD, P Eng

Objective—To evaluate whether changes in myoelectrical activity in the cecum and large colon of horses can be detected via multichannel electrointestinography (EIG).

Animals—6 healthy mature horses.

Procedures—Each horse underwent 3 EIG procedures. Intestinal myoelectrical activity (cecum and large colon) was recorded during a 20-minute period following IV administration of physiologic saline (0.9% NaCl) solution (20 mL; baseline), erythromycin lactobionate (0.5 mg/kg), or detomidine (0.015 mg/kg); intestinal contractions were concurrently viewed via B-mode ultrasonography. By use of computer software, 8-channel EIG recordings were analyzed and the mean of the dominant frequency (a measure of the rhythmicity of gastric electrical activity) expressed in cycles per minute (cpm) was obtained. Total power (µV²) was calculated, and treatment effect was expressed as the power ratio (ie, treatment-associated power divided by the baseline power).

Results—The dominant frequency cpm values were not stable, and no significant differences between treatments were detected. Compared with the effects of saline solution treatment, detomidine significantly reduced the mean cecal and colonic power ratio. Erythromycin significantly reduced the cecal power ratio and increased the colonic power ratio, although the increase was significant in only 1 channel. Ultrasonographic findings and total power (predominantly from the long-distance electrode pairs) were significantly correlated.

Conclusions and Clinical Relevance—In horses, EIG was useful for assessment of changes in myoelectrical activity in the cecum and large colon. Multiple electrodes should be used to cover a larger area of the intestine, and agreement between multiple channels is needed to make the analysis meaningful. (Am J Vet Res 2008;69:709–715)
For EGG in humans and dogs, recommended procedures include application of multiple electrodes in a row along the long axis of the stomach and recording of the signal with multiple channels. In this manner, both short- and long-distance channels can be used; thus, the stability of the dominant frequency of the EGG can be assessed, and as a result, accuracy of the EGG findings is increased. Multichannel EIG has not been used in horses, to our knowledge. Therefore, the purpose of the study reported here was to evaluate whether changes in myoelectrical activity in the cecum and large colon of horses can be detected via multichannel EIG. Our hypothesis was that multichannel EIG can detect changes in intestinal myoelectrical activity in horses (relative to normal myoelectrical activity). Additionally, we compared EIG findings with intestinal motility measurements obtained via B-mode ultrasonography.

Materials and Methods

Animals—Six healthy mature horses were used in a blinded, crossover study. Horses were 2 to 6 years old and weighed 417 to 490 kg (mean weight, 438 kg). None of the horses had gastrointestinal tract disorders or evidence of systemic disease and had not been treated with erythromycin, α2-adrenoceptor agonists, or anticholinergic drugs in the 7-day period preceding the start of the study. Throughout the study, horses were fed free-choice, first-cut hay; during experiments, horses were allowed access to hay while standing in stocks. The study was approved by the University of Guelph Animal Care Committee.

Study design—Each horse underwent 3 experimental procedures. First, a baseline motility measurement was obtained following IV administration of a 20-mL bolus of physiologic saline (0.9% NaCl) solution. The baseline assessment was immediately followed by administration of either treatment 1 or 2, as determined by computer randomization. A 24-hour washout period was allowed to elapse before the other drug treatment was administered and EIG performed. Drugs were administered via jugular venipuncture. Treatment 1 consisted of a bolus of erythromycin lactobionate (0.5 mg/kg), which was used to increase motility; treatment 2 consisted of detomidine (0.015 mg/kg, IV), which was used to decrease motility. Beginning 5 minutes after administration of either drug, EIG recordings from the cecum and large colon were obtained during a 20-minute period.

Electrode placement—Prior to electrode placement, the hair over the right flank and the left cranioventral portion of the abdomen was clipped and the skin was washed with antiseptic soap. Via transabdominal ultrasonography, locations of the cecum and left ventral colon and their respective long axes were determined. Along each long axis, the area where electrodes were to be applied was shaved and gently abraded with alcohol-soaked gauze squares. Then a small amount of conductive cream was applied, and foam conductive adhesive gel electrodes were applied. For the cecum, 5 active recording electrodes were placed in a row along the vertical long axis of the cecum, and a sixth ground electrode was placed parallel to the long axis in the center of the 5 electrodes (Figure 1). The left ventral colon was identified ultrasonographically at the level of the elbow joint (approx at the chondrocostal junction), and 5 active recording electrodes were placed in a row along the horizontal long axis of the colon; a sixth ground electrode was placed parallel to the long axis in the center of the 5 electrodes (Figure 2). The electrodes were left in place until data for the second drug treatment had been collected. Before each recording, locations of the cecum and the large colon relative to the electrodes were assessed via transabdominal ultrasonography to ensure that the electrodes remained in the correct anatomic location.

EIG recording acquisition—For the EIG procedures, an 8-channel bipolar recording system was used, which allowed recording of short- (channels 1 to 4) and long- (channels 5 to 8) distance channels (Appendix). During each recording session, motion of the horse was recorded to allow deletion of this
segment of raw signal before analysis of the EIG signal. The EIG signals were filtered in the frequency band of 0.03 to 0.2 Hz.\textsuperscript{20} Signals were amplified and digitized with a 10-Hz sampling frequency by use of a 16-channel analogue-to-digital converter\textsuperscript{4} that was controlled by a 486- to 66-MHz personal computer. For each channel, 3-dimensional plots in the range of 1.8 to 12 cpm were obtained by use of the fast Hartley transform.\textsuperscript{16} The dominant spectral peaks in these plots were connected with lines to form 2-dimensional time-frequency plots, and the probability density function of the frequencies present in each channel was determined.\textsuperscript{21} The mean cpm value, variance, and SD of the dominant frequency obtained from the time-frequency plots of the different EIG channels were calculated to evaluate the stability of the dominant spectral component.\textsuperscript{22} The EIG recording was considered stable if the SD of the dominant frequency was < 13 \% in at least 3 of 8 EIG channels.\textsuperscript{23} The absolute value of the amplitude (in \textmu V) of the EIG signal was calculated for each second; these values were each squared and averaged over the 20-minute recording session to provide the total power (\textmu V\textsuperscript{2}). Treatment effect (erythromycin or detomidine) was expressed as the difference in total power between drug and saline solution treatments or power ratio (ie, ratio of the power of the treatment measurement divided by the power of the baseline measurement).\textsuperscript{22,23}

B-mode ultrasonography—B-mode ultrasonography was used as previously described\textsuperscript{24,25} to evaluate intestinal motility of the cecum and large colon in the locations where electrodes were applied. Contraction rate (number of contractions/min) was recorded 3 times for each segment by an investigator (SGN) who was unaware of the treatment given.

Statistical analysis—A 2-way ANOVA for a mixed model that included the factors treatment and segment of intestine was performed\textsuperscript{26} on the obtained data (cpm value, power ratio, and number of contractions/min). Their interactions were modeled to determine whether there were any significant differences between the segments of intestine, treatments for any of the 8 EIG channels, or ultrasonographic measurements. A Shapiro-Wilk test was used to confirm whether the data were normally distributed. Log transformation was applied where appropriate to meet the assumptions of normality. A Tukey comparison of means was performed if the F test finding was significant. A multivariate t adjustment was used to determine whether power ratios following administration of treatment 1 or 2 were significantly different from a value of 1 (control value), and a post hoc Tukey test was used to compare power ratios between treatment groups. A Pearson correlation was performed to determine correlations among cpm value, power ratio, and contractions per minute. Significance was set at a value of $P \leq 0.05$.

### Results

#### B-mode ultrasonography—For the cecum, mean contraction rate following saline solution treatment (baseline) was 3.97 contractions/min (95 \% CI, 2.45 to 6.42 contractions/min). Following erythromycin

<table>
<thead>
<tr>
<th>Channel</th>
<th>Cpm value</th>
<th>Power ratio</th>
<th>Number of contractions/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.39 ± 1.86</td>
<td>4.18 ± 1.83</td>
<td>4.14 ± 1.56</td>
</tr>
<tr>
<td>2</td>
<td>4.69 ± 1.56</td>
<td>4.24 ± 1.75</td>
<td>4.17 ± 1.74</td>
</tr>
<tr>
<td>3</td>
<td>4.31 ± 1.88</td>
<td>4.25 ± 1.74</td>
<td>4.01 ± 1.64</td>
</tr>
<tr>
<td>4</td>
<td>4.14 ± 1.58</td>
<td>4.09 ± 1.56</td>
<td>3.95 ± 1.51</td>
</tr>
<tr>
<td>5</td>
<td>4.32 ± 1.69</td>
<td>4.62 ± 1.84</td>
<td>4.09 ± 1.61</td>
</tr>
<tr>
<td>6</td>
<td>4.40 ± 1.61</td>
<td>4.25 ± 1.77</td>
<td>4.18 ± 1.71</td>
</tr>
<tr>
<td>7</td>
<td>4.32 ± 1.62</td>
<td>4.29 ± 1.70</td>
<td>4.05 ± 1.59</td>
</tr>
<tr>
<td>8</td>
<td>4.29 ± 1.61</td>
<td>4.33 ± 1.66</td>
<td>3.89 ± 1.55</td>
</tr>
</tbody>
</table>

Mean power ratio was calculated as the power of the treatment measurement divided by the power of the saline solution (baseline) measurement. *P values were derived from comparison of treatment value with baseline measurement; a value of $P \leq 0.05$ was considered significant.
treatment, the rate was 2.28 contractions/min (95% CI, 1.41 to 3.69 contractions/min), and following detomidine treatment, the rate was 2.27 contractions/min (95% CI, 1.34 to 3.85 contractions/min). For the large colon, mean contraction rate following saline solution treatment (baseline) was 1.22 contractions/min (95% CI, 0.68 to 2.2 contractions/min). Following erythromycin treatment, the rate was 2.03 contractions/min (95% CI, 1.19 to 3.44 contractions/min), and following detomidine treatment, the rate was 1.06 contractions/min (95% CI, 0.59 to 1.91 contractions/min). Overall, there were significantly more contractions per minute in the cecum than in the large colon. Significantly (P = 0.03) fewer contractions per minute were observed in the cecum after detomidine administration, compared with the baseline measurement. Fewer contractions per minute were detected in the cecum after erythromycin administration, compared with the baseline measurement, but this difference was not significant (P = 0.06). Also, fewer contractions per minute were evident in the colon after detomidine administration, compared with findings after erythromycin treatment, but this difference was not significant (P = 0.10). Contraction rate increased in the colon after erythromycin administration, compared with the baseline measurement, but this difference was not significant (P = 0.09).

EIG—The mean cpm values and SDs of the dominant frequencies obtained from the time-frequency plots were calculated (Table 1). The criteria of stability for the dominant frequency were not met in any of the treatment groups, and no significant differences among treatment groups were detected.

Mean power ratios (or differences in total power between drug and baseline measurements) for the cecum and large colon were calculated (Table 2). Compared
with baseline measurements, detomidine treatment significantly reduced the mean power ratio in both the cecum and large colon in all 8 channels. Erythromycin treatment significantly reduced the mean power ratio in the cecum in 3 of the 8 channels. Erythromycin treatment increased the power ratio in 6 of 8 channels in the colon, but this difference was significant only in channel 2.

No significant correlation was present between the mean cpm value and ultrasonographic findings (contractions/min). A significant but weak to moderate (r = 0.3 to 0.4) correlation was detected between ultrasonographic findings and total power from channels 4 through 8 (Figure 3).

Discussion

In the study of this report, multichannel EIG was successful in recording changes in myoelectric activity of the cecum and large colon of horses. Consistently, recordings from all 8 channels indicated that myoelectric activity in both the cecum and the colon decreased following detomidine administration, as evidenced by the low power ratio. However, detection of an increase in myoelectric activity after erythromycin administration was not consistent in our study. In the colon, even though the power ratio was high in 6 of the 8 channels, the increase in myoelectric activity was significant in only 1 channel. With a larger number of horses, we would most likely have been able to identify a significant increase in colonic myoelectric activity in > 1 channel. In the cecum, a significant decrease in myoelectric activity, compared with baseline measurements, was evident in 5 of the 8 channels. This was surprising because cecal emptying is reportedly accelerated and myoelectric activity of the cecum is increased in healthy horses within a 45-minute period after IV administration of erythromycin. It is likely that erythromycin was not a good choice of drug to increase motility in the cecum in the present study because a reduction of cecal motility following erythromycin administration has been reported as well.

In humans, the EGG signal is usually examined on the basis of wave form, frequency, and amplitude. Extraction of useful information from visual inspection of EGG waveforms has been unsuccessful, and in our study, we only evaluated the raw EIG waveform to remove motion artifacts. With advancement of EGG technologies (ie, running spectrum analysis), dominant frequencies and signal amplitude dynamics of the signal may be assessed.

The dominant frequencies obtained by running spectrum analysis with EGG software were not useful in determination of changes in myoelectric activity in horses. In humans, the dominant frequency is thought to reflect the frequency of the slow waves and it is believed to be associated with the actual gastric contraction frequency. Diagnoses of bradygastria and tachygastria have been made in humans on the basis of an increase or decrease of the dominant frequency. However, it has recently been determined that the dominant frequency is not a useful indicator of changes in myoelectric activity in human patients with naturally occurring motility disorders, which is in agreement with results of the present study. The reliability of the resulting dominant frequency depends also on its stability; to be considered stable, the SD of the dominant frequency assessed from time-frequency plots must be < 15% in at least 3 of 8 channels. To make this determination, multichannel EGG is necessary; in humans, single-channel EGG is typically applied and the stability of the dominant frequencies cannot be assessed. In our study, the mean cpm value for the dominant frequency of the large colon was 4.3 with a mean SD of 40% (1.7 cpm), which, by extrapolation from findings in human medicine, indicated that the dominant frequency was not stable despite similarity across all channels. The large SD suggests that there was too much variety in the measured frequencies to assess which one was truly dominant. In another study in horses in which the usefulness of EIG for measurement of myoelectrical motility of the cecum was assessed, the range of the dominant frequency for the cecum was reported to be 5 to 7 cpm. However, in that study, only 2 electrodes were used, and it is not possible to determine whether the reported dominant frequency was stable; in contrast, 8 channels were used in the present study and stability could be evaluated.

The value of the mean amplitude of a recorded EGG signal is influenced by numerous factors: electrode-skin resistance, tissue conductivity, thickness of the body wall, and degree of distention of the intestine. Therefore, comparison of interindividual or intra-individual mean amplitudes is impractical. An established alternative is to assess the total power, which has been used to evaluate the effect of erythromycin on gastric motility in humans as well as in the horses of the study reported here. The thickness of the body wall, position and distance between electrodes, and method of spectral analysis each has an influence on the total power; therefore, it is recommended to clinically evaluate total power only in relation to a baseline measurement within the same individual. This is the main reason for calculating power ratios because it accounts for some of these factors. Much controversy exists in the clinical interpretation of total power values in humans—some groups believe that total power is directly related to the strength of intestinal contractions, whereas others believe that it can assess only myoelectric activity and not intestinal contractions. In a recent study in humans with delayed gastric emptying, increased power ratios (compared with baseline) were the only finding that was repeatedly correlated with delayed gastric emptying.

In the horses of the present study, there was a significant correlation between total power derived from the long-distance electrode pairs and the ultrasonographic assessment of contraction rate, but the correlation was only weak to moderate. On the basis of results of our study, we conclude that EIG-derived power ratios are somewhat useful for assessment of changes in myoelectric activity in horses, compared with baseline measurements, but that the strength of intestinal contractions cannot be assessed via EIG.

Previously, B-mode ultrasonography has been used as a noninvasive method of evaluating gastrointestinal motility in horses. A major limiting factor with this method of motility assessment is that the segment of intestine being examined may move out of the field of view and subsequent contractions are not observed and

AJVR, Vol 69, No. 6, June 2008 713

Unauthenticated | Downloaded 10/08/23 11:13 PM UTC
therefore not counted. Typically, this is a problem during evaluation of the small intestine because it is highly mobile within the abdominal cavity but is not usually an issue during evaluation of the cecum or colon. In the horses of our study, both the colon and cecum moved occasionally out of the field of view, so no conclusion as to the strength of contractions could be made because the change of distance from the body wall to the wall of the intestine could not be measured at all times. However, presently, B-mode ultrasonography still provides the best noninvasive method of assessing colonic and cecal motility. In our study, we found that the number of contractions correlated significantly with the total power, mainly from the long-distance channels, which would indicate that long-distance channels are more reliable in assessment of myoelectrical activity of horses. This is not surprising because long-distance electrode pairs are more sensitive to motion artifacts, but the obtained signal is stronger. Overall, multichannel EIG was somewhat useful in evaluating changes in myoelectrical activity in the large intestine of horses; however, it should only be used in combination with other techniques to evaluate intestinal motility.

b. Medi-Trace EKG Sol, Graphic Controls, Buffalo, New York, NY.
c. Suretrace, Conmed, Brossard, QC, Canada.
d. Labmaster 2000 g, Scientific Solutions, Vancouver, BC, Canada.

Appendix

Combinations of 5 active EIG electrodes (A through E) that composed the 8 bipolar EIG short- and long-distance channels used in the assessment of myoelectrical activity in the cecum and large colon of horses.

<table>
<thead>
<tr>
<th>Electrode combination</th>
<th>Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>A–B</td>
<td>1 (short distance)</td>
</tr>
<tr>
<td>B–C</td>
<td>2 (short distance)</td>
</tr>
<tr>
<td>C–D</td>
<td>3 (short distance)</td>
</tr>
<tr>
<td>D–E</td>
<td>4 (short distance)</td>
</tr>
<tr>
<td>A–C</td>
<td>5 (long distance)</td>
</tr>
<tr>
<td>A–D</td>
<td>6 (long distance)</td>
</tr>
<tr>
<td>A–E</td>
<td>7 (long distance)</td>
</tr>
<tr>
<td>B–E</td>
<td>8 (long distance)</td>
</tr>
</tbody>
</table>

References


