The Application of Electrocectography for Evaluation of Cecum Motility in Horses

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ABSTRACT. Electrogastrography (EGG), in which the electrical activity of the smooth muscular layer of the stomach is recorded percutaneously through the abdominal wall, has been applied in recent years to humans as a non-invasive method. In acute abdominal disease in horses, it is considered diagnostically useful to analyze digestive activity using EGG. Electrocectography (ECG) was examined to determine its effectiveness in evaluating equine digestive motility through comparison, after xylazine administration, between the results of the percutaneous ECG method and the results obtained using a strain-gauge force transducer (Force Transducer) chronically attached to the serous membrane of the cecum. As subjects, the test used six male thoroughbreds (average weight: 457.5 ± 9.2 kg). The test showed a reduction in both the percutaneous electrical potential of the cecum in ECG and in cecal contractions measured with the Force Transducer. After xylazine administration, an average rates of decrease of the amplitude from the control period were $17.8 \pm 3.4\%$ and $20.0 \pm 4.6\%$ respectively, demonstrating a significant correlation ($r=0.90$) between the two methods. On the other hand, power distribution centered around 6 cycles per minute in a Fourier transform (FFT) analysis of ECG, thought similar to the contraction frequency of 5.4 ± 3.0 per minute observed with the Force Transducer. After xylazine administration, the total frequency band (1.8–12 cycle per min) in the running spectrum total power in ECG decreased to $37.0 \pm 5.1\%$ of the pre-xylazine value. Based on these findings, it appears that the ECG potential reflected electrical activity of cecal origin, suggesting high clinical applicability of ECG to the percutaneous evaluation of equine cecal motility. — **KEY WORDS:** cecum, electrocectography, equine, motility, strain gauge force transducer.

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Horses have a high incidence of digestive system diseases. The analysis of equine digestive motility provides useful data for diagnosing and monitoring therapy of these cases. Equine digestive motility has been studied employing electromyograms [16, 20, 24–26, 30, 31] and strain gauge force transducers (Force Transducers) [19] in ponies. Both these methods, however, require surgery. No method for measurement and analysis that is applicable to adult thoroughbreds has been established so far. In this study we compare electrocectography (ECG), which percutaneously records electrical activity non-invasively via the abdominal wall, with the Force Transducer method, which requires laparotomy. Specifically, cecum contractions were suppressed by xylazine administration, the amplitude of change were compared, and ECG was assessed in terms of its effectiveness in the evaluation of equine cecum motility. At the same time, FFT analysis was conducted on ECG to observe the percutaneous potential frequency of the cecum and its total power.

MATERIALS AND METHODS

1. Horses

Six healthy male thoroughbreds (average weight of 457.5 ± 9.2 kg) were subjected to tests. These horses were fed on an ordinary three-meal diet with unrestricted water intake.

2. Installation & recording of force transducer.

1) Anesthetic method

To detect cecum contractions, experimental laparotomy was performed on the serous membrane of the cecum to

install the Force Transducer (F-121S; Star Medical, Japan). For anesthesia, after sedative administration with 1.0 mg/kg of xylazine, 400 ml of 10% guaiacol-glycerin ether mixed with 2 g of thiopental sodium was given to the subjects by rapid intravenous administration to render them unconscious. They were held on the surgical table in the supine position and anesthetized by inhalation of isoflurane and oxygen. Twenty minutes after starting anesthetization, dobutamine was intermittently administered, maintaining the subjects at the average arterial pressure of about 70 mmHg. A lactateal Ringer's solution was also given at 10 ml/kg/hr.

2) Surgical method

The surgical method used was basically the same as the one employed by Merritt and others [21]. That is, the abdomen was opened by median section to expose the cecum, and one Force Transducer unit was fixed on the serous membrane of the bottom of the cecum with a $4-0$ nylon suture to detect the contractions of the annular muscle. The lead cable was drawn out of the body through the withers, passing through the thorax subcutaneously.

3) Recording method

Immediately after surgery, contractions were recorded on the conscious horses at rest in the stable. Records were continuously obtained using a thermal array recorder (Nihon Kohden Kogyo) via a strain pressure amplifier (AP-100F; Nihon Kohden Kogyo) with the lead cable from the Force Transducer connected to a resistance box (FB:01; Star Medical). Recording was continued for 2 months.

3. Measuring Method with ECG

To measure the percutaneous potential of the cecum, a

Digitrapper EGG System (Synectics, Sweden) was used (Fig. 1) to synchronize with the measurement timing of the Force Transducer. After removing hair from the right abdomen, ECG electrodes were installed via the surface electrodes on three sites: the front edge of the right hook bone (ECG mini-amplifier), the intersection of the horizontal line extending from the hook bone and the rear edge of the last rib (uninductive electrode), and the apex of an inverted regular triangle formed by placing the other two electrodes on the other apexes (ECG- mini-amplifier) (Fig. 2). At the sampling rate of 1 Hz, the frequency was measured within the range of 1.8 to 12 cycles per minute (cpm).

4. Xylazine administration

Xylazine was administered to the horses 2 weeks after surgery, when they were considered to have almost recovered from experimental laparotomy. Cecum contraction was suppressed by intravenous administration of xylazine (1 mg/kg) to observe changes in the amplitude and frequency measured with ECG and the Force Transducer. The percutaneous potential of the cecum in ECG and the amplitude of cecum contractions observed with the Force Transducer were measured during the 10 min preceding xylazine administration and during the 10-min period starting 20 min after administration. The amplitude of change from the control period was calculated.

5. ECG analysis method

For ECG analysis, we employed a running spectrum method with fast Fourier transform (FFT) analysis, similar to the one adopted by Chen and McCallum [7]. The waveform was divided at 1 min intervals. The frequency was defined as the number of waves in one minute, and the amplitude as the average height of the waveforms. To determine the total power, the waveform for one minute was subjected to FFT analysis to calculate the power for the entire frequency band. The frequency band was classified into the low frequency band (1.8 to 5 cpm), the dominant frequency band (5 to 7 cpm), and the high frequency band (7 to 12 cpm).

6. Statistical method

The results obtained were represented in terms of the average $\pm$ standard deviation. For the determination of significant differences, the Wilcoxon Test and Spearman's correlation coefficient was employed.

RESULTS

Figure 3 shows changes in ECG and the Force Transducer after administration of xylazine. Before xylazine administration, the Force Transducer displayed regular tonic contractions with a basic pressure fluctuation at an average cycle of 16.5 ± 0.8 min. The cecum contraction frequency was 5.4 ± 3.0 cycle per min on average. Contemporaneously, ECG recorded a continuous waveform with an average amplitude of 844.0 ± 83.2 (μ V).

Fig. 1. Digitrapper EGG device used to make the reported measurement.

Fig. 2. Installation sites for ECG electrode, reference electrode and Force Transducer.

After xylazine administration, the Force Transducer reductions recorded in both amplitude and frequency. This condition continued for an average period of 60.0 ± 8.7 min. Similarly, for EGG, the potential decreased in both amplitude and frequency, continuing for an average of 61.5 ± 7.2 min. Thus, the changes in amplitude measured with ECG showed a significant correlation ($r=0.95$) with those measured with the Force Transducer.

Table 1 illustrates changes in the average amplitudes of the Force Transducer and ECG, as well as the magnitude, of changes measured during the 10 min period prior to xylazine administration and during a 10 min interval 20 min after administration. The average amplitude after xylazine administration on the Force Transducer was only $20.0 \pm 4.6\%$ of the control value, indicating a significant reduction from the control condition. Similarly, the amplitude in ECG decreased from 844.0 ± 83.2 (μ V) to 150.0 ± 28.0 (μ V),

Fig. 3. Changes induced in percutaneous cecum potential and cecum contractions by xylazine administration. ECG: Electroceography of the cecum. STG: Recording of the cecum motility using Strain Gauge Force Transducer. Shadowed boxes represent -10 to 0 min pre- and 20 to 30 min post-xylazine injection time intervals.

Table 1. Rate of change induced in percutaneous potential and cecum contractions by xylazine administration

	Pre -10-0 min	Post 20-30 min	Post/Pre %
Force Transducer (%)	100.0 $\pm$ 0.0	20.0 $\pm$ 4.6	20.0 $\pm$ 4.6*
ECG amplitude (mV)	844.0 $\pm$ 83.2	150.0 $\pm$ 28.0	17.8 $\pm$ 3.4*

n=6, mean $\pm$ SD, *P<0.05

-10-0 min: 10 minutes before Xylazine administration

20-30 min: 10 minutes after Xylazine administration

also a significant change. The post-xylazine value was $17.8 \pm 3.4\%$, demonstrating a significant correlation with the average rate of change in amplitude measured with the Force Transducer ($r=0.90$).

Figure 4 shows the power spectrum array in ECG before and after xylazine administration. The power distribution prior to administration centered around 6 cpm, and extended across a range from 2 cpm to 12 cpm. After xylazine administration, both the power and frequency (cpm) decreased, with the power centering around 3 cpm 20 min after administration. Table 2 shows the change in running spectrum total power ($\mu V^2 \times cpm$) from the control period to the corresponding period 20 min after administration. The average frequencies in each band, standardized to 100% for the control period, were $40.0 \pm 6.7\%$ for the low frequency band, $26.7 \pm 8.9\%$ for the dominant frequency band, and $33.3 \pm 4.4\%$ for the high frequency band, displaying a significant decrease with a mean over of $38.7 \pm 5.1\%$.

DISCUSSION

The Force Transducer method [19] is a laparotomic approach designed to quantitatively measure and record the contraction frequency, strength and tension in conscious subjects using a Force Transducer chronically attached to the serous membrane of the alimentary tract. It is not feasible, however, to apply this method in clinical practice for race horses.

EGG [3-8, 17, 22], on the other hand, is a non-invasive method that percutaneously records the electrical activity of the stomach via the abdominal wall. The first reported study on EGG was by Alvarez in 1922 [2]. At that time, accurate measurements were not available because of the low poor ability of the equipment to eliminate the potential accompanying body movements, noise occurring in the diaphragm due to cardiac and respiratory movements, and noise in the smooth muscles caused by their movements. However, recent advances in electronic equipment for

Fig. 4. Power spectrum of percutaneous cecum potential before and following xylazine administration. The gray section represents -10 to 0 min and 20 to 30 min post-injection. Both power spectrum array and frequency declined after xylazine administration.

Table 2. Rate of change induced in running spectrum total power ($\mu V^2 \times cpm$) of percutaneous cecum potential by xylazine administration

Low frequency: 1.8 to 5 cpm
Dominant frequency: 5 to 7 cpm
High frequency: 7 to 12 cpm

	Pre -10-0 min	Post 20-30 min	Post/Pre %
Low frequency	2850.8 $\pm$ 603.1	1081.0 $\pm$ 28.5	20.0 $\pm$ 6.7*
Dominant frequency	165.6 $\pm$ 41.2	42.4 $\pm$ 7.3	26.7 $\pm$ 8.9*
High frequency	910.4 $\pm$ 497.9	318.3 $\pm$ 133.6	33.3 $\pm$ 4.4*
Total	3926.9 $\pm$ 1142.2	1441.7 $\pm$ 154.8	38.7 $\pm$ 5.1*

n=6, mean $\pm$ SD, *P<0.05

-10-0 min: 10 minutes before Xylazine administration

20-30 min: 10 minutes after Xylazine administration

medical use have made it possible to record the minute action potentials of the smooth muscle of the alimentary tract. At present, EGG is clinically applied to the diagnosis of gastric ulcers and other diseases [12, 14, 27, 34].

The equine cecum occupies a relatively wide region of the right abdomen, facilitating the detection of its anatomical site from the body surface. For this reason, we selected the cecum for measurement to compare the ECG technique with surgically implanted Force Transducers. The administration of xylazine started 2 weeks after surgery, when the subjects had recovered from surgical invasion and returned to normal diet. Regular tonic contractions were observed with fluctuations in basic pressure at a cycle of 16.5 ± 0.8 min,

which continued for 24 hr. The waveform obtained was similar to the results reported by Ross and others [25, 26] who measured cecum motility by electromyography *in vivo*. The measurements resumed after surgery, at which time the Force Transducer recorded a stable waveform. This was presumably because the Force Transducer, sutured to the serous membrane, was covered with connective tissue [23, 24, 26]. This suggested that during a period beginning two weeks after surgery, reproducible results could be achieved in observation of changes in force in association with digestive contractions.

As an $\alpha 2$ -adrenergic agonist, xylazine has many applications, including premedication for anesthesia and as an analgetic sedative. This substance is known to exert a transient dose-dependent suppression effect on digestive motility [21, 23]. We used xylazine to suppress cecum contractions so as to observe changes before and after its administration. The dosage was 1 mg/kg, at which concentration cecum contractions were presumably suppressed for over 60 min [21, 23]. Both ECG and Force Transducers recorded decreases in cecum contractile magnitude (ECG amplitude force transducer force). The average decrease in ECG amplitude and the average suppression time after xylazine administration were very similar to those observed with the Force Transducer. The decreased amplitude of the original ECG waveform recorded with the electrode installed on the dermis was, therefore, considered to directly reflect the reduced cecum contractions recorded by the Force Transducer. In other words, ECG potential reflected electrical activity of cecal origin, with changes in its amplitude representing changes in cecal

contractions. Contractions of the smooth muscle of the alimentary tract are known to occur when an action potential called Electrical Response Activity (ERA) is imposed on the electrical control activity (ECA) of the smooth muscle [28, 33]. The EGG potential represents a difference in the bipolar induction range [28]. Brown and others assert that EGG does not evaluate ERA but records ECA from the body surface [3]. Further, Abell and others insist that the amplitude represents both ECA and ERA [1, 29, 33]. According to Chen and others, EGG reflects the electrical activity and contractions of the stomach [7, 9, 10, 33]. Although views are thus divided regarding how to interpret the origin of ECG, our experiment reinforced the interpretation by Chen and McCallum [7, 9].

Observation of the amplitude allows evaluation of the original waveforms in ECG. More precise assessment of the contractions requires frequency analysis to evaluate changes in frequency. Conventionally, EGG frequency analysis for humans has been based largely on the fast Fourier transform (FFT) [11, 32] method. Such analysis has indicated the relevance of EGG to diagnosing digestive diseases [4, 7, 28, 32, 33]. For example, because the frequency of the EGG potential in the human stomach centers around 3 cpm, the EGG potential frequency is classified into bradygastria for 3 cpm or below, and takygastria frequencies for above 3 cpm [7]. A gastric disorder is suspected when the median of the frequency is outside the range from 2 cpm to 4 cpm [7]. In contrast with the EGG frequency in humans, the percutaneous potential frequency of the equine cecum centered around 6 cpm, and was distributed over the range from 2 cpm to 12 cpm. This finding was considered to reflect the contraction frequency (5.4 times per minute on average) observed with the Force Transducer. This difference in frequency compared to humans may reflect the fact that the potential frequency of the smooth muscle is higher in the lower digestive system than in the stomach [18]. Therefore, in our FFT analysis the frequency was classified as low frequency below 5 cpm, and high as frequency for 7 cpm or above. After administering of xylazine, the total power obtained from FFT analysis declined across the entire frequency band ($38.7 \pm 5.1\%$), and the mean frequency decreased from 6 cpm to 3 cpm. ECG analysis appears to be excellent index of cecal activity, as measured by a surgically implanted Force Transducer. FFT analysis appears to be an effective approach to the quantitative evaluation of changes in frequency and amplitude in ECG. The analysis employed in our study should make it possible to quantitatively examine equine digestive motility in the case of a digestive disease such as a colic. The potential amplitude and frequency in horses recorded by ECG reflect electrical activity of cecal origin. Further, this approach should have high clinical applicability because it is capable of percutaneously evaluating equine cecum motility.

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