Clinical Applications of Electrointestinography in the Horse

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It is thought that in order to effectively treat gastrointestinal dysfunction, it should be detected at an early stage. The present study aimed to observe the movement via Electrointestinography (EIG) in the small intestine, cecum, right ventral colon and right dorsal colon, and to examine the procedure for assessing gastrointestinal function. Seven healthy thoroughbred horses were used. They were allowed food twice a day. EIG was measured at ten-minute intervals over a 24 hr period, and running spectral analysis was used. As a result, it was clear that EIG could non-invasively assess gastrointestinal function by setting the cut-off value of the frequency band to 1.8–12.0 cpm for a part of the digestive tract which is in a comparatively fixed position. The running spectral analysis could be used to visually interpret the change in the EIG power. In the small intestine, cecum, right ventral colon and right dorsal colon, a significant increase was observed for about 1–4 hr during which feeding took place at the maximum amplitude and the total power of the EIG wave. Because 3 cpm of the total power could be influenced by artifacts, analysis at 6 cpm is recommended, when the total power was assumed to be an indicator. In conclusion, it was considered capable of effectively detecting two indicators of 6 cpm of the total power and maximum amplitude for assessing change in the digestive tract voltage in medical practice.
Key words: *electrointestinography, equine, intestine, power spectral analysis, running spectral analysis*

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Gastrointestinal dysfunction with gastrointestinal motility disorder exists as a background factor of acute abdominal disorder in the horse [23]. It is thought that in order to effectively treat gastrointestinal dysfunction, it should be diagnosed at an early stage. The analysis of equine digestive motility which provides useful data for digestive motility has been studied employing electromyograms [20, 21] and strain gauge force transducer [11, 16, 23], but both these methods require surgery [7, 23]. No measurement and analysis that is applicable to the horse has been established so far.

Recently, the electrogastrography [1–3, 6] that measures the myoelectrical activity of the digestive tract from the body surface has been developed. It has been applied to the diagnosis and treatment of human gastroesophageal reflux disease [4, 25], gastric ulcer [2], and NUD (non-ulcer-dyspepsia) [17]. It has been proven to correlate with high cecum movement measured in the horse by electrointestinography (EIG) that measures the myoelectricity of the cecum from the body surface [22]. Therefore, it is considered that the state of the gastrointestinal tract function of the horse can be recognized non-invasively by using Electrointestinography.

The present study aimed to observe the circadian variation in EIG in the small intestine, cecum, right ventral colon and right dorsal colon, and to examine the assessment procedure for gastrointestinal tract function.

Materials and Methods

Animals: 7 healthy adult thoroughbreds were used (females, mean age 4.0 ± 0.0; mean body weight 467.0 ±

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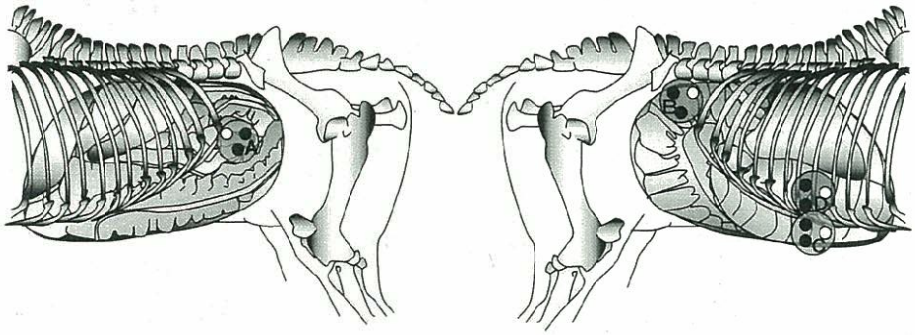

Fig. 1. EIG electrode position. A: Small intestine, B: Cecum, C: Right ventral colon and D: Right dorsal colon. ●: EIG mini-amplifier and ○: EIG in different electrodes.

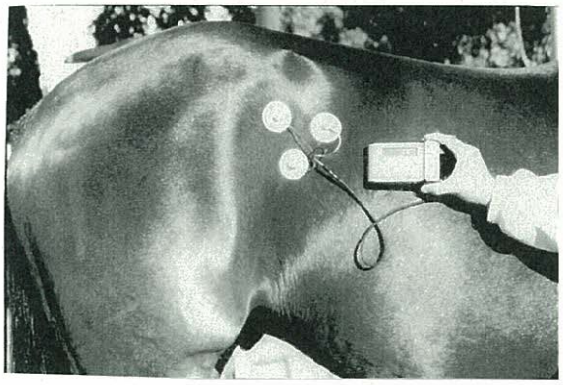

Fig. 2. EIG measuring equipment. The electrode shows the cecum measurement position.

10.3 kg). The breeding management involves two feedings at 8:00 and 16:00, with portions of dried grass 5 kg, oats 3 kg, aceration 2 kg, and soybean cake 0.5 kg. Drinking water was provided *ad libitum.*

Measuring Electrointestinography (EIG) position: The EIG measuring positions were the small intestine, cecum, right ventral colon and right dorsal colon (Fig. 1). At each measuring position, the EIG electrode was installed through a surface electrode. The EIG electrodes were installed at three sites: the front edge of the left hook bone (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 (mini-amplifier) in the small intestine. EIG electrodes were also installed at the front edge of the right hook bone (mini-amplifier), at the intersection of the horizontal line extending from the hook bone and the rear edge of the last rib (uninductive electrode), and at the apex of an inverted regular triangle formed by placing the other two electrodes on the other apexes (mini-amplifier) in the cecum. And two electrodes were placed on the ventral surface of the rib between the 10th and 11th ribs (mini-amplifier), and the apex of an regular triangle formed by placing the other two electrodes on the other apexes (uninductive electrode) in the right ventral colon. Finally, two electrodes were also placed on the ventral surface of the rib between the 10th and the 11th ribs (mini-amplifier), and at the apex of a regular triangle formed by placing the other two electrodes on the other apexes (uninductive electrode) in the left ventral colon. The position of each EIG electrode location and each area in the digestive tract was confirmed by means of ultrasonic diagnostic equipment (2.5MHz).

The procedure for measurement of Electrointestinography (EIG): The potentiometry of each digestive tract was examined with a Degetorappar EGG system (Syntectics Co., Sweden) (Fig. 2). Measurements were taken at 24 intervals from 00:00 to 24:00. At a sampling rate of 1 Hz, the frequency was measured within the range of 1.8 to 12 cycles per minute (cpm).

The EIG analysis method: EIG was analyzed by running spectral analysis employing fast fourier transform (FFT). That is, the maximum-minimum amplitude was calculated for ten minutes at one hour intervals. The EIG waves sampled with this time scheme were analyzed in FFT, and power (dB) was displayed in one minute

intervals as an FFT line. The frequency band was classified into 3 cpm (1.8 to 4.5 cpm), 6 cpm (4.5 to 7.5 cpm), 9 cpm (7.5 to 10.5 cpm) and 12 cpm (10.5 to 12.0 cpm). The total power ($\mu V^2 \times$ cpm) of each frequency band was calculated for ten minutes at one hour intervals.

Statistical method: Maximum-minimum EIG and total power were calculated during 10 min periods starting 1 hr before feeding and during the 10 min period starting 8 hr after feeding. The significance of all the data was examined by one-factor ANOVA. As a result, when a significant difference was revealed, the differences between the means of all groups were analyzed by Fisher's protected least significant difference. All differences with values of $p \leq 0.05$ were considered significant.

Results

The EIG wave of the cecum is shown in Fig. 3. It was observed that the fluctuation in the wave within a range of 100–180 μV repeated at about 5 to 6 cycles per minute. The EIG waves contained waves of various sizes. Running spectral analysis of the EIG in the cecum is shown in Fig. 4. Changes in the EIG power were assessed by sight in the area of the FFT line. That is, many units of power (dB) of about 3 cpm were seen for one hour (7:00–7:10) before the feeding, and a prominent increase in the power at 3 cpm and 6 cpm was observed for one hour (9:00–9:10) after the feeding.

Changes in the maximum EIG amplitude of the small intestine, cecum, right ventral colon and right dorsal colon are shown in Figs 5–8, respectively. The maximum-minimum amplitude of the EIG waves changed within the range 197.5–312.5 μV on average in the small intestine. As for maximum amplitude, a significant increase was observed in a period of 1–3 hr during which feeding took place. The maximum amplitude of the EIG waves changed within the range

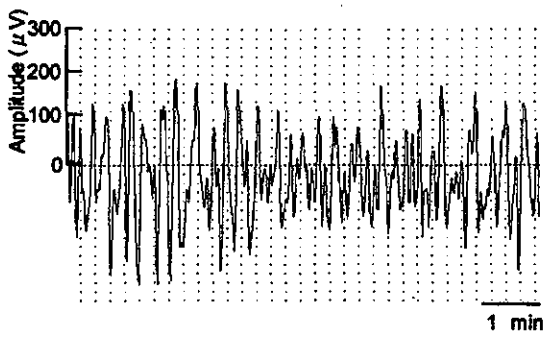

Fig. 3. The EIG wave in the cecum is shown.

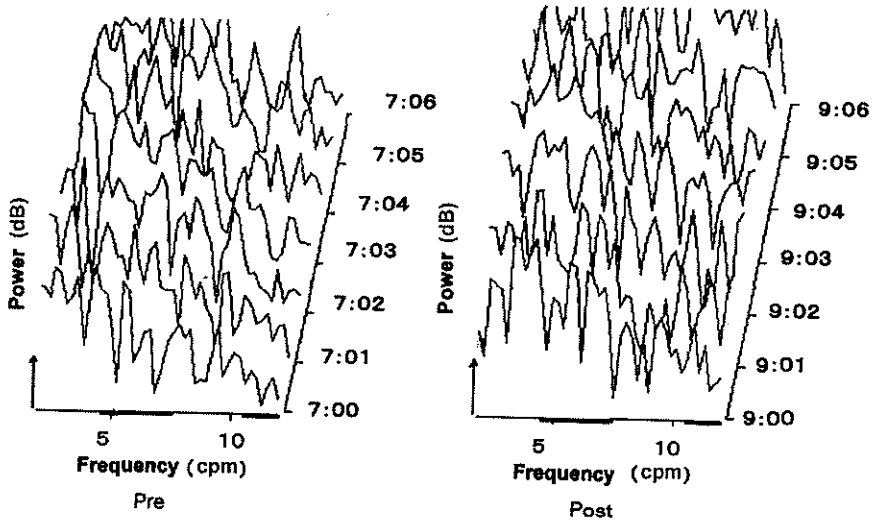

Fig. 4. EIG running spectrum. The EIG running spectrum of ten minutes in the cecum is shown before and after feeding. Feeding took place at 8:00. Power is shown as dB.

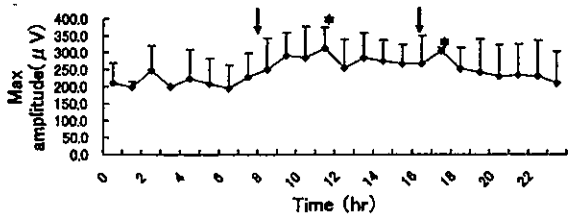

Fig. 5. Change of maximum amplitude in small intestine. The value shows mean ± standard deviation (mean ± S.D.). ↓: Feeding. *: There is a significant difference compared with one hour before the feeding ($P<0.05$).

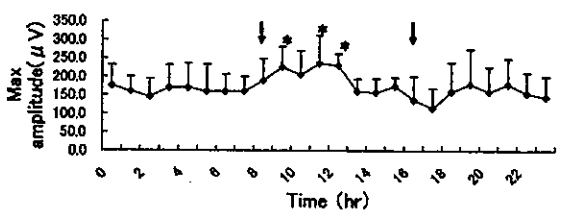

Fig. 6. Change of maximum amplitude in cecum. The value shows mean ± standard deviation.

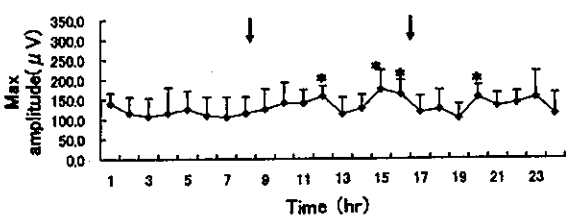

Fig. 7. Change of maximum amplitude in right ventral colon. The value shows mean ± standard deviation.

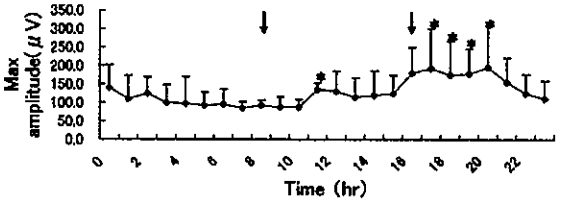

Fig. 8. Change of maximum amplitude in right dorsal colon. The value shows mean ± standard deviation.

137.5–225.0 μV on average in the cecum. The maximum amplitude in the cecum showed a significant increase for about four hours during which time feeding took place. The maximum amplitude of the EIG wave of the right ventral colon changed within the range of 105.0–175.0 μV on the average. As for maximum amplitude, a significant increase was observed for about 3–4 hr during which time feeding took place. The maximum amplitude of the EIG wave changed to 85.0–195.0 μV on average within the range in right dorsal colon. As for maximum amplitude, a significant increase was observed for about four hours during which time feeding took place.

Changes in the total EIG power of the small intestine, cecum, right ventral colon, and right dorsal colon are shown in Figs. 9–12, respectively. Average total power of the small intestine changed within the range 421.5–1510.1 ($\mu V^2 \times$ cpm) at 3 cpm, in the range 199.2–807.6 ($\mu V^2 \times$ cpm) at 6 cpm, in the range of 45.9–253.0 ($\mu V^2 \times$ cpm) at 9 cpm, and in the range 10.4 ± 5.6–48.0 ± 20.0 ($\mu V^2 \times$ cpm) at 12 cpm. A significant increase in total power was observed along with feeding. The average total power of the cecum changed within the range in 1250.0–5032.0 ($\mu V^2 \times$ cpm) in 3 cpm, in the range in 730.0–2497.3 ($\mu V^2 \times$ cpm) in 6 cpm, in the range of 224.9–1344.7 ($\mu V^2 \times$ cpm) at 9 cpm, and in the range 31.0–175.3 ($\mu V^2 \times$ cpm) at 12 cpm. Here as well, a significant increase in total power was observed along with feeding. At 3 cpm in the small intestine and the cecum, a fluctuation in total power was observed except for during feeding, and total power roughly correlated with the change in the maximum amplitude at 6 cpm, 9 cpm, and 12 cpm. The total power of the right ventral colon changed within an average range of 1249.4–4942.3 ($\mu V^2 \times$ cpm) at 3 cpm, within an average range of 472.9–1857.0 ($\mu V^2 \times$ cpm) at 6 cpm, within an average range of 149.0–948.0 ($\mu V^2 \times$ cpm) at 9 cpm, and within an average range of 34.0–189.6 ($\mu V^2 \times$ cpm) at 12 cpm. A significant increase in total power was observed during feeding. As for 3 cpm, a large difference was observed compared with the average powers of 6–12 cpm. The total power of the right dosal colon changed within an average range of 915.2–4632.0 ($\mu V^2 \times$ cpm) at 3 cpm, within an average range of 418.9 ± 1810.9 ($\mu V^2 \times$ cpm) at 6 cpm, within an average range of 112.8–1115.8 ($\mu V^2 \times$ cpm) at 9 cpm, and within an average range of 20–38.0 ($\mu V^2 \times$ cpm) at 12 cpm. A significant increase in

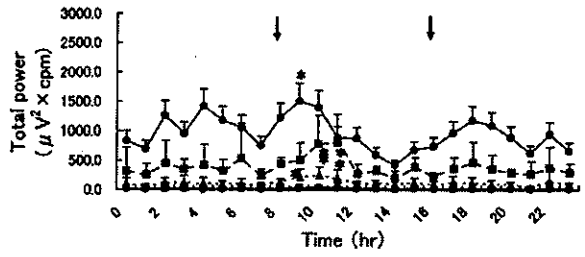

Fig. 9. Changes of total power value in the small intestine shown as mean ± standard deviation (mean ± S.D.). ●: 3 cpm, ■: 6 cpm, ▲: 9 cpm, ○: 12 cpm. ↓: Feeding. *: There is a significant difference compared with one hour before feeding ($P<0.05$).

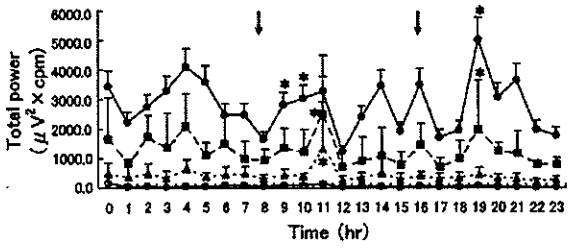

Fig. 10. Change of total power in cecum. Refer to the clarification for Fig. 9.

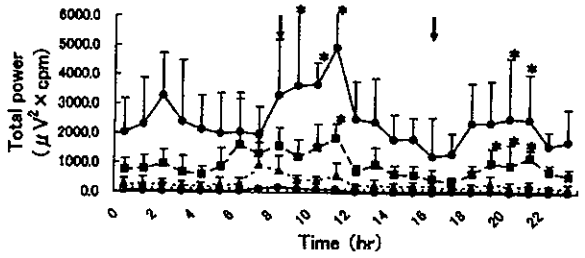

Fig. 11. Change of total power in right ventral colon. Refer to the clarification for Fig. 9.

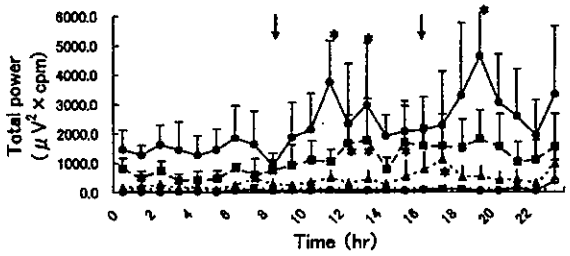

Fig 12. Change of total power in right dorsal colon. Refer to the clarification for Fig. 9.

total power was observed along during feeding. In 3 cpm on the right ventral colon and right dorsal colon, a big difference in total power was observed in comparison with 6 cpm, 9 cpm and 12 cpm.

Discussion

Electrointestinography (EIG) is a method for measuring the myoelectricity activity of the digestive tract from the body surface. It is a method which is non–invasive and can be applied to investigations of gastrointestinal tract function [2, 3]. In the human stomach, the voltage measured from the body surface reflects the amplitude of spikes and the frequency of slow waves [9, 24]. Moreover, EIG is known to be able to detect gastric motility disorder [1, 5]. Therefore, it is thought that the recognition of gastrointestinal motility disorders is also possible by the assessment of EIG in the horse. Thus, we measured the component selection to assess EIG.

EIG measurements were performed with a Degetorappar EGG made by the Synectics Medical Company. Because this EIG assembly is the shape and the size of a portable MD, is operated with only a nine volt battery, and can be easily carried, it could be used to obtain EIG measurements in a subconscious horse. Moreover, it was thought that this EIG measuring device could 24 measure for hours or more by adjusting the sampling frequency to 1 Hz, which makes the device applicable to the observation of gastrointestinal dysfunction.

Because the voltage of other digestive tracts is weak, and though the electrogastrogram is commonly applied to humans, such measurements are assumed to be difficult [2]. The present study assessed the gastrointestinal tract function of digestive tracts that are comparatively fixed in the anatomy and exist in the proximal body surface part [18]. For this reason, we decided to examine the small intestine via the right abdomen, the cecum via the left abdomen, and the right ventral and dorsal colons from between the 10th

Table 1. Frequency EIG component: cpm (cycles per minute)

	Component	Frequency (cpm)
Signal	3 cpm	1.8 – 4.5
	6 cpm	4.5 – 7.5
	9 cpm	7.5 – 10.5
	12 cpm	10.5 – 12.0
Noise	Respiration	12 – 20
	Electrocardiogram	30 – 45
	Motion artifacts	Whole range

and 11th ribs. As a result, it was thought that the gastrointestinal function of the small intestine, the cecum and the colon was appreciable overall. On the other hand, because it is thought that the digestive tract is not in its usual position in a horse suffering from a disease of the digestive system, it is recommended that the positions of the various parts of the digestive tract are confirmed by ultrasound before the electrodes are installed. Moreover, confirmation of the position of each part is difficult, and the thickness of the body surface and the distance to the digestive tract decrease the EIG voltage in the measurements of both the deep digestive tract (stomach and duodenum) and the flexibility of the digestive tract (left ventral colon and left dorsal colon) [2]. Therefore, it will be necessary to examine the approach to other digestive tracts in the future. The voltage of the EIG is weaker than that of other electric signals such as the electrocardiogram and breaths, and the involuntary body movements influence the EIG waves in the form of noise (Table 1). These noises can be deleted by setting the cut–off value of the frequency band within the range 1.8–12.0 cpm.

The shapes of the EIG waves were similar to those produced by contractions in gastrointestinal motility reported previously [20]. That is, the EIG wave was observed to increase and decrease in a constant cycle, and it is considered that these waves reflect the contractile strength [20] of the digestive tract. Amplitude and frequency are expressed in the EIG waves. As for the maximum amplitude, it is known that the indicator and the strength of myoelectricity on the digestive tracts [9]. In addition, because the maximum amplitude expresses the degree of digestive tract contraction, it is considered to be an indicator of the contractile force of gastrointestinal motility [22]. In the small intestine, cecum, right ventral colon and right dorsal colon, an increase in maximum amplitude was observed for about 1–4 hr during which time feeding took place. This is a consequence similar to the report that employed a force transducer [19, 21], and it is thought that the EIG's maximum amplitude reflects stomach colon contraction during the feeding [19, 23]. Because the fluctuations in the maximum amplitude express the fluctuations in digestive tract myoelectric activity and contractile motility, it was thought that the diagnosis of gastrointestinal dysfunction and assessment of the therapeutic effect could be possible based on the maximum amplitude of the EIG.

In general, power spectral analysis [8] and running spectral analysis [3, 6] have been used to analyze electrogastrography. Power spectral analysis employing Fast Fourier transform (FFT) has been used to assess wave frequency [8]. Moreover, the running spectrum is suitable for gathering information regarding time variation in addition to frequency [3, 6]. Because an increase in power observed during feeding was observed in the running spectrum before and after feeding, it was considered that the change in power could be observed visually. On the other hand, it is necessary to separate this power into each frequency band in order to assess the gastrointestinal tract function objectively. In humans, the frequency band is centered on three cpm in order to detect the coherency of slow waves of the stomach and to classify them as bradygastria, normal, and tachygastria [2, 10]. In the horse, because the total EIG power is distributed around 6 cpm [22], the frequency band was separated into 3 cpm (1.8 to 4.5 cpm), 6 cpm (4.5 to 7.5 cpm), 9 cpm (7.5 to 10.5 cpm) and 12 cpm (10.5 to 12 cpm). As for the range in a day, a trend toward increasing to more than the range of maximum amplitude was observed at 3 cpm of the total power. While the maximum amplitude shows the change in the EIG wave, the total power was amplified by calculation.

Moreover, the movement of 3 cpm of the total power in the right ventral colon and right dorsal colon showed a large standard deviation as compared with those at 6 cpm, 9 cpm and 12 cpm. Because the setting of 3 cpm is in the 1.8 to 4.5 cpm range, it was thought that it was influenced by the artifacts of the involuntary body movement that appeared in the low frequency band. Moreover, it is recommended that the analysis be centered on 6 cpm (4.5–7.5 cpm), because the changes in 9 cpm and 12 cpm are not clear after the feeding.

Therefore, it was clear that EIG could non-invasively assess gastrointestinal function by setting the cut-off value of the frequency band to 1.8–12.0 cpm for a part of the digestive tract which is in a comparatively fixed position. The running spectral analysis could allow the

effective visual interpretation of the change in the EIG power. It was considered capable of effectively detecting two indicators of 6 cpm of the total power and maximum amplitude for assessing change in the digestive tract voltage in medical practice.

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