DIAGNOSIS OF PARALYTIC ILEUS BY MEANS OF SMALL BOWEL MYOELECTRICAL SIGNAL RECORD

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Abstract: Paralytic ileus is a pathology of the small bowel produced generally by surgical interventions or drugs use. This pathology alters motility of the intestine by stopping bowel contractions.

The goal of this study is to obtain several parameters to discriminate a patient with paralytic ileus from a patient in physiological state.

Bioelectrical signal record from intestinal serosa (electroenterogram) from healthy and unhealthy dogs was obtained. A reversible pathology induction method was necessary to be developed. It was found that an efficient technique to produce paralysis was thiopental IV anaesthesia induction bolus (40 mg/Kg) and Sevorane (3%) anaesthesia maintenance.

Six dogs were recorded obtaining 18 valid sessions in physiological and 12 in pathological state. Spectral analysis of the recorded signal was made to obtain the energy above 2 Hz (EF2). This index was calculated because it is closely correlated to mechanical activity.

Statistical parameters calculated from EF2 temporal evolution of recorded sessions are evaluated in this work. Most significant differences ($p<0,001$) between physiological and pathological conditions were obtained by mean value and standard deviation of EF2.

This work can contribute to obtain a non-invasive diagnosis tool for paralytic ileus.

Introduction

Small bowel functions are to absorb nutrients, to mix and to transport chyme to colon. Contractions of small bowel are required to segment, mix and move its luminal content.

Mechanical activity is made by pressure waves produced by small bowel contractions. These contractions have an electric equivalent in intestinal smooth muscle cells [1]. This electric measure is known as internal electroenterogram (EEnG). Figure 1 shows a small bowel manometric and myoelectric signal record.

EEnG is composed by two signals: a slow wave (SW) and, occasionally, series of very rapid voltage peaks or spike burst (SB). SW is always present and it is considered electrical control activity. On the other hand, a direct relationship between SB and mechanical contractions has been demonstrated [1].

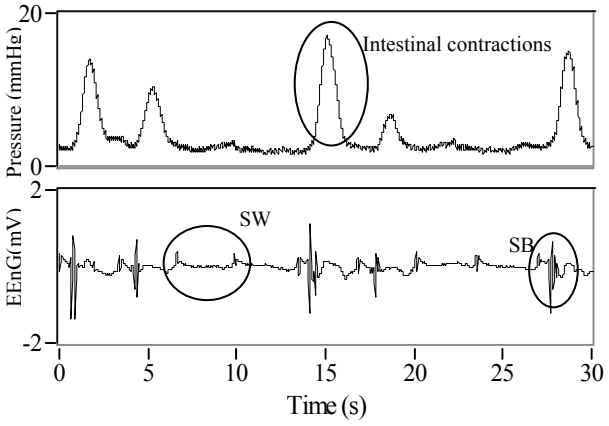

Figure 1: Recorded pressure inside intestinal tract. (upper trace). Myoelectric signal recorded on intestinal smooth muscle cells with 9 SW and 5 SB (lower trace).

SW and SB are shown in figure 1. Lower trace shows 9 complete SWs. SBs and the associated intestinal contractions can be seen in seconds 1, 4, 14, 17 and 27.

In fast state and physiological condition small bowel keeps on working to clean the luminal content. It generates the interdigestive migrating myoelectric complex (IMMC) [2]. IMMC can be divided in three phases, from no activity (phase I) to maximum contractile activity (phase III). Phase II has an irregular activity and it is produced prior to phase III. IMMC describes a characteristic pattern composed by a large period of phase I and then a period of phase II and, finally, a short period of phase III. After that, small bowel returns to phase I. This pattern is repeated continuously between food ingestions.

Some gastrointestinal pathologies affect IMMC pattern [3-5], thus electrical signal changes too. So EEnG and its pattern of activity are important because they are potential diagnosis tools of several pathologies.

Paralytic ileus is a pathological state of small bowel. In this situation, small bowel contractile activity stops in this situation [6,7]. It is due to the use of several drugs, surgical interventions or natural pathology.

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At present, diagnosis of paralytic ileus is made by means of auscultation of abdominal cavity. This source of information is quite ambiguous because there are a great number of sound sources. So this diagnosis method has a high variability which depends on clinical skills and experience.

The aim of this work is to provide a tool that could help to diagnose paralytic ileus by means of EEnG recorded in small bowel serosa.

Materials and Methods

Three healthy Beagle dogs were used to record small bowel myoelectrical signal. Their weights were between 10 and 12 Kg.

Six electrodes were implanted at jejunum and ileus serosal layer. Electrodes positions were constant between dogs to reduce the variability. Bipolar Ag-AgCl myolectrodes (interspacing 5mm) were sutured to the bowel serosa along the longitudinal axis.

The animals were fasted at least for 14 hours prior to the motility measurement. Recording sessions lasted 5-6 hours each. Sessions were classified in two categories: physiological and pathological state record. Physiological record was made with dogs in relaxed state during three hours or at least two complete IMMCs. Sessions of paralytic ileus were recorded after two complete IMMCs in physiological state. Then paralysis was induced and recording continued for about 3 more hours. The duration of pathological recording sessions is established in 3 hours because maximum duration of phase I in physiological conditions is 50 minutes and complete IMMC duration is 80-120 min in dogs [8]. Finally, first part of these sessions was separated and classified as physiological. So, the record was classified as pathologic only after paralysis induction. There were 18 valid records of physiological conditions and 12 of paralytic ileus conditions.

Reversible paralytic ileus state was induced in healthy dogs by means of drugs [6]. Anaesthesia induction was made with Tiopenthal (Penthotal Sodium). Unique intravenous bolus of 40 mg/Kg was required to induce anaesthesia. Maintenance was made under Sevorane (Fluorane) in concentration of 3%. After signal recording was stopped, maintenance anaesthesia was removed and animal recovered consciousness after a few minutes.

EEnG signal was amplified by a commercial biosignal conditioner (Biopac ECG 100C). A band-pass filter with cut-off frequencies of 0,05 and 35 Hz was applied to the bioelectrical signals. Amplifier gains were selected between 2000 – 5000. Recording was made by means of an acquisition board on a personal computer. Selected sampling rate was 100 Hz.

Intestinal motility index (IMI) was calculated. Energy above 2 Hz of unmodified periodogram was considered as intestinal motility index. EF2 calculation was made integrating spectral energy of every 1 minute window of signal. Frequency limits of this integration were selected in 2 and 35 Hz because of previous studies [9]. EF2 quantifies SB appearance and intensity and rejects SW constant energy.

Equation 1 shows IMI calculation from power spectrum density:

$$IMI \equiv EF2 = T \cdot \sum_{f=2}^{35\,Hz} PSD(f) \cdot \Delta f \qquad (1)$$

where T is the considerate time interval window (60 seconds), PSD(f) is unmodified periodogram and Δf is frequency resolution of spectral estimate.

In order to differentiate physiological small bowel conditions from paralytic ileus, several statistical parameters were studied from IMI distribution. Shape parameters as Skewness (γ_1) and Kurtosis (K) coefficients were calculated.

$$\gamma_1 = \frac{\sum_{i=1}^{N} \frac{(x_i - \bar{x})^3}{N}}{\sigma_x^3} \qquad (2)$$

$$K = \frac{\sum_{i=1}^{N} \frac{(x_i - \bar{x})^4}{N}}{\sigma_x^4} \qquad (3)$$

Other statistical coefficients as mean energy, standard deviation of this parameter, maximum and minimum and quartiles of the IMI were also calculated for both physiological and pathological state.

Significant differences between both states were evaluated by p-value obtained by means of ANOVA or Kruskal-Wallis analysis. Comparison among p-values of the different parameters was also studied.

Results and Discussion

EEnG's phase III is characterized by SBs presence and, hence, small intestine contractions. This situation is shown in upper trace of figure 2. In paralytic ileus conditions, no contractions are produced so anaesthetic method must stop all SB from EEnG (figure 2 lower trace). In this case, recorded EEnG signal is similar to EEnG in phase I of IMMC.

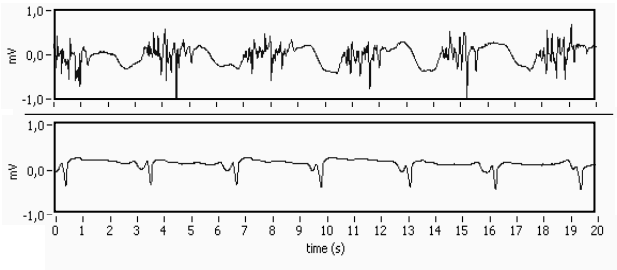

Figure 2: Physiological myoelectrical signal in maximum activity period. SW+SB (up). Myoelectrical signal of induced paralytic ileus, only SW (down).

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Sevorane anaesthetic dose was tested to produce paralysis induction and maintenance during 4 hours at least. Our experiences showed that minor dose than 1,5% of Sevorane maintained animal anaesthesia but did not depress animal reflexes and intestinal motility. Major dose of maintenance anaesthetic (1,5-2,5% of Sevorane) produced a depress of animal movements and reflexes, however mechanical activity appeared in small bowel. This activity is of greater intensity near the stomach and decreases distally. The amplitude of these contractions is smaller than in physiological state. Finally, dose of Sevorane 3% absolutely depressed intestinal reflexes and intestinal contractions during more than 4 hours. Efficiency of paralytic ileus induction method was checked by means of SB absence.

Table 1: Effect of diverse maintenance Sevorane dose.

Sevorane dose (%)	Effect
<1,0	No anaesthesia maintenance
1,0-1,5	Maintenance but reflexes
1,5-2,5	Surgical plane of anaesthesia but irregular intestinal activity
>3,0	Paralytic ileus induction

Figure 3 shows the IMI of a physiological state signal and its histogram (upper trace), and the IMI of a pathological state signal and its histogram (lower trace). In physiological conditions the IMI pattern has only a few minutes of maximum activity during IMMC, and its histogram has a high concentration near to minimum value. However, IMI in pathological state varies in a smaller range and its histogram is more similar to a normal distribution than physiological histogram.

These differences in the IMI distribution were quantified by means of Skewness and Kurtosis coefficients. Obtained average and standard error for Skewness and Kurtosis coefficients are shown in table 2 for both situations. Significance level to distinguish both states is included too. Obtained values show that Skewness and Kurtosis are non significant parameters to distinguish both states. This can be because of the high

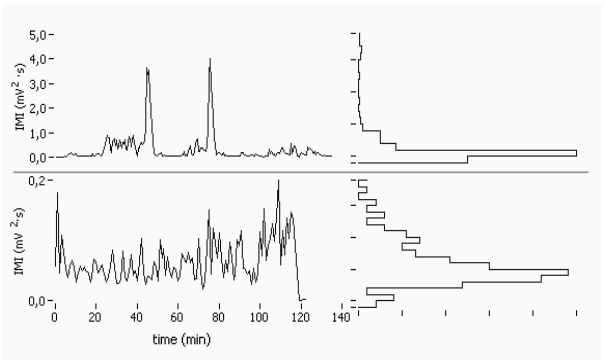

Figure 3: IMI time evolution of physiological patient signal and its histogram (upper trace). IMI of signal after paralysis induction and its histogram (lower trace).

Table 2: Calculated shape parameters for the IMI distribution in physiological and paralytic state. Mean value and standard error for all recording sessions.

Parameter	Physiological (n=18)	Paralytic ileus (n=12)	p-value
γ_1	2,82 1± 0,126	2,37 2± 0,444	0,2*
K	10,231 ± 0,939	10,711 ± 3,305	0,6*

* Kruskal-Wallis analysis

variability in shape among recording sessions that was found in paralytic ileus IMI.

Parameters of absolute values were also analyzed to obtain significant differences. Figure 4 upper trace shows the IMI of an EEnG of a physiological patient. The IMI parameter under physiological state presents periods of minimal value. These periods correspond to non contractile activity. More over, there are periods with high energy corresponding with phase III. On the other hand, after paralytic induction, all intestinal activity decreases. Thus the IMI is nearly 0 $mV^2 \cdot s$. This situation is similar to phase I. Figure 4 lower trace shows the IMI before and after anaesthesia.

These differences of absolute values allow studying IMI of myoelectric signal by means of statistic parameters as mean, standard deviation, maximum and minimum energy. However, these last two parameters were replaced by first and third quartile because maximum and minimum have a high sensibility to artifact presence. Moreover, median value of IMI distribution was evaluated too. All these parameters are shown in table 3 with their average value, standard error and significance.

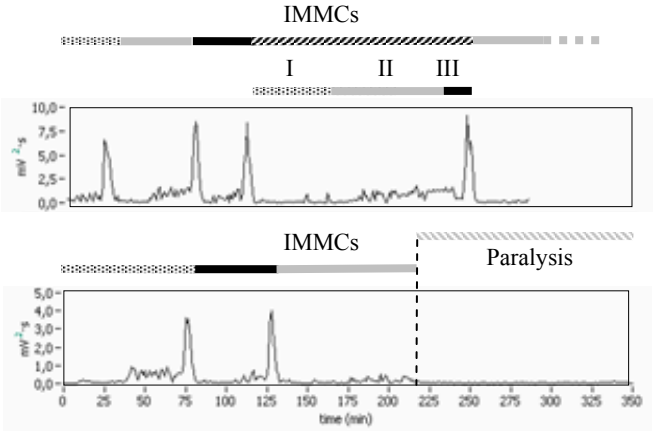

Figure 4: IMI of physiological patient signal. There are 3 complete IMMCs (upper trace). IMI of patient before and after paralysis induction, induced at min. 215. Before that, there are 2 complete IMMC and phase I of interrupted IMMC (lower trace).

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Table 3: Calculated parameters for IMI in physiological and paralytic ileus state. Mean value and standard error for all recording sessions.

Parameter ($mV^2 \cdot s$)	Physiological (n=18)	Paralytic ileus (n=12)	p-value
Mean	0,858 ± 0,107	0,030 ± 0,007	<0,001*
Sd	1,058 ± 0,122	0,020 ± 0,005	<0,001*
1st quartile	0,192 ± 0,040	0,024 ± 0,005	0,02**
Median	0,506 ± 0,084	0,031 ± 0,006	0,001**
3rd quartile	1,141 ± 0,146	0,041 ± 0,007	<0,001*

* Kruskal-Wallis analysis
** ANOVA analysis

Minimal IMI value represented by 1st quartile is a valid parameter to differ both states although it is not the best one (p=0,01). This result was expected because IMI in pathological conditions is similar to IMI in phase I of physiological IMMC. This effect decreases for median parameter because phase III of physiological IMMC increases its value, and its significance level is p=0,001. Finally, all other parameters are significantly different (p<0,001) for both conditions. Thus mean, standard deviation and 3rd quartile can be used to classify between small bowel in physiological and in paralytic ileus conditions.

This work could help to develop a non invasive method to diagnose paralytic ileus. So, it is an interesting line of investigation. At the moment, non-invasive recording of EEnG is being developed.

Conclusions

In the case of dogs, anaesthesia maintenance with 3% Sevorane induces a reversible small bowel paralysis that can be maintained.

Statistical parameters as mean value of EF2 of internal myoelectric signal for long recording sessions allow significant discriminating (p<0,001) between physiological conditions and paralytic ileus electroenterogram. Other significant parameters are standard deviation and 3rd quartile of this IMI distribution.

Proposed electroenterogram analysis can be a good tool to aid diagnosing paralytic ileus.

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