BOWEL SLOW WAVE FREQUENCY VARIATION IN FAST STATE

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Abstract: The intestinal myoelectrical activity known as electroenterogram (EEnG) regulates intestinal motility. The EEnG is composed of a permanent slow wave (SW), and spike bursts (SB) generated when smooth muscle cells contract. The SW (f≈18 cpm in dog) is always present and does not represent intestinal motility. The aim of this work is to study time evolution of SW frequency variation (SWFV) and to evaluate the relationship with the intestinal contractile activity degree. Bipolar electrodes where placed at different points of intestinal serosa of five Beagle dogs in order to acquire internal myoelectrical signals. Internal signals were acquired simultaneously in fast state. Autoregressive spectral estimation (AR) was used to determinate SW frequency distribution. Most maximum spectral peaks were obtained near 0.3 Hz (17 to 19 cpm) that corresponds to the SW frequency in normal conditions. However, SWFV were found and changes of up to 20% in frequency peak were obtained. SW frequency variation was studied along recorded sessions, and three types SWFV were obtained; type I without significant variations, type II time delayed and type III time-locked in relation to intestinal motility. Results show that it can exist a SW frequency pattern around phase III of the Interdigestive Migrating Myoelectric Complex.

Introduction

Difficult anatomic access is a technical problem for monitoring intestinal activity. There are several techniques to obtain the intestinal motility, but only two methods are widely used. The most direct method and extensively employed approach to date has been the recording of bowel pressure by means of manometric techniques. Although, these techniques introduce controversy due to the physiological and technical problems [1]. The other method is based on the myoelectric signal required for the smooth muscle cells to contract. Small intestinal electrical activity can be measured by implanting electrodes on the serosal surface of the small intestine during an abdominal surgical intervention. The relationship between mechanical and electrical activity is widely accepted [2 ,3]. The myoelectrical activity recording is an alternative to manometric techniques. However, the application of internal myoelectric techniques for clinical diagnostic purposes is restraint because surgery is required. A possible solution could be surface recording [4, 5].

Electroenterogram (EEnG) is the myoelectric signal of the smooth muscle of the small intestine. EEnG (figure 1) is the result of slow waves (SW) and sporadic spike bursts (SB). The SW also called basic electric rhythm is always present and does not represent intestinal motility. In dogs the SW frequency is about 18 cpm. On the other hand, SB are only generated when the smooth muscle cells contract and locate at SW plateau.

There are different patterns of intestinal mechanical activity in different bowel conditions: physiological/ pathological, fed/fast state. In physiological conditions and fast state, small bowel keeps on working to clean the luminal content which generates the interdigestive migrating myoelectric complex (IMMC) [2]. IMMC can be divided in three phases (see figure 5), from no contractile activity in phase I (SB superimposed at SW plateau ratio < 10%); phase II (10% < SB superimposed at SW plateau ratio < 90%) to maximum contractile activity in phase III (SB superimposed at SW plateau ratio > 90%) [2]. Phase III is the shortest phase with a duration of 5-8 minutes.

Application of spectral analysis in data processing has taken an important place in the last decade.

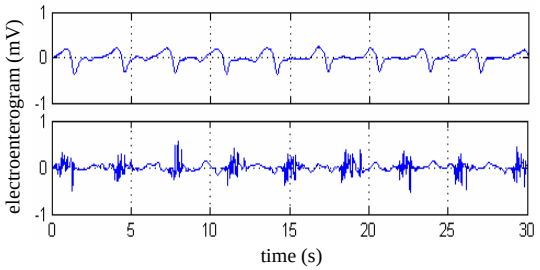

Figure 1. Internal electroenterogram in dogs (f≈18cpm) without contractions (upper trace) and with maximum contractions (lower trace).

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The limited frequency resolution of non-parametric techniques can be partially overcome by parametric spectral analysis based on linear models. The parametric approach is very attractive for processing signals from various areas, for example, electrogastrogram (EGG) [6], electrocardiogram (ECG), electroencephalogram (EEG) and of course electroenterogram (EEnG). Furthermore, linear modeling is altogether a versatile tool for signal analysis as it includes model selection, prediction, and description of signals by a few (model) parameters. It has been established that SW does not represent intestinal activity [3]. However SW variations have been observed in several studies [2,7]. This opens the possibilities for the existence of some relation among the SW parameters and IMI.

The purpose of present work is to study time evolution of slow wave frequency variations of EEnG and to evaluate its relationship with the degree of intestinal contractile activity.

Materials and methods

Eighteen recording sessions (alternative days) were taken in five Beagle dogs. Six internal bipolar electrodes were implanted along the small bowel, at the following points: duodenum, Treitz angle, 3 at jejunum (located at a distance of 45 cm, 90 cm and 135 cm from the Treitz angle), and ileum. Recording sessions were carried out with animals in fast state for more than 16 hours. Each session implied the recording of more than 3 hours of internal signal per analyzed point of measurement. Signals were amplified with a bandwidth of [0.05 Hz, 35 Hz]. The sampling frequency was 100 Hz. Only the myoelectrical signal from jejunum was used for this analysis.

Intestinal motility index (IMI) is calculated in order to represent the mechanical activity of the small bowel. The IMI of signals was obtained through filtering by a Butterworth high-pass filter with a cutoff frequency of 2 Hz and calculating the RMS value. This IMI is similar to energy over 2 Hz analyzed in previous works [3, 4].

In order to study SW frequency, signals were filtered by low pass filter with a cutoff frequency of 2 Hz and re-sampled at 5 Hz. For each session the AR method was applied to every minute of signal so as to determinate the SW frequency by the maximum spectral peak. AR estimator in this study uses prediction algorithms based on the autocorrelation matrix to find the coefficients of the autoregressive model of the original signal. An important aspect in AR models is the selection of the order (p) [8]. The order (p) was auto-adjusted for every minute of analyzed signal by diminishing the variability of the spectral estimation. Frequency resolution of $\Delta f = 0.005$ Hz was obtained in spectral analysis.

In order to estimate differences among frequency variations was eliminated 5% of frequency extreme values for each session. Then was determinate the box-Whiskers diagram and were normalize median values.

In order to relate slow wave frequency variation with IMI, mean and standard deviation of slow wave frequency within a 20 minutes window previous and posterior to phase III activity was analyzed. Similar analysis was held for each of the phases of IMMC. *T*-test for independent samples ($p<0.05$) was used in order to establish significant differences between slow wave frequency distribution in the different situations.

Results

Figure 2 shows the temporal evolution of power spectral density along one session recorded at jejunum in fast state. It can be observed that the SW frequency changes throughout time and it is represented by the maximum spectral peaks of the frequency estimation.

Figure 3 shows the normalized distribution for every analyzed session of five dogs. It can be observed that in some sessions the SW frequency is almost constant. In these cases, slow wave frequency variations do not reach 10%. These sessions are marked with an arrow. Nevertheless in other sessions, SW frequency reaches higher variations than 10%. These variations indicate significant changes in the SW frequency. Lower traces of figure 4 and figure 5 represent time evolution of SW frequency along two of the recording sessions that showed significant SW frequency variations. On the other hand, upper traces of figures 4 and 5 show simultaneous time evolution of intestinal motility index in fast state.

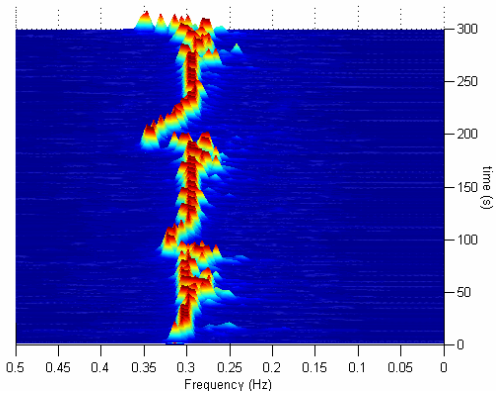

Figure 2. Time evolution of the power spectral density evaluated by AR method on jejunum EEnG signal during one recording session.

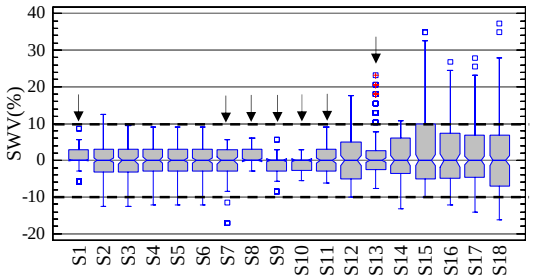

Figure 3. Normalized distribution of SW frequency variation in fast state in each analyzed session

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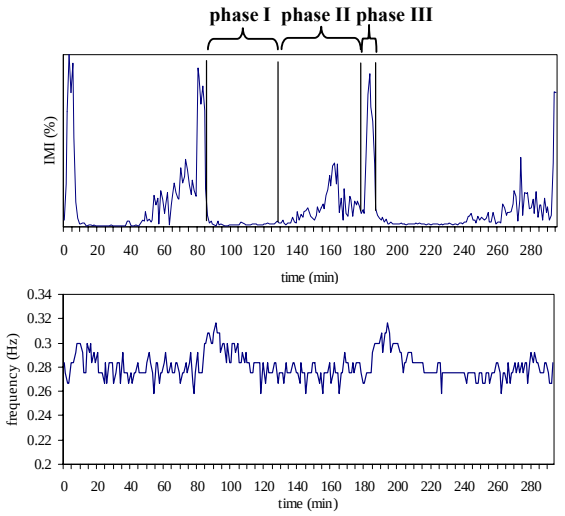

Figure 4. Intestinal motility index (upper trace) and slow wave frequency (lower trace) at dog's jejunum in fast state. Session 6, classified as type II.

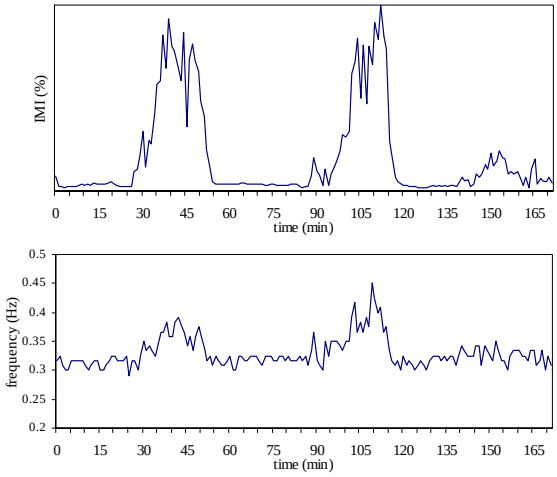

Figure 5. Intestinal motility index (upper trace) and slow wave frequency (lower trace) at dog's jejunum in fast state. Session 6, classified as type III

This motility pattern is well known and is called interdigestive motor complex. It can also be appreciated that the changes in SW frequency follow a similar pattern to that of IMI. In figure 4, it can be appreciated that there is a delay between time evolution of IMI and of the SW frequency. The slow wave frequency increment (lower trace) is reached when the phase III activity of IMI has already finished (upper trace). The maximum frequency level is reached a few minutes later than the phase III activity, i.e., with relation to IMI, SW frequency variation appears delayed. On the other hand, in figure 5 the SW frequency followed a similar evolution pattern to that of IMMC, but in this case both patterns visually coincided at the same time. As it can be observed, the SW frequency reached its maximum at the same moment of phase III.

According to these results, SW frequency patterns in fast state can be divided into three types: type I without

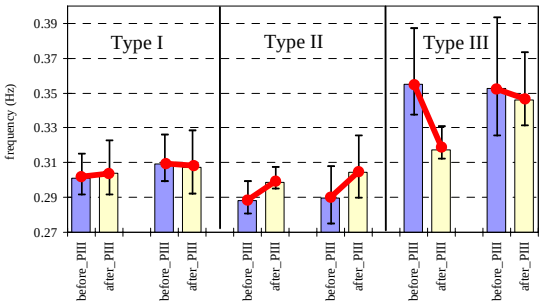

Figure 6. Mean and standard deviation of SW frequency in 20-minute window previous and posterior to phase III, for different recording sessions.

significant variations, type II time delayed and type III time-locked in relation to intestinal motility.

Figure 6 shows mean and standard deviation of SW frequency within a 20 minutes window previous to phase I and posterior to phase III. The three types of SW frequency behavior can be identified by a different trend in SW frequency distribution before and after phase III. Only 6 recording sessions are shown in order to simplify the graphical visualization. However, all analysed sessions could be classified in these 3 types. When the slow wave frequency variation was inferior than 10% (S1 and S8 of figure 3), there was not significant frequency change between both states (type I of figure 6). Type II is characterized by a significant ($p<0.05$) increase in SW frequency peak after phase III. Finally for type III patterns, the SW shows a significant slow wave frequency decrease when phase III finishes.

Figure 7 shows the behavior of slow wave frequency in relation to each phase of IMMC. Again, although only 6 sessions are shown, the same study was held for all recorded sessions. As it can be observed, in type I sessions there are negligible difference in SW frequency in each of the IMI phases. On the other hand, in type II, maximum SW frequency is reached in phase I, due to the delay with motor activity.

Moreover in this type o pattern, phase III presents slightly higher SW frequency that phase II. This is probably because the SW frequency raise although delayed, has already started. Finally, the third pattern of slow wave frequency in fast state (type III) can be clearly distinguished. In this case, in a similar way

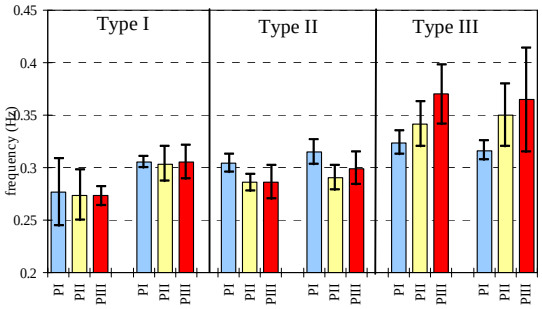

Figure 7. Mean and standard deviation of SW frequency in each of the phases of IMMC, for different recording sessions.

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to motor activity, SW frequency presents minimum values during phase I, increases in phase II and maximum values are obtained during phase III.

Discussion

The myoelectrical signal recorded at small intestine serosa was used to study time evolution of SW frequency and to evaluate the relationship of its possible variations with the intestinal contractile activity degree.

Three types of slow frequency patterns in fast state were found in this study. In the first type of SW frequency does not change significantly. This is in agreement with many authors that do not consider SW frequency variations in normal conditions [2, 4, 5]. According to some studies, this is the pattern obtained when IMMC is of ectopic origin [7]. Though, this fact has still to be demonstrated.

However, results of this work show that in many cases these SW frequency variations can be greater than 10% up to more than 20%. In these cases SW frequency followed a similar pattern to motor activity pattern (IMMC). This has also been previously described by other authors [7, 9]. However, these few previous works reported that the phase III began a few minutes before the start of the SW frequency pattern and ended a few minutes before the SW frequency reached its maximum [7]. These reports coincide with the type II of SW frequency pattern observed in present work. Nevertheless, a third type of SW frequency complex has been identified in the present study. This type III pattern of SW frequency is synchronized with the IMMC. In these sessions recording of slow wave frequency could be used to detect interdigestive motility complexes.

The SW frequency changes that can occur in normal conditions in fast state have to be taken into account in order not to be misinterpreted with frequency decrease of SW as a consequence of pathological conditions such as bowel ischemia [10].

Conclusions

In this work, it was shown that slow wave frequency can change throughout recordings sessions in fast state. In these conditions, intestinal motor activity follows the well known interdigestive migrating motor complex (IMMC). On the other hand, slow wave frequency can behave in three different ways: type I with no significant changes in SW frequency; type II when SW frequency follows a similar pattern to IMMC that appears time-delayed; and finally type III that is similar to type II, but SW frequency pattern occurs at the same time as IMMC.

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