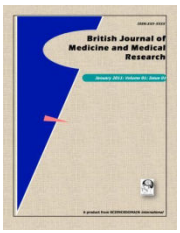

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Researches on Gastric Interdigestive Pressure Activity: Methods, Analysis and Interpretation

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Research Article

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ABSTRACT

Aims: To give researches on gastric interdigestive pressure activity, including gastrointestinal (GI) physiological motility recording method, data processing and analysis method, as well as to give reasonable interpretation on how to generate such gastric pressure activity.
Study design: Basic application study.
Place and Duration of Study: School of Medical Instrument and Food Engineering, University of Shanghai for Science and Technology (USST), between June 2010 and October 2011.
Methodology: We introduced a telemetric method to get the gastric physiological pressure activity inside the GI tract and the general process for processing such gastric Migrating Motor Complex (MMC) pressure activity including the process of abnormal value removing, medians of five-three-Hanning (53H) weighted average smoothing, and the fluctuation frequency estimation.
Results: Using the process of abnormal value removing, medians of five-three-Hanning (53H) weighted average smoothing, and the fluctuation frequency estimation, we well obtained gastric interdigestive pressure activity (MMC).
Conclusion: The methods introduced in the paper including abnormal value removing, the 53H weighted average smoothing, and the fluctuation frequency estimation were helpful for researches on gastric interdigestive pressure activity.

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Keywords: Migrating motor complex; abnormal value removing; weighted average smoothing; telemetric capsule.

1. INTRODUCTION

The normal function of the gastrointestinal (GI) tract is to mix food, grind and transport the contents to the lower tract when it carries out its normal digestive function. It is widely accepted in clinics that peristaltic movement of the gastrointestinal tract is organized by a network of enteric neurons in the myenteric plexus. Ascending contraction and descending relaxation of the gastrointestinal tract simultaneously occur to forward luminal contents along the whole gastrointestinal tract. Another factor that makes an essential contribution to the coordinated actions of the gastrointestinal motility through such a network is the interstitial cells of Cajal (ICC) (Nakayama et al., 2006, 2009; Rumessen and Vandervinden, 2003; Takaki, 2003). Actually in the gastrointestinal tract, surrounded the myenteric plexus between the circular and longitudinal muscle layers are pacemaker cells that initiate spontaneous electrical activity. In some stage of diseases, gastrointestinal motility disorders may be caused by functional impairment of ICC preceded by or not linked with its histological changes. Therefore, human spares no effort to develop devices for recording such electrical activity so as to evaluate ICC spatio-temporal activity.

Investigators have studied intracellular electrical and contractile activity of smooth muscle fibers, and reached a general agreement regarding the relationship between these two phenomena. They used many different terms to describe such gastric electrical activity, slow potential, slow wave, initial potential, control potential, spikes and etc. Electrical Control Activity (ECA) and Electrical Response Activity (ERA) are two major types of gastric electrical activity recorded in vitro (Irimia et al., 2006; Bowen, 1996). Such two different types of electrical activity, ECA and ERA, are clearly recognized in the cells of the distal two-thirds of the stomach. ECA is considered to be the initial rapid depolarization of the cell and is a necessary for contraction to occur, though it is not a sufficient condition for contraction to occur (see Figure 1a). It is periodic by nature, with a frequency of 3 cycles per minute, i.e., 3cpm. The ERA itself can be separated into two components: plateau and spikes (see Figure 1(b)). The spikes that superimposed over the plateau of the ERA may indicate that contraction will follow. The force of contraction that will follow in that case will not be higher than 0.25N (see Figure 1(c)). The presence of spikes indicates that a contraction with greater strength is expected.

During the gastric fasting state or the interdigestive (between meals) phase, such gastric electrical activity can display the features of migrating motor complex (MMC). The MMC can be separated into three phases: quiescent phase I, when only ECA is present; transitional phase II, in which both ECA and ERA are present; phase III, during which spike activity is always superimposed on the plateau of ERA, and ECA is always followed by ERA. In fact, the MMC is a wave of activity that sweeps through the intestines in a regular cycle. Such complex helps trigger peristaltic waves which facilitate transportation of indigestible substances from the stomach, through the small intestine past the ileocecal sphincter into the colon.

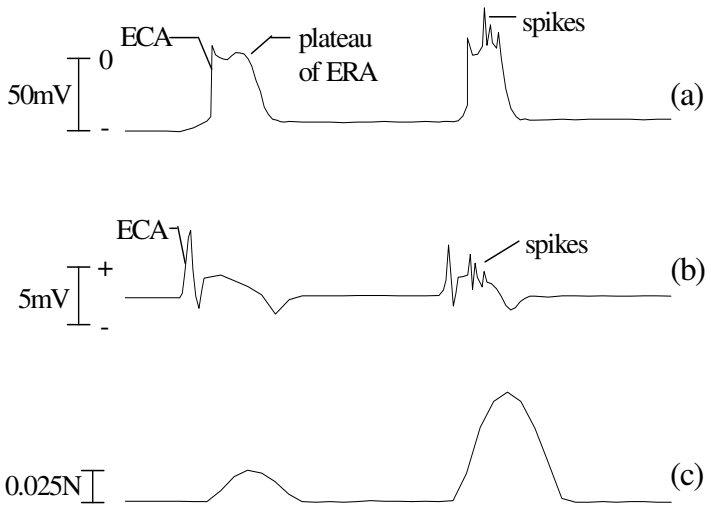

Figure 1. The Gastric Myoelectric Activity (GMA) and Contractile Activity of gastric smooth muscle cell
(a) Intracellular electrical activity.
(b) Extracellular electrical activity.
(c) Contractile force of the gastro smooth muscle cell.

2. MATERIALS AND METHODS

2.1 The Overview of the Diagnosis System

The GI motility recordings were acquired by using a telemetric capsule (see Figure. 2), invented in the past few years for diagnosing gastrointestinal functional diseases (Wang et al., 2005; Yan et al., 2006, 2008, 2010). The four main components of the diagnosis system were:

1) A capsule, which was the first component that performed data acquisition of physiological parameters like pressure within the gastrointestinal tract under the normal physiological conditions, sent the data wirelessly to the next component, i.e., the in-vitro pocket data recorder.

2) An in-vitro pocket data recorder, which could be mounted around the waist of the subject and received parameters from the telemetric capsule.

3) An ultrasonic locating unit, which performed detecting where the capsule was actually in the gastrointestinal tract.

4) An in-vitro data processing computer, which performed receiving the acquired data from the pocket data recorder via a universal serial bus (USB) interface and finally processed them under the instruction and guidance of clinical doctors.

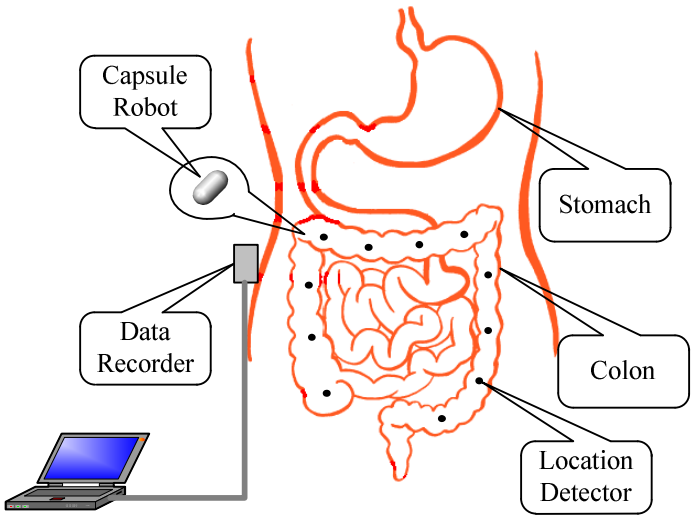

Figure 2. The practical measuring system for the intestinal tract.
The main components of the system was a capsule, an in-vitro pocket data recorder, an ultrasonic locating unit, and an in-vitro data processing computer.

The shape of the capsule looked like a cod liver oil pill with 21.1mm length, 10.0mm diameter and 2.9gram weight. The sampling frequency of the system was about 0.83Hz (that was, a sample every 1.2 seconds). This sampling rate was more than adequate to measure gastrointestinal motility signals that, in humans, lied in the range from 1 cycle per minute (cpm) to 12 cpm (0.016Hz to 0.2Hz).

2.2 Clinical Experiment

After the subject has swallowed the capsule with a cup of water, it began its journey in the gastrointestinal tract by the natural peristaltic motion (i.e., by human gastrointestinal motility) of the gastrointestinal tract until it was moved out normally outside the body through the anus. During the journey, the gastrointestinal pressure data were recorded in the capsule firstly. The data were, then, transported to the pocket data recorder via a Radio-Frequency (RF) transmitting module embedded in the capsule due to limited store memory on a chip. Finally, the data could be downloaded through a USB interface to our computer easily for further clinic diagnosis and study.

During the experiment, no subject complained of any discomfort except few volunteers had some difficulties to swallow at the beginning for their psychological factors and swallowed the capsules successfully with ease with another cup of water.

2.3 Data Analysis

2.3.1 Abnormal value removing

In statistics, for an observation X from a normally distributed random variable with the mean of the distribution μ and the standard deviation $\acute{o}$, the density function of such normally distributed random can be given,

$$f(X)=\frac{1}{\sigma\sqrt{2\pi}}e^{\frac{(X-\mu)^2}{2\sigma^2}},-\infty<X<+\infty \quad (1)$$

As we know, about 68.27% of the values lie within one standard deviation of the mean (ì-ó<P(X)<ì+ó), P(X) is the probability function that lies between ì-ó and ì+ó), about 95.45% of the values lie within two standard deviations of the mean (ì-2ó<P(X)<ì+2ó). And nearly 99.73% of the values lie within three standard deviations of the mean (ì-3ó<P(X)<ì+3ó). This rule called that 68-95-99.7 rule or three-sigma rule in statistics.

This rule can used to remove those abnormal values in the raw data, since such abnormal values are very few, and always do not lie within three standard deviations of the mean.

2.3.2 The medians of five-three-Hanning smoothing method

The medians of five-three-Hanning weighted average smoothing method, which is also termed the 53H method ("5" is a method for a median-of-five smoothing, "3" for a median-of-three smoothing, and "H" for Hanning smoothing) presented by Tukey (Tukey, 1977; 1981), adopts three times weighted smoothing to the raw data to produce the final smoothed estimates. Three steps for the signal pre-processing are five-point moving average smoothing (median-of-five smoothing), three-point moving average smoothing (median-of-three smoothing), and Hanning moving average smoothing.

Let the raw original data is {x(i)}, i=1, 2,…, n, where n is the total number of points in the signal. Then, three steps for the method can be expressed as follows:

(1) Five-point moving average smoothing. The first step is to form the first smoothed signal {y(i)} from the original time sequence {x(i)} using 5-point moving average smoothing method. For a 5-point smooth,

$$y(i)=\frac{x(i-2)+2x(i-1)+3x(i)+2x(i+1)+x(i+2)}{9} \quad (2)$$

for i=3 to n-2, where y(i) is the i-th point in the first smoothed signal, x(i) is the i-th point in the original signal. And, the four items missed in the first smoothed signal can be estimated as,

$$y(1)=y(2)=y(3),\ y(n)=y(n-1)=y(n-2) \quad (3)$$

(2) Three-point moving average smoothing. For the first smoothed signal, we use 3-point moving average smoothing method to form the second smoothed estimates. For a 3-point smooth,

$$z(i)=\frac{y(i-1)+y(i)+y(i+1)}{3} \quad (4)$$

for i=2 to n-1, where z(i) is the i-th point in the second smoothed signal, y(i) is the i-th point in the first smoothed signal. And, the two items missed in the second smoothed signal can be estimated as,

$$z(1)=z(2),\ z(n)=z(n-1) \quad (5)$$

(3) Hanning moving average smoothing. For the second smoothed signal, we take Hanning filter to obtain our final smoothed signal. For a Hanning smooth,

$$u(i) = \frac{z(i-1) + 2z(i) + z(i+1)}{4} \tag{6}$$

for i=2 to n-1, where u(i) is the i-th point in the final smoothed signal, z(i) is the i-th point in the second smoothed signal. And, the two items missed in the final smoothed signal can be estimated as,

$$u(1) = u(2)\ ,\ u(n) = u(n-1) \tag{7}$$

2.3.3 Fluctuation frequency estimation

In order to estimate fluctuation frequency of the gastric pressure activity, we first need to find all local maxima in the final smoothed signal u. And then, the fluctuation frequency can be estimated by the total number of all local maxima divided by the time that the signal presents.

To the smoothed signal u, the local maxima index can be expressed by,

$$index = find(diff(sign(diff(u))) < 0) + 1 \tag{8}$$

Where, diff is difference and approximate derivative. For the vector u, *diff*(u) equals [u(2)-u(1) u(3)-u(2) ... u(n)-u(n-1)]. In the above equation, sign is a signum function, sign(X) returns 1 if the element is greater than zero, 0 if it equals zero and -1 if it is less than zero for each element of a vector X. In the equation, find is a function to find indices of *diff*(*sign*(*diff*(u)))<0.

3. RESULTS

A representative gastric pressure activity (original raw data) of a healthy forty-two-year-old female volunteer was shown in the Figure 3(a). The subject ate no food before the experiment. The gastric pressure activity was recorded about one hour after the subject began the experiment and such type of gastric activity lasted about 47 minutes.

We firstly took the abnormal value removing method to get rid of those abnormal values. Abnormal values were sometimes caused by occasional strenuous exercise of the body, pressure sensor blocking caused by the gastrointestinal contents, temporary system failure, i.e., RF transmitter/receiver connection failure, pressure senor failure, or even no battery power. Then, we implemented the medians of five-three-Hanning (53H) weighted average smoothing method to get the smoothed one of the original raw data, and plotted it in Figure 3(b).

Abdominal radiography (X-ray) film confirmed that the position of the telemetric capsule was in the stomach (see Figure 4). It also confirmed that the pressure activity we acquired at this time was actually from the stomach.

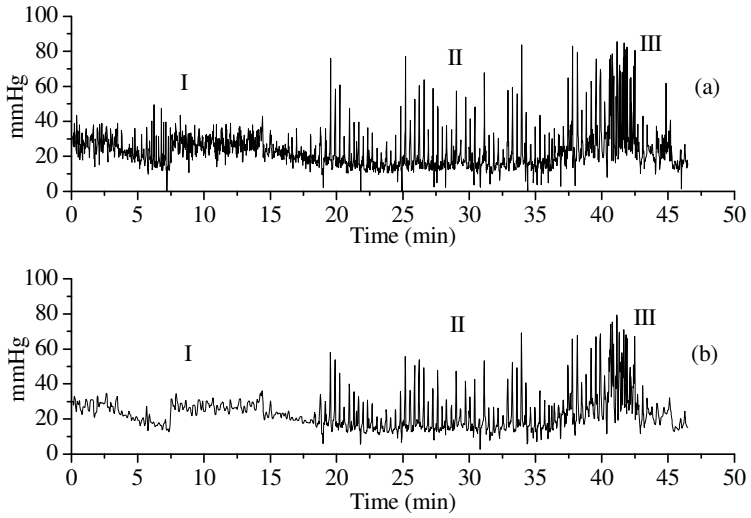

Figure 3. The representative gastric pressure activity and its preprocessed one

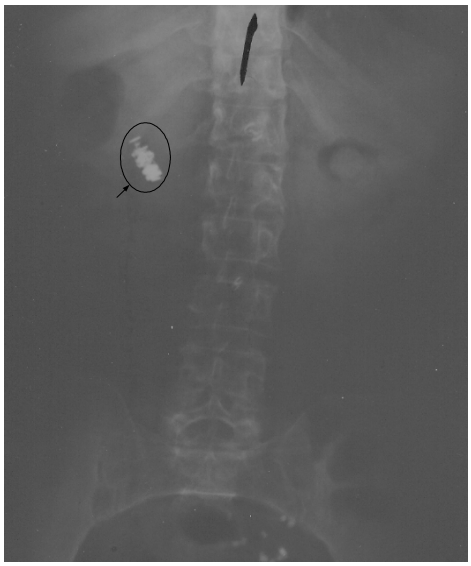

Figure 4. The radiography film confirmed the capsule in the stomach and the pressure activity was from the stomach

After removing those abnormal values and implementing the 53H weighted average smoothing of the original pressure activity, we could see that the pressure activity was obviously composed of three different phases: phase I, II and III. During the phase I, the pressure activity lasted about 20 minutes, and was nearly quiescent with small fluctuations or spikes. There were intermittent contractions with a certain rhythm in the phase II, which lasted also about 20 minutes. There existed powerful contractions in the phase III, which lasted less about 5 minutes. Such activity was considered to be gastric migrating motor complex (MMC).

Furthermore, we tried to find all local maxima in the phase II of the final smoothed signal to estimate the fluctuation frequency. However, due to nonstationary of the time series, we gave a parameter FILT, which was the number of passes of the small running average filter in order to get rid of small peaks. Default value, FILT=0, which means performing no filtering. Otherwise, we use a convolution between the final smoothed signal u and a 3-point running average filter to remove such small peaks.

The original MMC pressure activity was plotted in the Figure 5(a). In the Figure 5(b), the small running average filter parameter FILT was set to 40, and in the Figure 5(c), the parameter FILT was 12. The red asterisks both in the Figure 5(b) and Fib(c) were captured local maxima. Their differences were that, in the Figure 5(b), there were some local maxima could not be captured, and in the Figure 5(c), all local maxima were exactly captured. Accordingly, the fluctuation frequency estimated in the Figure 5(b) was f = 2.7cpm and it was smaller than its actual value estimated in the Figure 5(c) with f = 2.9cpm. Thus in practice, we adopted a combination of local maxima capturing and visual observation to estimate the fluctuation frequency. Our experience proved that FILT changing from 12 to 20 was better meeting our needs.

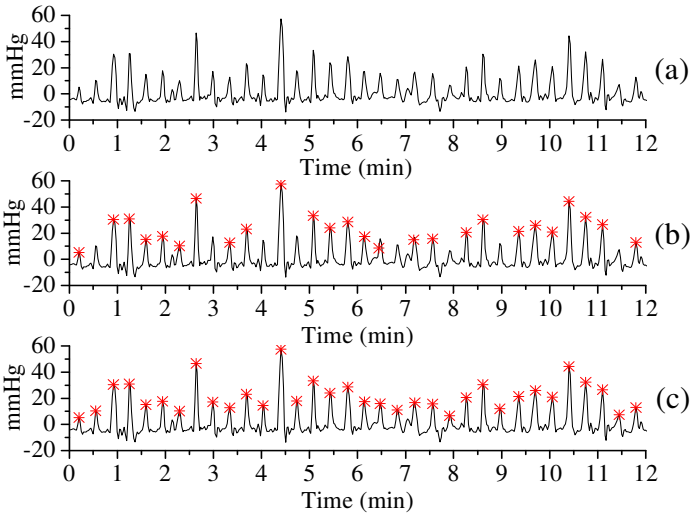

Figure 5. Fluctuation frequency estimation of the MMC pressure activity.
(a) The MMC pressure activity
(b) Local maxima capturing with FILT = 40, f = 2.7 cpm
(c) Local maxima capturing with FILT = 12, f = 2.9cpm

4. DISCUSSION

It is well known that there exists a spatiotemporal pattern called gastric myoelectrical activity (GMA) at cell level in the human stomach (Smout, 1980; Lin et al., 1999; Koch et al., 1993; Wang et al., 2004). The GMA includes temporal evolution from endogenous rhythmic oscillating (electrical control activity, or ECA, slow wave) of 3cpm originated in the pacemaker area, to bursting of spikes (electrical response activity, or ERA, fast wave) associated with contractions and modulated by neurochemical mechanisms, and also spatial propagation of the oscillating wave driven by the coupling mechanisms from cell to cell

(Sarna et al., 1993, 1976; Chen et al., 1995; Wang et al., 2004), which regulates the contractions and emptying of the stomach.

In order further to illustrate the transfer process of the MMC, we used resistance and capacitance circuits and their series and parallel ones in electronics to describe such transfer process of the MMC as shown in the Figure 6.

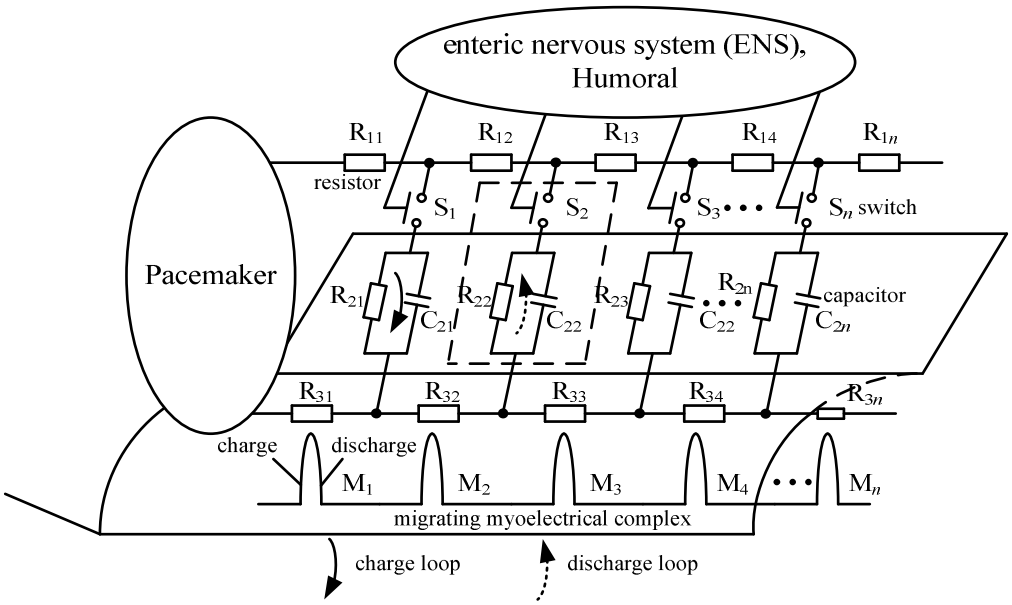

Figure 6. An electronic model of gastric MMC pressure activity

We pictured the gastric tissue as composed of an infinite number of electrotonic "patches" with each patch composed of a resistance R_{2i} and capacitance C_{2i} in parallel and a switch S_i dominated by the gastrointestinal enteric nervous system (ENS) or regulated by the hormone. Each patch was linked by two up and down resistances R_{1i} and R_{3i}, offering the flow of the local activity (see Figure 6). Each patch could be considered to be a charge and discharge circuit, whose charge or discharge process was controlled by the ENS or regulated by the hormone. The initial pressure was originated from the gastric pacemaker area. Such electrotonic patches could be used to produce and well illustrate the migrating of the gastric pressure activity from the stomach to the small intestinal tract.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Bowen, R. (1996). Electrophysiology of gastrointestinal smooth muscle. Retrieved February 12, 2008.

Chen, J.D.Z., Pan, J., McCallum, R.W. (1995). Clinical significance of gastric myoelectrical dysrhythmia. Digestive Disease, 13, 275-290.

Irimia, Andrei, Richards, William O., Alan Bradshaw, L. (2006). Magnetogastrographic detection of gastric electrical response activity in humans. Physics in Medicine and Biology, 51(5), 1347-1360.

Koch, K.L., Tran, T.N., R.M. Stern, et al. (1993). Gastric myoelectrical activity inpremature and term infants. Neurogastroenterology and Motility, 5(1), 41–47.

Lin, Z., Eaker, E.Y., Sarosiek, I., et al. (1999). Gastric myoelectrical activity and gastric emptying in patients with functional dyspepsia. The American Journal of Gastroenterology, 94(9), 2384-2389.

Nakayama, S., Shimono, K., Liu, H.-N., et al. (2006). Pacemaker phase shift in the absence of neural activity in guinea-pig stomach: a microelectrode array study. Journal of Physiology London, 576, 727-738.

Nakayama, S., Ohishi, R., Sawamura, K., et al. (2009). Microelectrode array evaluation of gut pacemaker activity in wild-type and W/Wv mice. Biosensors and Bioelectronics, 25, 61-67.

Rumessen, J.J., Vandervinden, J.-M. (2003). Interstitial cells in the musculature of the gastrointestinal tract: Cajal and beyond. International Review of Cytology, 229, 115-208.

Sarna, S.K., Bowes, K.L., Daniel, E.E. (1976). Gastric pacemakers, Gastroenterology, 70, 226-231.

Sarna, S.K., Otterson, M.F. (1993). Myoelectric and contractile activities, in: atlas of gastrointestinal motility in health and disease, Williams & Wilkins, Baltimore.

Smout, A.J.P.M. (1980). Myoelectric activity of the stomach, Gastroelectromyography and electrogastrograghy. Delft, The Netherlands: Delft University Press.

Takaki, M. (2003). Gut pacemaker cells: The interstitial cells of Cajal. Journal of Smooth Muscle Research, 39, 137-161.

Tukey, J.W. (1977). Exploratory data analysis, Addison-Wesley.

Tukey, P.A., Tukey, J.W. (1981). Graphic display of data sets in 3 or more dimensions, in interpreting multivariate data, Wadsworth, Belmont.

Wang, W.X., Yan, G.Z., Sun, F., et al. (2005). A non-invasive method for gastrointestinal parameter monitoring. World Journal of Gastroenterology, 11(4), 521-524.

Wang, Z.S., He, Z., Chen, J.D. (2004). Chaotic behavior of gastric migrating myoelectrical complex. IEEE Transactions on Biomedical Engineering, 51(8), 1401-1406.

Yan, R.G., Yan, G.Z., Zhang, W.Q., et al., (2006). Phase coupling analysis of gastric pressure activity via wavelet packet based diagonal slice spectra. Computer Methods and Programs in Biomedicine, 83,198-204.

Yan, R.G., Yan, G.Z., Zhang, W.Q., et al. (2008). Long-range scaling behaviours of human colonic pressure activities. Communications in Nonlinear Science and Numerical Simulation, 13, 1888-1895.

Yan, R.G., Yan, G.Z., Guo, X.D., et al. (2010). A practical measuring system for intestinal pressure activity and its clinical application. Biomedical Signal Processing and Control, 5, 82-86.