

# Gastric motility functional study based on electrical bioimpedance measurements and simultaneous electrogastrography\*

Li Zhang-yong<sup>1</sup>, Ren Chao-shi<sup>†‡1</sup>, Zhao Shu<sup>2</sup>, Sha hong<sup>2</sup>, Deng Juan<sup>2</sup>

(<sup>1</sup> College of Bioinformation, Chongqing University of Posts and Telecommunications, Chongqing 400065, China)

(<sup>2</sup>Institute of Biomedical Engineering, Chinese Academy of Medical Sciences & Peking Union Medical College, Tianjin 300192, China)

<sup>†</sup>E-mail: renbme@163.com

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**Abstract:** For some time now, the research on gastric motility and function has fallen behind in the amount of research on gastric endocrine, exocrine secretion, and gastric morphology. One of the important reasons is an absence of convenient and effective measurement methods. Research on the impedance method used to measure digestion course has mainly concentrated on gastric emptying measurement, and there is little research on extraction of gastric motility information. A noninvasive method to study gastric motility was developed by the authors, taking bioimpedance measurements over the gastric area simultaneously with the EGG. This is based on the concept of observing and analyzing simultaneously the intrinsic electrical gastric activities (basic electric rhythm) and the mechanical gastric activity. Additionally, preliminary clinical studies of healthy subjects and subjects with functional dyspepsia (FD) and gastritis were carried out. The measurement of impedance gastric motility (IGM) of the healthy and the FD subjects, were compared, along with the studies of the FD subjects before treatment, and after one week and three weeks of treatment. We also compared IGM measurement of healthy subjects and subjects with erosive gastritis, along with the results of studies of the subjects with erosive gastritis before treatment, and after one week of treatment. Results show that FD subjects have poor gastric motility ( $P < 0.01$ ). After a week of treatment the gastric motility of FD subjects was not yet improved although the EGG had returned to be normal by this time. By three weeks of treatment, the regular IGM rhythm returned in FD subjects. There was a significant difference of IGM parameters between the gastritis subjects and the healthy ( $P < 0.05$ ). The EGG rhythm of the gastritis subjects returned to normal at one week post-treatment, while IGM parameters showed a trend to improvement, ( $P > 0.05$ ). Results of the study suggest the possibility of clinic application of the proposed method.

**Key words:** gastric motility, electrical bioimpedance, electrogastrography, functional dyspepsia, gastritis

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## 1 Introduction

Gastric motility is one of the most critical physiological functions of the human body. Without coordinated gastric motility, digestion and absorption of dietary nutrients cannot take place. Impairment in gastric motility results in delayed emptying of the stomach and symptoms, such as nausea, vomiting, abdominal pain or discomfort, and so on (Chen *et al.*, 2000). For some time now, the research on gastric motility and function has fallen behind in the amount of research on gastric endocrine, exocrine secretion, and gastric morphology. One of the important reasons is an absence of convenient and effective measurement methods (Zhou *et al.*, 2005).

Electrical bioimpedance measurements are dependent on the electrical properties of tissues and organs, and include morphological and functional information. The method has the outstanding advan-

tages of being noninvasive, convenient, and providing considerable functional information. It can be considered a powerful tool in clinical diagnosis and medical research (Gajre *et al.*, 2006). There are many applications using bioimpedance signals for different pathological conditions, but their use in gastric motility assessment needs to be explored in detail (Hadi *et al.*, 2002).

Sutton *et al.* reported their research on extracting gastric movement signal by the electrical impedance method (Sutton *et al.*, 1985), and a curve reflecting gastric emptying was obtained. From the curve, gastric peristaltic information with a rhythm 2-4 cpm, which is in accord with gastric contraction, was extracted. Familoni *et al.* presented a technique to monitor gastric electrical activity (GEA) and mechanical activity as an aid in assessing gastric motor function (Familoni *et al.*, 1987). Kothapalli established a three-dimensional abdomen model to study the origin of changes in the epigastric signal (Kothapalli *et al.*, 1992), and analyzed the relationship between gastric

<sup>‡</sup> Corresponding author

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impedance signal and food capacity, resistivity of the test meal, and gastric contraction when the excitation electrode and measurement electrode were located at different positions.

Early research with the impedance method to measure digestion was mainly concentrated on gastric emptying measurement (Huerta *et al.*, 2009; Chaw *et al.*, 2001; Giouvanoudi *et al.*, 2003). There is little research on extraction of gastric motility information (Soulsby *et al.*, 2006, Garay *et al.*, 2006, Giouvanoudi *et al.*, 2008). One of the primary reasons is that the rhythm of gastric motility is much lower, about 3 cpm. It is more difficult to extract the gastric motility signal and eliminate respiration interference. Chen *et al.* reported their work on obtaining the electric impedance signal to reflect gastric contraction (Chen *et al.*, 1991a), and measurement devices were developed (Chen *et al.*, 1991b). However, the impedance signals obtained by the devices are all similar sine waveforms for both healthy and diseased subjects, because of incorrect filter processing. It has been difficult to differentiate normal or abnormal conditions from the signals. The authors of this paper have proposed a noninvasive electrical impedance method for gastric motility measurement and evaluation (Li *et al.*, 2007). Multi-resolution analysis of the wavelet is adopted to separate impedance gastric motility (IGM) signal from the mixed impedance signal obtained on the body surface (Li *et al.*, 2008).

## 2 Methods

### 2.1 The composite course from electrical gastric activity to mechanical gastric activity

Gastric contraction is a mechanical behavior of the electrical activity occurring on the cell membrane surface of smooth muscle. It begins from electric activity of the smooth muscle, followed by evoked contraction of the gastric corpus and antrum, and then transmits to the distal pylorus. It is a composite course from electrical activity to mechanical contraction, then to gastric peristalsis and transmission. Gastric contraction complies with the rhythm of electric activity, and is affected by amplitude, time limitation, transmission direction, and distance of the transmission contraction (Zhou *et al.*, 2005). Gastric motility is a complex composite course from electrical gastric activity to mechanical gastric activity, and it is very important to measure and evaluate gastric motility according to the composite course (Ren *et al.*, 2010).

There are two kinds of gastric myoelectrical activity to be observed, the slow wave and the spike potential. Gastric antrum contraction occurs only

when the slow wave occurs with the spike potential. The spike potential appears during the slow wave phase, and the rhythm of gastric contraction may be determined by the slow wave (Ma *et al.*, 2006). The electrogastragram (EGG) recorded from the body surface reflects the myoelectrical activity of different areas of the stomach, but corresponds to gastric slow wave accurately, and therefore can be used to investigate the rhythm of gastric contraction.

Stomach volume augments gradually when food is ingested. In the gastric active period, such as contraction and peristalsis after a meal, the content of the stomach changes greatly, as does the impedance of the stomach. Via the impedance measurement of the stomach during digestion, the information reflecting the stomach volume (gastric emptying) and gastric motility (contraction and peristalsis) can be extracted.

### 2.2 Experimental procedure of IGM and EGG

A study method of gastric motility based on electrical bioimpedance measurements and simultaneous EGG has been developed by authors of this paper (Li *et al.*, 2007 and 2008). The block diagram of the measurement system is shown in Figure 1.

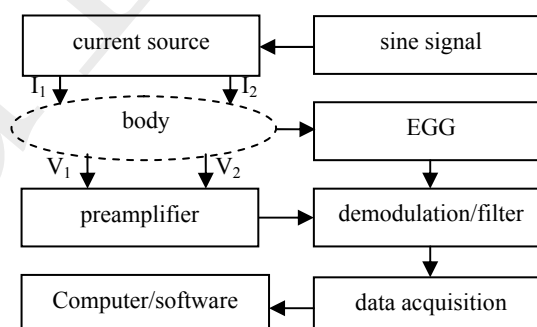


Figure 1 Diagram of gastric motility measurement system

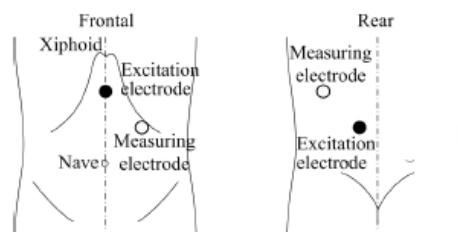


Figure 2 Position of the excitation and measurement electrode

The measurement system consists of a sine signal generator, current source, electrodes ( $I_1$ ,  $I_2$ ,  $V_1$ ,  $V_2$ ), preamplifier, demodulation/filter circuit, data acquisition system, and a computer. A measurement

current of 50 kHz, 2 mA provided by the current source goes into the abdomen zone of the measured subject via excitation electrode I1 and I2 (Figure 2). The impedance signal picked up from measurement electrode V1 and V2 is fed into preamplifier, then the demodulation/filter, and goes into data acquisition system where A/D convert and digitization processing are carried out. The digital data then is sent to a computer where the proprietary software is in charge of the IGM and EGG information extraction, analyzing, and parameter calculations. Gastric emptying measurement and IGM and EGG spectra analysis are also executed by the proprietary software in the computer.

The impedance signal acquired from the abdomen surface is a mixed signal. It contains not only IGM, but also the components of impedance blood flow, breath, and some other disturbances. The normal rhythm of IGM is about 3 cpm and the breath signal is about 12 cpm. Both IGM and the breath rhythm belong to the ultra-low frequency signal and the amplitude of the breath signal is usually much higher than that of IGM. It is a challenge to extract IGM information effectively from the mixed signal. A low-pass filter may eliminate the influences of high-frequency noise and heart activity interference; however, it is difficult to eliminate the influence of respiration, and separate IGM signal from the mixed signal. Thus, one uses a narrow band-pass filter and the high-order active low-pass filter. In the gastric motility measurement system of this paper, the wavelet transform is introduced and then IGM signal is separated successfully from the impedance signals of breath and blood flow among the mixed signal (Li *et al.*, 2007).

The rhythm of the IGM signal is classified. The rhythm of 2-4 cpm is the normal rhythm, while that below 2 cpm is bradygastria, and that above 4 cpm is tachygastria. Based on this classification, we carried out analyses of frequency spectra, energy spectra, dynamic spectra, running spectra, frequency instability coefficient (FIC), power instability coefficient (PIC), percentage of normal frequency (PNF), and percentage of normal power (PNP), for both IGM and EGG.

The definition of FIC and PIC are as below (Li *et al.*, 2008):

$$FIC = \frac{SD_F}{DF_{Av}}$$

$$SD_F = \sqrt{\frac{\sum_{k=1}^S (DF(k) - DF_{Avg})^2}{S}}$$

Here  $DF_{Av}$  is the average of the dominant frequency within 2-4 cpm among the signal segments analyzed.  $SD_F$  is the standard deviation of the dominant frequency.  $DF(k)$  is the dominant frequency for the  $k$ th signal segment analyzed.  $DF_{Avg}$  is average of the dominant frequency for all signal segments analyzed, and  $S$  is number of all the segments.

$$PIC = \frac{SD_P}{DP_{Av}}$$

$$SD_P = \sqrt{\frac{\sum_{k=1}^S (DP(k) - DP_{Avg})^2}{S}}$$

Here  $DP_{Av}$  is average of the dominant power within 2-4 cpm among the signal segments analyzed.  $SD_P$  is the standard deviation of the dominant power.  $DP(k)$  is the dominant power for the  $k$ th signal segment analyzed.  $DP_{Avg}$  is average of the dominant power for all signal segments analyzed, and  $S$  is number of all the segments.

### 2.3 The body measurement and statistical analysis

The measurement method of gastric motility used in the study is a noninvasive method. The study was approved by the ethical committee, and all subjects in the study signed a consent form.

In preparation for the measurement, the subject was calm and seated on a chair. The signals of IGM and EGG were recorded continually for 30-40 minutes after a test meal. The meal consists of milk (200 ml) and bread (100 g), 1300 kJ and 2850 kJ, respectively.

The statistical software SPSS13.0 was used to analyze the data. The data are expressed as mean±SD. Variance analysis between study and control groups was undertaken, and the significant difference was accepted when  $p < 0.05$ .

## 3 RESULTS

In order to validate the feasibility and show the potential applications of the proposed method in this paper, some preliminary studies of gastric motility measurements in healthy volunteers, subjects with functional dyspepsia (FD), and subjects with gastritis have been carried out (Li *et al.*, 2009, Liu *et al.*, 2009).

### 3.1 Gastric Motility Measurement of The Healthy

The raw IGM signal and the spectra analysis of the IGM and EGG signals for a healthy volunteer are illustrated in Figure3. In Figure 3, part 1 represents

the original mixed impedance signal comes from the abdomen surface, part 2 is the IGM signal extracted from the mixed signal, part 3 is the synchronous EGG, part 4 is the dynamic spectrum of IGM, parts 5 and 6 are the power spectrums before and after the test meal, respectively. The dynamic spectrum in Figure 3 (part 4) shows that the dominant frequency of IGM signals focuses on 2.8 cpm.

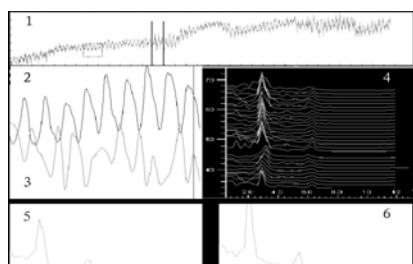


Figure 3 IGM measurement and spectra analysis result for a healthy volunteer

### 3.2 Gastric Motility Measurement of FD Patients

Gastric motility measurements of 30 healthy volunteers (control group) and 28 FD subjects (study group) were carried out. The volunteers were university teachers with ages of  $45.2 \pm 12.3$  years. Subjects with functional dyspepsia (FD) (aged  $40.9 \pm 9.7$  years) came from the First Affiliated Hospital of Chongqing University of Medical Sciences, and were diagnosed according to the Rome III classification for FD. Results of the IGM measurement are shown in Table 1. It can be seen from Table 1 that the PNF in the study (FD subjects) group is obviously lower than that in the control group ( $P < 0.01$ ), and the FIC is higher than that in control group ( $P < 0.01$ ). The PNP and PIC between the two groups are also different ( $P < 0.01$ ). This indicates that the FD subjects have a poor rhythm of gastric motility. The results are in accordance to gastric physiology and pathology principles for functional dyspepsia.

Table 1 IGM measurement result of healthy and FD patients (mean  $\pm$  SD)

GROUP	CASE	PNF <sup>a</sup>	PNP <sup>b</sup>	FIC <sup>c</sup>	PIC <sup>d</sup>
CONTROL	30	68.47 $\pm$ 26.43	60.13 $\pm$ 3.34	1.36 $\pm$ 0.08	0.18 $\pm$ 0.16
STUDY	28	28.32 $\pm$ 16.92	50.79 $\pm$ 9.90	2.08 $\pm$ 0.55	0.23 $\pm$ 0.05
P		<0.01	<0.01	<0.01	<0.01

<sup>a</sup>Percentage of normal frequency; <sup>b</sup>Percentage of normal power, <sup>c</sup>Frequency instability coefficient, <sup>d</sup>Power instability coefficient.

Figure 4 shows the EGG dynamic spectra of FD patients before and in a week treatment (Dompedone tablets, 10 mg, t.i.d. p.o, half an hour before meal), the interval of each spectrum line is 1 min. In Figure 4, EGG of FD patient is weak and the rhythm disorder

before the treatment (left), then in a week treatment, the EGG enhances and the rhythm gets back to 2-4 cpm (right). This suggests that the gastric electric activity of FD patients tend towards normal after a week treatment.

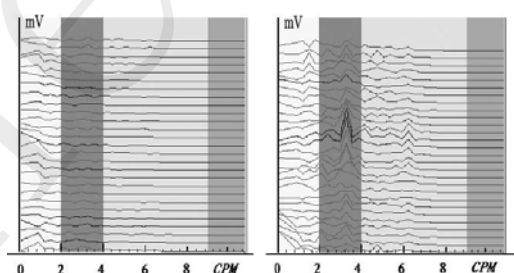


Figure 4 EGG dynamic spectra of FD patients before (left) and in a week treatment (right)

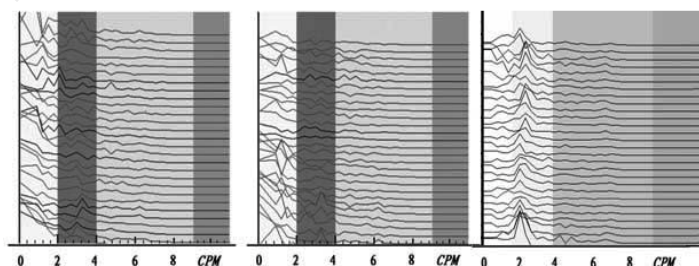


Figure 5 IGM dynamic spectra of FD patients before (left), in a week (mid) and 3 weeks (right) treatment

Figure 5 shows the IGM signal spectra of FD subjects before treatment, after one week of treatment, and after three weeks of treatment (Domperidone tablets, 10 mg, t.i.d, p.o, half an hour before meals). Compared with the EGG dynamic spectra in Figure 4, the IGM in Figure 5 shows little change after one week of treatment, and the rhythm also is disordered, until after three weeks treatment the IGM rhythm appears back to 2-4 cpm.

### 3.3 Gastric Motility Evaluation of Gastritis Patients

We conducted IGM parameter measurement of healthy volunteers and erosive gastritis subjects, compared the IGM and EGG parameters for the gastritis subjects before and after one week of treatment (Sodium rabeprazole tablets, 10mg, q.d, p.o, q.m.). Thirty healthy volunteers (control group) were university teachers with ages of  $45.2 \pm 12.3$  years. Thirty subjects with erosive gastritis (study group, aged  $50.5 \pm 13.0$  years) came from the First Affiliated Hospital of Chongqing University of Medical Sciences and were diagnosed by gastroscop examination. The statistic results of the studies are shown in Table 2, Table 3, and Table 4.

**Table 2. The IGM parameters for 30 gastritis subjects and 30 healthy subjects (mean  $\pm$  SD)**

GROUP	PNF <sup>a</sup>	PNP <sup>b</sup>	FIC <sup>c</sup>	PIC <sup>d</sup>
CONTROL	68.5 $\pm$ 26.5	60.1 $\pm$ 3.3	1.36 $\pm$ 0.08	0.18 $\pm$ 0.16
STUDY	36.1 $\pm$ 21.8	44.6 $\pm$ 4.8	2.23 $\pm$ 0.55	0.24 $\pm$ 0.05
P	<0.05	<0.05	<0.05	<0.05

<sup>a</sup> Percentage of normal frequency; <sup>b</sup> Percentage of normal power; <sup>c</sup> Frequency instability coefficient; <sup>d</sup> Power instability coefficient.

**Table 3. EGG parameter for 30 gastritis subjects before and after one week of treatment (mean  $\pm$  SD)**

TREATMENT	PP <sup>a</sup> (0-2 cpm)	PP <sup>a</sup> (2-4 cpm)	PP <sup>a</sup> (>4cpm)	FIC <sup>b</sup>	PIC <sup>c</sup>
BEFORE	24.0 $\pm$ 5.6	51.5 $\pm$ 11.1	24.4 $\pm$ 5.5	2.22 $\pm$ 0.43	0.34 $\pm$ 0.03
AFTER 1w	22.7 $\pm$ 3.4	54.3 $\pm$ 6.7	23.1 $\pm$ 3.3	1.77 $\pm$ 0.19	0.23 $\pm$ 0.02
P	>0.05	>0.05	>0.05	<0.05	<0.05

<sup>a</sup> Percentage of power; <sup>b</sup> Frequency instability coefficient; <sup>c</sup> Power instability coefficient.

**Table 4. IGM parameter for 30 gastritis subjects before and after one week of treatment (mean  $\pm$  SD)**

TREATMENT	PP <sup>a</sup> (0-2 cpm)	PP <sup>a</sup> (2-4 cpm)	PP <sup>a</sup> (>4cpm)	FIC <sup>b</sup>	PIC <sup>c</sup>
BEFORE	27.5 $\pm$ 2.4	44.6 $\pm$ 4.8	27.9 $\pm$ 2.4	2.23 $\pm$ 0.55	0.24 $\pm$ 0.05
AFTER 1w	27.4 $\pm$ 2.2	44.9 $\pm$ 4.4	27.8 $\pm$ 2.2	1.91 $\pm$ 0.65	0.21 $\pm$ 0.06
P	>0.05	>0.05	>0.05	>0.05	>0.05

<sup>a</sup> Percentage of power; <sup>b</sup> Frequency instability coefficient; <sup>c</sup> Power instability coefficient.

It is seen from Table 2 that there is a significant difference in the IGM parameters between control and study groups. The PNF and PNP of the study group are significantly lower than that of the control group ( $P < 0.05$ ). FIC and PIC of the study group are evidently higher than that of the control group ( $P < 0.05$ ). These results suggest that the gastric motility function of the gastritis subjects was reduced and the stomach peristalsis disordered.

Table 3 indicates that the EGG power of normal rhythm (2-4 cpm) for the gastritis subjects was raised and the power of the abnormal rhythm (0-2 cpm and >4 cpm) declined after one week of treatment, although this was not statistically significant ( $P > 0.05$ ). It is important that the FIC and PIC of the gastritis subjects was reduced ( $P < 0.05$ ). This suggests that the EGG of the gastritis subjects tended to be regular and

stable after one week of treatment, after which the EGG rhythm improved.

The IGM parameters in Table 4 show that the power ratios of IGM signals for the gastritis subjects in all frequency bands changed little before and after treatment ( $P > 0.05$ ), although the FIC and PIC showed a trend to decreasing ( $P > 0.05$ ).

## 4 DISCUSSION

The results of this study indicate that the IGM of functional dyspepsia (FD) subjects is not yet improved with one week of treatment while the EGG is returned to normal. After three weeks of treatment, the regular IGM rhythm of the FD subjects is normal and shows a recovery of contraction function of the stomach. The

gastric motility of human body is regulated by a series of sensory signals from the nervous system and has a close relationship with the electric activity of the gastric smooth muscle (Zhou L et al, 2005, Ma DS et al, 2006). While the EGG of the FD subject returned to normal after one week of treatment, this improvement may not yet couple or transfer to the mechanical activity of the stomach. After three weeks of treatment, when the influence of the electric activity has already coupled with or transferred to mechanical activity of the stomach via the regulation mechanism of nerve and electric activities, the normal IGM rhythm is seen in the spectra, and suggests the recovery of contraction function of the stomach.

We also found a significant difference between IGM parameters between the gastritis subjects and the healthy controls. After one week of treatment, the EGG rhythm of the gastritis subjects returned to normal, while some IGM parameters showed only a trend to improvement. This suggests that the influence of gastric electric activity may not have coupled with mechanical contraction of stomach after only one week of treatment. From the clinical point of view, although the subjects in the study had felt some alleviation after a week of treatment, the symptoms of the gastritis were not completely relieved. The fact coincided with the results of Table 3 and Table 4, and the suggestion is that continued treatment should be offered.

EGG reflects the gastric electric activity of the stomach and is more sensitive to the regulation mechanisms of nerve and electric activity. The improvement of the EGG after treatment is only the beginning of the improvement of gastric motility function, and it does not indicate the cure of gastric disorder or the recovery of gastric motility. IGM is a veritable measure of gastric contraction and peristalsis, and reflects the gastric motility function more effectively. Gastric study based on IGM measurement and simultaneous EGG is a noninvasive, convenient, and effective method.

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