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Parameters Analysis of Gastric Motility Signals in Time Domain and Frequency Domain

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Abstract: In order to assess gastric motility, a new noninvasive method was addressed. Firstly, bio-impedance and stomach electric signals were recorded from the healthy control group and the pathologic stomach group. Wavelet transform was used to remove the influence of the heart activity signals. By analyzing and processing the two signals of the time domain and frequency domain, we get the corresponding parameters of the two groups. According to all the parameters, several verification tests have been carried out, from the result of the statistics, we can find that in both time and frequency domains, impedance signal and synchronize EGG (electrogastrogram) have some similar features. However synchronize EGG cannot be totally instead by gastric motility, especially in morbid state, EGG is not correspondence to impedance signal. The gastric contraction or gastric emptying is a complex procedure including electrical and mechanical activity. Electrical impedance (EIP) and the synchronous EGG should be analyzed together. In conclusion, the parameters have the value to evaluate gastric motility.

Key words: Gastric motility, signals, wavelet transform, time domain, frequency domain.

1. Introduction

Motility (or contractions) is one of the most critical physiological functions of the human gut. Without coordinated motility, digestion and absorption of dietary nutrients could not take place [1, 2]. Impairment in gastric motility results in delayed emptying of the stomach and leads to symptoms of nausea, vomiting, abdominal pain or discomfort, and so on [3, 4].

EGG (electrogastrogram) is a non-invasive and convenience method used for the assessment of gastric motility [5]. Unfortunately, it only reflects frequency of myoelectrical activity and falls to provide enough information about gastric mechanical movement. Other methods such as radionucleide scintigraphy, intracavitary pressure measurement, barostat checking, gastroscopy, etc., fail to deliver a cost effective, simple to use and repeated use. The assessment of gastric motility is still a challenge in the biomedical engineering and different ways will be explored [6].

Bioelectric impedance can be considered as a powerful tool in diagnosis and medical research. Main advantages of using bioelectric impedance are its noninvasive nature, low cost and ease of operation. There are many applications using bio-impedance signals for different pathological conditions, but its use in assessment of gastric motility need to be explored in detail [7].

Gastric motility, stomach movement or emptying is a complex course from electrical activity to mechanical contraction and conduction. It begins from the electrical activity of smooth muscle, and then develops gastric corpus and pylorus. In gastric active phase, such as contraction, peristalsis, the form and bulk of stomach change greatly, so the impedance of it changes evidently. The change regularity of the impedance corresponds to gastric motility. In order to investigate the complex course of electrical and mechanical activity of the gastric motility, including rhythm,

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transmission, gastric emptying and the influences of them, it is necessary to extract gastric motility information of both electrical and mechanical activity [8].

The bio-impedance method is a noninvasive, high sensitive technique to obtain the electrical feature information corresponding to the gastric motility. Stain et al. used bio-impedance technique to detect body composition after gastric bypass and biliopancreatic diversion. Pereira et al. examined the impact of important weight loss on insulin inhibition of its own secretion during experimentally induced hyperinsulinemia under bariatric surgery. Murphy compared the effects of tramadol and morphine on gastric emptying in man [9].

The fundamental frequency of the gastric impedance signal is about 0.05 Hz. The frequency may have sudden changes over time, especially in abnormal situation. When healthy control group (CG) and pathologic stomach group (PG) were used to study the spectrum of gastric electrical impedance, the fluctuations of the curve were markedly different between them and the frequency of PG changes more obviously than CG over time. The frequency component was extracted by means of wavelet transform. We have reported our experiments for gastric emptying time curve with drinking pure water elsewhere. Our present study is an attempt to analyze spectrum of gastric electrical impedance, which reveals useful information regarding gastrointestinal motility and symptoms to assess gastric motility noninvasively.

2. Methods

2.1 Electrical Impedance Gastric Motility

Macroscopically human tissue can be considered as a free charge conductor for measurement frequencies less than 100 kHz. The stomach, additionally, being a muscular bag with a small volume in the fasting state (approximately 50 mL) and becoming larger when a meal is ingested, can be studied by electrical impedance (EIP). EIP is considered as the collection of data in the form of electrical impedance measurements at a suitable sampling rate, using surface electrodes from the gastric area [10].

EIP measurement system used in the present work generates an alternating current of 50 kHz, which can be adjusted in intensity from 1 to 4 mA. The sampling rate of the data collection is 5 Hz and a multiplexed system of electrodes is used to extract gastric impedance and synchronization EGG.

2.2 Analysis Process

2.2.1 Data Acquisition

Electrical impedance signals around abdomen of subjects were recorded for the offline analysis. Tetra-polar impedance plethysmography was used to record impedance changes. The hardware of system in our lab was mainly involved a constant current with 50 kHz, data acquisition system ADuC834 and a personal computer. The SPCOMM control component was employed to sample the signal from the ADuC834. The sampling rate is 5 Hz. Two outer electrodes insert 2 mA, 50 kHz constant current on epigastric surface of body, and voltage is measured using inner two electrodes.

2.2.2 Subject Selection and Experiment

Forty healthy adults called control group (CG) and 36 pathologic stomach adults called pathologic group (PG) in this paper. The pathologic adults were functional dyspepsia patients (FD). Each subject sat on a rigid table. The first experiment took place on 40 healthy adults. The second experiment took place on 36 volunteers with pathologic stomach from the First Attached Hospital of Chongqing University of [16] Medical Science. Age, sex, bodily form, relevant medical

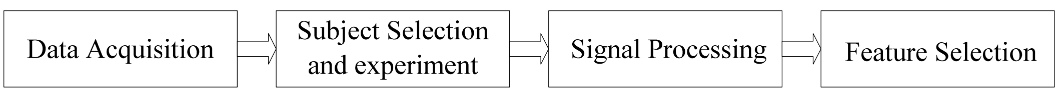


Fig. 1 System implementation diagram.

history, etc., were recorded. The signal was recorded 30 minutes in fasting state at 3:00 p.m. after lunch. The launch used as a standard meal is 200 mL milk, 100 g bread of energy 1,300 kJ and 2,850 kJ, respectively. All subjects were explained about the experiment.

2.2.3 Signal Processing

Wavelet theory is designed to give good time resolution and poor frequency resolution at high frequencies, and good frequency resolution and poor time resolution at low frequencies. This feature is useful for the signal with high-frequency components for short durations and low-frequency components for long durations. Then wavelet transform has been described as a mathematical microscope for the natural sciences [11].

WT (*a*, *b*), named as the wavelet transform of *f* (*t*), is the inner product of *f* (*t*) and the mother wavelet $\phi(t)$ under different scales and time displacement, i.e., (1) which is a two-dimensional function.

$$W(a,b) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{+\infty} f(t) \Phi(\overline{\frac{t-b}{a}}) dt \quad (1)$$

Signal *f* (*t*) can be reconstructed by (2).

$$f(t) = \frac{1}{c_\varphi} \int_{0}^{+\infty} \left[\left\{ \int_{-\infty}^{+\infty} Wf(a,b) \left[|a|^{\frac{1}{2}} \Phi\left(\frac{t-b}{a}\right) \right] \right\} db \right] \frac{da}{a^2} \quad (2)$$

In this paper, wavelet multi resolution analysis (MRA) is used to investigate the low-frequency feature of impedance signal. Choosing mother wavelet is difficult and usually finding the proper wavelet dependents on experiences and practice. But some famous wavelets have good performance. Such as the Morlet wavelet is excellent for achieving high-frequency resolution. The Mexicanhat wavelet has a poor frequency resolution but a good time resolution. The famous Daubechies wavelet has both good features and the widest application [12].

After simulate studies choosing various wavelet base functions in MATLAB platform, Daubechies wavelet base is chosen to analyze EIP signals. With many patients into experiment, according to the feature of EIP signal, DB series wavelet bases have been constructed in the paper. Fortunately, the DB series wavelet (form DB4 to DB7) has good effect to separate the EIP signal from breathing and heart activity signals.

2.2.4 Feature Selection

By the means of energy and frequency spectrum analysis technic, the signals can be classified according to the dominant power and dominant frequency. If the peak power was within 2-4 CPM range, we called it normal. Otherwise lower than 2 CPM, we called it gastric bradygastria, while higher than 4 CPM, we called it gastric tachygastria. If a running spectrum cannot be classified as bradygastria, normal, or tachygastria, it will be classified as arrhythmia. The classification is the index to decide the state of gastric movement [13].

The parameters of signal dynamic spectrum, dominant frequency, dominant power, frequency instability coefficient and power instability coefficient, percent of normal rhythm and percent of normal power, were used as temporal features for the subjects. EGG was recorded synchronously. Therefore, some indexes such as dominant frequency and dominant power of synchronous EGG were also calculated. The instability coefficients are very important index. The frequency instability coefficient could be calculated as:

$$IC_{Freq} = \frac{SD_{Freq}}{DF_{Avgnormal}} \quad (3)$$

Where, $DF_{AvgNormal}$ is the average of the dominant frequency in all RSA (Running Spectrum Analysis) segments classified as normal.

The standard deviation SD_{Freq} is calculated as:

$$SD_{Freg} = \sqrt{\frac{\sum_{k=1}^{s} (DF(k) - DF_{Avg})^2}{S}} \quad (4)$$

Where, *DF(K)* was the dominant frequency for the K'th RSA segment. DF_{Avg} was the average of the dominant frequency for all RSA segments and *S* was the number of RSA segments in the period [14].

3. Results

Fig. 2(A) shows the segment of EIP signal in 200 second, the EIP signal is submerged in breath and heart activity signals. The signals transformed by wavelet and reconstructed by approximate component are shown in Fig. 2(B). The reconstructed signals of EIP and EGG are smooth and glossy; some high frequency interferences such as breath and heart activity are filtered. The rest component is about 3 CPM of gastric contraction rhythm. In physiology, the electrical signal is the base of mechanical contraction. If shrinkage comes into existence, the actuating of EGG is the first present. On the contrary, the present of EGG may not correspond to a gastric shrinkage. In order to compare EGG with EIP, we collect the synchronize EGG. The impedance signal of gastric motility is shown in Fig. 2(B), and the synchronize EGG is shown in Fig. 2(C). Compared the two signals, EIP indicates the gastric mechanical activity; EGG expresses the gastric electrical activity. These two signals have some relationship and a big correlation coefficient, but they are not identical.

Some statistical indexes were shown in Table 1. Compared with the indexes of CG, the percentage of normal frequency is much smaller while the instability coefficient is much larger in PG group. We could also see the corresponding differences of percentage of normal power and power instability coefficient between the two groups. All the parameters have significant difference in statistics.

The running spectrum of impedance signal is shown in Figs. 3-4. The main frequency of the control group (CG) belongs to 2-4 CPM. It is clear and very regular. Compared with the CG, the main frequency of the PG is difficult to evaluate. It is disordered and major peak of the curve belong to 1-3 CPM. EIP and EGG are very slow and the main frequency generally is 2-4 CPM for health adults. The peak of frequency is variable over time, which is a phenomenon of physiological adaptation.

From the power spectrum (Fig. 5), we find that the

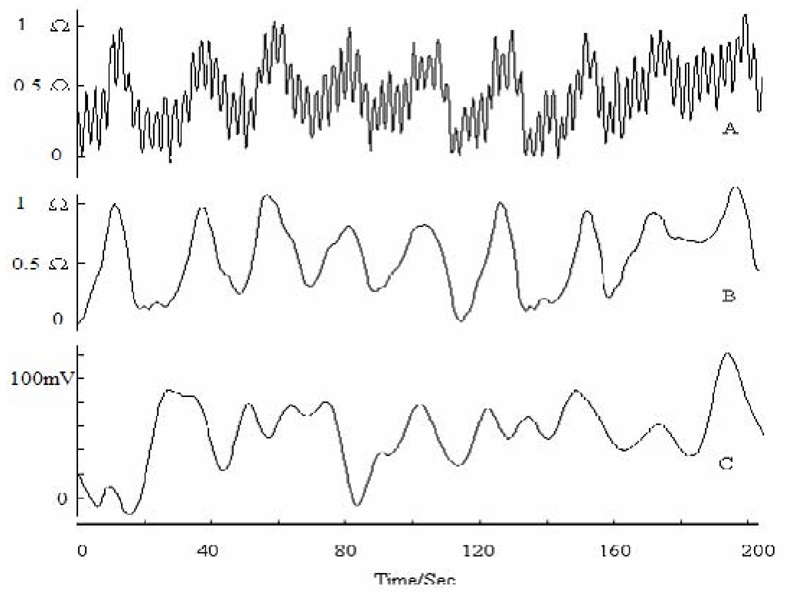


Fig. 2 Signals (A: original signal; B: impedance signal by wavelet; C: synchronize EGG).

Table 1 The results of the two groups to detect gastric motility for volunteers.

	Sample size	Percentage of normal frequency	Percentage of normal power	Frequency instability coefficient	Power instability coefficient
CG	40	0.704 ± 0.255	0.592 ± 0.044	0.182 ± 0.059	1.576 ± 0.481
PG	36	0.402 ± 1.145	0.468 ± 0.142	0.374 ± 0.086	4.006 ± 0.711
P value		< 0.01	< 0.05	< 0.01	< 0.01

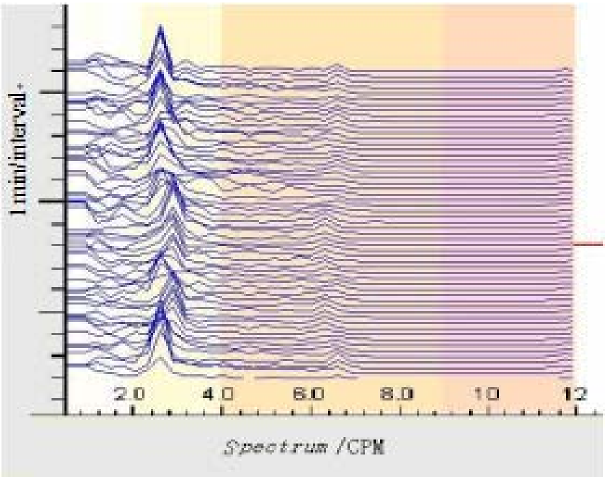


Fig. 3 Typical impedance signal running spectrum for control group.

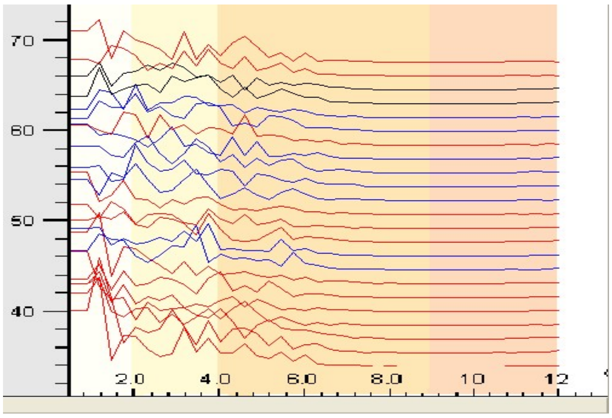
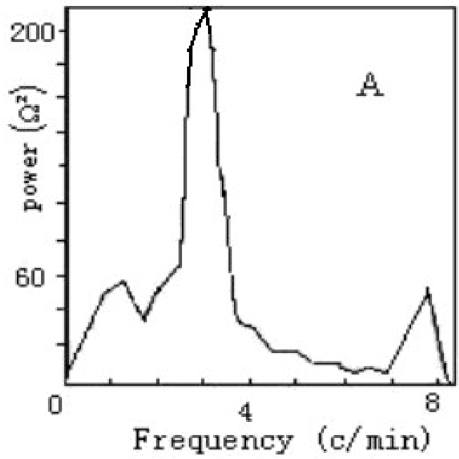
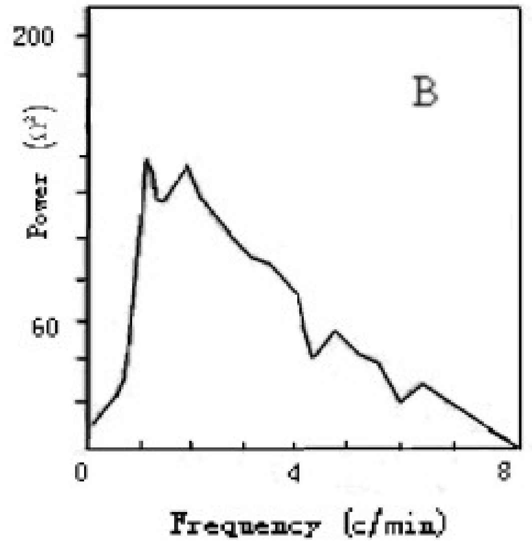


Fig. 4 Typical impedance signal running spectrum for pathologic group.



A: control group



B: pathologic group

Fig. 5 Typical power signal power spectrum.

peak of the maximal power of CG belongs to 2-4 CPM and the maximal power of the pathologic group belongs to 1-2 CPM. Though we could not make a conclusion that the symptom is gastric bradygastria, the specific frequency of maximal power is abnormal. The impedance is influenced by filling current and the electric resistance between electrodes, so we couldn't judge the strength of gastric motility from the amplitude of power.

4. Conclusion and Discussion

There are some methods to detect stomach function in clinical now. But most of the routine methods are invasive or dear. Bioelectrical impedance because of its noninvasive, safe, cheap, simple and functional information-rich features, is easy to be accepted by doctors and patients, having broad application prospects. As early as 1985, Sutton et al. [15] carried out the research of using impedance to extract gastric motility signal, then research in this area one by one. This test learned the previous gains and losses, more carefully considered various interferences and effectively filtered, achieved satisfactory results.

All of the elements in analysis processing are important to the test result. The precision of the data acquisition system is the base of others, it should be selected by experiment demand. ADuC834 is a chip collecting multiple functions into it, especially for temperature and pressure changes slowly and the measurement of DC or low frequency signals.

Additionally, it can sample gastric motility impedance signal in high-precision 24-bit, so it is possible that we observe the greatest range of impedance signals based on changes in gastric motility. Wavelet transform successfully removes the influence of the heart activity signals. It ensures that all the information used for analyzing is valid. Percentage of normal frequency, percentage of normal power, frequency instability coefficient and power instability coefficient are several of the most representative parameters which could clearly reflect the difference of CG and PG.

In both time and frequency domains, impedance signal and synchronize EGG have some similar features. However synchronize EGG cannot be totally instead by gastric motility, especially in morbid state, EGG is not correspondence to impedance signal. The gastric contraction or gastric emptying is a complex procedure including electrical and mechanical activity. EIP and the synchronous EGG should be analyzed together. We will make a great of experiments to obtain the relationship between EIP and EGG. All the procedure in digestion, such as EGG, gastric contraction, peristalsis and gastric emptying, have to be think over, the operative evaluation to gastric kinetics can be constructed. We will add more EIP parameters to improve the performance in further research. In turn this could lead to the development of a noninvasive method for the continuous recording of volume variability with gastric contraction.

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