Human Gastrointestinal Pressure Data Analysis Based on Wavelet Transform

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Abstract: - **Background** Recently with the improvement of people's living standards, eating fine, irregular life, lack of exercise and increased mental stress, the incidence of constipation is increasing. Gastrointestinal (GI) tract's pressure information can reflect the dynamic disorder of gastrointestinal physiological and pathological changes, which is important in early diagnosis and treatment of constipation. However, how to diagnose constipation with the wireless capsule is still not clear. The purpose of this paper is to analyze the GI tract's pressure data and compare the gastrointestinal motility index (MI) and the gastrointestinal transit time (GTT) in healthy subjects and patients with constipation to provide some reference for clinical diagnosis. **Methods** The sixteen subjects (ten healthy subjects and six patients with constipation) were recruited. Firstly, the large abnormal data caused by cough and electromagnetic noise were filtered by the threshold processing method. Secondly, the high frequency noise caused by breathing and other disturbance was removed by wavelet analysis. The GI tract's peristalsis wave was extracted. Then the MI and GTT of the sixteen subjects were computed. **Key Results** The patients with constipation showed significantly higher MI and longer GTT compared with healthy subjects. The results show that the wavelet transform provides a new way to research human gastrointestinal activities.

Key-Words: - Wavelet Transform; Gastrointestinal transit time; Wireless Capsule; Gastrointestinal Motility Index

1. Introduction

Extensive research data show that gastrointestinal function disorder has a high incidence and a rising trend. In the ordinary course of medical practice, nearly 50% of patients go to see their doctors because of abdominal distension, abdominal pain and other gastrointestinal symptoms, 30%-40% of whom are eventually diagnosed with constipation [1]. GI tract's pressure information can reflect the dynamic disorder of tract physiological and pathological changes, which is important in early diagnosis and treatment of constipation. Actually, the study on GI tract's physiological parameter with wireless capsule had appeared. In [2], L. KLOETZER et al. compared the motility of the antroduodenum in healthy and gastroparetics characterized by wireless motility capsule and found that diabetic subjects with gastroparesis showed significantly lower contractions and motility index (MI) compared with healthy subjects in both gastric and small bowel windows. Phase III migrating motor complexes, gastric emptying time, small bowel transit time, colonic transit time and motility were compared using wireless motility capsule and the conventional methods and found that wireless motility capsule offering a nonradioactive, standardized, ambulatory alternative to the conventional methods [3-10].

Different attempts to study GI tract's pressure data have been reported in the literature, but there was no report on comparing the gastrointestinal dynamic index with wireless capsule in healthy subjects and the patients with constipation. The aim of our study was to analyze the GI tract's pressure data and compare the gastrointestinal MI and the gastrointestinal transit time (GTT) in healthy subjects and patients with constipation to provide some reference for clinical diagnosis.

2. Pressure monitoring system

The gastrointestinal tract's pressure data were obtained by the wireless capsule developed by the Medical Precision Engineering & Intelligent System Institute of Shanghai Jiaotong University. The system includes a swallowable capsule, a recorder, a workstation, as shown in figure 1. The capsule is 11 mm across and 26 mm long that integrates pH, temperature and pressure sensors, can continuous monitor of pH, temperature and pressure information of the human gastrointestinal tract under normal physiological state with the sampling frequency of 0.83Hz. The capsule has battery life rated for 6 days. The pH sensor is accurate to within ±0.25 units, the temperature sensor is accurate to ±0.25 ℃ and pressure is accurate to ±2.5 mmHg.

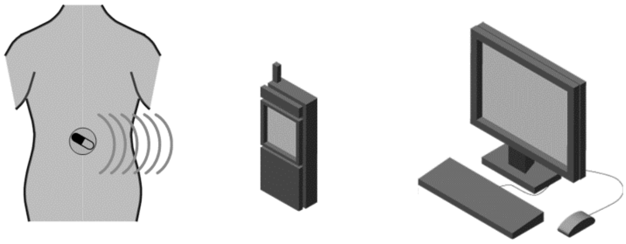

Fig.1. The wireless capsule system

The recorder records the data transmitted by the capsule in real time and stores them in the SD card. Then the recorder is connected to a computer through the USB interface after the experiment. The data in the SD card can be read out and is processed by the workstation. The process includes filtering, extracting the characteristic value, gastrointestinal tract disease diagnosis, displaying the processed pH, temperature, pressure curve of the gastrointestinal tract and providing the preliminary diagnosis. The final diagnosis result is determined by the doctor.

3. Data Analysis

The sixteen subjects (ten healthy subjects and six patients with constipation) were recruited for the clinical trials and the human experiments were performed in an authorized hospital, with the assistance and collaboration of a specially trained medical team, in accordance to all ethical considerations and the regulatory issues related to human experiments.

As the collected data may be contaminated by clutter such as breath noise, cough noise and electromagnetic noise, an adjusted threshold processing method is used for reducing the influence of disturbed signals. The filtered signal can be shown as follows,

$$p_i' = \begin{cases} p_i & i=1 \\ p_{i-1} & \left|2p_i-(p_{i-1}+p_{i+1})\right| > \Delta p \quad i=2,3,\cdots n \\ p_i & \left|2p_i-(p_{i-1}+p_{i+1})\right| \le \Delta p \quad i=2,3,\cdots n \end{cases} \quad (1)$$

$$\Delta p = 4.0 \ \ \textit{pressure threshold} \quad (2)$$

This method can remove the large abnormal data, but the high frequency noise in the data may still exist. To separate out the high frequency noise, the wavelet method is applied. Wavelet analysis is now becoming a common signal processing tool for analyzing variations in the biomedical signals. Analysis of biomedical signal at desired scales can be accomplished by decomposing the signal with wavelet basis functions that are well localized both in time and frequency domains. Also, the wavelet analysis method is able to overcome the limitations of the conventional methods. Nowadays, wavelets constitute an important and fairly new tool for signal processing because their main feature is the time frequency analysis capability using a single transformation, which makes it useful in applications such as signal noise reduction, wave detection, data compression, feature extraction, et al [11-18].

Discrete wavelet transform of a signal f is defined as:

$$P_{j-1}f = P_j f + Q_j f = \sum_k c_k^j \phi_{jk} + \sum_k d_k^j \psi_{jk} \quad (3)$$

Where $P_j f, Q_j f$ are respectively the j-class orthogonal projection of f on P and Q, and ϕ_{jk}, ψ_{jk} are respectively scaling function and wavelet transform function. The c_k^j and d_k^j are defined as follows:

$$c_k^j = \sum_{n=0}^{p-1} h(\mathrm{n}) c_{2k+n}^{j-1},$$
$$d_k^j = \sum_{n=0}^{p-1} g(\mathrm{n}) c_{2k+n}^{j-1}, \quad (4)$$
$$\mathrm{j} = 1,2,\cdots \mathrm{L}, \mathrm{K} = 0,1,\cdots N/2^j - 1$$

Where $h(\mathrm{n})$ and $\mathrm{g(n)}$ are respectively high pass filter function and low pass filter function, p , N are respectively the length of filter functions and the input signal, and L is the number of stages of the wavelet transform decomposition.

In this paper, the Daubechies wavelet with a decomposing tree of level 3 is used. The Daubechies wavelet can provide a well orthogonality to high frequency noise with a given number of vanishing moments [19]. The wavelet tree is shown in figure 2. According to the theory of wavelet analysis, if the analysis frequency of the original signal is f which is equal to 1/2 times of the sampling frequency, then the frequency range of the first layer's details $D1$ is $f/2 \sim f$, similarly, the second layer's details $D2$ is $f/4 \sim f/2$. In this paper, the sampling frequency of the signal is 0.83Hz, then the frequency range of $D1$ is 0.208Hz～0.415Hz, the frequency range of $D2$ is 0.104Hz～0.208Hz, the frequency range of $D3$ is 0.052Hz～0.104Hz. The study shows that the range of breathing rate is 0.15Hz～0.4Hz [20], while the range of gastrointestinal peristalsis frequency is 0.03Hz～0.2Hz [21], so D1 is respiratory wave which is thrown away as the interference signal in the gastrointestinal peristalsis wave reconstruction. D2 and D3 are denoised by using soft threshold, as soft threshold is more popular than hard threshold for it reduces the abrupt sharp changes that occurs in hard threshold and provides more visually pleasant recovered curves. Finally the gastrointestinal peristalsis wave is reconstructed by using A3 and modified D2 and D3.

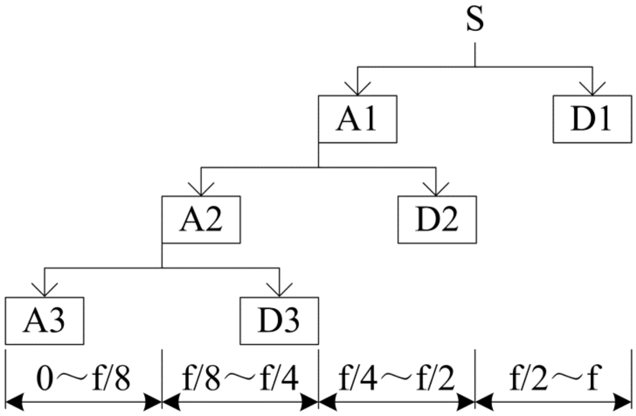

Fig.2. The wavelet tree of 3 scale wavelet decomposition

After extracting the gastrointestinal tract peristaltic waves, the GTT and the MI of the whole gastrointestinal tract are calculated. The GTT is the time between the wireless capsule and exit from the body. The MI is computed by the following formula:

$$\ln((\mathrm{WN}+1) * \mathrm{Am}/\mathrm{T}) \quad (5)$$

Where WN is the wave number of the gastrointestinal peristaltic waves, Am is the amplitude of the peristaltic waves and T is the gastrointestinal transit time.

4. Test results

The raw data which are varied with time is illustrated in figure 3(a). As can be seen from the diagram, some singular values existed in the raw data needed to be abandoned and are filtered by the threshold processing method, the filtering result is shown in figure 3(b). The threshold processing method can only remove the large abnormal data, but the high frequency noise in the data may still exist. To separate out the high frequency noise, the Daubechies wavelet with a decomposing tree of level 3 is applied. The filtering result with the wavelet transform is shown in figure 3(c).

The GI tract's peristalsis wave is extracted after filtering. Then the MI and the GTT of the sixteen subjects is computed. The computed result is shown in table I.

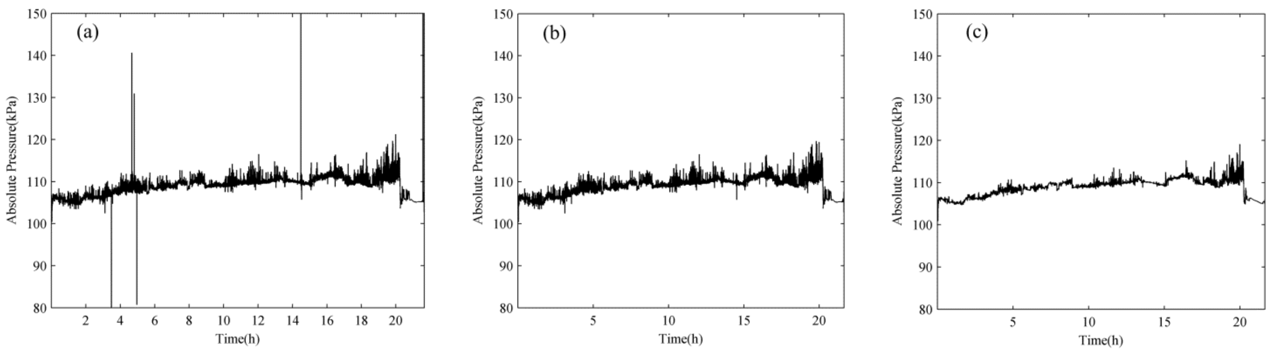

Fig.3. The results of data processing. Fig.3(a) is the raw data of pressure data, Fig.3(b) is the filtered data of the raw data filtering by the threshold processing method, Fig.3(b) is the filtered data of the pressure data filtering by wavelet transform

As can be seen from the table I, the range of the healthy subjects GTT is 16.35 hours～35.33 hours, while the patients with constipation is generally greater than 36 hours. The range of the healthy subjects MI is 9.12～10.36, while the patients with constipation is generally greater than 10.5. The subject of number 16 whose GTT and MI are normal is diagnosed with constipation, probably because his gastric MI or colon power index is abnormal which requires us to study more in-depth.

TABLE I. The gastrointestinal transit time and motility index of the sixteen subjects.

Number	GTT	MI	PC	Number	GTT	MI	PC
1	20:14	9.66	healthy	9	21:23	9.46	healthy
2	16:21	9.75	healthy	10	19:35	9.12	healthy
3	16:33	9.69	healthy	11	70:21	12.06	constipation
4	26:46	10.01	healthy	12	60:44	11.09	constipation
5	23:32	9.18	healthy	13	50:44	11.22	constipation
6	21:13	10.18	healthy	14	36:59	10.68	constipation
7	32:50	10.17	healthy	15	43:26	11.56	constipation
8	35:20	10.36	healthy	16	22:20	10.05	constipation

Note: GTT: gastrointestinal transit time, Format: hh:mm. MI: motility index.
PC: physical condition

5. Conclusion

In this paper, clutter such as breath noise, cough noise and electromagnetic noise are cleared by the adjusted threshold method and wavelet transform, then the GTT and the whole gastrointestinal MI and are computed. Finally, we compared the GTT and MI of the whole gastrointestinal tract in healthy and constipation characterized by the wireless capsule and find that the patients with constipation showed significantly higher MI and longer GTT compared with healthy subjects. The results show that the wavelet transform provides a new way to research human gastrointestinal activities.

However, more experiments on the subjects are needed to statistically verify the result that the patients with constipation showed significantly higher MI and longer GTT compared with healthy subjects. Furthermore, the difference of the gastric MI, colon power index and intestinal MI in healthy and patients needs to be studied in the future.

6. Acknowledgement

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