Approximate Entropy Based Pulse Variability Analysis

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Abstract

The dynamical analysis of pulse variability gives new insight into researches of cardiovascular system's dynamics. Firstly, long-term pulse variability analysis for the researches on cardiovascular system was proposed. Secondly, approximate entropy was applied to analyze three groups of long-term pulse waveform's variabilities and we found that the pulses' approximate entropies of patients with cardiovascular disease preferred to smaller value and less irregularity. What's more, the pulse variability of the patient with pacemaker newly implanted was also studied. Finally, the pulse variability's clinical value for cardiovascular system was concluded.

Keywords- Pulse variability, Approximate entropy, Cardiovascular system

1. Introduction

Various civilizations, especially in China, have used arterial pulse as a guide to diagnose and treat various diseases for thousands of years. This would obviously require the analysis of pulses according to their features and relationships to a variety of diseases.

Over the past few decades, the recording and storage of massive datasets of pulse waveform is allowed. However, long-term pulse was seldom researched. Through the long-term pulse signal, we found that the pulse and its feature parameters had variability [1]. Mikio Aritomo et al. have developed an arterial pulse system for continuous data acquisition in studies of resting heart rate and circadian rhythms [2]. But, they did not process and analysis the pulse data further. Having analyzed the pulse waveform with the conventional methods, we found that some dynamic characters of pulse waveform were undisclosed [3]. What's more, a number of nonlinear methods have been recently introduced to quantify complex heart rate dynamics [4]. One of the dynamical measure methods derived from nonlinear dynamics is approximate entropy (ApEn), which has potential application to a wide variety of relatively short data [5]. Motivated by the above idea, we employ the ApEn to disclose some clinical value of pulse variability.

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This paper aims at computing the variability of long term pulse waveform and analyzing its clinical value for cardiovascular system. In Section 2, the long-term pulse data collection and preprocessing are stated firstly. Then the approximate entropies analysis of long-term pulse and their corresponding experimental results are presented and compared in Section 3. Moreover, the variability analysis of patients' ApEns with pacemaker implanted is illustrated. Section 4 draws some conclusions.

2. Data collection and preprocessing

2.1. Data collection

In this paper, all the pulse data were acquired by our pulse monitoring and diagnosis system [1]. Pulse waveform recordings were available from 90 volunteers, who were divided into three groups:

1) 30 volunteer inpatients with cardiovascular disease;
2) 30 volunteer inpatients without any cardiovascular disorders;
3) 30 healthy persons without documented history of cardiovascular diseases and disorders, whose health conditions had been confirmed by physical examination.

For the further researches of the pulse variability's clinical value for the cardiovascular system, we also acquired the pulse from another 10 patients with pacemaker newly implanted. In quiet supine position, all of the 100 subjects were monitored for 600 seconds at the sampling rate of 100 Hz.

2.2. Pulse waveform preprocessing

The bandwidth of the acquiring system is usually from 0.05Hz to 100Hz with almost linear response, causing no distortion of the pulse waveform. However, distortion may arise from subject's movement, respiration and so on. Obviously, the detection of pulse complexity and variability is difficult due to baseline noise. Therefore, the pulse waveform needs preprocessing. First of all, we designed a wavelet based cascade adaptive filter in the paper [6] to remove the wander. Then we normalized the pulse further for ensuring the precise and validated ApEn computing. In brief, the preprocessing of pulse data includes two stages, pulse baseline removal and normalization.

3. Approximate entropy calculation and analysis

Over the past few decades, many researchers have studied the pulse waveform. However, the analysis and models used to study the pulse often assume linearity and stationary. Fig.1, the pulse's state space figure, illustrates that the pulse has some variability. The embedding dimension is 3 and the lag is 6. For the research of pulse variability, the nonlinear dynamical analysis must be introduced.

3.1. Approximate entropy calculation

Approximate entropy is a measure that quantifies complexity and organization. For example, a low ApEn means a high degree of regularity. ApEn has been repeatedly recommended as a relative measure for comparing data sets. The obvious advantage of this method is its capability to discern changing complexity from a relatively small amount of data and better outliers rejection ability.

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ApEn(m,r,N) is computed according to three parameters, m, r and N. Where, m is the dimention of the signal will be expanded; r is the threshold and N is the signal's length to be computed. Both theoretical analysis and clinical practices concluded that m=1or 2, and r is between 10% and 25% of the standard derivation of the data to be analyzed produce good statistical validity of ApEn(m,r,N). In this paper, we use m=2, r=0.2, N=300 to compute ApEn(m,r,N) (that means every segment includes 300 sampling points) [5]. Consequently the 10 minutes pulse recording (60000 sampling points) can be divided into 200 segments. Each segment contains 3-second pulse recording. Then the variability of these 200 ApEn values can be analysed and compared.

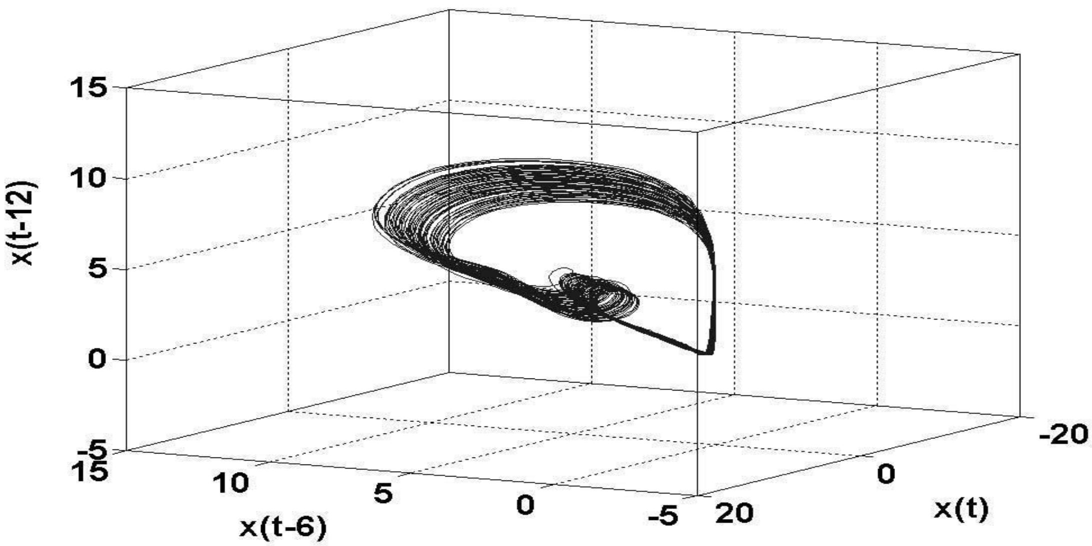

Fig. 1 The presentation of pulse in state space.

3.2. ApEn analyses and comparisons

Having applied the ApEn for variability analysis of three groups people's pulses, we found that the ApEn average values of these three groups do not have significant difference. Fig.2 illustrated the three groups' ApEn mean. The y-coordinate is the average of every subject's ApEns. Each groups contains 30 subjects and their **ApEn Means** all vary from 0.08 to 0.25. Usually, the 1st group's **ApEn Means** are smaller than the 2nd group and 3rd group's. But these three groups' ApEn variabilities do have significant difference. In Fig.3, the upper panel **ApEn1** is the ApEn of a patient with coronary heart disease; the middle panel **ApEn2** is the ApEn of a patient without any cardiovascular disease; the lower panel **ApEn3** is the ApEn of a healthy person without any disease history. All of the approximate entropies are typical enough to stand for their groups respectively. The y-axis is the value of ApEn and the x-axis is the segment's sequence number. From Fig.3, you can find that the ApEn of patient with heart disease fluctuates faster and more

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similarly, while the healthy person's ApEn fluctuates more irregularly. This means that the healthier of person's cardiovascular system is, the more variable of his pulse will be.

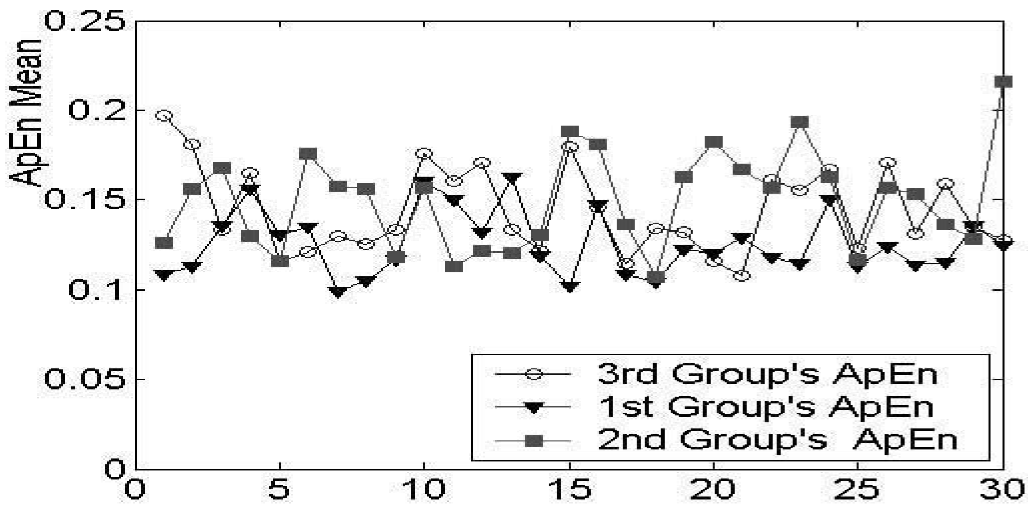


Fig. 2 The comparison of three groups' ApEns averages.

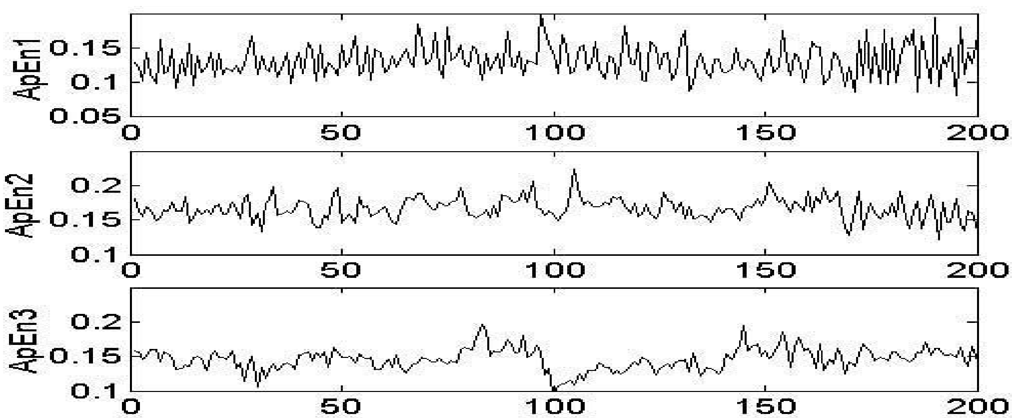
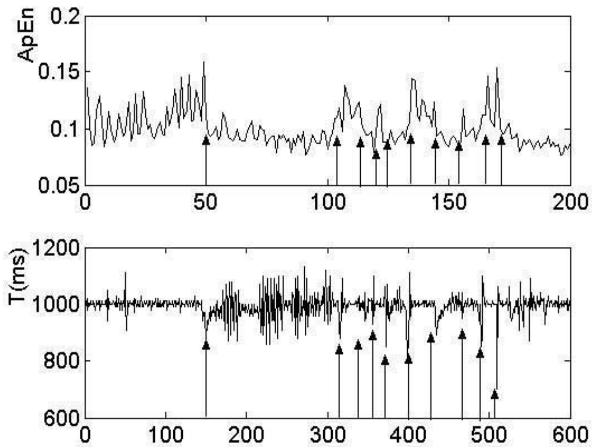


Fig. 3 The comparison of ApEns' variability.

For the further researches of these phenomena, we also analyzed the pulse variability of ten patients with pacemaker newly implanted and compared the ApEn fluctuations with their heart rate variability. In Fig.4, the upper panel is the **ApEn** of pulse variability. **T** is every heart period time. Both of them are computed from the same 10 minutes' pulse waveform. In lower panel, the x-axis is the number of the heart periods and the y-axis is heart period. In Fig. 4(a), the patient's pacemaker heart rate was set to 60. The lower panel is the heart rate variability. In the period of 600 seconds, his pulse includes 605 pulse beats. The heart period nearly fixes to 1000ms with little variability when the pacemaker functions. During this period, the heart is passive. But from the 150^{th} to 300^{th} period, which are marked by the arrows, the heart can actively work and the ApEn value gets smaller and has less fluctuation. Fig 4(b) shows the ApEn of a healthy person's pulse variability. This has proved that the ApEn of patients with some cardiovascular disease has less variability than the healthy person's, and the healthy person's pulse rate variability is more chaotic just like heart rate variability [7]. In this period of 600 seconds, his pulse has 779 pulse beats.



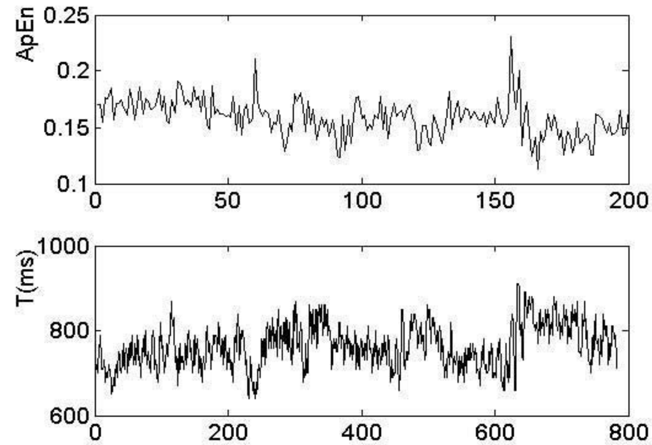


Fig. 4(a) Fig. 4(b)

Fig. 4(a) The ApEn and the heart rates of patient with pacemaker newly implanted.

Fig. 4(b) The ApEn and the heart rates of healthy person.

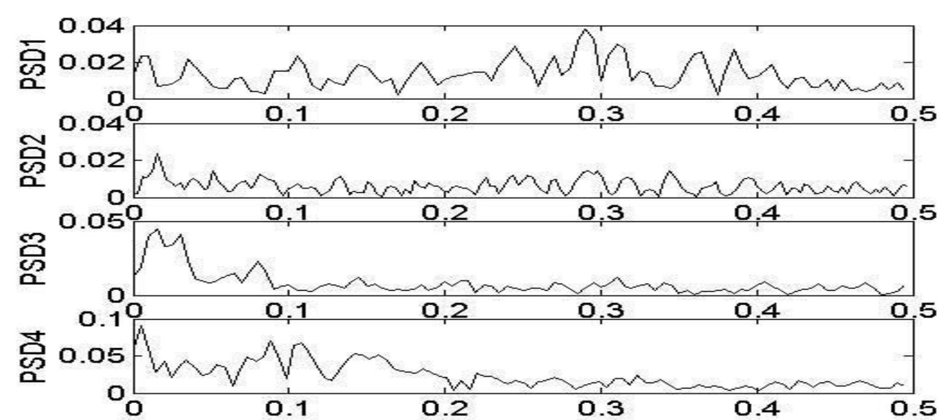


Fig. 5 The comparisons among different approximate entropies' power spectrum.

From the spectral point of view, we can also judge some notable relationship of pulse's variability with the cardiovascular system. Fig. 5 illustrates the power spectrum of different ApEns. All of them are computed from the ApEns of 10 minutes' pulse waveforms. The first row **PSD1** is the ApEn spectrum of patient with heart disease; the second **PSD2** is the ApEn spectrum of patient without any heart disease; the third row **PSD3** is the ApEn spectrum of healthy person; the last row **PSD4** is the ApEn spectrum of patient with pacemaker. You can find that the healthy person's ApEn has more low frequency contents, shown in **PSD3**. The **PSD4** has also some low frequency contents because the pacemaker performs some work. Both **PSD1** and **PSD2** both have some high frequency contents, but the **PSD1** has more high

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frequency contents than **PSD2**. The **PSD4** has less high frequency contents owing to the pacemaker. All of them are computed from the ApEns of 10 minutes' pulse waveforms. The low-frequency content means some 1/f content and stands for the chaotic and irregular characteristics of signal.

4. Conclusion

In this paper a dynamical analysis method of pulse waveform was presented to study cardiovascular system's dynamics, which opened up a new approach towards the assessment of normal and pathological cardiovascular behavior. The long-term pulse variability analysis suggests that the ApEn of healthy person's pulse has more irregularly fluctuation and prefers to higher value. This conclusion can be further proved by the ApEn variability of patient with pacemaker newly implanted. Therefore the ApEn can be used to classify and differentiate the cardiovascular condition. Future work needs to quantitatively analyze cardiovascular system's behavior on a larger dataset of pulse.

5. Acknowledgements

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