別紙様式５(Attached Form 5)

学位論文要旨 Abstract of Thesis

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Title of Thesis

Potential of Unbalanced Complex Kinetics Analysis of Heart Rate Variability: Physiological Investigation Toward Arrhythmia Estimation and Prognosis Prediction

Abstract（within 1600 words）

Cardiac autonomic dysfunction is one of the determinants of the development of cardiovascular diseases. Cardiac autonomic imbalances and reduction of its modulation are signs of disorders and conditions. Heart rate variability (HRV), a promising marker of those autonomic activities, can be measured non-invasively in order to observe the influence of the cardiac autonomic system on sinus node activity through changes in the cyclic variations of beat-to-beat (R-R) intervals. The physiological correlations of HRV and standards for its measurement have been proposed. An important marker is the frequency domain representation; however, the result of the high-frequency (HF) component might be influenced by breathing pattern. Similarly, the non-linear analysis representations of complex cardiac autonomic regulation do not reflect a clearly meaningful physiological correlates. Therefore, additional methods have been proposed to obtain more accurate estimates.

HRV is evaluated by observing R-R interval variations obtained from the electrocardiogram (ECG) signals. HRV reflects complex regulation of cardiac autonomic activity and possesses a non-linear representation. Since the HRV is non-linear, it is necessary to quantify it in a non-linear manner. We proposed a non-linear method called the “potentials of unbalanced complex kinetics” (PUCK) to observe the potential force of the R-R interval time series. Potential force is moving potential of the time series with its center given by the moving average of its own trace. The observation of potential forces has been used in the econophysics field to analyze the fluctuation of foreign exchange price.

Meanwhile, such a complex and non-stationary fluctuation was also found in the R-R interval time series variability caused by cardiac autonomic regulation. Therefore, this thesis focuses on the application of PUCK analysis in autonomic heart regulation. The PUCK analysis method was applied in various physiological and pathological conditions.

First we developed a long-term monitoring system for HRV that can be implemented in the ICU/HCU. The system has worked properly in the laboratory experiment with two subjects. This system also worked in the ICU/HCU and provided a monitoring tool for the medical staff. The problem underlying the development of this system is the emergence of the problem in the ICU regarding the smooth managements of ICU admission. We concluded that the long-term monitoring system for HRV is a promising tool to monitor the trend of patients' condition. Furthermore, we proposed a non-linear method PUCK analysis to extract various normal to a pathological condition. We demonstrated that the existence of potential force dynamics of the R-R interval time series is associated with cardiac autonomic modulation. The PUCK analysis method can quantify the cardiac autonomic function under the experimental conditions of different postures. In addition, significant reductions of SSD1 and SSD2 can be used as markers of age-related differences and are unaffected by breathing patterns. In conclusion, this could be an alternative method for observing cardiac autonomic function in clinical practice.

In the next observation, the PUCK analysis could extract the features of a short R-R interval data segment from the arrhythmia database. Although the use of a very short R-R interval data in PUCK analysis is still debated, this process characterized the R-R interval data containing arrhythmia with statistically significant accuracy. Our classification results showed that PUCK might improve the accuracy with which cardiac arrhythmia is detected. Compared to the use of just one type of HRV analysis, combining the features of these analyzes with a PUCK analysis improved the accuracy of arrhythmia detection. Because a simple statistical classifier using a decision-tree algorithm was employed in this study, we believe that the accuracy and classification performance could be enhanced further using various classifier algorithms.

We also demonstrated that potentials dynamic of HRV results would seem to be useful as an estimator of prognosis of patients with SAH in ICU. Reduced slope as a marker of sympathetic modulation and reduced SSD1 and SSD2 may contribute to the poor prognosis in these patients. The frequency domain analysis results (as a generally accepted standards for measuring the cardiac autonomic activity) do not show any significant difference between good and poor prognosis patients with SAH.

Finally, this thesis concludes that PUCK analysis results were able to elicit the cardiac

autonomic modulation. It was also applicable for detecting the abnormality in the beat-to-beat heartbeat signals. Moreover, the analysis can be used as an estimator of prognosis of patients with a certain disease.