Wavelet and Fourier Transform Analysis of ECG Signals in Peritoneal Dialysis Patients with Hyperparathyroidism

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ABSTRACT

Hyperparathyroidism is a condition from which parathyroid hormone (PTH) is produced excessively and plays an important role in the adverse effects to many organs. PTH known as a uremic toxin is more accumulated in chronic renal failure and can cause cardiomyopathy. A number of studies have investigated the association between the heart rate variability obtained from the Electrocardiogram (ECG) and parathyroid hormone levels in the chronic kidney disease patients. In this study, ECG signals were recorded from continuous ambulatory peritoneal dialysis (CAPD) patients with normal parathyroid hormone (N-PTH) and those with hyperparathyroid hormone (H-PTH) and were averaged to provide the signal-averaged ECG. The time interval of R peak for each patient was identified and the standard deviation (SD) of the R peak interval was evaluated by continuous wavelet transform (CWT) and Fourier transform (FT) for classification of the CAPD patients into N-PTH and H-PTH groups.

Keywords: CAPD; ECG; standard deviation; parathyroid hormone; hyperparathyroidism; continuous wavelet transform; Fourier transform;

1. INTRODUCTION

CAPD is one of the most popular treatment procedures for end stage chronic renal disease (ESRD) patients. The inadequate dialysis or the accumulation of uremic toxin such as blood urea nitrogen (BUN), creatinine, and parathyroid hormone often appears to be a considerable problem in these patients. Particularly, hyperparathyroidism is a condition from which PTH is produced excessively, resulting in an increase of morbidity and mortality. Although, the adverse effects of this hormone excess are not only osteoporosis but also cardiac malfunction (London et al, 1987), nowadays the PTH concentration monitoring is the invasive, expensive, and environmental pollution method.

Many investigations have published that the heart rate variability (HRV) obtained from the ECG was related to the chronic kidney disease patients. The HRV in CAPD patients was inversely associated to the PTH concentration (Ussawawongaraya et al, 2013). The standard deviation within the QRS duration of the analyzed ECG in the time domain was inversely related to hyperparathyroidism of the CAPD patients (Ussawawongaraya et al, 2014). For ESRD patients replaced with either hemodialysis or CAPD, their PTH concentrations have negative correlation to frequency and total power of the HRV achieved from the ECG (Polak et al, 2004 and Ussawawongaraya et al, 2014). Obviously, these studies showed that the PTH affected the ECG of the patients but the resolution may be not enough for the hyperparathyroidism categorization.

This study aims to provide the non-invasive, cost effective method that is considered as an innovative technique. In addition, it can be used to classify the CAPD patients into N-PTH and H-PTH by wavelet transform and Fourier transform.

2. MATERIALS AND METHODS

2.1 Data Collection

Both of the CAPD patients with N-PTH and those with H-PTH have been participated in this investigation. These chosen CAPD patients have the similar medical history and clinical characteristics. The criteria for the subject inclusion were a double bag system of dialysate solution with 1.25% dextrose, over 1.7 of Kt/V (dialysis adequacy index) and no sign of either infection or inflammation. The patients with any pathology causing ECG abnormalities, abnormal ECG with the other causes, regularly alcohol drinking and tobacco smoking and abnormal blood sample parameters except PTH concentration have been excluded from this study. The standard subject committee considered and approved the experimental protocol. The written consents of all volunteers were documented.

The PTH concentration in the CAPD patients that was less than 300 pg/ml and higher than 300 pg/ml were defined as the N-PTH and the H-PTH group, respectively. Each patient group involved 7 males and 5 females in this investigation.

All of the patients in the supine position for 20 minutes were in the comfortable room at 25°C and the vital signs were monitored using the vital sign monitor (Nihon Kohden Co, Ltd., Tokyo, Japan). Subsequently, the ECG signal in lead II for 15 min-

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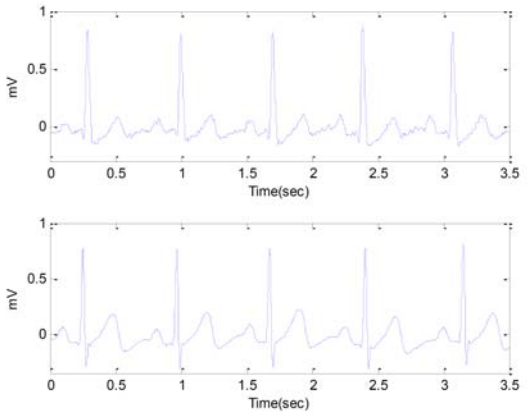

Fig.1:: Examples of ECG waveforms obtained from two CAPD patients with the N-PTH.

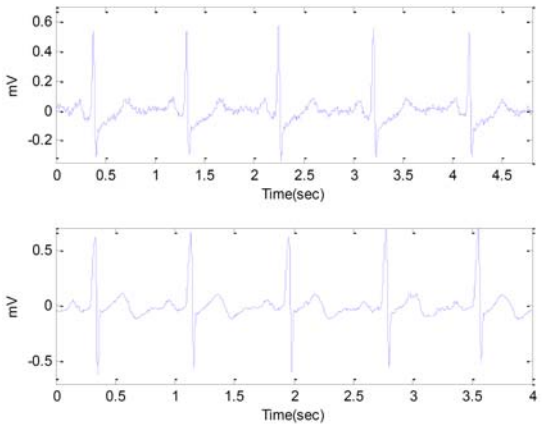

Fig.2:: Examples of ECG waveforms obtained from two CAPD patients with the H-PTH.

utes was recorded by the MP 36 Biopac system (Biopac System Inc., USA) for studying the characteristics of the ECG signal for each patient group.

One hundred heartbeats of ECG waveforms were recorded. Initially, the R wave for each beat was detected and then the P wave and T wave of its beat were identified. P wave was a wave before the R wave for 200 ms or 200 samples, while the T wave was a wave after the R wave for 400 ms or 400 samples. The R peak interval was specified as the time interval from 10 ms before the R peak to 10 ms after the R peak. The examples of five ECG waveforms obtained from two CAPD patients with the N-PTH and H-PTH are shown in Figures 1 and 2, respectively.

Consequently, many ECG waveforms were averaged in time to accomplish one averaged ECG waveform including the P, QRS complex, and T waves as shown in Figures 3 and 4. An important advantage of signal averaging is to diminish noise mixed with the ECG signal by which this ECG signal analysis will provide more accurate results.

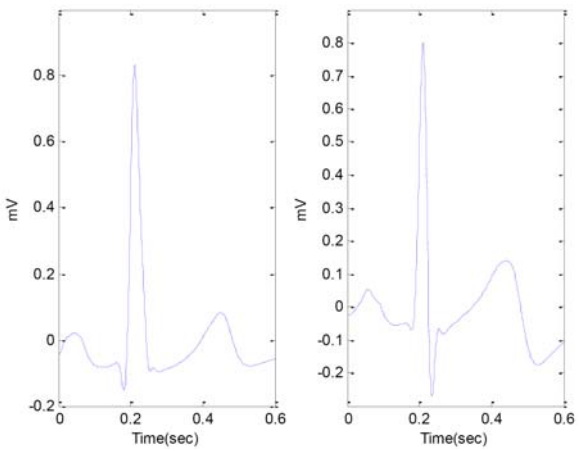

Fig.3:: Examples of one averaged ECG of two CAPD patients with the N-PTH.

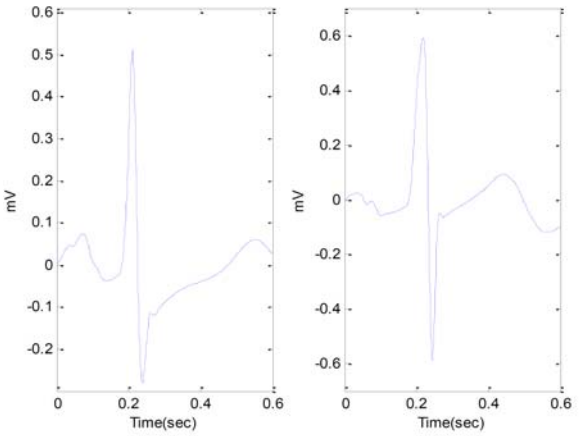

Fig.4:: Examples of one averaged ECG of two CAPD patients with the H-PTH.

2.2 ECG Analysis with Continuous Wavelet Transform

Signal analysis with wavelet is a signal processing method that has been very popular nowadays and applied widely in research areas such as digital image processing and biomedical signal processing, including an electromyogram signal, an electroencephalogram signal, and a heart sound signal. Especially, wavelet analysis of ECG signals provides the satisfactory results and is more accurate when compared with other methods of analysis (Bunluechokchai et al, 2008 and 2009)

The wavelet signal processing method is the analysis of the so-called time-scale domain. It usually shows a signal in the three-axis plot. The Z-axis exhibits the energy distribution. The X-axis is the time and the Y-axis is the scale. One advantage of wavelet analysis is to provide good details of the signal in both the time resolution and the frequency resolution.

This research aims to study the essential features

of the R wave to classify the patients with N-PTH and H-PTH by investigating the R peak interval within the duration of the QRS complex. The signal-averaged ECG was analyzed by the CWT, which can select the scale continuously and has a selection of different types of wavelet families.

Usually, a signal is shown and analyzed on the time-scale domain for wavelet transform. A mother wavelet (ψ) can be created by changing the scale and time as shown in Equation 1. It is used to generate the different sub-wavelets.

$$\psi_{a,b}(t) = \frac{1}{\sqrt{d}}\psi\left(\frac{t-b}{a}\right) \quad (1)$$

Equation 2 is the calculation of the CWT.

$$CWT(a,b) = \int_{-\infty}^{\infty} s(t)\psi^*_{a,b}(t)dt \quad (2)$$

where

$s(t)$ is the signal.
$\psi(t)$ is the mother wavelet.
a is the scale parameter.
b is the translation parameter
t is the time.
* denotes the complex conjugate.

Modifying the scale (a) will result in a change to the shape of the wavelet. If smaller scale value is chosen, the shape of the wavelet is forced to narrow it down. In contrast, if the higher scale is selected, the wavelet shape will be enlarged. Changing the shape of the wavelet is very useful for wavelet signal analysis because the narrow shape of the wavelet at small scale makes it possible to analyze signals with higher frequencies; however, the extended shape of the wavelet allows detecting the lower frequency signals. If analysis of a high-frequency signal is needed, the low scale of the wavelet should be used, whereas the detection of a low frequency signal is to use a high scale. That is to say that the wavelet method can analyze signals both low and high frequencies at the same time by choosing the scales for both high and low values corresponding to the frequency range within the signal itself.

Equation 2 provides the CWT (a, b) coefficients at scale a and time b. The coefficients are used to demonstrate the ability of the CWT whether it can analyze or detect the signal well. If the coefficients are high at scale a and time b, it means that the signal is detected well at scale a and time b, but if the coefficients are low, it indicates that the detection of the signal is not good at scale a and time b.

Type of wavelet used in this research was the Daubechies 2 (db2) and the wavelet scales between 20 and 66 were selected. CWT coefficients in the R peak interval of the analyzed ECGs were performed at those scales and then the standard deviations of the CWT coefficients were evaluated for the patients in both groups. This research has attempted to use the standard deviation as an indicator of the segregation of two patient groups.

2.3 ECG Analysis with Fourier Transform

The Fourier transform is traditionally an analytical method and has been widely used for signal analysis in the frequency domain. It is used to find the frequency components of the signal. The result of the analysis of the Fourier transform is often represented as a graph with two axes. The Y-axis shows the power of the signal and the X-axis displays the frequency. Equation 3 is the calculation of the Fourier transform.

The FT can be calculated from Equation 3.

$$X(k) = \sum_{n=0}^{N-1} x(n)e^{-i2\pi k\frac{n}{N}} k = 0, 1, 2..., N-1 \quad (3)$$

where

X(k) represents the Fourier transform coefficients,
N is the total number of the signal samples
x(n) is the signal.

The result of the calculation of Equation 3 is Fourier coefficients. The square of these coefficients will be the power of the signal. The power of the signal (Y-axis) is plotted against its frequency (X-axis). It is a graph to show that the signal has frequency components which are part of it.

In this study, the procedure of ECG signal processing with Fourier transform was similar to the CWT analysis method mentioned earlier. The only R peak interval in signal-averaged ECG was analyzed by the FT to compute the power of the processed ECG signal by squaring the Fourier coefficients. Eventually, the SD of the signal power in the R peak interval was estimated to distinguish the two patient groups.

2.4 Statistical Analysis

All of the achieved data were shown in mean ± SD and analyzed with the computer software. Mann-Whitney U test was used to compare the mean value between two patient groups because of non-normally distributed data. The p-value < 0.05 was the acceptable statistical significance.

3. RESULTS

The parameters of demographic and clinical characteristics were assessed in mean ± SD. There were no significant differences in all parameters of demographic and clinical characteristics. Exceptionally, the PTH concentration in H-PTH was higher than that in N-PTH (628.08 ± 284.80 vs 89.41 ± 56.59; p-value < 0.001). Moreover, the SD of R peak interval in the signal-averaged ECG of each CAPD patient in

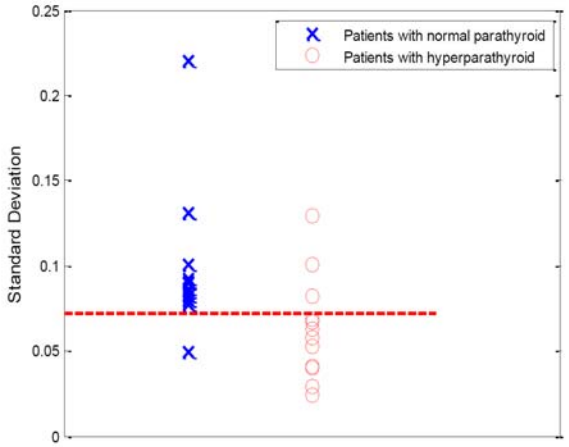

Fig.5:: Standard deviations computed by the CWT for the N-PTH and H-PTH patients

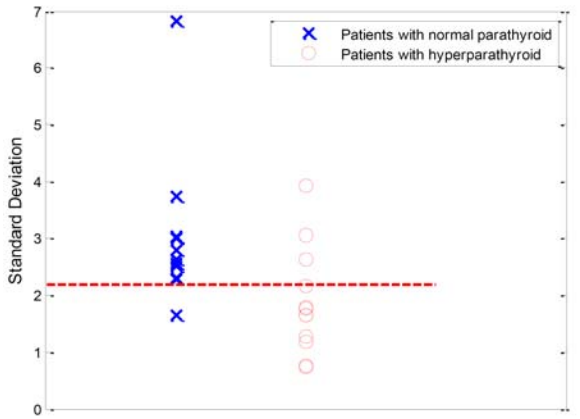

Fig.6:: Standard deviations achieved by the FT for the N-PTH and H-PTH patients.

both patient groups was evaluated using the CWT and FT. Table 1 shows demographic, clinical characteristics, and SD of both N-PTH and H-PTH groups.

SBP: systolic blood pressure, DBP: diastolic blood pressure, HR: heart rate, Kt/V: dialysis adequacy index, SD: standard deviation, FFT: fast fourier transform, and CWT: continuous wavelet transform. The values were shown as mean±SD. The p-value compared between N-PTH and H-PTH group were $^{*}p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$.

The CWT analysis found that the average of the SD of the N-PTH appear to be higher than that of the H-PTH (0.10 ± 0.04 vs 0.06 ± 0.03; p-value $= 0.008$) as shown in Figure 5. Note that there is a statistically significant difference of the standard deviations between the two groups at the p value of 0.008 by the Mann-Whitney U test.

In Figure 5, if a SD of 0.072 is empirically chosen (the dashed line) to distinguish between the two populations, this value may be used as an indicator of a population group. Consequently, the N-PTH and H-PTH would be grouped by the standard deviation over and below 0.072, respectively.

Table 1:: Demographic, clinical characteristics, and SD of both N-PTH and H-PTH groups

Parameter	N-PTH (n=12)	H-PTH (n=12)
Age (years)	52.25 ± 9.67	52.08 ± 12.50
Gender (M/F)	7/5	7/5
Duration of treatment (months)	36.67 ± 20.45	42.08 ± 15.89
Kt/V	9.43 ± 0.67	9.43 ± 0.95
P (mg/dl)	2.04 ± 0.24	1.98 ± 0.30
SBP (mmHg)	133.34 ± 10.73	142.50 ± 17.64
DBP (mmHg)	72.50 ± 6.21	75.83 ± 9.00
HR (bpm)	78.20 ± 10.08	83.40 ± 9.70
PTH (pg/ml)	89.41 ± 56.59	628.08 ±284.80***
SD (FFT)	2.97 ± 1.31	1.88 ±0.94*
SD (CWT)	0.10 ± 0.04	0.06 ±0.03**

The FT analysis showed that the average of the SD of the N-PTH appear to be higher than that of the H-PTH (2.97 ± 1.31 vs 1.88 ± 0.94; p-value $=$ 0.014 or p-value < 0.05). Note that there is a statistically significant difference of the SD between the two patient groups.

In Figure 6, if a SD of 2.2 is empirically chosen (the dashed line) to distinguish between the two patient groups, this value may be used as an indicator of a population group. Therefore, the N-PTH and H-PTH would be separated by the standard deviation over and below 2.2, respectively.

4. DISCUSSION AND CONCLUSION

This research proposes a new concept of the ECG signal analysis in kidney disease patients. The features in the QRS duration of the ECG obtained from the CAPD patient with N-PTH and those with H-PTH have been investigated, especially the R peak interval to classify between two patient groups. Approximately 1000 ECG waveforms were averaged in time to achieve one signal-averaged ECG. This signal was used to determine the R peak interval for each patient and then analyzed by CWT and FT. This paper considered the SD of the R peak interval for each patient group which is a key feature to distinguish between the two patient groups. It was found that the SD values of the H-PTH were likely to be less than those of the N-PTH.

The accomplished SD can be used as not only the index for classification but also may be utilized to evaluate the adequacy of peritoneal dialysis for PTH concentration. The steady increasing of SD after dialysis for a period of time may mean that the patient's dialysis effectiveness for PTH has higher performance. On the other hand, the decreasing of SD

in inadequacy of the peritoneal dialysis shows that the PTH concentration of the patients is increased. Consequently, these patients should be manipulated with the other suitable prescriptions by the dialysis care team.

This research is a preliminary study and proposes the standard deviation as an indicator for classification of the patient groups. Other indices should be investigated for further work. However, the volunteers in this study were not large enough. Accordingly, it should be studied further with more volunteers to confirm the results of this research.

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