Automatic Detection of the Wolff-Parkinson-White Syndrome from Electrocardiograms

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Abstract

In this paper, a new method of automatic detection of the Wolff-Parkinson-White (WPW) syndrome is proposed based on electrocardiograms (ECGs) signals. Firstly, with the continuous wavelet transform (CWT), the P wave, the T wave and the QRS complex are identified. Then, their durations are also computed after determination of the boundaries (onsets and offsets of the P, T waves and the QRS complex). Secondly, the PR interval, the QRS complex interval and the area of the QRS complex are determined in order to detect the presence or not of the delta wave. This method has been tested on ECGs signals from patients affected by the WPW syndrome in order to evaluate its robustness. It can provide assistance to cardiologists during the interpretation of the ECG.

1. Introduction

The WPW syndrome is a cardiac conduction problem associated with reentry tachycardia and it may even be responsible of sudden cardiac death [1]. This congenital abnormality corresponds to a short circuit between atria and ventricles due to the presence of an accessory pathway (AP). In Europe, the prevalence of the WPW syndrome is about 0.15 to 0.31%, and it is the second most common cause of paroxysmal supraventricular tachycardia. The WPW syndrome can be diagnosed on a 12-lead standard ECG, it is described in an ECG by three features [2]: Short PR interval, prolonged QRS duration and presence of a wave so-called delta in the QRS complex. Aside from medical anti-arrhythmic drugs, the main treatment is based on the physical eradication of the AP by applying radiofrequency energy with a dedicated lead on its precise location, using endovascular techniques. Up to now, its precise location around tricuspid or mitral annulus is based on non-practical algorithms that have been published over the years [3]. We have developed a completely new method based on the whole complex QRS morphology analysis, as opposed to previous algorithms based on delta wave patterns only. This method allows us to detect the P wave, the QRS complex and the T wave, and to determine their bounderies (onset and offset of the P, T waves and the QRS complex).

In figure 1, the different intervals in a typical ECG are shown, as well as the duration of each wave is illustrated with a heart rate is between 60-90 bpm. This algorithm allows us to effectively detect intervals and durations of the waves (P, QRS complex and T) as described on figure 1. It has been tested on real signals from the University Hospital of Dijon (UHD) database (see section 2) in order to confirm its robustness. Then, one computes the area of the delta wave to complete the detection criteria of the Wolff-Parkinson-White syndrome cited above.

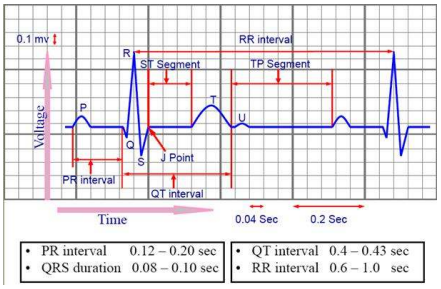

Figure 1. Illustration of waves and intervals in an ECG (Source:httpintranet.tdmu.edu.uadatakafedra).

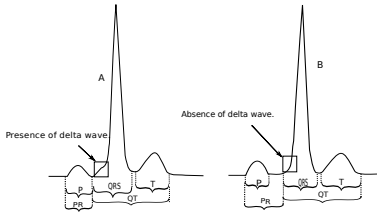

Figure 2. Schematic representation of the presence or absence of the delta wave: In (A) the QRS complex with a delta wave and (B) without the delta wave.

In figure 2, we show the difference between a QRS complex with delta wave and a QRS complex without the delta wave: The segment of the QRS complex with the delta

wave is greater to the segment of the QRS complex without the delta wave. However, the interval of PR with the delta wave is less than the interval of PR whithout the delta wave, and the QT interval is preserved.
After having determined the three criteria (PR interval, QRS complex interval and delta wave) correctly, this algorithm should help physicians in their daily clinical practice during treatment of the syndrome. This study is described as follows: In section 2, the database is described, then the developed algorithm is explained in section 3 thus, the calculation of the area of the delta wave. In order to illustrate our method, some results are illustrated in section 4. Section 5 presents the conclusion and the discussion.

2. Database

University Hospital of Dijon (UHD): This database contains ECGs signals with 12 channels. It contains 40 patients affected by the WPW syndrome. For each patient, we have 2 records before treatment and 2 records after treatment of WPW syndrome. Each signal is digitized at 1000 samples per second, with 16 bits resolution over a range of 5 mV. Figure 3 shows the delta wave. In figure 4, the patient has been successfully treated, and thus the delta wave has disappeared.

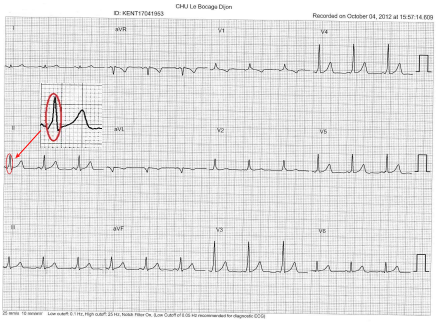

Figure 3. A standard ECG signal before treatment (from the UHD database).

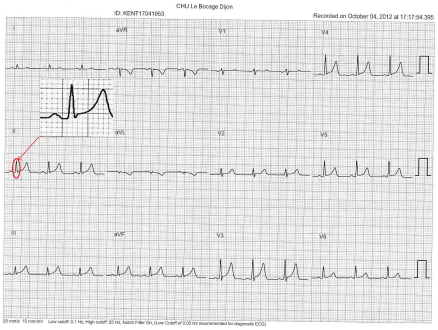

Figure 4. A standard ECG signal after treatment (from the UHD database).

3. Algorithm and Method

The method proposed in this paper is based on the continuous wavelet transform (CWT) [4–6]. We have previously developed an algorithm for the detection of the P wave, the T wave and the QRS complex in an ECG signal in order to detect the wave delta (see figure 5) [7]. The detection of the P wave, the T wave and the QRS complex in the ECG is an efficient way to diagnose different arrhythmias. In existing literature, multiple methods and tools are dedicated to this process in [8–12]. A real-time algorithm for detection of the QRS complex in an ECG based upon digital analyses of slope, amplitude and width is presented in [13]. However, these works are not dedicated to the WPW syndrome specifically. In order to adapt to real signals from the WPW syndrome, we have developed a new algorithm.

The CWT is frequently used to separate the ECG signal into a set of coefficients using a mother wavelet. The C(a,b) CWT of the signal $W(t)$ is defined as:

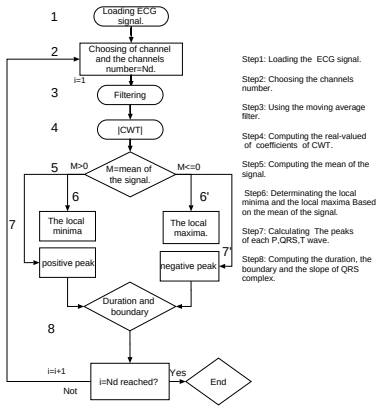

Figure 5. Flowchart of the algorithm

$$C(a,b) = \frac{1}{\sqrt{(a)}} \int_{-\infty}^{+\infty} W(t)\psi^*(\frac{t-b}{a})dt. \qquad (1)$$

Here, $W(t)$ a period of the ECG signal which contains the P wave, the T wave and the QRS complex. ψ^* is the complex conjugate of the wavelet function. $\psi(t)$ represents the so-called mother wave where a is the dilation parameter and b is the location parameter of the wavelet. There are several kinds of wavelets. After several tests, we have chosen the gaussian wavelet level 2 ('gaus2') with a scale value of 16, because it gives us the best results. $C(a,b)$ shows a function (or signal) as a weighted sum of these small waves dilated or translated.
After having loaded the signal, we can choose one lead or several leads. By filtering the selected signal with a moving average filter, the ECG signal is brought back to the iso-electric line like described in [14]. Then, the CWT of

the selected signal $W(t)$ is calculated and noted $C(a,b)$. In the first step, the local minima and maxima are computed depending the mean M of the signal $C(a,b)$:
- if $M > 0$ one computes the local minima,
- else one computes the local maxima.

As a second step, peaks of the P wave, the T wave and the R wave are also determinated depending on the mean of the signal S :
- if $M > 0$ the amplitude and the position of the peak of each wave are calculated,
- else the amplitude and the positions of the peak of each wave are also calculated.

As a third step, the closest local maxima and local minima to the position of each postive peak of each wave (P, QRS and T) or each negative peak of each wave (P, QRS and T) are automatically measured and located in time. After that, one determines the boundary, the interval and duration of each wave (P, QRS, T).

Knowing that the detection of the WPW syndrome requires the detection of three criteria mentioned above, the PR interval and the QRS complex duration are determined effectively. The final criterion is the detection of the delta wave. It is often difficult to see the delta wave on an ECG signal. To overcome this problem, one calculates the peak of the R wave noted M1 at time noted I1, then one computes the area A1 between the onset of QRS complex noted Q1 and I1. Then, area A2 is computed between I1 and the end of QRS complex noted Q2. Then, we calculate the ratio, noted A, between these 2 areas.

$$A = \frac{\int_{I1}^{Q2} W(t)dt}{\int_{Q1}^{I1} W(t)dt} \quad (2)$$

This criterion is an additional criterion, A is computed only in the QRS complex, if A is close to 1, there is no delta wave, if A is close to 0 or low, there is delta wave.

4. Results

Some results of the wave detection, intervals and the delta wave are shown here.

4.1. Waves detection

In this section, the rate of the wave detection is given for treated patients and not treated patients.

4.1.1. Untreated patient

When a patient is not treated, one can observe the presence of delta wave, because its presence disturbs the detection of the P wave, the interval of PR. The P offset and the QRS onset are the same. That is why in table 1, the rate of P wave is low, due to the existence of delta wave.

Table 1. Untreated patient: Cumulative mean of the intervals of PR, QT, QRS and the rate of waves detection.

UP	P	QRS	T
RWD	44.44%	80.07%	79%
	PRi	QRSi	QTi
CM	$0.106s \pm 0.003$	$0.306s \pm 0.05$	$0.072s \pm 0.004$

RWD=Rate of Wave Detection, UP=untreated patient, PRi=PR interval QTi=QT interval, QRSi=QRS interval, CM=Cumulative Mean.

Table 1 shows a short PR interval and a prolonged QRS interval.

4.1.2. Treated patient

One shows the rate of waves detection of a treated patient.

Table 2. Treated patient: Cumulative mean of the intervals of PR, QT, QRS and the rate of waves detection.

TP	P	QRS	T
RWD	76.19%	97.92%	86.46%
	PRi	QRSi	QTi
CM	$0.168s \pm 0.025$	$0.305s \pm 0.025$	$0.072s \pm 0.028$

RWD=Rate of Wave Detection, TP=Treated patient, PRi=PR interval, QTi=QT interval, QRSi=QRS interval, CM=Cumulative Mean.

Table 2 shows a better rate detection, because these patients have beeen treated and thus the delta wave has disappeared. As shown in table 2 the PR interval and QRS interval become normal in the case where the patient is treated. One can note that the PR interval is larger than the one obtained in the case of untreated patient. On the contrary, the QRS complex is smaller than the computed value presented in table 1.

4.2. Delta wave detection

In this case, we can quantify the delta wave by calculating the area of the QRS complex by using eq (2).

4.2.1. Rate of delta wave detection

Here, one presents the rate of delta wave detection and an illustration of the measure of the surface of wave delta. Our indicator has been tested on 80 ECGs signals from patients affected the WPW syndrome.

Table 3. Untreated patient: The rate of detection

RD	DWD(%)	DWND(%)
80 ECGs Signals	64 (80%)	16(20%)

RD=rate of detection, DWD = delta wave detected, DWND=delta wave no detected.

As shown on table 3, we have tested 80 ECGs signals, we have 80% of good detection and 20% of bad detection.

4.2.2. Untreated patient

When the delta wave exists, with the eq. (2), A is not close of 1.

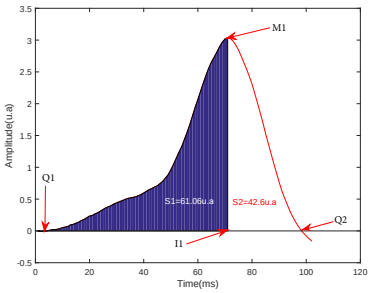

Figure 6. Representative schema and calculating the area of the QRS complex.

4.2.3. Treated patient

In the case presented in figure 7 the delta wave does not exist, the eq. (2) gives a value of A close to 1, that indicates the absence of the delta wave.

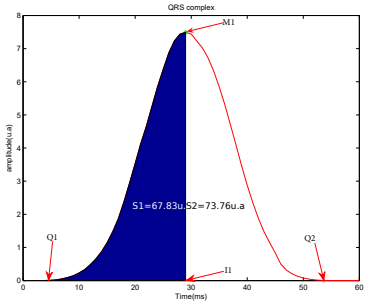

Figure 7. Representative schema and calculating the area of the QRS complex

5. Discusion and conclusion

In this study, we have determined the P wave, the T wave and the QRS complex in ECGs signals from patients affected by the WPW syndrome. Then, we have also localized their limits (onset and offset). Different intervals (PR interval, QT interval) and the QRS complex duration are computed. We have quantified the area where there may be the delta wave. Using our UHD database, we obtained 80% of good detection. An alternative way to quantify the delta wave could also be reached by modeling the QRS complex by the superposition of two gaussians waves using a Gaussian mixture model [15].

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