Continuous Multiparameter Monitoring of P Wave Parameters after CABG Using Wavelet Detector

S Sovilj[1], G Rajsman[2], R Magjarevic[1]

[1]University of Zagreb, Faculty of Electrical Engineering and Computing, Zagreb, Croatia
[2]Clinical Hospital Center Zagreb, Department of Cardiac Surgery, Zagreb, Croatia

Abstract

The aim of the study was to develop methodology for long- term study of ECG parameters, in particular the P wave parameters. In this study we address continuous monitoring of different P wave parameters in the group of patients after Coronary Artery Bypass Grafting (CABG) in order to examine potential predictors of atrial fibrillation. Lead II of the standard surface ECG was recorded in the period of typically 48 hours in patients after CABG. Dyadic wavelet transform analysis with first derivation of Gaussian smoothing function as a mother wavelet, was used for a QRS and a P wave detection, characterization and delineation. During the recording, for every patient, in every hour, vector of 108 P wave components was calculated, allowing continuous and deeper insight into atrial activity.

1. Introduction

Atrial fibrillation (AF) is the most common supraventricular arrhythmia and postoperative complication occurring in up to 40% of patients after CABG. Patients developing post-CABG AF usually have no previous AF history [1], [3], [5].

Different electrophysiological and morphological factors induce AF and there is no unique explanation for etiologic mechanisms behind AF. Today, probable causative factors are assumed: slow conduction and delay of intra-atrial and inter-atrial conduction lines, and inhomogeneous propagation of atrial impulses due to the shortening and dispersion of atrial refractory period [1], [3], [5], [7]. Patients have prolonged P waves indicating either a marked enlargement of the atria or slower conduction along the activation of the atria. Decreased and dispersed refractory state of the tissue is a pro-arrhythmic phenomenon [5], [6], [7].

In order to obtain different P wave parameters, automatic P wave detection was applied first with the algorithm based on wavelet decomposition as a robust, multi-resolution analysis technique. Automatic P wave detection and measurement is more reproducible and accurate than the manual one, and it allows continuous detection, measurement and monitoring of different P wave parameters.

2. Methods

Lead II of the standard surface ECG was recorded in the period of typically 48 hours in patients after CABG, with the sampling frequency of 1kHz and with the 12-bit amplitude resolution. So far, 38 patients were recorded, and more than 1800 hours of high resolution ECG has been acquired in collaboration with Clinical Hospital Center in Zagreb.

Dyadic wavelet transform analysis with first derivation of Gaussian smoothing function as a mother wavelet, was used for a QRS and a P wave detection, characterization and delineation. Zero-crossing of the wavelet transformation at all seven dyadic scales is used in detection criteria and zero-crossing at scale 2^1 is used as a mark for the R wave [2], [4]. The detection of the P wave was performed after a QRS complex detection in the backward searching time window. The onset and the offset of the P wave correspond to the modulus maxima pair with opposite signs, detected with the adaptive thresholds in the 200ms backward searching window before the onset of the QRS complex [2], [4].

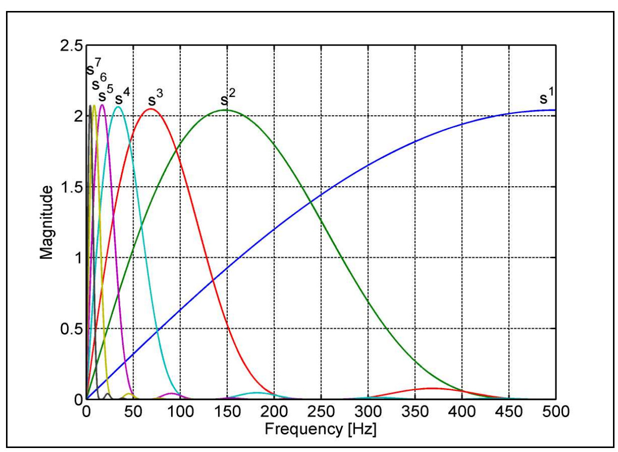

Figure 1. The normalized magnitude – frequency responses of equivalent digital filters for different wavelet scales, corresponding to 1000Hz sampling rate.

The wavelet decomposition scales represent signals filtered with equivalent digital filters illustrated in Figure 1. Cutoff and central frequencies of equivalent digital filters at different wavelet scales are listed in Table 1. For higher sampling frequency, it is necessary to create decomposition with larger number of sub-bands.

Table 1. The 3-dB bandwidths and central frequency of equivalent filters at different wavelet scales

wavelet scale	3-dB bandwidth [Hz]	central freq.[Hz]
$s=2^1$	250.9 ~ 500.0	500.0
$s=2^2$	61.5 ~ 235.4	148.4
$s=2^3$	34.2 ~ 104.5	69.3
$s=2^4$	17.6 ~ 52.7	35.2
$s=2^5$	6.8 ~ 28.3	17.6
$s=2^6$	4.9 ~ 14.6	9.8
$s=2^7$	1.9 ~ 7.8	4.9

After detection of P wave onset (Ponset), peak (Ppeak) and offset (Poffset), maximal positive slope (Pslope1) and maximal negative slope (Pslope2) at all wavelet scales, various parameters of the P wave were calculated and used for a trend presentation. Above mentioned characteristic points are illustrated in Figure 2.

The P wave detector first detects points of interest at 5th scale of wavelet transformation. After a successful detection, the algorithm detects the same, previously detected point at lower wavelet scale, but only in the narrow neighborhood where new point is expected. The procedure is terminated when all points are detected at all scales and at the lowest 1st wavelet scale. Detected points at the 1st scale are annotation marks at the ECG signal.

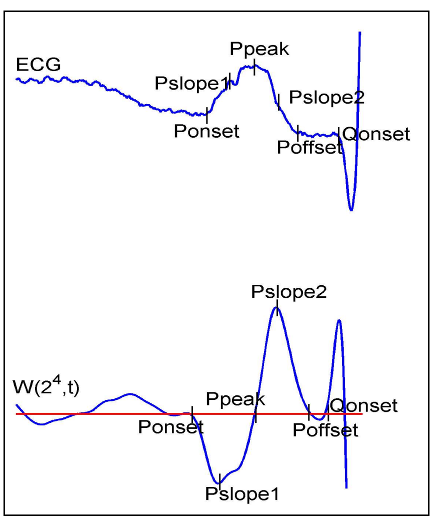

Figure 2. The P wave segment of Patient 3 ECG, and the 4th scale of the wavelet transformation. Marked points at ECG correspond to marked points at the 4th wavelet scale.

Because of the multi-resolution insight to sub-bands and the detection criteria that encounter all decomposition scales, the detection is robust on artifacts and a change in the ECG morphology within the same and within different subjects.

During the detection procedure, different P wave parameters were extracted. A probability distribution of the parameters within one hour was considered to be normally distributed, thus mean value and standard deviation of every parameter was calculated and stored for every hour during the recording. Figure 3. illustrates that the normal distribution is a reasonable probabilistic model.

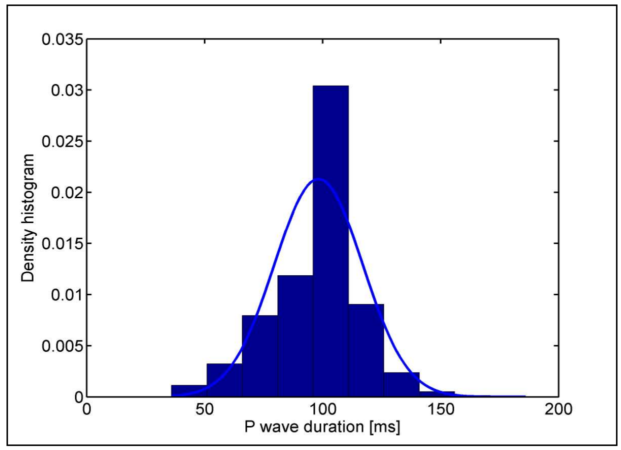

Figure 3. Normalized density histogram of the P wave duration within one hour, as one of the many measured P wave parameters. The curve represents a normal probability density function estimate.

Because of a wavelet decomposition of the signal, many P wave parameters were extracted from wavelet signals and coefficients at different wavelet scales.

The following parameters were considered:

- P wave duration
- P wave amplitude
- Surface area under the P wave
- PR interval duration
- PQ interval duration
- Duration between points Pslope1 and Pslope2 at different wavelet scales
- Value of wavelet coefficients Pslope1 and Pslope2 at different wavelet scales
- RR interval duration (heart rate)
- Absolute and relative wavelet energy at different wavelet scales
- Wavelet entropy

During the recording, for every patient, in every hour, vector of 108 P wave components was calculated, allowing continuous and deeper insight to atrial activity. The aim was to record many different variables relating to patients' atrial activities in order to learn which variables could best predict and discriminate the class of patients with likelihood of developing atrial fibrillation, from the class of patients who do not have that risk.

The collected data and variables were graphically explored without assumptions about probabilistic models, number of groups and relationships between variables. The variables were visualized as a time series in order to reveal patterns and trends.

3. Results

We assumed that a prolongation of the P wave duration or an atrial depolarization duration, measured on the surface ECG signal is associated with the decreased conduction velocity of the atrial tissue due to ischemic processes. Figure 4 represents a P wave duration trend over the recording time. The other time domain parameters related with the P wave like PQ and PR interval are also measured.

Simultaneously with the measurement of any P wave parameter a current heart rate value must be recorded because the values of some parameters correlate and adapt to the heart rate.

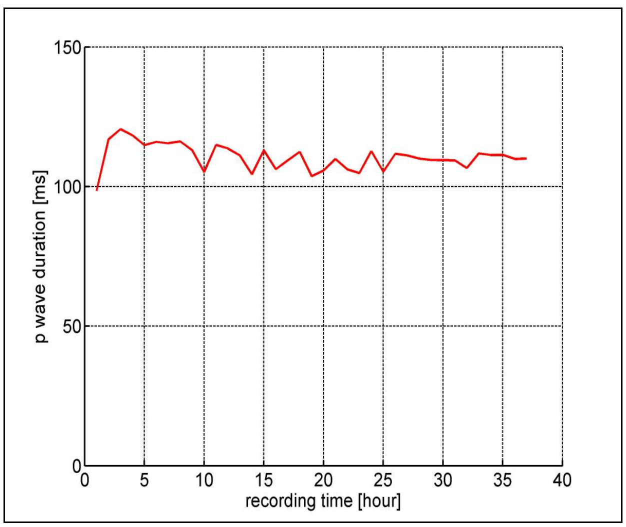

Figure 4. P wave duration in first 36 hour of Patient 3 who developed atrial fibrillation on the third day after the operation. Averaged P wave duration is 110ms ± 8.5ms.

At different wavelet scales, the values of minimum and maximum wavelet coefficients pair that correspond to the P wave, bring the information about P wave rising slope and P wave falling slope, respectively. A higher absolute value of the modulus maxima pair implies steeper P wave edges and this gives additional information about the P wave shape.

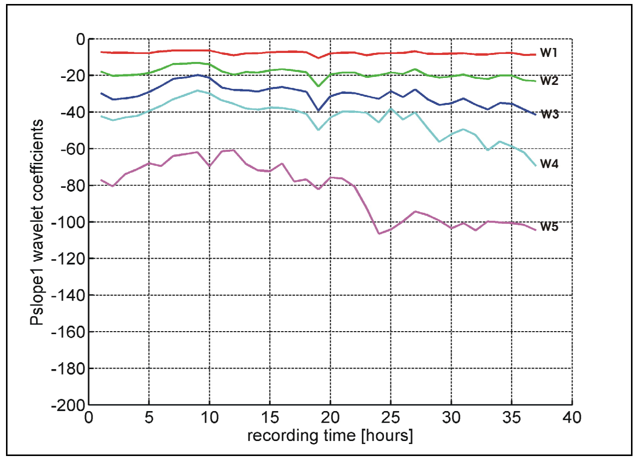

Figure 5. Wavelet coefficients of a Pslope1 of Patient 3. Lines are coloured as follows: red - 1st wavelet scale, green - 2nd, blue – 3rd, cyan – 4th, magenta – 5th. At the 5th wavelet scale, falling trend in coefficients of a P wave rising edge (Pslope1) is observable. This means that a slope of P wave rising edge is becoming steeper (shorter rising time).

Absolute and relative P wave energy at different wavelet scales offer insight in the layout of spectral components in the P wave structure. Wavelet entropy is a measure for the P wave energy dispersion at different frequency bandwidths (scales). Figure 6 represents wavelet energy of P wave at different wavelet bands.

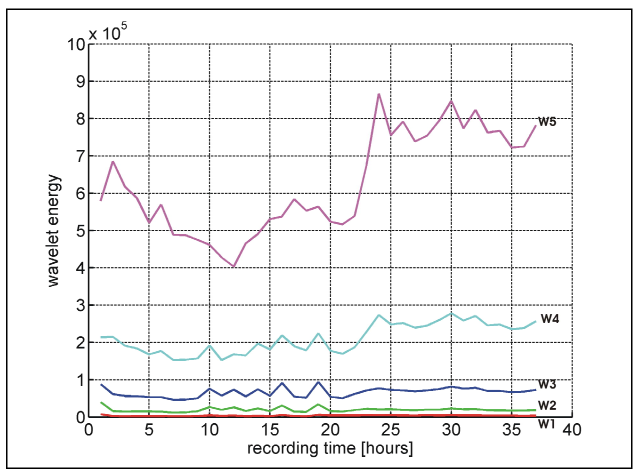

Figure 6. P wave wavelet energy of Patient 3. Lines are coloured as follows: red - 1st wavelet scale, green - 2nd, blue – 3rd, cyan – 4th, magenta – 5th. Noticeable is the rising trend in wavelet energy of a 5th wavelet scale, indicating the rise of energy around central frequency of 17.6 Hz.

The usage of the wavelet detector in the case of AF allows the measurement of dominant frequency in atrial fibrillation or in atrial flutter. Many investigations show that low frequency AF often terminates spontaneously while high frequency AF becomes permanent [7].

It is possible to display successively averaged P waves using R peak or, optionally, P peak as an averaging trigger. This methodology of continuous monitoring and presentation provides to physicians a better insight into the processes that precede atrial fibrillation.

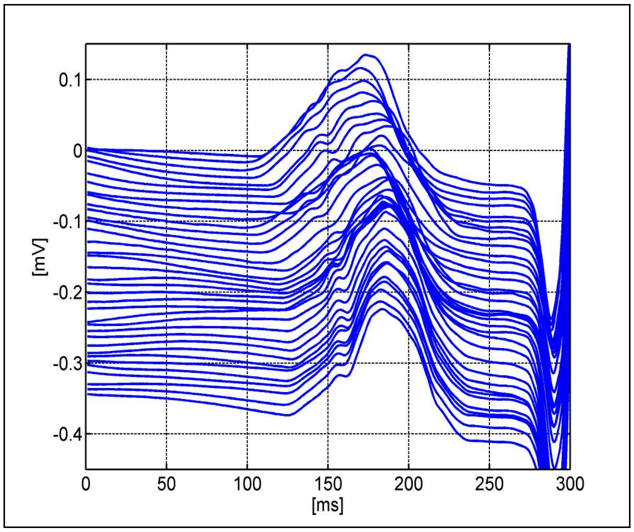

Figure 7. Hourly averaged P wave of Patient 3 synchronized on R wave peak. Patient 3 developed atrial fibrillation. Figure presents successively aligned 300ms of averaged P waves. Every line represents one averaged hour of recording.

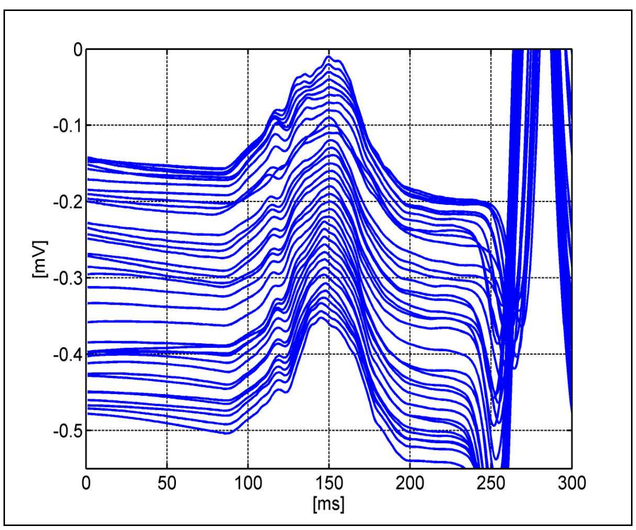

Figure 8. Hourly averaged P wave of Patient 3 synchronized on P wave peak.

4. Discussion and conclusions

Automatic P wave detection enables measurement and processing of the P wave parameters and also allows continuous trend monitoring of different parameters over the recording period. In such a way a large number of clinically interesting information can be extracted from the data. It is possible to adopt the developed software for further clinical application.

The use of the wavelet detector enables high quality detection, additional P wave parameters measurement and calculations, obtaining additional information on atrial function in multi-resolution domain. Continuous monitoring and trend presentation of multiple P wave parameters could show a change in trend before the appearance of atrial fibrillation.

Acknowledgements

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Address for correspondence

Sinisa Sovilj
Faculty of Electrical Engineering and Computing,
University of Zagreb
Unska 3, HR-10000 Zagreb, Croatia
sinisa.sovilj@ieee.org