Prediction of Atrial Fibrillation using Wavelet P-wave Detector

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INTRODUCTION

The aim of this study is to review existing methods developed for atrial fibrillation (AF) prediction and to analyse the possibility of finding parameters for reliable non-invasive clinical prediction of AF, occurring frequently after Coronary Artery Bypass Grafting (CABG).

OVERVIEW

Atrial fibrillation (AF) is the most common supraventricular arrhythmia and postoperative complication that occurs in up to 40% of the patients after CABG.[8] The highest occurrence of postoperative AF is usually between the second and third postoperative day.[8]

Clinical classification of AF is based on the true underlying mechanism. AF may revert to sinus rhythm, spontaneously or with medical assistance or never.

Post-CABG AF causes the complications like hemodynamic instability, postoperative hypotension, thromboembolism, ventricular arrhythmia, risk of stroke and can increase mortality and prolong hospitalisation.[3,5,6,7]

Although there were lot of attempts, there is still no ideal method to predict AF. Several investigations suggest and identify as possible predictors the following parameters:

- duration of P wave in Signal Averaged ECG, SAECG (usually at least 100 beats, aligned using QRS complex trigger or P wave trigger with or without cross correlation alignment) and duration prolongations greater than 110ms,[3,5]
- root mean square voltage for the last 20, 30 and 40 ms of the P wave,[3]
- P wave terminal force (duration of the negative part of the P wave in lead I multiplied by peak depth),[3]
- P wave dispersion (difference between maximum and minimum P-wave duration),[3]
- P wave variance (like P wave dispersion, but more reproducible. It is an indicator of conduction variability),[3]
- spatial conduction velocity (rate of change of the P wave voltage with respect to time),[3]
- prolonged PR interval from lead I,[3]
- low amplitude atrial late potentials (because they can reflect the late depolarization of tissue when re-entrant circuit exists), defined as a difference between the two P waves recorded at two different filter settings,[3]
- mean and maximum energy of the P wave in different frequency bands,[8]
- atrial premature complex detection using heart rate RR intervals variability analysis (number of ecoptic beats increase prior to the arrhythmia onset),[3]
- approximated entropy of RR intervals (lower values indicates reduction of repetitive patterns and precedes the onset of AF), same is for the measure of the strength of the short time correlation properties of the RR intervals,[3]
- shape parameters (for detection of symmetrically shaped P waves, slowly descending / ascending P wave values, bimodal and biphasic P waves),[1,2,3]
- left atrial diameter (dilatation, enlargement).[3,5,7]

The incidence of Post-CABG AF is also influenced by age and gender, as well as by the heart disease history:

- **pre-operative data**: AF history, old myocardial infraction history, acute

myocardial infraction, hypertension, diabetes mellitus, history of smoking, type of coronary artery lesion: stenosis ≥50% in proximal and median segments of the right coronary artery, left ventricular ejection fraction, chronic obstructive pulmonary disease complications,[6,5,7,8]

- **intra-operative data**: aortic cross-clamping time, duration of cardiopulmonary bypass (CPB), the fastest heart rate before CPB, resection of left ventricle aneurysm, off-pump procedure,[6,5,7,8]
- **post-operative data**: post-operative assistance of intra-aortic balloon pump, duration of ventilation, total amount of urine, average amount from the first, second and third day, total amount of administered fluid, average amount from the first, second and third day, usage of anti-arrhythmic drugs, β blockades, inotropic agents, digoxin.[6,5,7,8]

Different electrophysiological and morphological factors allow deterioration and AF. They all must be considered together to interpret the etiologic mechanisms behind AF. These factors are:

- slow conduction (prolongation and delay) of intra-atrial and inter-atrial conduction lines,[1,3,6,8]
- variability of conduction velocity,[3,6,8]
- dissociation, fraction and inhomogeneous propagation of the atrial activity impulses due to the shortening of atrial refractory period and non-uniform, anisotropic properties of atrial myocardium,[1,3,6,8]
- dispersion of atrial refractoriness,[1,3,6,8]
- obstacles in the conduction path and atrial remodelling.[1,3,6,8]

Patients have the prolongation of the P-wave, indicating either a marked enlargement of the atria or global or localized slowing of conduction along the activation of the atria. Decreased refractory state of the tissue, caused by an acceleration of repolarization is a proarrhythmic phenomenon in AF.[10]

Patients developing post-CABG AF usually do not have previous AF history. This means that the anatomic stresses as a result of surgery can trigger post-CABG AF.[3,8]

The goal is to predict AF in order to optimise and timely administrate prophylactic anti - arrhythmic medications or electrical pacing treatment, i.e. identify and to discriminate patients with high-risk predisposition of AF from low-risk predisposition subjects.

Today's prediction methods are not completely reliable yet although they show high predictive values and achieve best sensitivity of 95% (with specificity of 54% at the same time) or best specificity of 92% (with sensitivity of 75% at the same time) so their clinical application is still limited.[3,8] P wave duration techniques do not have universal definition of duration, so the use of different end points definitions makes the comparison of the results achieved by various groups difficult.[3] Automatic P wave delineations methods are more reliable and reproducible from manual methods.[3] Time domain analysis techniques are still considered more reliable compared to the more complex signal processing tools such as frequency domain analysis or non-linear techniques.[3]

METHODS

The P wave was analysed in lead II of standard surface ECG in the period after CABG, before the appearance of AF, with high resolution sampling frequency rate of 1kHz, 12 bit amplitude resolution and without knowledge of patient's clinical status.

Dyadic wavelet transform analysis with first derivate of a Gaussian smoothing function as a mother wavelet, was used for the QRS and P wave detection and the wave characterization and delineation. The wavelet transform at dyadic scale 2^j is given by:

$$Wf\left(2^j,\tau\right)=\frac{1}{\sqrt{2^j}}\int_{-\infty}^{\infty} f\left(t\right)\Psi^*\left(\frac{t-\tau}{2^j}\right)dt$$

The patients' ECG was continuously recorded in a period of typically 72 - 96 hours after the surgery. In collaboration with University Hospital Rebro in Zagreb, we have created our own signal database and stored it in the same format as the MIT-BIH database.

A detection of P wave, that is associated with atrial activity, is performed after QRS complex detection, in the backward searching time window.

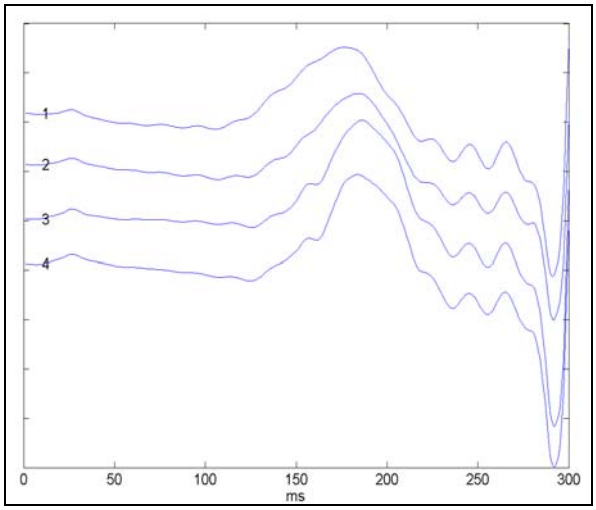

Figure 1: Averaged P-waves in 10 hours periods, successively sorted by time of appearance in first 40 hours after the surgery. Line "1" represents averaged P wave from first 10 hours of recording, line "2" represents averaged record of the next 10 hours of recording, etc.

ALGORITHMS

The mother wavelet we have used is the first derivative of the Gaussian smoothing function. Using this mother wavelet, the zero-crossing of the wavelet transformation at all four dyadic scales (2^1, 2^2, 2^3, 2^4) is used as a detection condition and zero-crossing at scale 2^1 is used as a fiductial mark for the R wave. Similar procedure is performed for detection of the P-wave peak. Onset and offset of a P wave correspond to the modulus maxima pair with opposite signs, detected with adaptive thresholds in the 200ms backward searching window before the onset of the QRS complex.[4,9]

After detection of P-wave onset, peak and offset, different parameters of the P wave were calculated and used for trend presentation. In this part of investigation, we were considering the following P-wave parameters for AF predictors:

- P-wave duration (many studies suppose that a long P-wave duration is a risk factor for AF), (fig.1),
- standard deviation (root of the duration variance) of P wave duration,
- surface area under the averaged P wave, (fig.3)
- RMS voltage for the last 20, 30 and 40 ms of the P wave, (fig.4).

The P-wave is averaged using R wave as a trigger for averaging. Because of reliability high-resolution sampling frequency (1kHz), high-resolution information about the P wave morphology is obtained.

Although the records are processed off-line, at this time the algorithm is adapted for future use in real-time.

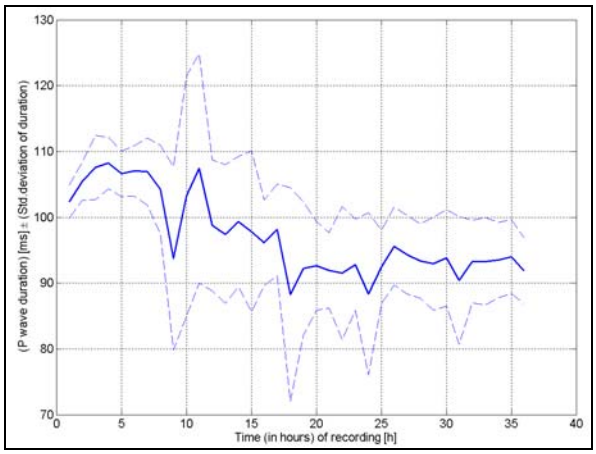

Figure 2: P-wave averaged duration trend for 40 hours of time with standard deviation of duration.

DISCUSSION

In order to develop reliable algorithms for AF prediction, we have decided to continuously record the post-operative ECG and extract as many information form the raw data as possible. We also find that the trends of some parameters should be considered as possible predictor.

Figures 2, 4 and 5 show the trends of parameters for one patient who did not have post-operative AF. In (Figure 2) P wave duration tends to decrease what probably implies AF risk falling. In (Figure 3) P wave duration variance descending we expected in the same patient cannot be observed in Figure 3. The high values of standard deviation is due to motion artefacts during the wake up process or introduced transposition of the patient. The influence of the artefacts will be removed in the new version of the software. Surface area under the P wave (Figure 4) has a falling tendency due to dominant decreasing of the P wave duration. RMS value of the P wave's last 30ms was expected to rise during the 40 hours recovery time but this trend is only weakly noticeable. In future work we intend to include the parameters of the time-frequency analysis we use for P wave detection and their trends are parameters for AF prediction.

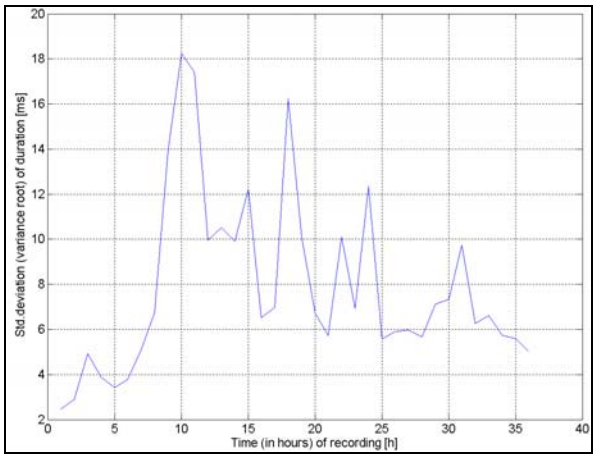

Figure 3: Standard deviation (variance root) for the P-wave duration in 40 hours of record time.

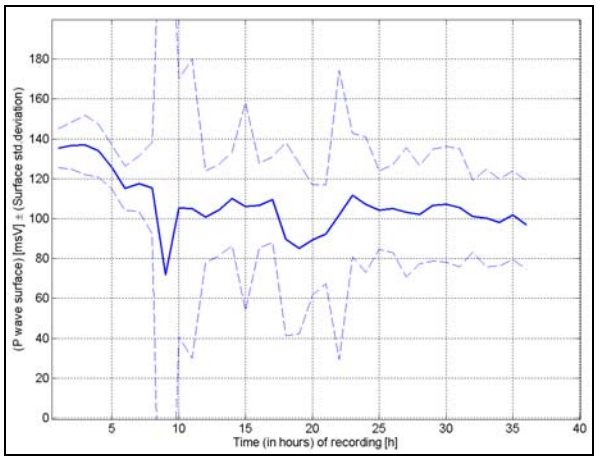

Figure 4: Surface area under the P-wave expressed in msV and it's trend in 40 hours with standard deviation.

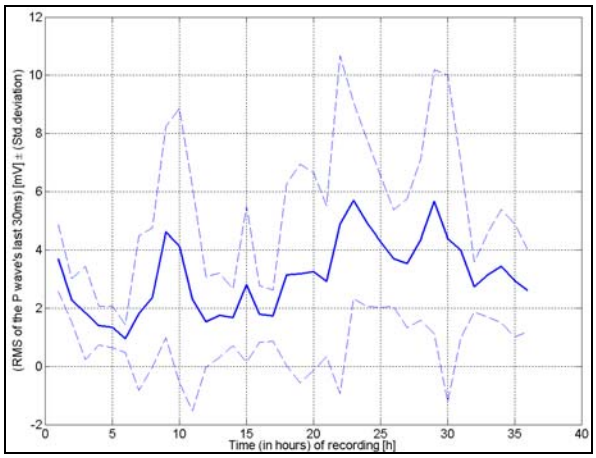

Figure 5: RMS value of the P wave's last 30ms. Trend for 40 hours with standard deviation of RMS value.

CONCLUSION

Continuous recording, and the extraction of predictors from the data can show trends in feasible development of post-operative AF. Greater detection accuracy and better alignment during P wave averaging can increase significance of parameter's trends, and insure that these tendencies are due to AF mechanisms.

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