Time-Domain and Morphological Descriptors of Paced and Spontaneous P-Waves in Patients Prone to Atrial Fibrillation

F Censi[1], G Calcagnini[1], C Ricci[2], RP Ricci[3], M Santini[3], P Bartolini[1]

[1]Dept of Technologies and Heath, Italian National Institute of Health, Rome, Italy
[2]Department of Statistics, Probability and Applied Statistics, Univ of Rome "La Sapienza", Italy
[3]Department of Cardiology, San Filippo Neri Hospital, Roma, Italy

Abstract

Aim of this study was to compare time-domain and morphological descriptors of paced and unpaced P-wave in patients prone to atrial fibrillation (AF). 17 patients (8 females, aged 73±8) affected by paroxysmal AF and implanted with dual chamber pacemakers (PM) were studied. Two 5-minute recordings were performed: during spontaneous and paced rhythm. ECG signals were acquired using a 32-lead mapping system. Patients were grouped into two classes: 8 patients without (low risk, LR) and 9 patients with (high risk, HR) AF episodes in the 6 months before the analysis. We found that all Time-domain and morphological descriptors of the P-wave but one succeed in discriminating LR and HR patients in spontaneous rhythm, while no significant difference has been observed during pacing for any parameters. However atrial pacing determines a significant increase in time-domain parameters and a more complex morphology.

1. Introduction

In the last years increasing interest has been shown towards atrial pacing as a possible strategy to prevent AF in pacemaker patients.

Since prophylactic atrial pacing determines resynchronisation of atrial depolarisation, it can be indicated in patients showing atrial conduction delays or in subjects whose episodes are mainly related to vagal mediated slowing of the sinus rate [1].

Up to date, contrasting results have been achieved from clinical trials examining the efficacy of atrial pacing [2-4].

The effect of pacing on atrial tissue is reflected in P-wave features such as duration and morphology.

Atrial septal pacing generates a short and smooth P-wave that may indicate a homogeneous atrial depolarisation, while pacing from the free right atrial wall or atrial appendage is believed to induce intra- and inter-atrial conduction delays that predispose to the arrhythmia and that are reflected in longer and polyphasic P-waves [2].

Irregularities of P-wave morphology have been also detected in patients with paroxysmal atrial fibrillation [5].

Different shapes of P-wave may represent the presence or absence of an underlying pathophysiological condition in patients prone to AF attacks [6].

Thus, P-wave morphological analysis can help detecting inter-atrial blocks, which predispose to the arrhythmia, even in patients who develop atrial fibrillation despite the absence of particular alterations in echocardiographic parameters [7].

Reliable automatic methods of analysis have not yet been developed, even though they might help detecting atrial abnormalities that could be reflected in morphological changes beyond visual classification [8].

A morphological analysis does not require the accurate localisation of P-wave onset and offset, thus it may also overcome the limitations suffered by time-domain techniques.

Besides conventional electrocardiography, multi-electrode ECG (MECG) is currently extensively used and it has been proven to highly ameliorate the accuracy of standard 12-lead ECG, especially in combination with signal-averaged ECG, for detection of cardiac alterations and pathologies.

Since MECG increases the spatial resolution of standard ECG it can improve the sensitivity of electrocardiographic markers that might have a lead-dependent accuracy, such as P-wave dispersion or morphological features [9].

In this study we examined and compared P-waves features during atrial pacing and sinus rhythm. Particularly, we performed both time-domain and morphological analysis of P-wave to investigate, besides consolidate time-domain indexes, morphological

characteristics of paced and spontaneous P-waves.

2. Methods

Experimental protocol

Study population consisted of 17 patients (8 females, aged 73±8) affected by paroxysmal AF and implanted with permanent dual chamber pacemakers (PM) with both AF monitoring and therapy functions. Two 5-minute recordings were performed for each patient: in the first recording the PM was programmed in DDD pacing mode set at 40/min, in order to have spontaneous rhythm; in the second recording, PM was set with atrial and ventricular pacing functions both activated (paced rhythm).

ECG signals were acquired using a 32-lead mapping system (sampling frequency 2048 Hz, 24 bit resolution).

Patients were grouped into two classes: 8 patients without (low risk, LR) and 9 patients with (high risk, HR) AF episodes in the 6 months before the analysis (figure 1), according to the AF episodes detected and collected by the device.

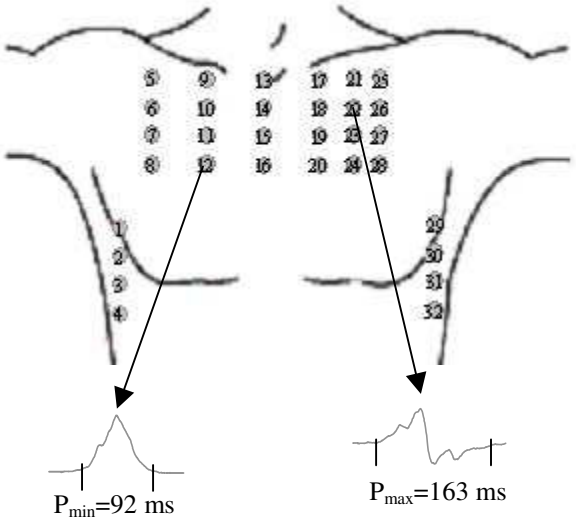


Figure 1. Positions of the 32 electrodes for the ECG mapping system. Examples of two P-waves extracted from 2 leads are also shown.

P-wave pre-processing

Every lead signal was pre-processed and analysed to extract the average P-wave characteristic. The first step is to detect P-waves from the acquired signals.

First each R-waves are detected using an algorithm similar to that proposed by Pan and Tompkins, which actually acts as a high pass filter on the ECG signals, enhancing the high frequency QRS complexes [10]. P-waves are then extracted in a 200ms-long window starting from 300ms before the R-wave.

Secondly, a beat-by-beat linear piecewise interpolation was used to remove baseline wander, on each P-wave. Fiducial points for linear interpolation were taken from TP and PQ tracks of each beat.

Ectopic atrial signals or P-waves with excessive noise were excluded by conventional template matching of each P-wave (cross-correlation coefficient lower than 0.9).

Before the averaging procedure, P-waves were aligned according to the lag at which the cross-correlation function between the current averaged P-wave and each single P-wave shows its maximum (coherent averaging procedure); P-wave alignment is necessary to take into account the variations in PR interval and/or the inaccuracy in R-wave detection.

The coherent averaging procedure went on until 200 beats were included. If the residual noise level remained at more than 1μV even after averaging of 200 beats, averaging procedure continued until the noise level reached a value lower than 1 μV. If it was impossible, the lead was excluded from the study. Residual noise was measured in the isoelectric segment before the P-wave (TP track) [11].

Time-domain descriptors

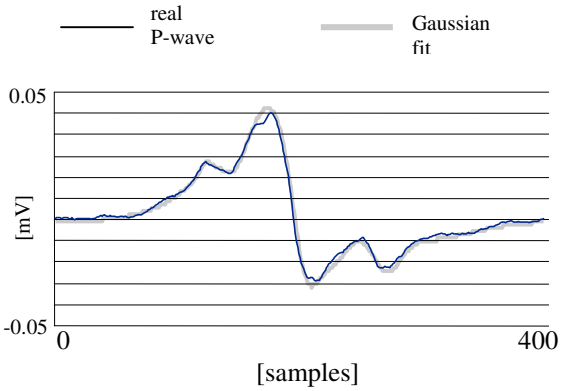
For each patient, maximum (Pmax) and minimum (Pmin) P-wave duration in any of the 32 lead have been extracted, together with P-wave dispersion (Pdisp=Pmax-Pmin) (figure 1).

Morphological descriptors

P-wave morphological analysis was based on a Gaussian fit, i.e. P-wave is modelled by the sum of up to 8 Gaussian functions [12]. The number of Gaussian functions needed to model the P-wave (model order, N), the number of zero crossings (NZ) and the sum of relative maxima and minima (MM) of the model have been defined as morphological parameters of the P-wave (figure 2).

Statistical analysis

Mann-Whitney U test for unpaired data has been used to evaluate P-wave analysis performance in separating the 2 risk classes LR and HR. Spontaneous rhythm vs. pacing results have been compared by a non parametric test for paired data (Wilcoxon).



Model order *N= 7*
Number of Zero Crossing *NZ=1*
Number of maxima and minima *MM=6*

Figure 2. Gaussian fit of a P-wave: best fit for a 7th order model. Values of NZ and MM are also reported.

3. Results

We found that all parameters but Pmin succeed in discriminating LR and HR patients in spontaneous rhythm (Mann-Whitney U-test, table 1).

Table 1. Time-domain and morphological parameters (mean ± standard deviation) for LR and HR patients in spontaneous rhythm, averaged over the populations. P-value obtained by Mann-Whitney U-test is also reported.

Spontaneous P-waves			
	LR	HR	p
Pmax (ms)	134.3±11.53	164.2±13.3	<0.001
Pmin (ms)	106.3±9.9	114.9±15.8	0.18
Pdisp (ms)	26.0±9.9	49.3±10.6	<0.001
N	5.6±0.7	6.8±0.5	<0.001
NZ	0.9±0.3	1.8±0.7	<0.001
MM	5.8±0.9	7.5±1.5	<0.01

During pacing, no significant difference has been observed for any parameters (table 2).
However differences were observed in single patients' characteristics when comparing spontaneous and paced rhythm.
Atrial pacing determines a significant increase in P_{max} (from 150.7±16.8 ms in spontaneous rhythm to 163.7±14.8 ms in pacing, p<0.01, Wilcoxon test), and in P_{min} (from 108.7±4.8 ms to 125.1±6.5 ms, p<0.01).

Table 2. Time-domain and morphological parameters (mean ± standard deviation) for LR and HR patients during pacing averaged over the populations. P-value obtained by Mann-Whitney U-test is also reported.

Paced P-waves			
	LR	HR	p
Pmax (ms)	158.69±16.61	166.70±17.21	0.33
Pmin (ms)	115.05±17.77	128.37±23.80	0.19
Pdisp (ms)	43.64±8.91	38.33±9.17	0.23
N	6.36±0.82	6.91±0.61	0.11
NZ	1.63±0.41	1.73±0.65	0.64
MM	7.36±1.51	7.99±1.20	0.30

P-waves recorded during atrial pacing also seem to have a more complex morphology, as shown by the significant increase of the model order (6.25±0.83 vs 7.69±0.74, p<0.02), and of the NZ (1.51±0.72 vs. 1.99±0.56, p<0.03) and of MM (6.82±1.42 vs 7.74±1.33, p<0.03).

Table 3. Time-domain and morphological parameters (mean ± standard deviation) during spontaneous and paced rhythm averaged over the population (LR and HR group). P-value obtained by Wilcoxon test is also reported.

	Spontaneous rhythm	**Paced rhythm**	p
Pmax (ms)	150.7±16.8	163.7±14.8	<0.01
Pmin (ms)	108.7±4.8	125.1±6.5	<0.01
Pdisp (ms)	38.93±14.52	40.69±9.20	0.67
N	6.25±0.83	7.69±0.74	<0.02
NZ	1.51±0.72	1.99±0.56	<0.02
MM	6.82±1.42	7.74±1.33	<0.03

4. Discussion and conclusions

In the last years sophisticated algorithms aimed at reducing the number of AF episodes and burden (cumulative time of AF) have been implemented in dual chamber pacemakers. These algorithms aim at reducing AF potential triggers by atrial pacing during sinus rhythm

for almost 100% of the time, preventing post-extrasystolic pauses after premature atrial complexes (PACs), and by applying more aggressive overdrive if an increase in PAC density is detected.

Even though this therapeutic option is now considered one of the most promising in AF risk reduction in pacemaker patients, contrasting results have been achieved.

The purpose of such an investigation was to evaluate the effect of atrial pacing on those P-wave parameters reflecting an abnormal atrial substrate that predispose to AF.

We found that LR and HR groups are discriminated by Pmax and Pdisp and by all the morphological parameters in spontaneous rhythm. During pacing, nor time-domain neither morphological descriptors succeeded in discriminating the two risk classes.

In addition, we found that paced P-wave duration values were significantly higher than the corresponding unpaced ones.

The model order of the Gaussin fitting, the number of zero crossing and the number of maxima and minima were also significantly increased in paced P-waves.

Indeed, P-waves appeared morphologically more complex and longer in duration during atrial pacing than in spontaneous rhythm. These results are in agreement with those from Keane and colleagues [13]. They found that pacing is associated with prolongation of SAECG P-wave duration and with considerable alteration in P-wave morphology in patients with AF and sinus node disease [13]. On the other hand, Gilligan and colleagues analysed the effect of biatrial pacing on paced P-waves and found a reduction in P-wave duration but no changes in P-wave dispersion [14].

Our findings suggest that atrial pacing does not affect the tissue substrate as reflected by analysis of surface P-wave. The characteristics that are a reflection of atrial conduction abnormalities appeared worsened during atrial pacing. If a positive effect derives by atrial pacing, then it might be probably attributed more to a reduction in AF triggers, as shown by Padeletti and colleagues [15], than to a modification of the conduction pathways.

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Address for correspondence

Federica Censi
Department of Technologies and Health
Italian National Institute of Health
Viale Regina Elena 299 - 00161 Roma
federica.censi@iss.it