Automated System for the Analysis of Heart Monophasic Action Potentials

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Abstract

In this paper we present an automated system, which can be used in real time for the analysis of heart monophasic action potentials (MAPs) in order to analyze the behaviour of the myocardium under pathological or normal conditions. The system can be described as a three-stage procedure. In the first stage MAPs are acquired using epicardiac electrodes or MAP Franz catheters and the noise is removed using a combination of notch and band pass filters. In the second stage several features of the signal are extracted. In the third stage statistical analysis is performed. The obtained results can be used for the assessment of the electrophysiological status of the atrial muscle, ventricular muscle, and the evaluation of the effects of antiarrhythmic drugs. The validation of the system indicated that it can provide with reliable information on the myocardium condition.

1. Introduction

Monophasic action potentials (MAPs) are exrtacellular recordings that have been found to correlate sufficiently with intracellular action potentials (IAPs) [1]. There are many reports investigating the effects of electrophysiological and pharmacological interventions in the MAP of the intact heart [2,3]. The development of contact MAP electrodes allows quick and easy recording of MAPs in clinical settings [2,3]. Standard recording techniques using paper traces often lack quality and resolution, and require time consuming manual processing. There have been several attempts to automate the analysis of sampled MAPs [4,5,6] but only few of them have been evaluated for their accuracy and reliability [4].

It is the aim of our work to develop an automated system for the extraction and analysis of MAP features to understand myocardium condition. The system consists of three stages: signal acquisition, feature extraction and statistical processing. The MAP features which are extracted with high accuracy are: MAP amplitude, action potential duration (APD) at all repolarization levels (10-90%), the baseline and amplitude. The proposed system has been used for the analysis of MAPs from two series of experiments.

The system performs well despite the morphological differences of the signals. The drug effect on MAPs is recorded and useful input can de acquired for the myocardium condition.

2. Materials and methods

The proposed MAP automated analysis system consists of three stages: (a) signal acquisition, (b) feature extraction, and statistical feature processing. Those stages are described in detail below.

2.1. Signal acquisition

The acquisition module includes the epicardiac probe or the MAP Franz catheter, the MAP preamplifier, the A/D converter, and software, which has been developed using Labview 6.1. Parameters such as sampling rate, recording time and type of filter can be adjusted to achieve the desirable MAP signal quality criteria as stable baseline, MAP morphology, fast upstroke, upstroke duration < 2ms and amplitude [5]. The recording software has been validated with a pulse generator, recording and analyzing a sequence of 400 square waves with amplitude 1 mV and cycle length 400, 300, 200, 150 msec.

The MAP signal is heavily contaminated by noise (power line interference and motion artifacts), which is removed by a combination of filters (notch, low, band and high pass). Due to the power line interference at 50 Hz the digital notch filter has a transfer function

$H(z) = \frac{1 - 2\cos(\omega_0)z^{-1} + z^{-2}}{1 - 2r\cos(\omega_0)z^{-1} + r^2 z^{-2}}$ where ω_0 is the angular frequency corresponding to the interference frequency and $Q = \frac{\omega_0}{2(1-r)}$ is a quality factor with $r < 1$ [13].

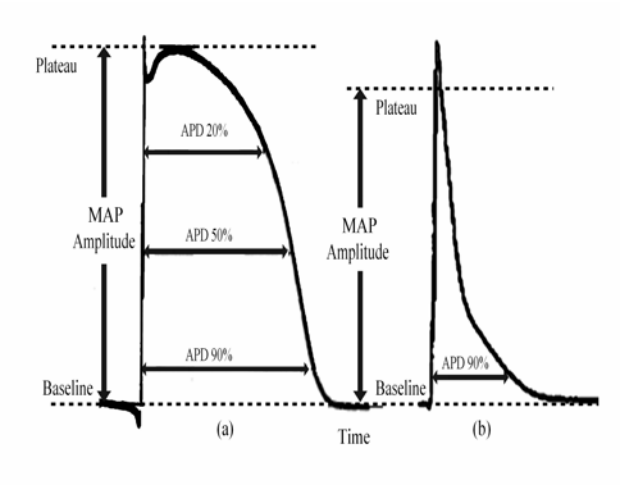

Fig. 1. Morphological differences and MAP characteristics in: (a) pig and (b) rat.

2.2. Feature extraction

In this stage the MAP signal features are extracted. The MAP morphology and the MAP used features for pigs and rats are shown in Fig. 1. The feature extraction procedure is illustrated in Fig. 2. Initially, the used threshold values are set and the signal is fed into the system. The algorithm can extract upstroke, the baseline, the plateau and the APDs. To make easier the analysis a window is used, whose length is adapted when an upstroke is found. A baseline is acceptable when it compares well (using a threshold value) with the average of the previous five baselines. The feature extraction ends when both plateau and APDs are detected. The algorithm starts again looking for a new upstroke starting from the end point of the last MAP. The whole procedure is based on the following rules:

- The start time of the MAP is determined being the upstroke of the detected MAP.
- For 5msec sliding window in the range (upstroke-30msec) to (upstroke-10msec) the average value of the first derivative is computed. The window with the lowest average derivative is selected and the baseline is defined as the average voltage of this window.
- Similarly, for 5msec sliding window in the range (upstroke+10msec) to (upstroke+30msec) the average value of the first derivative is computed. The window with the highest average derivative is selected and the average voltage of this window defines the MAP plateau.
- The amplitude of the MAP is derived as the absolute difference between the plateau and the baseline.
- If the percentage of repolarization is defined as x the corresponding voltage of the MAP signal from the baseline is: $V_X = \text{Plateau} - \frac{x}{100}\text{Amplitude (in mV)}$.
- The APDx% is given as the difference between the ending point of baseline and the projection of V_X in the time axis.

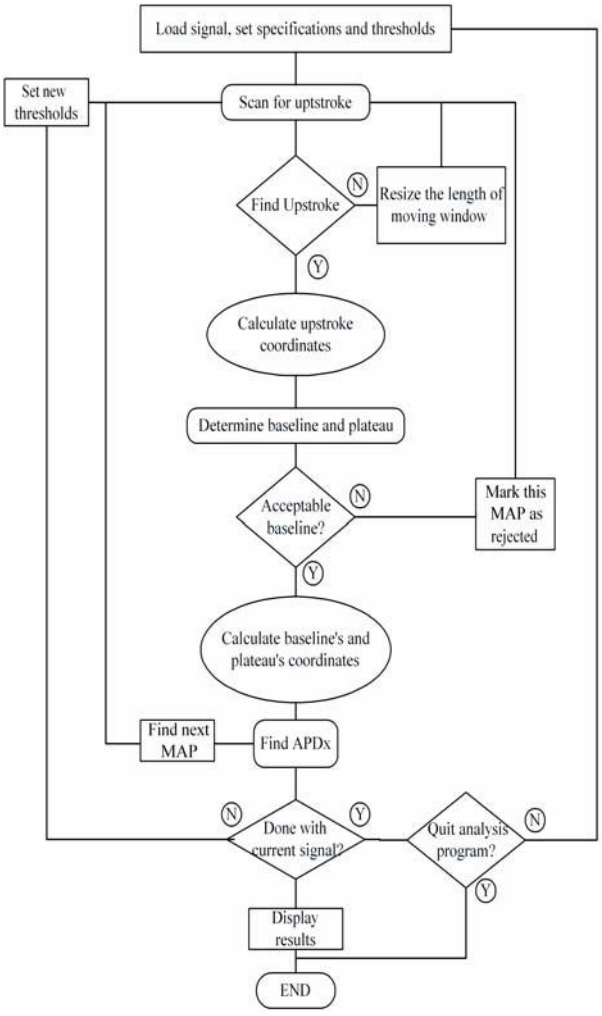

Fig. 2 . Feature extraction procedure.

2.3. Statistical feature analysis

The average value and standard deviation of upstroke intervals, baseline intervals, plateau intervals and APDs are computed. Those must be extracted for various conditions, even for cases when antiarrhythmic drugs are used. Those values correspond to certain myocardium condition profiles and easily can be compared with existing data from the literature.

3. Experiments

We performed two series of experiments. In the first the use of growth hormone as an antiarrhythmic agent, in arrhythmias caused from coronary artery blockage is investigated. We recorded MAPs from 10 pigs to assess local ischemic electrophysiological changes. The recordings were performed endocardiacly in left ventricular. The effect of BQ-102 ET-A (endothelin receptor antagonist) after the myocardium infraction was examined in the second series of experiments. Myocardium infraction experimental simulated with the blockage of artery lad. Experiments in 20 rats were performed and we recorded epicardiac MAPs, 9 of those were in normal condition and 11 suffered from left ventricular myocardium infraction and received BQ-102 ET-A treatment.

4. Results

We analyzed about 2000 MAPs from both series of experiments. All MAP signals were automatically analyzed and an example of the calculated rat MAP features is shown in Fig. 3. In this example the sampling frequency was 1 kHz and no filters were used. In Fig. 4 baseline intervals with APD75% are shown.

5. Discussion and conclusions

We have developed an automated system for the analysis of MAPs. The system includes hardware and software modules and operates in real time. The obtained values of the necessary for diagnosis signal features follow the proposed quality criteria. This is due to efficient removal of noise, which appears to be a critical factor, especially during epicardiac recordings. The system has been tested in obtained MAPs from two diverse series of experiments. The system responds well to a wide variety of application in clinical electrophysiology as drug treatment and local acquisition of MAP signals.

The system can be further expanded to include medical knowledge in order to provide with diagnosis options.

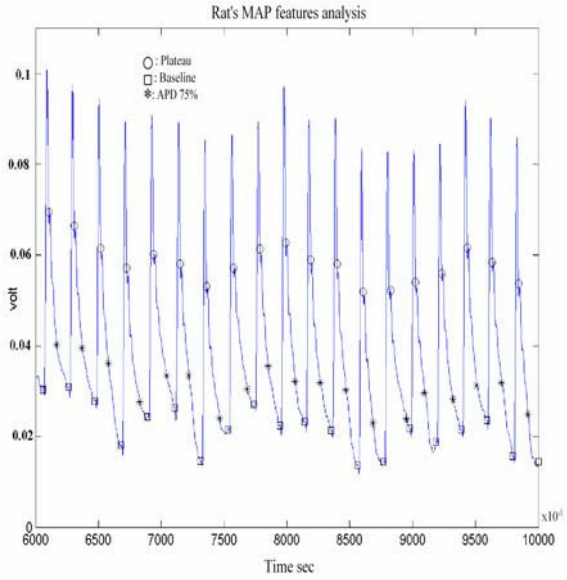

Fig. 3. Rat's MAP signal analysis for a 4 sec interval.

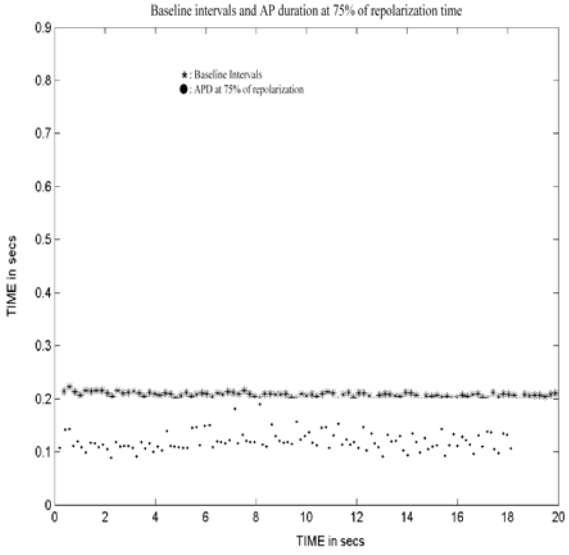

Fig. 4. Graphical display of baseline intervals and APD75% for a 20 sec interval

Acknowledgements

This work is part funded by the Greek Secretariat for Research and Technology (P.E.N.E.D: “Investigation of growth hormone in myocardium after infraction” - 01ED511).

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