Intraoperative Recordings of Monophasic Action Potentials with Chronically Implantable Pacemaker Leads in the Right Ventricle

B. ZRENNER, C. SCHMITT, A. SCHÖMIG
Deutsches Herzzentrum München, Munich, Germany

D. MÜSSIG, M. SCHALDACH
Department of Biomedical Engineering, University of Erlangen-Nuremberg, Germany

Summary

The transmembrane potential of a single heart cell results from the sum of different ion currents. These currents are generated when ion channel gates open and close to vary the concentration gradients of ions inside and outside the cell. The autonomic nervous system controls the intensity of the different currents. Thus, the myocardial action potential reflects also the activity of the autonomic nervous system. The aim of this study was to investigate monophasic action potential (MAP) measurements with chronically implantable pacemaker leads in the right ventricle. In 15 patients, dual-chamber pacemakers with two fractal coated leads were implanted. The leads differed in geometric design, and the surface area of the different electrodes ranged from 1.3 mm^2 to 7 mm^2. The interelectrode distance varied from 5 mm to 30 mm. The leads were fixated either passively by anchoring with tines or actively with a screw that is electrically insulated from the electrodes. All leads showed typical MAP morphologies if the electrode was stabilized with a mandrin. Without this stabilization, the MAP morphology changed when the interelectrode distance exceeded 10 mm. The active fixation of the lead with a screw provided higher MAP amplitudes and a better MAP morphology than the passive fixation with tines. During the stimulation protocol, the typical shortening of the repolarization phase with increased pacing rate was observed.

Key Words

monophasic action potential (MAP), fractal coated pacemaker lead, electrical stimulation

Introduction

Pacemaker leads as the interface between alloplastic implants and living tissue determine the quality of the detected signals as well as the efficiency and power consumption of the stimulation. Recent developments in pacemaker therapy focus on the detailed analysis of intracardiac signals. With these innovations, electrotherapy of the heart attains a physiologic character. The growing complexity of modern pacemaker systems allows automatic adaptation of therapeutic parameters to support diagnosis and to enhance therapy. However, a physiologic restoration of the lost natural cardiac function requires exact information about the myocardial state [8].

Franz and coworkers established the "contact electrode technique" in the early eighties [6][7]. With this technique, atrial and ventricular MAPs can be measured and recorded using Ag/AgCl coated electrodes. Among the advantages of this technology is the possibility of directly monitoring myocardial repolarization. Due to the limited stability of Ag/AgCl coating, measurements can be performed only for short periods of time. Therefore, the vast field of chronic clinical applications is limited to leads possessing long-term stability. Decisive in this arena was the development of fractal coated leads, which are generally approved in pacemaker therapy for pacing and measuring ventricular evoked potentials: due to their surface structure, these leads exhibit excellent properties of transmitting cardiac potentials and displaying negligible polarization artifacts. The inert precious metal iridium is used for fractal coating, thus affording unrestricted long-term stability. Chronically implanted fractal coated

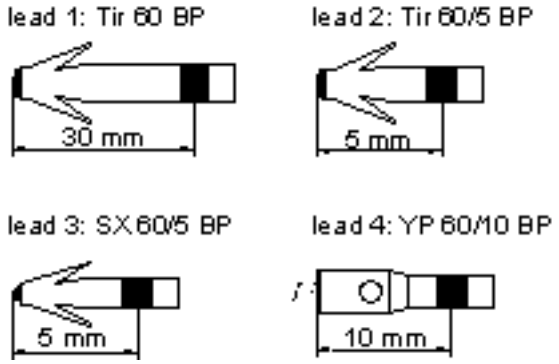

Figure 1. Chronically implantable pacemaker leads for monitoring monophasic action potentials.

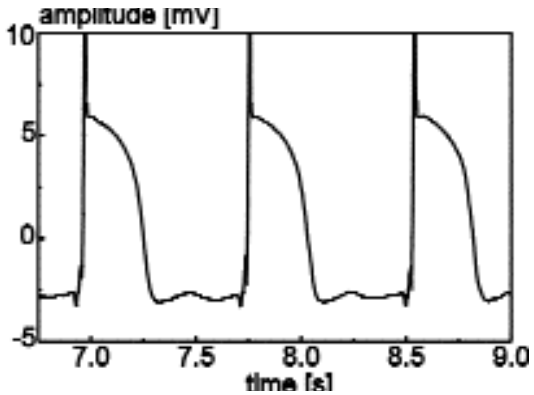

Figure 2. Ventricular MAP measured with a mandrin-stabilized TIR 60 BP lead.

electrodes can be used to monitor cardiac sum potentials over long periods of time.

The purpose of this study was to compare the quality of atrial and ventricular MAP measurements of various fractal coated pacemaker leads.

Methods

In 15 patients (6 male, 9 female, age 68.9 ± 16.1 years) with symptomatic AV block, dual-chamber pacemakers (PHYSIOS CTM01, BIOTRONIK) with two fractal coated leads were implanted.

For the study, various fractal coated pacing leads were developed which stimulate with low pacing amplitudes and subsequently record artifact-free MAPs. The first three leads implanted were passively fixed anchor leads. In leads 1 and 2, the surface area of the different electrodes was 6 mm^2; the indifferent electrodes, 48 mm^2. In lead 1, the distance between the electrodes was 30 mm; and 5 mm in lead 2. Lead 3 possessed a 1.3 mm^2 different electrode, a 48 mm^2 indifferent electrode, and a 5 mm distance between the two electrodes. Lead 4 was an actively fixed screw-in lead with a ring-shaped different electrode possessing a 7 mm^2 surface area; the indifferent electrode had a 48 mm^2 surface area. The interelectrode distance was 10 mm. Protruding from the center of the ring, the screw was electrically insulated from the different electrode. The designs of the implanted leads can be seen in Figure 1. After positioning the leads, pacing and sensing thresholds were determined (ERA300, BIOTRONIK). Monophasic action potentials were recorded continuously using an isolation amplifier (cut-off frequency 0.01 Hz to 500 Hz, range ± 250 mV), digitized (1000 Hz sampling frequency, 12 bit resolution), and stored on a PC. Stored signals were analyzed with automatic MAP evaluation software (BIOVIEW, BIOTRONIK). The standard MAP parameters (MAPd25/50/90, plateau amplitude, cycle length) and morphology were then extracted for study.

Results

At first, the sensing amplitudes and pacing thresholds were established for all leads. The threshold voltage measured with a pulse width of 0.5 ms was very low for all MAP leads used. The leads showed excellent sensing performance with high values for acute R-wave amplitudes. The results of the pacing and sensing measurements with the ventricular implanted MAP pacing leads are summarized in Table 1.

Figure 2 shows spontaneous ventricular MAPs measured with a TIR 60 BP pacemaker lead. The lead was stabilized with a mandrin. The measured potentials displayed excellent morphology, the amplitude reached 8.3 mV. The characteristic MAPd50/90 were 267/310 ms for a cycle length of 800 ms. When the

Lead	Sensing Amplitude [mV]	Pacing Threshold [V]
TIR 60 BP	9.8 ± 4.4	0.35 ± 0.12
TIR 60/5 BP	8.1 ± 6.0	0.43 ± 0.05
SX 60/5 BP	12.4	0.3
YP 60/10 BP	11.7 ± 4.1	0.73 ± 0.33

Table 1. Sensing amplitudes and pacing thresholds of the implanted MAP leads.

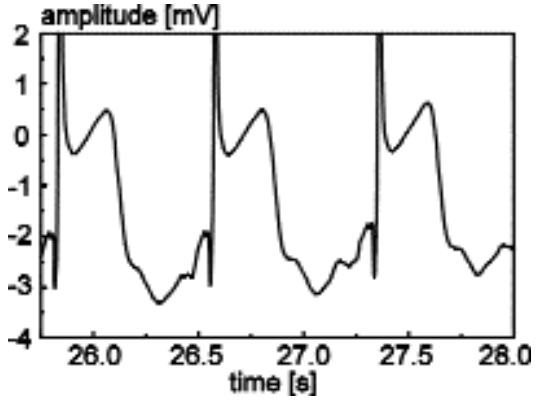

Figure 3. Ventricular MAP measured with a TIR 60 BP lead without mandrin stabilization.

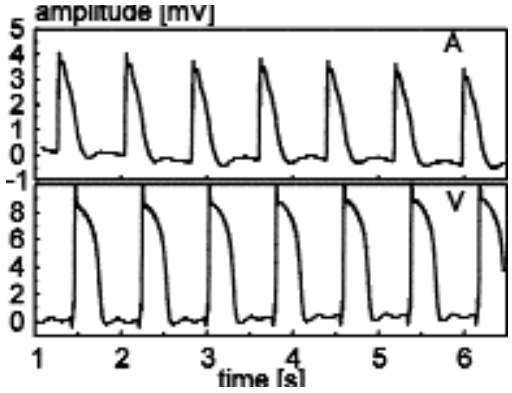

Figure 5. Similar recordings of spontaneous atrial and ventricular MAPs measured with an atrial YP 53/10 BP lead and a ventricular TIR 60/5 BP lead.

mandrin was extracted, the MAP morphology changed significantly. Figure 3 shows a measurement of the same patient, but 10 s later. The MAPs indicated an enlarged T wave, and the amplitude decreased to 3 mV. Amplitude reduction was due to the absent mandrin, which had been offering support and allowing more pressure to be exerted on the myocardium through the lead. The change in morphology was due to the large interelectrode distance in this lead design. With a 30 mm distance, the quality of measured signals was more susceptible to changes in electrode position in relation to the myocardial electrical field.

To achieve stable MAP morphology, the distance between different and indifferent electrodes was decreased to 5 mm. In Figure 4, a spontaneous ventricular MAP with a cycle length of 980 ms and a paced ventricular MAP with a cycle length of 600 ms are both depicted. Both signals possessed typical MAP morphology and amplitudes of 12 mV. However, the paced MAP showed an expected shortening of the repolarization phase, which is typical for a decreased cycle length.

Ventricular MAP recordings with passively fixated leads indicated that the MAP amplitude is correlated to the lead pressure at the myocardium. To increase this pressure in the absence of a mandrin, a screw-in lead was implanted in the atrium. Ventricular MAPs were recorded with an anchor lead as in the previous measurements. In Figure 5, the recorded MAPs can be seen. The atrial MAPs had the typical triangular morphology with amplitudes reaching 4 mV. The second channel recorded the ventricular signals.

As a consequence of the excellent MAP recordings with screw-in leads in the atrium, these leads were also then implanted in the ventricle. Figure 6 shows ventricular MAPs and the surface ECG recorded simultaneously. The MAP morphology was typical, and the

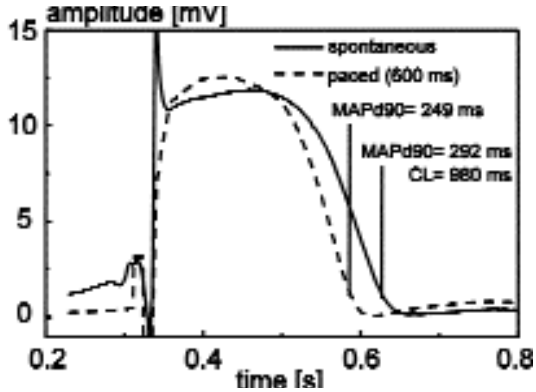

Figure 4. Comparison of spontaneous and paced ventricular MAPs as recorded with a TIR 60/5 BP lead.

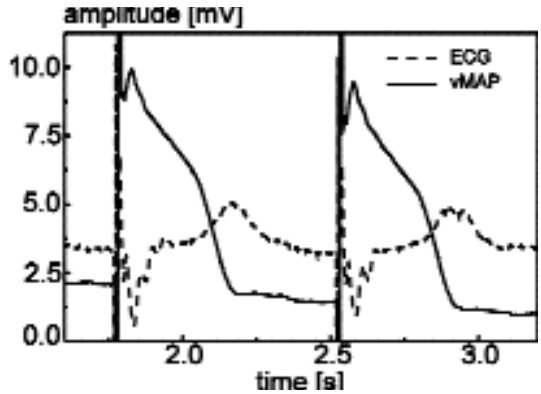

Figure 6. Recording of ventricular MAPs measured with a YP 60/10 BP lead and surface ECG.

amplitude reached was 7 mV. The parameters MAPd50 and MAPd90 were used to analyze the heart rate dependency of the MAP. While the parameter MAPd90 reflects the duration of the action potential, the MAPd50 parameter is influenced by changes in duration and also morphology. In Figure 7, the analyzed MAP durations MAPd50 and MAPd90 were recorded as a function of the pacing rate. The corresponding pacing rate is illustrated in the lower half of the figure.

The pacing frequency was incrementally increased by 20 bpm from 80 bpm to 120 bpm during the recording. The figure clearly shows the inverse proportionality between pacing rate and MAP duration. Previous studies showed that within the first few beats of a sudden pacing increase, the action potential duration drops sharply. Following this change, a slower, progressive shortening ensues until a steady state is reached after several minutes. The sharp, initial drop of the action potential duration has been attributed to an incomplete recovery of plateau conductances[9], while the subsequent slow change is due to either the accumulation of an ion or metabolite or to a change in the Na^+/K^+ pump activity[2][3].

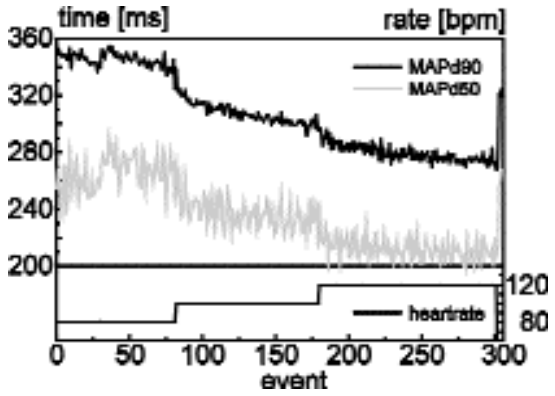

Figure 7. Effects of a varying pacing rate on MAPd50 and MAPd90 as measured by a YP 60/10 BP lead.

Discussion

For chronically implantable pacemaker leads, the feasibility of MAP monitoring could be shown immediately after intraoperatively fixing the lead. Proper MAP morphology was attained by monitoring the MAPs via an external recording system with a bandwidth of 0.01 to 500 Hz. During these intraoperative measurements, it could be noted that the actively fixed screw-in lead yielded higher MAP amplitudes than the passively fixated lead with tines. Both MAPd50 and MAPd90 values displayed the typical shortening of the repo-larization phase when the pacing rate was increased.

In the next generation of chronically implantable MAP pacemaker leads, different and indifferent electrodes should be very small, and the distance between the electrodes should not exceed 10 mm. To ensure high MAP amplitudes, active fixation with a screw insulated from the electrodes should be used.

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