Long Term Monitoring of the Intrinsic Ventricular Monophasic Action Potential with an Implantable DDD Pacemaker

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Summery

The monophasic action potential (MAP) represents the summed signal of the transmembrane action potential of a limited number of cells around the different electrode of the lead. The MAP changes its course dependent on the transmembrane ion currents. The aim of this study was to investigate the MAP measurement (ventricle, intrinsic) with chronically implantable pacemaker leads up to 26 weeks after implantation via the telemetric unit of the implanted pacemaker. The actively fixated pacemaker lead (YP-60 BP/10, BIOTRONIK, Germany) in combination with the DDD pacemaker (Physios CTM01, BIOTRONIK, Germany) provides MAP recordings via high-resolution telemetry. This study included 10 patients (age 64 ± 15 years). Intraoperatively, all leads showed typical MAP morphologies with an average amplitude of 8.1 mV. One week after implantation, the amplitude decreased to less than 2.8 mV on average. Half a year after implantation, the measured intrinsic signals look like a surface ECG with QRS complex and T wave. This study shows that the actively fixated leads and pacemaker system used provide the recording of intrinsic ventricular MAP intraoperatively and up to four weeks postoperatively. To record the MAP for longer than four weeks after implantation, the pacemaker leads must be redesigned to passively fixated leads, combined with a small tip, a shorter tip-ring distance and an indifferent electrode with the same surface size as the tip.

Key Words

Monophasic action potential, active and passive fixation, fractal coated pacemaker lead, long-term monitoring

Introduction

Recordings of the monophasic action potential (MAP) open new ways in experimental and clinical electrophysiology [1][2]. The MAP is measured by a bipolar electrode between tip and ring and shows local cellular effects near the electrode tip. It allows monitoring of the influences of heart rate, antiarrhythmic drugs and pathological changes on the electrical state of the heart. Until recently, however, MAP recordings were possible only during electrophysiologic investigations. No studies regarding long-term recordings of the MAP were available, because MAP measurements require special kinds of leads and electrode surfaces like silver-silver chloride (Ag/AgCl) or fractal coating [3]. These coatings allow transmission of intracardiac signals over a broad range of frequency. But the Ag/AgCl coating does not possess long-term stability. Thus, only fractal coated electrodes provide long-term MAP monitoring. The second requirement is a pacemaker system that allows MAPs to be measured and stored on an external device. Later the data can be analyzed to extract the physiologic information. The telemetry of implantable devices has been adapted to measuring the MAP, and thus it must offer a low cut-off frequency [4]. The Physios CTM01 pacemaker (BIOTRONIK, Germany) has been designed to allow the analysis of intracardiac potentials [5].

This paper presents clinical data about recording the intrinsic ventricular MAP with an implantable pacemaker using endocardial leads 6 months after implantation.

Materials and Methods

The pacing and sensing performance of the pacing lead largely determines the quality of the pacemaker system. The most important condition for low threshold stimulation and good sensing of cardiac signals is an electrode-tissue interface with a high capacity. For that reason, the electrochemical active surface of the electrodes must be enlarged, and the geometrical surface area should not be larger than a few mm^2 [4]. To solve the apparent contradiction between the need for a large active surface but small geometrical dimensions, the surfaces of modern pacing leads must be structured [3][6]. Therefore, the electrodes (YP-60 BP/10, BIOTRONIK, Germany) used were coated with iridium fractal structures. Fractal surface structuring provides an optimal ratio between the active and geometrical surface area (more than 1000:1) [3][6]. The large active surface area reduces polarization artifacts, improving the detection of cardiac signals like the MAP after a pacing impulse. The bipolar YP-60 BP/10 lead was actively fixated to ensure the same position and the same pressure between electrode tip and myocardium intraoperatively and postoperatively. The surface area of the different electrode was 7 mm^2, and the surface area of the indifferent electrode 48 mm^2. The measured interelectrode distance is 10 mm.

Exact analysis of intracardiac signals requires the use of an implantable pacemaker system to investigate the different influences on the signal's waveform. The dual-chamber pacemaker, Physios CTM01, has been developed for high-resolution online monitoring with atrial and ventricular monitoring channels. Besides this special feature, Physios CTM01 includes all therapeutic and diagnostic options of a conventional DDD pacemaker. The bandwidth of the internal filtering was adapted to the frequency spectrum of the MAP with a lower cut-off frequency of 0.33 Hz and a higher cut-off frequency of 200 Hz. After frequency modulation of the measured MAP, the signals are transmitted to an external receiver via the telemetry coil. Following frequency demodulation, the signals are transmitted to a computer for A/D conversion, signal analysis, and date storage [5].

In 10 patients (age 64 ± 15 years) with DDD indications, YP-60 BP/10 leads were implanted in the right atrium and ventricle. The actively fixated bipolar leads were implanted by direct puncture of the left subclavian vein. Intraoperatively, the standard parameters (threshold, P and R waves, amplitude, impedance), as well as MAP, were measured. The MAPs were measured using an isolation amplifier with adjustable amplification (range: ± 250 mV to ± 5 V). The signals were digitized with a 500 Hz sampling frequency and stored on a PC with 12-bit resolution. Only lead positions with stable MAP recordings were accepted. Afterwards, the DDD Physios CTM01 pacemakers were subcutaneously implanted on the left side. The standard parameters, as well as stimulated and intrinsic MAPs, were measured at 1, 4, 12, and 26 weeks following implantation. Postoperatively, the MAPs were sent via the analogue telemetry in the pacemaker to an external receiver (Physios CTM01 Receiver, BIOTRONIK, Germany). This receiver was connected to the same isolation amplifier and PC that were used intraoperatively.

Next, the standard MAP parameters (MAP duration, amplitude, cycle length [2]) were evaluated using the semiautomatic evaluation program (Bioview, BIOTRONIK, Germany). After 26 weeks, the intracardiac signals were analyzed for the maximal peak, amplitude, T wave, and signal duration.

Results

Initially, the sensing amplitudes, pacing thresholds, and impedance were intraoperatively established in the atrium and ventricle. These standard parameters were determined during every follow-up (table 1). The values demonstrate that the actively fixated pacemaker leads used possess the same electrical attributes as passively fixated leads. Moreover, the sensing amplitudes in the atrium were higher than the known values for standard leads with a 30-mm tip-ring distance. The measured intrinsic ventricular MAP showed a typical morphology. During spontaneous heartbeats, the amplitudes reached an average of 8.1 mV ± 5.6 mV. Concerning the plateau of the MAP morphology, the signals showed a MAPd25 value that amounted to 264 ms ± 11.5 ms (table 2). Figure 1 shows an intraoperatively stored, ventricular MAP of patient EH-19. The heart rate, the amplitude, and the MAP duration at 25 %, 50 %, and 90 % repolarization of all patients are represented in table 2.

One week after implantation, the amplitude of the intrinsic MAP decreased. The ventricular amplitude was reduced from an intraoperative average of 5.26 mV to 1.46 mV. Figure 2 depicts the MAP of pa-

	OP	1 Week	4 Weeks	12 Weeks	26 Weeks
P (mV)	2.4 ± 0.9	2,7 ± 0,8	2,9 ± 1,5	3,4 ± 1,6	3,4 ± 1,6
R (mV)	12.7 ± 4.8	10.5 ± 5.8	13.3 ± 5.7	11.1 ± 5.5	13.4 ± 4.7
A Threshold /0.5ms (V)	0.5 ± 0.2	1.2 ± 0.9	0.8 ± 0.2	1.1 ± 1.4	0.7 ± 0.4
V Threshold /0,5ms (V)	0.4 ± 0.1	0.7 ± 0.3	1.2 ± 0.7	1 ± 0.2	0.9 ± 0.4
A Impedance (Ω)	425 ± 83	355 ± 86	519 ± 109	372 ± 63	381 ± 54
V Impedance (Ω)	628 ± 131	388 ± 75	573 ± 116	458 ± 93	462 ± 89

Table 1. Sensing amplitudes, pacing threshold, and impedance of the implanted leads YP60/10-BP up to half a year after implantation.

tient EH-19 one week after implantation. Figure 3 shows the MAP of the same patient four weeks after implantation. The plateau of the MAP decreased to less than 10 % of the intraoperatively measured signal, and the MAP indicated an enlarged T wave.

Half a year after implantation, typical MAP morphology of the intrinsic ventricular signals could no longer be recognized. The MAP amplitude decreased to less than 1 mV, and furthermore the signals indicated a T wave. The morphology of the signals can be divided into two groups. The analyzed values are depicted in figures 4 and 5. Figure 4 shows one example from the T^+ group. The morphology of the first group (T^+ type) indicated a large negative peak, low amplitude, and a positive T wave (figure 4). A large positive peak, low amplitude, and a negative T wave were the characteristics of the second group (T^- type) (figure 5). On the average, the negative peak was -7.12 mV; the T wave was 0.77 mV; and the amplitude decreased to 0.45 mV (table 3). At 320 ms, the signal ended, followed by an isoelectrical line until the next heart action. The T^- group was characterized by a positive peak of 9.22 mV on average and by an MAP amplitude of -0.12 mV (figure 5). The T wave became negative, increasing in amplitude to an average value of -1.65 mV (table 4). The duration of the intracardiac signal amounted to 432 ms. Tables 3 and 4 show the values for each patient. Figure 6 depicts bipolar intracardiac electrogram (IEGM) recordings and a surface ECG (V2) half a year after implantation. The peaks of the IEGM at the beginning of the ventricular action corresponded to the QRS complex of the surface ECG. Furthermore, figure 6 shows the congruency of the T waves on the surface ECG and the IEGM. There was

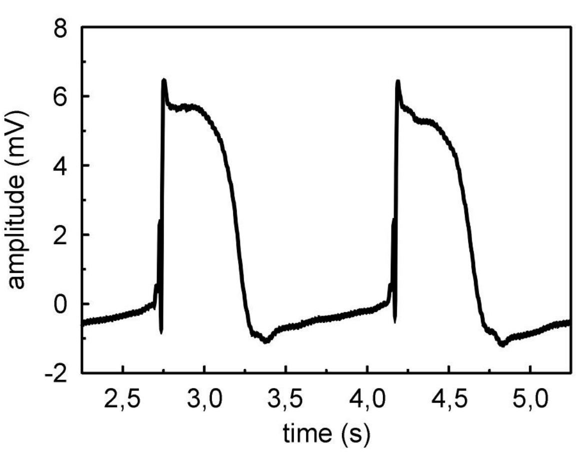

Figure 1. Intrinsic ventricular MAP measured intraoperatively (patient EH-19).

	Ventricle	Standard Deviation
Amplitude mV	8.1	5.6
MAP d25 (ms)	254	11.5
MAP d50 (ms)	113	10.5
MAP d90 (ms)	356	10.8
Heart Rate (bpm)	58.3	4.5

Table 2. Amplitude, duration, and heart rate of intraoperatively measured MAPs.

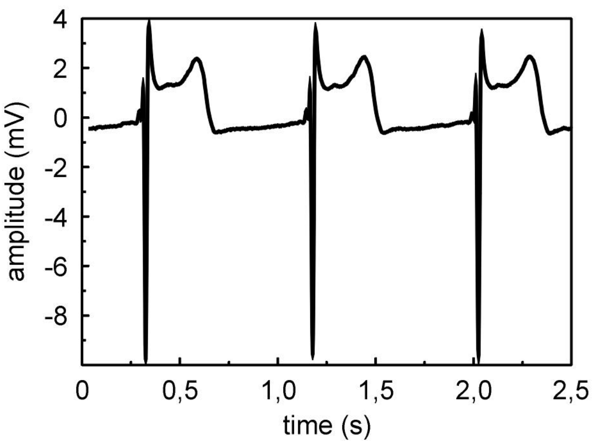

Figure 2. Intrinsic ventricular MAP measured one week after implantation (patient EH-19).

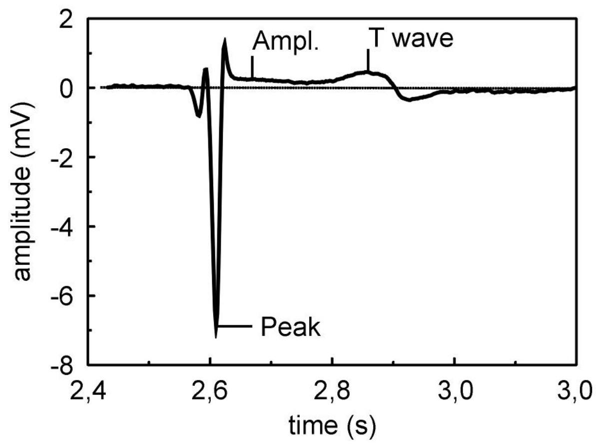

Figure 4. Intrinsic ventricular IEGM measured bipolarly 26 weeks after implantation, showing a positive T wave (T^+ type).

no difference between the positive and negative T waves of the IEGM concerning to the congruency of the T waves and the ECG. Half a year after implantation, IEGMs that corresponded with ECG morphology could be observed during all examinations and IEGM recordings.

Discussion

Fractal coated pacemaker leads showed very good MAP monitoring immediately after intraoperative lead fixation. Furthermore, these leads and the pacemaker system used provide MAP recordings for up to four week after implantation. But the amplitude of the MAP clearly decreased. This effect was caused by the demarcation potential of the actively fixated lead. Over the next 5 months, MAP morphology of the intrinsic signals completely disappeared. There are different reasons for this effect. The intrusive lead causes scarring of the myocardium. This resulting scar tissue constitutes an area of the heart that does not contribute to the spread of excitation. Furthermore, this tissue shows no action potential. Theoretical findings indicate that a potential proportional to the transmembrane potential may be recorded if the different electrode has stable contact with the myocardium [7]. But this can only

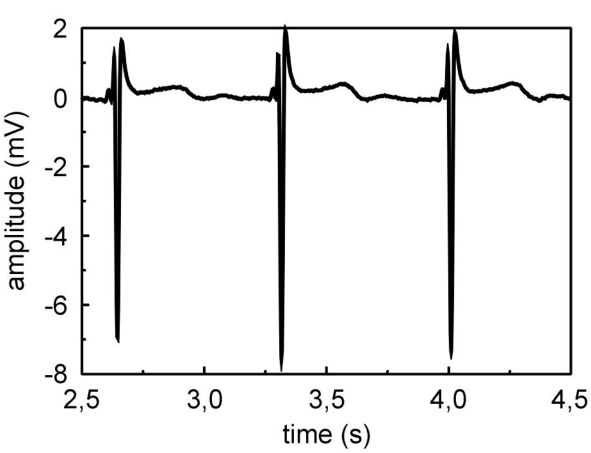

Figure 3. Intrinsic ventricular MAP measured four weeks after implantation (patient EH-19).

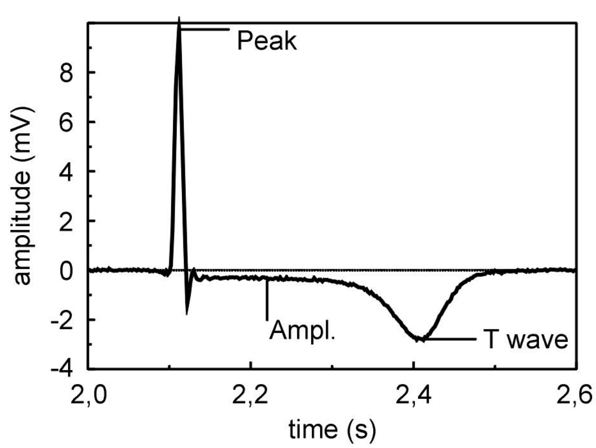

Figure 5. Intrinsic ventricular IEGM measured bipolarly 26 weeks after implantation, showing a negative T wave (T^- type).

Patient	Peak (mV)	Amplitude (mV)	T wave (mV)	Duration (ms)
GA_25	-8.09	0.32	0.11	318.30
HS_36	-7.61	0.61	0.66	307.40
IR_28	-10.02	0.48	0.60	312.00
EW_30	-1.91	0.24	1.46	432.10
FW_20	-7.87	0.72	0.70	238.50
average	-7.12 + 3.05	0.45 + 0.21	0.77 + 0.40	370 + 70.11

Table 3. Peak, amplitude, T wave, and duration of intrinsic ventricular IEGMs measured bipolarly 26 weeks after implantation (T^+ type).

Patient	Peak (mV)	Amplitude (mV)	T wave (mV)	Duration (ms)
PM_27	9.93	0.01	-5.93	469.90
LG_30	10.36	-0.24	-2.60	393.10
EZ_32	9.61	0.04	-1.33	529.60
FJB_27	10.58	-0.40	-0.93	407.40
EH_19	5.62	0.01	-2.57	340.00
average	9.21 + 2.05	-0.17 + 0.20	-1.65 + 0.85	432 + 76.59

Table 4. Peak, amplitude, T wave, and duration of intrinsic ventricular IEGMs measured bipolarly 26 weeks after implantation (T^- type).

occur if the cells underlying the tip electrode are depolarized and the impedance between electrode and myocardium is less than that of the indifferent electrode [7]. However, due to the scar tissue, the cells underlying the electrode tip cannot depolarize. Moreover, examinations show that the bipolar signals indicate an enlarged T wave. Newer experimental results confirmed that MAP recordings using leads with a greater tip-ring distance and larger ring surface are distorted by artifacts in the repolarization course. They temporally correlate to the T wave of the surface ECG [7]. Therefore, the tip-ring configuration used provided only temporary MAP measurement for up to four weeks after implantation. Six months after implantation, the bipolar signal was dominated by a potential similar to that of an ECG.

Conclusion

The represented results show that the actively fixated leads and pacemaker system used provide the recording of intrinsic ventricular MAP intraoperatively and for up to four weeks postoperatively. The MAP morphology was attained by monitoring the MAP via an external device with a bandwidth of 0.01 Hz to 500 Hz (intraoperatively) and the DDD Physios CTM01 pacemaker with a bandwidth of 0.33 Hz to 200 Hz (postoperatively). Later on, the stored intrinsic signal was increasingly dominated by a potential resembling that of an ECG. According to newer experiments [7], the use of passively fixated leads, combined with a small tip, a shorter tip-ring distance, and an indifferent electrode with the same surface size as the tip, could provide long-term stable MAP recording.

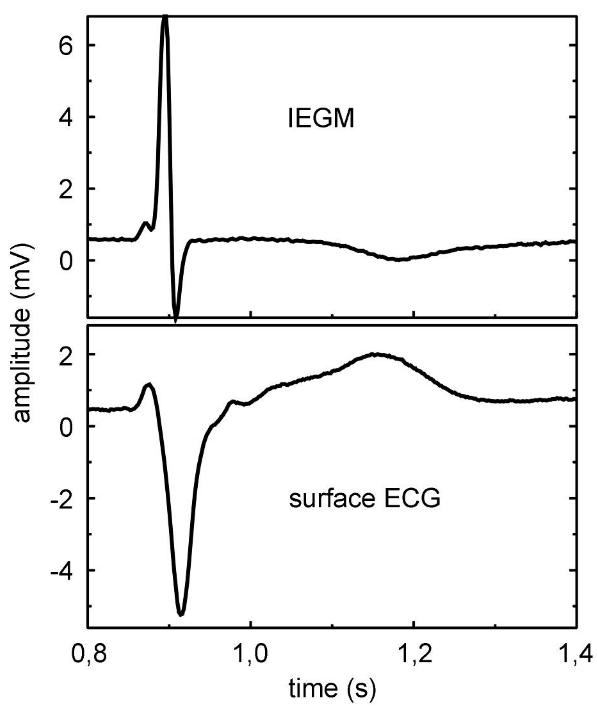

Figure 6. Intrinsic ventricular IEGM, measured bipolarly 26 weeks after implantation, and surface ECG.

References

[1] Franz MR. Bridging the Gap Between basic and clinical electrophysiology: What can be learned from monophasic action potential recordings. Journal of Cardiovasc Electrophysiol. 1994; 5(8): 699-710.

[2] Yuan S, Blomström-Lundquist C, Olsson BS. Monophasic action potentials: Concepts to practical applications. Journal of Cardiovasc Electrophysiol. 1984; 5: 287-308.

[3] V. Lang, et al. Optimizing the geometry of implantable leads for recording the monophasic action potential with fractally coated electrodes. PACE, Vol. 1998.

[4] Bolz A. Die Bedeutung der Phasengrenze zwischen alloplastischen Festkörpern und biologischen Geweben für die Elektrostimulation. Berlin: Schiele & Schön 1995.

[5] Stokes KB. The effects of ventricular electrode surface area on pacemaker lead performance. Rom: Simposio Meridionale di Cardiostimulazione 1992, 505-514.

[6] R. Hardt, et al. Clinical experience with low threshold pacing leads. Progress in Biomedical Research. 1996.

[7] W. Dauer et al. High resolution monitoring of intracardiac signal with a DDD-pacemaker. Progress in Biomedical Research. 1996; 4(1): 50-55.