Simultaneous Monitoring of Monophasic Action Potentials during Radiofrequency Ablation with Fractally Coated Catheters in Dogs

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Summary

Up to now all known, recordings of the MAP during RF ablation were performed with custom designed catheters with 2 additional Ag/AgCl electrodes for MAP monitoring. To overcome this restriction, fractal coated ablation catheters with an established quadripolar electrode design (AlCath, BIOTRONIK) were developed. The fractal coating of the catheter poles was optimized for reliable spontaneous as well as stimulated MAP measurements via the distal tip and the second electrode before, during and after RF delivery. The preamplifier of the ablation device (AbControl/A, BIOTRONIK) guarantees the suppression of RF and stimulation interferences with the DC coupled MAP signals. Methods: At 18 left ventricular sites in 4 dogs RF was applied under temperature control with set points of 70°C and 90°C for 60 sec. The fractal coated catheters and the ablation device mentioned above were used for ablation as well as for MAP detection and filtering throughout the whole ablation procedure. Results: The basic MAP parameters were as follows: amplitude 7.1 ± 1.4 mV, upstroke velocity (UV) 0.75 ± 0.29 V/s, and $MAPD_{90}$ 203 ± 18 ms. Indicating the growth of the lesion during RF delivery artifact-free MAP signals with decreasing amplitudes (3.8 ± 1.8; $p < 0.05$), and shortened $MAPD_{90}$ (168 ± 33 ms; $p < 0.05$) were observed in all RF applications without correlation with the temperature. The decrease of the MAP amplitude stopped and reached steady state after 32.0 ± 5.6 s at 70°C and after 48.2 ± 3.1 s at 90°C. The UV appeared to be almost unchanged (0.72 ± 0.32 V/s; p = NS). Conclusions: For the first time, reliable MAP measurements were performed using fractal coated catheters with an established mechanical design in combination with a commercially available ablation system during RF-delivery. The obtained results prove that the MAP signals measured by the method discussed above allow the on-line monitoring of the RF ablation effect.

Key Words

RF ablation, MAP monitoring, fractal coated catheter

Introduction

The monophasic action potential (MAP) represents a summed signal of transmembrane action potentials of myocardial cells surrounding the tip of the catheter [1]. Thus, the MAP reproduces the time course of the underlying transmembrane action potentials with high accuracy. MAP recording using contact electrode technique in vivo is suitable for studying the characteristic of local myocardial repolarization and identifying the basis of triggered ventricular arrhythmias, in this way connecting basic and clinical electrophysiology [2]. The radiofrequency (RF) ablation is a highly effective therapeutic method based on transcatheter elimination of an arrhythmogenic substrate. New clinical applications of MAP recordings for the diagnosis and therapy of tachycardias may be the localization of the focus of triggered arrhythmias by the detection of afterdepolarizations allowing a reliable ablation using a MAP-ablation catheter [3]. Thus, another MAP application for improvements of the RF ablation procedure is the analysis of the time course of the MAP before, during and after RF delivery to assess the ablation effects [4,5].

	Before RF	After RF	p	Change (%)
MAP amplitude (mV)	7.1 ± 1.4	3.8 ± 1.8	< 0.05	- 48.4
Upstroke velocity (V/s)	0.75 ± 0.29	0.72 ± 0.32	NS	- 3.2
$MAPd_{25}$ (ms)	151 ± 12	126 ± 23	< 0.05	- 17.1
$MAPd_{50}$ (ms)	169 ± 14	142 ± 24	< 0.05	- 15.6
$MAPd_{90}$ (ms)	203 ± 18	168 ± 33	< 0.05	- 16.5

Table 1. Comparison of MAP parameters before and after RF delivery.

However, the conventional measurements of MAP during stimulation and/or RF delivery at the measurement site were performed with special designed Ag/AgCl catheters. Beside the two sensing poles, the MAP-stimulation combination catheters contain two additional electrodes for stimulation [6,7] and the known MAP-ablation combination catheters have two additional electrodes for RF delivery [4]. Artifact-free monitoring of spontaneous and stimulated MAP with fractal and electroactive coated mapping catheters overcoming the above mentioned restriction of the MAP-stimulation combination catheters was already proven [8,9,10,14]. The aim of this study was the registration and evaluation of the MAP recordings obtained with fractal coated ablation catheters at stimulation and at spontaneous rhythm during radiofrequency energy application.

Materials and Methods

At 18 left ventricular sites in 4 pentobarbital anesthetized open chest dogs RF ablation was applied under temperature control (70°C and 90°C) for 60 s. Fractal coated catheters with an established quadripolar electrode design (AlCath Green fractal, BIOTRONIK) and non-coated -polished platinum- catheters (AlCath Green, BIOTRONIK) were used for RF application, stimulation and for MAP and intracardiac electrogram (IEGM) detection. MAP measurements, RF delivery, and stimulation were simultaneously performed via the poles 1 and 2. The electrodes 3 and 4 of these catheters were used for conventional IEGM monitoring as usual in RF ablation therapy.

The fractal Ir-coating of the catheter poles has considerably lower interface impedance compared to polished platinum and Ag/AgCl electrodes. Thus, a frequency independent damping is guaranteed in the frequency range above 0.1 Hz, which provides a sufficient band width for MAP and IEGM monitoring. The benefits are the following: excellent signal-to-noise ratio, long-term stability of the electrical properties, biocompatibility of the materials and optimized stimulation and subsequent artifact-free recording of MAP and IEGM due to the low polarization of fractal coated electrodes [11,12,13].

For RF ablation and filtered MAP and IEGM detection throughout the whole ablation procedure, the fractal coated ablation catheters were used with a new ablation system (AbControl/A, BIOTRONIK), which is optimized for suppressing any RF and stimulation interference. The characteristics of the integrated RF filters enable in combination with fractal coated catheters the artifact-free measurement of intracardiac signals before, during and after the RF delivery period. The MAP is DC-coupled (0-700 Hz) and the IEGM is AC-coupled (10-700 Hz) detected by this ablation system. The signals were continuously recorded prior, during and following RF energy application at spontaneous rates and stimulation.

The signals were amplified, digitized and stored on PC. Afterwards, the signals were semi-automatically evaluated and the MAP parameters cycle length, upstroke velocity, amplitude, duration ($MAPd_{90}$, $MAPd_{50}$, $MAPd_{25}$) were calculated.

Results

As demonstrated in Figure 1 before radiofrequency ablation spontaneous and stimulated MAP signals with stable amplitudes, and MAP duration measured with the fractal coated catheters have nearly the same morphology. For comparison, Figure 2 shows signals measured via the poles 1 and 2 of non-coated catheters immediately after stimulation via the same electrodes. The stimulation artifact disables a reliable analysis of the underlying intracardiac signal.

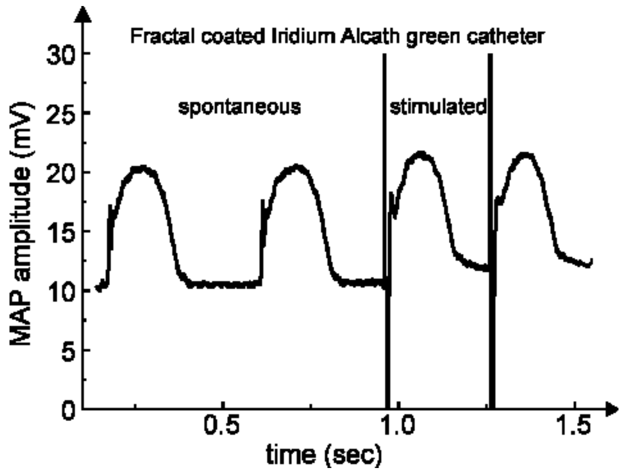

Figure 1. Morphology of spontaneous and stimulated MAP signals recorded by fractally coated catheters.

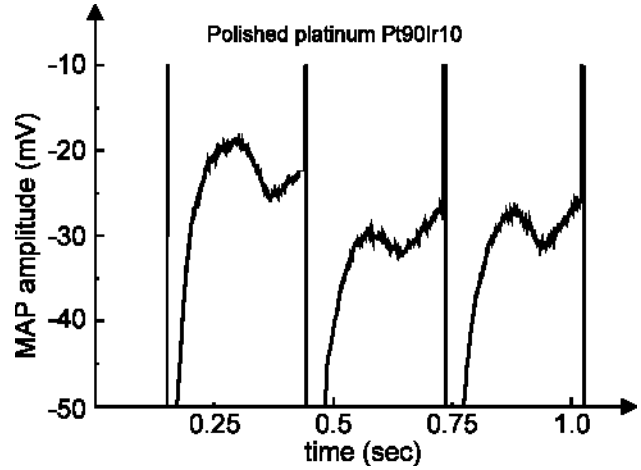

Figure 2. Morphology of stimulated MAP signals recorded by uncoated catheter electrode.

The MAP recorded with fractal coated catheters was shown to be significantly changed by RF ablation. Immediately after the onset of RF delivery, a change of the MAP parameters was initialized. At the end of the RF delivery period, an important reduction of the MAP amplitudes and duration were observed (Table 1).

The decrease of the MAP amplitude did not occur continuously. During the first seconds after the RF onset, an increase of the MAP amplitude was observed. After about 5s, the maximum MAP amplitude is reached and the amplitude decreases continuously until a steady state is reached (Figure 3). The steady state MAP amplitude remaining constant after the end of RF delivery was significantly lower compared with the MAP amplitude before RF ablation in all observations. MAP duration at 90 - 50 - and 25 percent repolarization was also significantly shorter after the ablation procedure. The RF application had no significant effect on the upstroke velocity.

The time of reaching the steady state of the MAP amplitude was shown to be correlated to the ablation temperature (at 70°C after 32.0 ± 5.6 s, at 90°C after 48.2 ± 3.1 s). This is demonstrated on the basis of two examples in Figure 4 with an ablation temperature of 70°C and in Figure 5 with an ablation temperature of 90°C. In contrast to the decrease of the MAP amplitude, the decrease of the MAP duration did not correlate with the ablation temperature.

The MAP amplitude and duration were shown to be significantly effected by RF energy application ablation. The ablation dependent initial increase of the MAP amplitude within the first 5s of the RF delivery period could be caused by the damage of the endocardium. The temperature correlated decrease of the MAP amplitude could be explained with progressing ablation process, meaning with growing lesion size, the number of cells contributing to the MAP signal decreases and therefore, the MAP amplitude is decreased. According to this hypothesis, the reaching of the steady state of the MAP amplitude indicates the reaching of the final lesion size during RF ablation. If this theory can be proven, the MAP amplitude can be used for optimizing the RF delivery time in RF ablation therapy in future. The morphology of the MAP is

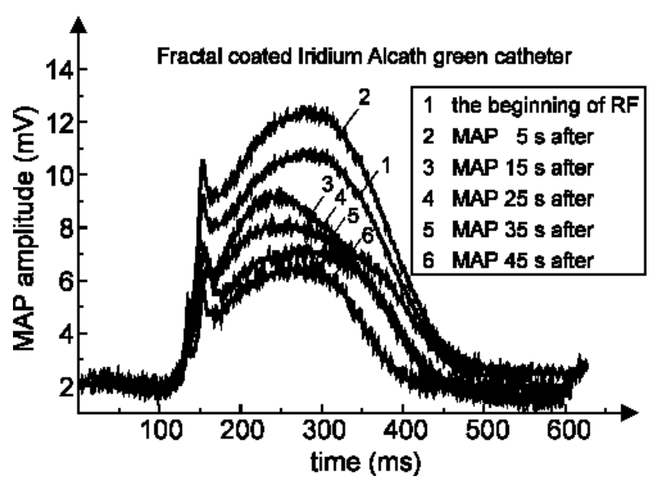

Figure 3. Change of MAP morphology during temperature controlled RF ablation (T = 90°C).

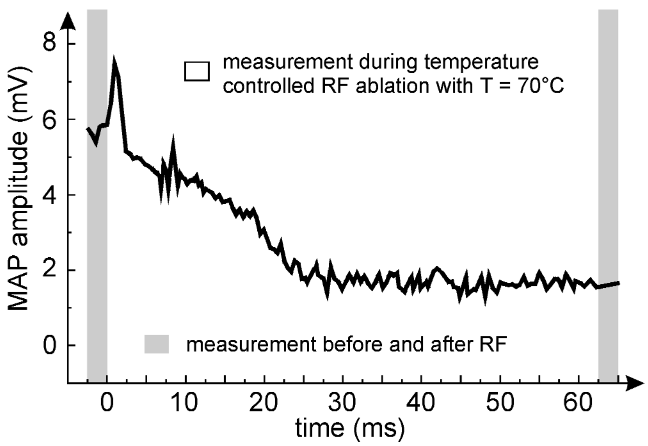

Figure 4. MAP amplitude before , during and after RF delivery (temperature controlled RF ablation, T = 70°C).

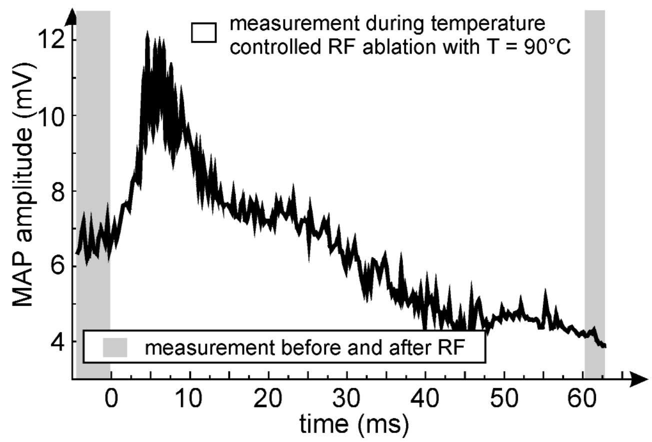

Figure 5. MAP amplitude before , during and after RF delivery (temperature controlled RF ablation, T = 90°C).

characterized by the time course of the underlying action potentials of the cells near the catheter tip. Therefore, significant changes of the MAP morphology can be an indicator for myocardial tissue destruction, e.g. for the successful ablation of arrhythmogenic focus. However, this has to be evaluated in detail in further studies.

Conclusion

Reliable MAP measurements were performed during RF delivery with a commercially available ablation system and fractal coated catheters based on an established mechanical design. The obtained results promise an important step forward in on-line monitoring of the MAP signals during ablation. They may help in the localization of the arrhythmogenic substrate (EAD and DAD), and in the evaluation of RF ablation effect, which have to be investigated in further experimental and clinical studies.

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