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Research Article

Electrode Model and Simulation of Catheter Ablation of Supraventricular Tachycardia

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Abstract

The high frequency (HF) catheter ablation is the gold standard for the therapy of many cardiac tachyarrhythmias, such as atrioventricular node re-entry tachycardia (AVNRT), atrioventricular re-entry tachycardia (AVRT) or atrial flutter (AFL). The aim of the study was to simulate the HF ablation of AVNRT, AVRT, AFL and its heat propagation in reference to the supplied power with different electrode material and electrode size. The modeling and simulation were performed with the thermal and electromagnetic simulation software CST® (Computer Simulation Technology, Darmstadt). The modeling and simulation were carried out using ablation catheters with 4 mm tip electrode and 8 mm tip electrode with different electrode materials. Both electrode types were made of platinum and gold respectively. For the measurement of the heat propagation in the heart tissue, the catheters were integrated in the Offenburg heart rhythm model. The HF ablation procedures were performed with the 4 mm platinum tip electrode, with an application duration of 45 seconds and a power output of 40 watts. The HF ablation of the atrioventricular node slow pathway produced a maximum temperature of 66.33°C. The Kent bundle HF ablation in the left atrium achieved a maximum temperature of 67.14°C. The HF ablation of the right atrial isthmus resulted 65.96°C. The 8 mm distal platinum tip electrode and a power output of 60 watts reached 72.85°C. The 8 mm distal gold tip electrode and a power output of 60 watt reached 64.66°C, due to the improved thermal conductivity of gold. Virtual heart and ablation electrode models allow the static and dynamic simulation of HF ablation with different electrode material and electrode size. The 3D simulation of the temperature profile may be used to optimize the AVNRT, AVRT and AFL HF ablation.

Keywords: Catheter Ablation; HF Ablation; Supraventricular Tachycardia; Electrode Model; Catheter Model; 3d Heart Simulation; Thermal Simulation; Heart Rhythm Model

Introduction

The high frequency (HF) catheter ablation is the gold standard for the therapy of many cardiac tachyarrhythmias, such as atrioventricular node re-entry tachycardia (AVNRT), atrioventricular re-entry tachycardia (AVRT) or atrial flutter (AFL). The HF ablation destroys specific structures of the myocardium because of the heat development, which is induced by the applicated high-frequency current [1]. The simulation of ablation procedures could show the heat propagation according to the applicated power and therefore the depth and the width of the lesions.

The aim of the study was to simulate the HF ablation of AVNRT, AVRT, AFL and its heat propagation in reference to the supplied power with different electrode material and electrode size.

Materials and Methods

The modeling and simulation were performed with the thermal and electromagnetic simulation software CST® (Computer Simulation Technology, Darmstadt). The modeling and simulation were carried out using ablation catheters with 4 mm tip electrode and 8 mm tip electrode with different electrode materials. Both electrode types were made of platinum and gold respectively. The catheters were modelled on the basis of the technical manuals of the manufacturers Medtronic, Biotronik and Osypka. For the measurement of the heat propagation in the heart tissue, the catheters were integrated in the Offenburg heart rhythm model (see Figure 1) [2]. In figure 1 for example, the Biotronik AlCath Fullcircle with a 4 mm platinum tip electrode was integrated in the right atrium near the AVN.

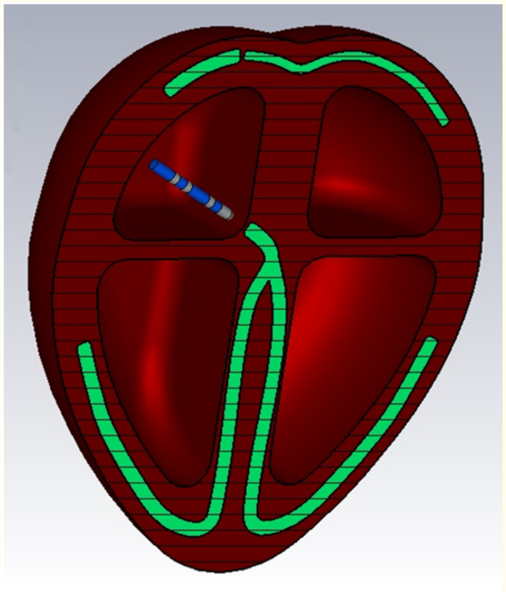


Figure 1: Offenburg heart rhythm model with integrated HF catheter in the right atrium near the AVN (Biotronik AlCath Fullcircle platinum).

The red component of the Offenburg heart rhythm model represents the myocardium and the green structures correspond to the nerve pathways of the conduction system of the heart. Also, the blood flow in the heart chambers, in relation to the convection cooling, is considered in this virtual heart model.

The HF ablation was carried out using a power output in the range of 5 - 40 watts for the 4 mm tip electrodes and 50 - 80 watts for the 8 mm tip electrodes.

Results

One aim was it to optimize the ablation temperature and adapt it to the reality. For this, many special settings in the thermal program interface of CST® were determined. Secondly, supraventricular ablation procedures were presented in the Offenburg heart rhythm model and simulative measurements were performed [3]. Additionally, the differences of tip electrodes made of platinum and gold were examined by simulation

Optimization of ablation temperature

40°C ablation temperature should be the result of a supplied power of 5 watts. This was the reference value to approximate the heat development to the reality. After special settings for the simulation were found, ablations with different power outputs were implemented. The ablations for the optimization were performed in the right atrium near the AVN with 4 mm platinum tip electrode (see Figure 1). The ablation temperatures were measured at 5, 10, 20, 30 and 40 watts (see Table 1).

5 watts	10 watts	20 watts	30 watts	40 watts
40.67°C	44.34°C	51.76°C	59°C	66.33°C

Table 1: Measured temperatures in relation to the supplied power.

All these temperatures are the maximum temperatures measured at the catheter tip electrode. The temperature also was captured in the depth of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0 mm depth in the myocardium. In addition, the temperature at the esophagus was measured. Below the temperature profile with a power output of 40 watts is shown (see Figure 2).

Simulation of ablation procedures

Three supraventricular HF ablation procedures were simulated, the HF ablation of AVN slow pathway, Kent bundle and right atrial isthmus. For the ablation of AVN slow pathway for example, the slow pathway was modelled in the Offenburg heart rhythm model (see Figure 3).

The HF ablation of the atrioventricular node slow pathway produced a maximum temperature of 66.33°C. The ablation was performed with the 4 mm platinum tip electrode, with an application duration of 45 seconds and a power output of 40 watts. The heat propagation and the depth of lesion are seen below (see Figure 4). The lesions occur at a temperature of 48°C corresponding to the light blue and light green of the color scale.

Note that this simulation is a simplified model and only an approximation to the reality. Normally, the heat develops in the myocardium and not at the electrode tip.

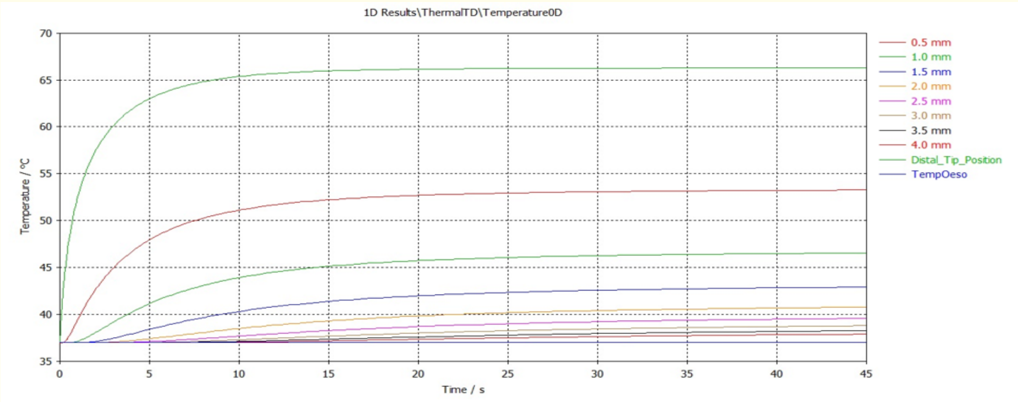


Figure 2: Temperature profile for 40 watts power output and application duration of 45 seconds.

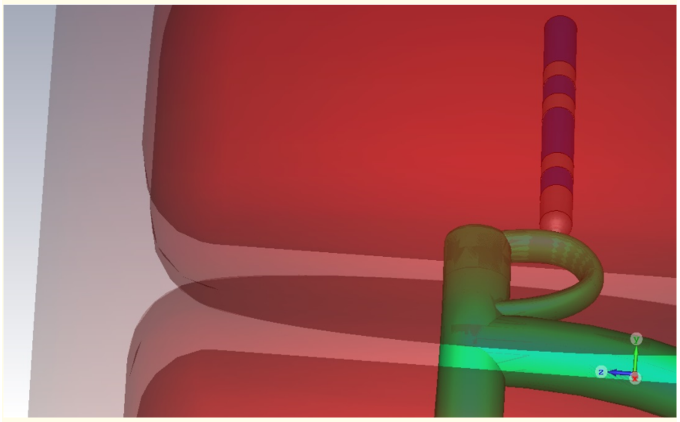


Figure 3: Simulation of the HF ablation of the atrioventricular node slow pathway in the Offenburg heart rhythm model.

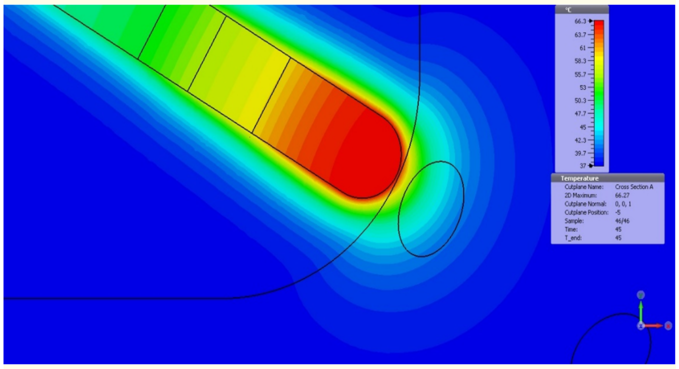


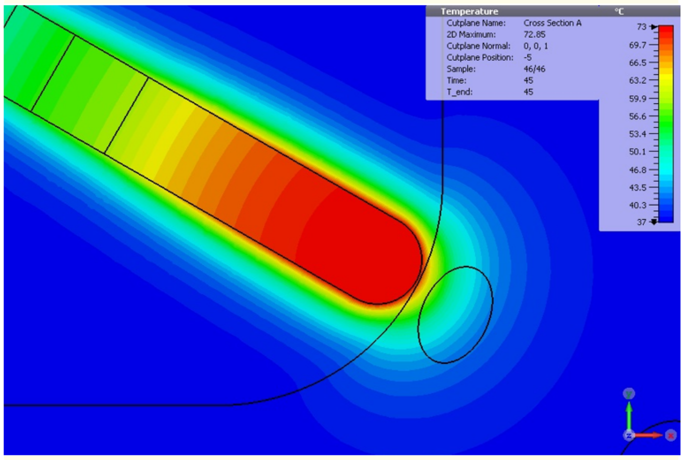
Figure 4: Heat propagation of HF ablation of the AVN slow pathway in heart tissue, plotted in cross section with color scale.

The Kent bundle HF ablation in the left atrium achieved a maximum temperature of 67.14°C. The HF ablation of the right atrial isthmus resulted 65.96°C. These simulations were performed analogous to the HF ablation of the AVN slow pathway.

Comparison of tip electrodes

An 8 mm platinum tip electrode was compared to an 8 mm gold tip electrode. The 8 mm distal platinum tip electrode and a power output of 60 watts reached 72.85°C. The 8 mm distal gold tip electrode and a power output of 60 watts reached 64.66°C, due to the improved thermal conductivity of gold (see Figure 5).

The 8 mm tip electrode in comparison with the 4 mm tip electrode can be applied with increased power without exceeding the temperature limit of 70°C. To reach the same temperature as the 4 mm tip electrode, the 8 mm tip electrode can be performed with additional 20 watts.



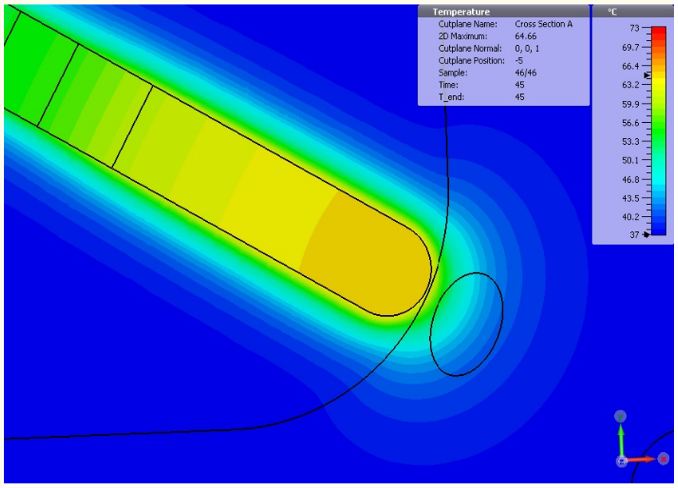


Figure 5: The temperature development of the 8 mm platinum electrode (diagram above) compared with the 8 mm gold electrode (diagram below).

Discussion and Conclusion

Giedrimas and Goldberger evaluated catheter ablation therapies available for supraventricular tachycardia and discussed management strategies [4]. In their opinion, the improvement of procedural safety and efficiency, while maintaining the impressive success rates, are the future goals for electrophysiologists. The simulation of catheter ablation of supraventricular tachycardia could improve the safety and efficiency for these applications.

Virtual heart and ablation electrode models allow the static and dynamic simulation of HF ablation with different electrode material and electrode size. The 3D simulation of the temperature profile may be used to optimize the AVNRT, AVRT and AFL HF ablation.

Authors Statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use has been complied with all the relevant national regulations, institutional policies and in accordance the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee. Financing: The article processing charge was funded by the Baden-Wuerttemberg Ministry of Science, Research and Culture and the University of Applied Sciences Offenburg in the funding programme Open Access Publishing.

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