Robin Müssig*, Matthias Heinke, Johannes Hörth

Cryoballoon model and simulation of catheter ablation for pulmonary vein isolation in atrial fibrillation

Abstract: Pulmonary vein isolation (PVI) is a common therapy in atrial fibrillation (AF). The cryoballoon was invented to isolate the pulmonary vein in one step and in a shorter time than a point-by-point radiofrequency (RF) ablation. The aim of the study was to model two cryoballoon catheters, one RF catheter and to integrate them into a heart rhythm model for the static and dynamic simulation of PVI by cryoablation and RF ablation in AF. The modeling and simulation were carried out using the electromagnetic and thermal simulation software CST (CST, Darmstadt). Two cryoballons and one RF ablation catheter were modeled based on the technical manuals of the manufacturers Medtronic and Osypka. The PVI especially the isolation of the left inferior pulmonary vein using a cryoballoon catheter was performed with a -50 °C heatsource and an exponential signal. The temperature at the balloon surface was -50 °C after 20 s ablation time, -24 °C from the balloon 0,5 mm in the myocardium, at a distance of 1 mm -3 °C, at 2 mm 18 °C and at a distance of 3mm 29 °C. PVI with RF energy was simulated with an applied power of 5 W at 420 kHz at the distal 8 mm ablation electrode. The temperature at the tip electrode was 110 °C after 15 s ablation time, 75 °C from the balloon at 0,5 mm in the myocardium, at a distance of 1 mm 58 °C, at 2 mm 45 °C and at a distance of 3 mm 38 °C. Virtual heart rhythm and catheter models as well as the simulation of the temperature allow the simulation of PVI in AF by cryo ablation and RF ablation. The 3D simulation of the temperature profile may be used to optimize RF and cryo ablation.

1 Introduction

The development of new ablation catheters or their further development means high costs for a company. Added to this is the time required to produce the prototypes and test them in a real environment. With the possibility of virtual simulation, suitable materials or the composition of the product or special simulations could be carried out in advance of the actual prototype construction. Thus, not only costs but also time are saved [1]. Today pulmonary vein isolation (PVI) is one of the most common treatment methods for atrial fibrillation (AF). The conventional PVI by radiofrequency (RF) energy is much more complex, since the lesions must be placed point by point around the pulmonary vein here. The danger here is to leave a gap between two lesions, whereby the unwanted propagation of the excitation from the pulmonary vein (PV) into the left atria is not prevented. This is reflected in the procedure time again. In the "Fire and Ice" study, Medtronic compares the average duration of a PVI by cryoablation with the PVI performed by RF ablation. Both the left atrial residence time and the processing time are significantly shorter when ablation using the cryoballoon catheter [2].

2 Methods

The modeling and simulation were carried out using the electromagnetic and thermal simulation software CST (CST Darmstadt). Two cryoballoons (see Figure 2) and one RF ablation catheter were modeled based on the technical manuals of the manufacturers Medtronic and Osypka.
The 23 mm cryoballoon and a circular mapping catheter were integrated into the Offenburg heart rhythm model (see Figure 1) especially the pulmonary vein for the simulation of the

_____

*Corresponding author: Robin Müssig: Department of Electrical Engineering and Information Technology / Medical Engineering, University of Applied Sciences, Offenburg, Germany, rmuessig@stud.hs-offenburg.de

Matthias Heinke: Department of Electrical Engineering and Information Technology / Medical Engineering, University of Applied Sciences, Offenburg, Germany, matthias.heinke@hs-offenburg.de

Johannes Hörth: Department of Electrical Engineering and Information Technology / Medical Engineering, University of Applied Sciences, Offenburg, Germany, johannes.hoerth@hs-offenburg.de

thermal field spread at a PVI (see Figure 5). The simulation of a PVI using RF energy was performed with the integrated RF ablation catheter close to the PV.
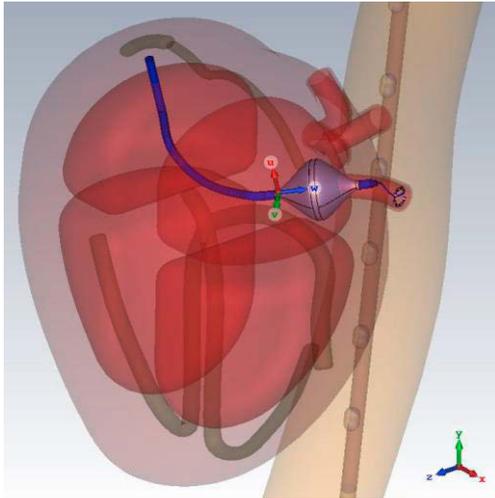

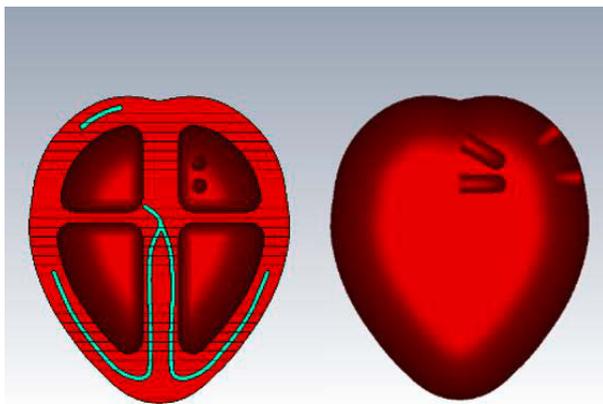**Figure 1:** Arctic Front Advance in left inferior pulmonary vein
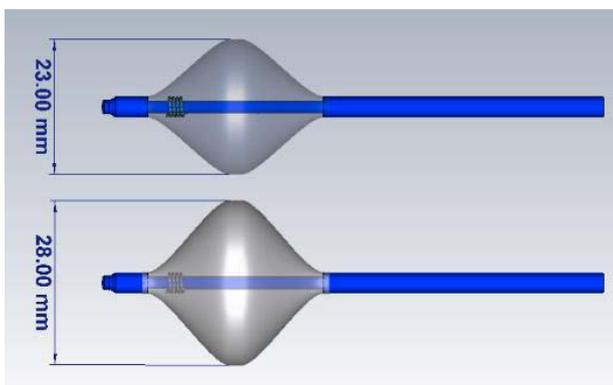

Figure 3: Offenburger heart rhythm model

Figure 2: Cryoballoon Arctic Front Advance 23mm and 28mm

3 Results

PVI especially the isolation of the left inferior pulmonary vein using a cryoballoon catheter was performed with a -50 °C heatsource and an exponential signal. The used temperature is the average temperature of the PV at PVI shown in a study by Metzner et al. [3]. The spread of the temperature was measured at seven points. The temperature at the balloon surface was -50 °C after 5 s ablation time, -17 °C from the balloon 0,5 mm in the myocardium, at a distance of 1 mm 10 °C, at 2 mm 32 °C and at a distance of 3mm 36 °C. The esophagus kept its temperature of 37 °C during the procedure. After 10 s, the temperatures at the measuring points described above were -50 °C, -21 °C, 2 °C, 25 °C and 33 °C.

After 20 seconds -50 °C, -24 °C, -3 °C, 18 °C and 29 °C.

Figure 5 shows the temperature spread in the tissue graphically after 0,5 s, 7 s, 15 s and the temperature profile over the whole ablation time of 180 s (see Figure 3).
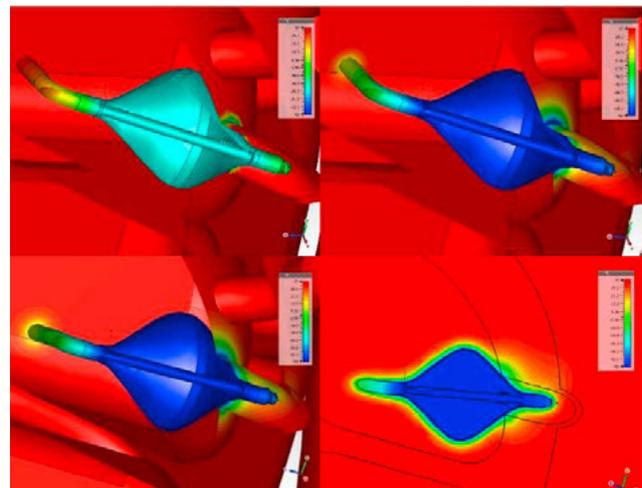

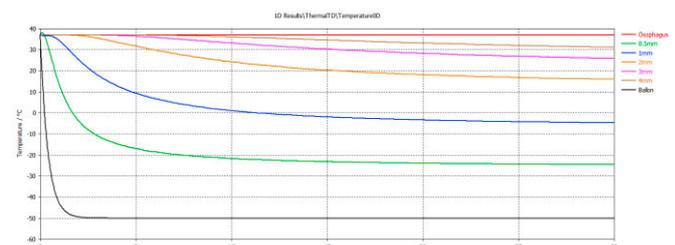**Figure 5:** Temperature spread while cryoablation

Figure 4: Temperature profile while cryoablation

PVI with RF energy was simulated with an applied power of 5 W at 420 kHz at the distal 8 mm ablation electrode. The temperature at the tip electrode was 83 °C after 2 s ablation time, 53 °C from the balloon at 0,5 mm in the myocardium, at a distance of 1 mm 43 °C, at 2 mm 37 °C and at a distance of 3 mm 37 °C. After 5 s, the temperatures at the measuring

points described above were 101 °C, 65 °C, 50 °C, 39 °C and 37 °C. After 15 seconds 110 °C, 75 °C, 58 °C, 45 °C and 38°C.

Figure 7 shows the temperature spread in the tissue graphically after 1 s, 5 s, 15 s and the temperature profile over the whole ablation time of 15 s (see Figure 6)
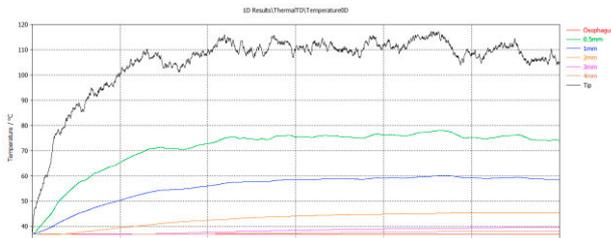

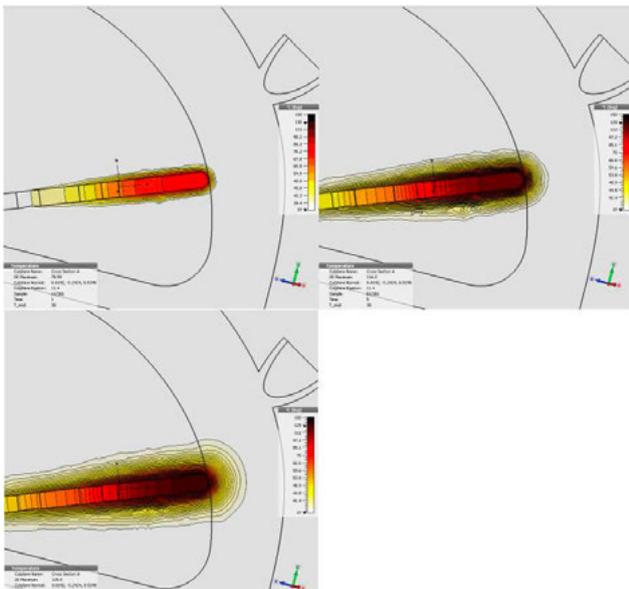**Figure 7:** Temperature profile while RF ablation

Figure 6: Temperature spread while RF ablation

4 Discussion

Cryoballon catheter and heart rhythm models as well as the simulation of temperature profiles allow the static and dynamic simulation of PVI by RF ablation as well as cryoballoon ablation. It should be mentioned that during an RF ablation under real conditions, a thermal detector in the catheter tip controls the power automatically when a temperature of 40 to 55 °C at the catheter tip is achieved to avoid carbonisation of blood and tissue.

CST software offers other voxel models that can be used for simulations, for example the VHP Female 3.0 or HUGO. Both are created based on the Visible Human Project. Due to the anatomical structures and heart rhythm conduction systems the Offenburger heart rhythm model was preferred for this study.

Patients MRI or CT scans could create a personal heart model and locate the most favourable position for example the AF ablation, which reduces the treatment time and the exposure of the patient to harmful radiation [1].

Author Statement

References

[1] M. Krämer, M. Heinke, R. Echle und J. Hörth, „Simulation of Electrical Fields in Cardiac Resynchronisation Therapy and Temperature Spread in HF Ablation," SAJ Biotechnol 4:102, Dezember 2017.

[2] „Medtronic FIRE AND ICE: AF Ablation Clinical Trial: Establishing a New Gold Standard in AF Ablation," [Online]. Available: www.medtronic.com. [Access at 5 October 2017].

[3] Metzner et al., „Increased Incidence of Esophageal Thermal Lesions Using the Second-Generation 28-mm Cryoballoon," August 2013.