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3d print of heart rhythm model with cryoballoon catheter ablation of pulmonary vein

Abstract: The visualization of heart rhythm disturbance and atrial fibrillation therapy allows the optimization of new cardiac catheter ablations. With the simulation software CST (Computer Simulation Technology, Darmstadt) electromagnetic and thermal simulations can be carried out to analyze and optimize different heart rhythm disturbance and cardiac catheters for pulmonary vein isolation. Another form of visualization is provided by haptic, three-dimensional print models. These models can be produced using an additive manufacturing method, such as a 3d printer. The aim of the study was to produce a 3d print of the Offenburg heart rhythm model with a representation of an atrial fibrillation ablation procedure to improve the visualization of simulation of cardiac catheter ablation. The basis of 3d printing was the Offenburg heart rhythm model and the associated simulation of cryoablation of the pulmonary vein. The thermal simulation shows the pulmonary vein isolation of the left inferior pulmonary vein with the cryoballoon catheter Arctic Front Advance™ from Medtronic. After running through the simulation, the thermal propagation during the procedure was shown in the form of different colors. The three-dimensional print models were constructed on the base of the described simulation in a CAD program. Four different 3d printers are available for this purpose in a rapid prototyping laboratory at the University of Applied Science Offenburg. Two different

printing processes were used and a final print model with additional representation of the esophagus and internal esophagus catheter was also prepared for printing. With the help of the thermal simulation results and the subsequent evaluation, it was possible to draw a conclusion about the propagation of the cold emanating from the catheter in the myocardium and the surrounding tissue. It was measured that just 3 mm from the balloon surface into the myocardium the temperature dropped to 25 °C. The simulation model was printed using two 3d printing methods. Both methods, as well as the different printing materials offer different advantages and disadvantages. All relevant parts, especially the balloon catheter and the conduction, are realistically represented. Only the thermal propagation in the form of different colors is not shown on this model. Three-dimensional heart rhythm models as well as virtual simulations allow very clear visualization of complex cardiac rhythm therapy and atrial fibrillation treatment methods. The printed models can be used for optimization and demonstration of cryoballoon catheter ablation in patients with atrial fibrillation.

Keywords: 3d print, heart rhythm model, pulmonary vein isolation, atrial fibrillation, cryoablation, cryoballoon, virtual simulations, esophageal catheter

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1 Introduction

The optimal use of new technologies and innovations usually means a long development process and high costs for a company. Virtual simulations created in advance, and the production of a prototype are useful ways of making this development process more efficient. With the help of virtual simulations, a wide variety of materials and their properties can be tested at an early stage of development. The production of a resulting prototype creates a further visualization option that provides an impression of the optics and haptics of the product. To produce these prototypes additive manufacturing methods, such as 3d printing, are increasingly being used. The combination of both possibilities offers significant advantages in product

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development and presentation of therapy methods. For example: A possible presentation therapy method is the isolation of the pulmonary vein, which is used to treat atrial fibrillation. A study by Medtronic shows that the use of a cryoballoon catheter is particularly useful for the isolation of the pulmonary veins [1]. Cryoablation offers some advantages over conventional high-frequency ablation, therefore it is becoming more and more popular.

2 Methods

2.1 Simulation: Cryoablation of the left inferior pulmonary vein

The simulation was carried out using the electromagnetic and thermal simulation software CST (Computer Simulation Technology, Darmstadt). The Arctic Front Advance™ catheter 28 mm and a circular mapping catheter were integrated into the Offenburg heart rhythm model following the technical manuals of the manufacturer Medtronic (see Figure 1 and 2) [2, 3, 4].

Figure 1: Balloon catheter Arctic Front Advance™, 28 mm

Figure 2: Arctic Front Advance™ in left inferior pulmonary vein of the Offenburg hearth rhythm model using CST software

2.2 3d printing: Cryoablation of the left inferior pulmonary vein

To print the model three-dimensionally, it had to be prepared with CAD software (PTC Creo Elemts Direct Modeling) (see Figure 3) [5]. It could then be printed using two different 3d printing processes. 1. a binder jetting printer with polymer gypsum and 2. a multi-material printer with photopolymer. The first three-dimensional print model made of polymer gypsum was printed with the Projet 660Pro from 3D systems in a powder bed. The second model was printed with a Stratasys multi-material printer using photopolymer. The print models are designed so that they can be divided to look inside the model. A further model with additional representation of the esophagus and esophageal catheter as well as a holder was additionally prepared for printing (see Figure 4).

Figure 3: CAD-Model - Lower and upper part of the print model

Figure 4: Transparent front view of the prepared CAD model

3 Results

The pulmonary vein isolation of the left inferior pulmonary vein using a cryoballoon catheter was performed with a -50°C heatsource and an exponential signal. After evaluating the simulation results, it was possible to draw conclusions about the behaviour of the cold in the myocardium and the surrounding tissue. The results are displayed in the model as different colors (see Figure 5 and 6). A certain temperature is assigned to the different colors. In addition, the course of the simulation can be represented graphically. The temperature profile in Figure 7 shows the simulation results. For example: 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 3 mm 36°C .

Figure 5: Simulation results of pulmonary vein isolation of the left inferior pulmonary vein using CST software

Figure 6: Larger view of simulation results of the pulmonary vein isolation of the left inferior pulmonary vein using CST software

Figure 7: Temperature profile during cryoablation with -50°C

After the printing processes, two presentation models are now available. These are divisible into two halves. Inside the models, the conduction and the balloon catheter are shown. The printing time for the first three-dimensional print model made of polymer gypsum (see Figure 8) was about 90 minutes and then had to be cooled down in the powder bed for another 90 minutes. The model was additionally processed after printing to make the surface more resistant (infiltration). The colors were designed in the same way as the CST simulation model and are shown to their full advantage.

The second 3d printed model made of photopolymer (see Figure 9), was ready after about 10.5 hours of printing and did not need to be reprocessed. Because of the expensive printing materials, the colors are limited here. However, the second printed model is twice as expensive as the first model, but it offers better material properties. The first model is more fragile because of the gypsum material.

Figure 8: First 3d printed model "Offenburg heart rhythm model with cryoballoon catheter" made of polymer gypsum

Figure 9: Second 3d printed model “Offenburg heart rhythm model with cryoballoon catheter” made of photopolymer

4 Discussion

Smerling et al. tested the benefits of teaching medical students with 3d printed cardiac models including various pathologies. The result was that incorporating 3d heart models increased knowledge and provided more detail than standard 2d teaching methods [6].

Cryoballoon catheter and heart rhythm models as well as the simulation of temperature profiles allow the static and dynamic simulation of pulmonary vein isolation by cryoballoon ablation. The simulations can be used to plan and design complex ablation catheters. Therefore a variety of different supraventricular tachycardia was simulated in CST Studio Suite™ Software. The Offenburg heart rhythm model can be continuously improved and supplemented with further components.

To achieve even more realistic patient-specific results, MRI or CT scans can be used by converting into CST software.

Parallel to the developed simulations, the three-dimensional print models can be used as presentation models on teaching and research or for patient education.

It is also possible to develop these models further. They could be supplemented by further components (e.g. heart valves) or by conductive materials. In addition, the thermal

propagation in the form of different colors on the print model could be augmented.

5 Conclusion

Three-dimensional heart rhythm models as well as virtual simulations allow very clear visualization of complex cardiac rhythm therapy and atrial fibrillation treatment methods. The printed models can be used for optimization and demonstration of cryoballoon catheter ablation in patients with atrial fibrillation. In further work, various complex cardiac rhythm therapies could be created in the CST software and printed out in 3d.

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