Electrode Model and Simulation of His-Bundle Pacing for Cardiac Resynchronization Therapy

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Introduction

Virtual simulations can be used to create realistic models that simulate tissue and material properties of a biological system. Within such models the effects of electrical impulses on tissue can be evaluated. His-bundle pacing represents a new and promising possibility for physiological cardiac resynchronization. Therefore, a single pacing electrode is implanted at the lower septal end of the right atrium in close proximity to the His- bundle. Conventional ventricular resynchronization is made of two pacing electrodes. One electrode is floated into the coronary vein sinus and another is located in the right ventricular apex. This work examines the electric field spread during His-bundle pacing within the simulation environment of the Offenburg heart rhythm model. The comparison of the electric field spread of several pacemaker pacing within the Offenburg heart rhythm model has been analyzed in this study.

Methods

Modelling and simulation activities were performed in the software CST (Computer Simulation Technology). For pacing, Medtronic's Select Secure 3830 electrode was modelled (see Figure 1) on the basis of its manual and integrated into the virtual Offenburg heart rhythm model (see Figure 2).

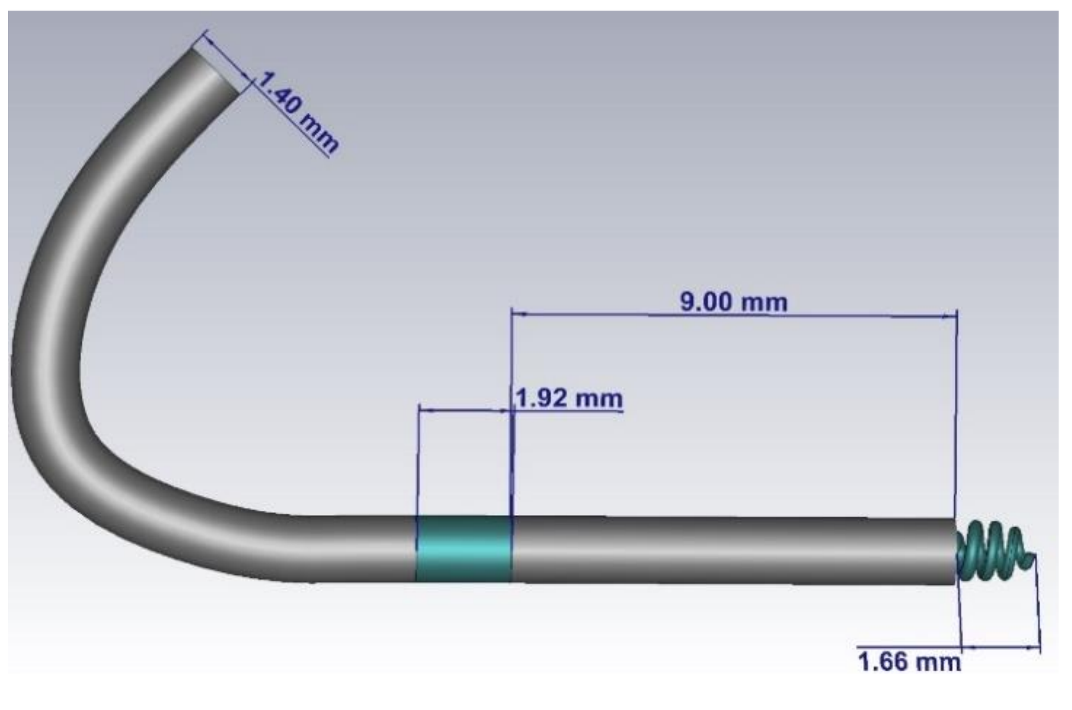
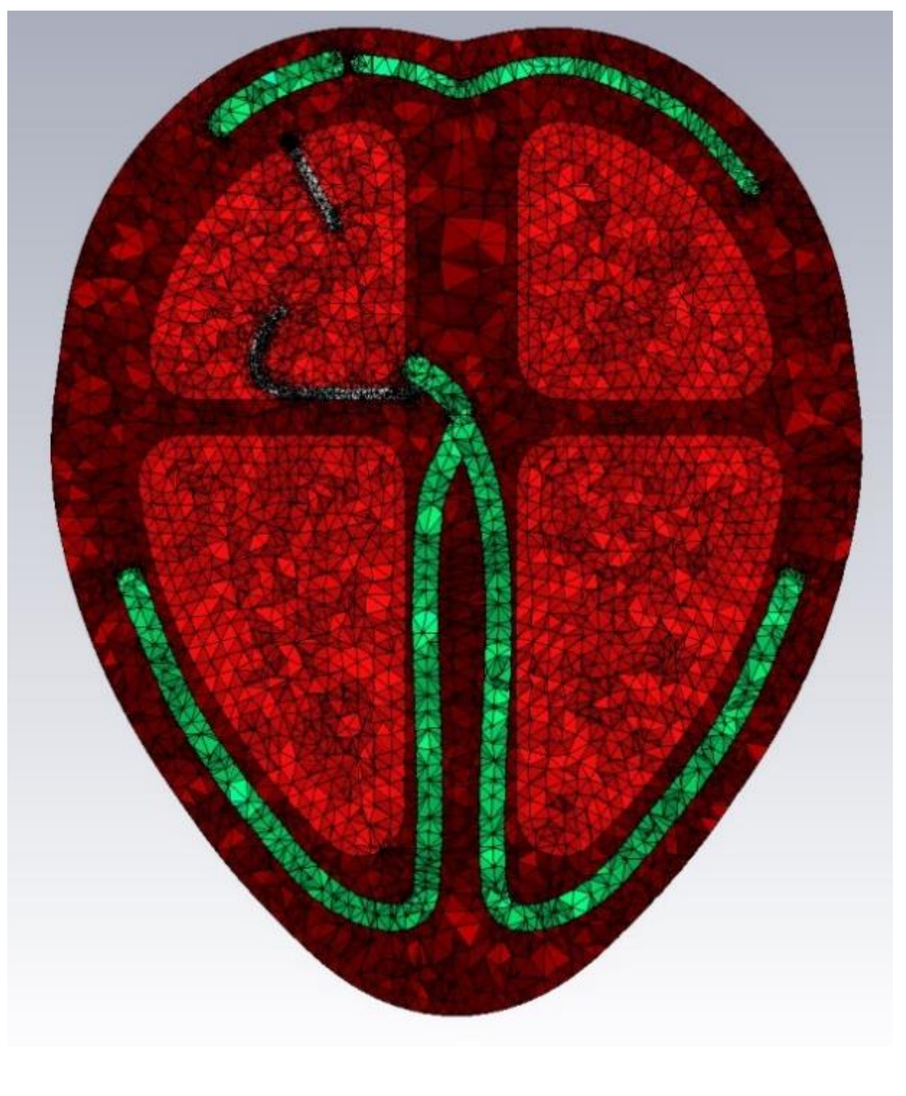


Figure 1: 3D-model of the Select Secure 3830 Electrode by Medtronic

This model consists of a heart with blood-filled atria and ventricles, muscle tissue and an electrical cardiac conduction system. For the investigated study, the left Tawara branch is diseased at an anterior left bundle branch block (LBBB).

An additional Select Secure 3830 electrode is located in the right atrium, which is designed for sensing intrinsic signals of the right atrium. The magnetoquasistatic field approximation ensures a chronological sequence of the heart signals and the pacing pulses.



In total the Offenburg heart rhythm model and the inserted electrodes contains 4.284.204 tetrahedrons. For the exact evaluation of the electric field strength four 3D field monitors were installed in the model.

Figure 2: Mesh View of the Offenburg heart rhythm model and two Select Secure 3830 Electrodes by Medtronic. Blood-filled Atria and Ventricles (bright red), Cardiac conduction system (green), muscle tissue (dark red)

Results

The 3D field monitors, which are listed in Table 3, provide exact measured values.

	3 V	2 V	1,5 V
Electrode tip	**23,6 V/m**	**15,76 V/m**	**11,84 V/m**
3D field monitor 1 [tip + 2 mm]	**9,5 V/m**	**6,3 V/m**	**4,74 V/m**
3D field monitor 2 [tip + 4 mm]	**3,36 V/m**	**2,25 V/m**	**1,68 V/m**
3D field monitor 3 [tip + 6 mm]	**1,97 V/m**	**1,32 V/m**	**0,99 V/m**
3D field monitor 4 [tip + 8 mm]	**1,39 V/m**	**0,93 V/m**	**0,69 V/m**

Table 1: Measured electric field at the various 3D field monitors

As expected, the electrical field (E-field) decreases with increasing distance from the electrode. The E-field indicates its highest value at the electrode with 23,6 V/m during 3.V pacing. At the measuring point 8 mm from the tip, the E-field strength after such pacing is 1,39 V/m. With a 2 V pacing pulse, the E-field at the electrode is 15,79 V/m. An E-field strength of 0,93 V/m can be measured at the measuring point 8 mm from the tip. For a distance of 2 mm from the tip the simulated E-field is 4,74 V/m, for distance with 4 mm from the tip, the E-field is 1,68 V/m.

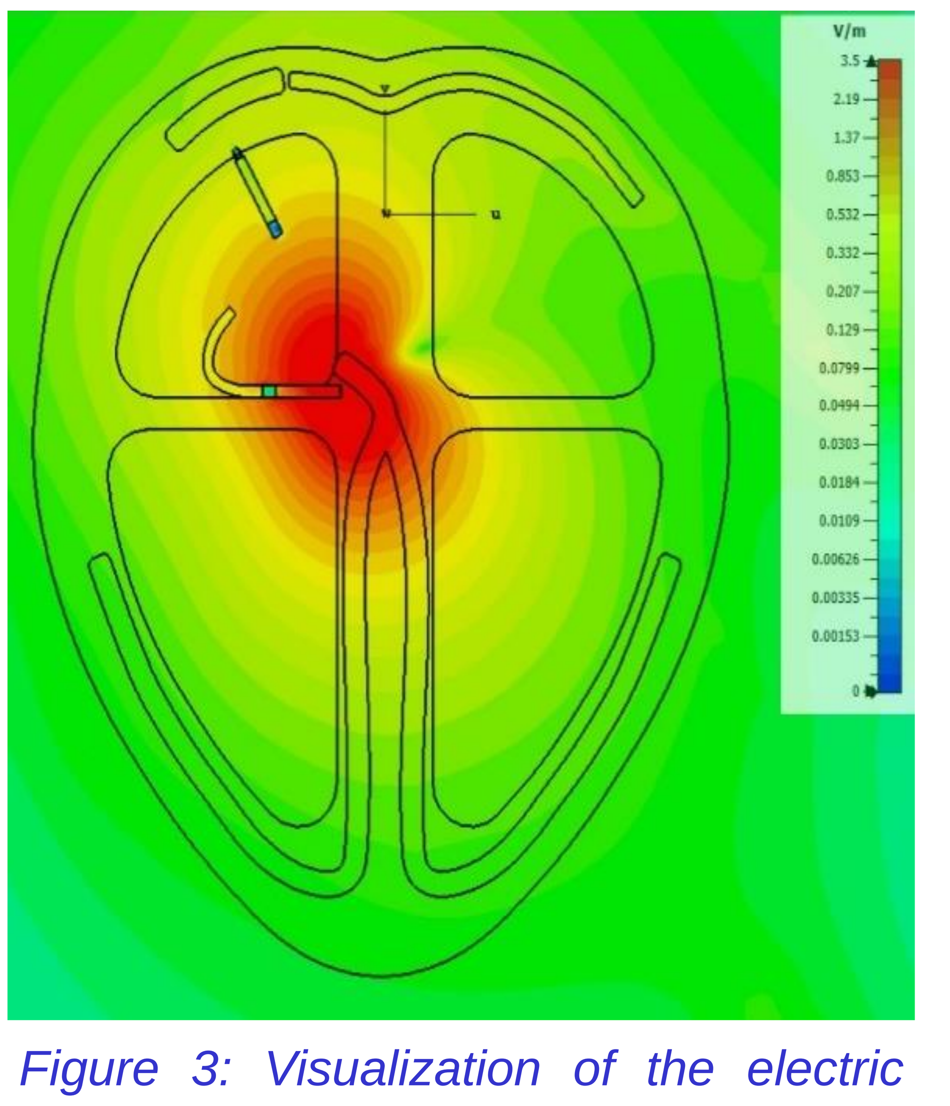


Figure 3: Visualization of the electric field at a pacing pulse of 3 V

In Figure 3 it is obvious clear that in any case a disease of the AV-node can be treated very well. The anterior left bundle branch block can be bridged by such pacing. Especially in the immediate vicinity of the bifurcation of the Tawara branch there is a high E-field, which theoretically would be sufficient for effective pacing.

Conclusions

The simulation results show that His-bundle pacing generates an electric pacing field that spreads over a wide area. The electric pacing field seems to be able to ensure effective ventricular pacing of the left-anterior Tawara branch. Since it is a low-frequency electric field, a pacing pulse of 2 V amplitude may also be sufficient to produce effective ventricular pacing of an anterior left bundle branch block. The results of the present study are limited by the defined mesh. As denser the mesh is and as more tetrahedrons are calculated, the more realistic the measurements become. Additionally, the Offenburg heart rhythm model is a static model, which is anatomically very close to reality, but has anatomical simplifications. Nevertheless, this model can accurately simulate electrodynamic processes and provide a better understanding of them.

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