Christian Quester, Matthias Heinke, Johannes Hörth

Simulation and Visualization of the electrical Activity of the Heart with focal ventricular tachycardia in a 3D Model

Abstract: Patients with focal ventricular tachycardia are at risk of hemodynamic failure and if no treatment is provided the mortality rate can exceed 30%. Therefore, medical professionals must be adequately trained in the management of these conditions. To achieve the best treatment, the origin of the abnormality should be known, as well as the course of the disease. This study provides an opportunity to visualize various focal ventricular tachycardias using the Offenburg heart rhythm model. Modeling and simulation of focal ventricular tachycardias in the Offenburg heart rhythm model was performed using CST (Computer Simulation Technology) software from Dessault Systèms. A bundle of nerve tissue in different regions in the left and right ventricle was defined as the focus in the already existing heart rhythm model. This ultimately served as the origin of the focal excitation sites. For the simulations, the heart rhythm model was divided into a mesh consisting of 5354516 tetrahedra, which is required to calculate the electric field lines. The simulations in the Offenburg heart rhythm model were able to successfully represent the progression of focal ventricular tachycardia in the heart using measured electrical field lines. The simulation results were realized as an animated sequence of images running in real time at a frame rate of 20 frames per second. By changing the frame rate, these simulations can additionally be produced at different speeds. The Offenburg heart rhythm model allows visualization of focal ventricular arrhythmias using computer simulations. By selecting the frame rate, the speed of the simulation results can be adjusted accordingly to visualize the electric field lines of focal ventricular tachycardias in more detail. The static and dynamic simulation results could be used in the future for teaching and research, including the training of medical professionals.

Keywords: 3D simulation, ventricular tachycardia, heart rhythm simulation, cardiac modelling, Offenburg heart rhythm model

https://doi.org/10.1515/cdbme-2021-2005

1 Introduction

Due to the progress of research, more and more diseases of the heart are found which must be treated by trained professionals. However, for these professionals to be successful in the treatment of these diseases, they must be familiarized with the new techniques of treatment and have a good understanding of the disease in the patient's heart. Because of the different learning types, for some of the students, be it medical students aiming to become doctors or medical engineering students aiming to treat patients with heart related problems with a pacemaker or ICD, a learning help via a visualization of the arrhythmia can be beneficial for the learning success. Furthermore, if possible simulated diseases and the corresponding bio signals could be compared to bio signals of real patients, to rule out beforehand which disease the patient is having and to where the anomaly should be located, to cut down the procedure time of an electrophysiological study with a laborious search for the anomaly before the actual treatment. Since ventricular tachycardia or extrasystoles can occur frequently even in healthy patients [1] and, in contrast to supraventricular tachycardia, are more dangerous, they require further diagnosis and therapy if sufficiently indicated. Therefore, in this study typical focal ventricular arrhythmia, especially the focal ventricular tachycardia originating in the right ventricular outflow tract, were simulated and visualized.

2 Methods

For the modelling and simulation, the software Computer Simulation Technology (CST) by Dessault Systèms was used.

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In the software there is already the Offenburg heart rhythm model (OHRM), which was created in a previous study and builds the base for this study [2]. The OHRM is a simplified model of a heart with blood-filled atria and ventricles and an electrical cardiac conduction system. This cardiac conduction system consists of the sinoatrial node, the Bachmann-bundle, the AV-node, the His-bundle and the three Tawara branches. Also, each different type of tissue of the heart has its material properties described in the material library to enable a realistic simulation (as shown in Table 1).

Table 1: Tissue properties from the material library database of the Offenburg heart rhythm model

	Heart muscle	Blood	Spinal tissue
Density [kg/m³]	1060	1060	1038
Thermal Conductivity [W/K/m]	0,54	0,51	0,46
Blood Flow Coefficient [W/K/m³]	54000	10^6	40000
Metabolic Rate [W/m³]	9600	0	7100

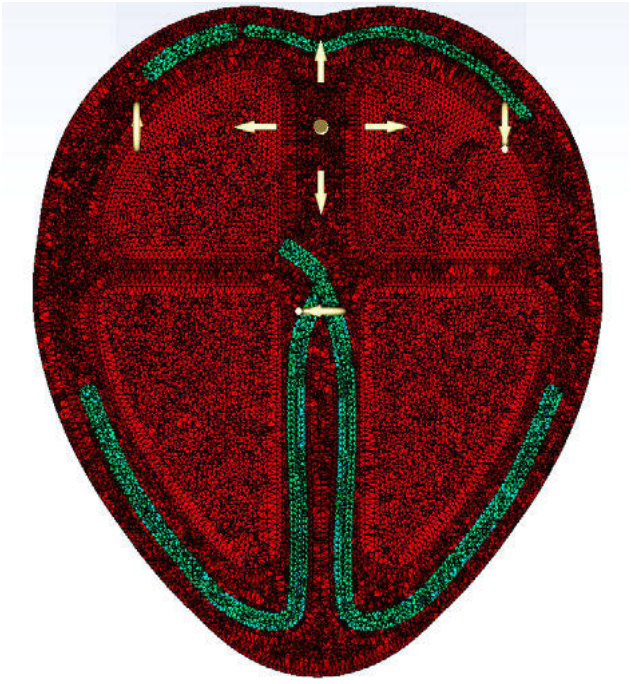

Figure 1 Meshed Offenburg heart rhythm model: Blood-filled atria and ventricles (bright red), cardiac conduction system (green), muscle tissue (dark red)

The magnetoquatistatic field approximation was used for the calculation of the heart rhythms. For the simulation focal rhythm origins were injected into the Offenburg heart rhythm model which then had to be meshed. In meshing the 3D-object gets cut down into many little tetraodons. For this study, the typical count of tetraodons was 5354516. The meshed Offenburg heart rhythm model is shown in Figure 1. This was needed so that CST could calculate the electrical fields of the heart. This is calculated by solving the Maxwell-equations on each edge of these tetraedons. After the insertion of the focus, the origin of an excitation was placed onto it, as seen in Figure 2.

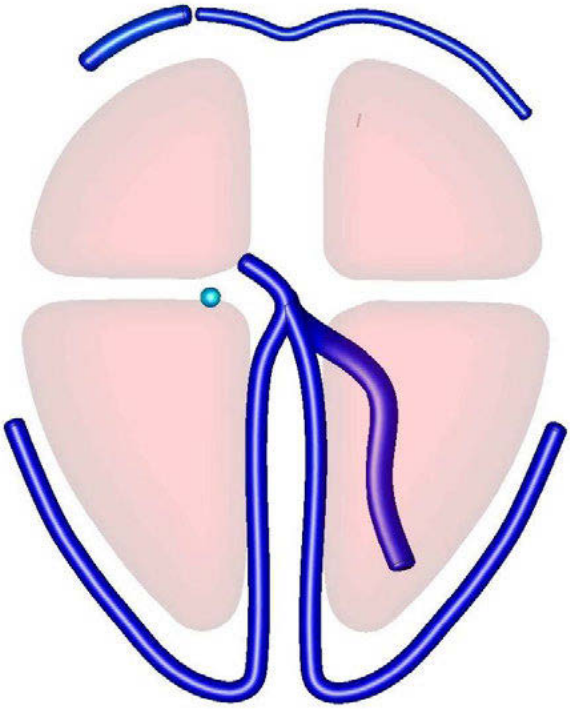

Figure 2 Offenburg heart rhythm model with a right ventricular focus in the RVOT (light blue sphere)

With this origin and an excitation signal, which also had to be defined, the focus could now be the origin of a heart rhythm. For each of these conductions a so-called voltage path is present. On these voltage paths the electrical excitation can progress. In the case of an AV-blockage the voltage path could be shut off, so that the excitation could not progress further. Now different excitation signals could be placed onto the voltage path to show different rhythms. For example, a tachycardic rhythm onto the ventricle and a normal sinus rhythm onto the atrium. In this case the AV node was switched off to represent an AV node blockage. Also, for every voltage path the excitation signal and the specific time when it activates had to be defined. In the case of the focal ventricular tachycardia the excitation signal from the Tawara branches all had different delays of the activation depending on the placement of the focus. For the creation of the excitation signals CST has an own tool integrated, but with this tool only periodic signals can be generated. Because of that excitation

signal of extra systoles and focal ventricular tachycardia could not be generated with the integrated tool. For that CST can read an external generated file in which the signal is described in a pre-defined format. Because of that every imaginable rhythm is possible.

3 Results

After the simulation, the resulting electrical field over the time is calculated. This can be rendered into a short video. In Figure 3 the individual images of a right ventricular focal tachycardia with an AV Node conduction are shown. Progressing in 0.05 second steps from the top left to the bottom right.

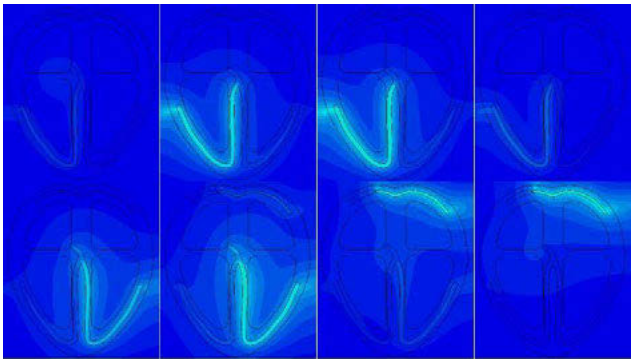

Figure 3 Frames of the resulting video of a focal right ventricular tachycardia with AV conduction

In it the progression of the excitation from the focus onto the ventricles and the atrium can be observed. The same was done with a simulation of a focal left ventricular tachycardia. The resulting images are shown in Figure 4.

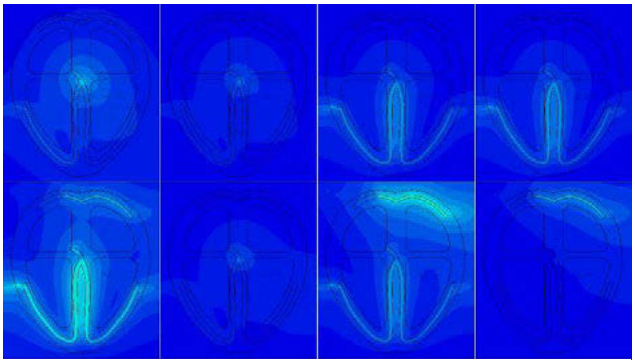

Figure 4 Frames of the resulting video of a left ventricular tachycardia with an AV conduction

4 Discussion

As Lilienfield and Broering have proved in their study, a good visualization of the cardiac physiology and pathology can be a great benefit for the learning success of students [3].
Because of that, simulations, which highlight the electrical activity in the heart for different ventricular arrhythmias, were created and the results were saved as short videos, so that through watching these videos, students could easier grasp where the origin of the arrhythmia lies and how it progresses. In the case of the simulation with CST only the resulting electrical field could be show. Also, every activity progressed on a predefined voltage path and was not calculated by the simulation software. Because of that the simulation had to be modelled after the arrhythmia and it must be known how the excitation progresses when the arrhythmia ist active. The thought of comparing the bio signals of real patients with simulated ones have shown to be not possible with the approach of this study. Also, in real patients the bio signals progress through the tissue and because of that there is a time delay between the excitation at two different points. In CST only the electrical field is calculated and because there is no calculation of the spreading of the electrical excitation in the tissue only the differences in electrical field density can be observed and not a delay.

5 Conclusion

In summary, it can be stated that with the help of CST, illustrative simulations can be created which show the excitation formation and propagation in a comprehensible way. These simulations can be used well in the form of short videos in teaching to ensure a better understanding of the underlying disease. With the approach of this study, however, no comparability of signals to real patient signals could be established.

Author Statement

Research funding: The author state no funding involved. 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 complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

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