Pacing electrode modeling and simulation of cardiac contractility modulation

Abstract: Cardiac contractility modulation (CCM) is a device-based therapy for the treatment of systolic left ventricular chronic heart failure. Unlike other device-based therapies for heart failure, CCM delivers non-excitatory pacing signals to the myocardium. This leads to an extension of the action potential and to an improved contractility of the heart. The modeling and simulation was done with the electromagnetic simulation software CST. Three CCM electrodes were inserted into the Offenburg heart rhythm model and subsequently simulated the electric field propagation in CCM therapy. In addition, simulations of CCM have been performed with electrodes from other device-based therapies, such as cardiac resynchronization therapy (CRT) and implantable cardioverter/defibrillator (ICD) therapy. At the same distance to the simulation electrode, the electric field is slightly stronger in CCM therapy than in CCM therapy with additionally implanted CRT or ICD electrodes. In addition, there is a change in the electric field propagation at the electrodes of the CRT and the shock electrode of the ICD. By simulating several different therapy procedures on the heart, it is possible to check how they affect their behavior during normal operation. CCM heart rhythm model simulation allows the evaluation the individual electrical pacing and sensing field during CCM.

Keywords: Cardiac contractility modulation, cardiac resynchronization therapy, heart failure, heart rhythm disturbance, heart rhythm model, heart rhythm simulation

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1 Introduction

Cardiac contractility modulation is a new form of device-based therapy for the treatment of systolic left ventricular chronic heart failure with reduced left ventricular ejection fraction and normal electrical ventricular conduction. Cardiac contractility modulation delivers non-excitatory pacing signals to the ventricular myocardium and is safe therapy with OPTIMIZER [1]. This leads to an extension of the action potential and to an improved contractility of the heart. Cardiac resynchronization therapy is a biventricular pacing therapy for heart failure patients with reduced left ventricular ejection fraction and electrical ventricular desynchronization. Transoesophageal focused ECG allow the non-invasive evaluation of electrical ventricular desynchronization [2, 3].

The aim of the study was to model different pacing electrodes, integrate them in the Offenburg heart rhythm model and simulate the electrical pacing field of cardiac contractility modulation in combination with cardiac resynchronization therapy and implantable cardioverter/defibrillator therapy.

2 Methods

The modeling and simulation was done using the CST (Computer Simulation Technology, Darmstadt) design and simulation software. A bipolar right ventricular LivaNova-BEFLEX with active fixation, 4mm² distal electrode and 44mm² proximal electrode was modeled on the basis of the technical manuals of the manufacturer LivaNova (Fig. 1).
Three cardiac contractility modulation electrodes were inserted into the Offenburg heart rhythm model and subsequently simulated the electric field propagation in cardiac contractility modulation therapy (Fig. 2). Electromagnetic cardiac simulation was performed with CST STUDIO SUITE® (CST – Computer Simulation Technology, Darmstadt) (Fig. 3).

**Figure 1**: Bipolar right ventricular LivaNova-BEFLEX with active fixation, 4mm² distal electrode and 44mm² proximal electrode was modeled on the basis of the technical manuals of the manufacturer LivaNova.

**Figure 2**: Cardiac contractility modulation electrode positioning in the right atrium and in the right ventricle in the Offenburg heart model - in a front view throughout.

**Figure 3**: Electrical bipolar pacing field of active cardiac contractility modulation electrode in the right ventricle septum in the Offenburg heart model - in a front view throughout. V/m – electrical pacing field.
3 Results

In addition, simulations of cardiac contractility modulation have been performed with electrodes from other device-based therapies, such as cardiac resynchronization therapy and defibrillator therapy. At the same distance to the simulation electrode, the electric field is slightly stronger in cardiac contractility modulation therapy than in cardiac contractility modulation therapy with additionally implanted cardiac resynchronization therapy or implantable cardioverter/defibrillator electrodes. In addition, there is a change in the electric field propagation at the electrodes of the cardiac resynchronization therapy electrodes (Fig. 4) and the shock electrode of the implantable cardioverter/defibrillator (Fig. 5).

Figure 4: Electrical bipolar pacing field of active cardiac contractility modulation electrode in the right ventricle septum and cardiac resynchronization therapy in the Offenburg heart model - in a front view throughout. V/m – electrical pacing field.

Figure 5: Cardiac contractility modulation and implantable cardioverter/defibrillator electrode positioning in the right atrium and in the right ventricle in the Offenburg heart model - in a front view throughout.

4 Discussion

Abraham and co-workers evaluated the safety and efficacy of cardiac contractility modulation in 160 patients with New York Heart Association functional class III and IV, left ventricular ejection fraction between 25% and 45%, QRS duration <130 ms and with the OPTIMIZER system [1]. The cardiac contractility modulation therapy during 24 weeks was safe and improves exercise tolerance and quality of life in the heart failure patients. Stipdonk and co-workers evaluated delayed left ventricular lateral wall activation in patients with non-specific intraventricular conduction delay using coronary venous electroanatomical mapping [4]. Virtual heart and electrode models as well as the simulations of electrical pacing fields and electrical sensing fields allow the static and dynamic simulation of cardiac contractility modulation in combination with cardiac resynchronization therapy and implantable cardioverter/defibrillator therapy. Cardiac contractility modulation heart rhythm model simulation allows the evaluation the individual electrical pacing and sensing field during cardiac contractility modulation. The 3D simulation of the electrical sensing and pacing fields may be used to optimize cardiac contractility modulation.
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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.

References