Cardiac Pacing in an MRI Environment

G. H. Payne[1,2], G. Vergara[2,3], R. Ranjan[2,3], K. Vij[4], N. Volland[1,2], E. Kholmovski[1,2], S. Vijayakumar[1,2], J. Blauer[2,5], K. Johnson[2,3], G. Gardner[2,5], G. Meredith[6], T. Meng[6], R. MacLeod[2,5], and N. F. Marrouche[2,3]

[1]UCAIR, Department of Radiology, University of Utah, Salt Lake City, UT, United States, [2]CARMA Center, University of Utah, Salt Lake City, UT, [3]Department of Cardiology, University of Utah, Salt Lake City, UT, United States, [4]SurgiVision, Inc., Irvine, CA, United States, [5]SCI, University of Utah, Salt Lake City, UT, United States, [6]Center for Applied Medical Imaging, Siemens Corporate Research, Princeton, NJ, United States

Introduction

During an RF ablation procedure for the treatment of atrial fibrillation, pacing is sometimes used to create a normal sinus rhythm at a specific rate [1 2]. Low levels of electrical current are delivered to the endocardial tissue via a catheter in order to incite a contraction. A periodic delivery of the pacing current induces a steady cardiac rhythm. There is increasing interest in being able to use MRI to guide ablation procedures [3]. Electro-anatomical mapping and electrogram (EGM) recordings at 1.5 Tesla magnetic fields have been reported previously [4]. The goal of this work was to demonstrate the feasibility of pacing on a porcine subject inside a 3 Tesla magnetic field.

Methods

The system electronics were designed to satisfy the four main requirements of the catheter system (SurgiVision, Inc., Irvine, CA): (1) the position of the catheter is trackable in real-time during navigation, (2) RF energy is delivered from the tip during ablation, (3) bipolar EGM signals are sensed at the endocardial surface via the tip and a secondary ring, and (4) stimulation current is delivered by the catheter tip.

The catheter was initially used for sensing EGMs to map endocardial voltages. However, concerns about delivering electrical current to the cardiac tissue while inside the MR environment needed to be addressed. The pacing equipment (EP-4 Cardiac Stimulator, St. Jude Medical, St. Paul, MN) was designed for use in non-MR environments, and was located outside the MR suite. It was necessary to ensure that voltages induced by the scanner's magnetic gradients did not influence the pacing equipment. It was also necessary to prevent electronic noise from the scanner control room from entering the MR suite and interfering with image quality. Custom filtering (SurgiVision, Inc., Irvine, CA) was created in order to prevent unwanted signal transfer in either direction. Figure 1 shows a schematic of the experimental setup.

The catheter has two closely-spaced metal contact surfaces. The first surface is the tip used for ablation, and the second is a ring slightly behind the tip. The interface box (SurgiVision, Inc., Irvine, CA) is designed to switch between delivering RF ablation power and lower-power pulses for stimulation. When recording EGMs, the catheter's tip and ring signals are recorded by the data acquisition system.

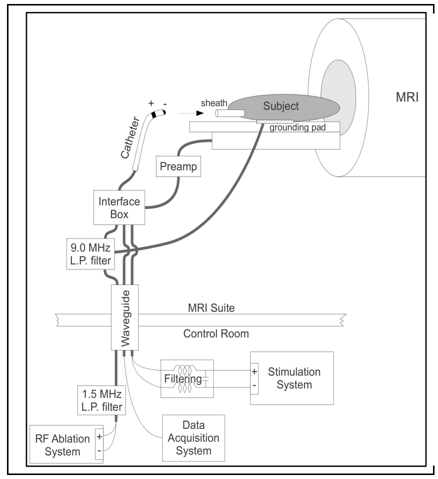

Figure 1. Equipment Setup for Pacing.

The procedure was performed in a 3T scanner (MAGNETOM Verio, Siemens Healthcare, Erlangen, Germany). Pacing was first performed without scanning. The first experiment was with the animal on the scanner table but outside the isocenter. This was later followed by the animal in the isocenter of the bore. Next, pacing was performed during a real-time HASTE sequence. The sequence included tracking the catheter position, which was used to verify the location for delivery of the pacing current. Pacing capture is defined as successfully driving the subject's heart at the specified pulse cycle rate. The capture level was compared with the case without scanning to see if the gradients and/or excitation pulses of the scanner would affect pacing. No direct comparisons were made between pacing inside and outside the MRI environment. Instead, the pacing current levels were compared against those typically seen in patients.

Results

The performance of the pacing was evaluated by considering the pacing parameters at capture, and the animal's heart rate. Pacing parameters included pulse width, pacing current, and cycle time. The cycle time was always set to be less than 85% of the animal's normal cycle time. Capture threshold was determined by reducing the current until the animal's heart rate was no longer responding to the pacing. In Figures 2a – 2c, the top trace is the animal's surface ECG. In Figure 2a, the bottom trace shows an atrial EGM signal sensed by the catheter. In Figure 2b, a pacing signal at a 600ms rate (100 bpm) is generated, and the surface ECG shows that the animal's heart is contracting in step with the pacing. Figure 2c shows a similar situation at a 400ms (150 bpm) rate. All traces shown were obtained at the isocenter of the scanner. During pacing, the catheter position tracking data showed that no catheter motion occurred as a result of the pacing current.

Figure 2a. Without pacing: Surface ECG above.

Figure 2b. Pacing at 600ms cycle, capture achieved.

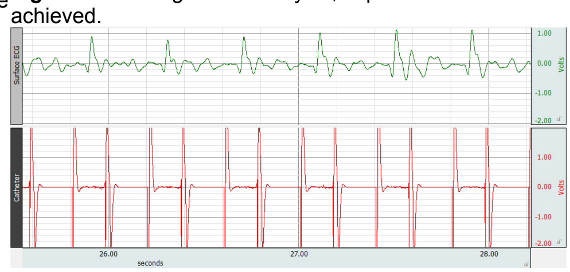

Figure 2c. Pacing at 400ms cycle, capture achieved.

Conclusion/Discussion

Cardiac pacing in the MRI scanner was successful, and no problems were observed. The pacing behavior and threshold were within expected limits for the animal.

Cable filtering protected the pacing system electronics from voltages induced by the scanner gradients. Pacing pulses in the presence of the magnetic field did not induce catheter movement, which was verified by the real-time tracking of the catheter position.

Acknowledgments

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References

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