Preclinical Evaluation of an MR-EP Suite including an MR-EP Navigator and Dedicated MR-EP Catheters

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Introduction: Cardiac arrhythmias, e.g. atrial fibrillation and ventricular tachycardia, are increasingly treated by electrophysiological (EP) interventions [1]. Applying MR for guiding these interventions offers advantages like 3D visualization of the cardiac soft tissue in relation to the catheter, visualization of the treatment effect and absence of ionizing radiation [2,3].

The step towards clinical MR-guided EP interventions requires a focus on RF safety of the devices, localization accuracy of the catheters, guidance of the procedure, intra-cardiac signal quality and procedure workflow.

Here, an MR-EP suite based on an MR-EP Navigator application with a real-time interface to the MR system and therapy equipment is demonstrated along with specialized MR-EP catheters. These catheters are based on RF-safe concepts for both, MR- and EP functionality [4,5]. RF-safety, localization accuracy and EP signal quality of these devices are demonstrated in vivo. The operation of the MR-EP suite and the workflow of the MR-EP Navigator are demonstrated in pre-clinical MR-guided EP experiments.

Materials and Methods: All experiments were performed on a clinical whole-body 1.5T MR scanner (Achieva I/T, Philips Healthcare, Netherlands) equipped with an in-room display.

7F MR-EP catheters with ring electrodes and a tracking coil were used in 12 pigs. The RA and RV were catheterized via venous access. Intra-cardiac and tracking signals were transferred via high resistance wires (HRW) and a transformer-based transmission line to increase RF safety [4,5], respectively. Intra-cardiac signal quality, tracking accuracy and RF-safety were assessed in vivo.

3D b-FFE soft tissue images and 3D CE-MRA angiograms were acquired prior to the catheterization of the pigs to serve as roadmaps. The MR-EP Navigator was linked to the host computer of the MR system and to the EP equipment (EP Tracer, CardioTek, The Netherlands) via fiber-optic ethernet. The MR-EP Navigator visualizes MR real-time 2D-images and tracking positions or 3D images (roadmaps) as well as real-time EP-data from the EP-recorder and serves as the main control point for the procedure. Surface renderings of the e.g. atrium and other relevant structures can be displayed together with reformatted 2D slices at the catheter position, which can be angulated freely or using the geometries from the planned scans. Real-time MR images can be added to the 3D scene according to their imaging geometry. The MR-EP Navigator allows for automatic segmentation of the left atrium on human MR data-sets (Fig.1 top) [6]. The real-time MR-system interface moreover provides means for the interactive control of the scanner by the MR-EP Navigator and for receiving of data (besides images and tracking data e.g. metadata, raw data or physiology data).

EP data are transferred between the EP equipment and the MR-EP Navigator in real-time. The MR-EP Navigator provides a method for on-the-fly manual evaluation of the intra-cardiac signals and produces updated interpolated color-maps, when new data become available.

The MR-EP Navigator is based on a rapid prototyping platform that allows a flexible combination of the visualization and control techniques for the MR-guided EP workflow.

Fig. 1: Top: MR-EP Navigator application. Center: Exemplary in-bore EP recordings at two selected positions showing an atrial signal (left) and a ventricular signal (right). Bottom: Real-time imaging artifacts without filtering in comparison with a typical intra-cardiac signal using HRW [5].

Results: The MR-EP suite allowed performing EP interventions very efficiently and accurately under MR-guidance. The in vivo tracking jitter with the catheter resting in the vena cava was 0.49mm. This jitter includes some residual physiologic motion. Due to the excellent guidance achieved by combining high resolution 3D soft tissue images with angiograms, real-time images and accurate tracking, fast mapping of e.g. 40 points in RV in 20min was typically possible.

The in-bore intra-cardiac recordings using HRW [5] were of excellent quality (Fig. 1, center), and artifacts induced by real-time MRI were acceptable even without additional filtering (Fig. 1, bottom). Thus, real-time imaging-guided mapping of the heart is possible with this set-up. However, in order to resolve smaller EP-signals, e.g. from the His bundle, and to simplify in-room communication, scanner operation was halted during acquisition of a data point for storage in the database. The MR-EP Navigator supports the quick evaluation of activation times with an accuracy of 1ms and updates time and voltage maps on-the-fly.

Atrial and ventricular pacing was achieved via the MR-EP catheters. Successful stimulation was confirmed by recording with a second MR-EP catheter and in the surface ECG.

In vivo safety testing of the MR-EP catheters showed a maximum temperature increase of 0.7K after 10min of 4W/kg global SAR (expected heating without device 0.6K). Thus, device related heating is extremely low and almost non-measurable.

Conclusion: The experimental setup of the MR-EP suite and the MR-EP Navigator application provided excellent guidance and an efficient workflow for MR-guided EP interventions. The MR-EP devices based on RF-safety technology described in [4,5] showed very good localization accuracy and intra-cardiac signal quality in vivo, while device-related RF-heating was not observed. The presented MR-EP suite is, therefore, suitable for initial clinical MR-guided EP interventions.

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