Evaluation of a novel MR-RF Ablation Catheter with full clinical Functionality

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Objective: MR-guided electrophysiology (MR-EP) ablations for treatment of arrhythmias have the potential to visualize ablation-induced tissue changes [1,2] and to improve navigation. Effective measures to ensure RF safety of diagnostic MR-EP catheters have been proposed, including use of active tracking via transformer-based cables and recording of intracardiac ECG via highly resistive (HR) wires [3]. Ablation catheters must additionally provide the functions ablation, impedance measurement, and temperature measurement of the ablation electrode. The initial evaluation of a switchable cable for RF safe ablation and impedance measurement has been presented recently [4]. An additional requirement in clinical EP procedures is to measure the temperature of the ablation electrode, which is kept constant by a feed-back loop by adjusting the ablation power. It is the objective of this work to develop a system for such temperature-controlled ablation that is compatible with current clinical equipment and that maintains a high degree of RF safety in MR. It is a further objective to realize all required functions in one catheter and to evaluate its function and RF safety pre-clinically.

Materials and Methods: Standard RF generators provide electronics to read out ablation catheters equipped with thermocouples or thermistors. Fiber-optic sensors would enable an intrinsically RF safe temperature measurement but they are not supported by standard RF generators. Here, the thermistor option was used because initial experiments revealed a much larger sensitivity in V/K than for a thermocouple. As a reference, the resistance characteristics of the thermistor used in a standard EP catheter (Cool Path, St.Jude Medical, St.Paul, MN) was measured. Such a thermistor was then connected to a pair of HR wires (2 x 9 kΩ) known to effectively reduce RF heating in diagnostic catheters [3]. A custom-made circuit to compensate for the additional resistance was introduced between the handpiece of the catheter and the RF generator (1500T11, St.Jude Medical)(Fig.1). The such corrected temperature reading at the RF generator was validated. Temperature measurement was repeated inside the MR system (Achieva 1.5T, Philips Healthcare, Best, NL) during scanning to evaluate for artifacts in temperature reading and MR images.
An MR-EP ablation catheter (8 F, 100 cm length) was implemented that integrates above temperature sensing components together with an ablation cable that comprises four mechanical switches distributed along the catheter, segmenting the cable into safer short sections. The switches are controlled from the handpiece of the catheter and are closed only during ablation and kept open at all other times. For RF safe active tracking and IEGM recording, a tip tracking coil connected to a transformer-cable and EP electrodes connected to HR wires were integrated into the catheter. The RF safety of the fully integrated MR-ablation catheter was evaluated by fiber-optic temperature measurements during scanning in a phantom in comparison to a catheter equipped with a standard cable. The EP functionality of the MR catheter was evaluated by MR-guided ablation procedures in temperature-controlled mode in the RA of a pig using the standard RF generator.

Results: Temperature measurement via HR wires and the resistance compensation unit showed a precision of ±1 K (Fig.2a). No deviations due to MR scanning were detected. In the RF safety measurements, the tip temperature increase for the MR-RF ablation catheter with open switches was limited to 1.5 K in thermal equilibrium, while an increase of up to 35 K was measured in only 2.1 s for the standard catheter. Successful ablations were performed initially in an ex-vivo pig heart and later in the RA of live pigs in MR-guided procedures using active tracking. Created ablation lesions were confirmed after explantation (Fig.2b). Temperature-controlled ablation, impedance measurement and recording of intracardiac electrograms performed reliably.

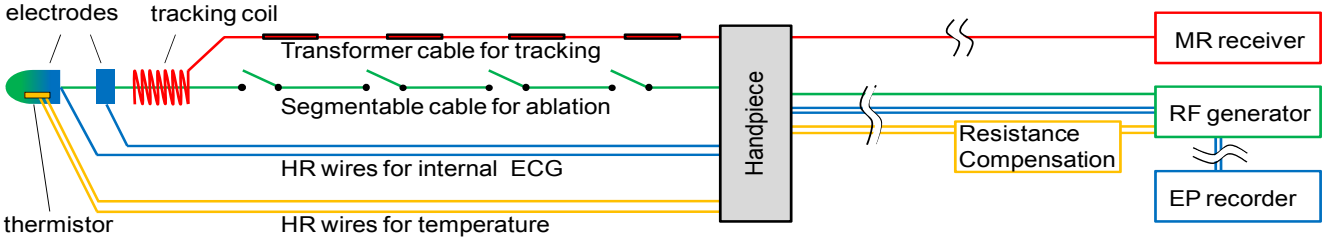


Figure 1. MR-RF ablation catheter connected to read-out hardware. The ablation electrode is connected to the RF generator by a segmentable cable (green). The integrated thermistor is connected via HR wires and a resistance compensation unit (yellow). Tip and ring electrodes are connected to HR wires for sensing (blue), and the tip coil for active tracking is read-out via a transformer-cable (red).

Figure 2a. Temperatures displayed at RF generator when connected to MR-RF ablation catheter (red) and standard EP catheter (blue) coincide with actual temperatures given by water bath (green).

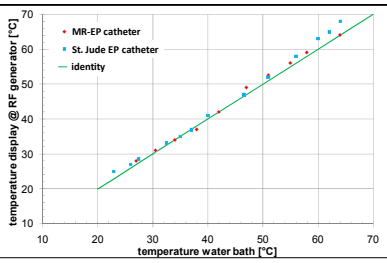
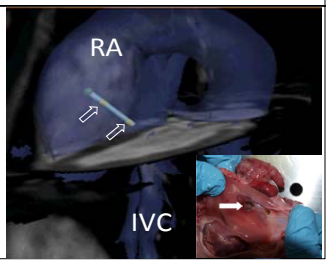


Figure 2b. Real-time 3D visualization provided by the MR-EP Navigator software [5] used to support the MR-guided ablation procedures. The MR-RF ablation catheter was in this case equipped with two tracking coils (arrows) and guided into the RA of the pig. The inset shows one of the created ablation lesions (arrow).



Discussion & Conclusion
An MR-RF ablation catheter has been designed that implements all required functions for clinical procedures. Measurement of the ablation electrode temperature with a thermistor as used in standard catheters but connected via HR wires provides increased RF safety and compatibility with standard RF generator hardware. All wiring used in this catheter either dampens RF resonances by high resistance or avoids RF resonances by segmentation of long cables into short sections using transformers and switches. RF safety of the catheter is demonstrated by RF heating measurements, and EP functions are evaluated during MR-guided ablation procedures.

[1] Peters et al. Radiology 2007;243:690. [2] Vijayakumar et al. ISMRM 2010. p285. [3] Weiss et al. MRM 2010. In press. DOI: 10.1002/mrm.22669 [4] Weiss S et al. 7th Interventional MRI Symposium. 2010; V48. [5] Krueger et al. ISMRM 2010. p.284.