Diagnostic MR-electrophysiology catheter with highly resistive wires for reduction of RF-heating

D. Wirtz[1], O. Lips[1], B. David[1], S. Krueger[1], and S. Weiss[1]

[1]Philips Research Europe - Hamburg, Hamburg, Germany

Objective

The use of MRI for guidance of cardiac electrophysiology (EP) procedures is gaining attention, because MRI avoids the large X-ray dose, allows the visualization of the catheter in relation to the myocard potentially including ablation monitoring and the assessment of cardiac function. MR-EP procedures have been demonstrated in animals [1], but the safety of MR-EP catheters still has to be addressed [2]. While RF-safety for transmission of MR signals at high frequencies (e.g. for active catheter tracking) can be realized using transformers in the transmission line [3], this method is not applicable to low frequency signals like an electrocardiogram (ECG). One way to reduce the risks in this case is the insertion of current-limiting resistors in the leads [4]. In this paper, the feasibility of using highly resistive wires as RF-safe ECG leads inside electrophysiology catheters is discussed.

Materials and Methods

The influence of the wire resistance, wire length, wire diameter, and the number of wires in a catheter on the RF-heating and specific absorption rate (SAR) at the tip and three ring electrodes of an EP sensing catheter prototype were studied. To this end, electromagnetic simulations as well as measurements were used. Moreover the resistive heating along the wire was investigated. For simulations and measurements, a 6F catheter was used that contained wires connected to the tip and to ring electrodes all being in contact with phantom tissue (agarose gel, σ=0.5 S/m, ε=81). The SAR at the electrodes was calculated for various wire lengths, diameters, resistances and number of wires using the method of moments tool FEKO (EM Software & Systems, Stellenbosch, South Africa). For the RF-heating experiments, a catheter was put in a water basin of 2m length, which was placed parallel to the B_0 field and as close as possible (approx. 10cm) to the body coil of the MR system (Philips Achieva 1.5T, Philips Medical Systems, Best, The Netherlands) to maximize the electric field interaction during transmission. Measurements were carried out for catheters containing wires of various lengths made of copper (200µm diameter, 0.55 Ω/m), various highly resistive alloys (ISAOHM, 20-35µm diameter, 1.3-2.7kΩ/m, Isabellenhütte Heusler GmbH & Co. KG, Dillenburg, Germany) as well as gold sputtered nylon threads with a resistances of 22kΩ/m using an SSFP sequence. The temperature was monitored using a Luxtron 790 fiber optic thermometer whose sensors made contact with the electrodes and were surrounded by a block of agarose gel to provide reproducibility and avoid convective heat transfer. To evaluate the quality of the ECG signal transmission for resistive wires, ECG signals were recorded using all wires mentioned above as leads. Furthermore, the ECG quality was evaluated experimentally for resistances up to 2MΩ using lumped resistors in the leads.

Results and Discussion

The measured temperature increase at the tip after 1.7s (copper) and 46s (ISAOHM wires) scan time vs. immersed catheter length is shown in Fig.1 for different wire diameters and resistances. The copper wire shows a pronounced temperature increase around a length of 110cm due to resonance. Since the exact position of the temperature probe to the catheter tip is crucial, the data point at 95cm is very likely an artifact due to a change in positioning while cutting the catheter. All ISAOHM resistive wires exhibit a significantly lower temperature increase, which is observed at much shorter lengths. No temperature increase is observable for the sputtered 22kΩ/m wire. These findings correspond well with the SAR simulations and hold true also for placing several wires in a catheter. The simulated resistive heating (per wire segment of unit length) of a resonant 30µm-wire vs. resistance is presented in Fig.2. Resonance is defined here as the catheter length resulting in maximum SAR at the tip electrode. Marked are the resistances, where measurements were carried out (cf Fig.1). It is obvious that, besides the tip heating (Fig.1) also resistive heating decreases rapidly with increasing resistance above several 100Ω/m. In Fig.3, a comparison of a surface ECG transmitted via copper leads and additional resistances of 200kΩ in the leads is shown. Note, that the SNR is almost unaffected which is due to the input impedance of a typical ECG recorder of the order of MΩ. Moreover, the thermal noise voltage $U_{noise}=(8kTR\Delta f)^{(-1/2)}$ generated by highly resistive wires with a resistance of R of several 10kΩ for sample bandwidths Δf of a few kHz is still small compared with the signal voltage, which is of the order of mV.

Conclusion

The heating at the tip of an electrophysiology catheter prototype could be reduced to a non-measurable level using highly resistive wires. This result holds true also for several wires present in the catheter lumen. Moreover, resistive heating also decreases to a physiologically non-relevant level for higher resistances. Provided a high impedance amplifier is used, the signal quality of the ECG is preserved, since thermal noise is not affecting the SNR either. It can be concluded, that clinically applicable diagnostic RF-safe EP mapping catheters can be designed using highly resistive wires.

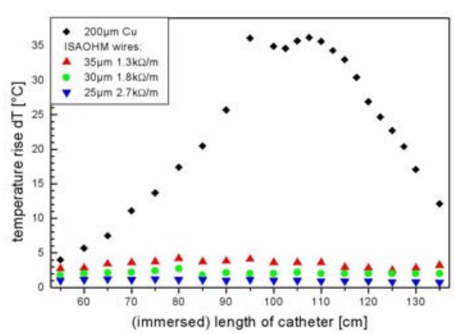

Fig. 1: Measured tip heating vs. catheter length for wires of different diameter and resistivity

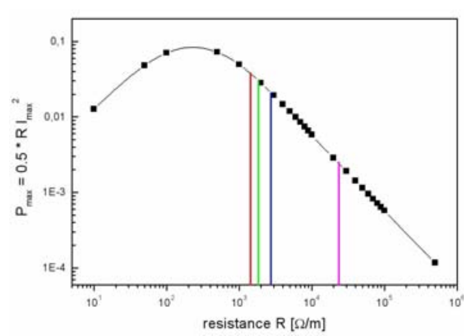

Fig. 2: Maximum ohmic power along resonant (max. SAR @ tip) 30µm-wire vs. resistance.

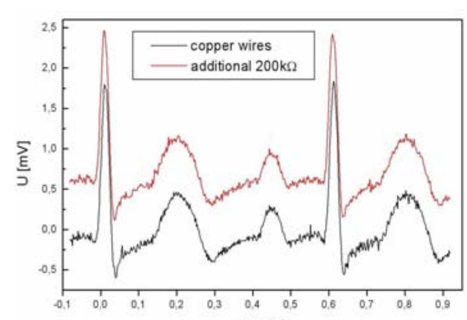

Fig. 3: Surface ECG transmitted via copper wires and additional resistance of 200kΩ

[1] Mallozzi R. P. et al, Proc. ISMRM 14, 272, (2006)
[2] Nitz W.R. et al. J. Magn. Reson. Imaging 13:105-114 (2001)
[3] Weiss S. et al. Magn. Reson. Med. 54:182-189 (2005)
[4] Lemieux L. et al. Magn. Reson. Med. 38:943-952 (1997)