RF-safe, multi-polar, diagnostic MR-EP Catheter employing resistive Leads and a Transformer-based Transmission Line

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Objective

The use of MRI for guidance of cardiac electrophysiology (EP) procedures is gaining attention, because MRI avoids X-ray dose, allows the visualization of the catheter in relation to the myocard, the assessment of cardiac function and ablation monitoring. 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). In this paper, the feasibility of using multiple resistive wires as RF-safe ECG leads inside multi-polar electrophysiology catheters for 1.5T is discussed, also including the tracking functionality with tip-coil and transformer based-transmission line. Both, electromagnetic simulations and subsequent temperature measurements were applied.

Materials and Methods

The influence of the wire resistance and the number of wires in a diagnostic multi-polar 7F catheter-model on the RF-heating and the resulting specific absorption rate (SAR) at the tip and numerous ring electrodes at 1.5T was studied. Electromagnetic simulations as well as measurements were applied. A 7F catheter was used that contained wires connected to the tip (~5mm length) and to ring electrodes (1.5mm width), all being in contact with phantom tissue (agarose gel, σ=1.2 S/m, ε=81 for measurements, dielectric cylinder (100mm in diameter, 600mm long) with σ=0.5 S/m, ε=77 in simulations) (Fig.1). The SAR at the electrodes was evaluated for various numbers of wires present, while the wire resistance was varied using the method of moments tool FEKO (EM Software & Systems, Stellenbosch, South Africa).
For the RF heating experiments, a catheter was put in a basin of 2m length, which was placed parallel to the B_0 field and as close as possible (~10cm) to the body coil of the MR system (Philips Achieva 1.5T, Philips Healthcare, Best, The Netherlands) to maximize the electric field interaction during transmission. Measurements were carried out using catheters containing leads with a resistance of 9kΩ/m using an SSFP sequence with 4W/kg. 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. Furthermore, the catheter model described above was modified by adding an insulated tracking coil (11 windings) between the second and third ring electrode (Fig.1). The coil was connected to a wire model of a transformer-based transmission line, and again, the SAR was evaluated at all electrodes as well as in the vicinity of the tip-coil. Moreover, the optimum distribution of transformers in the transmission line used for active tracking was determined.

Results and Discussion

The FEKO catheter model presented in [4] was further parameterized allowing for modeling numerous ring electrodes connected to ECG wires as well as a tracking coil connected to a transformer-based transmission line (Fig.1). Results of simulations using up to 13 wires (each 1m long, one connected to the tip and 12 to the rings) are: The tip-SAR (Fig.2) as well as the ring-SAR values (not shown) replacing Cu-wire by resistive leads of 10kΩ/m drops by a factor of ~300 for 2 wires and ~75 for 13 wires. Secondly, tip- and ring-SAR values do not depend strongly on the number of wires in a catheter for wire resistances beyond 4kΩ/m (Fig.2). This indicates safety for multiple electrode devices, once the '1-wire-case' is shown to be safe. Note that resonance effects resulting from wire lengths vanish with sufficient resistance in the leads [4]. Resonance frequencies of up to 10 1m long Cu-wires in a catheter are found between 90-95MHz resulting in an underestimation of the SAR values (Fig.2) by a factor of up to 3 when compared to the resonant case. Even slightly reduced SAR for increasing number of wires (Fig.2, Cu-wire) is found due to coupling. This trend is also visible for the wire resistances up to 2kΩ/m in Fig.2. Fig.3 shows the fiberoptically measured temperature increase of 0.3°C for a deka-polar device equipped with 9kΩ/m leads. Obviously, the proximal ring-electrode shows the most intense heating. ECG signal transmission using resistive wires up to MΩ values without significant loss in SNR has been demonstrated before [4].
In a second study, the optimum placement of the 3 transformers in a transmission line of 1m length for 1.5T in presence of multiple resistive mapping wires was derived: Minimum SAR in the vicinity of the tracking coil is found, when two transformers were placed close to the tracking coil (l_1=l_2=8 cm), while the third one follows in a distance of l_3=16cm. Here the transformers are assumed to be located at the end of a piece of transmission line of length l_1, l_2 and l_3. Fig.4 shows the most promising distributions found from extensive simulations. The y-scale on the plot indicates, that a number of transformer distributions are almost equal in SAR-performance providing some freedom in the setup of transformer based transmission lines. As expected, the SAR at the tip and the ring electrodes is not influenced significantly by the position of the transformers.

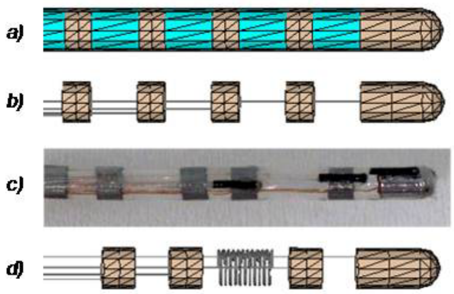

Fig.1: a), b) FEKO catheter model of a multi-polar mapping device c) mapping catheter prototype equipped with temperature sensors. d) catheter model including tracking functionality

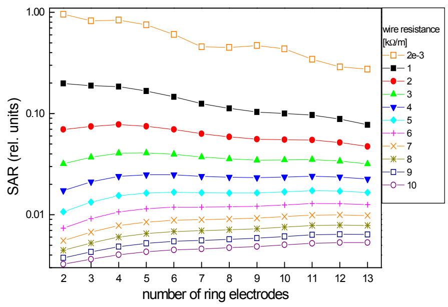

Fig.2: Relative SAR-values @ the catheter tip vs. number of wires in the catheter for various resistances.

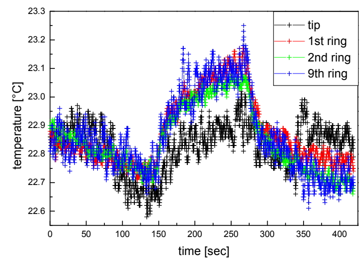

Fig.3: Heating measured at the catheter tip and 3 ring electrodes of a deka-polar mapping catheter.

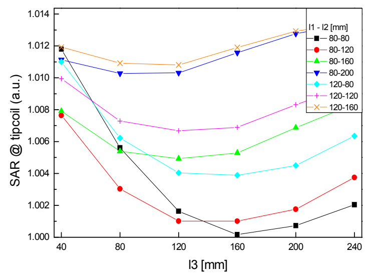

Fig.4: Relative SAR-values @ the tracking coil for various trafo distributions (description see main text).

Conclusion

We have demonstrated RF safety for multi-polar diagnostic EP catheters employing resistive leads for ECG-mapping using simulations and measurements. Furthermore, it was found that the presence of a transformer based transmission line and a tracking coil does not alter RF safety of such a device. Finally, favorable distributions of transformers in the transmission line resulting in low SAR around the tracking coil were derived.

[1] Mallozzi R. P. et al. Proc. ISMRM 14, 272, (2006), [2] Nitz W.R. et al. JMRI 13:105-114 (2001), [3] Weiss S. et al. MRM, 54:182-189 (2005), [4] Wirtz, D. et al, Proc. ISMRM 15, 738, (2007)