On the heating of small inductively coupled RF coils mounted on an intravascular model catheter during MR imaging

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Introduction/Purpose

Small inductively coupled RF coils have already been suggested or used as MR reference markers for various purposes, for example automatic patient registration, stereotactic planning, and visualization of devices inside the magnet [1-4]. Such markers may also be suitable for the guidance of intravascular devices (catheters) because they require no electrical connection to the scanner. On the downside, inductive coupling of these devices may lead to a considerable heating during RF-intense MR imaging which may pose a safety hazard [3,4]. Therefore, the goal of this work was to assess the heating behavior of a catheter-mounted, semi-active marker design under various experimental conditions in a vessel phantom.

Materials and Methods

The ICRF coil consisted of four turns of an insulated 0.3 mm copper wire and was wound around a silicone tube (outer diameter 4 mm) which served as intravascular catheter in a simplified model (Fig. 1). The wires were coiled obliquely instead of perpendicularly around the tube. For a real application, this will have the advantage that an insufficient inductive coupling due to a wrong coil orientation with respect to the B_0 field could be resolved by rotating the catheter axially. The inductive heating of this semi-active marker was measured as a function of various parameters. Inductive coupling was varied by changing the coil orientation and corresponded to ≈50 and 100%. The specific absorption rate was varied by changing the repetition time of the applied fast single-shot spin-echo sequence (HASTE) and was reported as 2.0 and 2.8 W/kg. The volume water flow inside a 6-mm wide vessel submerged in a water container (Fig. 2) was controlled via the rotation speed of a peristaltic pump (Ismatec ISM 1079, Wertheim) and corresponded to 0, 59, and 590 ml/min. Temperatures were measured with a 4-channel fiber optic thermometer (Fluoroptic 700, Luxtron, CA). Two probes were placed inside the "catheter" near the coil center (#2) and ≈1 cm away (#3), one probe (#1) was taped on the outside, and the last one (#4) was placed as reference in the surrounding water (Fig. 1c). The temperatures were monitored 1 min prior to heating (baseline), 10 min during RF (HASTE) exposition (heating), and further 10 min after RF exposition (cool down). All temperatures were rounded to the nearest 0.1°C. Feasibility of the marker design for 3D catheter localization was evaluated by using a previously described technique to automatically detect the marker signals on three standard 2D views [1]. After subtraction of a linear fit to the recorded reference temperature (probe #4) the temperature curves during heating and cool down have been fitted by exponential functions of the form $\Delta T_{max}\cdot\{1-\exp(-t/\tau_{heat})\}$ and $\Delta T_{max}\cdot\exp(-t/\tau_{cool})$.

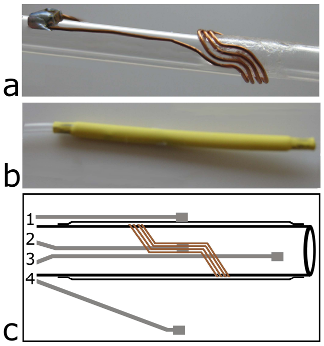

Fig. 1. a) Inductively coupled RF coil with ceramic chip capacitor mounted on a model catheter and **b)** covered by heat shrink tube. **c)** Sketch indicating the placement of the fiber optic probes.

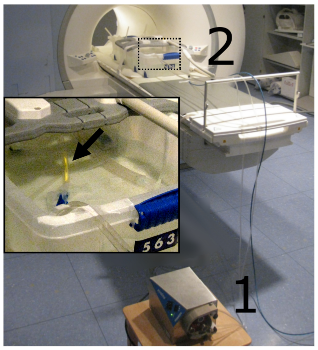

Fig. 2. Experimental setup with peristaltic pump inside the MR room (1) and vessel phantom (2) on patient table. Inset shows model catheter (arrow) inside a model vessel.

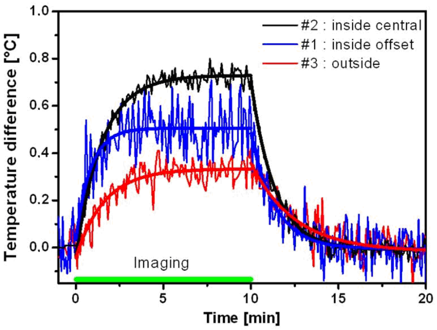

Fig. 3. Temperature evolution during 10 min RF exposition (HASTE sequence, 100% coupling, SAR=2.8 W/kg, no flow) of the model catheter and subsequent cool down. Plot shows temperature curves of probes #1-3 obtained after subtraction of a linear fit to the recorded reference temperature (probe #4) with exponential fits to the data.

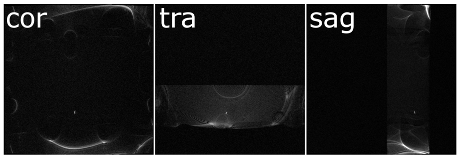

Fig. 4. Balanced SSFP (TrueFISP) marker images in three standard views. The marker signals are clearly discernible on all images despite the accumulation of the water background signals from across the 300 mm thick slices. Marker could also be automatically localized with an existing tool [1].

Tab. 1. Summary of measured temperature changes for 100% coupling.

Volume flow	SAR	Temperature increase [°C]		
[ml/min]	[W/kg]	mean	SD	max
0	2.8	0.7	<0.1	0.8
	2.0	0.5	<0.1	0.7
59	2.8	0.1	<0.1	0.2
	2.0	<0.1	<0.1	0.1
590	2.8	<0.1	<0.1	0.2
	2.0	<0.1	<0.1	0.3

Results

Under extreme RF exposition (100% coupling, SAR=2.8 W/kg, no flow), the mean (fitted ΔT_{max}) and maximum (measured) temperature differences were 0.7°C and 0.8°C (Fig. 3).The time constants τ for the heating and cool down phases of the central probe were almost identical (89 vs. 81 s). During moderate RF exposition (100% coupling, SAR=2.0 W/kg) a volume flow of 59 ml/min was already sufficient to limit the temperature increase to 0.1°C (Tab. 1). Fig. 4 illustrates the feasibility of this coil design for the localization of a submerged catheter under flow.

Discussion and Conclusion

In water at rest, inductive coupling leads to a considerable heating of the attached marker coils. Under "physiological" conditions, however, it appears that a small volume flow is already sufficient to effectively remove the generated heat by the flow of water. The remaining temperature increase observed here can be neglected for all practical purposes. These initial results provide valuable quantitative data to evaluate the safety of such intravascular devices for in vivo applications.

References
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