Simulation of Targeted RF-Heating at 1.5T, 3.0T, 7.0T, 9.4T and 11.7T MR

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Introduction:

Combining RF hyperthermia and MR imaging is conceptually appealing to pursue spatially and temporally controlled and monitored RF heating. The benefits of this approach could be used as an adjunctive therapy for established cancer treatments including radiotherapy and chemotherapy [1], targeted drug delivery [2] and targeted MR contrast agent delivery [3]. The purpose of this simulation study is to evaluate the feasibility of targeted RF heating at MR frequencies ranging from 64 MHz to 500 MHz. For this purpose two different coil designs were used including a stripline array and a bowtie shaped radiative dipole antenna configuration. The simulations are an essential precursor for designing and building a hybrid applicator suitable for imaging and targeted RF heating.

Methods:

A simulation study of an eight channel array with spin excitation frequencies at 1.5T (64MHz), 3.0T (127MHz), 7.0T (297MHz), 9.4T (400MHz) and 11.7T (500 MHz) was performed and evaluated on the ability to create a localized hotspot inside a phantom. The elements were positioned symmetrically around a cylindrical phantom with tissue properties ε_1=50.5, σ_1=0.657 S/m. Numerical electromagnetic field and transient thermal simulations were performed using CST Microwave Studio (CST GmbH, Darmstadt Germany). Post-processing of the 3D simulations was done within the RF circuit simulator of CST (Design Studio, part of CST Studio Suite 2010) as described in [4]. The mesh resolution inside the phantom was below 2x2x2mm³. To validate the simulated fields a cylindrical phantom (r_1=90mm,l=250mm, ε_2=75, σ_2=0.72 S/m) was built. All point SAR calculations were performed for 1W accepted power at each port. Two different designs of transmit applicators were used, stripline elements and radiative dipoles. Both designs could provide a suitable setup for a hybrid applicator due to their imaging properties at ultrahigh fields [5-6]. For evaluation iso-SAR 25%, iso-SAR 50%, iso-SAR 75% and iso-SAR 90% contours were defined for the centric area inside the phantom as well as for the surface volume.

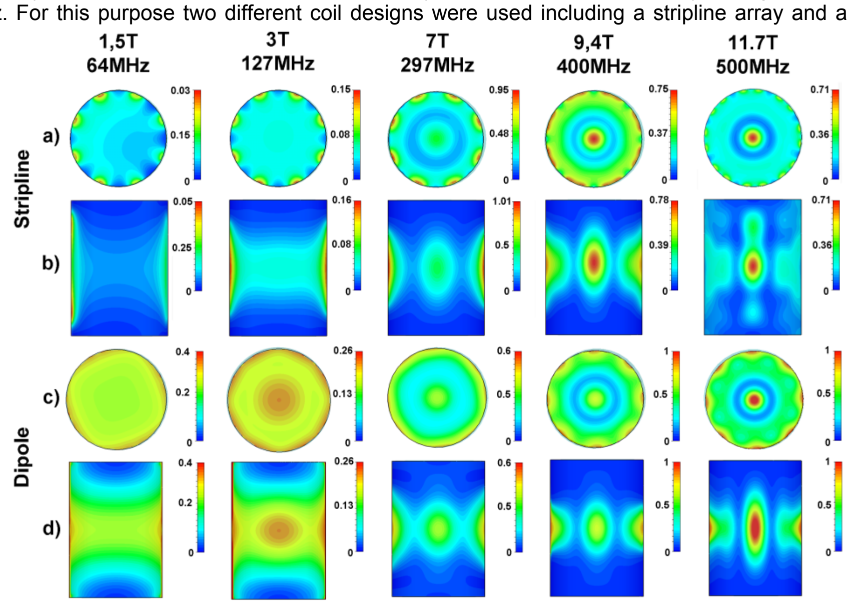

Fig. 1: Comparison of the point SAR pattern [W/kg] of different operating frequencies for a modified stripline array in axial (a) and coronal (b) view of a cylindrical phantom (ε_1=50.5, σ_1=0.657 S/m) and a dipole antenna array in axial (c) and coronal (d) view.

Results:

The results of the point SAR calculations obtained for an eight channel TX/RX configuration are depicted in Fig. 1. At 64 MHz and 127 MHz the SAR pattern for the eight channel stripline array is distributed rather uniformly over the object. A local SAR hot spot inside the phantom is not achievable. From 127MHz (dipole) and 297MHz (stripline) onwards focal regions of SAR increase can be formed with the eight channel array. (Fig. 1, Tab. I). Due to the shorter wavelength inside the phantom at higher frequencies, the area of the focal hotspot is as small as 12x12mm iso-SAR 90% at 500 MHz. The dipole antenna showed improved focusing parameters at 297MHz yielding an iso-SAR 75% of 12x12mm² , iso-SAR 50% of 48x48mm² in tissue and an iso-SAR 90% of 18x18mm² , iso-SAR 75% of 22x22 mm² inside the phantom which comes close to that area of the hotspots achieved with the strip line configuration at 400MHz. The smallest focal SAR (iso-SAR 90%, 12x12mm²) could be achieved with the stripline array at 500MHz. The simulated SAR pattern of the dipole antenna at 297MHz generates a temperature difference inside the phantom between the central hotspot and the surface area of ΔT=5K (Fig. 2).

*ε_2,σ_2		main area				surface area	
	[MHz]	25%	50%	75%	90%	75%	90%
Stripline	64	172x172	-	-	-	20x8	12x4
Stripline	127	172x172	-	-	-	14x4	2x2
Stripline	297	54x56	-	-	-	18x4	2x2
Stripline	400	60x60	40x40	28x28	16x16	20x6	8x4
Stripline	500	48x48	34x34	20x20	12x12	14x4	-
Dipole	297	170x170	48x48	12x12	-	170x170	32x2
Dipole*	297	74x74	48x48	30x30	18x18	22x2	-

Tab. I: iso-SAR areas in [mm²] for frequencies ranging from 64 MHz to 500 MHz. iso-SAR values were derived from surface regions (surface area) and center regions (main area) of a central axial slice of the cylindrical phantom. The missing values (-) indicate, that no iso-SAR contour could be calculated.

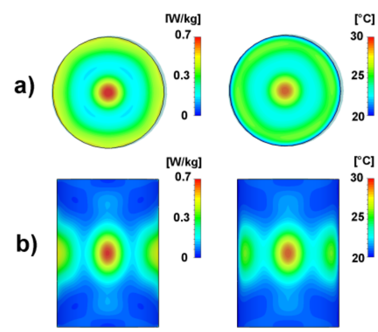

Fig. 2: Point SAR simulations (left) of an eight channel dipole antenna applicator at 297MHz and related temperature simulations (right) for 25W continuous wave heating for 5 minutes in an axial (a) and coronal (b) slice. Phantom properties: ε_2=75, σ_2=0.72

Conclusion:

The results of this study suggest that a hybrid applicator for imaging and heating is feasible. At ultrahigh fields focal hotspots can be created using a coil design which supports both RF heating as well as imaging. The size of the focal hotspot decreases with the decrease in the wavelength. Dipole antennas show improved properties for localized RF heating compared to a stripline design at 297MHz. A larger number of channels will be beneficial to further reduce surface SAR values. The same approach would increase the degree of freedom for controlling and steering the geometry and position of focal SAR hotspots and an extension towards a two-dimensional array would allow a three-dimensional steering of these focal SAR hotspots. The results of this study will be used to build a hybrid applicator at 7.0T both for imaging and RF-heating.

References: [1] Issels, R.D., et al., Lancet Oncol, 2010; [2] de Smet, M., et al., JCR, 2010; [3] Peller, M., et al., Inv Radiol, 2008; [4] Kozlov, M. and R. Turner, JMRI, 2009; [5] Gregor Adriany, P., et al., MRM, 2005; [6] Raaijmakers, A., et al., MRM, 2011