Flip angle and SAR maps induced by a head displacement in parallel transmission and with Cartesian feedback

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Introduction: Taming the specific absorption rate (SAR) when using parallel transmission is one of the most challenging problems in MRI at high fields. Using sophisticated simulation tools, it has been shown that the peak local SAR varies with anatomy, but also with the resolution, size and other parameters of the numerical head model [1, 2]. When using 8 transmit channels, the parameter space at one instant in time is 16-dimensional (amplitude and phase for each channel) and hence grows as 16×n, where *n* is the number of sub-pulses, or discretization steps, used in the RF pulse design and played on each channel. In such a large space, the maximum local SAR value found over the irradiated volume can show considerable variations [3]. There remains, however, the question of how robust both SAR and flip angle (FA) landscapes remain with respect to small perturbations. A head displacement for instance not only changes the solutions of Maxwell's equations but also alters the tuning, matching and interactions of the coils and thereby the currents flowing in them. Now Cartesian feedback [4] has been proposed as a solution to the latter problem. We therefore present the results of simulations showing the effects of small rotations of the head upon the FA and SAR landscapes with and without Cartesian feedback being applied.

Methods: The head coil used in this study consisted of eight stripline dipoles distributed every 40-degrees on a cylindrical surface of 27.6 cm diameter, leaving an open space in front of the eyes (Fig. 1). Full-wave simulations with the finite element method (HFSS, Ansoft, Pittsburgh, PA), which take into account tuning, matching and mutual coupling, returned the electric and magnetic fields which were then projected onto a 5 x 5 x 5 mm^3 mesh. All dipoles were tuned and matched ($S_{11} < -10$ dB) to a 50-ohm line impedance, ideally at 297 MHz corresponding to the proton Larmor frequency at 7T, and for the central head position. The nearest neighbour mutual coupling was around -10 dB. For this study an eight-anatomical structure human head model (provided by Aarkid, East Lothian, Scotland) was placed in the centre of the coil. For the central head position, a pulse based on a 5-spoke k-space trajectory [5] was designed to homogenize the FA (target of 20°) in a central slice of the brain (1 spoke sinc pulse duration = 0.7 ms, time-bandwidth product = 4), yielding a total pulse duration of 3.5 ms. The parameter space in this example hence had 80 dimensions. The electromagnetic simulations were then repeated for the head rotated by 10° about X and Z and used to compute the new FA and SAR distributions when using the previous pulse. Lastly, the third scenario investigated was with the same RF pulse and head displacement, but this time artificially incorporating the Cartesian feedback technique [4] to correct for the detuning of the coils. Tiny virtual loops were modelled close to the individual channels to return magnetic fluxes. Given an excitation vector **b** entered on the console, magnetic fluxes Φ are induced via a matrix $[\mathbf{\Phi}_{ref}]$ or $[\mathbf{\Phi}_{rot}]$: $\Phi=[\mathbf{\Phi}_{ref,rot}]\mathbf{b}$ for the reference and rotated head positions respectively. Hence Cartesian Feedback was artificially incorporated by right-multiplying the initial excitation vector by $[\mathbf{\Phi}_{rot}]^{-1}[\mathbf{\Phi}_{ref}]$. Lastly, the worst-case SAR values were also calculated for different head positions, and with Cartesian feedback, using the work reported in [6].

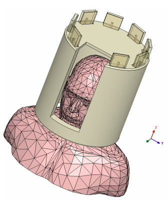

Fig. 1: coil and human head models used for the electromagnetic field simulations.

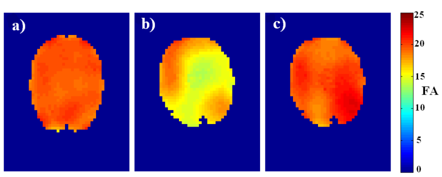

Fig. 2: Flip angle results for: a) the reference, b) the rotated, and c) the rotated head with Cartesian feedback.

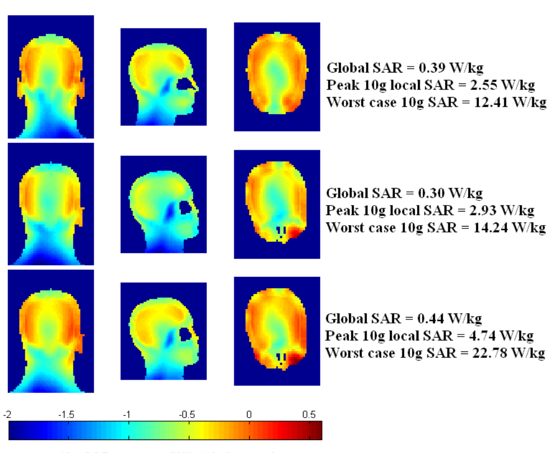

Fig. 3: 10-g average SAR values in logarithmic scale, computed for a 5 spokes RF pulse. From top to bottom: reference, rotated and, rotated position with Cartesian feedback. On the right hand side are indicated the global and peak 10-g average SAR values, in addition to the worst case scenarios [6].

Results and Discussion: Fig. 2 shows the simulated FA distributions for the different head positions and techniques. The calculations returned normalized root mean square errors of 3.3 % (reference position), 19.4 % (head rotated) and 5.2 % (head rotated with Cartesian feedback). This shows in this case that Cartesian feedback can indeed provide a better control of the FA distribution despite small perturbations. Channel 1 was detuned the most by head rotation because the nose in our model approached it (S_{11} went from -19 dB to -7 dB). The corresponding 10-g average SAR maps are provided in Fig. 3 along with their global, peak and worst-case SAR values [6]. One can see that without Cartesian feedback, the peak 10-g SAR value indeed increased, but only moderately with a 15 % increase. Although the nose and left eye got closer to channel #1, which resulted into a higher E-field, the latter channel became unmatched so that more power was reflected. It follows that compensation of this power loss using Cartesian feedback amplified the peak-SAR value (Fig. 3 bottom row). What is also interesting to note is the fact that the worst case scenarios are roughly the same for the reference and rotated head positions. For this particular coil, this suggests that if conservative safety measures were taken to ensure patient's safety, they could be reasonably robust with respect to head displacement. It is also possible that a head displacement could induce a better matching of the probe because individual coils are never perfectly tuned and matched initially. This time, in such a case Cartesian feedback would maintain the currents in the coils and compensate, yet not fully, for the increased electric fields in the tissue approaching the emitting dipoles.

Conclusion: We have calculated global and local SAR values for different head positions, and for a particular coil design. Our results suggest that in spite of the drastic differences in local SAR one may encounter in the 16×n -dimensional parameter space [3], a given SAR result can be reasonably robust with respect to small perturbations. As a result, measures less conservative than the ones based on worst case scenarios could potentially be taken. Finally, we have also shown that Cartesian feedback helps maintain FA homogeneity when coils are detuned due to the approach of tissue. However, on a cautionary note, the maintenance of currents and voltages in the coils does not mean the increased SAR associated with closeness is compensated for.

References: [1, 2] Z. Wang et al. in Proc. of the 17th ISMRM meeting, p 4775 and p 4797 (2009). [3] B. van den Bergen et al. in Proc. of the 16th ISMRM meeting, p 73 (2008). [4] D. I. Hoult et al. Magn Reson Mater Phy 21:15-29 (2008). [5] S. Saekho et al. MRM 55: 719-724 (2006). [6] O. Brunner et al. in Proc. of the 17th ISMRM meeting, p 4803 (2009).