RF Energy Deposition and RF Power Requirements in Parallel Transmission with Increasing Distance from the Coil to the Sample

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Introduction

Parallel transmission with multiple RF coils enables homogeneous excitations at ultra high magnetic field strengths, while minimizing the specific absorption rate (SAR) over the entire volume of the sample [1, 2]. However, electric fields generated by transmit coils placed closer to the sample may cause dangerous hotspots, even though average global SAR remains small over the duration of excitation. On the other hand, if the coils are placed at a distance from the body, the RF power required to achieve a given flip angle distribution may be high, and it may be feared that this will result in increased global SAR. Furthermore, increasing the distance between the transmit array and the sample widens the area of overlap between individual coil sensitivities, which may compromise the performance of parallel transmission techniques. SAR dependence on array geometry in parallel transmission was studied by Katscher et al. [3], by changing the relative orientation between two transmit coils placed at a fixed distance from the center of a spherical object. In this work we investigate global and peak SAR behavior and the corresponding RF power requirements with respect to the separation between the transmit elements and the surface of the object, in the case of a dielectric sphere at 3T and 7T main magnetic field strengths. We explore various array geometries as well as the ultimate intrinsic case [2].

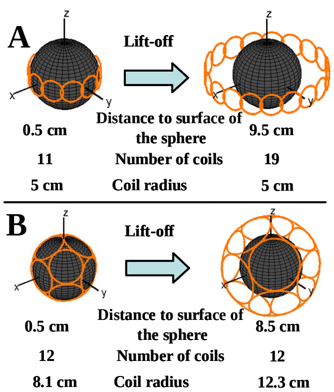

Figure 1. Transmit array geometries. **A:** belt-like design in which coil size is kept constant and the number of coils is increased during lift-off. **B:** symmetric design in which the number of coils is kept constant and coil radius is increased during lift-off.

Methods

A dyadic Green's function (DGF) formulation [4] was used to derive the full-wave electromagnetic fields inside a dielectric sphere from a complete basis of current modes, which were defined on a spherical surface concentric with the object. Following a method recently described [5] we employed this basis set to calculate ultimate intrinsic SAR [2], the theoretical smallest RF energy deposition for a given target excitation, independent of any particular array geometry. By appropriate weighting of current modes, we also calculated minimum SAR for finite arrays of transmit loop coils [5]. The corresponding input RF power requirements were estimated by adding the RF power dissipated in coil conductors to the RF power deposited in the sphere.

The excitation of a uniform target profile on a transverse plane through the center of the sphere was simulated for the case of a 32x32 EPI excitation trajectory, using a SAR minimization algorithm for parallel transmission [1, 2]. The sphere radius was 15 cm and average brain tissue dielectric properties from Ref. [6] were assumed. SAR behavior for increasing distance between the object and the transmit elements was investigated by varying the radius of the spherical surface where the current distribution was defined. For the case of finite arrays, two different strategies were proposed. In the first simulation, an increasing number of loop coils were arranged like a belt around the sphere equator, fixing coil radius to 5cm (Figure 1A). In the second simulation, a fixed number of coils were symmetrically packed around the sphere, with individual coil radii scaling up with increasing lift-off (Figure 1B). Calculations were performed in MATLAB (Mathworks, Natick, USA) for different lift-offs, coil numbers and field strengths using 13122 current modes in the basis set.

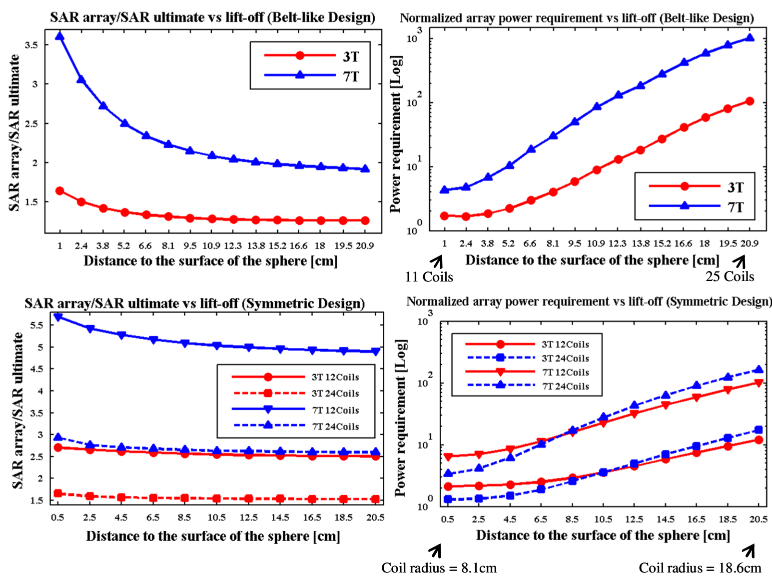

Figure 2. Optimized global SAR and RF power requirements versus lift-off, for the belt-like (top row) and symmetric (bottom row) array design. Each plot is normalized to the ultimate intrinsic SAR at the corresponding magnetic field strength.

Results and Discussion

The target excitation profile was achieved in all cases. Figure 2 shows minimum global SAR and RF power requirement as a function of the distance of the finite arrays to the surface of the sphere. Results are presented for 3T and 7T main field strengths and for different coil designs (belt-like and symmetric). Each plot is normalized to the ultimate intrinsic SAR of the corresponding main magnetic field strength, which notably remains constant for different lift-offs. In the ultimate case, local SAR also does not change with lift-off, suggesting that there is a single optimal electromagnetic field distribution that minimizes SAR while maintaining profile fidelity, and it can be always achieved choosing the appropriate combination of modes in the basis set. It is apparent from the left-hand column of Figure 2 that global SAR is reduced, approaching more closely the theoretical smallest value, as coils are moved further from the object. However, in the right-hand column we see that, if the same B_1+ field distribution is used as a target, the corresponding RF power requirements increase dramatically with increasing radius. Both global SAR and RF power requirements are higher at 7T than at 3T in all cases. RF power requirements for the 24-element symmetric array are lower than for the 12-element array when the coils are close to object, but power requirements grow more rapidly with lift-off, since individual coil dimensions increase and lead to larger dissipation. Spatial distributions of local SAR in the center of excitation *k*-space and peak SAR during the entire excitation are shown in Figure 3 for different lift-offs, in the case of the belt-like array design. It appears that when the coils are near the surface of the sphere, electric fields are larger and cause higher RF energy deposition.

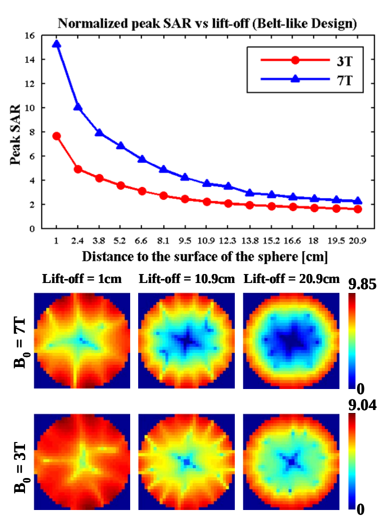

Figure 3. Peak SAR (top) and local SAR (bottom) versus lift-off for the belt-like array design, at 3T and 7T. Normalized spatial SAR distribution (base-10 log scale) within the FOV, during excitation of the center of *k*-space is shown for the smallest (1 cm), and intermediate (10.9 cm) and the maximum (20.9 cm) lift-off value.

Conclusion

In this work, we found that for parallel transmission there are SAR benefits in moving the transmit coils away from the object, especially at higher field strengths. However, the increase in corresponding RF power requirements may constitute a practical limitation to these benefits. Ultimate SAR is independent of coil lift-off and can be used in this case as an absolute reference.

References: [1] Zhu Y, (2004) MRM 51:775-784 [2] Lattanzi R et al, ISMRM 2008, 614 [3] Katscher U et al, (2005) MAGMA 18: 81-88 [4] Tai CT, Dyadic Green Functions in Electromagnetic Theory (1994) [5] Lattanzi R and Sodickson DK, ISMRM 2008, 78 [6] Wiesinger F et al, (2004) MRM 52: 376-390