SAR implications of different RF shimming techniques in the body at 7 Tesla

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Introduction

The development of ultra high field MRI systems has introduced serious challenges for body imaging with respect to SAR and B_1^+ field non-uniformity, which results in signal voids in the region of interest (ROI). RF shimming can remove these signal voids by optimizing the phases and amplitudes of the individual RF excitation elements. We present an overview of the implications of three different RF shimming techniques both for the average SAR and for the local maximum SAR (peak SAR).

Methods

The electromagnetic RF fields in a realistic patient model in a twelve element TEM body coil were simulated using the finite difference time domain method (FDTD). We looked at different RF shimming techniques that improve the B_1^+ field:

Method A: Use 'generic optimized settings' from a homogeneous elliptical phantom [1]. All optimizations are done off-line for generic patient models (or phantoms). The optimized settings are then applied to the actual patient anatomy. The large advantage of this method is that the off-line optimization can include SAR minimization since the electric field can be computed.

Method B: Focus the B_1^+ field inside the region of interest [2]. The optimization parameter for this method is the 'focus factor', which is the average B_1^+ in the ROI, divided by the average B_1^+ outside this region. In practice this can be done by an on-line optimization after the B_1^+ field maps for each RF transmit element are acquired.

Method C: Matching the phases of the individual $\mathbf{B_1}^+$ fields in the centre of the ROI by giving all elements a phase shift that is calculated based on the B_1^+ phase maps for the individual RF transmit elements [3,4].

For evaluation purposes we have included the results of a patient specific optimization with SAR limitation for the anatomy that we used [1]. Such an individual optimization is in practice not possible, but it can be used to see how good the different methods perform. These individual optimization results (roughly half a million) are shown in the background of figure 1a. Together they form the '*low-SAR, high B_1^+ uniformity*' corner of all possible phase amplitude combinations for the used patient anatomy.

Results

The results for the different optimization methods are shown as individual points (A, B and C) in figure 1. For reference also the result of a quadrature excitation is included (Q). Figure 1a shows that method B does not reduce the local maximum SAR at all. Method C gives a much better result, but only method A can come close to the limit which can be reached by patient specific optimizations. Figure 1b shows an expected strong correlation between the focus factor and the average SAR. All three methods increase the focus factor and thus reduce the average SAR. Surprisingly, figure 1c shows that there is no correlation between the focus factor and the local maximum SAR. Despite the fact that method B has the best focus factor, it also has the highest peak SAR.

Discussion and conclusions

Focussing the B_1^+ field in the optimization region can be accomplished by constructive interference in the optimization region, but also by destructive interference outside this region. Method C only uses the constructive interference in the centre, which is a sensible approach to reduce the SAR since it reduced the required power for a given excitation strength, although there remains a risk of increasing local SAR peaks. The destructive interference of the B_1^+ field outside the optimization region that is accomplished by method B does not imply that there will also be destructive interference of the electric field in this region. In fact the extra B_1^+ shaping is likely to introduce high local SAR peaks, as can be seen in figures 1c and 2. Method A has the best results both for the average and for the peak SAR. The fact that all optimizations can be done off-line, makes this method very fast and simple for daily practice.

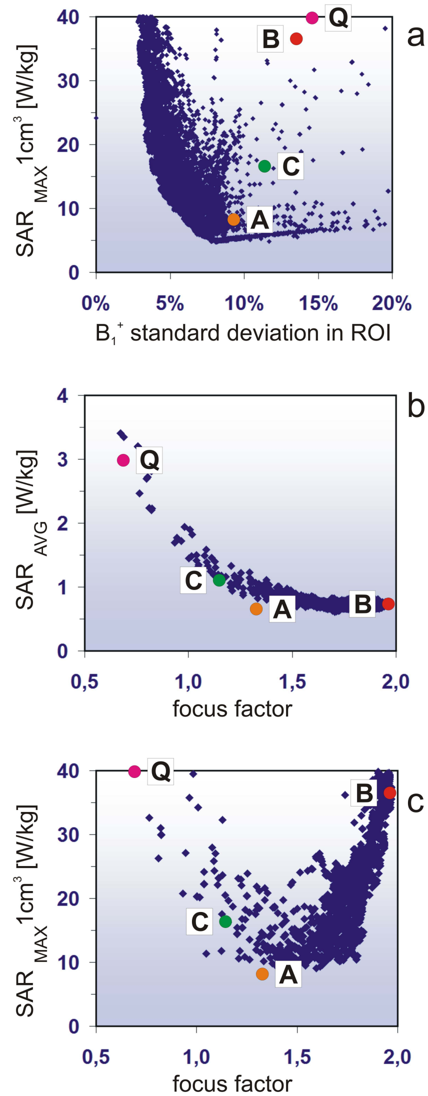

Figure 1. (a) Relation between peak SAR and B_1^+ standard deviation, (b) Average SAR as function of the focus factor (see text) and (c) Peak SAR as function of the focus factor. Indicated points refer to the optimization method (A, B and C) or quadrature excitation (Q).

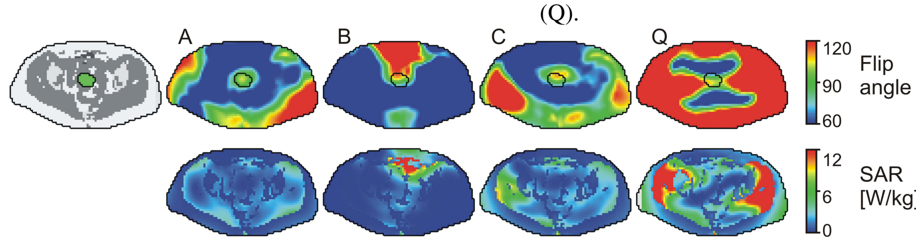

Figure 2. Flip angle (top) and SAR patterns (bottom) for different SAR-B_1^+ optimization techniques (A, B and C) and quadrature excitation (Q).

References

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