A Study of the Relationship between B1-field Uniformity, Body Aspect Ratio and SAR for Whole-Body RF Shimming at 3.0T

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Introduction

In a 3T whole body MRI system, the body tissue dielectric effects become important. It can considerably decrease B_1-field homogeneity and affect image quality. Experiments show that B_1-field non-uniformity varies with a scanning subject's loading position and body shape. Clinical 3.0T MRI systems with MultiTransmit RF technology have recently been introduced and can greatly improve image quality [1]. To study the optimal B_1 shimming methods for various subjects with different body shapes, while keeping SAR within RF safety limits, the Finite Difference Time Domain (FDTD) method is used to evaluate the relationship between the optimized $|B_1^+|$-field, the whole-body SAR and the maximum local SAR for human body models with different aspect ratios. Results are compared to the conventional quadrature driven case.

Methods

EM simulations are performed using the XFDTD software package (Remcom, Inc., State College, PA) [2]. A 3.0T whole body coil is modeled and driven at the frequency of 128MHz using multi-independent RF sources. As an example here, we present the results when using two voltage sources placed on two rungs located 90° apart. An original male model with 40 distinct types of tissues is linearly rescaled in the anterior-posterior (A-P) dimension and meshed to generate five human body models with different body shapes (aspect ratio). The aspect ratio (no units) is defined as the ratio of the thickness in A-P direction to the width in left-right (L-R) direction in the center transverse slice excluding the arms. These human body models are then loaded into the body coil model with the liver centered (see Fig.1). Steady-state solutions of B-field and E-field are recorded from each RF source. $|B_1^+|$-field in the rotating frame using the formula in Ref [3], whole body SAR (SAR averaged over the whole body) and local SAR (SAR averaged over 10g tissues) are then calculated off-line by varying the amplitude and phase between the two voltages. For the quadrature driven case, the two voltages have equal amplitudes and a 90° phase difference. Three B_1-shim methods are investigated: (1) minimize the $|B_1^+|$ standard deviation (no units as normalized to mean $|B_1^+|$-field) over the center transverse slice; (2) minimize the whole body SAR; (3) minimize the maximum local SAR. All SAR values are normalized to the square of the mean $|B_1^+|$ over the center transverse slice for the comparison.

Results

In Fig. 2(a), we plot the percentage change of $|B_1^+|$ standard deviation with respect to the quadrature driven case vs. patient aspect ratio. It shows that: (1) The method of minimizing $|B_1^+|$ standard deviation achieves the best uniformity improvement (more negative is better). For the liver centered, the upper limit for optimal $|B_1^+|$ uniformity is ~34% better than the quadrature case; (2) Improvement is greater for small aspect ratio (more elliptical) vs. large aspect ratio (more round). For aspect ratio >0.8, less improvement of $|B_1^+|$ uniformity is found; (3) Minimizing the maximum local SAR can also improve $|B_1^+|$ uniformity except for largest aspect ratio; (4) Minimizing whole body SAR has the least $|B_1^+|$ uniformity improvement. Figure 2(b) shows the percentage change of whole body SAR with respect to the quadrature case. It shows that: (1) The method of minimizing $|B_1^+|$ standard deviation can reduce whole body SAR for smaller aspect ratio and may increase SAR for large aspect ratio; For large aspect ratio the change is within ±13% relative to the quadrature case; (2) Minimizing the maximum local SAR can also result in lower whole body SAR. Figure 2(c) shows the percentage change of the maximum local SAR with respect to the quadrature case. It shows that: (1) the method of minimizing $|B_1^+|$ standard deviation may increase or decrease the maximum local SAR to some degree. For liver centered, the maximum local SAR is increased by a maximum of 14% for aspect ratio < 0.7 and decreased by 25% for aspect ratio ~0.8; (2) By trading off some improvement of $|B_1^+|$ uniformity, minimizing the maximum local SAR is possible and can be beneficial. For example, at aspect ratio of 0.56, method 1 gives a decrease of $|B_1^+|$ deviation of 34% vs. method 3 of 27%, but the maximum local SAR from method 1 increases by 14% vs. method 3 where it decreases by 30%.

Conclusions

For 3T whole body imaging, RF shimming can provide an improvement for $|B_1^+|$-field uniformity for various subject aspect ratios. Compared to rotund/roundish subjects, a subject with smaller aspect ratio can benefit more from B_1-shiming compared with the conventional quadrature driven case. Any $|B_1^+|$ shimming method needs to consider the effect on SAR. The study here shows that the degree of $|B_1^+|$ uniformity improvement can be traded off to realize lower SAR. The method chosen to minimize the $|B_1^+|$ standard deviation can provide an overall better solution. With the combination of two or more $|B_1|$-shim methods, such as combining minimization of $|B_1^+|$ deviation and the maximum local SAR, the benefit of more homogeneous $|B_1^+|$ and lower SAR limit can be achieved. This is shown for the example case of two channel RF shimming for Liver centered at different aspect ratios.

References

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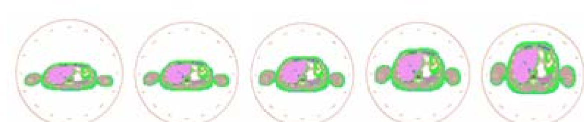

Fig. 1. Five human body models with different A-P aspect ratios with liver centered inside a 3T whole body coil model.

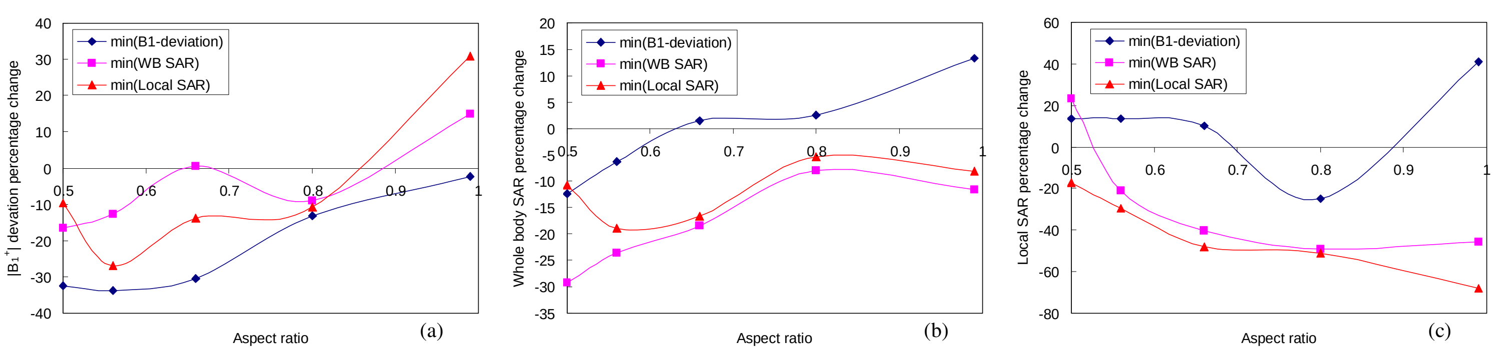

Fig. 2. The comparisons of three $|B_1^+|$-shim methods with the conventional quadrature driven case applied to five human body models with different aspect ratios: (a) the percentage change of $|B_1^+|$ standard deviation; (b) the percentage change of whole body SAR; (c) the percentage change of maximum local SAR.