RF Shimming Considering Both Excitation Homogeneity and SAR

Z. Wang[1], S-H. Oh[1], M. B. Smith[1], and C. M. Collins[1]
[1]Radiology, The Pennsylvania State University, Hershey, PA, United States

Introduction: In recent years a number of methods for improving image homogeneity in high field MRI utilizing transmit arrays have been proposed including RF shimming (1), transmit SENSE (2), and array-optimized composite pulses (3). But when the B_1 field distribution is changed the SAR distribution is also altered to some new pattern, introducing a safety concern. van den Berg *et al.* (4) provided a method to get better homogeneity and constrain the SAR simultaneously in RF shimming of the human torso. With consideration of the relative importance of SAR and homogeneity, in this paper, a simple cost function is utilized in the RF shimming process to investigate the different optimal weight on B_1 homogeneity and SAR.

Method: A 3D digital human head model was adapted from previous studies (5, 6). It consists of 23 different tissue types with a 5 mm isometric resolution. An elliptical array coils containing 16 stripline TEM elements was modeled and driven at 300 MHz. In each element of the 16-element array, two current sources were used to connect the conductive element to the shield element, one at each end of every element. The RF field was calculated using the finite-difference time-domain (FDTD) method with commercially-available software ("xFDTD"; REMCOM; State College, PA). At first each element in the 16-element array was excited with identical current source magnitudes with the phases of the current sources following the azimuthal positions of the coil elements. Then the amplitude and phase for each element were modified individually for the optimization. During optimization the value of a simple cost function η*inhomogeneity+(1-η) *SAR was minimized to reduce both the RF inhomogeneity and the SAR simultannsously. In this study the inhomogeneity was defined as the standard deviation of the sine of the flip angle in the volume of interest (whole brain) after a 3ms pulse and the SAR was defined as the whole-head average SAR during the pulse, but other measures of inhomogeneity and SAR could be used depending on the purpose. The value for η was also varied from 1 to 0.6 to examine its effect on B_1^+ homogeneity and SAR change.

Results and Discussion: In Fig 1, the signal intensity of B_1^+ distribution of original, η =1(only adjust the homogeneity) and η =0.8 are shown. Comparing the B_1^+ distribution of the original configuration and that optimized with η=1, it is easy to see that the homogeneity is highly improved after the optimization procedure. Numerical values for the changes in inhomogeneity and SAR are given in Table 1. Clearly, homogeneity is better and SAR is higher in the optimized field distributions than in the original, but when η=0.8 a significantly lower SAR is achieved with little cost to homogeneity compared to when η=1. Considering the mean B_1^+ in the brain changes significantly during optimization (Table 1) it is also important to show that the effect on SAR is not merely due to a change in the mean B_1^+ magnitude. If the fields were normalized to produce a mean B_1^+ of 1.7 in all cases this would result in an average SAR of 1.46 W/kg in the original case, 3.21 W/kg when η=1, and 1.61 W/kg when η=0.8 - so the effect of changing η is still significant. From Fig 1, the difference in homogeneity between the second row (α=1) and third row (α=0.8) is not obvious, but the decrease in SAR is obvious in Fig 2. These results demonstrate that with use of a simple cost function, consideration of SAR while optimizing magnetic field homogeneity with numerical calculations is practical and promising. With this approach phase/amplitude controlled transmit arrays can produce nearly as homogeneous excitations as methods considering only homogeneity, but with dramatically lower SAR levels.

Table 1. Inhomogeneity (standard deviation of sine of flip angle) and SAR for different cases.

	Inhomogeneity	Max. local SAR (W/kg)	Head Ave. SAR (W/kg)	Mean B_1^+ (μT)
Original	0.172	9.92	0.58	1.07
Optimized: η=1	0.060	280.07	3.29	1.72
Optimized: η=0.8	0.072	20.99	1.56	1.67

References

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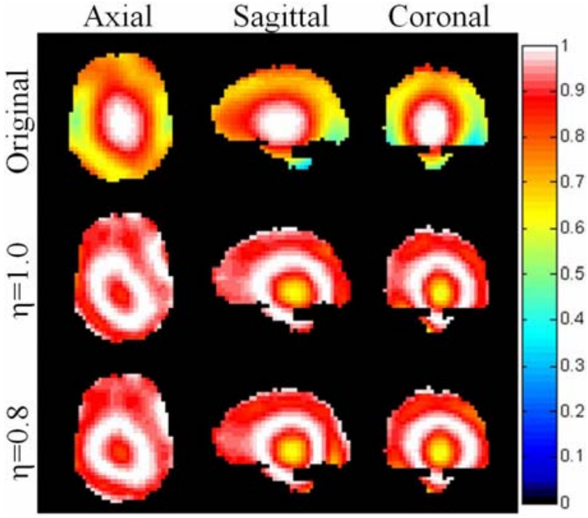

Figure 1. Relative signal intensity distributions before optimization (top) and after optimization with different weighting functions η. Value equal to sine of flip angle (5).

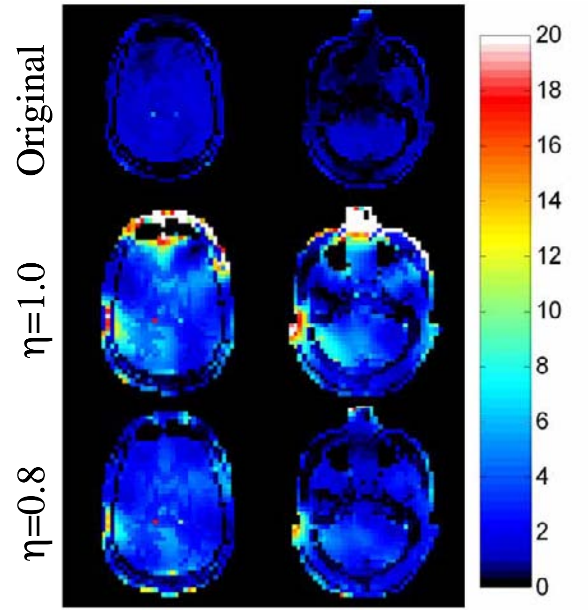

Figure 2. SAR distributions (W/kg) on two different axial planes before optimization (top) and after optimization with different weighting functions η.