SAR and Temperature Evaluations for B1 Shimming at 7 tesla

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Introduction

In high field MRI, the increased interactions between the electromagnetic waves and the biological tissues may give rise to heat and thermal hazards. This is clearly apparent for multi-transmit array applications where the electromagnetic fields are heavily manipulated in the subject to be imaged. In this work we provide complete 3D predictions of the B_1^+ fields, MRI images, energy absorption by the head and corresponding specific absorption rate (SAR) distributions, temperature rise distributions over the whole head for MRI experiments associated with quadrature and multi-transmit (B_1 shimming) operations at 7 tesla.. Analysis on the relation between B_1^+ field distributions, MR images, SAR and ΔT (temperature change due to the RF excitation) distributions is conducted.

Methods

In our work, the full wave method based on finite difference time domain (FDTD) was used to calculate B_1 and the electric fields at 7 tesla. Using B_1 shimming mechanisms, we improved B_1^+ field homogeneity over three dimensional (3D) brain regions while minimizing the total energy absorption as well as the local SAR by the human head. SAR and **Δ**T calculations were then simulated under the both excitation conditions: B_1 shimming and with quadrature excitation.

1.SAR calculation: 10-gm (IEC limit) SAR was evaluated in order to obtain average intensity of the B_1^+ field over the brain region equal to 2.936 micro Tesla (µT), which is the B_1^+ field strength needed to produce a flip angle of π/2 with a 2-msec rectangular RF pulse.

2.Bio-heat model: The temperature changes within the head associated with B_1 shimming and with quadrature excitation were calculated using the following bio-heat equation: $C_p \frac{\partial T}{\partial t} = K\nabla^2 + A_0 - B(T - T_b) + \rho SAR + P_{chip,density}$,where C_p (J/kg ºC) denotes the specific heat, K (J/m s ºC) denotes the thermal conductivity, A_o (J/m^3 s) denotes the basal metabolic rate, and B (J/m^3 s ºC) denotes the blood perfusion coefficient [3]. The time step, Δt, was set to 1.1 ms and the initial body temperature, T_b, was set to 37 ºC [3]. The transfer of heat between the domain and the surrounding environment is proportional to temperature difference between the surface and the environment, so the following boundary condition was applied: $K\frac{\partial T}{\partial n}(x,y,z) = -H_a(T_{x,y,z} - T_a)$, where H_a denotes the convective transfer coefficient (a constant with a value of 20 J/m^2 s ºC). The ambient temperature, T_a, was set to 24 ºC [3]. The thermal properties of the biological tissues within the head were obtained from [1]. Heat diffusion between the head and the environment as well as basal metabolic heating effects within the head, were allowed to continue until the temperatures in the brain leveled to steady-state [2].

Results and Discussion

The coefficient of variation of B_1^+ field distribution over the brain region was improved from 0.22 to 0.15 using B_1 shimming while keeping the total power deposition to be the same (as that with quadrature excitation) over the whole head: 12.45 Watts. Also using B_1 shimming, peak SAR over any 10 gram of tissue decreased from 22.22 W/kg to 19.25 W/kg. Figure shows B_1^+, MR image, SAR and ΔT distributions under quadrature and B_1 shimming conditions, and Table 1 gives the corresponding numerical values for those quantities. Under quadrature excitation, the peak hot spot due to SAR caused ΔT as high as 0.76 ºC; while under B_1 shimming, the peak ΔT was 0.38 ºC. While the peak SAR occurred in the vicinity of the highest temperature rise for the B_1 shimming case, this was not observed for quadrature excitation. According to the International Commission on Non-Ionizing Radiation protection, no adverse health effect are expected if the increase in body core temperature does not exceed 1 ºC for whole-body exposure to MRI apparatus. Thus the both presented cases are considered to safe (for 90^o flip angle while violation are likely to occur for higher flip angles especially for quadrature excitation) in terms of temperature criteria although both SAR peaks are relatively high and exceed the limits set by the IEC.

	B_1^+ in Brain (µT)		B_1^+ in Head (µT)		SAR in Head (W/kg)		ΔT in Head (^{o}C)	
Excite Condition	**Qua**	**Opt**	**Qua**	**Opt**	**Qua**	**Opt**	**Qua**	**Opt**
Maximum	4.96	4.35	4.96	4.79	22.22	19.25	0.76	0.38
Average	2.94	2.94	2.59	2.66	3.24	2.81	0.05	0.04
Minimum	1.28	1.42	0.96	0.84	0	0	0	0

Table 1: Numerical results the quantities shown in Fig. 1

References

[1] Demarco, S. C., et al. *IEEE TAP*, vol. 51, pp. 2274-2285, 2003.
[2] Lazzi, G., et al. *IEEE TAP,* 51, pp. 2286-95, 2003.

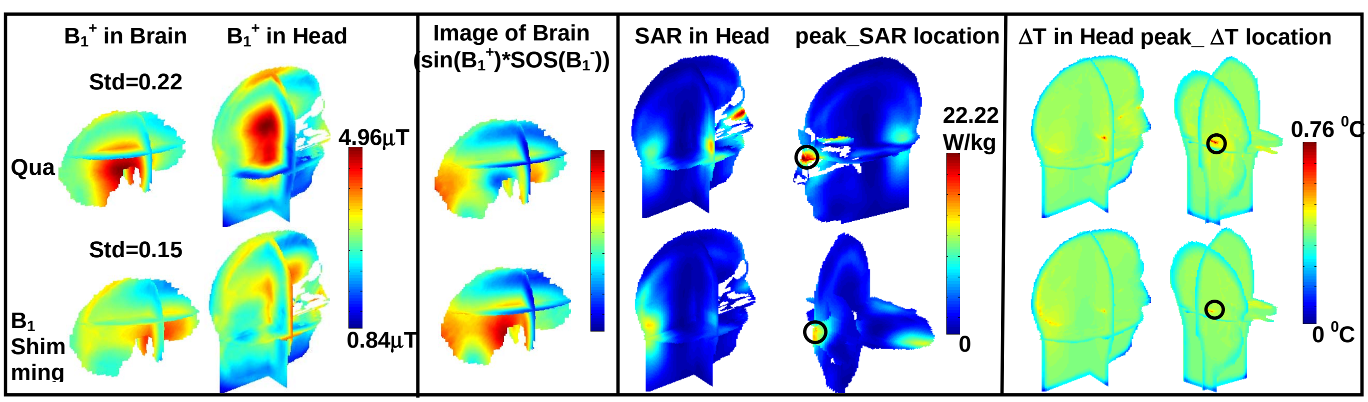

Fig. 1: B_1^+ in brain region and whole head, MR image in brain region, SAR distribution and peak SAR location in head and ΔT distributions peak ΔT location are compared under quadrature (Qua) and B_1 shimming excitation conditions. The peak SAR/ΔT locations are circled.