Comparison of Transmit Efficiency for Head Imaging at 3T and 7T

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Introduction

Head imaging at 3T is becoming routine in clinical settings. There is growing interest in head imaging at even higher fields, such as 7T, for higher signal-to-noise ratio and resolution. For image quality and RF safety reasons, one needs to understand two factors at 7T: (i) The B_1-field behavior in the head due to a short RF wavelength equivalent to the head size; (ii) SAR limits due to the increased frequency. Here we studied two birdcage T/R head coils, one at 3T and the other at 7T. Comparisons suggest the advantages of RF power scaling on per slice basis at 7T.

Methods

Two bandpass birdcage T/R head coils for use at 3T and 7T are modeled. They have similar coil configurations – both have 12 coil rungs and a closed back end plate. The coil diameters are both 30cm. The 3T head coil is 23cm long, while the 7T head coil is 4cm shorter at 19cm. Rung capacitors are distributed along each coil rung to reduce peak electric field along the rung conductors. To reduce radiation loss, a local RF shield with a diameter of 35cm is used to enclose the 7T head coil. There is no local RF shield for the 3T head coil. A commercial software package (Remcom, Inc., State College, PA) based on Finite Difference Time Domain (FDTD) method is used to model the two head coils [1,2]. Copper is modeled as a conductor with conductivity $\sigma = 5.8\times10^7$ S/m. End ring and rung capacitors are modeled by assigning passive loads in the gaps opened at their locations. A realistic 5mm resolution human body model (Remcom, Inc.) is used to load the two head coils at 3T and 7T, respectively. The loaded coil models are tuned to the NMR resonance of 128MHz (3T) and 298MHz (7T) and are driven in quadrature by two 50Ω-sources near the end plate. Steady-state solutions are saved. B_1^+-field in the rotating frame is calculated using the formula in [3]. Head SAR is calculated by averaging SAR over a head mass of 5kg and local SAR is calculated by averaging 10 grams of tissues in the head.

Results

In Fig. 1, we plot the calculated average $|B_1^+|$-field over each transverse slice vs. the z-axis for the 3T and 7T head coils, respectively. The values of $|B_1^+|$-field are normalized to the average $|B_1^+|$-field over the central transverse slice across the isocenter of each head coil. Z = 0 indicates the closed end plate. At 3T (blue curve), the average $|B_1^+|$ per slice is nearly flat in most parts of the head. There is ~24% average $|B_1^+|$ fall-off at z = 18cm. This indicates that $|B_1^+|$-field non-uniformity along the z-axis is not a big issue for 3T head imaging. Considering RF power scaling in the center transverse slice, for example, is good enough to generate uniform image intensity through out the head slices. At 7T (pink curve), the average $|B_1^+|$ per slice is dramatically different from that of the 3T, which is the highest at the top of the head and decreases toward the front end of the coil. The non-uniform $|B_1^+|$-field along the z-axis was further verified by a phantom image in a Philips 7T MRI system using the described 7T head coil. In Fig. 2, we show the central sagittal image of a 20cm-diameter phantom (σ = 0.88S/m, ε_r = 80) using a low flip angle gradient echo sequence and the simulated gradient echo image from calculated transmit $|B_1^+|$-field and receive $|B_1^-|$-field distributions in the phantom [4]. They show almost identical patterns with higher intensity near the closed end plate and much lower intensity near the front end of the 7T head coil. If one considers the RF power scaling in the center transverse slice of a head, those slices on the top of the head will be over tipped while the slices below the center slice will be under tipped. The strong non-uniform $|B_1^+|$-field will ultimately cause non-uniform transverse image intensity along the z-axis. To solve this problem, scaling RF power according to the average $|B_1^+|$-field on a per slice basis is beneficial for 7T head imaging.

In Table 1, we list the calculated head SAR and maximum local SAR for the 3T and 7T head coil configurations. For the purpose of comparison, the RF duty cycle is fixed at 3% and the average $|B_1^+|$-field over the central transverse slice is set to 10μT. It shows that the IEC's head SAR and local SAR guidelines are both satisfied for the 7T head coil [5]. At 7T, the maximum local SAR is the leading SAR limit rather than the head SAR. It is four times that at 3T. Thus at 3T one can apply much higher B_1^+-field or higher duty cycle than at 7T while the IEC's SAR guidelines can be met. Due to the non-uniform B_1^+-field along the z-axis at 7T, conducting RF power scaling on a per slice basis rather than on the center transverse slice can allow one to use higher B_1^+-field in some brain slices while keeping the same SAR values in the head. Thus scan efficiency will be improved.

Conclusions

Our calculations for specific 3T and 7T T/R head coil designs show that, head imaging at 7T can be conducted within the IEC's SAR guidelines, as with 3T, as long as B_1^+-field or RF duty cycle is restricted. At 7T, one may expect much higher B_1^+-field non-uniformity along the z-axis in the head than at 3T. Knowing the variation of B_1^+-field with the head anatomy allows one to optimize the transmit efficiency of a head coil. RF power scaling on the per slice basis rather than at a fixed transverse slice can be used to produce images with more uniform intensity. B_1^+-field strength or duty cycle per slice can be adjusted in the scan software to either increase scan efficiency or reduce SAR. For 3T head imaging, RF scaling per slice appears to be of little benefit due to relatively uniform B_1^+-field along the z-axis.

References

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3% duty cycle at 10μT	3T	7T
Head SAR (W/kg)	0.8	2.3
Max. Local SAR (W/kg)	2.5	10

Table 1. Calculated SAR for a 3T and 7T T/R head coil.

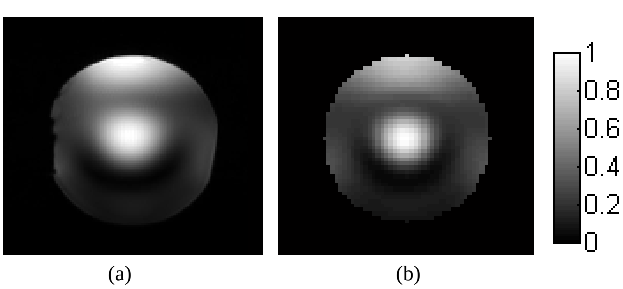
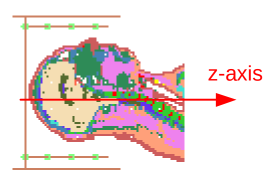


Fig 2. (a) Central sagittal image of a spheres phantom at 7T using a gradient echo sequence; (b) Simulated gradient echo image from the calculated $|B_1^+|$ and $|B_1^-|$ distributions.



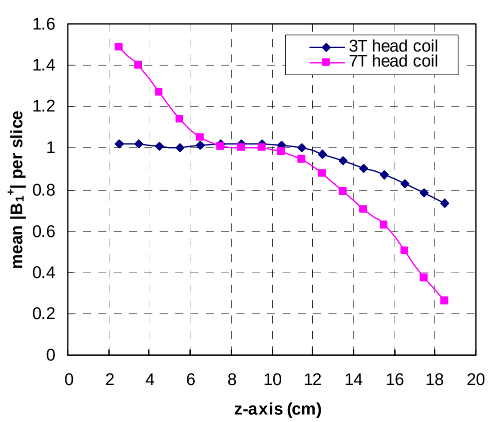


Fig 1. Normalized average B_1^+-field per slice vs. z-axis for a 3T and 7T head coil,