Comparison of Three Applied Volume Coils at 7T

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Introduction:

Ultra-high field (4T+) MRI has inherent signal-to-noise (SNR) and image resolution advantages. However, high-field human imaging systems also introduce challenges in wavelength effect, SAR issue etc. With distributed elements and shielding, TEM [1] and microstrip [2] volume coils can be used for ultra-high field. Improved birdcage coil with tight RF shield, widening rung, etc. also can be used at 7T [3]. Several studies have concerned a certain coil for high field; however, little work has been done to compare the performance of all the three volume coils at ultra-high field with same conditions [4][5]. In this study, we calculate $\mathbf{B_1}^+$ and $\mathbf{B_1}^-$ field with unloaded and loaded cases for three kinds of volume coils (Birdcage, TEM and Microstrip) at the resonant frequency of 300MHz. SNR and SAR in the head-sized phantom are also investigated.

Methods:

The finite-difference time-domain (FDTD) method is used to calculate the transient $\mathbf{B_1}$ fields of all volume coils through time-dependent Maxwell's equations at resonant frequency of 300MHz. A region of interest (ROI), 66×66×65 cm^3 was divided into a mesh of 2,265,120 Yee cells, where the basic element of 3D meshes in FDTD method is 5 mm/cell in each dimension. Shielded bandpass birdcage, TEM and microstrip volume coils were modeled in the ROI. All the coils have identical dimensions (26-cm i.d., 21-cm length), and all are open on both ends. Each coil consists of 16 rungs. The conductivity of copper (5.95×10^7 S/m) is assigned to the coil cells. The diameter of birdcage shield is 32 cm. Equal passive components (capacitors) are placed at the center of each rung and in the middle of each end ring segment of birdcage coil. Legs of birdcage are modeled as thin wires, while end rings are modeled with entire Yee cell cubes. For TEM coil, the relative permittivity of dielectric materials in the rung is 2 and out diameter is 32cm. For microstrip volume coil, the relative permittivity of dielectric materials between strip line and ground is 1.2 and out diameter is 28 cm. For better shield effect, the length of the RF shields of Birdcage and microstrip volume coils are extended 2cm longer on both ends. All the three kinds of volume coils are tuned to 300MHz and driven in quadrature by two 50Ω sources. The phantom used in this work is an 18cm diameter sphere (relative permittivity is 51.898, conductivity is 0.553 s/m) which can be used to represent average brain tissue at 300MHz. SAR was calculated after solving electrical fields in the phantom. Circularly-polarized components of the $\mathbf{B_1}$ field ($\mathbf{B_1}^+$ and $\mathbf{B_1}^-$), which are necessary for calculating signal intensity and SNR by reciprocity principle [6], are also calculated from two sets of transient $\mathbf{B_1}$ fields which are a quarter period apart in time. All simulation results are calibrated to the same conditions that the total signals in the phantom achieve maximum for all three volume coils.

Results and Discussion:

For comparison, the amplitude of $\mathbf{B_1}^+$ fields ($|B_1^+|$) at the center of all coils are normalized to 100%. Within the central axial plane, the variation over 18cm distance is about 14% for birdcage coil, 23%for TEM coil, 38% for microstrip coil, and within the central sagittal plane, the variation over 18cm distance is about 19% for birdcage coil, 34% for TEM coil and 52% for microstrip coil. It seems that birdcage structure has advantage than TEM and microstrip coils in terms of unloaded $|B_1^+|$ field homogeneity. But with loaded conditions, the percentages of samples on axial plane with $|B_1^+|$ field within ±20% of plane mean are 55%, 72% and 59% for shielded birdcage, TEM and microstrip volume coils respectively. TEM coil has the best $|B_1^+|$ field homogeneity after loading (shown in Fig.1). On the other hand, $|B_1^+|$ field homogeneity of microstrip coil is litter better than that of birdcage coil under loaded condition. It is mainly caused by wavelength effect. Average SAR and maximum local SAR for birdcage, TEM and microstrip volume coils are shown in Table 1. Microstrip volume coil has the lowest average SAR and the lowest maximum local SAR because its electric fields are mainly restricted between strip line and ground. Simulated images of the head-sized phantom are illustrated in Fig.2. After normalization, the normalized SNR on central axial plane for shield Birdcage, TEM and Microstrip volume coils are 1, 1.14, and 1.58 respectively. Microstrip coil seems better in terms of SAR and SNR than other two coils at ultra high field MRI.

	Birdcage	TEM	Microstrip
Average SAR(W/kg)	3.21	2.54	1.98
Max. Local SAR (W/kg)	6.69	5.82	3.49

Table 1: *SAR* comparison for Birdcage, TEM and Microstrip coils when the average $|B_1^+|$ is normalized to 1.17 μT (for a 90° flip angle and a pulse of 5ms duration.)

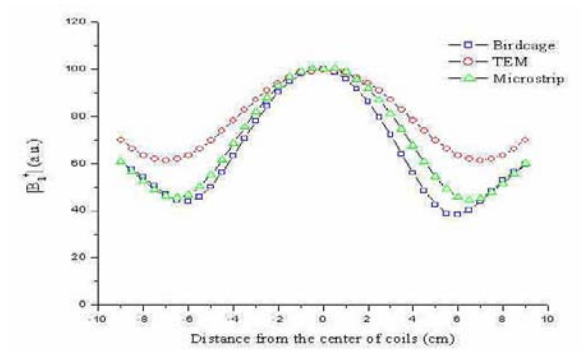

Fig.1 Simulated $|B_1^+|$ field distributions in the transverse direction for loaded volume coils. Amplitudes of $\mathbf{B_1}^+$ field at the center of all coils are normalized to 100%. TEM has better loaded $\mathbf{B_1}^+$ field homogeneity than Birdcage and Microstrip coils

Acknowledgement:

This work was supported by RGC Grant 7045/01E, 7170/03E and 7168/04E.

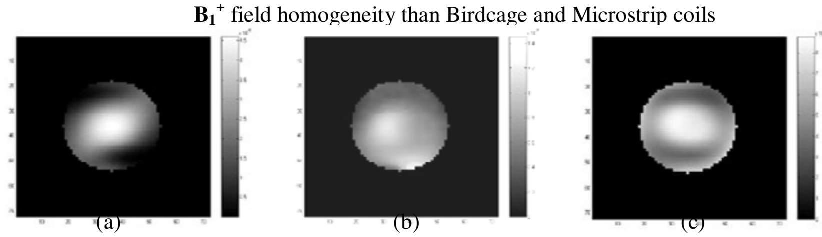

Fig.2 Simulated images of sphere phantom on the central axial plane (a) Shielded Birdcage coil, (b) TEM coil, (c) Microstrip coil. The average relative *SNR* for shield Birdcage, TEM and Microstrip coils are 1, 1.14, and 1.58 respectively.

References:

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