Numerical Comparison Between TEM Head Coil and Birdcage Head Coil at 7T

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Introduction

A TEM T/R head coil and a shielded birdcage T/R head coil operated at 298MHz/7T were both modeled using the Finite Difference Time Domain (FDTD) method. The two coils have approximately the same physical size. B_1-field and SAR were calculated for the two head coils loaded with a realistic human head model. B_1-field comparison shows a slightly better B_1-field uniformity inside the head for the birdcage coil design. SAR comparison shows, that for the same average B_1-field strength over the center slice of the head, the birdcage head coil gives lower head and local SAR.

Methods

Two kinds of T/R head coils for use at 7T were designed. The first one was a head coil based on TEM theory [1]. It has a copper cavity shell with the diameter of 35cm and the length of 18cm. Two copper end plates are connected to the cavity shell at the front and back. The back end plate is a closed cap with slots, and the front end plate is open with a 28cm-diamter patient aperture. There are 16 tunable coil elements located at a diameter of 30cm within the cavity shell. The second head coil was a shielded bandpass birdcage [2]. The geometry of the birdcage is based on that of the TEM coil. The front end plate of the TEM coil was removed and replaced with a 1cm-wide copper strip for the birdcage end ring. Gaps were opened in the end ring and ring capacitors with the value of 10pF were inserted. The 16 elements of the TEM coil were used as the birdcage rungs with distributed capacitors. To reduce the peak E-field along the coil rungs, one additional capacitor was placed in the middle of each rung. An RF shield was included for the birdcage coil at diameter of 35cm. For better shield effect, the length of the RF shield was extended 3cm longer in the front past the end-ring. The closed end cap, which is connected to the RF shield, was also included in the birdcage coil. The two coils have about the same physical size. In Fig. 1, we show the equivalent circuits of the two head coils. XFDTD software package (Remcom, Inc., State College, PA) was used to model the two coils with 2mm isotropic resolution [3]. Copper was modeled as a conductor with conductivity $\sigma = 5.8\times10^7$ S/m. Capacitors were modeled by assigning passive loads in the gaps opened at their locations. A 2mm resolution human head model with portions of the shoulders was generated from the raw data of a segmented human body model obtained from [4]. Head tissue conductivities and relative permittivities were assigned at the frequency of 298MHz using [4]. The head model was placed in the TEM and birdcage head coils. Both head coil models were tuned to 298MHz and driven in quadrature by four 50Ω-sources near the end cap. Steady-state solutions were obtained. B_1^+-field in the rotating frame was then calculated using the formula in [5]. Head SAR and local SAR were also calculated with respect to a constant average B_1^+-field strength over the central slice - the transverse slice at the isocenter of two head coils.

Results

In Fig. 2(a), we plot the normalized $|B_1^+|$-field with respect to the field at the isocenter along the z-axis for the unloaded TEM and birdcage head coils. It shows that, the TEM coil curve has a higher B_1^+-field near the end cap that monotonically decreases toward the front of the coil. The birdcage coil B_1^+-field curve is relatively flat near the end cap and decreases similarly to the TEM curve toward the front of the coil. In this comparison, the birdcage has better B_1^+-field homogeneity along the z-axis than that of the TEM coil. With the loading of a human head model, we found, that the B_1^+-field inside the head is dramatically deviated from the unloaded field by the dielectric head tissues and eddy current effects. In Fig. 2(b), we plot the normalized average B_1^+-field per slice with respect to the central slice vs. z-axis. In this case, the two curves show a similar trend but with slightly better B_1^+-field uniformity in the brain for the birdcage coil. In Fig. 2 (c), we also plot the corresponding B_1^+-field standard deviation per slice vs. z-axis. It shows that, B_1^+-field homogeneity within a slice generally improves as one moves from the neck to the brain. In the brain slices, B_1^+-field standard deviation is below 11% for both head coils.

In Table 1, we listed the calculated head SAR and maximum local SAR for the two head coil configurations. For purposes of comparison, the RF duty cycle is fixed at 2.4% and the average B_1^+-field field strength is 10μT over the central slice. It shows, that the IEC's local SAR limit (≤10W/kg) is reached first in the head for the TEM coil. Head SAR is also higher for the TEM coil. For the same average B_1^+-field strength, the birdcage coil has ~29% lower head SAR and ~27% lower local SAR compared to the TEM head coil.

Conclusions

Our numerical simulations for two T/R head coil designs at 7T show that birdcage coils are still applicable at ultra-high fields. The birdcage head coil can have comparable or better B_1^+-field uniformity along the z-axis in the head than a similarly sized TEM head coil. TEM head coil and birdcage head coil have somewhat similar B_1^+-field inhomogeneity due to the dominant head tissue effects. The birdcage head coil seems to benefit from lower SAR than a similarly sized TEM head coil.

References

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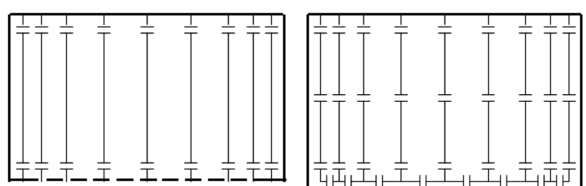
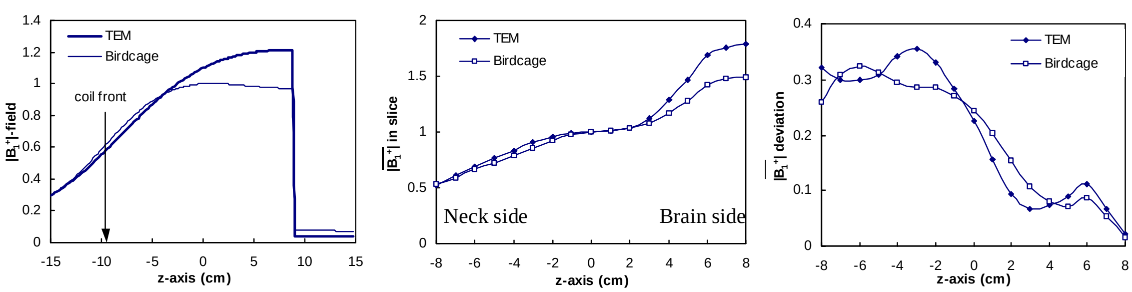
2.4% duty cycle at 10μT	TEM	Birdcage
Head SAR (W/kg)	3.1	2.2
Max. Local SAR (W/kg)	10	7.3

Table 1. Calculated SAR for TEM T/R head coil and birdcage T/R head coil.



(a) (b)

Fig 1. Equivalent circuits of two half-closed head coils at 7T: (a) TEM head coil; (b) Birdcage head coil.



(a) (b) (c)

Fig 2. (a) Normalized center B_1^+-field vs. z-axis for the unloaded TEM and birdcage head coils; (b) Average B_1^+-field in transverse slice vs. z-axis for the loaded TEM and birdcage head coils; (c) Corresponding B_1^+-field standard deviation from (b).