Experimental Comparison of TEM and Birdcage Small Animal Volume Coils at 9.4 T

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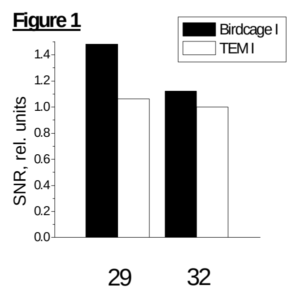
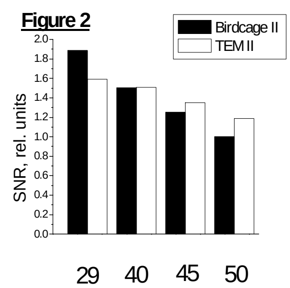
Introduction: Previously, in search for an optimal high-field (>3T) head sized MRI coil, the two most common types of RF volume coils, birdcage (BC) (1) and TEM (2), were evaluated (3-6). However, the optimal design of smaller animal volume coils also requires evaluation at higher fields where the coil size becomes comparable to the RF wavelength. In this work we evaluated the performance of small animal TEM and birdcage volume coils at 9.4T (400MHz) as a function of coil size and sample loading.

Methods: Since radiation losses, an important factor in coil optimization at high frequency, depends strongly on coil size, we built four quadrature T/R coils (two TEM and two high-pass BC) of two different sizes (mouse and rat sizes, Table 1). The smaller coils (#1 and #2) had eight rungs while both larger coils (#3 and #4) consisted of 12 elements. The resonance elements of smaller TEM coil were constructed of copper strips terminated at the ends by capacitors. The resonance elements of larger TEM coil used 3.2 mm OD coaxial elements (2). To accommodate the coaxial elements of the larger TEM (coil #4) the diameter and the shield OD was slightly larger than BC coil #3. The TEM coils were driven in quadrature by capacitive coupling to two 90º-separated elements while inductive coupling was used in the BC coils. Both BC coils and the smaller TEM (coil #2) utilized the common shield design with the shield positioned on a cylindrical holder of larger diameter. The shield of larger TEM (coil #4) was constructed similar to (2). Since the coil sensitivity ~ $(\eta_H Q_L)^{1/2}$ (Q_L the loaded coil quality-factor and η_H the magnetic field filling factor) we evaluated the dependence of coil sensitivity on Q_L and η_H using five cylindrical phantoms with diameters varying from 29 to 50 mm (Table1) containing 50 mM NaCl. The ratio of the phantom OD to the corresponding coil diameter gave an estimate of η_H. The SNRs of the coils were obtained using gradient echo transaxial images and measuring the SNR in the center of the phantom. These data were confirmed by measuring the RF power required to obtain a 90º-pulse at the same location. To mimic real animal loads, the length of the phantoms exceeded that of the RF coils, thus only the diameters of the phantoms are reported in Table 1.

Table 1. Coil parameters

Coil Description	Coil OD (cm); Shield OD (cm); length (cm)	Q_U	Q_L (29 mm)	Q_L (32 mm)	Q_L (40 mm)	Q_L (45 mm)	Q_L (50 mm)
1. Birdcage I	4.4; 7; 4.8	200	85	52			
2. TEM I	4.4; 6.4; 4.5	258	163	141			
3. Birdcage II	7; 10; 6.8	320	181		63	<30	<20
4. TEM II	7.6; 10.8; 6.8	590	322		126	70	50





Phantom OD, mm

Results and Discussion: Figures 1 and 2 compare the measured SNRs of TEM and BC coils for different phantom sizes. In these data the smallest SNR, obtained with the largest phantom, was scaled to 1.0. Both BC coils had better SNR at smaller filling factors, while with increasing filling factors the TEM sensitivity becomes comparable to and exceeds the birdcage SNR for larger coils. BC coil #1 has about 40% higher SNR than the TEM of the same size for the smallest phantom. For the larger phantom, the BC performance was only ~ 10÷15% better. Similarly, the larger BC (coil #3) performed ~ 20% better than TEM (coil #4) for the smallest phantom (OD 2.9 cm), and, vice versa, the TEM had about 20% better SNR for the largest phantom. These measurements are in good agreement with the measured Q_L value (Table 1), which represents the coil sensitivity. The BC's Q_L decreases with increasing phantom size substantially faster than the TEM's Q_L. Also, it is noteworthy, that the ratio of the phantom OD to the coil OD (essentially η_H) at the point, where both types of coils provided similar performances, decreased from ~ 75% for the smaller coils (#1 and #2) to ~ 55% for the larger coils (#3 and #4). Both types of coils, TEM and BC, provided very similar transaxial plane homogeneities. In comparison to the BC coil, the TEM coil provided ~20% greater region of homogeneous RF magnetic field ($\Delta B_1/B_{1max} < 40\%$) along the longitudinal axis. The smaller TEM coil #2 was shorter than BC of the same diameter but had slightly larger (~ 5 %) region of homogeneity. For this reason the length of TEM coils can be made shorter, which would further improve the TEM coils' performances.

Conclusion: Birdcage coils were shown to perform better than TEMs for small filling factors. The sensitivities of both types of coils become comparable with increasing filling factor (or phantom diameter). For larger diameter coils (coils #3 and 4) the TEM coil provided slightly better performance at large filling factors ($OD_{phantom}/OD_{coil} > 0.55$). Thus for small coils with small samples (mouse imaging) BC coils may provide an optimal design. However, for larger rat sized body coils, TEMs are likely to provide better performance. Other factors that may also affect the coil performance such as the shield geometry (6) should be considered.

References: 1) Hayes CE et.al., J Magn Reson 1985;63:622-6218. 2) Vaughan JT et.al., MRM 1994;32:206-218. 3) Vaughan JT, Proc. ISMRM 1998, 646. 4) Tropp J et.al. Proc. ISMRM 2001, 1119. 5) DeMeester GD et.al. Proc. ISMRM 2004, 35. 6) Liu W et.al. MRM 2004;51:217-221.