Looking for T/R Coils with Long Field of View for 7T head Imaging

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Introduction

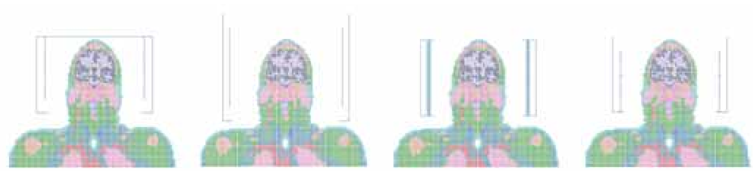
At this time, the most common use of a 7T whole body MRI system is for head imaging. The shortcoming of some head T/R coils is the limited B_1-field coverage along the z-axis in the head. These coils are good for brain studies but lack enough SNR for the lower part of the head near the neck and carotids. Here, we shed some light in the search of a T/R head coil which could give a long FoV. We numerically modeled four different T/R head coils. Analysis reveals that, birdcage coils have the advantages of higher coil transmit efficiency and lower SAR, but less FoV. With special arrangement of a coil design, axial B_1-field coverage can be improved but at the cost of B_1 non-uniformity, lower coil efficiency and higher SAR.

Methods

Four kinds of T/R head coils at 7T are modeled using a FDTD numerical method [1,2]: (1) a shielded half-closed 12-element band-pass birdcage coil with one front end ring and a closed back end cap; (2) a shielded 16-element high-pass large volume birdcage coil with both ends open; (3) a conventional 16-element TEM coil; and (4) a 12-element hybrid coil where the back plate of a TEM coil is replaced with a birdcage end ring that results in a half TEM and a half birdcage resonant structure. In Table 1, we list all the dimensions for these coils. A XFDTD software package with a human head model plus portions of the shoulders is used in the study (Remcom, Inc., State College, PA). To reduce power loss through the shoulders, a shoulder shield is placed in the radial direction at the front end in both birdcage coils. The head model is loaded deep into the head coils. In Figure 1, we show the four coil models with the head load. All coil models are tuned to the resonant frequency of 298MHz and driven with 4-port feed in quadrature. Steady-state solutions are obtained then $|B_1^+|$-field (B_1-field in the rotating frame) is calculated using the formula in [3]. To compare with FoV along the z-axis, $|B_1^+|$-field in the central coronal and sagittal slices of the head are calculated. Coil transmit efficiency is calculated as $|B_1^+|_{ave}/P_{abs}^{1/2}$, where $|B_1^+|_{ave}$ is the average $|B_1^+|$ over the central transverse slice and P_{abs} is the total absorbed power. Since local SAR is the dominant SAR in the head at 7T, the maximum local SAR (average SAR over 10g tissues) is also calculated for a fixed $|B_1^+|_{ave} = 1\mu T$.

T/R head coils	Coil diameter	Coil length	Shield diameter
Half-closed birdcage	30cm	19cm	35cm
Large volume birdcage	34cm	24cm	38cm
TEM coil	30cm	23cm	35cm
Hybrid coil	30cm	19cm	35cm

Table. 1. The dimensions of four 7T T/R head coil models.



(1) (2) (3) (4)

Figure 1. Four 7T T/R head coil models with the load of a head model.

Results

In Figure 2, we show the normalized $|B_1^+|/|B_1^+|_{iso}$ in the central coronal and sagittal slices of the head model in the four T/R head coils, where $|B_1^+|_{iso}$ is the $|B_1^+|$ at the center of these head coils. As seen, at 7T, the $|B_1^+|$ non-uniformity is dominant by the head load. The overall $|B_1^+|$ distribution patterns for four head coils show great similarities, which have a bright $|B_1^+|$ spot in the center of the head, and weak $|B_1^+|$ bands along the head periphery. However, with different coil structure arrangements, $|B_1^+|$ coverage along the z-axis can be different. For the two head coils with the same coil diameter and length, the half-closed birdcage coil shows the least $|B_1^+|$ coverage along the z-axis in the head, while the hybrid coil has the longest $|B_1^+|$ coverage which extends to the neck. For the longer head coils, the TEM coil has better $|B_1^+|$ coverage than that of the large volume birdcage coil. The existence of the end rings in a birdcage coil reduces the $|B_1^+|$-field uniformity along the z-axis.

To numerically compare FoV along the z-axis for the four head coils, $|B_1^+|$-field standard deviation (no unit) is calculated at FoV = 14cm and 23cm, respectively. For FoV = 14cm, the imaging area is mainly in the brain. For FoV = 23cm, the imaging area is extended from the top of head to the chin region. As seen from Table 2, the TEM coil has the lowest $|B_1^+|$ deviation in both FoVs, indicating more uniform head sagittal and coronal imaging. The birdcage coils have higher transmit efficiency and lower local SAR, indicating higher imaging SNR. The birdcage coils are good for brain imaging but lack enough SNR in the extended imaging region beyond brain. The large volume birdcage coil has better performance than the smaller half-closed birdcage coil. It can be used as a T/R coil or as a transmit coil together with SENSE receive coils. However, with the smaller size and addition of a closed end cap, the half-closed birdcage head coil has the highest $|B_1^+|$ sensitivity in the top part of the brain, making it an ideal T/R coil for brain study. The hybrid coil can extend the $|B_1^+|$ coverage further to the neck region, but at the cost of the lowest transmit efficiency and the highest local SAR.

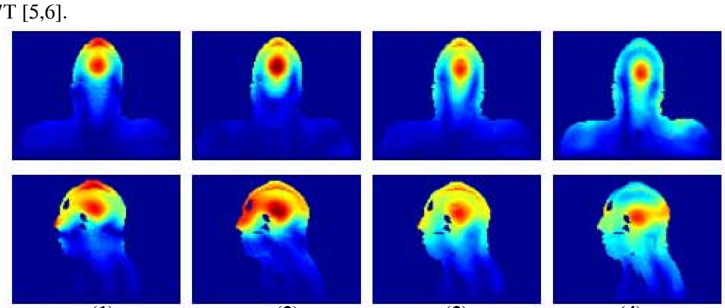
Conclusions

Our numerical analysis shows that, it is challenging to design a 7T T/R head coil with both long $|B_1^+|$ coverage in the z-axis and high transmit efficiency. TEM head coils can provide long uniform FoV along the z-axis but have less coil efficiency and higher SAR. On the other hand, birdcage head coils can have high coil efficiency and lower SAR but lack of extended $|B_1^+|$ coverage for imaging the lower part of the head. In practice, one would need both types of head coils and use them according to the needs. It is possible to further extend $|B_1^+|$ coverage to the neck region with a hybrid coil, in this example, a head coil in which the front end is a TEM coil type and the back end is a birdcage end ring type. However, extending $|B_1^+|$ coverage will inevitably increase absorbed power, thus reducing coil transmit efficiency and causing higher local SAR. Such a coil may have limited use due to the strong $|B_1^+|$ non-uniformity as the imaging region extends. Applying RF shimming with a multi-channel large volume coil may be the next step for long FoV head imaging at 7T [5,6].

References

T/R head coils	Sagittal $|B_1^+|$ deviation		Coronal $|B_1^+|$ deviation		Transmit efficiency	Max. local SAR
	z=14	z=23	z=14	z=23		
Half-closed birdcage	0.23	0.47	0.36	0.66	$0.43\mu T/W^{1/2}$	2.8W/kg
Large volume birdcage	0.18	0.54	0.33	0.60	$0.46\mu T/W^{1/2}$	2.1W/kg
TEM coil	0.15	0.29	0.30	0.39	$0.33\mu T/W^{1/2}$	3.3W/kg
Hybrid coil	0.28	0.29	0.37	0.39	$0.26\mu T/W^{1/2}$	4.9W/kg

Table 2. Coil performance comparison of four 7T T/R head coil model.



(1) (2) (3) (4)

Figure 2. Calculated $|B_1^+|/|B_1^+|_{iso}$ in the central coronal and sagittal slices of the head model in four T/R head coils: (1) half-closed birdcage; (2) large volume birdcage; (3) TEM coil; and (4) a hybrid coil.