Shoulder Shield for 7.0T T/R Brain Coil

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Introduction

When using a shielded birdcage 7T T/R brain coil for brain imaging, some unwanted signals and loading come from the shoulders outside the coil. This can be attributed to the increased coupling and power loss to the shoulders at 298MHz. To reduce the shoulder effect and increase SNR, a shoulder shield, which can be treated as the extension of the RF shield in the radial direction, is introduced. Numerical analysis reveals that, the openness of the shoulder shield and its distance to the end ring of the birdcage affect the performance of the T/R coil as well as the degree of coupling to the shoulders. A shoulder shield with optimal openness and position can increase coil efficiency without increasing head and local SAR.

Methods

A shielded 12-element band-pass birdcage T/R brain coil was designed for human brain imaging at 7T. The brain coil has the rung diameter of 30cm and length of 19cm. It has one front end ring. The other side of the coil is closed with a conducting end cap, which is connected to a 35cm-diameter RF shield. To reduce power loss through the shoulders, a shoulder shield is placed in the radial direction at the open end of the coil and is connected to the RF shield. In Fig. 1(a), we show the schematic of a coil with the shoulder shield. To study the effect of the shoulder shield on the performance of the T/R coil, we vary the open diameter of the shoulder shield *D* and its distance to the edge of the coil end ring *L* and conduct the numerical analysis using a numerical FDTD method [1,2]. A XFDTD software package (Remcom, Inc., State College, PA) is used to model the T/R coil with 5mm isotropic resolution. To load the coil model, we make a head plus portions of the shoulder model from a 5mm-resolution heterogeneous human body model (Remcom, Inc.), as shown in Fig. 1(b). The head model is placed inside the coil with 5mm space left between the top of the head and the end cap. To simplify the modeling, we fix the values of the rung capacitors and excite the loaded coil in the end ring at 298MHz. We place twelve RF voltage sources in the gaps opened at the positions of the end ring capacitors based on the birdcage resonance theory [3]. Steady-state solutions are obtained and B_1-field in the rotating frame is then calculated using the formula in [4]. For the coil in transmit mode, we calculated and compare the percentage of absorbed power by the shoulders P_s/P_{abs}, head SAR (average SAR in 5.5kg head) and maximum local SAR (average SAR over 10g-tissue) for each (*D*, *L*) with a fixed RF scale value of $|B_1^+|_{ave}$, where $|B_1^+|_{ave}$ is the average transmit $|B_1^+|$-field over the transverse slice crossing the isocenter of the coil and P_{abs} is the total absorbed power. For the coil in receive mode, we calculate and compare $|B_1^-|_{ave}/P_{abs}^{1/2}$ per unit current in the coil rungs, since SNR $\propto |B_1^-|_{ave}/P_{abs}^{1/2}$ when assuming the same transmit field $|B_1^+|_{ave}$ [5]. Here $|B_1^-|_{ave}$ is the average receive $|B_1^-|$-field over the same center slice.

Results

First, we fix the distance *L* and study the effects of open diameter *D* of the shoulder shield. Fig. 2(a) is the plot of P_s/P_{abs} vs. *D* for fixed *L* = 4cm, where *D* = 35cm is the coil without the proposed shoulder shield. It is seen that, as we decrease the openness of the shoulder shield, the power absorbed by the shoulders decreases from 22% for the coil without the shoulder shield (*D* = 35cm) to 4% for the coil with a shoulder shield of *D* = 25cm. Adding the shoulder shield effectively reduces the power loss. Fig. 2(b) is the plot of the normalized ratio $|B_1^-|_{ave}/P_{abs}^{1/2}$ vs. *D*, where all values are normalized to the coil without a shoulder shield (*D* = 35cm). As seen, the ratio increases as *D* decreases. It indicates that we could increase SNR by 12% if we implement a shoulder shield with 25cm-openness on our original coil without a shoulder shield (*D* = 35cm case). Comparisons of the head SAR and maximum local SAR also show less than ±5% changes from the values of the coil without a shoulder shield. The benefits of having a less-open shoulder shield is clearly seen. However in practice, we should use a shoulder shield that has sufficient openness to fit a majority of human head sizes. *D* = 28cm gives a reasonable compromise.

Next, we fix the open diameter *D* and study the effects of distance to the end ring *L*. Fig. 2(c) is the plot of P_s/P_{abs} vs. *L* for fixed *D* = 28cm. At *L* = 5.5cm, the absorbed power is 14%, where at *L* = 1cm, it reduces to 2%. As expected, the closer the shoulder shield is placed to the end ring, the less power will be absorbed by the shoulders. Fig. 2(d) is the plot of the normalized ratio $|B_1^-|_{ave}/P_{abs}^{1/2}$ vs. *L*, where all values are normalized to the coil without a shoulder shield (*D* = 35cm case in Fig 2(b)). The ratio increases as the shoulder shield is moved closer to the end ring. However, when the shoulder shield is too close to the end ring, such as *L* = 1cm case, we see a drop of the ratio due to the faster reduction of $|B_1^-|_{ave}$, indicating a negative effect of the shoulder shield to $|B_1^-|$-field contribution from the end ring. For *D* = 28cm, we find *L* = 1.5cm is an optimal distance with the value of 1.16. Comparisons of the head SAR and maximum local SAR at *L* = 1.5cm also show that both values are less than those of the original coil without a shoulder shield.

Conclusions

Our numerical analysis shows that, with the implementation of a shoulder shield for a shielded birdcage T/R brain coil at 7T, power loss to the shoulders can be considerably reduced. The effectiveness of the shoulder shield depends on its open diameter and its distance to the end ring of the birdcage. The smaller the inner diameter of a shoulder shield is made, the more effective it is. However, the addition of a shoulder shield should not reduce the coil access for the majority of human head sizes. An optimal shoulder shield with the proper openness and distance to the end ring of the birdcage can reduce SAR and increase SNR by quite a substantial degree. The concept of shoulder shield can be implemented in other variations for ultra-high field imaging at 7T and above.

References

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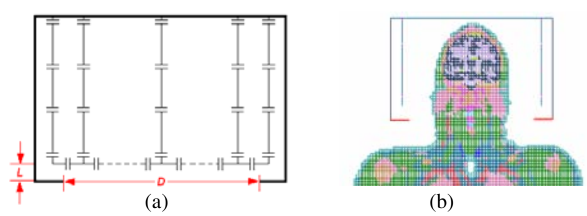

Fig 1. (a) Schematic of a birdcage 7T T/R brain coil with shoulder shield of (*D*, *L*); (b) FDTD model of the head loaded coil with portions of the shoulders.

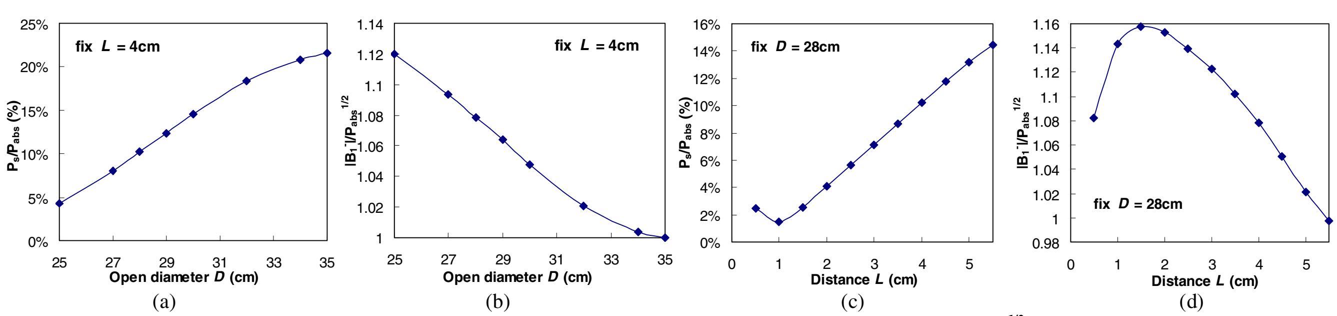

Fig 2. A 7T T/R brain coil with shoulder shield of (*D*, *L*): (a) P_s/P_{abs} vs. *D* for fixed *L* = 4cm; (b) $|B_1^-|_{ave}/P_{abs}^{1/2}$ vs. *D* for fixed *L* = 4cm; (c) P_s/P_{abs} vs. *L* for fixed *D* = 28cm; (d) $|B_1^-|_{ave}/P_{abs}^{1/2}$ vs. *L* for fixed *D* = 28cm. Note: (b) and (d) are normalized to the value of (*D* = 35cm, *L* = 4cm).