Signal-to-Noise Ratio gain at 3T using a thin layer of high-permittivity material inside enclosing receive arrays

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TARGET AUDIENCE

Radiofrequency (RF) coil designers and anyone interested in electromagnetic field behavior.

PURPOSE

Cushions of high-permittivity material (HPM) can be placed near or adjacent to the sample to increase signal-to-noise ratio (SNR), decrease specific absorption rate (SAR) and improve B_1 homogeneity and transmit efficiency of RF coils in a region of interest near the HPM (1-4). Here we report a semi-analytical investigation of the SNR advantage of completely covering the inside surface of enclosing RF coil arrays with a thin continuous layer of HPM.

THEORY AND METHODS

We employed a dyadic Green's function (DGF) framework for multi-layered spherical geometries (5) to extend a previously proposed formalism for rapid analytic SNR calculations inside a uniform sphere (6). With this method, any current distribution can be expressed as a weighted combination of the elements of a complete basis of current modes, defined on a spherical surface at a fixed distance from the object. We modeled an 8.4 cm radius (r_S) uniform sphere with average brain electrical properties at 3T (ε_r = 63, σ = 0.46) and we defined enclosing loop arrays with an increasing number of symmetrically packed RF coils (8, 16, 32, 48, 64) at a distance of 2 cm (r_C = 10.4 cm) from the surface of the object (Fig. 1). A continuous layer of HPM with thickness = 1 cm, σ = 0 and ε_r = 500 was modeled under the coil elements (Fig. 1), leaving a 1 cm air gap between the coils and the object (r_O = 9.4 cm). We simulated the SNR for a transverse and a sagittal section through the center of the sphere (SNR^{HPM}) and we compared it with the SNR in the absence of the HPM (i.e., 2 cm air gap between the coils and the object).

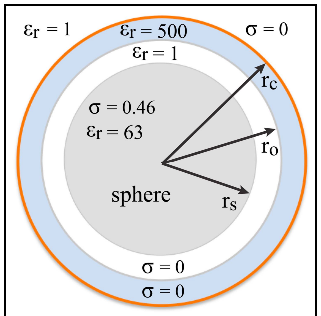

Fig. 1. Schematic of the multi-layer spherical geometry. A layer (1 cm) of HPM (blue ring) was placed under the coil conductors (orange circle).

RESULTS

Adding a layer of HPM increased the average SNR within the field-of-view (FOV) in all cases (Fig. 2). The largest SNR gain was observed near the surface of the object in all cases except for the 16-element array in the transverse FOV. In general, SNR gain was smaller in the central region of the sphere, but only for the 8-element array it was negative for large regions of the FOV. When there were at least 32 RF coils in the array, the SNR gain was always positive, although it varied spatially within the FOV. For the 64-element array, SNR improved on average by 13% with a maximum of more than 30% near the surface and a minimum of 1.1% in the center.

DISCUSSION

Here we show that it is possible to improve the SNR of an encircling receive array by adding a thin layer of HPM close to the coil elements. Although for some anatomies (e.g., abdomen) flexible receive arrays can be positioned in close contact to the body, in brain imaging it is common to have a gap between the subject's head and the inside of the helmet-shaped head coil. Our results suggest that using part of this empty space to incorporate a layer of HPM directly in the substrate of a detector coil array could be an inexpensive method to improve SNR. SNR gain varied spatially within the FOV and was less circularly symmetric for lower number of array elements, reflecting the less uniform packing of the coils. When the array had at least 32 coils, SNR gain was more homogeneous and improved everywhere in the FOV. Although the array simulated in this study fully surrounded the sphere, SNR distribution would not be affected substantially if the same number of coils were arranged to accommodate the neck and the face of a patient (7). The SNR gain observed in the presence of HPM is likely due to a combination of factors, but a comprehensive theoretical explanation has not been established yet. Part of the advantage is likely due to the fact that the HPM layer improves matching in the near field of the coils (8), therefore reducing radiation losses. This suggests that in-vivo SNR gain could be even higher than what we observed, as the presence of the HPM would facilitate capture of a larger amount of the magnetic flux from the head, while reducing the detected noise from the rest of the body (mostly neck and shoulders). Although a limitation of this study is the use of a uniform sphere to approximate the human head, similar simulation studies have provided useful physical insights for RF coil design (6).

CONCLUSION

This study suggests that adding a layer of HPM in the design of a head array with at least 32-elements could increase SNR everywhere in the FOV. Future work will include a search for the optimal dielectric constant of the HPM, numerical simulations with full-body human models to confirm the hypothesis of further SNR gain associated with improved matching, as well as experimental validation at 3T.

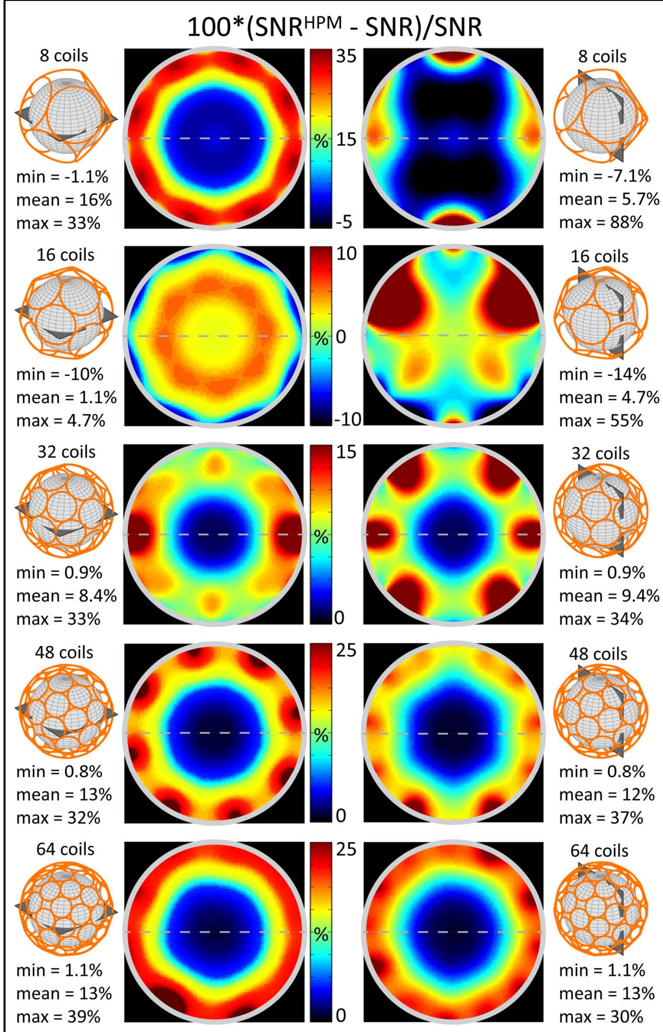

Fig. 2. SNR gain using a 1 cm layer of HPM (ε_r = 500) under the coil elements of an enclosing array. Average SNR gain in the FOV is always greater than one and grows for increasing number of coils. SNR gain varies spatially and in all but one case reaches its maximum near the surface of the object, indicated by the gray circle. The dotted gray line shows the intersection of the transverse (left) and sagittal planes (right). The color scale is adjusted independently for every row.

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