

Design Criteria of an MR-PET Array Coil for Highly Parallel MR Brain Imaging

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Introduction: Simultaneous acquisition of MR and PET images has the potential to combine high spatial resolution and high contrast MR data with specific functional molecular imaging in a wide range of clinical and research applications. Highly parallel MR imaging has proven valuable for increased image sensitivity and acquisition speed [1]. However, the development of a 32-channel brain array for MR-PET is highly constrained by the small geometry of the current generation MR-compatible Brain-PET scanners and the γ -ray attenuation of materials from the MR transmit coil and receive array. The latter results in decreased sensitivity (i.e. increased image noise or longer PET acquisition times to make up for the counts absorbed by the MR array) as well as in the introduction of artifacts if the coil attenuation is not accounted for [2]. In this study, we evaluate design criteria of a 32-ch MR-PET coil (31-ch receive array / 1-ch volume receive), designed to have a sparse configuration of 511 keV absorptive materials and optimized arrangement of components (e.g. preamplifier, cables, and cable traps) inside the PET insert. The design considerations presented in this work target improved performance of SNR and parallel imaging, while minimizing the interference with γ -ray detection from the PET camera.

Materials and Methods: The major criteria for the design of a PET-compatible parallel phased array are (1) sensitivity of the MR image compared to current coil designs by implementing a 32-ch parallel phased array on a tight-fitting helmet, (2) to fit into the tight bore of the Brain-PET camera, (3) to remove all possible components (i.e. the preamplifiers) outside the field of view (FOV) of the PET camera, (4) to choose coil components within the PET-FOV for minimal attenuation of 511 keV γ -rays while maintaining sensitivity from the MR signal. The latter criterion requires experimental/simulated data of material properties to find materials optimized for both MR and PET performance. We investigated all components that might attenuate the PET signals and assessed the effect of low attenuating components on MR sensitivity. For the conductor material of the loops, we compared the attenuation of Aluminum (Al) and Copper (Cu) and measured the SNR of the MR image from a single loop of Al ("soldered" with conductive glue), Cu foil and 16 awg, 18 awg and 24 awg Cu wire. Since Al has a significantly lower atomic number ($Z=13$) compared to Cu ($Z=29$), as well as a lower density, Al is a low-attenuation alternative to Cu [3], as is a thinner Cu wire. Calculations were made using the Beer-Lambert law $I/I_0 = \exp(-(\mu/p)x)$ with mass attenuation coefficients (μ/p) taken from the literature [4] at 511 keV. Additionally, test samples were measured with the PET scanner. The tradeoffs associated with reducing the size of the coaxial cable that connects a loop to the preamplifier was assessed since this component is necessarily in the middle of the PET-FOV. MR SNR measurements were balanced against losses and artifacts of the 2.2 mm and 0.8 mm diameter coaxes in a simulated PET image. The PET simulation was carried out using linear attenuation coefficients for different coaxial cables derived from a CT scan. The attenuation from a simulated half-ring of 12 cables was used in the reconstruction of real PET data from a cylindrical Ge-68 PET phantom. To reduce the attenuation from the helmet material, the optimal thickness was found from calculations of attenuation for plastics. The helmet containing the receive array was tightly fitted to an average adult head shape such that sensitivity of the MR coil is maximized. It was designed in a CAD program and built with an ABS 3D printer.

Results: The CAD design of the helmet (Figure 1) shows the placement of the preamplifiers outside the PET-FOV. The dimensions of the coil were fitted to the PET-FOV with diameter of 285 mm and length of 195 mm. The hexagonal patterns demonstrate the location of the 31 loops around the head. The attenuation of transmitted beams for Al and Cu show that for thin cables of up to 1 mm there is a negligible (<5%) difference in the attenuation between using Al and Cu (Table 1). Furthermore, SNR values from a loop of Al foil was 21% lower than for Cu foil (Figure 3(a)). Experimental PET data showed no difference in the attenuation of Cu or Al. The relative MR-SNR of the 16 awg, 18 awg, 24 awg wires were 1, 0.93, and 0.64 respectively (Figure 3(b)). Results from PET simulations showed increased artifacts from the thicker coaxial cable compared to the thin coaxial cable (Figure 4). Considering that the MR SNR is not significantly different for these cables (Figure 3(a)), reduction of the cable diameter was judged a good trade-off.

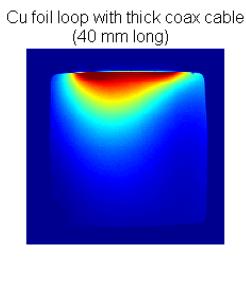


Figure 2: SNR map of MR phantom

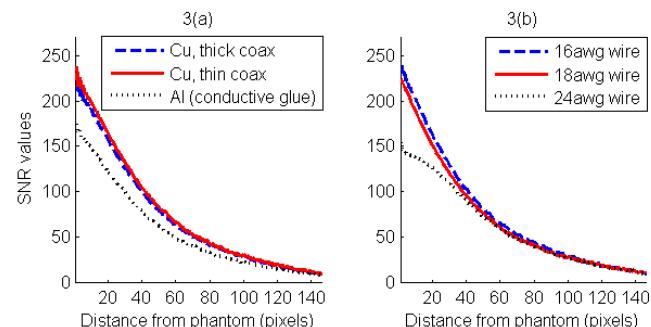


Figure 3: SNR profiles taken from middle column of Fig. 2 for (a) Cu, Al foil and different coax cables thicknesses (b) for different Cu wire thicknesses.

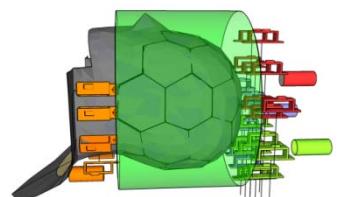


Figure 1: CAD design of 32-ch receive array, with preamplifiers outside the PET-FOV (green).

Thickness	I/I ₀ for 511keV	
	Al	Cu
1 μ m	1	0.99
100 μ m	0.99	0.99
511 μ m (24 gauge)	0.99	0.97
1024 μ m (18 gauge)	0.98	0.93

Table 1: Fraction of transmitted beams for Al and Cu at different thicknesses at energies 500 keV.

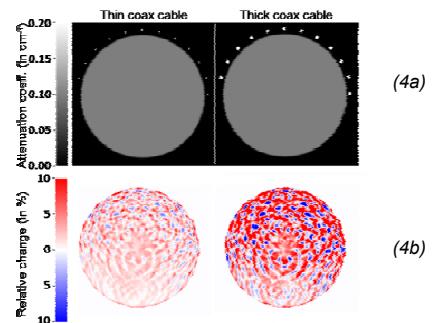


Figure 4: (a) Simulated attenuation maps with coaxes on top of phantom. (b) Relative change of PET data including effect of simulated attn. maps.

Conclusion: The final materials for the design of the 32-ch parallel phased array were chosen to be: Cu (18 awg) for the loop wire due to better SNR with minimal increased attenuation, thin coaxial cable for minimization of possible PET image artifacts, 3 mm thickness for the helmet for minimal PET attenuation. The layout of the final design is shown in Figure 1.

References: [1] Wiggins, G.C. et al. (2006) MRM 56:1, 216-23. [2] Catana, C. et al. 2010, JNM 51 :1431-8. [3] Rieke, V. et al. (2004) Proc. ISMRM 11, 379. [4] Hubbell, J.H. (1982) *Intl. J. Appl. Radiat. Isot.* 33, 1269-90. [5] Roemer, P.B. et al. 1990, MRM 16:2, 192-225.