Constraints imposed on MRI in a mixed modality PET/MRI system

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Introduction

Mixing the modalities of PET and MRI is an important direction to take for both clinical and small animal imaging. It allows: the excellent soft tissue contrast and anatomical information of MRI to be combined with the functional information of PET; direct co-registration of images; truly simultaneous image acquisition (unlike in PET/CT[i]); and the exciting possibility of tracking individual cells, radioactively labeled as they are injected into a subject. However, any material that can act as a source of attenuation and/or scatter can and will have an effect on the collection and interpretation of the two 511 keV γ-ray photons used in PET.

The effects of the gradient/shim insert and RF coil and shield on the collection of PET data and the final PET image have been investigated using a Monte Carlo simulation tool based on the GEANT libraries[ii]. The tool has been used to quantify the effect of the various components of an open MRI system (in this case the field-cycled MRI system nearing completion at the University of Western Ontario) upon the quality of PET data, and in particular to answer the question of whether standard RF technology can be used. The conclusions drawn are general for combining any MRI system with PET using ^{18}F.

Method

The MRI components modeled include the RF coil and shield (both 1 mm thickness of copper), combined shims and gradients (modeled as an amorphous mixture of copper and epoxy of 1cm thickness) and the polarizing and readout magnets used by field-cycled MRI[iii,iv] as shown in Figure 1(modeled as large volumes of copper). The PET ring in the simulation was composed of 24 rings of 314 LSO detector elements[v]. Positrons were created with the energy spectrum of the ^{18}F decay[vi] at six points within a spherical tissue sample of radius 5 cm and were tracked until an annihilation occurred, producing the two 511 keV γ's, which were themselves tracked. All hits were recorded and used to form sinograms for imaging using a filtered back-projection technique. A set of simulated data was created as each piece of the MRI system was included, so that the attenuation and scattering caused by each component could be studied. An additional study with no gradients or shims was performed to investigate the effects of varying the RF shield thickness.

Results

The total number of coincidence events, where both of the γ-rays detected had their energy within the window 350 keV - 650 keV, was used to calculate the attenuation of the γ-ray flux and is shown in Figure 2. Three sets of simulations were studied to look for artifacts and resolution problems caused by the scattering of γ-ray photons passing through the MRI system components: that of the PET system alone; after the addition of the rf coil and shield; and after the addition of the gradient/shims. Images created using these data sets are shown in Figure 3. The effect of the RF shield was investigated independently by varying its thickness and normalizing the number of coincidences using the bare PET system integral. The attenuation is shown in Figure 4, which is fitted with an exponential function to quantify the expected loss of signal as a function of the shield thickness.

Discussion

Clearly, the greatest problem facing PET data acquisition is due to the gradient/shim insert, which causes a 25% loss in detected coincidences. This loss can be alleviated by the use of open shims and gradients, which have no high *Z* material, (i.e. copper wire), in the annulus around the imaging volume. This would be essential in higher field systems due to the larger gradients required, which would cause more attenuation. The losses caused by the RF shield are more problematic for low field systems, such as the field-cycled system, which operates at 5 MHz, and a probable RF shield thickness of 500 microns would result in a loss of ~3 % of the signal, which while significant does not require drastically longer scanner times.

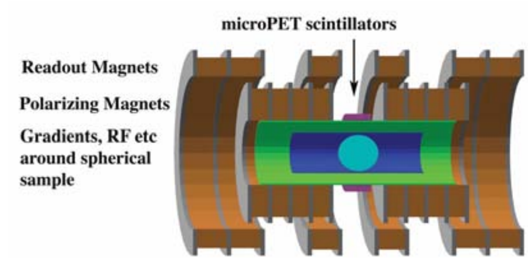

Figure 1 A cross section of the combined mixed modality system modeled

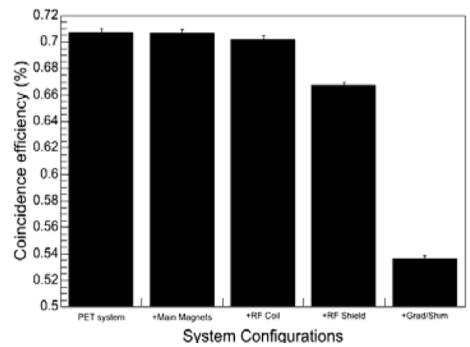

Figure 2 The attenuation of the 511 coincidences as components are added to the system.

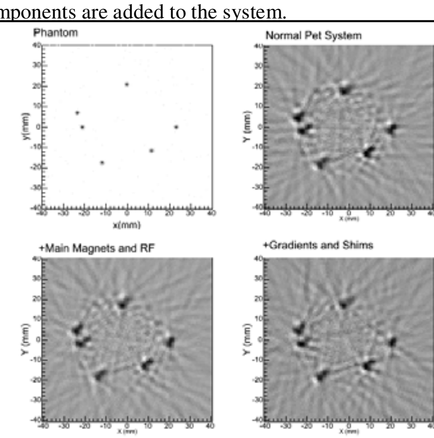

Figure 3 Images reconstructed from three of the

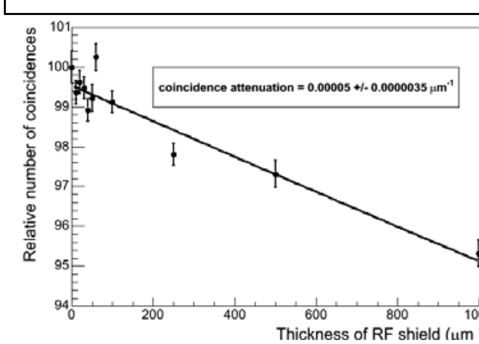

Figure 4 The number of coincidences normalized to a bare PET system as the RF shield is changed in thickness.

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[i] Beyer et al, "*A Combined PET/CT Scanner for Clinical Oncology*", J. Nucl. Med., **41**
[ii] Agostinelli et al. "*GEANT4- a simulation tool kit*" NIMA (2003)
[iii] K. Gilbert et al., Proc. 13th ISMRM, 865 (2005).
[iv] A. Macovski & S. Connoly. "*Novel Approaches to low cost mri*" MRM, (1993)
[v] T. Ludziejewski et al IEEE Trans. Nucl. Sci. (1995)
[vi] E. J. Konopinski. "*The Theory of Beta Radioactivity"* (1966)