On the Effects of Magnetic Fields up to 9.4T on PET Image Resolution and Quality Measured with an MR-BrainPET

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Introduction

The development of hybrid MR-PET scanners has recently gained momentum following on from the announcement of prototype devices by two major manufacturers of clinical imaging equipment. Although the development of integrated hybrid MR-PET machines is a major engineering challenge which might be viewed as a disadvantage, it does offer new possibilities in that spatial as well as temporal coherence is a given. In such an instrument, there is another, incidental, advantage that comes to the fore; that is, the range of the emitted positron is somewhat more circumscribed because of the presence of a large static magnetic field. The circumscribed range should therefore manifest itself in an improved spatial resolution in the PET image in the two directions perpendicular to the main magnetic field of the MR magnet. Here, we report investigations performed in a newly-installed MR-PET scanner comprising a 9.4 T human whole-body MR scanner and an APD-based BrainPET insert in the MR bore.

Methods

The MR component of the 9.4T MR-BrainPET is a whole-body MR scanner newly constructed in a collaborative effort between Siemens and the Forschungszentrum Juelich. The magnet has a free bore of 90 cm and the inner bore of the gradient coil is 60cm into which the BrainPET can be inserted. The BrainPET detector uses 12 x 12 arrays of LSO crystals each sized 2.5x2.5x20 mm^3 and arranged in 6 rings. An image from a point source (source A) of 1 mm^3 was measured with the source positioned in the middle of a 20x20x20 cm^3 block of polyethylane foam with a density of 0.1 g/cm^3. A second point source (source B) of 1 mm^3 was imaged in a cylindrical block of polyethylane foam with a diameter of 25 cm, an axial length of 20 cm and a density of 0.027 g/cm^3. Finally, a 10x10x10 cm^3 block of polyethylane foam with a density of 0.1 g/cm^3 containing a line source (source C) was imaged**.** In order to mimic the human brain, a newly developed phantom (subsequently referred to as the "Iida brain phantom" herein), which simulates detailed grey matter, white matter and the skull of a young healthy volunteer, was constructed from a photo-curable polymer with density of 1.07 g/ml by using a laser-modelling technique (Fig. 1) [1]. The grey matter compartment of the brain phantom with a volume of 600 ml was filled with water containing about 20 MBq of ^{18}F and, in a second study, ^{120}I. ^{120}I was chosen because of its very high maximum positron energy of 4 MeV. ^{120}I has a half-life of 81 min and a positron abundance of about 50% [2]. Source A was filled with 10 MBq ^{18}F and, in a second experiment, with 6 MBq ^{120}I. Source B was filled with 8 MBq ^{18}F. Source C was filled with ^{15}O-water. ^{15}O is a positron emitter with a half-life of 2 mins and a maximum positron energy of 1.72 MeV. Measurements were carried out at different positions in the magnet and outside it; these corresponded to 9.4 T, 7 T, 3 T, and about zero.

Figure 1: Iida Brain phantom [1].

Results

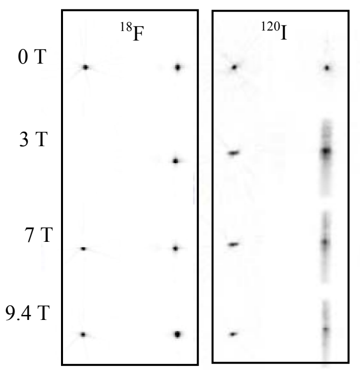

Figure 2: Point spread images of source A filled with ^{18}F (left), and filled with ^{120}I (right). For each source the left column shows the transaxial view (x-y-plane), and the right column the coronal (x-z-plane) with the z-direction up-down. From top to bottom: results at 0, 3, 7 and 9.4 T.

Images of the ^{18}F point source A yielded a FWHM averaged over horizontal and vertical profiles of 3.23 mm at 0 T and 3.02 +/- 0.01 mm between 3 T or 9.4 T (Fig. 2, left). The analysis of the ^{18}F point source B showed no trend from 0 T to 9.4 T with an averaged FWHM of 3.05 +/- 0.05 mm. In the case of the ^{18}F-filled point sources the "base" of the profiles characterized the FWTM showed no dependence on the field strength. When source A was filled with ^{120}I, the vertical and horizontal point spread profiles were different (Fig. 1, right). The vertical profiles showed a FWHM of 4.5 mm at 0 T which decreased to 3.2 mm at 9.4 T. The horizontal profiles displayed a broadening from 0 T to 3 T which became narrower towards 9.4 T. In addition, pronounced tails in the direction of the magnetic field appeared from 3 T to 9.4 T. The FWTM of the vertical profiles decreased from 10 mm at 0 T and 8.8 mm at 3 T to 5.6 mm at 9.4 T. When the Iida brain phantom was filled with ^{18}F, the image quality was only slightly influenced by the magnetic field, i.e. the cortical structures were somewhat better delineated. A quantitative analysis showed an improvement of the grey/white matter ratio by 6.3% when the phantom was scanned at 9.4T compared to 0T. The average uptake in the frontal cortex and in the thalamus relative to the whole brain increased by just 3% and 2%, respectively, from 0T to 9.4T. When the same Iida Brain phantom was filled with ^{120}I the influence of the magnetic field became more obvious (Fig. 3). Since the magnetic field with its orientation along the z-axis reduces the positron range in the transversal (x-y) plane, images viewed in the sagittal (z-y) plane are expected to show an improved resolution just in the y-direction. The results presented in Fig. 4 constitute experimental confirmation of this statement. In this experiment the grey/white matter ratio increased by 25% when the phantom was scanned at 9.4 T as compared to 0 T. The average uptake in the thalamus related to the whole brain increased by 9% from 0 T to 3 T and by another 1.6% to 9.4 T.

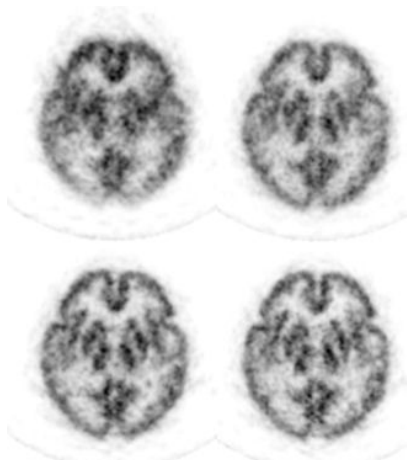

Figure 3: Transversal images of the Iida Brain phantom filled with ^{120}I and measured at 0 T (top left), 3 T (top right), 7 T (bottom left) and 9.4 T (bottom right).

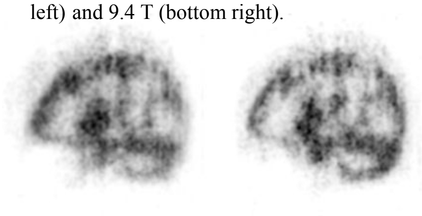

Figure 4: Sagittal images of the polymer brain phantom filled with ^{120}I and measured at 0 T (left) and 9.4 T (right).

Conclusion

The results of the experimental study presented above demonstrate that the range reduction of the positron in a magnetic field does have an appreciable influence on the resolution and contrast of the PET image. The effects are greater for the more energetic emitter ^{120}I than they are for ^{18}F.

References

1. Iida *et al.*, J. Nucl. Med., 2010, Suppl2. 51:259 **2.** H. Herzog *et al.*, Eur. J. Nucl. Med., 2006; 33:1249–1257.