Simultaneous PET and MR Imaging with a Newly Developed 3TMR-BrainPET Scanner

Christoph Weirich, Jürgen Scheins, Michaela Gaens, Lutz Tellmann, Elena Rota Kops, Joachim Kaffanke, Jon Shah, Hans Herzog

Institute of Neuroscience and Medicine – 4, Forschungszentrum Jülich
c.weirich@fz-juelich.de

Abstract. A prototype of a new bimodal scanner was installed in our laboratory. This scanner combines magnetic resonance imaging (MRI) and positron emission tomography (PET) for brain studies. As the PET detector is located within the bore of the MRI scanner, simultaneous measurements become possible. The MR-component consists of a commercial 3T MRI scanner MAGNETOM Tim-Trio, whereas the PET detector BrainPET has been newly developed. The readout electronics of the PET are based on avalanche photodiodes (APDs) which can be applied in the magnetic field. The inner diameter of the PET ring, which consists of 32 cassettes, is 36 cm so that an MRI head coil can be inserted into this ring. First tests were carried out to analyse the countrate behaviour and the image resolution. To assess the image quality of simultaneous MR-PET, phantom studies were performed. The image resolution in the centre was between 2.1 and 2.5 mm in x,y and z directions. First MR-PET studies showed no visible artefacts of the MR image and FDG-PET images provided high-resolution delineation of the cortex.

1 Introduction

Combining imaging technologies that integrate the strengths of two modalities, and at the same time eliminate one or more weaknesses of an individual modality, offers the prospect of improved diagnostics, therapeutic monitoring and preclinical research. Research groups have been developing MR-PET scanners for small animal imaging [1] such that anatomical information can be obtained by MRI and at the same time PET can observe metabolic function. Recently, some prototypes of an MR-BrainPET scanner for simultaneous human brain studies were built. The feasibility of MR-PET imaging was demonstrated in a human volunteer [2]. One of these prototypes developed by Siemens and combining an industrial 3T MRI scanner with a newly developed PET detector has recently been installed in our PET laboratory and is currently being tested. Here we report our experience with the new hybrid scanner.

2 Material and Methods

2.1 Design Characteristics

The MRI component of the MR-BrainPET consists of the slightly modified MAGNETOM Tim-Trio with a magnetic field of 3 T (Fig. 1(a)). One modification is the replacement of the standard head coil by a combined transmit/receive coil which causes less attenuation of radiation. The BrainPET component has an outer diameter of 60 cm and fits in the MR bore. It consists of 32 copper shielded cassettes each with six compact detector modules (Fig. 1(b)). The front-end of the detector module has 12 × 12 LSO crystals of 2.5 × 2.5 × 20 mm^3 each which are read out by an array of 3 × 3 avalanche photodiodes (APDs).

While typical PET scanners use photomultipliers as readout electronics, the presence of a strong magnetic field requires solid state components such as APDs which are not magneto-sensitive.

2.2 Phantom Studies

The countrate performance was tested with a cylinder of 25 cm length and 22.5 cm diameter filled with ^{11}C-solution. The activity at the beginning was 417 MBq. During the measurement of 11 half life times ($T_{1/2}$=20 min) the radioactivity concentration dropped from 80 to 0.3 kBq/cc. The transaxial resolution was studied with a ^{18}F-filled 0.5 mm thin line source and the axial resolution with a 0.25 mm ^{22}Na point source. Point spread images were obtained by iterative 3D-OSEM reconstruction [3] using 16 subsets and 6 iterations. Image resolution was determined as the full width at half maximum (FWHM) of a Gaussian fit to a profile, which crossed the maximum voxel of the reconstructed point. To study the image quality systematically and to localise image artefacts, several phantom studies were performed. Correction procedures such as

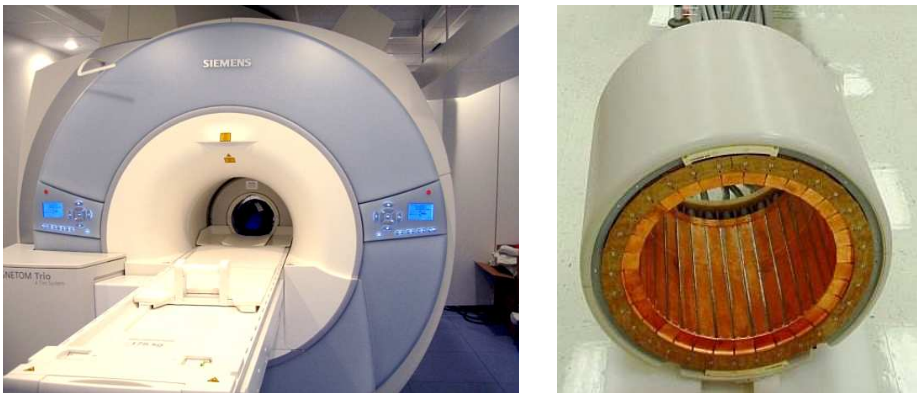

Fig. 1. The 3TMR-BrainPET hybrid scanner. Left: 3T MR scanner MAGNETOM Tim-Trio with BrainPET insert within the MR bore; Right: MR-compatible BrainPET scanner with 32 copper shielded cassettes.

normalisation and corrections for attenuation, Compton scatter and random coincidences have been developed, optimised and tested. These promising results allowed us to perform first qualitative human studies.

2.3 Human Studies

^{18}F-FET-Study: a first combined human MR-PET study was performed in a patient with a malignant brain tumour. After injection of about 200 MBq ^{18}F-fluoroethyltyrosine (^{18}F-FET) [4], the clinical study was performed in the Siemens ECAT Exact HR+ for 50 min. Subsequently the patient volunteered to be scanned in the MR-BrainPET for another 30 min without further radiotracer injection (Fig. 2). During the PET scan different MR sequences were performed.

^{18}F-FDG-Study: another combined human MR-PET study with the radiotracer ^{18}F fluordeoxyglucose (^{18}F-FDG) was performed to visualise the glucose metabolism of the brain. A tumour patient (non-brain tumour) was injected

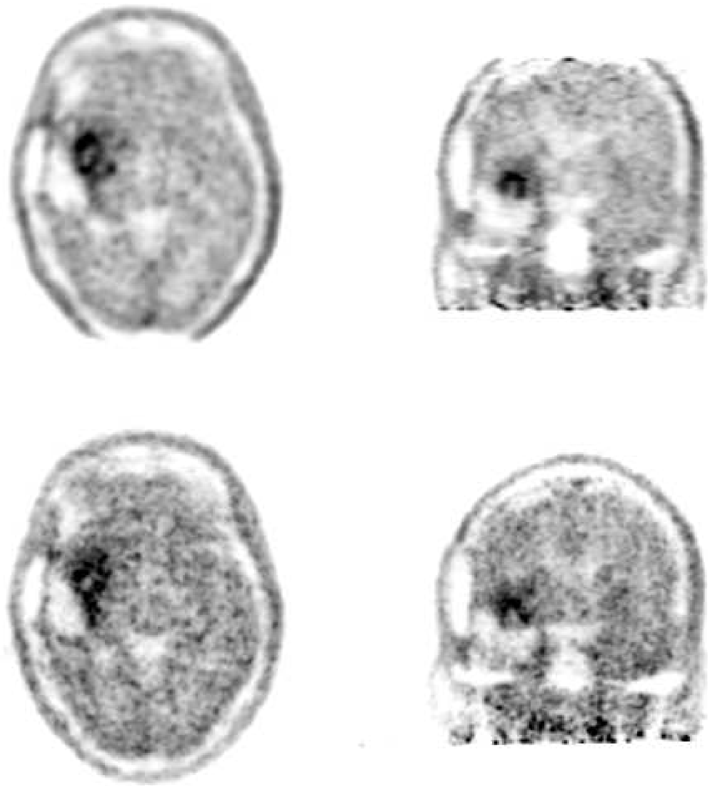

Fig. 2. Upper row: ^{18}F-FET image acquired with the whole body PET scanner HR+. Lower row: ^{18}F-FET image acquired with the BrainPET insert.

342 MBq of ^{18}F-FDG. Prior to the diagnostic whole body scan in the HR+-scanner, the patient volunteered to be scanned in the 3TMR-PET. The acquisition started 30 min after injection (p.i) and was acquired for further 20 min. During the PET scan several MR sequences were performed.

The MR data were processed with the common Syngo software. PET images were reconstructed using the 3D-OSEM reconstruction with 1 subset and 42 iterations (Fig. 3). Prior to the reconstruction varying crystal efficiencies were corrected by a component based normalisation. Since attenuation correction cannot be based on transmission scans due to the lack of a transmission source, it is achieved using attenuation templates derived from transmission measurements in the HR+ and adapted to the individual T1-weighted MP-RAGE image [5].

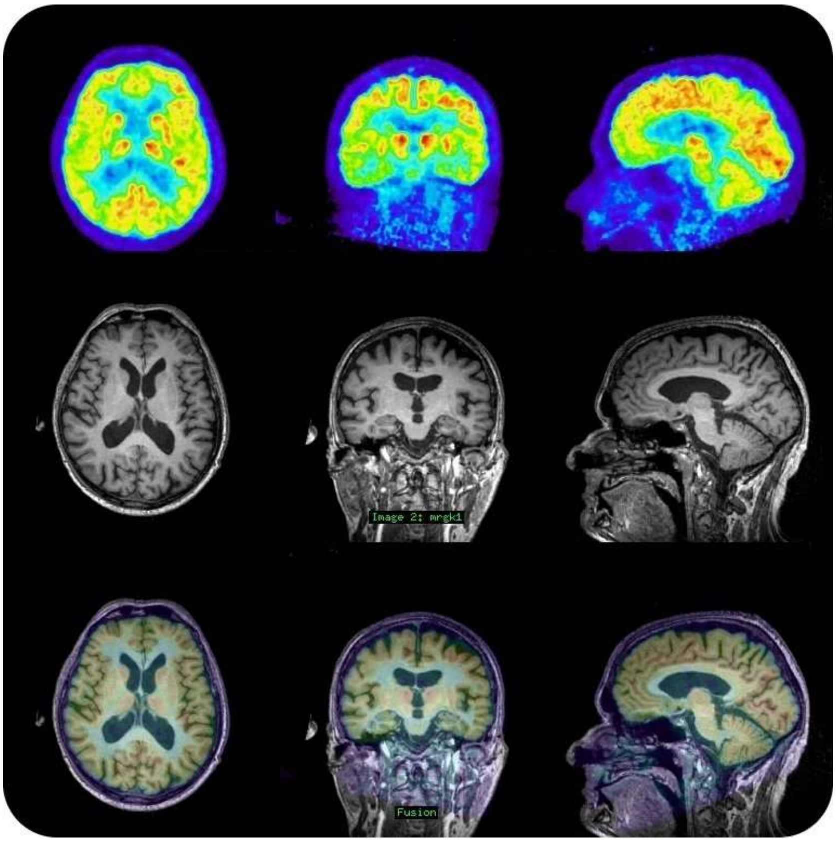

Fig. 3. Simultaneously measured PET and MR images. First row: ^{18}F-FDG image of a 20 min scan. Second row: T1-weighted MR image (MP-RAGE). Third row: Fusion of FDG and MP-RAGE image. Left transversal, middle coronal, right sagittal view. The PET-images were reconstructed using the image reconstruction platform PRESTO [6].

3 Results

Performing the decay experiment with the cylinder, the prompt countrate started to saturate at an activity concentration of about 62 kBq/cc. The netTrue counts as the difference of prompt and delayed counts had a peak of 670000 cps at 52 kBq/cc.

The analysis of the reconstructed point spread images yielded a tangential resolution (FWHM) of 2.4 ± 0.2 mm ($r = 0$, 2.5 and 5 cm) in a central transversel plane and a radial resolution ranging from 2.1 mm via 3.3 mm to 5.5 mm for the three radii. Within the 15 central image planes the axial resolution was 2.5 $\pm$ 0.2 mm at $r = 0$ cm and 3.1 ± 0.2 mm at $r = 5$ cm. In comparison to the HR+ scan, the PET images obtained with the BrainPET qualitatively show a higher spatial resolution (Fig. 2). The high resolution of the BrainPET scanner is confirmed by the FDG image of the combined human MR-PET scan in Fig. 3.

4 Discussion

The preliminary tests reported here confirm that simultaneous MR-PET imaging is possible with the newly developed hybrid scanner. In the human studies, MR images show minimal artefacts. The BrainPET detector provides an excellent image resolution. The PET system saturates at activity concentrations which are higher than those expected in brain studies of glucose or receptor metabolism. To date the system is not yet quantitative, since reconstructed images deliver counts instead of activity concentrations.

It is planned to continue with further development of the correction procedures which allow for quantitative PET imaging. Additionally more detailed tests will be performed to obtain further experience in human brain studies.

References

1. Wehrl HF, Judenhofer MS, Pichler BJ, et al. Pre-clinical PET/MR: technological advances and new perspectives in biomedical research. Eur J Nucl Med Mol Imag. 2009;36, Suppl 1:56–68.
2. Schlemmer HP, Pichler B, Ladebeck R, et al. Simultaneous MR/PET imaging of the human brain: feasibility study. Radiology. 2008;248:1028–35.
3. Lonneux M, Borbath I, Michel C, et al. Attenuation correction in whole-body FDG oncological studies: the role of statistical reconstruction. Eur J Nucl Med. 1999; p. 591–8.
4. Pauleit D, Floeth F, Langen KJ, et al. O-(2-[18F]fluoroethyl)-L-tyrosine PET combined with MRI improves the diagnostic assessment of cerebral gliomas. Brain. 2005;128:678–87.
5. Rota Kops E, Qin P, Herzog H, et al. Attenuation correction of PET scanning based on MR images. IEEE Nucl Sci Symp and Med Imag Conf Rec. 2006.
6. Scheins J, Boschen F, Herzog H. Analytical calculation of volumes-of-intersection for iterative, fully 3-d PET reconstruction. IEEE Trans Med Imaging. 2006;25.