Design of a Combined PET and Field-Cycled MRI System for Small Animal Imaging

G. A. Bindseil[1], W. B. Handler[1], T. J. Scholl[1], K. M. Gilbert[1], H. Peng[2], and B. A. Chronik[1]

[1]Department of Physics & Astronomy, University of Western Ontario, London, Ontario, Canada, [2]Department of Radiology, Stanford University, Stanford, California, United States

Introduction

Recent efforts to combine functional and anatomical imaging modalities have resulted in the successful development of PET/CT systems, which have found widespread clinical and research use [1]. PET/MRI would offer significantly better soft tissue contrast and provide high-resolution anatomical information. Research to combine PET and MRI faces many technical challenges, one of which is the inherent incompatibilities between the photomultiplier tube-based (PMT) PET detectors used in commercially available PET systems and the high magnetic fields used in conventional MRI systems [2].

Current approaches to PET/MRI either (a) alter PET hardware to make it compatible with conventional MRI, or (b) modify MRI in some manner to make it compatible with conventional PET. One approach of the first type has been to use avalanche photodiodes (APD), which are unaffected by magnetic fields, in place of PMTs in an MR-compatible PET insert [3]. An approach along the second tack is to use field-cycled (FCMRI) with a conventional PMT-based PET ring [4]. Combining PET with FCMRI would enable the use of currently available, highly optimized PET systems with little physical modification. In this abstract, the authors present their current designs for a PET/FCMRI system specifically based on the Siemens Inveon small-animal PET.

Methods

In FCMRI, two sets of resistive electromagnets independently produce the polarizing and readout magnetic fields. The polarizing field must be strong, but need not have high spatial or temporal uniformity. Conversely, the readout field must have high spatial and temporal uniformity, but need not be strong [5]. A fully-functional FCMRI system has been built (Figure 1) and has generated images of good quality (Figure 2). The magnetic fields of the FCMRI system can be turned on and off during a scan allowing PMTs to operate normally during the time the field is off. Proof-of-principle tests have shown that linear and mesh PMTs recovered normal operation within several milliseconds of the field being turned off with no long-term effects [4,6]. In addition, it has been shown that PMT-based PET systems can successfully operate when interleaved with an operational FCMRI system (Figure 2).

The authors are developing a PET/FCMRI system for small-animal imaging. A Siemens Inveon PET system (Siemens Medical, Knoxville, TN) has been purchased. The detector consists of a ring of 16 PET modules, each consisting of a row of four LSO crystal blocks (1.59x1.59x10mm crystals in 20x20 block) coupled to four position-sensitive photomultiplier tubes (PSPMT).

A larger-scale FCMRI system with an axial gap is under development for integration with the Inveon PET system. The proposed geometry is shown in Figure 3. At 60 kW, the polarizing magnet produces a polarizing magnetic field of 0.5 T. Calculations show that the readout-field inhomogeneity after mechanical shimming is expected to be less than 100 ppm over a 10 cm diameter sphere. Resistive shimming will be used to further reduce the inhomogeneity to better than 10 ppm.

The proposed system offers increased flexibility in PET/MRI sequences. Figure 4 shows a simple interleaved sequence. This will necessarily result in a reduced duty cycle for both modalities compared with simultaneous PET/MRI approaches. Alternate sequences could conduct MR while the animal metabolizes the radiotracer and then acquire subsequent PET images interleaved with further MRI data acquisition.

Discussion

The proposed PET/FCMRI approach could have several advantages over other PET/MRI approaches. While APD-based PET detectors can achieve timing and energy resolutions comparable to current PMT methods [7], as of this writing, APD-PET is still in development and there are no commercially available systems. The current approach uses the commercially available Inveon system offering state-of-the-art timing resolution, energy resolution, and highly optimized event processing hardware. In addition to their position-sensitive ability, PSPMT detectors have higher gain and signal-to-noise ratio than APD detectors.

While FCMRI is less mature than conventional MRI, it is likely more critical to achieve the best possible PET resolution rather than maximize MR image quality. FCMRI image quality is more than sufficient for the anatomical detail required for image coregistration. Furthermore, FCMRI has several advantages over conventional MRI: the ability to vary the amplitude and duration of the polarizing field offers novel T1 dispersion contrast possibilities; substantially reduced susceptibility artifacts enable imaging around metallic implants; lower required RF power drastically reduces the specific absorption rate [5]; gradient operation in the readout magnetic field only renders the system virtually silent.

Integration of the new FCMRI system with the Siemens Inveon PET system will be completed soon. The final PET/FCMRI system is to be installed within a research hospital environment for performance evaluation and preclinical studies.

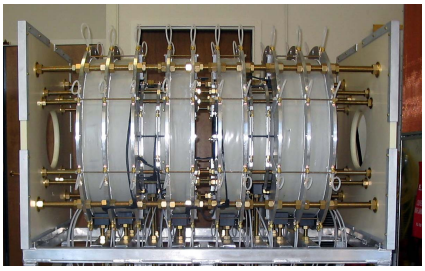

Figure 1. FCMRI System with gap for PET ring shown.

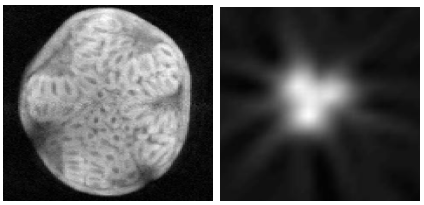

Figure 2. (left) FCMRI image of a pomegranate and (right) PET image of triangular arrangement of three point sources taken in an interleaved sequence with a cycling field of magnitude 43mT.

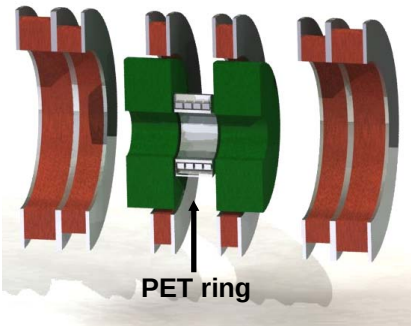

Figure 3. Cross-sectional view through a design of a PET/FCMRI system showing PET ring (center), polarizing magnet (green inner coils) and readout magnet (brown outer coils). The inner diameter is 16 cm.

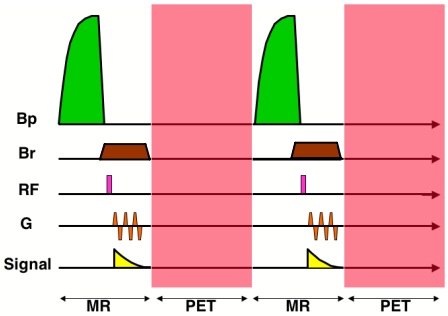

Figure 4. Prototypical operational sequence for interleaved PET/FCMRI system.

[1] Beyer, T., *et al. J. Nucl. Med.* (2000) **41**:1369-1379
[2] Gaa, J., *et al. Eur. J. Med. Res.* (2004) **9**:309-312
[3] Judenhofer M., *et al. Radiology* (2007) **244**:807-814
[4] Handler,W., *et al. Phys. Med. Biol.* (2006) **51**:2479-2491
[5] Matter N., *et al. Magn. Reson. Med.* (2006) **56**:1085-1095
[6] Peng H., *et al. Proc. 14th ISMRM* (2006) p1359
[7] Grazioso, R., *et al. IEEE Trans. Nuc. Sci.* (2005) **52**:1413-1416