

Resolution improvement of PET in PET/MRI combined system

H. Peng¹, W. H. Handler¹, J. W. Odegaard¹, P. J. Simpson¹, B. A. Chronik¹

¹Physics & Astronomy, University of Western Ontario, London, Ontario, Canada

Introduction: The integration of anatomical and functional imaging modality such as PET/CT and PET/MRI has caused intensive interests in the recent years, which provide more accurate diagnosis information and effective patient management [1-3]. PET resolution is mainly determined by the point spread function (PSF) of isotopes, detector size and system diameter. MRI can improve the PET system resolution by reducing the PSF. This effect is most significant in small animal PET system and for high energy isotopes such as ⁶⁸Ga and ⁸²Rb. There are two limitations in the previous studies: the magnetic fields of interests were above 3 T and the systems were not small animal PET dedicated, in which the improvement effect of magnetic field on PET resolution may be underestimated.

Methods: We implemented a Monte-Carlo simulation of the positron diffusion PSFs for three different isotopes (¹⁸F, ⁶⁸Ga and ⁸²Rb) as a function of the magnetic field. The distribution of positron emission energies for each isotope are shown in Fig.1. The magnetic field was applied along the Z direction and the motion of the positrons in XY plane was affected by the Lorentz forces and their distribution was reduced as shown in Fig.2. A fixed system configuration was used (based on a small animal PET system [4]): system diameter of 200 mm and detector pitch of 2 mm.

The system resolution was calculated as the convolution of the PSF, detector response, and system diameter response. PSF reduction factors (calculated as the resolution in the magnetic field divided by the resolution in zero field) were analyzed in terms of the FWHM (full width half maximum) and FWTM (full width tenth maximum) of the final system PSF. All positron emissions were assumed to be isotropic. The continuous-slowning-down approximation and multiple scattering processes were applied before the positrons reach the thermal equilibrium and finally stop. The end points were recorded and used to analyze the 1D PSFs. In total, 10,000 particle emissions were used in each simulation. The fixed step size was 0.02 mm and the cutoff energy threshold was 0.001 MeV.

Results: The PET system resolutions as a function of field strength were shown in Fig.3.a.b, for three different isotopes. The resolution reduction factors, characterized as the resolution in the field relative to that without the field, were shown in Fig.3.c.d. Due to the reduction of PSF in the magnetic field, the PET system resolutions show significant reduction for ⁶⁸Ga ($E_{\max}=1.89$ MeV) and ⁸²Rb ($E_{\max}=3.15$ MeV) all the way up to 10 T, while only slight improvement for ¹⁸F ($E_{\max}=0.635$ MeV) above 5 T. In the field strength of 10 T, the system resolution (FWHM/FWTM) is 1.4 mm/2.5 mm and 1.5 mm/2.7 mm for ⁶⁸Ga and ⁸²Rb, respectively, which is comparable to 1.4 mm/2.6 mm of ¹⁸F even without the magnetic field.

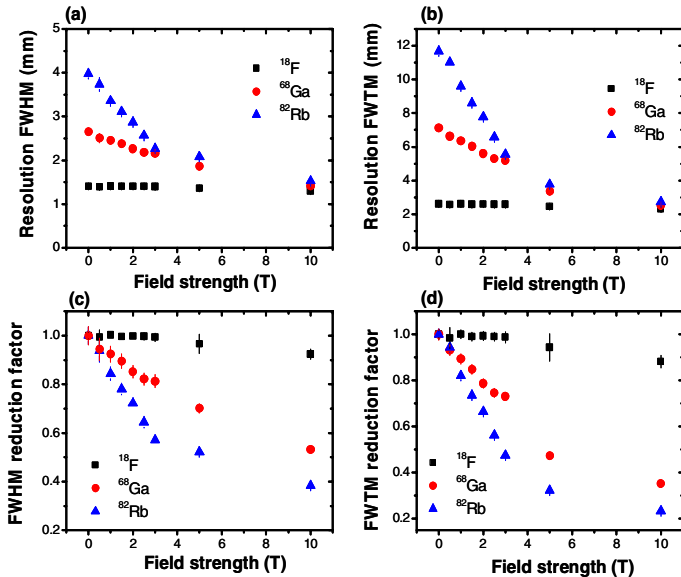


Fig.3. (a) PET system resolution FWHM (b) PET system resolution FWTM (c) reduction factor of FWHM (d) reduction factor of FWTM as a function of magnetic field strength.

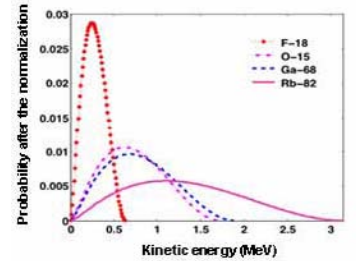


Fig.1. Different energy distribution of positron emission for four commonly used radioisotopes

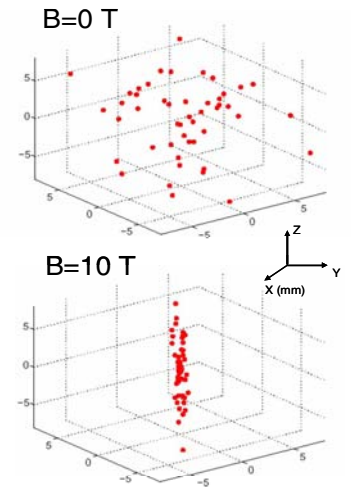


Fig.2. Illustration of PSF reduction in high magnetic field (⁸²Rb, N=50, each dimension is in mm)

The improvement effect is most significant for ⁸²Rb. In terms of the field of 3 T, the improvement effect for ⁸²Rb is, nearly 45% and 50% for FWHM and FWTM, respectively. For ⁶⁸Ga, the improvement effect is nearly 20% for FWHM and 25% for FWTM. As the field strength increases up to 3 T, a continuous system improvement can be obtained while the improvement gradually saturates above 3 T.

Discussion: Positron range effect is a severe problem in small animal PET resolution and has limited the choice of radiopharmaceuticals to those radionuclides of low energy such as ¹⁸F [5]. The potential application of simultaneous PET/FC-MRI may allow the evaluation of new pharmaceuticals due to the resolution improvement shown above, such as ⁶⁸Ga for lymphoma diagnosis and ⁸²Rb for cardiac perfusion imaging. Based on this simulation, it is possible to optimize the system configuration of magnetic field strength, system diameter, detector width, as well as the PET detector location in the PET/FC-MRI dual modality engineering.

- [1] H. Peng, et al, ISMRM 13th, (2005)
- [2] R. Grazioso, et al, ISMRM 13th, (2005)
- [3] N. Shaw, et al, SMRM 13th, (2005)
- [4] S. Cherry, et al, IEEE Trans Nucl Sci, (1999)
- [5] R. Hichwa, J Nucl Med, 35, 1396-1397, (1994)