# Retrospective Evaluation of Brain PET-MR Registration

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**Introduction:**

In recent years, 18F-fluoro-2-deoxyglucose (FDG) positron emission tomography (PET) has become a well-established imaging technique to evaluate various types of malignancies. Although FDG PET images are intrinsically quantitative and functional, few anatomic details are obtained. In contrast, magnetic resonance (MR) images provide good details of anatomic features. Therefore, PET images are often registered to MR atlases for interpreting regional metabolic activities. Several registration methods have been developed and used for different purposes, but no objective evaluation has been made of registering PET to MR images, except for a study by Koole et al. in 1999.[1] The purpose of our study was to evaluate the accuracy of PET-MR registration of several well-accepted registration methods.

**Methods:**

PET images from 25 patients treated for Hodgkin disease or malignant lymphoma tumors with no involvement of the central nervous system were registered to the ICBM 452 brain atlases on the basis of T1 MR images (http://www.loni.ucla.edu/Atlases). We evaluated 5 registration methods: (1) a linear registration based on normalized mutual information (NMI) implemented in a commercial software package by Hermes (Hermes Medical Solutions, Sweden); (2) an affine registration based on ratio image uniformity (RIU) implemented in Automated Image Registration (AIR)[2]; (3) a nonlinear registration based on NMI, using a discrete cosine transformation (DCT) provided by Statistical Parametric Mapping 2 (SPM2)[3]; (4) an affine registration based on cross correlation (CC) ratio implemented in Medical Image Processing, Analysis and Visualization (MIPAV) (http://mipav.cit.nih.gov/); and (5) a free-form deformation (FFD) registration method based on NMI provided by CISG.[4]

In addition to visually inspecting registration accuracy, we calculated tissue concordances between the registered PET images and the atlas: (1) a fuzzy c-mean algorithm implemented in MIPAV was used to segment the gray matter (GM) from white matter (WM) and cerebrospinal fluid (CSF); (2) GM images of atlases were generated from probability tissue maps from the ICBM452 atlas; (3) kappa indices between the GM images from registered PET images and the atlas were calculated.

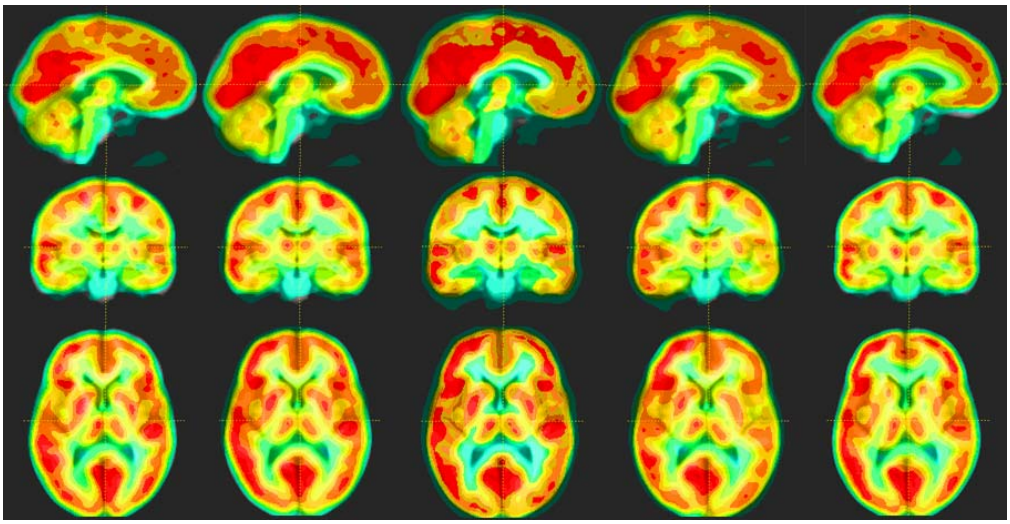

**Fig. 1** – Registration results of overlaying registered PET from a patient to the atlas by using 5 registration methods. From left to right, (1) NMI/DCT (SPM2), (2) NMI/linear (Hermes) (3)RIU/Affine (AIR), (4)CC/linear (MIPAV), and (5) NMI/FFD (CISG). The colors from blue to green, yellow, and red represent increasing FDG uptake of PET images. AIR provided best accuracy by aligning low FDG uptake on PET with CSF/WM on the MR atlas.

**Results:**

Figure 1 shows results of a patient's registered PET images overlaid on the ICBM452 atlas by using the 5 methods. On the basis of visual inspection of all registration results of 25 patients, the AIR registration algorithm provided the best results. The average tissue concordance measures of the 5 registration methods are as follows: NMI/DCT (SPM2) 0.52, NMI/linear (Hermes) 0.59, RIU/Affine (AIR) 0.71, CC/linear (MIPAV) 0.64, and NMI/FFD(CISG) 0.56.

**Discussion:**

We retrospectively evaluated the accuracy of PET-MR atlas fusion of 5 well-accepted registration methods, using data acquired for purposes of clinic care. Data from patients were used to provide a "real" performance testing environment instead of using images acquired for particular research purposes. Because these data were acquired without detailed neuroanatomic landmarks, we used tissue concordance to evaluate the accuracy of the registration. The similarity between the GM from the aligned PET and those from the MR atlas was used because differentiation of GM from other brain tissues on PET images is robust due to its high FDG uptake. We found that nonlinear registration does not provide better results than linear or affine registration with the same objective function of NMI. This finding is consistent with that from a previous study that retrospectively evaluated the performance of registration methods on MR images across subjects and found no significant difference between results of nonlinear and linear registration.[5] Another possible explanation for this finding in our study is that the PET images used have a low resolution of $3.9 \times 3.9 \times 4.25$ mm$^3$.

**Conclusion:**

We evaluated the accuracy of 5 registration methods when they are applied to PET-MR atlas registration, using images acquired from cancer patients. Both visual inspection and quantitative analysis showed that the affine registration based on RIU is the most accurate for PET-MR atlas registration.

**References:**

(1) Koole M et al. *Nuclear Medicine Communications*, 1999, 20:659-69; (2) Woods, RP. *Journal of Computer Assisted Tomography* 1998, 22: 139-52 ; (3) Maes F et al. *IEEE Transactions on Medical Imaging*, 1997, 16: 187-98; (4) Studholme C et al. *Pattern Recognition* 1999, 32 :71-86 ; (5) Hellier P et al. *IEEE Transactions on Medical Imaging* 2003, 22: 1120-30.