# Hybrid Brain Imaging with MRI/PET

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## Abstract

Hybrid imaging and mapping of the brain has been a growing area. This has been driven by: a) the complimentary information provided by different technologies and b) the growing awareness that functional, metabolic and molecular events often occur in times too short to be captured by sequential imaging by different modalities. To address these needs Positron Emission Tomography (PET) and Magnetic Resonance Imaging (MRI) have been integrated into one platform. To achieve this PET technology had to be significantly modified and MR technology appropriately adapted. The technical challenges that have been met and the future benefits anticipated will be presented.

## 1. Introduction

Initially the first approach to combine complimentary information from different imaging technologies was to use software to register (i.e. fuse) in three dimensions brain images acquired at different times (see Figure 1). However this puts severe limitations on the need for similarity in spatial image information. This was then addressed by acquiring images from different modalities wherein registration (fusion) was achieved by hardware implementation rather than software. This avoided spatial similarity needs but did not address the need of simultaneity. To address both spatial similarity and simultaneity needs a number of research laboratories and at least one major medical imaging equipment manufacturer has incorporated magnetic resonance imaging and spectroscopy (MR) with positron emission tomography (PET) into a hybrid platform capable of true simultaneous data acquisition (1).

The bringing together of Positron Emission Tomography (PET) and Magnetic Resonance Imaging and Spectroscopy (MR) into one hybrid platform capable of simultaneous data acquisition has been on the one hand, technically challenging and, on the other hand, of considerable future anticipated value.

PET will, over the next 10 to 20 years, be the modality to drive molecular imaging in personalized medicine. In the past PET provided quantitative functional imaging (e.g. brain blood flow) and metabolism (e.g. brain glucose metabolism). In the near future its role will be to lead molecular imaging needed to understand and diagnose diseases such as mental health disorders (e.g. schizophrenia, affective disorder) and other neurological disorders (e.g. Parkinson's, dementias). PET will lead human molecular imaging because a) it has the greatest sensitivity of any non-invasive imaging modality as it can be used to detect picomolar concentrations of a PET probe and b) it is the only non-invasive medical imaging modality with a proven track record of getting new imaging probes into human use.

MR is an ideal partner to PET because a) it provides anatomical information equivalent to that of x-ray CT without an increase in risk from ionizing radiation, b) it has the greatest soft tissue contrast of any anatomical imaging modality and c) it can provide complimentary function information such as brain blood flow and/or brain water diffusion and/or brain fiber track information. In addition it has recently been shown that electroencephalography (EEG) and electromyography (EMG) can be acquired simultaneously with MRI allowing MR/PET to expand to MR/PET/EEG/EMG hybridization.

## 2. Technical Challenges

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Simultaneous acquisition of PET and MR data is on the one hand possible because both of these modalities use volume acquisition strategies without the need of moving detectors but on the other hand technically difficult to achieve without losses in performance as compared to stand-alone PET and MR platforms.

The major adaptation that had to be achieved for the PET part of the MR/PET platform was the replacement of the magnetic field sensitive photo multiplier tube with an avalanche photo-diode technology (2). This has recently been achieved but the slower avalanche photo-diode technology does not allow time-of-flight image reconstruction technology.

The major adaptation that still has to be achieved for the MR part of the MR/PET platform is the determination of attenuation and scatter correction of the 511 keV annihilation photon used in PET. Correction for the attenuation and scatter is essential otherwise images are badly distorted and quantitation not possible. The problem is that MR data is dependent on proton density and nuclear magnetic resonance (NMR) relaxation rather than electron density. Unfortunately this NMR relaxation is so fast in cortical bone and lung that conventional MR imaging retrieves no signal from these two tissues which have the greatest (bone) and smallest (lung) 511 keV attenuation coefficients. Currently this challenge is being addressed by segmenting out different tissues from the MR images and assigning to them 511 keV attenuation coefficients (3,4). However these are average coefficients that vary between subjects and direct measurement would improve quantitation. More recently a new MR imaging approach called Ultrashort TE (UTE) may resolve this impasse by allowing the needed signal to be retrieved from bone and lung.

## 3. Anticipated Benefits

It is anticipated that simultaneous PET with MR (imaging and spectroscopy) will greatly add to our knowledge of brain diseases (5). Some specific examples:

a) each coincident detection of 511 keV photons will be corrected for subject motion which would improve PET spatial resolution more than time-of-flight correction could achieve for the brain
b) PET data will be synchronized to physiological motion including cardiac and respiratory
c) PET images of metabolism will be matched to brain blood flow images. Note that a major limitation of PET is that it is unispectral that is it can only image one radioactive nucleus at a time. This will be the first time that metabolism by PETcan be simultaneously linked to blood flow
d) In schizophrenics the dopaminergic neurotransmitter pathway (by PET) will be compared simultaneously, for the first time, to the glutamatergic neurotransmitter pathway (by MR spectroscopy)
e) In pain opioid receptor occupancy (by PET) will be compared to neuronal activation in the pain matrix (by MR imaging)
f) In Alzheimer disease the plaque burden (by PET) will be compared to micro vascular disease as measured by quantitative blood flow (by MR imaging)
g) In Parkinson's disease the impact of transplanted adult progenitor cells (by PET) will be compared to their location (by MR imaging)

Of course many more examples come to mind. The exciting part is that this is just the beginning as new PET molecular probes are being developed monthly and MR techniques continue to evolve. For example a hybrid platform in which EEG is added to MR/PET would allow the determination of how neuronal events on the time scale of a 100 ms (EEG) are related to blood flow changes (MR imaging) and receptor activation/occupancy (PET)(7,8,9). New drugs designed to treat disease such as affective disorders will be investigated with respect to effects on brain electrical activity (by EEG), receptor occupancy (by PET) and blood flow (by MR imaging).

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Figure 1

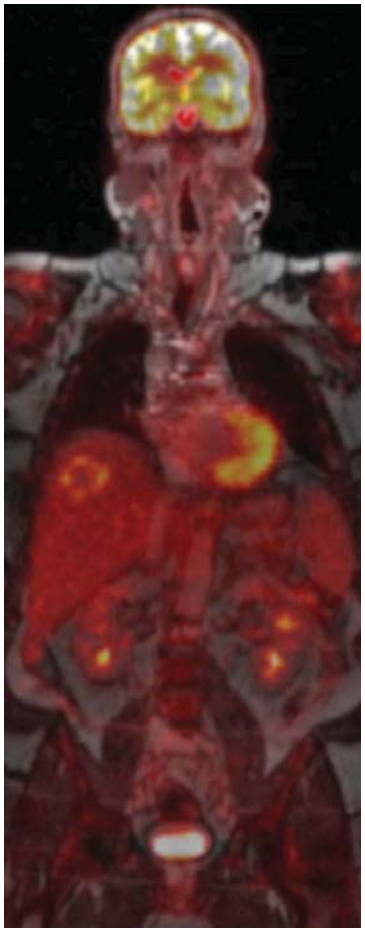

Figure 1 – PET/MRI hybrid image achieved with both software and hardware registration. The whole body $^{18}$F-FDG PET image was acquired with a hybrid PET/CT platform, that is using hardware registration. Then a whole body MRI was acquired. The CT and MRI whole body 3-D images were then registered using software. As the

PET and CT images are registered using hardware the PET and MRI images are automatically registered once the CT image was registered to the MRI