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Combined Positron Emission Tomography and Magnetic Resonance Imaging: A Technical Challenge

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Editorial

A clinical prototype of combined Combined Positron Emission Tomography (PET) / Computed Tomography (CT) system went under the clinical evaluation in 1998. After three years of research and clinical evaluation first clinical combined PET/CT system was installed in a clinic in 2001 [1-3]. Gradually clinical utilization of combined PET/CT increased tremendously particularly in oncological imaging [3-6]. The success of PET/CT as a medical diagnostic device led to the development of other combined modality like SPECT/CT. the superiority of Magnetic Resonance Imaging (MRI) over CT as anatomical imaging device in providing unmatched soft tissue details along with a reasonable array of functional information through techniques such as MRI spectroscopy and functional MRI imaging has led to development of combined PET/MRI system. The first PET/MRI combined modality introduced in nuclear medicine practice for brain imaging to diagnose the complex disease processes based on improved and reliable anatomical and functional information provided by this combined system and gradually whole body PET/MRI is developed for clinical use [7]. Combining Positron Emission Tomography (PET) and Magnetic Resonance Imaging (MRI) in a single device was a challenging task as both the imaging device faced lots of interference from each other resulting in many new developments and changes in both the system [7-14]. Hence it is very important to understand the real technical problem faced by two systems in the process of combining with each other.

Ways in Which PET Can Affect MRI

The introduction of PET detectors inside the gradient coil and magnet can lead to interference [7-10].

- PET Scintilation detector like GSO and LGSO may cause small differences in magnetic susceptibility within the magnet bore may result in an in homogeneity in the main magnetic field (B0) [8].
- Gradient of MRI may induce eddy current in shielding material and electronics of PET scanner may lead to distortion and non linearity in MRI image [8].
- PET electronics and power cable interfere with RF detection and can interfere with FR pulse detection [8].

Ways in Which MRI Can Affect PET

The high static magnetic field (B0), quickly changing gradient fields (B1), and radiofrequency signals (RF) from the MRI scanner prevent the normal operation of photomultiplier tubes and front-end electronics of PET detectors used in current generation PET/CT System [7-10].

- **Main magnetic field:** The magnetic field perturbs the paths of electrons moving from the photocathode down the dynode chain to the anode resulting in a loss of gain [7-9].
- **Gradient fields:** Rapidly switching magnetic fields can induce eddy current loops in any conductive components introduced into the magnet bore, including PET circuitry. In addition to signal interference, these can lead to heating and mechanical vibration [7-8].
- **RF interference:** Any electronics situated within the magnet bore may be susceptible to RF interference generated by the MRI transmit coil. This effect is responsible for the drop in PET count rate that is observed in many MRI-compatible PET systems during MRI acquisition [7-8].

MRI Compatible PET Detectors

The most widely used PET scintillators LSO, LYSO and BGO, have a magnetic susceptibility

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similar to that of human tissue and have been demonstrated to have negligible effects on MRI. Scintillators containing gadolinium, such as GSO and LGSO, are not suitable; however these are less commonly used for PET nowadays [9].

MRI Compatible PET Photomultiplier

Electrical photomultiplier tube (PMT) can be replaced by solid-state photo detectors i.e. avalanche photodiode (APD) which is functionally stable under high magnetic field of MRI magnet and also doesn't distort the magnetic field. The electronic multiplication in APD is much lower than that of PMT [10].

MRI Compatible PET Shielding

Conventionally used lead based shielding material is replaced with MRI compatible material like tungsten.

MRI Compatible PET Electronics

PET electronics pin were coated with nickel to avoid MRI interference to the PET electronics and vice versa.

PET/MRI Development Approach

Sequential v/s simultaneous imaging: PET/MRI system development was based on two major approaches, namely, sequential imaging and simultaneous imaging. Based on these two approach two different models, separate gantry model and integrated gantry model were developed [7-8,11-14].

Sequential imaging: In sequential imaging approach, both the gantries were placed axially side by side like PET-CT. Due to interference from MRI magnetic field to the PET component and increased time of imaging has never allowed this concept to evolve [8,10,11]. Another sequential approach has been utilized by separating the PET and MRI gantries coaxially and patient table was placed in between. Because of separation of gantry by large distance allowed minimal interference from each other (Figure 1). This approach requires no modification in the standalone PET and MRI system except software [11,12]. Philips Ingenuity TF PET-MRI is an example of sequential imaging approach gantry separated coaxially [11,12]. All PET and MR applications that are available on standalone systems are available on the hybrid PET-MR.

Simultaneous imaging: In simultaneous imaging approach, PET gantry is integrated in MRI gantry (Figure 2). Several modifications were required to develop such system. Inability of PMT to work in side magnetic field was the major challenge to develop such a system. Hence PMT was replaced with new generation of solid-state photo detectors i.e. Avalanche Photodiode (APD) which do not get influenced in magnetic field. Other electronics associated with PET were shielded for magnetic and RF interference for proper operation in the MRI gantry [7-14].

Siemens Biograph mMR and GE Healthcare SIGNA PET/MRI are the truly integrated PET-MRI system available in the market for clinical use [13,14]. This PET/MRI system is capable of performing simultaneous imaging. These two PET/MRI systems consist of a dedicated whole-body PET scanner built into a dedicated 3T MRI scanner [13,14].

MRI based Attenuation Correction in PET

Since MRI signals do not have the same properties as gamma photon and unable to produce attenuation value as CT scan, hence MRI based attenuation correction in PET was one of the major challenges in PET/MRI fusion. Two approaches have been extensively tested for MRI based attenuation correction of PET image i.e. Atlas based approach and Segmentation based approach [15-19].

Atlas-based attenuation correction: A template MRI image is created from multiple subjects (atlas) and the attenuation values on it are assigned by using transmission or CT scans of the same subject. These template images can then be co-registered with the MRI image of subject, and the attenuation values can then be assigned to the PET image. Atlas creation and co-registration is the main issue with this method [15,16,19].

Segmentation based attenuation correction: Usually T1 weighted images or two point Dixon sequence images are segmented into areas with different attenuation values for air, lung, soft tissue, fat and uniform attenuation value are assigned to one class of tissue and then this attenuation map is applied to the PET images. Bone segmentation is not possible in this method and assigned the attenuation valued of soft tissue. In segmented based method differentiation between air and bone is not possible hence quantification based error [17,19].

Methods to reconstruct the attenuation map from emission data: This method exploit information about tissue attenuation contained in PET emission data of time of flight imaging. Attenuation map cannot be generated from non time of flight imaging data by this method. Maximum likelihood reconstruction of activity and attenuation (MLAA) algorithm are used to estimate the attenuation map from TOF emission data [18,19]. Due to the simplicity of segmentation based approach, this has been utilized in most of the clinical PET/MRI scanners available commercially.

Clinical Utility of PET/MRI

Integrated PET-MRI systems may potentially be used for a number of indications in oncology, neurology and cardiology but clinical utility over the PET/CT scanner yet to be established. Primarily this modality should be used for the functional assessment of cancer, in particular those cancers that are difficult to assess using CT, such as head and neck, brain and prostate cancer [20].

Conclusion

PET-MRI is a modality with tremendous potential to quantify the molecular pathways and pathology *in vivo* with excellent anatomical details can establish this modality in cardiology, neurology and oncology as a diagnostic tool of choice.

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