International Journal of Health Sciences and Research
www.ijhsr.org ISSN: 2249-9571

Review Article

A New Hybrid Imaging Modality: PET/MRI

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Received: 15/02/2016 *Revised: 08/03/2016* *Accepted: 11/03/2016*

ABSTRACT

Multimodality imaging has made great strides in the imaging evaluation of patients with a variety of diseases. Positron emission tomography/magnetic resonance imaging (PET/MRI) is recently been established onto the market after several years of research and has high potential due to offer functional, morphologic and molecular information at the same session. The simple notion of combining the molecular capabilities of the PET and its difference available radiotracers with the excellent tissue resolution of the MRI and wide range of multiparametric imaging techniques has generated great expectations upon the possible uses of this technology. PET/MRI combines the unique features of MRI including excellent soft tissue contrast, diffusion-weighted imaging, dynamic contrast-enhanced imaging, fMRI and other specialized sequences as well as MRI spectroscopy with the quantitative physiologic information that is provided by PET. The current data show that particular applications demanding multiparametric imaging capabilities, high soft tissue contrast and/or lower radiation dose seem to benefit from this novel hybrid modality and could open new horizon to PET/MRI. The lower radiation dose compared to PET/computed tomography will be particularly valuable in the imaging of young patients with potentially curable diseases. Furthermore, integrated PET/MRI appears to have added value in oncologic applications and also have potential benefit for cardiac and brain imaging, where MRI is the predominant modality. In this article, we aimed to summarize and basic review of potential clinical applications and technical features of PET/MRI.

Key words: Positron emission tomography/Magnetic resonance imaging (PET/MRI), nuclear medicine, oncology.

INTRODUCTION

Hybrid imaging systems are the new imaging modalities of the latest technology. The combination of PET and computerized tomography (CT) has been used more than a decade in routine diagnosis especially in clinical oncology. PET/CT does not give much information especially in brain imaging and research due to low soft tissue contrast of CT. [1] Whole body PET/MRI hybrid system based on simultaneous PET and MRI acquisition was approved by the US Food and Drug Administration (FDA) for human use in 2011. PET/CT has limitations on anatomic resolution such as in head and neck cancers, thyroid cancer, lung cancer with chest wall invasion, characterization of liver lesions, gynecologic and anorectal malignancies. [2] MRI has excellent soft tissue contrast, functional imaging parameters such as dynamic contrast enhancement and diffusion-weighted imaging with lack of ionizing radiation. [3] Parallel acquisition of

PET and MRI provides continuous acquisition of anatomical images that can be used for motion correction of PET data. In cardiac, lung and bowel imaging, quality of PET images can be increased without respiratory and electrocardiography gating. [4] Functional components of MRI and identification of its clinical utility is an ongoing trend in the recent years. MRI can give both anatomical and functional data which will develop further as technology improves. [5] Up to date, three different models were presented. Sequential PET and MRI imaging in different rooms, sequential PET and MRI imaging in the same room with an integrated scanner and simultaneous PET and MRI imaging with an integrated scanner. [6]

Technical Statement

First attempt for an advanced PET/MRI system was performed on an integrated prototype PET/MRI system in the preclinical imaging field. [7] Clinical PET/MRI scanner was first introduced to brain imaging as a brain PET scanner coupled with a standard 3.0-Tesla MRI scanner. [8] During the historical development, hybrid PET/MRI systems have been categorized to be three different styles according to the acquisition and processing of PET and MRI data. These are as follows: a) sequential PET and MRI imaging in separate rooms b) sequential and integrated PET and MRI imaging in same room c) simultaneous and integrated PET and MRI imaging in same room. [8-12] The third-mentioned has been evolved by two similar technical designs. One of them has PET scanner inserted between radiofrequency coil and gradient set of MRI scanner but the other one is fully converting design of two scanners in same gantry. [8,9,12] Simultaneous and integrated systems offer a stable acquisition technique without the need for repositioning of the patient in the same position as well as simultaneous imaging time. [10,11] Today, the big three imaging system vendors have whole-body PET/MRI systems, too. Commercially available PET/MRI hybrid systems that are capable for sequential or simultaneous imaging are present. [8,9,12] These are as follows: GE Signa PET/MRI and GE Trimodality PET/CT + MRI, Philips Ingenuity TF PET/MRI and Siemens Biograph MRI. Each of these systems is working at 3-T field strength.

A combining of PET and MRI systems is an important issue because of their unique specialties. While PET allows functional imaging with a high sensitivity (10^{-11}-10^{-12}mol/l) and good special resolution (~4 mm) for detection of radiotracers MRI provides structural and/or functional information with a good sensitivity (10^{-3}-10^{-5}mol/l) and very high spatial resolution (1 mm), that obtained by the interactions of protons in a strong magnetic field. In addition MRI has some advantages over CT, including better soft-tissue contrast, additional functional information, true multi-planar data acquisition and absence of ionizing radiation. [10,11,13] On the other hand, when compared the hybrid PET/MRI and PET/CT systems, there are also some technical weaknesses of MRI over CT; more difficult attenuation correction, worse lung imaging, lower standardization due to having more options in MRI protocols, more mismatching errors in the abdomen, more costly and more variable scanning time. [10]

In the area of combined PET/MRI instrumentation has been dynamic changes in especially the last decade. Technologist and scientist have met various technical problems during painful development period of an advanced combined PET/MRI device. However, they have taken important strides to solve the problems and find valuable solutions to some of them in time. [8] One of the most important developments is the novel detector technologies. [7,14] Researchers have found some beautiful designs and methods to solve this problem. The light guides to take the scintillation light out of the MRI system, the avalanche photodiodes or silicon photomultipliers working in Geiger mode that are insensitive to magnetic fields are some of those. [9,14]

Silicon detector technology offers fast timing resolution to obtain feasible TOF information in the integrated PET/MRI system. Other very important issue to diagnostic accuracy is MRI-based attenuation correction. Components of photon attenuation in the PET/MRI system are related to patient tissues and display unit elements. The MRI signals don't reflect the tissue density directly. While different tissues can give similar signal characteristics in typical MRI sequences, these tissues can cause the high or low attenuation levels in PET. The use of attenuation maps obtained for PET from MRI images using simple linear curves is not a valid method, and there has been need for further applications. Today, there are some newer templates for transformation of MRI intensity values by images that obtained from T1 weighted sequence or specific MRI sequences with several approaches. [1,9,13,15] Some authors categorized and defined in detail these MRI-based attenuation correction applications in the four subgroups; template-based approaches, atlas-based approaches, direct segmentation-based approaches, and sequence-based approaches. [15] Currently, newer solutions and improvements are necessary to overcome various challenges in this topic, including the better assignment of the values, more reliable reconstruction and registration, truncation artifacts, issues related coils, communication and evaluation. [9, 12, 15,16]

Clinical Applications of PET/MRI

Oncology

Potential advantages of PET/MRI over PET/CT is the better characterization of certain incidental lesions, reduction in radiation dose to children and pregnant women, local staging due to superior soft tissue contrast, identification of metastatic lesions with high background FDG uptake such as in liver, brain and heart, MRI based motion correction techniques. [17] Fusion imaging is more effective for staging based on lymph node spread or systemic metastases rather than initial diagnosis and useful for treatment response and postoperative evaluation. [18] Cerebral metastases are the most common brain tumors and represents relatively short survival. Solitary or few metastases are associated with rather favorable prognosis and sensitive detection is essential for appropriate therapy. [19] Fink et al. mentioned that PET/MRI imaging optimize patient care and improve outcomes in neurooncology. Radiotracers beside F18-FDG, including F18-FLT, F18-fluoromisonidazole, C11-methionine, F18-FET, and F18-FDOPA have promising results for characterizing different aspects of brain tumor biology. [20]

Although some studies did not shown the advantage of PET/MRI over PET/CT, PET/MRI has an advantage in selected body sites such as head and neck, liver and the pelvis. [21] Partovi et al. concluded that F18-FDG PET/MRI and F18-FDG PET/CT provide comparable results in the detection of lymph node and distal metastases in head and neck cancer and SUV values derived from PET/MRI can used reliably. For local staging of head and neck cancer, high spatial and contrast resolution of MRI can delineate the tumor invasion and lymph node involvement from surrounding normal tissue. [22]

Schwenzer et al. found similar lesion characterization and tumor stage in the comparison of PET/MRI and PET/CT. PET/MRI is feasible and provides diagnostic image quality in the assessment of pulmonary masses [23] Kong et al. showed that integrated PET/MRI mammography had advantage of combining high resolution breast images with metabolic images and PET/MRI could provide an accurate diagnosis in ductal carcinoma in situ that are less than 1 cm in size. [24]

PET/MRI had diagnostic impact on clinical decision in the detection of liver metastases. Reiner et al. found similar diagnostic accuracy for the detection of liver metastases with PET/MRI and contrast enhanced PET/CT [25] Kang et al. suggested that PET/MRI may help the selection of more appropriate treatment strategies in colorectal cancer. PET/MRI added diagnostic value to contrast enhanced CT in the detection of metastases and characterization of indeterminate lesions, but PET/MRI had limited performance in small pulmonary nodules. [26]

T1-weighted turbo spin-echo sequences in PET/MRI was superior to PET/CT for anatomic delineation and allocation of bone lesions especially in primary bone tumors, early bone marrow infiltration and tumors with low uptake on PET. [27] PET/MRI is useful for the preoperative planning of tumor resection in soft tissue tumors, because surgical tumor excision is often based on the depth of infiltration found on MRI. [28] PET/MRI is feasible for staging of lymphoma. PET/MRI especially with diffusion-weighted imaging could give data about tumor cellularity and can improve tumor detection. [29]

PET/MRI seems to be effective in the oncologic indications that require high soft tissue contrast for diagnosis. PET/CT will probably keep ahead in indication that soft tissue contrast is of limited importance. [28]

Neurology

PET/MRI brain imaging is easier and faster when compared with whole body imaging, because the brain can be scanned within one bed movement. Various MRI sequences can be used such as T1 and T2 dependent images with or without contrast, MRI angiography, diffusion-weighted imaging, perfusion-weighted imaging, MRI spectroscopy and diffusion tensor imaging. [30]

PET/MRI may improve diagnostic accuracy for the surgery and radiotherapy planning of brain tumors. Combination of these modalities may change the target volume that is important for radiotherapy and patient outcome. [31] Garibotto et al mentioned the advantage of PET/MRI as acquaring both images in a single session on a hybrid system, minimizing patient discomfort while maximizing clinical information and the effective radiation dose is reduced related to CT that is important mainly in pediatric population. [32] The imaging of β-amyloid deposits with PET/MRI may be useful in the differentiation of Alzheimer’s disease, Lewy body dementia, dementia in the course of Parkinson’s disease. PET/MRI seems to be an ideal method for the stroke by the data from diffusion weighted MRI and quantitative cerebral blood flow assessment in PET. [30] Drzezga et al concluded that PET/MRI has great potential to improve early and differential diagnosis of neurodegenerative diseases and may be beneficial in frug testing. [33] Vercher-Conejero et al showed neocortical amyloid load together with vascular lesions that directs the diagnosis of mixed Alzheimer’s disease-vascular dementia. [34]

Cardiovascular

Cardiovascular imaging with PET/MRI is a new research area. PET/MRI may be useful in acute and chronic myocardial infarction, myocarditis, sarcoidosis, cardiac tumors, congestive heart failure, rare cardiomyopathies such as cardiac amyloidosis and hypertrophic cardiomyopathy, atherosclerosis and vasculitis. [35] PET/MRI systems may also be useful in the evaluation of patients with suspected coronary artery disease. The strengths of MRI and PET each may compensate the weakness of the other. [36] But these indications should be researched for the routine clinical usage. Ripa et al. believed that the synergy between PET and MRI justify its use in atherosclerotic imaging despite its higher cost. [37] Success of PET/MRI seems to be associated with the development of molecular imaging probes which will increase its strengths. [38]

CONCLUSION

PET/MRI is one of the most exciting developments in imaging in recent years and various studies have demonstrated the feasibility of simultaneous PET/MRI in many applications, from examinations of the brain to hybrid cardiac imaging. Other studies have found added value of integrated

PET/MRI compared to PET/CT or stand-alone MRI, such as MRI-based motion correction of PET data, lower radiation exposure, and multiparametric assessment of pathologies. However, there are difficulties like inaccurate attenuation correction and longer examination times that require further technical improvements. Ongoing technical innovation on scanner hard/software is needed to eliminate current issues like attenuation correction, and fully exploit new opportunities like MRI-based motion correction. Quantitatively accurate multiparametric PET/MRI data sets will likely improve diagnosis of disease and help guide and monitor the therapies for individualized patient care. It is expected that as exact clinical indications are defined in the near future, the other important logistical issues (clinical workflow, regulatory and reimbursement) will also be worked out.

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How to cite this article: Atilgan HI, Sadic M, Gultekin SS. A new hybrid imaging modality: PET/MRI. Int J Health Sci Res. 2016; 6(4):450-455.

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