PET/MR Imaging for Chest Diseases

Review of Initial Studies on Pulmonary Nodules and Lung Cancers

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KEYWORDS

• Hybrid imaging • PET • MR imaging • Lung cancer • Lung lesion detection • Lung cancer staging

KEY POINTS

- Integrated PET/MR imaging systems for the evaluation of lung cancer may be feasible owing to the development of new hardware systems with MR attenuation correction.
- PET/MR imaging showed highly correlated standardized uptake values of lesions and equivalent performance in terms of lesion detection and staging when compared with PET/CT according to several initial studies on this new hybrid modality.
- The synergistic benefits of integrated PET/MR imaging beyond simply adding the capabilities of the 2 modalities need to be validated with dedicated, time-efficient PET/MR imaging protocols.

INTRODUCTION

Multimodality imaging can be a powerful tool for the simultaneous evaluation of both anatomic and functional information and may potentially improve patient management, leading to better patient outcomes. The strengths of multimodality imaging have already been proven by the introduction of PET/computed tomography (CT) systems in oncologic imaging, which have enormously contributed to better diagnosis, treatment, and prediction of prognosis in cancer.[1,2] Indeed, the PET/CT system has become a vital imaging modality in the evaluation of lung cancers often preferred over previous conventional staging methods.[3–5] Recently, a new multimodality imaging combining PET and MR Imaging has been proposed as an alternative to PET/CT because it offers various kinds of contrast resolutions, which can reflect cellular density, perfusion, hypoxia, as well as metabolic features in addition to its inherent advantages of not requiring radiation exposure.[6,7] However, it is unclear as of yet whether the PET/MR imaging system can truly offer better diagnostic performance compared with the PET/CT system for chest diseases, particularly lung cancer, because there are considerable obstacles in pulmonary MR imaging owing to the low proton density of air, large magnetic inhomogeneity in the lung parenchyma, and cardiac and respiratory motion.[8] Although the underlying difficulties in pulmonary MR imaging have not yet been fully resolved, various designs of PET/MR imaging systems have already been implemented

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with several preliminary studies having been published on chest diseases. In this review, the PET/MR imaging system is briefly introduced and a series of recently published initial studies is reviewed to allow readers to better comprehend and specify the expected role of the PET/MR imaging system for chest diseases.

TECHNICAL ASPECTS OF PET/MR IMAGING

Hardware Design

Early generations of PET/MR imaging systems included the usage of software developed for the spatial registration of PET and MR images were acquired in 2 completely separate systems.[6] Although varying degrees of success have been achieved using many different computation algorithms,[9,10] this system suffered from innate limitations (ie, the bulk position of the patient's body tended to differ between PET and MR scanning as the patient was required to move and lie in different beds for PET and MR scanning, and there was an unavoidable temporal mismatch in the acquired images). Thus, to develop an integrated PET/MR imaging system that can overcome these limitations, modifications of the PET subsystem was necessary to make it insensitive to the strong magnetic fields of the MR imaging subsystem.[11]

Sequential System

To mitigate different body positioning required between the separate PET and MR imaging scanning, the sharing of a patient bed with sequential allocation of PET and MR imaging systems nearby was adopted for a new generation of PET/MR imaging systems, either in the same space (Ingenuity TF; Philips Healthcare, Best, Netherlands) or in 2 separate spaces (Discovery PET/CT and MR imaging system; GE Healthcare, Milwaukee, WI, USA). This secondary strategy also allowed a decrease in the temporal differences between PET and MR scanning because scanning was performed sequentially with a minimum delay for the movement of the patient bed. The Discovery PET/CT and MR imaging system adopted a trimodality system combining both PET/CT and MR imaging systems, and the Ingenuity TF system omitted the CT component of the PET/CT system and combined only the PET component with the MR imaging machine. The latter system was able to reduce the radiation dose compared with the trimodality system at the expense of CT-based attenuation correction and by using MR-based attenuation correction instead. With this evolution of PET/MR imaging systems, temporal and spatial mismatches were decreased compared with previous coregistered PET/MR images; however, sequential PET/MR imaging systems still were not free of temporal and spatial misalignments.[7]

Simultaneous System

Thus, there were 3 major challenges for the integration of the PET/MR imaging scanner into a single gantry. First, a magnetic field–insensitive photodetector was warranted because the photomultiplier tube used in pre-existing PET detectors was vulnerable to static, gradient magnetic fields, and abrupt changes in radiofrequency signals. Second, PET detectors mounted within MR scanners should not interfere with any MR signal or magnetic field gradient. Third, simultaneous acquisition of PET and MR images should be possible without mutual interference. Among these major technical difficulties, designing a PET system using avalanche photodiodes (APDs), which is a photodetector insensitive to magnetic fields, was the most crucial hurdle that needed to be cleared to enable the integration of the PET/MR imaging system. Recently, Biograph mMR (Siemens Healthcare, Erlangen, Germany), a fully integrated system using APDs in which PET and MR imaging scanning can be performed simultaneously, was developed. In addition, as time-of-flight (TOF) PET is not yet possible in PET systems using APDs, despite its magnetic insensitivity, a whole-body TOF PET/MR imaging system using a silicon photomultiplier detector has been also introduced recently (Signa PET/MR imaging; GE Healthcare). Theoretically, TOF should be able to improve the image quality of PET with higher structural detail and provide a better signal-to-noise ratio. Compared with the sequential type of arrangement, simultaneous PET/MR imaging systems have merits in minimizing potential anatomic and temporal mismatches and thus can offer more robust interpretation of PET/MR images.[7]

MR-based attenuation correction

Another important factor is the accurate attenuation correction of photons emitted from radiotracers throughout the body so as to quantify the activity concentration of radiotracers used in the PET system. As attenuation of the emitted photon occurs inhomogeneously according to the characteristics and heterogeneities of body tissue, an attenuation map needs to be created for quantification by assigning continuous attenuation coefficients. In the PET/CT system, linear attenuation coefficients of emitted photons at 511 keV can be assessed by converting the Hounsfield units of CT images. However, there is no direct relationship between the attenuation of emitted photons and the signal intensity on MR images.[12] The currently used strategy of MR attenuation