1 Introduction

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Contents

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PET/MRI in Clinical Practice

Following the path of clinical applications of hybrid PET/CT it would seem logical that PET/MR can provide an innovative and attractive alternative taking full advantage of the superiority of MR over CT in differentiating soft tissue characteristics with a reduction in radiation exposure by replacing CT with MR imaging. The challenges of PET/MR are still numerous both on the technical side as on the practical and clinical side.

From PET/CT to PET/MR

The development of PET/MR started even before the first prototypes of PET/CT were developed. As described in details in the next chapter, the technical challenges were considerable to overcome the interference and cross-talk effects between magnetic field and the photomultipliers of PET detectors. Several alternatives have emerged and lead to the first hybrid devices to appear on the market for clinical applications. Whether it is through a combination of separate coplanar systems or by integrating solid-state PET detectors inside an MRI they provide the means to explore the potential clinical applications of whole-body PET/MR in clinical practice.

Given the broad range of applications of PET imaging, it is oncology that remains today the clinical domain where PET is mostly used. PET imaging was shown to be superior to other imaging techniques in staging and follow-up of numerous specific tumors. The advent of PET/CT has reinforced the clinical utilization of PET by allowing combined PET and CT studies to be acquired quasi-simultaneously with perfect alignment of anatomical and metabolic imaging data. While most clinical studies showed relatively modest improvement in diagnostic accuracy through the sensitivity and specificity of hybrid PET/CT over PET

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and CT performed separately, several studies demonstrated however a significant improvement in diagnostic confidence when both studies were acquired together and images were interpreted with fusion of both modalities. Uncertainties of diagnostic findings that could occur when PET images are interpreted without accurate anatomical localization can be avoided when CT images are co-registered with PET images and provide the necessary anatomical references. Conversely, diagnostic criteria of CT based on structural and morphological observations can be often misleading and subject to difficult interpretation and can be significantly improved when additional metabolic information of PET is provided with combined PET/CT images. While MRI has replaced CT in many clinical applications by providing ability for higher tissue characterization and functional imaging, the added value of PET/MR over PET/CT still remains to be demonstrated in clinical practice. The most immediate application might be in patients that require both PET/CT and MRI in their clinical workup and could benefit from a single study combining PET and MR when CT is of no significant additional value.

Potentials and Challenges of PET/MR

Technical designs of hybrid PET/MR devices differ considerably between different vendors as shown in the next chapter of this book. While integrated system my represent the most logical solution they remain technically more challenging and coplanar systems combining two scanners adjacent to each other provide an alternative that resembles in its design current PET/CT systems where the patient is moved from one to the other modality sequentially. In oncology applications both sequential and simultaneous acquisition of images may provide similar results they differ only on the imaging protocols used.

The remaining challenge of all hybrid PET/MR systems is the calculation of tissue attenuation correction maps similar to those calculated from whole body CT scans in hybrid PET/CT devices. Several techniques of attenuation correction were explored, but the emphasis has been mainly on MR image segmentation for derivation of an attenuation map. Besides image segmentation, other technical challenges for effective attenuation correction in a whole-body PET/MR, including compensation for MR image truncation and correction for RF coils and accessories also need to be implemented. Accurate calculation of tissue attenuation aims mainly toward providing quantitative measurement of PET tracer uptake in tissue. Semi-quantitative calculation of standard tracer uptake (SUV) is the most common technique used today and provides an attractive simple method to estimate the amount of tracer uptake in different tissues. While it can allow for differentiating between benign physiological and potentially pathological tissue tracers uptake, it has only marginal added value in routine clinical practice when PET findings are combined with observations from other imaging modalities such as CT and MR and confronted with multiple other criteria in clinical decision making. It remains however necessary to achieve the best and most accurate correction of tissue attenuation to use PET imaging technology at its full potential and benefit from the added value of quantitative imaging over visual interpretation of PET findings.

The Challenge of Hybrid Imaging Protocols

Depending on the scanner design, imaging protocols can differ significantly depending on the ability to perform sequential or simultaneous acquisitions of both modalities. It remains however that one of the most challenging aspect of hybrid PET/MR is the complexity and heterogeneity of MR protocols that are being used in clinical practice. The wealth of different types of imaging parameters that MRI provides and the diversity and lack of standardization of different imaging protocols have lead to significant differences in protocols used in clinical practice. The general trend is that MR imaging protocols have considerably been extended to include several sequences for better tissue characterization and extraction of functional and physiological parameters of different tissues and organs. The combination for such complex protocols together with additional whole-body imaging sequences of PET and MRI can lead to significantly longer examination time. Therefore, additional efforts and research is needed to optimize hybrid imaging protocols to benefit from the best potential capabilities of each modality while maintaining reasonable imaging time that is compatible with routine clinical practice.

Domains of Clinical Applications of PET/MR

The primary clinical applications of PET/MR that we elected to cover in this book are in oncology. But there are other emerging applications in cardiovascular, in inflammatory and infectious disease as well as in neurodegenerative diseases. MRI has gained a wide adoption in cardiology for the detection of ischemic disease, myocardial viability ad cardiac function. The added value and complementarity of PET in providing a better sensitivity and quantitative analysis of myocardial perfusion and myocardial viability can become good clinical justifications for combined PET/MR studies.

Brain imaging for acute as well as chronic disease often rely on combination of multiple imaging modalities such as PET and MR. In brain imaging however, the rigidity of the head and the easily identifiable skull structures, allow software-based registration technique to provide adequate fusion of different imaging modalities. A wider availability of hybrid PET/MR can however facilitate the use of hybrid imaging for brain studies with more convenience to the patient that does not have to undergo separate studies on different scanners.

Another factor that favors MRI over CT for hybrid imaging is the reduction in radiation exposure. Although for elderly patient and patients under palliative treatment for cancer, radiation exposure may be of minor impact, reduced radiation exposure of PET/MRI compared with PET/CT may be relevant in non-oncological patients and in younger patients with potentially curable disease.

Future of PET/MR in Oncology

This book highlights the potential applications of whole-body hybrid PET/MR in oncology. While it is still a collection of convincing anecdotal cases, it only reflects early observations of two academic centers that were first in adopting this new technique in clinical practice. The diversity of cases and broad scope of clinical domains covered in the different chapters of the book underline the potential applications in oncology but also in other clinical domains. The use of different radiolabeled tracers such as ^{18}F-fluorocholine and ^{18}F-fluorotyrosine show the potential of PET beyond the conventional ^{18}F-FDG tracer in clinical applications of hybrid PET/MR. However this new imaging modality has only been recently introduced for clinical use and will face the same challenges and skepticism that PET/CT technique encountered when it was first introduced. The lack of tangible added value of combined PET/MR over the two examinations acquired separately is the first issue that needs to be addressed both from a clinical perspective and from a medico-economic point of view. It is however foreseeable that increasing demand for objective criteria in determination of adequacy and efficacy of new treatments, in particular in oncology, will drive the development of new tracers and innovative hybrid imaging protocols that take full advantage of complementarity of PET and MR modalities.

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