The benefits of Combined PET/CT and PET/MRI technologies for cancer care

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Abstract: Cancer is one of leading causes of morbidity and mortality in developed countries. Most radiologic procedures map the anatomy and morphology of tumors with little or no information about their metabolism. Positron emission tomography (PET) is a coalition of physics, chemistry, physiology, and medicine united in an effort to measure physiologic parameters noninvasively. The combination of PET and CT has matured into an important diagnostic tool. During the same period, concepts for PET scanners integrated into an MR tomography have emerged. The excellent soft-tissue contrast of MRI and the multifunctional imaging options it offers, such as spectroscopy, functional MRI, and arterial spin labeling, complement the molecular information of PET. These combination have many benefits for the evaluation and early detection of pathological characterization, and recognized individualized treatments, particularly for cancer disease. This evaluation can provide valuable and important aspects for improving the survival of cancer patients. This research paper is focus on describing and explore the benefits of new development radiological techniques and discuss the various imaging characteristics for diagnosis and treatment of cancer offering great potential for improvements in the care of cancer patients in the near future.

Key Words: Cancer ; positron emission tomography ; technology ; PET/CT; PET/MRI ; oncology

I. Introduction:

Imaging is becoming an increasingly important tool in both research and clinical care. A range of new imaging technologies now provide unprecedented sensitivity to visualization of structure and function from the level of individual molecules to the whole body. Techniques in molecular imaging have developed from stand alone modalities to multimodality methods. Among these, the combination of positron emission tomography (PET) with computed tomography (CT) and magnetic resonance imaging (MRI). Combination of positron emission tomography (PET) and computed tomography (CT) is a successful imaging method and has become an important tool in clinical practice. Technological approaches that combine magnetic resonance imaging (MRI) with positron emission tomography (PET) have now been introduced. PET/MRI and the resulting combination of molecular, morphological and functional information will pave the way for a better understanding of physiological and disease mechanisms in preclinical and clinical settings, we describe its use in the study of cancer.

Cancer is of great public health importance, with approximately 1.5 million new cases last year in the US (1). Obviously, other fields of research such as neurology (2) and cardiology (3) also comprise fields where PET/MRI can be applied. Cancer exhibits not only a highly heterogeneous pathology with respect to the cell type and tissue origin, but also involves multiple pathways and fundamental cellular processes such as persistent growth signals, the evasion of apoptosis, insensitivity to antigrowth signals, unlimited replicative potential, angiogenesis, invasion and metastasis (4). Furthermore, changes in the cellular metabolism (5), tumor stroma, pluripotent stem cells and intercellular communication via gap junctions play important roles in carcinogenesis (6). Therefore, imaging techniques illuminating the biology and pathophysiology of cancer also have to be sophisticated and multilayered.

II. PET/CT technology

Accumulation can easily be confused with normal physiologic uptake, leading to false-positive or false-negative findings. Coregistration of PET scans with CT using a combined PET-CT scanner (Figure 1-1) improves the overall sensitivity and specificity of information provided by PET or CT alone. Advantage is ability to correlate findings at two complementary imaging modalities in a comprehensive examination. Hence, PET-CT provides more precise anatomic definition for both the physiologic and pathologic uptake. In combined PET/CT, cross-talk effects are virtually nonexistent and CT data can be used directly for the PET attenuation correction and image reconstruction. Clinical studies have demonstrated the advantages of PET/CT over separately performed PET and CT, itself helpful in accurate localization of small areas of increased radiotracer activity that would have been hard or not possible to localize on PET images alone. Also it helps in distinguishing structures that normally show high metabolic activity from those with abnormally increased
activity. PET-CT combines the advantages of the excellent functional information provided by PET and the superb spatial and contrast resolution of CT, in addition to attenuation correction for quantitative or semi-quantitative assessment of data is possible by using the CT data and the technology has evolved rapidly into a powerful diagnostic tool, particularly in the field of oncology (7). Thus, PET and CT have already proven to be ideal partners.

III. PET/MRI technology:

The concept of PET is to radiolabel a bio-compound, inject it into the patient, and then measure its biodistribution as a function of time to determine physiologic quantities associated with the bio-compound. All PET compounds are radiolabeled with positron-emitting radionuclides. The main principle of PET is based on the annihilation coincidence detection of positron-emitting radionuclides. Following positron decay, two 511 keV photons are emitted at an angle of approximately 180° and simultaneously detected by scintillation crystals. The light of the scintillation crystals is further converted into electrical signals, which are adequately processed and reconstructed to deliver image data. By contrast, MRI exploits the magnetic properties of the hydrogen atoms in an object (human body or animal) and its interaction with an external magnetic field and radio waves. Radio waves alter the alignment of the hydrogen magnetization and produce induced MR signals detectable by the scanner (8).

The idea to combine PET and MRI (Figure 1-3) arose as early as the mid 1990s, even before PET/CT was introduced. The PET/MRI combination requires 3 risky technologic steps that modify state-of-the-art PET and MRI. First, the photomultiplier technology must be replaced with magnetic field-insensitive photodiodes. Second, compact PET detectors must be constructed so that it shouldn’t interfere with the field gradients or MR radiofrequency. Finally, the MRI scanner must be adapted to accommodate the PET detectors and to allow simultaneous data acquisition without mutual interference. It is reasonable to expect that brain PET/MRI will provide new insights in the field of neuroscience and neurologic disorders, such as neurodegeneration, brain ischemia, neurooncology, or seizures (9). It is feasible with current prototypes and future-generation systems to simultaneously study brain function, metabolism, oxygen consumption, and perfusion. The exact spatial and temporal coregistration of data will allow the attribution of functional and molecular information to even anatomically small brain structures. For the first time, it may become possible to study the correlation of local radiotracer uptake and brain perfusion. Time-dependent processes such as perfusion changes in stroke patients may rely on simultaneous diffusion-weighted imaging and detection of PET perfusion to determine the optimal therapy procedure. In neurooncology, an accurate spatial match between PET and MRI data is mandatory for both radiation therapy planning and biopsy guidance. PET may detect especially small lesions with higher sensitivity than MRI (Fig. 1-2).
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Cancer increasingly account for morbidity and mortality. Therapeutic success with these chronic and often incurable diseases is linked to early diagnosis, accurate staging, and therapy monitoring. This requires repeated whole-body assessment of the extent of the disease, relapses, complications, and concomitant diseases. Clinical studies comparing 18F-FDG PET/CT and whole-body MRI indicate that therapeutically relevant information is frequently obtained by PET or MRI but not necessarily by CT. For example, MRI is more sensitive than PET/CT in the detection of brain, bone, and liver metastases, whereas PET/CT is more accurate in the detection of lymph node metastases, characterization of soft-tissue masses, and therapy monitoring. PET/MRI could be particularly useful for early tumor detection and functional therapy monitoring in oncology. It will likely be an ideal tool for investigating the effect of novel drugs, such as inhibitors of angiogenesis or modulators of the immune system. Integrated information on individual cell metabolism and microenvironment and their response to therapy will help elucidate the mechanism of action and optimize treatment schedules. Real-time monitoring of the success of radiofrequency ablation by PET may be an emerging application for PET/MRI.

Figure 1-2 PET/CT and PET/MRI of the brain shows frontobasal meningioma in olfactory region

IV. Advances in oncology

Based on initial findings, physicians foresee the first routine applications in tumor delineation and characterization. PET/MR’s ability to detect small lesions in soft-tissue is promising for diagnosis and treatment of a wide range of cancers, including those of the head and neck, the liver, lung, and prostate, as well as endometrial, ovarian, and cervical cancers.

“PET/MR is effective due to high soft-tissue contrast and the additional metabolic information, especially for primary tumor and local tumor recurrence, for example, in the liver. Overall, malignancies in the pelvic region will be a possible future application for PET/MR.”

The advantage of using MR over CT for tumor detection in the liver is notable because MR is a more specific test for characterizing liver pathology than CT.

Compared to individual modalities, PET/MR may pick up additional lesions in patients with extensive metastatic spread. “In patients with metastatic spread, the high sensitivity of diffusion-weighted imaging combined with PET may help identify additional lesions. It will also enhance detection of metastases in the liver, lymph nodes, and bone, as well as those in the brain and head and neck.

In patients with multiple myeloma and lymphoma, “there is the benefit of the added contrast and the bone marrow where some patients with multiple myeloma all have bone marrow involvement where CT is not

Figure 1-3 Images of MRI PET scanner
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as good as MRI in discriminating. The combination of MR and PET adds perfusion information to dynamic PET data. These techniques might play an important role for therapy adoption and when working with specific PET tracers. The advantage of the additional perfusion information is twofold: On one hand, it will be relevant in monitoring anti-angiogenic strategies. On the other, dynamic-contrast imaging plays an important role in tumor characterization and lesion detection.

V. Conclusion:
Having witnessed an impressive technologic development of PET detector technology, first PET/CT prototype systems, and MRI-based PET, advantage of PET/MRI over PET/CT is that PET/MRI not associated with significant radiation exposure. In addition to higher soft tissue contrast discrimination. Furthermore, MRI allows for additional techniques—such as angiography, functional MRI, diffusion, spectroscopy and perfusion techniques within a single examination. PET/MRI will provide new insights in the field of neuroscience and neurologic disorders. In oncology, an accurate spatial match between PET and MRI data is mandatory for both radiation therapy planning and biopsy guidance.

results, we now seek opportunities to translate these technologic advances into clinical benefits.

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References: