

Clinical Experience in Body MR-PET

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Initiated by the success story of hybrid imaging with the combination of positron emission tomography (PET) and computed tomography (CT) in PET/CT, integrated whole-body positron emission tomography (PET) / magnetic resonance (MR) scanners have recently been introduced and potentially offer new possibilities in hybrid imaging especially of oncologic patients.

Such an integrated MR/PET system comes with diagnostic advantages in cases where MR exceeds the performance of CT (ie, increased soft tissue contrast and reduced radiation dose) with clinical potential in oncology, neurology, cardiology as well as monitoring of early therapeutic success.

Simultaneous measurement of PET and MR datasets enables acquisition of a variety of imaging parameters during a single examination including anatomical as well as functional information, such as perfusion, diffusion and metabolism. Numerous studies have shown that the combination of these parameters can improve the diagnostic accuracy for many applications.

Background

In contrast to CT, magnetic resonance imaging (MRI) offers a superior soft-tissue contrast and a broad spectrum of functional methods such as spectroscopy, diffusion weighted imaging (DWI) or BOLD (blood oxygenation level-dependent).

In addition, MRI offers anatomical information without the need of ionizing radiation. With sensitivity in the picomolar range, PET is ideally suited for the visualization of specific molecules in organisms. Various parameters derived from PET (e.g. metabolism, blood flow) can be cross-correlated to anatomy and to information from functional MRI.

However, PET lacks the spatial resolution offered by MRI, which in turn lacks sensitivity. Therefore, the combination of PET and MRI is highly complementary. For example, one possible application is the examination of DWI and PET tracer uptake in oncology; furthermore, drug-receptor interactions and MR spectroscopy or PET-based perfusion and MR BOLD measurements in brain studies can be analyzed.

Technical challenges

In general, when talking about combined MR/PET systems, two different approaches are available: a sequential and a simultaneous approach.

In the sequential approach, which resembles the image acquisition of the sequentially performed PET/CT, standard hardware can be used and the patient will receive MR and PET at two different systems, whereas the simultaneous approach allows data acquisition within one single examination. Here, the PET and MR acquisition can be performed simultaneously since the PET detector is integrated in the MR scanner. Major advantage of the sequential approach is the fact, conventional system components can be used which markedly reduces the costs of these systems and probably facilitates the technical support. On the other hand, the simultaneous approach offers the possibility to correlate a broad spectrum of different parameters and radiotracers. Furthermore, MR-based partial volume correction can improve the PET quantification accuracy; MR-based motion correction of PET datasets could enhance the PET image quality.

However, the sequential approach leads to clearly longer examination times which could reduce the acceptance of the patients. The simultaneous approach allows for a number of advanced data processing which is not possible in sequential MR/PET, but it requires substantial changes of the PET detector technology.

Integration of PET in a whole-body MR system is technically demanding: standard PET detectors cannot be placed in the isocenter of an MRI scanner because they consist of scintillation crystal blocks read out by photomultiplier tubes, which are highly susceptible to magnetic fields.

Magnetic resonance compatible detectors had to be developed, substituting photomultiplier tubes with avalanche photodiodes (APD). These detectors are able to detect gamma quanta even inside of strong magnetic fields and convert the detected events from scintillation light to electrical signals.

Moreover, new approaches to attenuation correction of PET data based on MR imaging are mandatory. Attenuation correction of PET data is an important precondition when quantification of PET data results is required.

As the photons traverse tissues with different electron density and thickness, the photons are attenuated differently. In PET/CT, the so-called attenuation maps can be created from transforming CT transmission images into maps of attenuation coefficients at 511 keV. In MR/PET no transmission data is available since MRI gives no information about electron density. Therefore, several approaches have been proposed: one promising algorithm is segmentation based using the Dixon technique. This straightforward approach divides the body into four tissue classes (air, lung, soft tissue, fat). Based on this information, attenuation maps with predefined attenuation factors can be created. Due to our experience, results from combined PET/MR data acquisition showed very good spatial coregistration and did not reveal systematic spatial mismatches between PET and MR data.

Workflow aspects

In the sequential approach, the time of PET and MRI adds up. Therefore, MR sequences should be chosen with care to prevent long examination times. Of course, additional sequences can be acquired, depending on the clinical demands.

In the simultaneous approach the MR examination is performed during PET data acquisition. Usually, the distribution of the tracer is recorded for 2–4 min per bed position at a steady state.

A whole-body examination can be performed with five bed positions covering the head, neck, thorax, abdomen, and pelvis up to the thighs.

The choice of MR sequences determines the imaging workflow. Whereas PET data acquisition simultaneously runs in the background, various MR sequences, weightings, and slice orientations can be acquired for each bed position but prolong the examination time. Localizer and Dixon sequences for AC need to be acquired first. T1-weighted and T2-weighted fat suppressed and contrast-enhanced T1-weighted sequences are usually performed in oncologic imaging and may be accompanied by diffusion-weighted imaging. Accordingly, the imaging workflow will have to be focused on the specific clinical needs to maximize the MR/PET information in a reasonable acquisition time.

In principle, each MR sequence, including DWI, contrast-enhanced imaging, MR angiography or even MR spectroscopy, could be used in conjunction with the

simultaneous acquisition of PET data. The inclusion of these data can probably add further functional information to the fluordesoxyglucose metabolism and gain new insights into tumor biology in selected cases. Nevertheless, the MRI functionality is not limited by the PET.

Limitations

Due to the amount and the complexity of the acquired multiparametric data there is a need for advanced analytical tools, such as methods of parameter selection and data classification.

Conclusion

Integrated MR/PET hybrid imaging is feasible in a clinical setting without loss of diagnostic information when compared with PET/CT serving as the intraindividual standard of reference. MR/PET offers the possibility to assess anatomic, functional, and metabolic information in one examination. Furthermore, it offers several advantages such as radiation-reduced examination and superior soft-tissue contrast when compared to PET/CT.

Magnetic resonance based attenuation correction of PET data can be performed sufficiently with Dixon sequences, although bone is disregarded. The administration of specific radiotracers and dedicated imaging sequences will help to identify the full diagnostic potential of this new hybrid imaging modality in various indications.

References

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