The physical principles of Positron Emission Tomography in the context of hybrid PET/MRI

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Purpose: With the most recent advent of commercially available imaging systems, combined hybrid Positron Emission Tomography/Magnetic Resonance Imaging (PET/MRI) as a new imaging modality became clinical reality [1, 2]. Traditionally, however, MRI and PET have been separate fields and researchers and physicians either specialized in MRI or in PET. In the context of the new PET/MR hybrid imaging systems, it seems of mutual scientific benefit to bring those two fields closer together by introducing the basics and physical principles of PET to a broad audience of MR specialists.

Outline of Content: In this work, the physical principles as well as some clinical aspects of PET will be presented.

In PET the radiation emitted by radioactive substances that are injected into a patient's body are imaged. These radioactive substances – the so called radiotracers – are usually metabolites that are chemically modified (i.e. labeled) to contain a radioactive isotope with rather short half-life. The most common of these radiotracers is ^{18}F-Fluorodeoxyglucose (^{18}F-FDG) which is a glucose analog that was labeled with the radioactive isotope ^{18}F. ^{18}F-FDG follows the same metabolic path as glucose, however glycolysis is not possible. This results in the ^{18}F-FDG being trapped inside the cells and thus depicting glucose metabolism. Hypo- and hyperactive glucose metabolism have been shown to be good indicators of certain types of cancer.

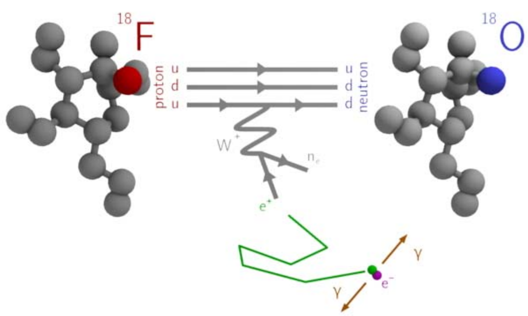

Figure 1: *Origin of the PET signal*

As the name "PET" already states, the radioactive isotope used is always a positron emitter. In the above example of ^{18}F, in the Fluor atom one proton is converted into a neutron while emitting a positron. The resulting atom is then ^{18}O. Other examples are ^{11}C, ^{13}N or ^{15}O. Half-life is 20 min for ^{11}C, 10 min for ^{13}N, 2 min for ^{15}O and 110 min for ^{18}F.

The emitted positron then has a certain mean free path (< some mm) before annihilating with an electron in the body tissue. In this annihilation process, two photons with the defined energy of 511 keV each are emitted in an angle of 180°. It is these photons that can then be detected outside of the patient's body. To be able to deduce the actual location of the annihilation process, both of the two generated photons have to be measured. This is detected as a so called coincidence event or line of response (Fig. 1).

To actually measure the emitted photons, several techniques exist. In traditional PET and PET/CT, scintillating crystals together with photomultiplier tubes (PMTs) are used. In PET/MRI, however, PMTs can only be used under great effort, as the paths of the electrons that are generated in the PMTs are greatly distorted by the strong magnetic field of the MR scanner. In combined PET/MRI scanners, either the light emitted by the scintillating crystals is transported to PMTs outside of the strong magnetic fields by means of light guides, or other detection techniques must be used [3]. Alternatives for PMTs that are compatible with magnetic fields are for example avalanche photodiodes (APDs) or silicon photomultipliers (SiPMs).

When several millions of these coincidence events have been recorded, reconstruction can be performed and the distribution of the radiotracer in the patient's body can be deduced (Fig. 2). Corrections necessary to gain a correct representation of the tracer distribution are decay correction, singles subtraction, normalization, randoms correction, attenuation correction and scatter correction. Especially attenuation correction of PET data is still a challenge in PET/MRI, as information about linear attenuation coefficients of the patient's body tissues have to be gathered from MRI sequences that cannot provide any direct information about soft tissue attenuation. The correction steps are typically performed before or during the reconstruction process. Due to the low statistics the reconstruction process itself is performed iteratively which is computationally quite intensive. On modern hardware, however, the complete reconstruction including all necessary corrections takes only several minutes.

The distribution of the radiotracer in the patient's body is usually displayed in units of activity (i.e. Bq/ml) or as Standardized Uptake Value (SUV) which relates the measured activity to the injected activity and the patient's weight.

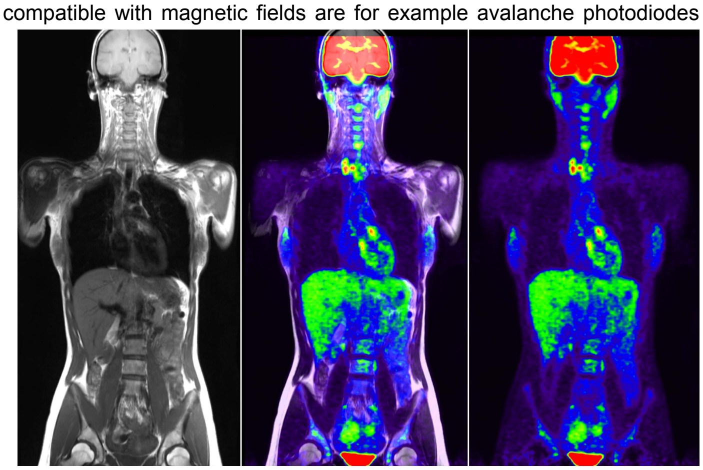

Figure 2: *Hybrid whole-body PET/MRI dataset. T1 TSE (left), 18F-FDG PET (right), fused PET/MRI dataset (center).*

Summary: The physicals principles underlying PET are completely distinct than those of MRI. Integration of both imaging modalities thus is inherently challenging. However the combination of both modalities promises to provide physicians with a wealth of diagnostic information about each individual patient, potentially allowing earlier, faster and more accurate diagnosis. Moreover PET/MR hybrid imaging is a highly innovative research field where physicists and clinicians jointly develop and evaluate new techniques to further broaden the range of clinical applications.

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[2] O. Ratib and T. Beyer. Whole-body hybrid PET/MRI: ready for clinical use? European Journal of Nuclear Medicine and Molecular Imaging 2011 Volume 38(6):992-995
[3] H. H. Quick, R. Ladebeck and J.-C. Georgi. Whole-Body MR/PET Hybrid Imaging: Technical Considerations, Clinical Workflow, and Initial Results. Magnetom FLASH 2011 Volume 46:88-100