Systematic Investigation and Correction of MR Influences on Simultaneous PET Measurements

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Introduction: Hybrid MRI and PET measurements offer the prospect of improved diagnostics, therapeutic monitoring and preclinical research. MRI provides high-resolution anatomical images with unchallenged soft-tissue contrast, whereas PET allows for highly sensitive measurement of metabolic function. A prototype hybrid 3T MR-PET dedicated brain scanner was installed in our laboratory in October 2008. The system allows for simultaneous measurement of MRI and PET with the advantage of temporal co-registration. This is important when matching functional information from MRI and PET. Recent studies indicate that simultaneously performed MR scans can influence the PET measurement, potentially influencing the ability to quantify the PET images [1]. This study aims to investigate this phenomenon and to derive a correction method for the observed count rate drops.

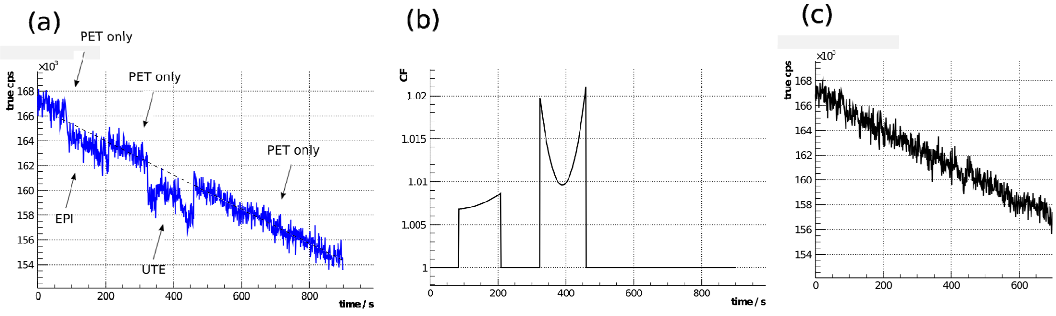

***Figure** 1: True PET counts during PET only, EPI and 3D-UTE acquisition. The dashed line indicates the linear fit used to derive the correction factor (b) Correction factor derived from a c) Corrected true PET counts*

Methods: All measurements were performed on a Siemens 3T MR-BrainPET hybrid scanner. This consists of a Tim Trio MR Scanner, with a BrainPET component insert. The PET detector consists of LSO scintillation crystals, sized 2.5mm x 2.5mm x 20mm. The readout electronics are based on avalanche photodiodes (APD), which are non-magneto sensitive [2]. The detector blocks with crystals, APDs and pre-processing electronics are positioned in the MR bore. To limit the exposition of the PET electronics to the time dependent magnetic fields, the detector cassettes are shielded with copper. The MR gradient system is capable of a maximum slew rate of 200 mT/(m*ms) and a maximum gradient amplitude of 40 mT/m. All measurements were performed with the PET phantom placed within the vendor-provided TX/RX head coil. Previous studies have shown an instantaneous decrease of the PET count rate, especially during MR sequences with strong demands on gradient switching, e.g. UTE and EPI. To demonstrate these effects, measurements with standard, vendor provided EPI and 3D-UTE (radial sampling) sequences were conducted. For a systematic investigation, a dedicated MR sequence (no imaging) that allows for selective switching of single gradients with variable amplitude and slew rate was programmed. PET data were acquired during the time that the MR sequences ran. A calibration phantom (cylinder 20cm length, 20cm diameter) filled with F-18 (half-life time: 109min) immersed in water with an initial activity of 120 MBq was used. During the PET measurements the physical x,y and z gradients were switched on for a total duration of 1.13ms with a fixed amplitude 20mT and constant ramp up- and down times of 130us. The repetition time (TR) was set for each gradient to be 20ms, 10ms, 5ms, 2.5ms and 1.2ms.. The sequence was repeated for approximately 60s followed by a PET-only acquisition to observe the undisturbed count rate. The overall measurement time (15 gradient settings plus PET only) was 1800s. Since the decrease of the count rate is homogeneously distributed over the whole PET detector ring, a global correction value can be applied to scale the measured counts. A count rate based correction was obtained by calculating the ratio of expected count rate to measured count rate. The expected value is derived by interpolating values from adjacent count rates when no MRI sequences were performed. The derived time-dependent correction was applied to the PET data. Additional measurements (not shown here) were performed to check the linearity of the count rate drops under the action of multiple gradients, the sensitivity to an increased gradient duration and RF influences.

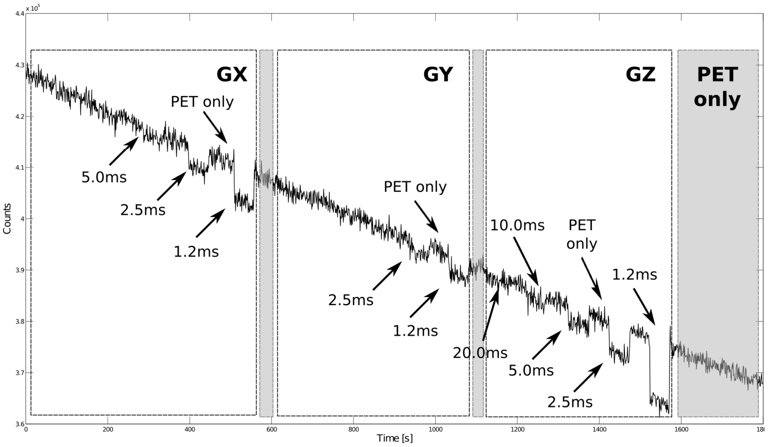

***Figure** 2: True PET count rate during a 1800s measurement with simultaneous action of gradients (one gradient active at a given time). For each gradient direction all repetition times (20.0,10.0,5.0,2.5,1.2 ms) were measured while only visible count rate drops are labelled in the Figure (arrows with corresponding repetition time). Each measurement was separated by a PET only interval of approximately 60s.*

Results: Figure 1(a) shows the measured true counts during the PET measurements in combination with the EPI and UTE sequences. The count rates shown here are neither corrected for the exponential decay of the isotope nor for dead time effects of the detector. Furthermore, the true count rates contain the prompts minus the delayed counts and includes the number of scattered events. The derived correction factor is shown in Figure 1(b) with the corrected head curve displayed in Figure 1(c). The EPI and UTE sequences have a different influence on the PET measurements. This is due to the individual k-space sampling, and, therefore, gradient waveforms, of each sequence. This implies a different sensitivity to the individual gradient axes since the UTE sequences utilises a radial readout scheme that uses varying combinations of the physical gradient directions. The presented correction effectively removes the count rate drop. The systematic measurements of the individual gradients (Figure 2) support the assumption of differential sensitivity of the PET count rate to the individual gradient axes. The z gradient shows the largest effect on the PET count rate while the y gradient shows the least effect. While the symmetry of the gradient coil design offers a reasonable explanation for the difference in sensitivity between x,y and the z gradient it does not explain the varying sensitivity between the x and y gradient. However, this effect can be explained by a scaling factor. The onset of the count rate drop occurs immediately following the start of the sequence and the relative drop stays constant, as long as the applied gradient waveforms are repeated. We found no measurable influence of RF even at the maximum allowed SAR values. The relative count rate drop appears to be linear when several gradients are active. A prolonged gradient flat top duration while keeping a constant ramp has no effect on the count rate drop, supporting the hypothesis that eddy currents are the origin of the observed artefacts.

Conclusion and Outlook: The results suggest a nearly linear dependence of the relative count rate drop on the time derivative of the gradients (per unit time). Current investigations focus on deriving the exact dependence of the relative count rate drop on the MR sequence timing. An appropriate model should allow for the correction of the count rate drop during arbitrary MR sequences, as long as their exact gradient waveforms are known. For this purpose we propose to model the relative count rate drop as being proportional to the time-averaged sum of the time derivative of the gradient shapes, where each direction is weighted with a specific weighting factor. Verification of this modelling is currently in progress.

References: [1] Kaffanke et al. Proc. ISMRM p.3951 (2010) [2] Grazioso et al, Mol Imaging 4:391(2005)