Integrated PET/MR: Phantom Studies Towards Radiotracer Dose Reduction

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Target audience: MR Researchers and physicians who are working in the new field of PET/MR hybrid imaging.

Introduction: Integrated PET/MR in selected clinical applications may reduce the overall patient radiation dose when compared to PET/CT due to replacing ionizing CT imaging by MR imaging. Further potential for radiotracer dose reduction in integrated PET/MR may be achieved by turning the comparatively prolonged PET/MR data acquisition times into an advantage: In conventional PET/CT hybrid imaging, the PET data acquisition times last around 2-3 minutes per bed position. In integrated PET/MR hybrid imaging data acquisition times are in the range of 5-20 minutes per bed position depending on the clinical application [1] [2]. The longer imaging times in PET/MR are associated with MR data acquisition using various contrast weightings with corresponding imaging sequences. Increasing the PET data acquisition times in combination with the increased sensitivity of the APD-based PET detectors used in integrated PET/MR systems [3] may allow for decreasing the injected patient radiotracer dose when compared to PET/CT while maintaining image quality. Initial results from a clinical study indicated that prolonged PET acquisition times per bed may allow for reduced tracer dose [2]. To systematically verify this hypothesis under controlled circumstances and exclude potential biophysical changes in lesion activity over time, this study was performed using a standardized phantom following the National Electrical Manufacturers Association Image Quality (NEMA IQ) protocol [4].

Material and Methods: All measurements were performed on an integrated PET/MR whole-body hybrid system (Biograph mMR; Siemens AG Healthcare Sector) which enables simultaneous PET and MR examinations. The NEMA image quality phantom simulates the shape of the human torso and contains an air filled spongeous insert simulating lung tissue. Additionally, the phantom includes six hollow glass spheres with different inner diameters (Fig. 1A). The four smallest spheres (10, 13, 17, 22 mm) were filled with radioactivity ("hot") and the other two (28, and 37 mm) filled with water only ("cold"). The background volume of 9.5 liters was filled with water and a total activity of 50.35 MBq of ^{18}F-FDG. The ratio between background activity and the four hot-spheres is 1:8. PET data blocks of 20 min acquisition time each, were acquired in listmode format. The data acquisitions were started periodically at multiples of the ^{18}F-FDG-half-lifes (every 110 min) and additionally in between 2 half-lifes (Fig.1C). For better statistics, the experiment was repeated three times. From the 20 min listmode files different sinograms (2, 4, 8, 16 min long) were reconstructed. Attenuation correction (AC) of the hardware and the filled phantom was performed using a CT-based μ-map template and image registration of the template to the position of the phantom. The attenuation corrected PET images were then evaluated following the NEMA IQ protocol. Contrast recovery, background variability and signal-to-noise ratio (SNR) were calculated for each image out of 6 regions of interest (ROIs) for the spheres and 360 ROIs in the phantom background (Fig. 1B). The goal was to compare images and quantitative parameters with half the activity and twice the acquisition time, i.e. 100% activity and 2 min acquisition, 50% and 4 min, 25% and 8 min, 12.5% and 16 min. These images were compared quantitatively by the calculated parameters, as well as qualitatively by image readers that were instructed to determine visual differences in image quality.

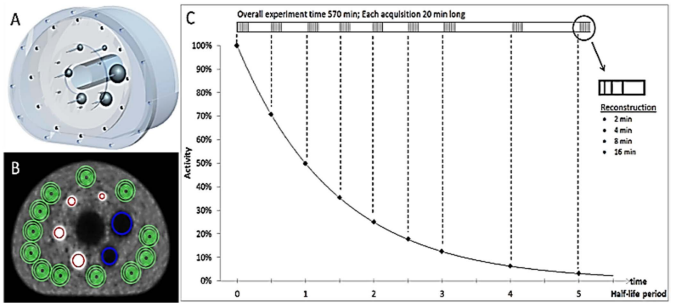
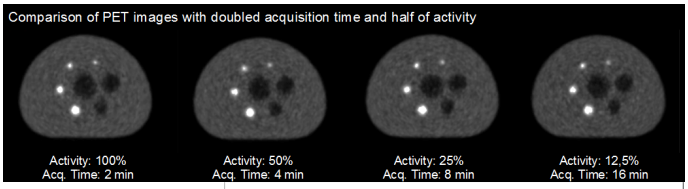


Fig. 1: 3D Modell of the NEMA IQ Phantom (A). The 4 hot lesions (red) and 2 cold lesions (blue) ROIs and 60 green concentric background ROIs on the PET image used for evaluation (B). Time schedule of the experiment, with the 20 min listmode along the six half-life periods (C of FDG radiotracer activity decay.

Results: The PET images at different tracer activity levels and acquisition times show no visible difference in image quality (Fig. 2). The SNR of the four hot spheres change only slightly over the four different acquisition setups (see graph in Fig. 2). The largest variation in SNR of the smallest sphere (10 mm diameter), compared to the reference image with 100% tracer activity and 2 min acquisition time, was 15% at the third half-life period. SNR remained nearly constant before (variation 1%). The maximum change in SNR was +10% for the 13 mm sphere, +5% for the 17 mm sphere and +4% of the 22 mm sphere. In a blind study, image readers could not distinguish between the different PET acquisitions setups (images in Fig. 2).



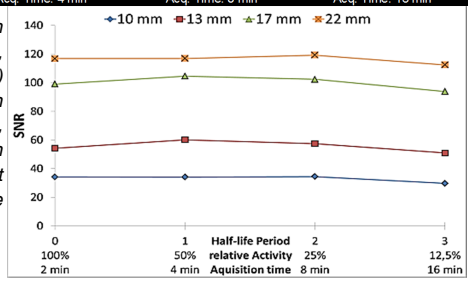


Fig. 2: PET images with halved activity (100%, 50%, 25%, and 12.5%) but doubled acquisition time (2 min, 4 min, 8 min, 16 min). SNR mean values for the four hot spheres plotted over time and decreasing activity.

Discussion: The changes in SNR are slightly measurable. The largest variation in SNR (up to 15%) results in the smallest sphere in the last half-life period, where effects like partial volume come into play. The study demonstrates that the hypothesis of maintaining PET image quality when lowering dose while increasing acquisition time is valid. These results were determined by NEMA IQ phantom evaluation and clinical recommendations can be derived.

Conclusion: The hypothesis to maintain PET image quality at lower injected tracer activity by increasing the acquisition time is viable as shown in this standardized phantom study and under idealized experimental conditions. In integrated PET/MR, MR data acquisitions and thus also simultaneous PET data acquisitions in general terms are prolonged when compared to PET/CT data acquisitions. The longer acquisition time per bed position enables the reduction of the administered PET tracer activity while maintaining image quality and can therefore lead to a dose reduction. Therefore, this experiment may serve as a basis for further clinical PET/MR studies using reduced tracer activity as compared to conventional PET/CT studies.

References: [1] Quick et al., Invest Radiol 2013, 48(5): 280-289. [2] Hartung-Knemeyer et al., Invest Radiol 2013, 48(5):290-294. [3] Delso et al., JNM 2011, 52:1914-1922. [4] NEMA Standards Publication NU 2-2007 Rosslyn, VA; 2007: 26-33.