Advancements in molecular medicine

Philips Ingenuity TF PET/MR performance

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Introduction

The Ingenuity TF PET/MR (Philips Healthcare, Cleveland, OH) is a newly released whole body hybrid imaging system with a Philips Achieva 3T system and a Philips Astonish TF PET. We report the standard NEMA NU2 measures for spatial resolution, sensitivity, count-rate capability and contrast recovery for the scanner. The NEMA NU 2 standard is a useful benchmark for characterizing performance of PET scanners as it facilitates comparison between different scanner models[1].

Methods

Ingenuity TF PET/MR scanner

The Ingenuity TF PET/MR is a sequential hybrid imaging system, similar to a PET/CT. In this design, a turntable between the MRI and PET facilitates patient motion between the two systems. Compared to PET/CT, modifications to the PET were made to avoid mutual system interference and deliver exceptional performance which is equivalent to the standalone systems.

The PET gantry was redesigned to introduce magnetic shielding for the PMTs which assured their operation in 'normal' flux levels close to the Earth's magnetic field. The design was guided by the requirement that no shielding material was to be placed in the direct path of gamma rays. Furthermore, stringent electromagnetic noise requirements of the MR system necessitated the removal of PET gantry electronics to be housed in the PET/MR equipment room.

The Ingenuity TF PET/MR is a 3D scanner comprised of 28 modules arranged in a cylinder that is 90 cm in diameter by 18 cm axially. Each LYSO crystal element is 4 x 4 x 22 mm^3 in size. Data are acquired in list-mode with indices of the activated detectors recorded along with the differential time of arrival using a 460 keV lower-level discriminator. Reconstruction is typically performed to yield slices containing 144 x 144 pixels that are 4 x 4 x 4 mm^3 for body and 2 x 2 x 2 mm^3 for brain. The MR was used for attenuation correction of PET, using a specifically designed MRAC technique[2].

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sense and simplicity

Scanning

All PET calibrations and measurements were done with the MRI ramped to 3T, shimmed and calibrated.

Sensitivity was measured using 8.8 MBq of ^{18}F-FDG in a 70 cm long line source placed inside five concentric aluminum sleeves. Coincidence rates were measured for 1 through 5 of the sleeves in-place while the source was centered and at 10 cm from scanner axis. Count rates were obtained from list-mode files and interpolated to obtain the rate with zero thickness of aluminum under the assumption that all positrons would be annihilated in the absence of attenuating material.

Spatial resolution was measured using approximately 1 mm ^{18}F-FDG point sources in glass tubing. Sources were measured at standard locations: 1 cm and 10 cm from center of the scanner. Images were reconstructed using filtered back-projection not making use of TOF information.

Hot-sphere contrast recovery (ratio of observed contrast to true contrast) and variability (standard deviation of sphere background) were measured using the IEC phantom with spheres using an initial concentration of 5.4 kBq/mL ^{18}F-FDG in the background and 4 times higher concentration in the 10, 13, 17 and 22 mm spheres. The larger 28 and 37 mm sphere were filled with water to assess ***cold-sphere contrast recovery*** (CSRC). Attenuation correction of the PET image was done using a custom MR acquisition and image processing, slightly different than that for patient imaging. Images were reconstructed using a list-mode OSEM using 3 iterations with 33 subsets each, a blob basis function, TOF information and accounting for attenuation, scatter and random events in the system matrix.

Noise-equivalent count rate [$NEC = Trues^2/(Trues + Scatter + Randoms)$] performance vs. activity and *scatter fraction* were measured using the 20 cm diameter x 70 cm long phantom with 555 MBq in a 70 cm line source at 4.5 cm from the central axis of the cylinder.

Results

The table below shows Gemini TF PET/CT typical NEMA values compared to Ingenuity TF PET/MR (n≥4 for PET/MR data). *Timing resolution and energy resolution* of the PET/MR system (not NEMA standard measurements) were stable over time and measured to be 520 ps and 12%, respectively. Scatter fraction for larger cylinders with diameter 27 and 35 cm were 32% (38%) and 41% (46%), and NEC was measured as 45 kcps (46 kcps) and 16 kcps (18 kcps), respectively with PET/CT values in parentheses[3]. Figure 1 shows typical NEMA count rate performance of the PET/MR system, with an IEC phantom image in Figure 2. Representative patient images obtained from the system are shown in Figure 3.

Specification	Gemini TF PET/CT		Ingenuity TF PET/MR	
Spatial res 1 cm transverse (FWHM)	4.7 mm		4.7 ± 0.1 mm	
Spatial res 10 cm radial (FWHM)	5.1 mm		5.1 ± 0.1 mm	
Spatial res 10 cm tangential (FWHM)	5.1 mm		5.1 ± 0.1 mm	
Spatial res 1 cm axial (FWHM)	4.7 mm		4.7 ± 0.2 mm	
Spatial res 10 cm axial (FWHM)	5.2 mm		5.2 ± 0.4 mm	
Sensitivity 0 cm/10 cm (cps/MBq)	7000/7200		7000 ± 155/7200 ± 142	
Scatter Fraction -20 cm	30%		26% ± 3%	
NECR Max (kcps) -20 cm	110		90 ± 3	
NEC peak location (kBq/mL) -20 cm	16		14.2 ± 0.6	
IEC 4:1 contrast	**Contrast**	**Background variability**	**Contrast**	**Background variability**
10 mm sphere (%)	33	5	30 ± 5	7 ± 0.5
13 mm sphere (%)	51	4	50 ± 5	6 ± 0.3
17 mm sphere (%)	63	4	66 ± 1	5 ± 0.7
22 mm sphere (%)	64	3	70 ± 2	5 ± 1
28 mm sphere (%)	77	3	72 ± 2	4 ± 1
37 mm sphere (%)	80	2	77 ± 3	3 ± 1

Discussion

The concept of hybrid PET/MRI arose in the 1990s, even before PET/CT was introduced, but it is a technical challenge to maintain PET PMT functionality in a high magnetic field. The design presented here introduces magnetic shielding for the PET gantry for hybrid PET/MR imaging. The NEMA results obtained with PET/MR are comparable to typical Gemini TF PET/CT results. System energy and timing resolution were comparable to PET/CT, demonstrating the effect of magnetic shielding to maintain the PMTs in normal flux levels. There was a slight decrease in peak NECR, which can be attributed to a thicker patient table used in the PET/MR system. A minor increase in IEC background variability was also ascribed to the same reason. Overall, the results demonstrated that both PET and MRI can function in close proximity without compromising PET imaging performance and quality. Attenuation correction for clinical imaging represents the biggest challenge facing the field of PET/MRI. We implemented a 3-segment approach for generation of MR-based attenuation maps. PET images obtained from the PET/MR system (Figures 3 and 4), reconstructed with default reconstruction method portrayed good image fidelity, qualitatively comparable to PET/CT.

In conclusion, we report the design of a whole-body hybrid PET/MRI system where PET performance is comparable to standalone Gemini TF PET/CT system.

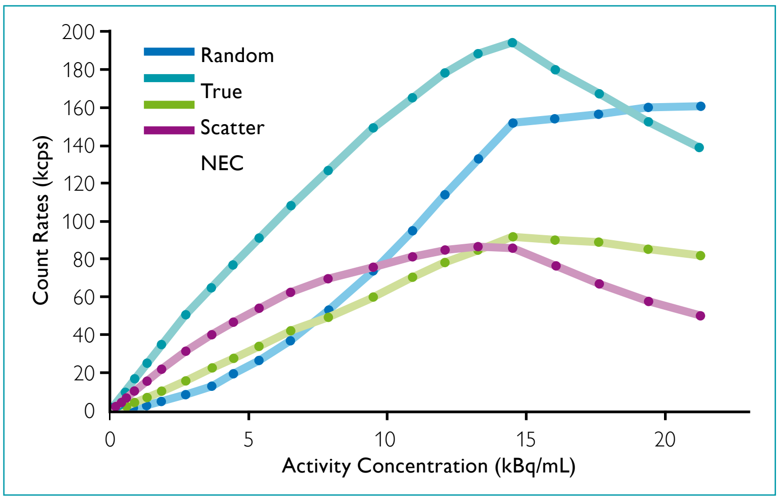

Figure 1 Count-rate performance, NEC

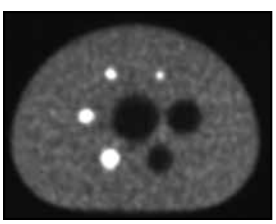

Figure 2
IEC phantom

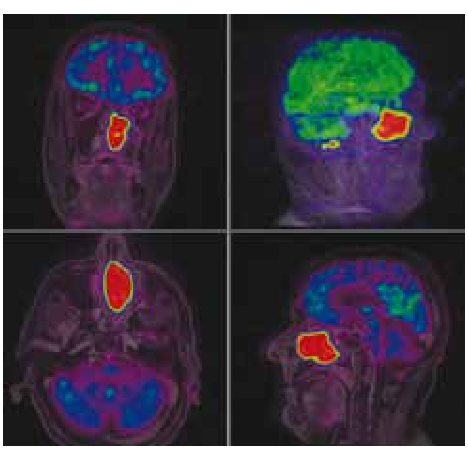

Figure 3 PET/MR fusion

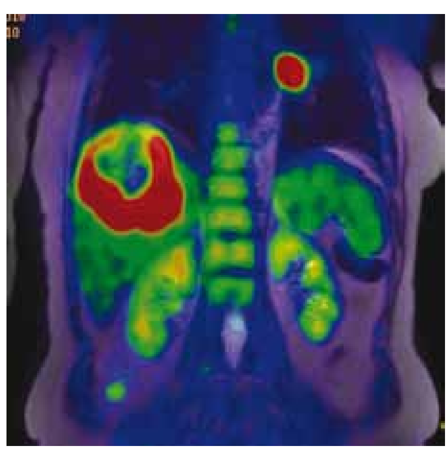

Figure 4 PET/MR fusion

Acknowledgements

We thank Mt Sinai Medical Center, NY and Hôpitaux Universitaires de Genève (HUG), Geneva for support during system installation and testing.

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Printed in The Netherlands.
4522 962 81651 * DEC 2011