NEMA NU 2012 Performance Evaluation of the SiPM–Based and conventional PMT-based Time-of-Flight systems

Paulo Caribé[1], Michel Koole[2], Ana M. Marques da Silva[3], Yves D'Asseler[1], H Bertin[4], Stefaan Vandenberghe[1]

[1]*Medical Imaging and Signal Processing - MEDISIP, Ghent University, Gent, Belgium*
[2]*Division of Nuclear Medicine and Molecular Imaging, KU Leuven, Belgium*
[3]*Laboratory of Medical Imaging - NIMed, PUCRS, Rio Grande do Sul, Brazil*
[4]*GE Healthcare, BeNeLux*

Resumo: Uma nova geração de detectores SiPM em sistemas PET, melhora a sensibilidade ao fóton e a resolução espacial em comparação com os detectores de PET convencionais com fotomultiplicadoras (PMT). Essas melhorias prometem aprimorar a detecção de lesões em imagens de pacientes com baixas doses, o planejamento e avaliação do tratamento individualizado. O objetivo deste estudo é avaliar o desempenho dos sistemas TOF-PET com base nessa nova geração de detectores SiPM, comparando-os com os sistemas convencionais. Para este propósito, foram realizadas medidas de qualidade da imagem no *phantom* NEMA NU 2–2012 para caracterizar a recuperação de contraste (CR), resolução espacial (SR), sensibilidade, qualidade de imagem (IQ), taxa de contagem de ruído equivalente (NECR) e linearidade, no equipamento *GE Signa integrated* PET/MR, *Discovery* MI PET/CT (DMI) e *Biograph* mCT Flow PET/CT. Foram avaliados os primeiros sistemas TOF-PET/CT e PET/MR baseados em detecção SiPM. Os resultados demonstraram que a nova geração de sistemas baseados em SiPM apresenta maior sensibilidade, melhor desempenho em condições de alta taxa de contagem e melhor qualidade de imagem, comparados aos sistemas convencionais.
Palavras-chave: PET/CT; PET/MR; NEMA; caracterização; Instrumentação; SiPM.

Abstract: *A new-generation of PET detectors have SiPM that improves the photon sensitivity, time resolution, and spatial resolution compared to the conventional photomultiplier (PMT) PET detectors. These improvements are expected to enhance lesion detection, low-dose patient imaging, and individualized treatment planning and evaluation. The aim of this study is to assess the performance characteristic of new-generation SiPM-based and conventional PMT-based time-of-flight PET systems. For this purpose, NEMA NU 2–2012 performance measurements for characterizing contrast recovery (CR), spatial resolution (SR), sensitivity, image quality (IQ), noise equivalent count rate (NECR) and linearity were performed on GE Signa integrated PET/MR, Discovery MI PET/CT (DMI) and Biograph mCT Flow PET/CT (Biograph). We evaluated the first commercial GE SiPM-based TOF PET/CT and PET/MR systems. The results demonstrated that the new-generation of SiPM-based TOF PET/CT system has higher sensitivity, better performance (under high count-rate conditions) and better image quality than the conventional.*
Keywords*: PET/CT; PET/MR; NEMA; characterization; instrumentation; SiPM.*

Introduction: PET/CT is an essential imaging modality for evaluating staging, recurrence, and the outcomes of treatment in oncology. Up to now, PET detectors have been meanly based on photomultiplier tubes (PMT), however these detectors have a limited photon-to-electron quantum conversion efficiency and relative bulkiness[1]. A new-generation of solid-state silicon photomultiplier (SiPM) photon detector has been commercially used in the last few years. Improvements in photon sensitivity, time resolution, and spatial resolution are expected to enhance lesion detection, low-dose patient imaging, and individualized treatment planning and evaluation[2]. The aim of this study is to assess the performance characteristic of new-generation SiPM-based and conventional PMT-based time-of-flight PET systems. For this purpose, NEMA NU 2–2012 performance measurements for characterizing spatial resolution (SR), sensitivity, image quality (IQ), noise equivalent count rate (NECR) and linearity were performed on GE Signa integrated PET/MR, Discovery MI PET/CT (DMI) and Biograph mCT Flow PET/CT (Biograph).
Methods: NEMA NU-2 2012 testing was performed independently on GE Signa integrated PET/MR, installed at KU Leuven and the others at Ghent University. For the SR measurements, a ^{18}F-FDG point source inside a glass capillary tube was positioned at 1 and 10 cm off-center in the field of view. Sensitivity tests at both institutions, plastic tubing (70 cm in length, 1 mm in inner diameter) was filled with an averaged calibrated activity of approximately 20.0 MBq of ^{18}F-FDG The line source was placed in an aluminum sleeve ensuring complete annihilation of all positrons. NECR were measured using a 70-cm-long polyethylene cylinder with a diameter of 20 cm and a line source inserted axially into the cylinder 4.5 cm off-centered filed with 871.0, 883.0 and 865.0 MBq of ^{18}F-FDG (at first frame start) for all systems. PET image quality tests were evaluated using the NEMA IQ phantom with a 4:1 ratio for the hot sphere to background activity concentration, which equals 52.0 MBq for a 9800 ml phantom. The scatter phantom line source was filled with activity between 116 – 120 MBq at scan

start. For the all systems, the accuracy of the attenuation and scatter correction were determined from the uniform background and could lung insert regions.

Results: The contrast recovery for small spheres is better for the Discovery MI 4 rings than for any of the other commercially available systems in Table 1. This better contrast recovery should lead to an improvement in the system's ability to detect, visualize, and quantify smaller lesions. The spatial resolution testing showed that, taken as a whole over all 3 resolution directions and the different distances from the center of the FOV, the Discovery MI performs comparably to the other systems.

Table - 1 Image quality based on contrast recovery, spatial resolution, lung error and sensitivity results for all systems.

	GE Healthcare			Siemens
Parameter	Discovery MI PET/CT 3 Rings	Discovery MI PET/CT 4 Rings	SIGNA PET/MR	Biograph mCT Flow PET/CT
Axial FOV (cm)	15	20	25	22.1
Transaxial FOV (cm)	70	70	60	70
Contrast Recovery [%]				
10 mm–Radioactive	44.2	53.7	48.7	28.5
13 mm–Radioactive	53.4	64.0	62.9	42.3
17 mm–Radioactive	66.4	73.1	68.1	58.4
22 mm–Radioactive	70.7	82.7	76.1	70.7
28 mm–Non-Radioactive	81.6	86.8	87.1	72.1
37 mm–Non-Radioactive	84.5	90.7	92.7	78.3
Lung Error [%]	7.8	4.4	1.6	5.6
Spatial Resolution FWHM*				
Radial, 1 cm	4.65	4.10	4.46	4.33
Axial, 1 cm	4.47	4.48	5.35	4.25
Tangential, 1 cm	4.36	4.19	4.08	4.33
Radial, 10 cm	5.54	5.47	5.81	5.16
Axial, 10 cm	5.44	6.01	6.75	5.85
Tangential, 10 cm	4.75	4.49	4.44	4.72
Radial, 20 cm	7.41	7.53	8.42	5.55
Axial, 20 cm	5.78	6.10	7.30	7.80
Tangential, 20 cm	5.18	4.90	5.27	6.48
Sensitivity – Center of (cps/kBq)	7.26	13.7	22.9	9.60

* Filtered backprojection

Fonte: The authors (2019).

The sensitivity of the Discovery MI (4 rings) is the highest of all the PET/CT systems although still lower than that of the GE Signa PET/MR system, with longer PET axial FOVs and smaller transaxial FOVs, as shown in Table 1. Table 2 summarizes counting rate metrics measured at both UGhent and KU Leuven systems.

Table – 2 Counting Rate Measurements.

	GE Healthcare			Siemens
Type of measurement *	Discovery MI PET/CT 3	Discovery MI PET/CT 4	SIGNA PET/MR	Biograph mCT Flow
Scatter Fraction at Peak	41.7 %	40.4 %	43.4 %	33.5 %
Peak NECR	102.7 kcps	201.1 kcps	216.8 kcps	185 kcps
Activity at Peak NECR	24.70 kBq/ml	22.1 kBq/ml	18.6 kBq/ml	29.0 kBq/ml
Maximum Absolute Error	3.19 %	3.86 %	2.92 %	3.7 %

* ^{18}F-FDG PET imaging

Fonte: The authors (2019).

Discussion e Conclusions: NEMA NU-2 2012 testing of the SiPM-based Discovery PET/CT systems points to improved diagnostic sensitivity for small lesions and a wide range of promising applications, from low-dose oncology studies to high-dose studies with short-lived isotopes. However, sensitivity was substantial lower as compared to GE Signa PET/MR system, with longer PET axial FOVs and smaller transaxial FOVs and slightly lower in terms of counting rate measurements. In addition, comparisons with other PET/CT systems demonstrate the substantial performance improvements possible with the new generation of SiPM-based TOF PET/CT systems.

Referências:

1. Ell PJ. The contribution of PET/CT to improved patient management. Br J Radiol. 2006;79:32–36.
2. De Ponti E, Morzenti S, Guerra L, et al. Performance measurements for the PET/CT Discovery-600 using NEMA NU 2-2007 standards. Med Phys. 2011;38:968–974