Performance Evaluation of the SiPM-based Siemens Biograph Vision PET/CT System

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Abstract-The Siemens Biograph Vision PET/CT is a SiPMbased scanner composed of detector blocks consisting of 5x5 arrays of 3.2x3.2x20mm³ LSO crystals coupled to a 4x4 SiPM array. The axial FOV is 26.3 cm with 8 rows of detector blocks in each module and 19 modules in the ring. Measurements on the production system recently installed at the University of Pennsylvania demonstrate significant improvement in the TOF resolution over previously reported measurements made on prototype systems, and range from 210 ps FWHM at an effective average radioactivity concentration of 5.3 kBq/cc to 215 ps FWHM at peak NECR (30.9 kBq/cc). There is only a 2.0% degradation in timing resolution over the clinically relevant activity concentration range. Contrast recovery coefficients measured using the IQ phantom filled according to the reconstruction harmonization initiative ranged from 39.9% for a 10-mm diameter sphere up to 85.3% for a 37-mm diameter sphere, with OP-OSEM reconstruction using TOF+PSF with 4 iterations and 5 subsets and a 5 mm FWHM Gaussian postfilter. Scans of other contrast phantoms, including the ACR PET and SNMMI CTN oncology phantoms demonstrated improved lesion detectability compared to a 4-ring Biograph mCT, using clinically relevant reconstruction parameters. In this paper we present a detailed report of the performance measurements from the production model Biograph Vision PET/CT installed at the University of Pennsylvania in September-October 2018.

I. INTRODUCTION

THE Siemens Biograph Vision is a new SiPM-based PET/CT scanner composed of detector miniblocks, each having a 5x5 array of 3.2x3.2x20mm³ LSO crystals coupled to a 4x4 SiPM array constructed by Hamamatsu Photonics. One readout channel is a 2x2 array of miniblocks, and two channels are packaged into one detector. Two detectors transaxially and eight detectors axially are packaged into a detector module with readout electronics, and 19 modules form the detector ring, which has a 82 cm diameter and 26.3 cm axial length. Data are acquired in 64-bit listmode and analytic and iterative reconstructions are available with options for PSF and TOF modeling. Factory measurements previously reported from a prototype system included transverse spatial resolution of 3.71 mm at 1 cm, system sensitivity of 16.2 cps/kBq, energy resolution of 10.1% FWHM at 511 keV, and TOF timing resolution of 240 ps for a source activity of 5.3 kBq/cc [1].

In late September 2018 the first production model of the Biograph Vision PET/CT in a clinical setting was installed at the University of Pennsylvania. Acceptance testing was conducted in early October and the system was put into clinical service immediately thereafter. The goals of this study were to: (1) fully characterize the system performance in order to establish baseline measurements that future measurements can be compared to, and (2) assist the clinicians in integrating this SiPM-based scanner into an existing clinical practice with seven PMT-based PET/CT scanners.

II. METHODS

A. System Energy Resolution

The energy resolution at 511 keV was derived by scanning a Ge-68 line source approximately 0.3 ml in volume, with a diameter of approximately 2 mm using the Siemens 'PET Service Tools' software. The energy window used was 435 to 585 keV.

B. Spatial Resolution

The spatial resolution was measured using a Na-22 point source < 0.25mm in diameter, scanned according to the NEMA NU 2-2018 standard [2]. Reconstruction was FORE+FBP with matrix size 880x880x317. Voxel size was 0.825 x 0.825 x 0.830 mm³.

C. System Sensitivity

The system sensitivity was measured according to the procedure in Section 5 of the NEMA NU 2-2018 standard, using a 70 cm line source containing 4.35 MBq (0.12 mCi) F-18 inside five nested metal sleeves. Measurements were made as the sleeves were sequentially removed while the source was suspended in the center of the transaxial field of view, then repeated with the source moved to 10 cm radial offset from the center. Axial sensitivity profiles at both source positions were generated by plotting the sensitivity for each slice.

D. Trues, Scatter and Randoms

The system true event rate, scatter and random event rates and noise equivalent count rate (NECR) were derived according

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to Section 4 of the NEMA NU 2-2018 standard using a 70 cm line source containing 35 mCi inside of the 70-cm long polyethylene scatter cylinder, which was scanned in 35 4-minute frames at 20-minute intervals over 11.4 hours.

E. Accuracy of Corrections for Count Loses and Randoms and Time-of-Flight Resolution

The same data set described in Section D above was used to calculate the accuracy of corrections for dead time losses and random event counts and the time-of-flight resolution, using the procedures in Sections 6 and 8 of the NEMA NU 2-2018 standard.

F. Image Quality Phantom

In accordance with the procedure used in the reconstruction harmonization project [3], [4] the NEMA Image Quality phantom was filled with a sphere to background ratio of 9.71:1 then scanned for 30 minutes. This dataset then was split into ten 3-minute noise realizations. Regions of interest (ROIs) were drawn according to the procedure in Section 7 of the NEMA NU 2-2018 standard, and contrast recovery coefficients (CRCs) and percent background variability were calculated.

G. Clinical Images

Images from several typical clinical scans were selected to illustrate the image quality.

III. RESULTS

A. System Energy Resolution

Fig. 1 shows the histogram of energy versus counts. The calculated system composite energy resolution is 9.0% FWHM.



Fig. 1. System energy resolution at 511 keV was 9.0% FWHM measured with Siemens PET Service Tools using a Ge-68 line source and energy window: 435 to 585 keV.

B. Spatial Resolution

Fig. 2 lists the spatial resolution in radial, tangential and axial directions for a Na-22 point source positioned at 1 cm, 10 cm and 20 cm away from the center of the field of view (FOV).

Radial Distance (cm)	Direction	FWHM (mm)	FWTM (mm)
I	Radial	3.5	6.9
I	Tangential	3.7	6.9
I	Axial	3.6	7.2
10	Radial	4.6	8.5
10	Tangential	3.9	7.0
10	Axial	4.3	8.8
20	Radial	5.8	10.5
20	Tangential	3.5	6.4
20	Axial	4.4	9.6

Fig. 2. NEMA NU 2-2018 spatial resolution measured with Na-22 point source (< 0.25 mm diam). Reconstruction: FORE+FBP, matrix: 880x880x317, voxels: 0.825x0.825x0.830 mm³.

C. System Sensitivity

The measured system sensitivity was 15.1 kcps/MBq when the line source was centered in the FOV, and 15.6 kcps/MBq when the line source was 10 cm offset from center. Fig. 3 shows the axial sensitivity profile when the source was 10 cm offset from the center of the FOV.



Fig. 3. Axial sensitivity profile measured with line source positioned 10 cm from the center of the FOV. Energy window: 435 to 585 keV.

D. Trues, Scatter and Randoms Rates

Fig. 4 shows the trues, scatter and randoms event rates, and the NECR calculated with the smoothed randoms method. Peak NECR was 296 kcps, occurring at 30.9 kBq/ml. The trues count rate was still rising at the highest activity measured, so the only statement we can make is that the peak trues rate occurs above 58 kBq/ml.



Fig. 4. Trues, scatter and randoms count rates measured according to NEMA NU 2-2018. The shaded rectangles show the range of activities at scan start used at our institution for clinical FDG wholebody scans (gray) and Rb-82 cardiac perfusion scans (red). Please see the Discussion for a full explanation of this calculation.

Fig. 5 shows that the scatter fraction is 39% at peak NECR, and 37% at 5.3 kBq/ml.



Fig. 5. Scatter fraction ranges from 37% to 39% at peak NECR (indicated by vertical blue dashed line). The shaded rectangles show the range of activities at scan start used at our institution for clinical FDG wholebody scans (gray) and Rb-82 cardiac perfusion scans (red).

E. Accuracy of Corrections for Count Loses and Randoms

Fig. 6 shows that the highest maximum bias below the peak NECR is 5.2%, which occurs at the lowest activity measured. In the clinical range of activities, indicated by the gray and red shaded rectangles, the maximum bias remains below 3% and the mean bias below 1%.



Fig. 6. NEMA NU 2-2018 accuracy of corrections for count losses and randoms. The maximum bias below peak NECR is 5.2% and occurs below the range of activity concentrations used at our institution.

F. Time of Flight Resolution

Fig. 7 shows the NEMA NU 2-2018 time of flight (TOF) resolution. The shaded rectangles show the range of activities at scan start used at our institution for clinical FDG wholebody scans (gray) and Rb-82 cardiac perfusion scans (red). The TOF resolution is 215 ps at peak NECR (30.9 kBq/ml) and improves to 210 ps at 5.3 kBq/ml.



Fig. 7. The NEMA NU 2-2018 time of flight resolution is 215 ps at peak NECR and 210 ps at 5.3 kBq/ml.

G. Image Quality Phantom

Fig. 8 shows a transaxial slice through the hot spheres from a 3-minute noise realization of the IQ phantom, reconstructed with and without a Gaussian postfilter. The table on the right side of Fig. 8 shows the percent background variability. As expected, the Gaussian postfilter reduces the background variability.



Fig. 8. Transaxial slices through the IQ phantom filled according to the reconstruction harmonization protocol with a sphere to background ratio of 9.71:1. Corresponding background variability is displayed on the right.

Fig. 9 shows the contrast recovery coefficients for the six hot spheres in the 30-minute long dataset. The error bars are derived from the ten 3-minute noise realizations. With no postfiltering the CRCs range from 58.3% for the 10 mm diameter sphere to 89.8% for the 37 mm diameter sphere. When the reconstruction includes a Gaussian postfilter with a 5mm FWHM, the CRCs range from 39.9% for the 10 mm sphere to 85.3% for the 37 mm sphere.



Fig. 9. Contrast Recovery Coefficients for reconstructions of IQ phantom with and without a Gaussian postfilter with FWHM = 5 mm. The ratio of sphere-to-background concentrations was 9.71 to 1.

H. Examples of Clinical Images

Fig. 10 shows transaxial, coronal and sagittal slices from a clinical ¹⁸F-FDG wholebody scan. The patient was injected with 15 mCi and scanned 54 minutes later using continuous bed motion (CBM) with a table speed of 1.4 mm/s, resulting in a scan duration of 11 min. The reconstruction method was OP-OSEM, PSF+TOF, 4 iterations, 5 subsets, with a 5 mm FWHM Gaussian postfilter, which are our current default settings. Matrix size was 440x440. Voxels are 1.65 x 1.65 x 4 mm³.



Fig. 10. Clinical wholebody scan of a 41 yo female with breast cancer, BMI: 43.6. Patient was injected with 15.0 mCi FDG and scanned 54 min later. Continuous bed motion acquisition with table speed of 1.4 mm/s, resulting in a scan duration of 11 min. The crosshairs are on a bony metastasis in the thoracic spine.

Fig. 11 shows transaxial, coronal and sagittal slices from a 18 F-FDG brain scan. The patient was injected with 15.1 mCi and scanned 46 minutes later for 10 min. The reconstruction method was OP-OSEM, PSF+TOF, 8 iterations, 5 subsets, with a 2 mm FWHM Gaussian postfilter. The matrix size was 440x440. Voxels are 0.825 x 0.825 x 2 mm³.



Fig. 11. FDG brain scan of a 27 yo female with drug resistant epilepsy. Patient was injected with 15.1 mCi FDG and scanned 46 min later for 10 min. The crosshairs are on an area of decreased FDG uptake in the left anterior and mesial temporal lobe, consistent with a left-sided seizure onset.

Table I summarizes our performance measurements of the Biograph Vision and compares them to our performance measurements of a 4-ring Biograph mCT, which represents the previous generation of PMT-based scanners.

	Siemens Biograph Vision (2018)	Siemens Biograph 4-ring mCT (2011)
Energy	9.0%	11.3%
Resolution		
Spatial	3.6 mm at 1 cm	4.2 mm at 1 cm
Resolution		
Sensitivity at	15.6 kcps/MBq	10.0 kcps/MBq
10 cm offset		
Peak Trues	> 1,323 kcps at	609 kcps at
	58 kBq/ml	37.4 kBq/ml
Peak NECR	296 kcps at 30.9	181 kcps at 25.2
	kBq/ml	kBq/ml
Scatter Fraction	39% at peak NECR	36% at peak NECR
TOF Resolution	215 ps FWHM at	538 ps FWHM
	peak NECR	

TABLE I. COMPARISON OF SIEMENS BIOGRAPH VISION PERFORMANCE MEASUREMENTS TO PREVIOUS GENERATION SCANNER

IV. DISCUSSION AND SUMMARY

The Siemens Biograph Vision SiPM-based PET/CT demonstrates excellent TOF resolution, ranging from 210 ps FWHM at an effective average radioactivity concentration of 5.3 kBq/cc to 215 ps FWHM at peak NECR (30.9 kBq/cc). There is only a 2% change in timing resolution over the clinical range of activities.

At our institution the standard administered FDG doses are 185 MBq (5 mCi) for sarcoid studies and 15 mCi for oncology and neurology studies. After a 60-min uptake period, the activity concentration present at scan start for a 70 kg patient ranges from 1.8 to 5.4 kBq/ml. This range is represented in the Figures by a gray shaded rectangle. For Rb-82 cardiac studies our standard administered dose had been 30 mCi, with imaging starting immediately after injection. For a 70 kg patient that resulted in an activity concentration of 15.9 kBq/ml. Because Rb-82 studies now have been moved to the Biograph Vision, the standard administered dose was reduced to 20 mCi, resulting in an activity concentration at scan start of 10.6 kBq/ml for a 70 kg patient. On the Figures this range of activity concentration is represented by a red shaded rectangle.

The small crystal size (3.2x3.2x20mm³) yields better spatial resolution compared to a state-of-the-art PMT-based scanner, with improved lesion contrast.

The system is now in routine clinical use, scanning 11 to 15 patients per day. Due to the system's high sensitivity acquisition times have been reduced for most scan types.

The current reconstruction parameters were chosen by the clinicians to better match the image characteristics of our existing base of PMT-based scanners. In future work we will work on optimizing the reconstruction parameters to better leverage the enhanced performance characteristics of this scanner in order to improve clinical metrics.

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