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Experiment for Performance Characteristics of a Clinical Whole-Body PET/CT Scanner

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1. Introduction

Positron Emission Tomography (PET) has been a useful tool in clinical diagnosis and study. In special, hybrid PET/CT system that is combined X-ray computed tomography (CT), has made whole-body PET imaging significant procedure in accurate diagnosis of oncological disease. Recently, major manufacturers of PET/CT have made their effort to develop PET/CT system and improve it. To use and maintain the newly developed PET/CT system, proper evaluation of the PET/CT performance characteristic has to be performed.

In this study, we have executed physical experiment to evaluate performance characteristics of a newly installed clinical whole-body PET/CT system.

2. Methods and Results

The PET/CT system used in this study was a clinical whole-body scanner (Biograph-6 HIREZ, Siemens Medical, Knoxiville, TN). The system was consisted of the both portions of PET and CT. The PET portion have 3-dimensional (3D) only acquisition mode and axial range of 16.2 cm, and employed detector-blocks composed of lutetium oxyorthosilcate (LSO) crystals (4 × 4 × 20 mm^3 each) and improved detection electronics. The settings of high- and low-energy threshold during experiments were 650 and 425 keV, respectively. The experiments to obtain estimates for evaluation of performance characteristics of this system have been performed, as described below, according to the guideline in National Electrical Manufacturers Association (NEMA) NU2-2001 standards. In the experiment, radioactive source of F-18 was used, and the parameters estimated were spatial resolution, sensitivity, noise equivalent count (NEC) rate and scatter fraction.

2.1 Spatial Resolution Measurement

In the measurement, point source located at 6 different positions in the field of view of the scanner. A hematocrit capillary tube filled with volume of 1 μL F-18 solution was used as point source. The 6 positions were (1) x = 0 cm, y = 1 cm, (2) x = 0 cm, y = 10 cm, (3) x = 10 cm, y = 0 cm for both z = the center of axial FOV and 1/4 shifted position in axial direction, respectively. Each acquired data was rebinned to 2D sonogram using Fourier Rebinning (FORE) and reconstructed to volumetric image using filtered back-projection in Fourier space (DIFT) with all-pass filter. From the each reconstructed image, 3 profiles (tangential, radial, and axial direction) of the point source were obtained to obtain point-spread function (PSF). The PSF was fitted using Gaussian function to estimate full-width-half-maximum (FWHM). In the calculation of values of FWHM and FWTM in each direction, the equation described in NEMA NU-2 2001 standards was used. The estimated values of spatial resolution in reconstructed image were summarized in table 1.

Radial distance (cm)	Direction	FWHM (mm)
1	transverse	4.1
1	axial	4.8
10	transverse radial	5.0
10	transverse tangential	4.6
10	axial	5.7

Table 1. Estimated values of spatial resolution obtained by NEMA NU 2-2001 protocol

2.3 Sensitivity Measurement

In this measurement, a polyethylene tube (length = 70 cm) was filled with very weak total radioactivity of F-18 solution that will not make additional scatter component during acquisition. The long tube was placed in the center of 5 concentric aluminum sleeves of sensitivity phantom (Data Spectrum Corp., Chapel Hill, NC). The phantom was placed on the center of radial FOV during acquisitions. The first acquisition began with all the aluminum sleeves of phantom. After completing the first acquisition, the most external sleeve was pulled out and acquisition was performed repeatedly. The acquired raw data were used in analysis of estimating scatter fraction. The value of estimated sensitivity at the center of FOV was 4191 cps/MBq and the value of detector efficiency during the measurement was 0.42%.

2.2 NEC and Scatter Fraction Measurement

In this measurement, a cylindrical phantom with size of 20.3 cm of radial diameter and 70 cm of axial length, was used. The cylindrical phantom was made of polyethylene and has a long hole at off-center in which a fillable 80 cm long tube can be inserted. In the fillable tube, F-18 solution with sufficiently strong radioactivity was filled without air, and inserted into the hole of the polyethylene cylindrical phantom. The phantom with

line source was placed on the patient table of PET/CT system, and positioned in the center of axial and radial FOV, by moving patient table.

After setting the phantom positioning, serial acquisition of 35 frames was performed during 15 hours. During acquisition of every frames, the information of total, true, and randoms counts was recorded, and used in the further calculation of NEC rate and scatter fraction.

The NEC rate was calculated as,

$$NEC = \frac{R_{trues}^2}{R_{trues}^2 + R_{scatter}^2 + kR_{randoms}^2}$$

where R_{true}, $R_{scatter}$, and $R_{randoms}$ are count rates of trues, scatter, and randoms, respectively.

The scatter fraction (SF) for each slice (i) at each activity(j) was calculated as,

$$SF_{i,j} = \frac{R_{scatter,i,j}}{R_{trues,i,j} + R_{scatter,i,j}}$$

In the above both equation, Rscatter was calculated as below.

$$R_{scatter,i,j} = R_{Total,i,j} - R_{trues,i,j} - R_{randoms,i,j}$$

Figure 1 is the curve of NEC rate acquired from this experiment.

The estimated values of peak true and NEC rate was summarized in table 2.

Quantity	Value	Units
$R_{t,peak}$	3,08E+05	cps
$a_{t,peak}$	5.10E-02	MBq/mL
$R_{NEC,peak}$ (k = 0)	9.33E+04	cps
$a_{NEC,peak}$	3.27E-02	MBq/mL
$R_{NEC,peak}$ (k = 1)	6.46E+04	cps
$a_{NEC,peak}$	2.73E-02	MBq/mL

Table 2. Estimated value of peak true and NEC rate and radioactivity concentrate making the peak values

The value of scatter fraction was 36%.

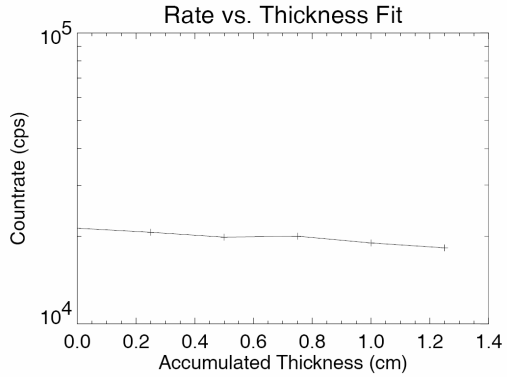

Figure 1. Count rate for sensitivity estimation of PET/CT system at the center of radial FOV (R = 0 cm)

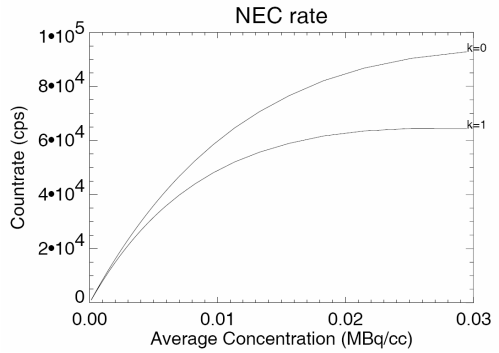

Figure 2. Estimated curve of NEC rate of the PET/CT

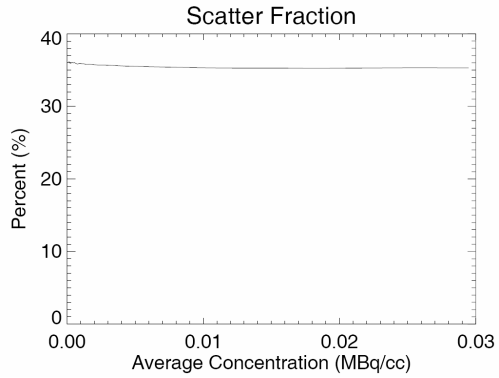

Figure 3. Estimated SF of the PET/CT system

3. Conclusion

In this study, we could perform the experiment for evaluation of PET/CT performance characteristics successfully, with NEMA NU 2-2001 standards, and obtain the results of each characteristic, which were close to the reference values reported from the manufacturers. To know and understand the performance characteristics of a PET/CT system would contribute to help in planning and making clinical protocol and study design more suitable and efficient.

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