SPATIAL RESOLUTION PERFORMANCE OF WHOLE-BODY LSO PET/CT SCANNER

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ABSTRACT

Spatial resolution of Biograph 16 HI-REZ PET/CT system has been performed following the NEMA NU 2-2001 protocols. Three types of point source made with capillary tube, tiny foam bead, and ion exchanged resin were used for this purpose. ImageJ software was used to analyze the reconstruction image on PC. The results from three types of point source were in acceptance limit. In this study, point source made with resin was easy to be prepared and small size for spatial resolution performance.

Key Words: LSO, PET/CT, Biograph 16 HI-REZ

INTRODUCTION

Spatial resolution is one of the performance parameter for PET/CT scanner. This represents its ability to distinguish between two points of radioactivity in an image. The full description of spatial resolution requires two components; a transaxial component in the planes perpendicular to the scanner axis, and an axial component parallel to the axis (slice thickness). In addition, for off-center positions, transaxial resolution is usually given in terms of a radial (along the radius) and a tangential (perpendicularly to the radius) components. Common methods to measure this in emission tomography are to image a point source giving a point spread function (PSF), or a line spread function (LSF). Usually, the resolution is expressed as the full width at half maximum (FWHM) of the profile. Good approximation used frequently to this profile is Gaussian function. There are many factors that influence the resolution in a PET reconstruction. These include non-zero positron range after radionuclide decay, non-colinearity of the annihilation photons due to residual momentum of the positron, distance between the detectors, width of the detectors, stopping power of the scintillation detector, incident angle of the photon on the detector, the depth of the interaction of the photon in the detector, number of angular samples, and reconstruction parameter (matrix size, windowing of the reconstruction filter, etc.).[1,2] The detector array of current clinical scanners may consist of many rings of detectors, which are aligned axially. A volumetric PET data set is commonly reconstructed by collection a stack of two-dimensional (2D) transaxial image perpendicular to the axial (bed) direction. Thus, images along the axial direction, i.e., in the coronal or sagittal planes, are generated by re-sampling the volume voxel matrix along these plane.[3] Accordingly, while in the transaxial plane, the spatial resolution is partly limited by the width of the detectors, the resolution along the axial direction is affected by the spacing of the detector rings.

The National Electrical Manufacturers Association (NEMA) has recommendation for standard PET performance measurement, NU 2-2001.[4] The measurement is performed by imaging point sources in air, and then reconstructing images with no

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smoothing. Although this does not represent the condition of imaging a subject in which tissue scatter and a limited number of acquired events require the use of a smooth reconstruction filter, the measured spatial resolution provides a best case comparison among scanners, indicating the highest achievable performance.

NU 2-2001 specifies that the activity be contained in a glass capillary tube with an inside diameter of 1 mm or less and outside diameter of less than 2 mm. The axial extent of activity in the capillary shall be less than 1 mm. The purpose of this study is to used another type of point sources such as foam bead and ion resin to perform spatial resolution compare to capillary tube method.

MATERIAL AND METHODS

The LSO-based whole body PET/CT scanner, Siemens Biograph 16 HI-REZ, combines a sixteen slices helical CT, Somatom Sensation 16,. This CT scanner can acquire slice thickness range 0.6 to 10 mm. The tube current can be varied between 28 and 500 mA and tube voltage can be set to 80, 120 and 140 KVp. The anode heat storage capacity was 5.3 MHU. The PET/CT 16 HI-REZ includes the Pico-3D electronics to improve count rate performance. PET component of the tomography has no septa, thus allowing 3D-only acquisitions. The main PET specification was summarized in Table 1.

Table 1 Specification of Siemens Biograph 16 HI-REZ PET/CT scanner

Parameter	Value
Detector material	LSO
Crystal dimensions (mm^3)	4.0 x 4.0 x 20
Crystal array	13 x 13
Crystal per detector block	169
Number of detector blocks	144
Photomultiplier tubes (PMTs)	4 per block
Detector ring diameter (mm)	830
Detector per ring	624
Number of detector rings	39
Total number of detectors	24,336
Transaxial FOV (mm)	585
Axial FOV (mm)	162
Number of image planes	81
Plane spacing (mm)	2
Coincidence time window (nsec)	4.5
Upper level energy discriminator (KeV)	650
Lower level energy discriminator (KeV)	425
Patient port (mm)	700

Point source preparation

Glass capillary tubes of 1 mm inner diameter (ID), 1.4 mm outer diameter (OD), and 75 mm length were filled with ^{18}F-FDG solution of approximately 0.5 GBq/ml for 1 mm in length and well sealed to form point source.

Soaking the beads of tiny foam and resin in 18F-FDG solution of approximately 0.5 GBq/ml for 1-2 min to form point source. Three beads of foam and resin will had total activity less than 10 MBq. The ratio of random to total evens would be less than 5% in the FOV. These three beads of point sources were placed on a piece of tape which was then suspended from a needle.

Point source positioning

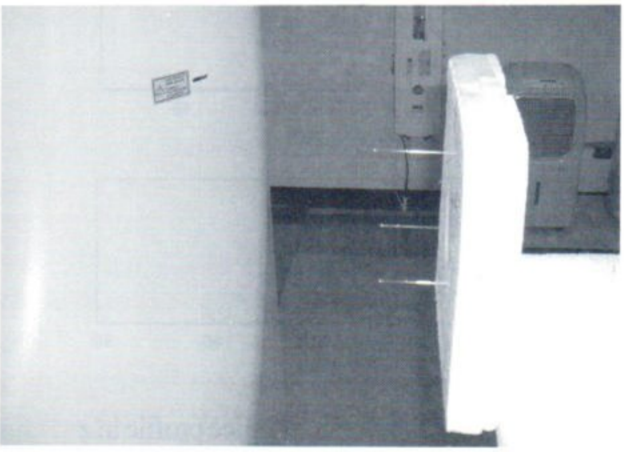

Fig.1 Capillary point sources were suspended by a fixture.

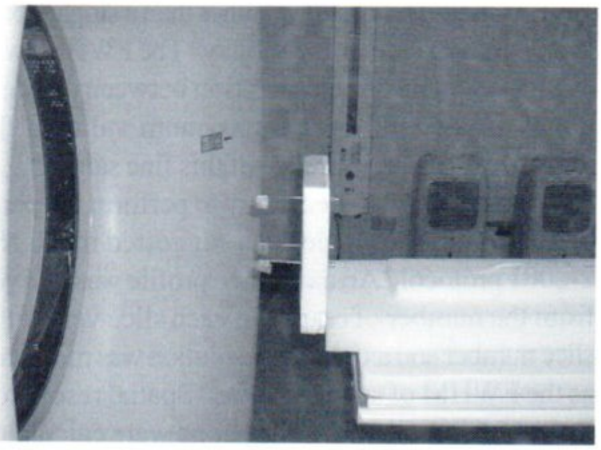

Fig.2 The needle with foam point sources were suspended by a fixture

Source holder made of foam plate was used as a fixture to position the point source (Fig.1, 2). The point source was positioned at three different locations (x,y) defined by (0,1) cm, (10,0) cm, and 0,10) cm. The point source is not to be placed at the center of the FOV, (0,0), where inconsistent results may arise from the high density of lines of response (LOR).[5] Once in place, the 3 point sources were aligned (axially) in the scanner FOV by use of laser lights. Two sets of emission measurements were obtained with the sources centered at 2 axial positions in the scanner FOV, as shown in Figure 3, in the center and at one quarter of the axial FOV (4.05 cm). Two millions net true counts were acquired for each position to ensure adequate statistic.

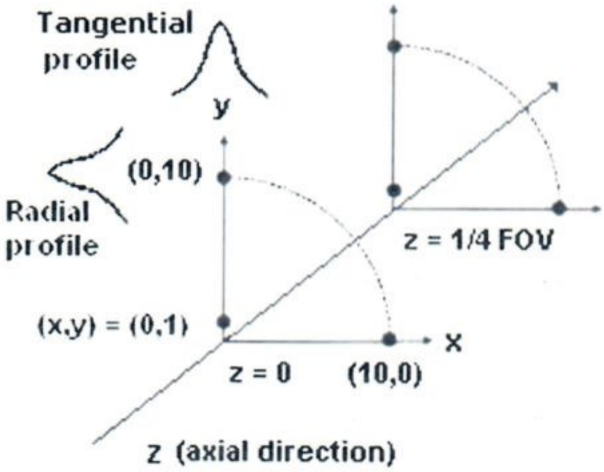

Fig.3 Position of the point sources in FOV for resolution measurement

To measure the pixel size and slice width of image plane, two resin point sources were fixed on linear graph paper 10 cm apart with a piece of tape, and placed on center of the transaxial FOV aligned with the axis of tomograph by using laser alignment device. Two millions net true counts were acquired.

Reconstruction and data analysis

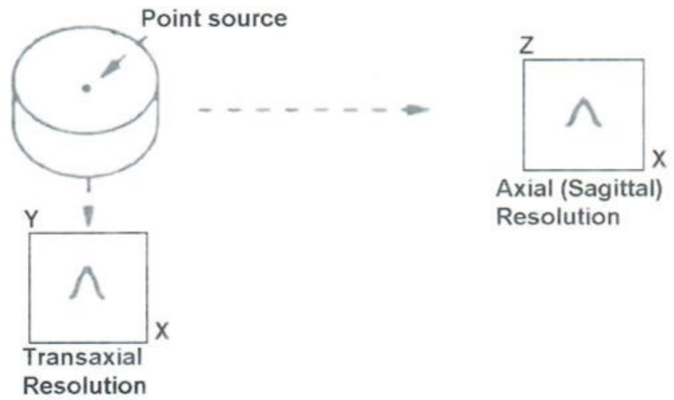

Fig.4 For 3D acquisition, a point source can be used to simultaneously measure both transverse and axial resolution[6]

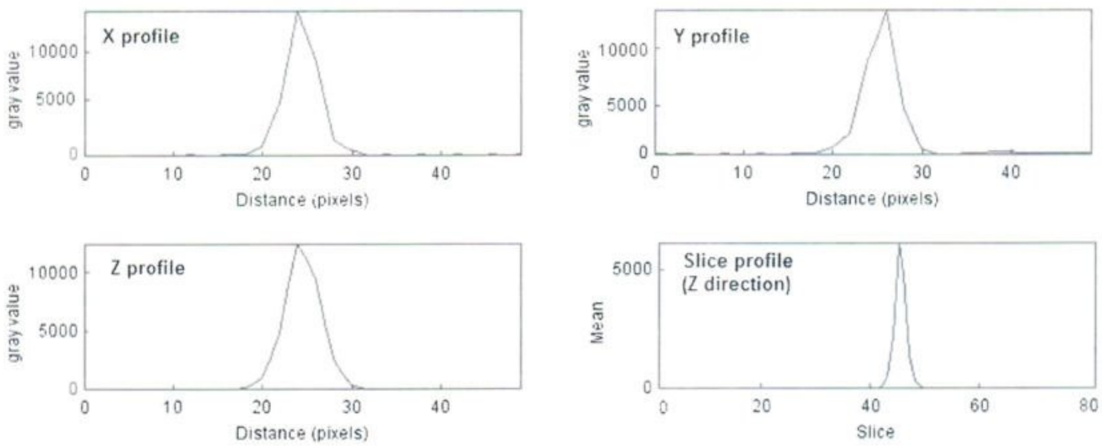

Fig.5 Example of profile curves of resin at point (0,1) in all three directions and slice profile in z direction

All corrections were applied to data. For each position, the images were reconstructed using the FBP algorithm onto a 336x336 matrix with all pass filter and reconstruction zoom was set to 2. Due to limitation of the system, the reconstruction images were transferred to CD in DICOM format and used ImageJ version 1.38 to analysis in personal computer (PC). As x and y define the transaxial plane and z defines the axial direction as show in Figure 4. The FWHM were determined in all three directions by forming one-dimensional (1D) response functions (as show in figure 5) through the peak of the distribution in three orthogonal directions. The width of profile curve was approximately 2 times of the expected FWHM in those directions, rather than a single pixel, to reduce measurement variability.[7] The FWHM were calculated by linear interpolation between adjacent pixels at one half on the maximum value of the response function. Because of this fine sampling, it was not regarded as necessary to perform the parabolic fit of the curve peak as suggested in the NU 2-2001 protocol.[8] An axial slice profile was derived from the number of counts in each slice versus the slice number and axial slice resolution was measured as the FWHM of such a profile.[9] Spatial resolution measured in x, y, and z-directions were calculated by formula as shown in table 2, and reported as values of system resolution.

Table 2 Formulas for computing spatial resolution report values (RESx, RESy, and RESz refer to the spatial resolution measured in the x, y, and z-directions)

	Formula
At 1 cm radius	
Transverse	$RES = \{RESx_{x=0, y=1, z=center} + RESy_{x=0, y=1, z=center} + RESx_{x=0, y=1, z=1/4FOV} + RESy_{x=0, y=1, z=¼FOV}\}/4$
Axial	$RES = \{RESz_{x=0, y=1, z=center} + RESy_{x=0, y=1, z=1/4FOV}\}/2$
At 10 cm radius	
Transverse radial	$RES = \{RESx_{x=10, y=0, z=center} + RESy_{x=0, y=10, z=center} + RESx_{x=10, y=0, z=1/4FOV} + RESy_{x=0, y=10, z=1/4FOV}\}/4$
Transverse tangential	$RES = \{RESy_{x=10, y=0, z=center} + RESx_{x=0, y=10, z=center} + RESy_{x=10, y=0, z=1/4FOV} + RESx_{x=0, y=10, z=1/4FOV}\}/4$
Axial resolution	$RES = \{RESz_{x=10, y=0, z=center} + RESz_{x=0, y=10, z=center} + RESz_{x=10, y=0, z=1/4FOV} + RESz_{x=0, y=10, z=1/4FOV}\}/4$

RESULTS

The reconstructed imaged for pixel size determination of 336x336 matrixes with zoom 2 was 1.015 mm in x, y, and z direction, and slice thickness was 2 mm. The results of the FWHM measurement on each plane were given in Table 3. By using formula in table 2 to calculate spatial resolution of the system and compared the result with performed by Bercier et al,[10] which these values were used as Siemens typical specification of Biograph 16 HI-REZ PET/CT system, as show in table 4.

Table 3 The reconstructed image resolution expressed as FWHM (mm)

Position	Axis	Capillary		Foam		Resin	
		Center	Off center	Center	Off center	Center	Off center
(0,1)	x	4.350	4.366	4.430	4.311	4.431	4.196
	y	4.519	4.383	4.737	4.725	4.397	3.989
	z	4.853	4.925	4.631	5.216	4.484	4.606
	slice	4.952	5.017	4.993	5.093	4.693	4.387
(10,0)	x	5.144	4.919	5.085	4.769	5.101	5.082
	y	4.951	5.066	5.112	5.455	5.088	5.221
	z	6.070	6.345	6.260	6.365	5.941	6.407
	slice	6.633	7.015	6.833	6.996	6.674	7.259
(0,10)	x	4.667	4.874	4.960	5.034	4.938	4.829
	y	5.149	4.915	5.445	5.268	5.207	5.179
	z	5.393	5.655	5.740	5.716	5.319	5.683
	slice	5.855	5.882	5.891	5.824	5.793	5.700

Table 4 NEMA NU 2-2001 Spatial resolution (mm)

Radial position and parameter	Capillary	Foam	Resin	Bercier
1 cm offset				
Transverse	4.4	4.5	4.2	4.2
Axial	4.8	4.9	4.5	4.5
Slice	4.9	5.0	4.5	-
10 cm offset				
Transverse tangential	4.8	5.1	5.0	4.6
Transverse radial	5.0	5.1	5.1	5.0
Axial	5.8	6.0	5.8	5.5
Slice	6.3	6.3	6.3	-

DISCUSSION

For capillary point source, the small volume of the source (~1 mm in length) necessitates a very high specific activity to get a reasonable counting rate. It is difficult to accurately draw up this amount of fluid without wetting the walls of the capillary beyond the desired region as pointed out by Erdi et al.[11] Figure 6 show an example of small excess activity at middle source due to the problem of source preparation. This will make its not real point source as we need. Tiny foam bead was used to perform point source. We perform size screening first. Foam bead that can insert to 1 mm ID of capillary tube was selected. We found that, its very light and easy to blow away. Ion exchange resin was the third choice because of very small size. Both foam and resin can be soaked in ^{18}FDG solution to make the point source.

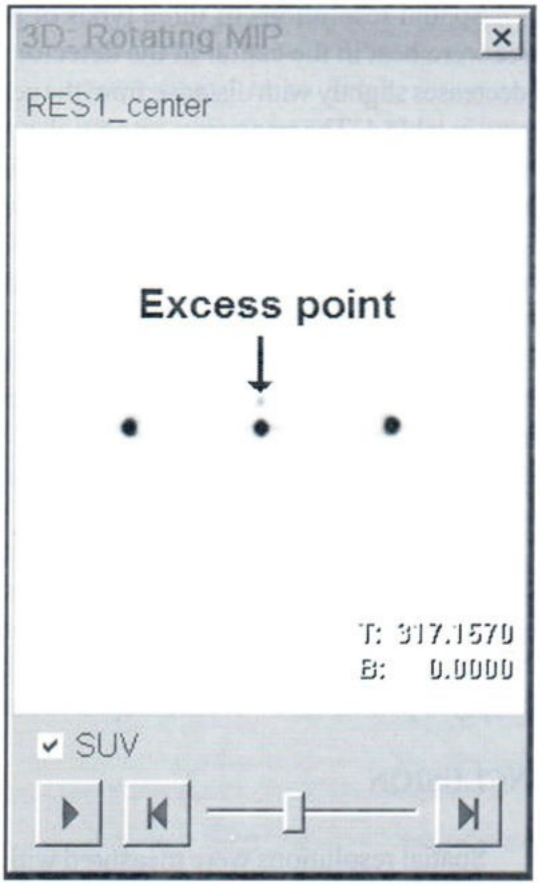

Fig.6 Maximum Intensity Projection (MIP) image of Capillary point source, middle source have excess activity due to contamination of inner wall.

Table 5 Summary results of spatial resolution (mm)

Parameter	Capillary	Foam	Resin	Acceptance Test	Acceptance Limit[12]
Transaxial Resolution					
FWHM @ 1 cm	4.4	4.5	4.2	4.5	≤ 4.6
FWHM @ 10 cm	4.9	5.1	5.0	4.8	≤ 5.3
Axial Resolution					
FWHM @ 1 cm	4.8	4.9	4.5	4.5	≤ 4.9
Slice @ 1 cm	4.9	5.0	4.5	-	-
FWHM @ 10 cm	5.8	6.0	5.8	5.4	≤ 6.1
Slice @ 10 cm	6.3	6.3	6.3	-	-

Spatial resolutions of three types of point source were best in the center of the detector ring and decreases slightly with distance from the center, as show in table 4. The transverse resolution across the FOV of the scanner is fairly good. This is an importance feature since lesions at any location within the body could be identified with the same resolution. Slice thickness resolution is greater than z resolution due to larger multiplication factor, 2 mm in thickness and 1.015 mm thickness in z pixel size, but reflects exactly the clinical situation. So, image with fine pixel would have better spatial resolution. This PET/CT system was installation more than 1 year, and replaced some block of detector for two times. So, this will make the worse resolution than we perform at acceptance test, as show in table 5. Resin point source had good result at central point (0,1) same as Bercier study, but worsen at 10 cm radius. However, these three types of point source were in acceptance limit.[12]

CONCLUSION

Spatial resolutions were measured with the point source made with thin capillary tube, foam bead, and ion exchange resin. The results were in acceptance limit. Ion exchanged resin was most easy to perform point source. ImageJ is free software and can be used to analyze the image on PC. So, we can check resolution and other performance parameters at any time such as post system service or periodical check.

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