*Bangladesh Journal of Physics, Vol. **30**, Issue 2, pp. 57–67, June 2023*

PERFORMANCE EVALUATION OF THE GE DISCOVERY IQ PET/CT SYSTEM ACCORDING TO THE NEMA NU2−2012 STANDARD

MD SHOHAG MIA[1], MD. NAHID HOSSAIN[1], TANVIR AHMED BIMAN[1], M F FAZLUL KABIR[2]

[1]National Institute of Nuclear Medicine and Allied Sciences (NINMAS), Bangladesh Atomic Energy Commission (BAEC), Dhaka-1207,Bangladesh

[2]Everecare Hospital Dhaka, Dhaka 1229, Bangladesh

**Corresponding author e-mail: shohagsh@baec.gov.bd*

Received on 18.12.2022, Revised received on 17.05.2023, Accepted for publication on 22.05.2023

DOI: *https://doi.org/10.3329/bjphy.v30i2.68384*

ABSTRACT

A PET/CT Scanner -Discovery IQ 5 ring. GE Medical system was installed at Evercare Hospital Dhaka. Total of 11252 BGO crystal elements are arranged in 5 circular rings providing 260 mm axial and 700 mm trans axial field of view. The aim of the test was to assess the performances of the PET/CT scanner GE-Discovery IQ 5 ring. Spatial resolution, Image Quality, and Sensitivity tests were carried out as per NEMA NU2-2012 Standard guidelines. Spatial resolution for radial, tangential and axial directions was carried out at (x,y): (0,1), (0,10), and (0,20) cm locations. Sensitivity was calculated from the activity concentration factor. Image reconstruction algorithm VPHD was used. The radial, tangential, and axial FWHM 4.2 mm, 4.74 mm, and 4.82 mm at 1 cm; 5.72 mm, 4.82 mm, and 4.57 mm at 10 cm off center; 8.17 mm, 4.85 mm, and 4.92 mm at 10 cm off center respectively. In NEMA image quality, the hot contrast recovery values for 10-13-17-22 mm spheres were 25.7-50.3-56.1-69.7 % respectively and cold contrast recovery values for 28 mm and 37 mm spheres were 75.5 and 77.7 % respectively; the corresponding background variability values were 7.2-6.9-6.6-5.9-5.5-4.7 %. The lung error residual mean was 16 %. Overall, PET performances of the Discovery IQ whole body scanner were satisfactory and passed the entire NEMA NU2- 2012 acceptance test.

Keywords: *Positron Emission Tomography/Computed Tomography, National Electrical Manufacturers Association, VPHD, FWHM*

1. INTRODUCTION

Positron Emission Tomography (PET) is now a promising diagnostic tool that can provide useful functional information aiding in the diagnosis, staging, and evaluation of cancer, radiotherapy planning, and the diagnosis of some types of dementia [1]. Advancement in PET detector and electronics technology have evolved dramatically in recent decade since the first PET/CT system became operational in 1998, [2,3] with many advances in system hardware and software. Since the introduction of hybrid PET/CT scanners, most commercial manufacturers have chosen to include high-time-resolution detectors based on [4,5] and [6,7] crystals to improve time-of- flight localization. GE Healthcare continues to provide PET/CT scanners with lutetium oxyorthosilicate (LSO), lutetium-yttrium oxyorthosilicate (LYSO), bismuth germanium oxide (BGO) detectors In present scenario in molecular imaging, The Discovery MI, MI DR, IQ Gen- are the GE Healthcare's next generation PET/CT scanners following Discovery IQ (D-IQ) scanner [8]. Though Discovery MI, MI DR, IQ Gen PET scanners have the higher sensitivity and good image quality, Discovery IQ is still using in many PET centers all over the world because of its better performance. The high sensitivity of the D-IQ has been achieved by using the 3- dimensional mode, which does not have any interplane septa and boosts sensitivity by a factor of 4-6 over the 2-dimensional mode [2]. Sensitivity can also be increased with large axial field of view (FOV), with an 81% gain reported [9]. GE Healthcare recently deviated from its non-time-of-flight PET/CT scanner series in designing the Discovery IQ (D-IQ), which uses a new detector block configuration that allows the number of detector rings to be increased from 2 to 5 along the axial FOV [10,11]. Whole body PET scans are traditionally time consuming, taking up to 20-25 minutes to complete each scan, which is uncomfortable for the patient and sometimes introduces human motion artifacts as well as decreases the machine's throughput. Because this, PET system has the greatest axial FOV, it can perform scans faster, reduce the likelihood of motion-based artifacts, and boost system throughput. The diagnostic quality of acquired images depends on the detectors, the detection technology, electronics, reconstruction software, and a good installation process. So, it is necessary to conduct a thorough acceptance test of the PET/CT system and we have done this before the functional operation of the system. The National Electrical Manufacturers Association (NEMA) has released a number of techniques, referred to as NEMA NU2 performance tests, to assess the physical performance of PET systems [12] Periodically, this NEMA standard is updated, and the most recent revision resulted in the NEMA NU2 2012 standard, which was released in February 2013 [12]. We followed the National Electrical Manufacturers Association (NEMA) NU2-2012 standard for acceptance testing and system comparison.

The quality of the PET/CT images of a patient depends primarily on the performance of the PET/CT system. A good clinical outcome is more important to deliver a good report to the patient. Therefore, our first purpose in this study was to assess the performance of the newly installed Discovery IQ PET/CT scanner in its 5-ring configuration.

2. MATERIALS AND METHODS

The performance evaluation of a PET system requires standard and reliable methods to allow the comparison of different PET systems using accepted measurement standards for the system. For acceptance and annual testing (baseline and follow-up measurements), The National Electrical Manufacturers Association (NEMA) NU 2-2012 standard was followed for the performance evaluation of the PET subsystem [6]. The spatial resolution of the system, normalization and well counter correction (WCC), and image quality were carried out according to the NEMA NU2-2012 Standard after the completion of installation. Glass capillary tube (Hirschmann Laborgerate, Hamatokrit-Kapillaren) with ^{18}F-FDG point source for spatial resolution, ^{68}Ge annulus phantom for normalization, cylindrical water phantom for well counter correction (WCC), and image quality body phantom (Data Spectrum Inc., Durham, NC) for the image quality test, were used very cautiously.

2.1 Characteristic of the Discovery IQ 5 ring PET/CT system

Discovery IQ 5 ring GE PET/CT system installed at Evercare Hospital Dhaka has the highest sensitivity [7]. The detector of this system is BGO (Bismuth Germinate) based scintillation crystal having high stopping power [8]. Its detector consists of 5 rings with a 740 mm diameter providing 260 mm axial FOV. A total of 11252 crystal elements with 6.3 mm × 6.3 mm × 30 mm crystal dimensions are available in this system. There are 720 PMTs available in this system. The system allows 3-dimensional and 4–dimensional acquisition modes, with an axial coincidence acceptance of 639 planes [9]. This PET/CT system has VUE Point HD (VPHD) and a Q. Clear reconstruction algorithm. The bore size of the gantry is 700 mm.

2.2 National Electrical Manufacturers Association NU2-2012 measurements

2.3 PET Spatial Resolution

Spatial resolution is a measure of the ability to distinguish between two points after the image is reconstructed. It is typically defined as the full width at half-maximum (FWHM) of a point spread function (PSF) and is calculated from the line profile through a reconstructed image of a point source of radioactivity in the air. Three ^{18}F-fluorodeoxyglucose (^{18}F-FDG) point sources (size <1 mm × 1 mm × 1 mm) were taken inside of each 50-mm long glass capillary tube shown in figure 1. To keep dead time losses and randoms below 5% of the total events, activity concentration was 27mCi/ml, as suggested by the NEMA NU2-2012. Initially, the activity of the point source in the capillary tube was 1.0 MBq. Acquisitions were done at three different trans axial locations (x, y): (0,1), (0,10), and (0,20) cm and at two axial positions (z) within the PET FOV: At the center and three-eighth off-center of axial FOV. The acquisition was taken for one minute at each position. Capillary tubes were placed using a source holder. The acquired data were reconstructed with the VPHD reconstruction algorithm into a 256 × 256 matrix with 1 mm × 1 mm pixel size. The full width at half maximum (FWHM) and the full width at tenth maximum (FWTM) were obtained for all the acquired positions according to the NEMA NU2-2012 standard [6]. Spatial resolution was calculated as full-width at half-maximum and full-width at tenth-maximum of the reconstructed point-spread function using the manufacturer’s software.

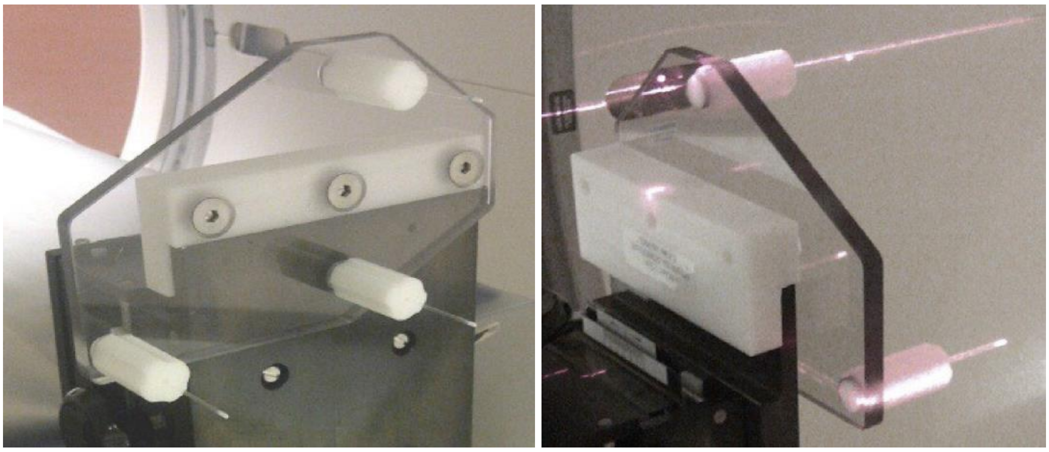

Fig. 1: Capillary tube (Hirschmann Laborgerate, Hamatokrit-Kapillaren) and holder for Spatial Resolution Measurement

2.4 Normalization and Activity Concentration Factor

The activity concentration factor used to convert counts per second (sensitivity) to an activity concentration is a secondary parameter that is simple to monitor. This factor is produced when the PET detectors are calibrated for sensitivity and activity using a consistent 18F-FDG water phantom or a prefilled Ge-68 phantom. This activity concentration factor was determined to mimic the Vendor-Specific sensitivity of the system. For Activity Concentration Factor, ^{68}Ge annulus phantom and a cylindrical 5640 ml water phantom were used. Normalization was done using ^{68}Ge annulus phantom shown in figure 2a, following the NEMA NU2-2012 protocol [6]. The cylindrical water phantom shown in figure 2b, for activity concentration factor was filled with water and 20 MBq of

^{18}F was injected into the phantom. Water in the phantom was mixed well to make a homogenous solution and bubbles were removed carefully. The image acquisition was performed as prescribed NEMA NU2-2012 for the single-bed position for 20 min subsequent to a CT transmission scan (tube voltage: 120 kVp, current: 200 mA, matrix: 512 × 512 with 3.75-mm pixel size, and pitch: 0.65 mm) for attenuation correction. Acquired data were reconstructed by using VPHD Sharp IR reconstruction algorithm by applying normalization and corrections for random coincidences, scatter, dead time, losses, and attenuation.

Fig. 2a: Ge-68 Annulus Phantom for Normalization

Fig. 2b: Cylindrical water phantom for Well Counter Correction

2.5 Image quality

For the image quality test, NEMA IQ (Data Spectrum Inc., Durham, NC) body phantom was used shown in figure 3. It has an internal capacity of 9.7 L. it consists of six spherical inserts with internal diameters of 1.0, 1.3, 1.7, 2.2, 2.8, and 3.7cm. The 2.8 and 3.7 cm spheres were filled with cold water to mimic cold lesion imaging. The 1.0, 1.3, 1.7, and 2.2 cm spheres were filled with an ^{18}F solution having 4 times higher radioactivity concentration than the background. The lung inserts with an average density of 0.3 g/ml, positioned in the center of the phantom, was used to provide a non-uniform attenuation distribution in the phantom. The one-fourth of the phantom was filled with water. The water solution of 371 MBq of ^{18}F-FDG was used to fill the four smaller spheres to create a target-to-background ratio of 4:1. Water in the phantom was mixed well to make a homogenous solution and bubbles were removed carefully. The NEMA IQ phantom was positioned with all spheres aligned within the same trans axial plane in the center of the axial FOV. The image acquisition was performed as prescribed by NEMA NU2-2012 [5] for the single-bed position by using NEMA IQ acquisition protocol for 180s subsequent to a CT transmission for attenuation correction. Acquired data were reconstructed by using VPHD Sharp IR reconstruction algorithm by applying normalization and corrections for random coincidences, scatter, dead time losses, and attenuation. Images of the IQ phantom were reconstructed, and IQ was evaluated as per the NEMA NU2-2012 standard by using software provided by the manufacturer. Contrast recovery for hot and cold sphere background variability and lung error residual means were also calculated and compared with the specification provided by the manufacturer.

Fig. 3: NEMA Image quality body phantom (Data Spectrum Inc., Durham, NC)

3. RESULTS

3.1 Spatial resolution

Spatial Resolution for three locations of the point sources were taken in terms of FWHM and FWTM. Spatial resolution were assessed at center of axial FOV and 3/8 of the axial FOV from the center of the FOV accordingly. Figure 4 shows the spatial resolution results obtained for the different positions of the point source as per NEMA NU2-2012 protocol. Results are summarized in Table 1.

Table 1: Spatial resolution for radial, tangential and axial at (x,y)**:** (0,1) cm, (0,10) cm and (0,20) cm off axis center position of point sources obtained from GE Discovery IQ PET/CT

	At 1 cm radius		**At 10 cm radius**		**At 20 cm radius**	
	FWHM (mm)	FWTM (mm)	FWHM (mm)	FWTM (mm)	FWHM (mm)	FWTM (mm)
Radial direction	4.20	9.45	5.72	11.85	8.17	14.89
Tangential direction	4.74	10.11	4.82	9.70	4.85	10.52
Axial direction	4.82	11.40	4.57	11.20	4.92	11.63

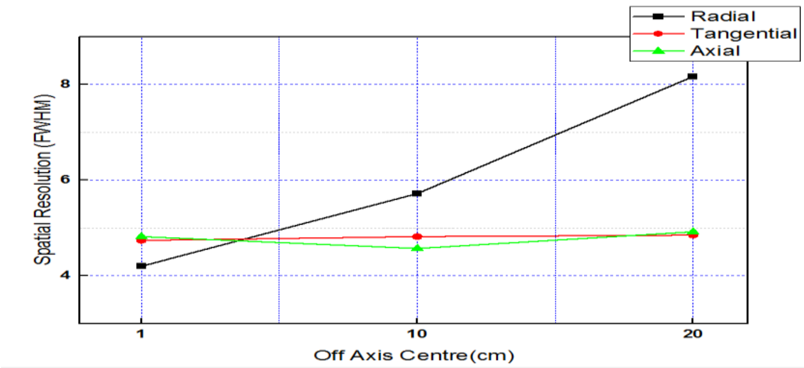

Fig. 4: Radial, Tangential and Axial resolution (FWHM) results for three Off axis center location of the point sources, performed on Discovery IQ PET/CT scanner**.**

Figure 4 shows that, in radial direction, FWHM increases as the point source move away towards the off-axis center meaning that the spatial resolution degrade gradually**.** In contrast, axial and tangential direction, FWHM remains almost same for any off-axis center meaning that the axial and tangential resolution remain consistent**.**

3.2 Activity Concentration Factor

For the accurate SUV measurement, conversion of sensitivity to activity concentration were evaluated for this system. This approach is considered sub-optimal to Option 1 as there are errors introduced by the corrections applied in the calibration procedures. However, It has the advantage of not requiring any additional phantoms or imaging. Each manufacturer has a different name for this factor, such as well counter correction (WCC) factor, ECAT calibration factor, etc. and different factors for each system. Figure 5 shows the activity concentration factor curve obtained for the cylindrical water phantom. The mean slice sensitivity factor seen from the curve is 1.2 which is similar to vendor-specific activity concentration factor. This activity concentration factor mimics the system sensitivity and it is 21.6 cps/kBq.

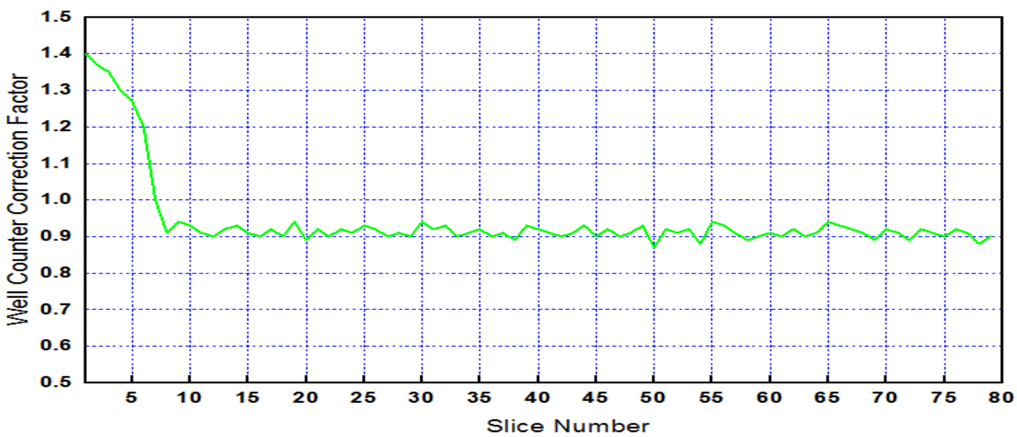

Fig. 5: Activity Concentration Factor result obtained from Well Counter Correction (WCC) test, performed on Discovery IQ PET/CT scanner**.**

3.3 Image quality

PET image quality for different size of sphere with same concentration of 18F-FDG was carried out under conditions similar to those encountered in the clinical use. Figure 6, 7 and 8 shows the contrast recovery, Background Variability and Lung Residual error results obtained for the NEMA image quality phantom as per the NEMA NU2-2012 protocol [6]. Results are summarized in Table 2.

Tabe 2: Contrast recovery and Background variability and Lung Residual mean results for various spheres diameter obtained from GE Discovery IQ PET/CT

Sphere diameter (mm)	Contrast recovery (%) VPHD	Background variability (%) VPHD
10	25.7	7.2
13	50.3	6.9
17	56.1	6.6
22	69.7	5.9
28	75.5	5.5
37	77.7	4.7
Lung residual **(%)**		16.2

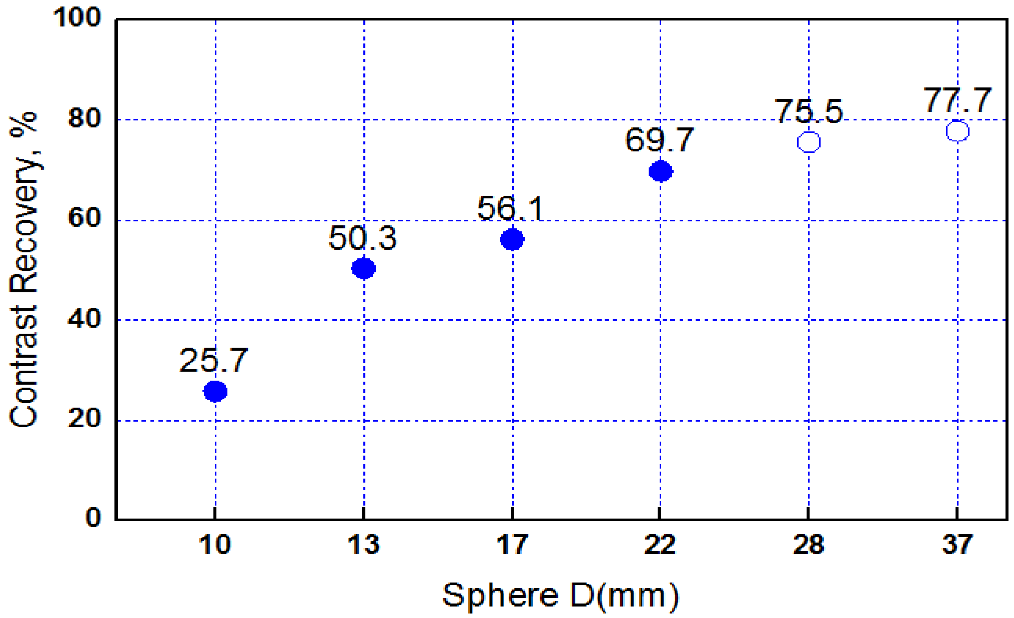

Fig. 6: Contrast recovery test results for hot **(**4**:**1**)** and cold spheres reconstructed with VPHD technique on GE Discovery IQ positron emission tomography/computed tomography scanner.

This test measures the system's ability to differentiate between the target and the background and to accurately quantify the contrast of the target. A higher contrast recovery indicates a better ability to detect and measure small changes in contrast. Contrast recovery are very prominent as the diameter of the sphere increases. Figure 6 shows that for the sphere diameter 10, 13, 17, 22 mm (hot), 28 and 37 mm (cold), contrast recovery values are 25.7 %, 50.3%, 56.1% 69.7% 75.5% 77.7% indicating the better visualization of the image.

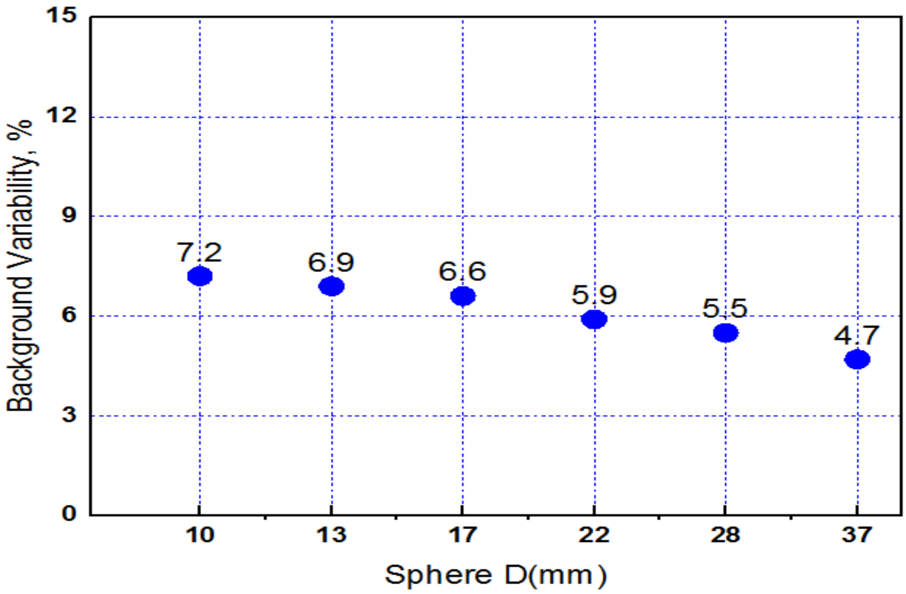

Fig. 7: Background variability test results for various spheres reconstructed with VPHD technique on GE Discovery IQ positron emission tomography/computed tomography scanner.

In a medical imaging system, it is important to distinguish between true changes in contrast caused by the object of interest and variations in the background. High background variability can introduce noise and reduce the system's ability to detect small changes in contrast. Therefore, a good imaging system should have low background variability, resulting in a clearer differentiation between the object and the background. Background Variability decreases as the diameter of the sphere increases. Figure 7 shows that for the sphere diameter 10, 13, 17, 22 mm (hot), 28 and 37 mm (cold), Background Variability values are 7.2%, 6.9%, 6.6%, 5.9%, 5.5% and 4.7% indicating the clearer differentiation between the object and the background.

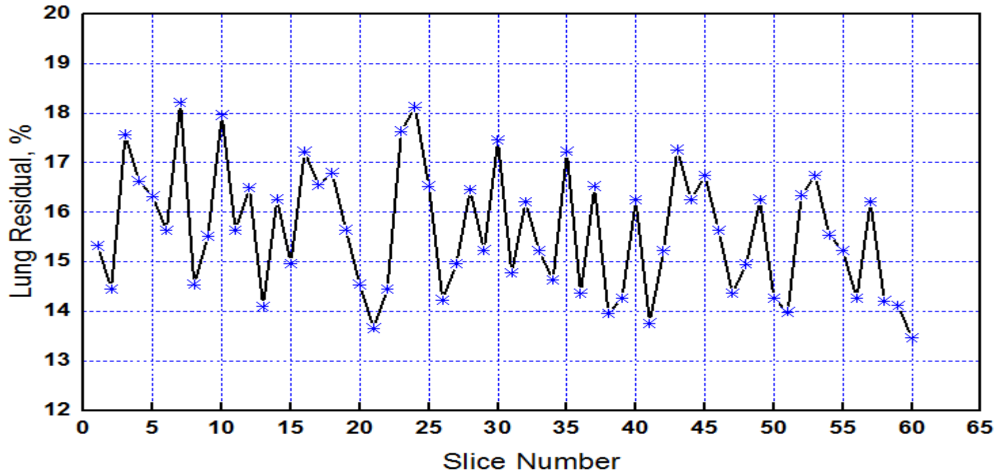

Fig. 8: Lung Residual test result for Lung Insert reconstructed with VPHD technique on GE Discovery IQ positron emission tomography/computed tomography scanner.

The lung is a challenging area to image due to its low contrast and high variability in tissue density. In this NEMA test, lung variation is assessed using a lung insert that mimics the characteristics of lung tissue. The test measures the system's ability to visualize and distinguish subtle changes in lung structures, such as nodules or small lesions. Figure 8 shows that A good imaging system should have low noise and high contrast sensitivity in lung imaging, enabling the accurate detection and characterization of lung abnormalities.

4. DISCUSSION

The Discovery MI, MI DR, IQ Gen- are the GE Healthcare's next generation PET/CT scanners but The D-IQ is the GE Healthcare's BGO PET/CT scanners, succeeding the Discovery-LS (13), Discovery-ST (14), Discovery STE (8) and Discovery-600 (D-600) (9) series. The D-IQ was created especially for cancer PET imaging, with applications in both radiotherapy and diagnostics, to enhance the development of the radiation treatment plan based on the fused CT and PET images. The D-IQ combines a cutting-edge multi-slice helical CT scanner with a cutting-edge PET tomograph that operates in both 2D and 3D acquisition modes and is based on BGO detectors. The physical characterization of the D-IQ PET performance in accordance with NEMA standard standards was the goal of this investigation. The N-12 standards was taken into account. Parameter by parameter, the results of the physical characterization are reviewed below with regard to the viability of the tests carried out. Additionally, the D-IQ results are compared to the capabilities of a popular PET tomograph, the GE ST, GE D-600, made by the same company and using a similar architecture. Measuring axial, tangential, and radial resolutions, the NEMA test provides a comprehensive assessment of the spatial resolution performance of a PET system in different directions. These measures help evaluate the system's ability to resolve fine details and are crucial for accurate imaging in clinical applications. Spatial resolution was tested on images reconstructed with an iterative approach (VPHD). In comparison with the D-ST and D-600 BGO PET scanner, the transverse (6.29 mm and 4.9 mm) and axial (5.68 and 5.6mm) resolution at 1 cm off center is lower than D-IQ (transverse 4.5 mm and 4.82 mm) (15,16). The spatial resolution is influenced by the number of planes which contribute to the generation of direct and cross planes.

The D-IQ5's sensitivity (21.6 cps/kBq) is twice that of the D-600 (9.6 cps/kBq) (17,18). The formers should higher axial FOV of 26.0 cm and 5 ring detector blocks, VPHD, Q. Clear, and a Bayesian penalized likelihood reconstruction should provide gain in sensitivity.

The hot contrasts for 10, 13, 17, and 22 mm spheres were 41%, 51%, 62%, and 73% and the cold contrasts for 28 and 37 mm spheres were 68% and 72% for D-600 (16) whereas D-IQ showed good contrast recovery for hot and cold spheres. The addition of Q. Clear significantly enhances image quality, boosting contrast recovery coefficients and decreasing background variability. Spatial resolution at radial, tangential and axil direction was satisfactory. The present study followed the guidelines suggested by the manufacturer and simulated more realistic conditions with a worse combination of acquisition time and phantom activity concentration.

5. CONCLUSION

Overall, contrast recovery, background variability, and lung variation are crucial factors in assessing the performance of medical imaging systems. These parameters help determine the system's ability to accurately detect and quantify changes in contrast, differentiate between the object and the background, and visualize subtle details in challenging imaging scenarios such as lung imaging. The Discovery-IQ PET/CT BGO-based scanners with 5-ring detector blocks have the highest overall performance, with improved sensitivity. This system offers the potential to reduce scan times or injected activities through increased sensitivity. Spatial resolution at radial, tangential and axil direction, higher recovery coefficients and lower background variability of the acquired image reconstructed with the VPHD algorithm indicate good image quality. The Discovery-IQ has good performance for the NEMA NU 2-2012 parameters, particularly in improved sensitivity compared to the scanners of the same Discovery family, D-ST and D-600.

References:

1. Ell PJ. The contribution of PET/CT to improved patient management. Br J Radiol. 2006;79:32–36
2. Townsend DW. Combined positron emission tomography-computed tomography: The historical perspective. Semin Ultrasound CT MR 2008;29:232-5
3. Beyer T, Townsend DW, Brun T, Kinahan PE, Charron M, Roddy R, et al. A combined PET/CT scanner for clinical oncology. J Nucl Med 2000;41:1369-79
4. Martí-Climent JM, Prieto E, Domínguez-Prado I, et al. Contribution of time of flight and pointspread function modeling to the performance characteristics of the PET/CT Biograph mCT scanner.Rev Esp Med Nucl Imagen Mol. 2013;32:13–21
5. Rausch I, Cal-González J, Dapra D, et al. Performance evaluation of the Biograph mCT flow PET/ CT system according to the NEMA NU2-2012 standard. EJNMMI Phys. 2015;2:26
6. Bettinardi V, Presotto L, Rapisarda E, Picchio M, Gianolli L, Gilardi MC. Physical performance of the new hybrid PET/CT Discovery-690. Med Phys. 2011;38:5394–5411.
7. Teoh EJ, McGowan DR, Macpherson RE, Bradley KM, Gleeson FV. Phantom and clinical evaluation of the Bayesian penalized likelihood reconstruction algorithm Q.Clear on an LYSO PET/CT system. J Nucl Med. 2015;56:1447–1452.

8. Teräs M, Tolvanen T, Johansson JJ, Williams JJ, Knuuti J. Performance of the new generation of whole-body PET/CT scanners: Discovery STE and Discovery VCT. Eur J Nucl Med Mol Imaging. 2007;34:1683–1692
9. Jakoby BW, Bercier Y, Watson CC, Bendriem B, Townsend DW. Performance characteristics of a new LSO PET/CT scanner with extended axial field-of-view and PSF reconstruction. IEEE Trans Nucl Sci. 2009;56:633–639.
10. Moses W. Time of flight in PET revisited. IEEE Trans Nucl Sci 2003;50:1325-30
11. Zanzonico P. Positron emission tomography: A review of basic principles, scanner design and performance, and current systems. Semin Nucl Med 2004;34:87-111
12. National Electrical Manufacturers Association. Performance Measurements of Positron Emission Tomographs. NEMA Standards Publication NU 2-2012. Rosslyn, USA: National Electrical Manufacturers Association; 2012
13. Bolard G, Prior JO, Modolo L, et al. Performance comparison of two commercial BGO-based PET/CT scanners using NEMA NU 2-2001. Med Phys. 2007;34:2708– 2717
14. Mawlawi O, Podoloff DA, Kohlmyer S, et al. Performance characteristics of a newly developed PET/CT scanner using NEMA standards in 2D and 3D modes. J Nucl Med. 2004;45:1734–1742
15. Valentino Bettinardi1, Massimo Danna1. Performance evaluation of the new whole-body PET/CT scanner: Discovery ST, Journal of Nuclear Medicine and Molecular Imaging July 2004European 31(6):867-81
16. E De Ponti 1, S Morzenti, L Guerra. Performance measurements for the PET/CT Discovery-600 using NEMA NU 2-2007 standards, Med Phys 2011 Feb;38(2):968-74
17. Kajisako M, Kawase S, Mitsumoto K, Tatsuno K, Higashimura K, Nakamoto1 Y, et al. Performance evaluation of the Bayesian Penalized Likelihood Reconstruction Algorithm Q.Clear on BGO PET/CT system, according to NEMA NU2-2012 standard. J Nucl Med 2016;57 Suppl 2:2627
18. Morzenti S, De Ponti E, Guerra L, Zorz A, Landoni C, Crivellaro C, et al. Performance evaluation of the discovery IQ-GE PET/CT scanner according to NEMA NU2-2012 standard. J Nucl Med 2015;56 Suppl 3:1846