Performance Evaluation of the Nuclear Medicine Imaging Modalities at NINMAS

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ABSTRACT

Performance evaluation of the imaging systems of nuclear medicine have been checked and compared with the previous data which were collected at the time of acceptance testing at the National Institute of Nuclear Medicine & Allied Sciences (NINMAS). Performance measurements that have been carried out for the SPECT and SPECT-CT system recently were according to NEMA NU 2-2012 standard and IAEA Human Health Series No.1. Phantoms required for these tests to be performed were supplied by the vendors. Performance tests checked for the SPECT system were intrinsic flood field uniformity, intrinsic spatial resolution, center of rotation (COR), offset and alignment of axes, sensitivity and total performance test. The CT Phantom tests have been carried out for the visual inspection of resolution, contrast, noise and uniformity of the CT system. In these studies, performance evaluations of nuclear medicine imaging modalities including SYMBIA Evo Excel Dual Head SPECT Scanners, SYMBIA T16 SPECT-CT System and Nucline TH-45 Single Head Gamma Camera for Thyroid have been done to ensure the quality of service given to the patients. Performance measurements of these imaging modalities have shown satisfactory image quality. All data were compared with the acceptance testing data which were carried out during installation at the institute.

Key words: Performance Evaluation, SPECT System, Quality Control, CT Number, Resolution.

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INTRODUCTION

The nuclear medicine imaging systems such as gamma camera/SPECT's primary function is to produce an image from the radioactivity injected to the patient. The radionuclide produces gamma rays that can escape from the body and be detected by a gamma camera. The gamma camera is made up of a detector that detects gamma rays and calculates their location and energy (1). This is then processed further by the console's electronics before being shown on a monitor. The radionuclide in the patient emits a gamma ray, which moves towards the detector. The gamma rays must then pass via the collimator, which ensures that only gamma rays traveling at a specific angle relative to the detector crystal reach the detector. The gamma ray is converted into light by the Sodium Iodide NaI(Tl) crystal (2,3). The photomultiplier tubes turn the light into electrical impulses. These electrical signals are then used to calculate the gamma ray's position and energy signals. A single count or event is captured and saved in computer memory if the energy signal falls within the range of energies set by the pulse height analyzer energy window. Many of these observed gamma rays are combined to create a picture of the patient (4-6).

To recognize how to make the best use of the nuclear medicine imaging modality, it is essential to know the capabilities and limitations of the system. For diagnostically adequate images, proper camera settings and quality control are required. To guarantee that cameras are working effectively and to detect problems before they affect clinical research, a minimal level of routine Quality Control (QC) is essential. One of the most important reasons to undertake camera QC is to guarantee that the camera is working properly and does not add artifacts or damage the image. For example, a cold region in the flood could readily be mistaken for a lesion, leading to a misinterpretation of the study. Thus, before these imaging modalities have an impact on clinical study, they must be evaluated and functional status checked (7-9).

At present, there are two dual head gamma cameras including SPECT system, one SPECT-CT system and one single head gamma camera (small field of view) for thyroid scan were installed around six years ago at NINMAS. Also, we have two old gamma cameras at our institute which were installed around 14 years ago but

still functioning. All equipment is going to be getting old thereby reducing performance ability. At the time of installation, several acceptance testings were carried out for all equipment. It is very essential to do the performance evaluation for all equipment from time to time for proper functioning. Routine QC tests are done regularly but these are not sufficient for measuring all performance parameters of the equipment. To assess the performance of imaging modality, identify the lacking and improve the functional capability with image quality is quite necessary.

OBJECTIVES

The purpose of this research is to evaluate the performance and improve the image quality of the dual head SPECT systems, thyroid gamma camera, and SPECT/CT imaging modalities; all of which were installed in our institute several years ago.

MATERIALS AND METHODS

Intrinsic Uniformity

The SPECT system's main assumptions are that the camera system's response to uniform irradiation is uniform within given ranges. By uniformly flooding the detector crystal with gamma radiation without the influence of a collimator, the count density fluctuation over the gamma camera useful field of view (UFOV) and central field of view (CFOV) can be measured. With a 0.4 mCi Tc-99m point source and standard technique, intrinsic flood field uniformity was measured. At least five times larger than the detector UFOV, the point source is centrally placed above the detector. On the other hand, a distance of four times the UFOV is sufficient. With an image matrix size of 256x256, flood images were acquired (10-12).

Visual inspection and calculation of the integral uniformity (IU) and differential uniformity (DU) within the camera's CFOV and UFOV were used to assess the flood field uniformity. For proper evaluation, a sufficient count density must be obtained. According to the NU 1-2012 standard, the flood image includes about 30 million counts within the camera UFOV. The image detector area is referred to as UFOV, while the 75 percent usable FOV is referred to as CFOV. Within the Region of Interest (ROI), the maximum and minimum pixel counts have been recorded. Integral uniformity is determined in each of these fields of view using the equation below.

$$\text{Integral uniformity (\%)} = \frac{\text{maximum pixel count - minimum pixel count}}{\text{maximum pixel count + minimum pixel count}} \times 100$$

The greatest count difference in any 6 consecutive pixels has been established for each row or column of pixels in the X and Y directions within the UFOV and the CFOV. It has been discovered what the largest value of this maximum count difference in the sets of rows and columns is. The differential uniformity, DU, is then given by

$$DU = \frac{(Hi-Low)}{(Hi+Low)} \times 100$$

Where Hi and Low are the pixel counts giving the highest value of the maximum count difference. Figure 1 shows the intrinsic uniformity test for the SPECT system at NINMAS which was processed by the processing software of the imaging system.

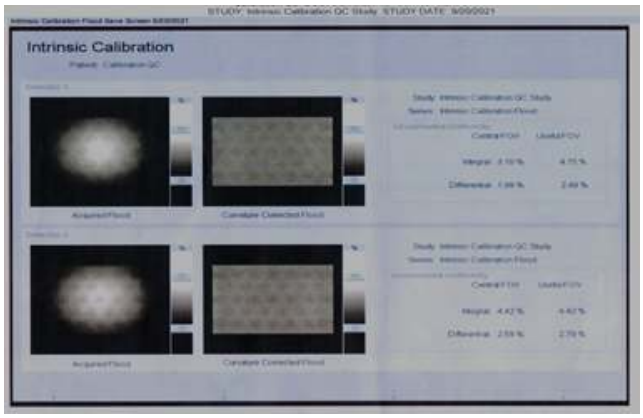

Figure 1: Uniformity test for the SPECT system at NINMAS

Spatial Resolution

Spatial resolution was achieved using a resolution bar phantom and another approach using a 1mCi Tc-99m point source. The detector UFOV was covered by a quadrant bar phantom consisting of four separate panels of parallel bars of decreasing size and spacing. In the smallest quadrant, the bar phantom has a bar width that is roughly half of the expected inherent spatial resolution (the smallest bars are 2 mm). The goal of this bar phantom test is to find the image's smallest quadrant

of bars. The line spread function (LSF)'s width at half maximum (FWHM) is around 1.6 times the smallest visible bar size (13).

Sensitivity

The sensitivity of the SPECT system is evaluated in counts per minute per unit activity, CPM/KBq (CPM/μCi) using radioactive sources located within the camera's UFOV. The sensitivity was calculated using the count rate of a known radionuclide in a disk source with low attenuation and scatter for a certain collimator. The measurement of the sensitivity for Tc-99m was obtained using a parallel-hole and low-energy high-resolution (LEHR) collimator (11). Figure 2 shows the Sensitivity profile of the SPECT system which was acquired from the camera.

Figure 2: Sensitivity profile of the SPECT system at NINMAS

Centre of rotation (COR)

COR, which must evaluate the center of rotation offset, alignment of the camera Y-axis, and head tilt with respect to the axis of rotation, is one of the most significant

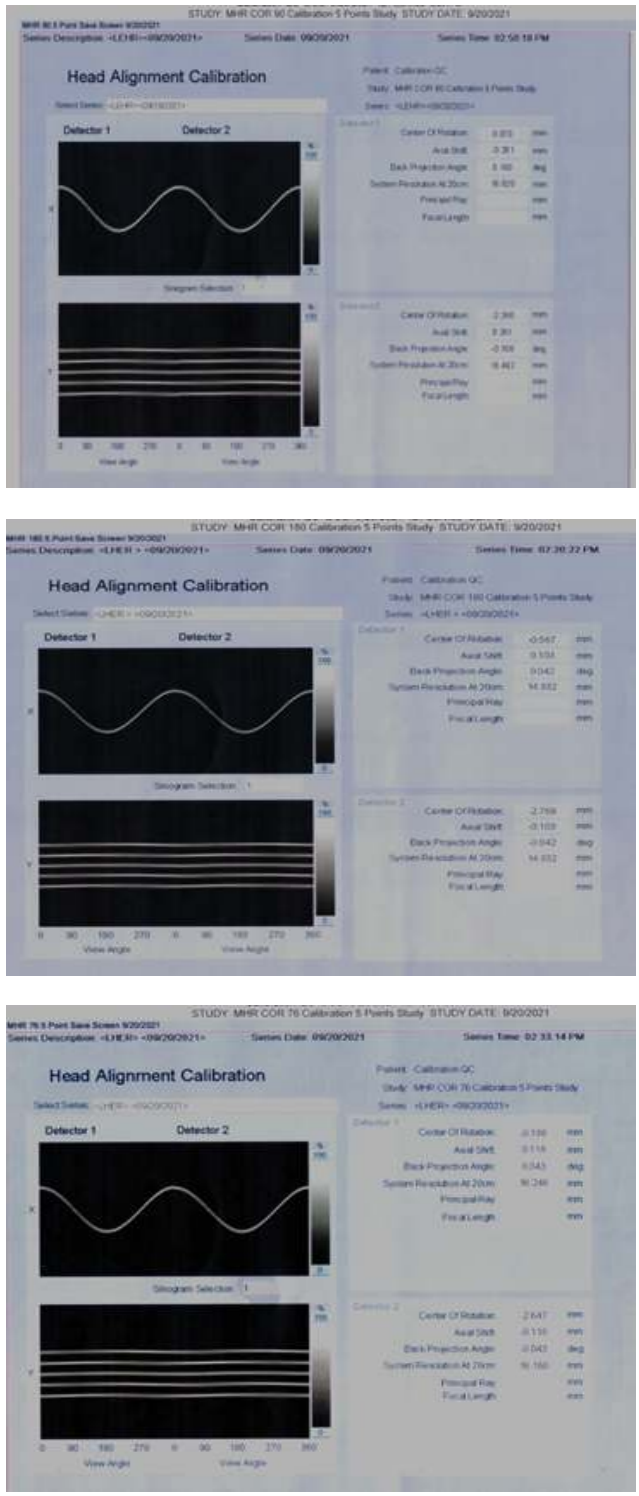

Figure 3: COR test for 180, 90, 76 degrees angle configuration

acceptance tests for the SPECT system. If an error is discovered during the resolution in an air test, this test should be conducted. For this experiment, 99mTc point sources were used. Tomographic acquisition was carried out with the smallest digital matrix size possible, with around 10,000 counts collected at each angular location. For this test, an acquisition of 32 angles across 360° is sufficient. Throughout the tomographic acquisition, it's critical to keep the point sources within the camera's field of view at all times. Figure 3 shows the COR test for 180, 90 and 76 degrees angle configuration which were processed by the processing software of the COR test for SPECT system at NINMAS.

Total performance test was done with Jaszczak Phantom. All tests were carried out according to NEMA NU 1-2012 and IAEA Human Health Series No.6.

CT Number Accuracy, Uniformity and Noise

A CT number accuracy test is performed to ensure that the equipment manufacturer's CT number criteria are met. A range of 0-3 Hounsfield units (HU) at the center of the image and 0-5 HU at the periphery is acceptable. The CT number of water could be out of range due to a miss calibration of the algorithm that generates CT numbers. Field uniformity is measured by comparing attenuation in a region of interest (ROI) at the center of the uniform field vs along the edges, and it relates to CT number (HU) fluctuations in a uniform field (typically a water or water-equivalent phantom). The benchmark for field homogeneity is a center ROI of 3 HU and four ROIs in the periphery that are measured within 5 HU of the center ROI. Image noise is a statistical variation in CT numbers of individual picture elements within an uniform ROI at a local level. The standard deviation (SD) of the HUs in a given ROI in a uniform area of the image represents the degree of noise. The amount of detected photons, matrix size (pixel size), slice thickness, methodology, electronic noise (detector electronics), scattered radiation, and object size all contribute to CT noise. The noise SD should be around 3. The noise is 0.3 percent since CT values range from 1000 HU. The maximum difference in SD between the ROI's center and any periphery ROI is 5 HU (14-17).

With a head CT water phantom of 20 cm in diameter, CT Number Accuracy, Uniformity and Noise were performed. For the tests, images were taken according to the brain protocol with Symbia T16 CT Scanner. Water phantom was attached to the table with the phantom holder and positioned at the center of the CT gantry (CT scan mode). Center of the phantom was aligned by using internal CT laser light. The ROIs were drawn at the center, top, bottom, left and right of the acquired images. CT number accuracy, CT number uniformity and Noise were evaluated from the value shown for each ROI.

The CT numbers were obtained for water and for air from the acquired images. CT field uniformity was measured for the mean water values obtained at the 5 regions of interest. Image noise is a statistical variation in CT numbers of individual picture elements within the uniform ROI and it is the Standard Deviation of a given ROI in a uniform area of the image.

Performance testing of Single Head Gamma Camera for Thyroid

Performance tests for thyroid gamma cameras were performed also. Intrinsic flood field uniformity, Intrinsic spatial resolution and sensitivity were measured with standard phantoms. Phantoms and sources were prepared with standard protocols. Sensitivity was measured for the low energy all purpose (LEAP) collimator. All tests were carried out according to NEMA NU 1-2012 and IAEA Human Health Series No.6.

RESULTS AND DISCUSSIONS

All values of intrinsic flood field uniformity were found <4.50% for the SPECT system. Intrinsic spatial resolution was 3.8 mm FWHM for both CFOV and UFOV. Also, resolution was provided by using bar phantom with visual inspection. Sensitivity was measured 207cpm/μCi for the LEHR collimator. The mean value of the COR offset was found <2 mm. For confirming uniformity and resolution, visual inspection was done with Jaszczak Phantom. The details of the performance measurement of the SPECT system have been shown in Table1 with comparison to the acceptance data which were carried out at the time of installation of the machine at NINMAS. Figure 4 has shown the resolution of the SPECT system by using the bar phantom which was visually shown satisfactory.

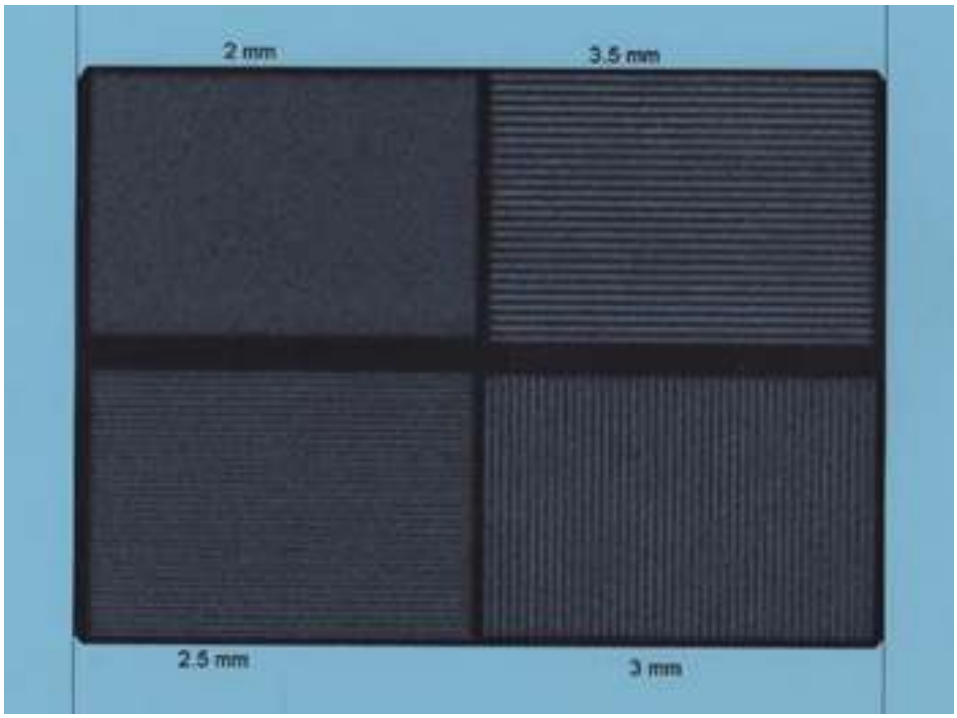

Figure 4: Resolution by using bar phantom

Table 1: Present performance assessment of SPECT system with acceptance data

Sl No.	Performance Test	Present status	Acceptance test results
SPECT System			
1	Intrinsic uniformity	All values were <4.50% for both CFOV and UFOV	All values were 3.50% for both CFOV and UFOV
2	Intrinsic spatial resolution	4.1 mm FWHM for both CFOV and UFOV	3.8 mm FWHM for both CFOV and UFOV
3	Resolution by using bar phantom with visual inspection	Satisfactory	Satisfactory
4	Sensitivity	>202 cpm/μCi	>207 cpm/μCi for LEHR collimator
5	COR (MHR 180, 90 & 76)	Offset <3 mm	Offset <2 mm
6	Visual inspection of Jaszczak phantom imaging	Satisfactory	Satisfactory

CT Number for water and air was found from Figure 5, Mean CT Number for five ROI's were assessed from Figure 6 and Standard Deviation was measured from Figure 7 which were all taken from the same image. CT number for water and air, Field uniformity for water and image noise are presented in Table 2. Mean CT numbers for water and air, field uniformity for the identified five ROIs were within the tolerance values of 5 HU. The mean CT number for water across the five ROI's ranges from – 0.5 to – 2.9 HU while the maximum standard deviation of the mean CT number is 2.6.

Table 2: CT Number for water and air, Mean CT Number for five ROI's and Standard Deviation.

CT Number for water (HU)	CT Number for Air (HU)	CT Uniformity					Image Noise (SD)
		R_1	R_2	R_3	R_4	R_5	
0	-1010	-1.4	-2	-2.5	-2.9	-0.5	2.6

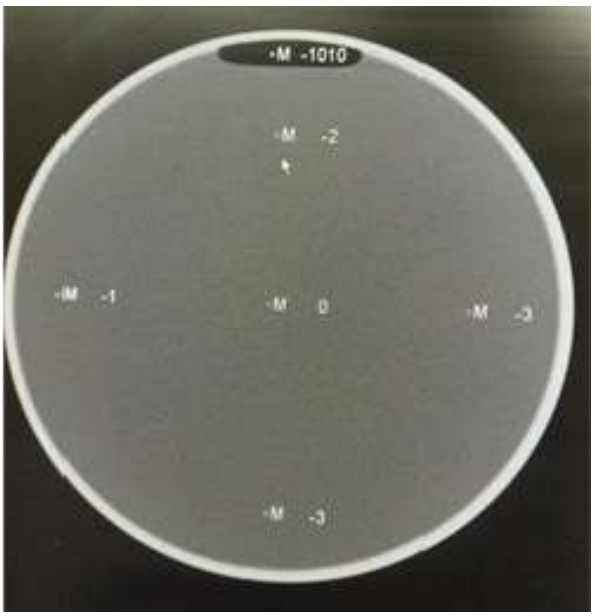

Figure 5 : Image of the CT number for water and air.

Figure 6: Field uniformity image

Figure 7: Image Noise

For the thyroid gamma camera, all values of the of intrinsic flood field uniformity, Intrinsic spatial resolution and sensitivity were measured accordingly <2.8%, 3.0 mm FWHM for both CFOV and UFOV and 230 cpm/μCi for LEAP collimator. The details of the performance measurement of thyroid gamma camera have been shown in Table 3 with comparison to the acceptance data. Figure 8 has been shown the resolution of the Camera system by using the bar phantom which was visually shown satisfactory.

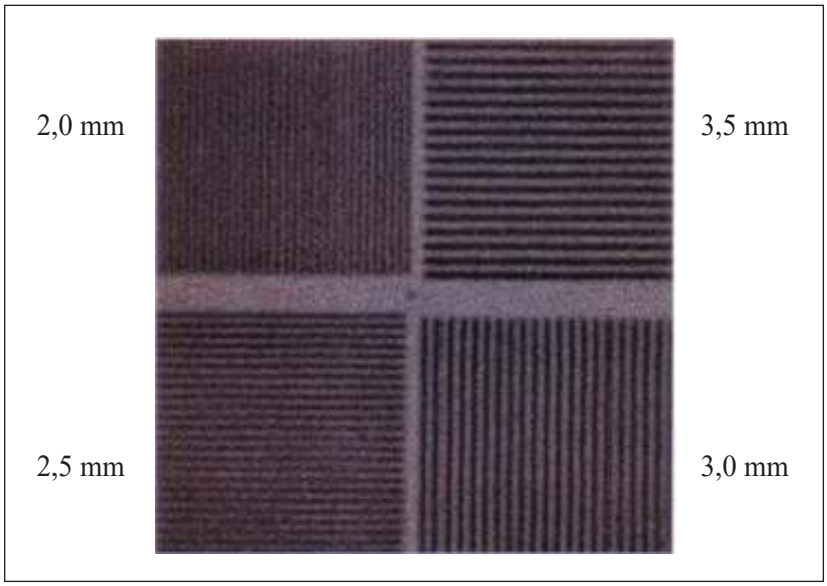

Figure 8: Resolution by using bar phantom

Table 3: Present performance assessment of Thyroid Gamma Camera with acceptance data

Sl No.	Performance Test	Present status	Acceptance test results
Thyroid Gamma Camera			
1	Intrinsic uniformity	All values were <3.5% for both CFOV and UFOV	All values were <2.80% for both CFOV and UFOV
2	Intrinsic spatial resolution	3.5 mm FWHM for both CFOV and UFOV	3.0 mm FWHM for both CFOV and UFOV
3	Sensitivity	>215 cpm/μCi for LEAP collimator	>230 cpm/μCi for LEAP collimator

The detailed results of the performance measurement data have been clearly shown that all values of measured data are very close to the acceptance data. All nuclear medicine imaging modality typically performs a little bit poorly after a certain period of time due to their advanced age. All findings from our tests are in acceptable range and these are very close to the acceptance testing data.

All test methods and results must be meticulously documented and archived so that future quality control tests can be accurately compared to these performance measurement data obtained from this project. This data serves as the acceptance testing data for the instrument's logbook or digital record.

CONCLUSION

Performance evaluation of nuclear medicine imaging equipment is important as it is related with the image being taken of a patient. In this study performance evaluations of SPECT, SPECT-CT and Thyroid Gamma Camera Systems of NINMAS have been done to ensure the quality of service given to the patients. Performance measurements of all imaging systems show the satisfactory image quality.

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REFERENCES

1. Faulkner K. The Radiological Accident in Lilo. International Atomic Energy Agency, pp. 103, 2000 (IAEA, Vienna, Austria), £20 ISBN 92-0-101300-0; The Radiological Accident in Istanbul. International Atomic Energy Agency, pp. 75, 2000 (IAEA, Vienna, Austria), £16 ISBN 92-0-101400-7. The Radiological Accident in Yanango. International Atomic Energy Agency, pp. 41, 2000, (IAEA, Vienna, Austria), £11 ISBN 92-0-101500-3. The British Journal of Radiology. 2001. pp. 297–297. doi:10.1259/bjr.74.879.740297
2. INTERNATIONAL ATOMIC ENERGY AGENCY. Quality Assurance for Radioactivity Measurement in Nuclear Medicine. [cited 31 Jan 2022]. Available: https://www.iaea.org/ publications/7480/quality-assurance-for-radioactivity-measurement-in-nuclear-medicine
3. INTERNATIONAL ATOMIC ENERGY AGENCY. IAEA Quality Control Atlas for Scintillation Camera Systems. [cited 31 Jan 2022]. Available: https://www.iaea.org/ publications/6337/ iaea-quality-control-atlas-for-scintillation-camera-systems
4. INTERNATIONAL ATOMIC ENERGY AGENCY. Applying Radiation Safety Standards in Nuclear Medicine. [cited 31 Jan 2022]. Available: https://www.iaea.org/ publications/7116/ applying-radiation-safety-standards-in-nuclear-medicine
5. INTERNATIONAL ATOMIC ENERGY AGENCY. Nuclear Medicine Resources Manual. [cited 31 Jan 2022]. Available: https://www.iaea.org/publications/7038/nuclear-medicine-resources-manual
6. Sharma SD, Prasad R, Shetye B, Rangarajan V, Deshpande D, Shrivastava SK, et al. Whole-body PET acceptance test in 2D and 3D using NEMA NU 2-2001 protocol. J Med Phys. 2007;32: 150–155.
7. EANM Physics Committee, BusemannSokole E, Płachcínska A, Britten A, EANM Working Group on Nuclear Medicine Instrumentation Quality Control, Lyra Georgosopoulou M, et al. Routine quality control recommendations for nuclear medicine instrumentation. Eur J Nucl Med Mol Imaging. 2010;37: 662–671.
8. BusemannSokole E, Płachcínska A, Britten A, EANM Physics Committee. Acceptance testing for nuclear medicine instrumentation. Eur J Nucl Med Mol Imaging. 2010;37: 672–681.
9. Coca Perez MA, Torres Aroche LA, Bejerano GL, Mayor RF, Corona CV, López A. Establishment of a national program for quality control of nuclear medicine instrumentation. J Nucl Med Technol. 2008;36: 203–206.
10. Gar-Elnabi MEM, M. Ali W, Omer MAA, Sam AK, Edam GA. Development and assessment of quality control phantom for linearity and uniformity. Open J Radiol. 2015;05: 59–65.
11. Rep S. Quality Control of Nuclear Medicine Instrumentation and Protocol Standardisation: EANM Technologists Guide. 2017.
12. Zanzonico P. Routine quality control of clinical nuclear medicine instrumentation: a brief review. J Nucl Med. 2008;49: 1114–1131.
13. Halama J, Graham D, Harkness B, CheenuKappadath S, Madsen M, Massoth R, et al. Acceptance Testing and Annual Physics Survey Recommendations for Gamma Camera, SPECT, and SPECT/CT Systems. 2019. doi:10.37206/184.
14. Oliveira PM, Horta MA, Magalhães MJ, Santana PC. Assessment of Computerized Tomography Devices in Minas Gerais. INAC; 2011.
15. American College of Radiology Imaging Network. Quality Control and Performance Testing Manual of Operations for CT. Version 1.3: ACRIN;2003.
16. Joseph N, Rose T. Quality Assurance and the Helical (Spiral) Scanner;2012.
17. European Commission. European Guidelines on Quality Criteria for Computed Tomography EUR 16262 EN. Luxemburg: European Commission; 1999.