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Evaluation of Parameters Affecting Intrinsic Uniformity to Perform Best Optimum Daily QC

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ABSTRACT
Nuclear Medicine plays a vital role in the diagnosis of benign and malignant cancer tissues. The quality assurance program of gamma cameras in nuclear medicine provides an artifact-free diagnosis. One of the most important quality control (QC) is to test the response of detectors to a uniform distributed source called as uniformity test. The QC of image uniformity test includes intrinsic uniformity (IU) and Differential uniformity (DU) of CFOV (Central Field of View) and UFOV (Useful Field of View). The purpose of this study is to evaluate the best value of parameters for getting the best uniformity results and set as a benchmark for checking the performance of gamma cameras in the future. It is analyzed that using an energy window placed at 140 KeV at 20%, with a matrix size of 256 x 256, acquiring 60 million counts and the source activity close to 500 μC obtained images are good and both uniformities are within the manufacturer's requirements, however, increasing the number of acquired counts and by mounting a source at a distance larger than 2m, images become better.

Introduction

Nuclear medicine is the most important tool for physicians to study about physiology and spread of disease [1]. It is a diagnostic technique based on gamma-ray detection of scintillators, mounted on a Gamma Camera, being emitted from a radionuclide-injected patient [2]. Unlike X-ray and CT, nuclear medicine images are produced with restricted low dose rates, considering patient safety regarding radiation protection [3].

Besides inherent limitations of NM image quality, there are many parameters associated with the Gamma camera system that affect image quality. I-e Spatial resolution, sensitivity, uniformity, and contrast [4]. Performance measurement of scintillation cameras includes pixel size calibration, linearity measurements, rotational sensitivity, mechanical alignment, energy distribution, and count rate capabilities [5]. Completed clinical studies for unacceptable patient motion and incomplete views must be checked.

Quality Control tests of gamma cameras must be performed daily before injecting patients to avoid any artifact in clinical studies [6]. Also, it is important to detect changes in the performance of the Gamma camera [7]. However, because of the daily heavy workload of patients, only a small amount of time can be dedicated to QC tests. So it's necessary to choose the most sensitive QC test for analyzing the performance of the gamma camera [8]. The uniformity test is the most sensitive test which depends on energy, energy window, PMT performance, crystal condition, and linearity correction [9] The uniformity of a Gamma camera refers to its ability to produce a true uniform image for a uniform radiation-striking flux [10].

Uniformity of gamma camera can be performed in two ways i-e intrinsically and extrinsically. An intrinsic uniformity test is performed by getting an image of the Tc99m point source placed at an axis centered over an uncollimated detector about 5 times UFOV away from the detector surface. The uniformity of a system is quantitatively described in two parameters i-e Integral Uniformity (IU) and differential uniformity(DU) [11].

Integral uniformity is based on maximum and minimum pixel counts in an image.

$$IU=100\%\ X\ \frac{max\ pixel\ counts-min\ pixel\ counts}{max\ pixel\ counts+min\ pixel\ counts}$$

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Whereas Differential uniformity depends on the maximum and minimum count difference for any 5 consecutive pixels in all the rows and all the columns

$$DU= 100\% \; X \frac{high\text{-}low}{high+low}$$

(Physics in Nuclear Medicine, Sorenson)

The aim of the study is first to find out the uniformity response of the Gamma Camera on variation of source activity, energy window, matrix size, total counts, and the distance between detector surface and source. And secondly to evaluate the best values of all these effecting parameters for the best optimum uniformity image.

Literature Review

Intrinsic Uniformity test is performed to get ideally the uniform response of the detector field of view for uniform flux but even a fine-tuned Gamma Camera shows 10% variability in response [12]. IU depends on the response of PM tubes, X-Y positioning of detected pulses, and edge packing.

There are many studies performed on finding the value of parameters for obtaining the best daily QC results. The value of these parameters is also recommended by the manufacturer but it might not be feasible in a specified hospital because of heavy workload or other reasons. Once these parameters are evaluated, one can perform daily QC easily and thus determine the performance of the gamma camera.

Counting statistics involves a lot in nuclear medicine imaging quality. There is a strong trade-off between contrast, noise, and resolution of the image. Four Million counts/image is necessary to negate the stochastic response of the detector in the intrinsic uniformity test [13]. Similarly, a source activity of 70-200 MBq of Tc99m having a volume range of 0.2-0.7ml is required for best IU results [14]. The distance of the source to the detector and the counts per image should be 3m and 16-60M respectively for best IU results. The IU remains the same for all matrix sizes. It is worth mentioning that IU varies from detector to detector of an individual gamma camera. In the studies, different gamma cameras have been used in of different manufacturers. Therefore the best parameters of these studies might not be the reference for the best parameters of any other gamma camera.

The width of the energy window and its centered energy location are also very important for image quality [15]. Most of the gamma cameras' default energy window setting is 15%. The energy window centered on the energy value of the radioisotope being used gives the best image quality. An offset energy window either reduces the count density of low-gain PMTs or increases the contribution of scattered photons. A narrow energy window setting increases the resolution but reduces the sensitivity and hence noise increases. The effect of energy window width on IU results and concluded that 15-20% energy window width is best for optimum uniformity. Similarly the offset energy window shift in the range of 0-2% does not affect the uniformity.

Absolute quantification of the 3D distribution of a radionuclide within a patient has been one of the greatest challenges of nuclear medicine [16]. This is because nuclear medicine images are degraded by several factors, which limit the quantitative ability of this modality. Quantitative SPECT has wide applications in many areas in nuclear medicine from radiation dosimetry calculations to clinical applications. It has been used in image analysis studies to extract information about areas, volumes, and/or amounts of radioactivity in specific regions of interest. The information derived from these studies is then applied to estimate radiation dosimetry, and volumes or to aid in clinical diagnoses. Absolute quantitation means precise and accurate measurements of volume and the amount of radioactivity in a specific region of interest. For absolute quantitation of volume, the measurements can be expressed in cubic centimeters, for radioactivity in μCi or Bq. Quantitation of organ volumes using the planar imaging technique is a procedure often performed in nuclear medicine but faces difficulties due to a structure containing radioactivity, which overlies or underlies the organ of interest [17]. SPECT overcomes these difficulties since it can separate these structures in the reconstructed images, which have higher contrast than planar images.

Material and Methods

The effect of variation of three parameters i-e Technecium-99m (Tc-99m) Activity as a point source, the distance of the source from the detector surface and the counts per image/test on intrinsic uniformity image has been studied. it has been ensured that the background of the gamma camera bunker should be as low as possible. This study is performed on the first three days of equilibrium of the generator (~24hrs), therefore the activity is concentrated and the point sources are fine in size.

The point sources are made by inserting a small cotton ball in the bottom of the cap of the syringe and injecting the required activity in it. The point source is mounted on a stand, ensuring the point source is facing exactly the center point of the detector. The distance of the point source is changed from the detector surface by moving the stand along a white tap pasted on the floor (calibrated with measuring tape). Due to the limitation of the bunker room, the distance cannot be changed farther from 2.9 meters. The total counts per uniformity image have been varied by using the GE Infinia acquisition system. The score of uniformity obtained by the GE Infinia acquisition system has been noted for each test.

Results and Discussion

The detector of the gamma camera is set on L-mode. For both detectors, all uniformity tests are performed separately. The activity of the Technecium-99m point source is varied from 102 to 703μCi & 100 μCi to 697μCi for detector-1 & detector-2 respectively as shown in Table 1 and Table 2. For each test, the matrix size is 256*256, the total count is 60M and the distance of the point source from the detector is 290 m. The score of uniformity for UFOV and CFOV improves as the activity of the point source increases. The best uniformity image for UFOV and CFOV of both detectors against ~500μCi is shown in Figure 1 and Figure 2.

Table 1: Response of Detector-1 on variation of activity of point source

Activity	IU(UFOV)	IU(CFOV)
102	2.2317	1.7418
204	1.3614	1.3104
298	1.3425	1.125
401	1.3047	1.1074
506	1.28	0.9874
599	1.2711	0.9721
703	1.2529	1.0541

Table 2: Response of Detector-2 on variation of activity of point source

Activity	IU(UFOV)	IU(CFOV)
100	2.1818	1.6048
208	1.4104	1.2155
297	1.39	1.089
408	1.3926	1.0614
503	1.2784	0.9279
603	1.2937	0.9617
697	1.2474	1.0983

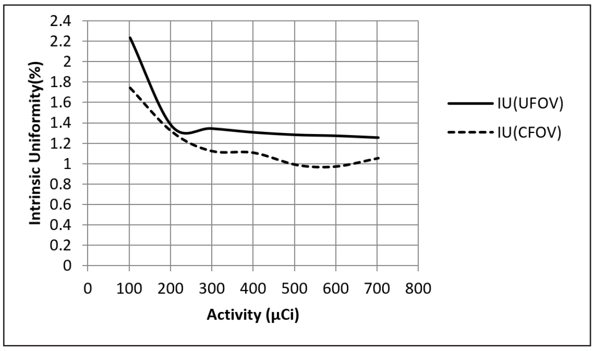

Figure 1: Response of Detector-1 on Variation of Activity of Point Source

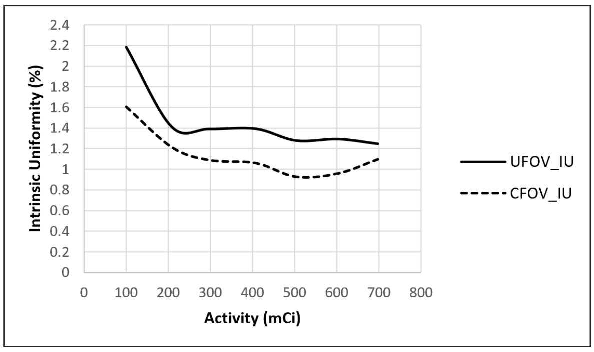

Figure 2: Response of Detector-2 on the variation of activity of point source

By variation of the total counts of images, the uniformity value of UFOV & CFOV for both detectors decreases (the uniformity gets improved) as shown in Table 3 and Table 4. These tests are performed having matrix size 256*256, activity 494±4 µCi, and distance 290 cm. As the increase in counts means the increased time of each test, which might be a problem on busy machines. Therefore optimum counts should be selected for detectors to compensate time factor as well. From Figure 3 and Figure 4, 60Million counts are the optimum counts for the machine used in this study.

Table 3: Response of Detector-1 on Variation of Counts (Mcts)

No. of Counts (Mcts)	CFOV-IU	UFOV-IU
30	1.2452	1.6147
40	1.2374	1.5324
50	1.1526	1.5317
60	1.1231	1.5277
70	1.0974	1.5328

Table 4: Response of Detector-2 on variation of Counts (Mcts)

No. of Counts (Mcts)	CFOV-IU	UFOV-IU
30	1.222	1.5898
40	1.2364	1.54733
50	1.1272	1.5438
60	1.1142	1.5411
70	1.0947	1.5884

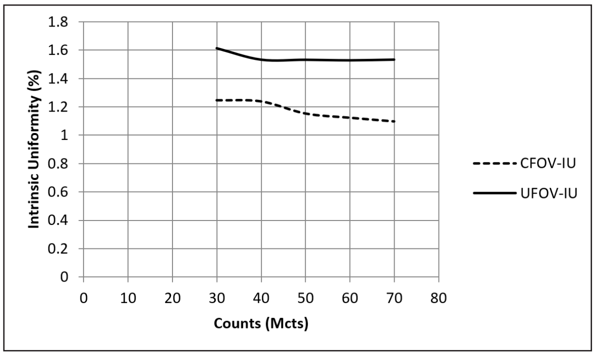

Figure 3: Response of Detector-1 on the variation of Counts (Mcts)

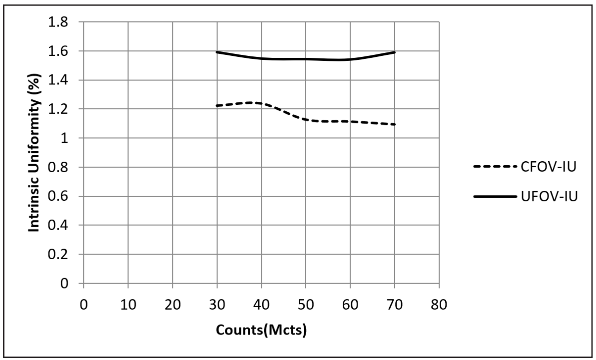

Figure 4: Response of Detector-2 on variation of counts (Mcts)

The distance from a point source to the detector surface is crucial for performing a uniformity test. In this study, the test performed at a 90cm distance for both detectors shows poor uniformity as shown in. At a distance of 190cm, the uniformity of both detectors improves abruptly. This shows that the source must be at 5 times to the dimension of UFOV.

Table 5 and Table 6. At a distance of 190cm, the uniformity of both detectors improves abruptly. This shows that the source must be at 5 times to the dimension of UFOV.

Table 5: Response of Detector-1 on the variation of Distance of point source to the detector surface

Distance (cm)	CFOV-IU	UFOV-IU
90	7.7489	9.7856
190	1.5774	1.8674
250	1.0641	1.35
290	1.0749	1.4658

Table 6: Response of Detector-2 on the variation of distance of point source from the detector surface

Distance (cm)	CFOV-IU	UFOV-IU
90	7.663	10.8696
190	1.42183	1.989
250	1.04767	1.2458
290	1.08198	1.4387

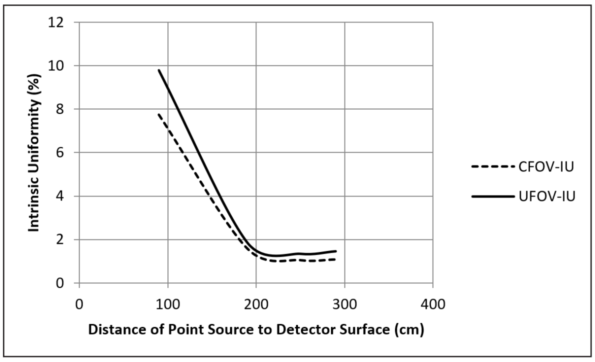

Figure 5: Response of Detector-1 on variation of Distance of point source to detector surface

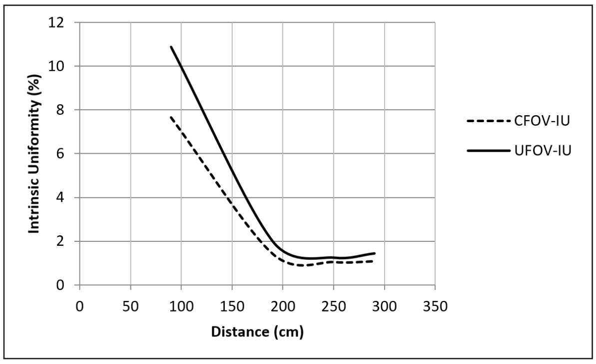

Figure 6: Response of Detector-2 on variation of distance of point source from detector surface

Conclusion

This study thoroughly analyzed the characteristics that influence intrinsic uniformity in a Gamma Camera, illustrating critical elements such as Tc-99m activity, distance from the detector surface, and counts per image. The findings emphasize the importance of these factors for achieving perfect uniformity results, providing useful insights into regular quality control operations in nuclear medicine. The discovered benchmarks, specifically an energy window at 140 KeV with a 20% setting, a 256 x 256 matrix size, and a 60 million count collection, provide realistic guidance for producing artifact-free and high-quality diagnostic images. These findings not only add to the current body of knowledge in nuclear medicine but also serve as an asset for practitioners seeking to improve the performance of Gamma Cameras in clinical settings. The comprehensive research and determination of ideal parameters reported in this paper lay a solid foundation for improving the accuracy and reliability of nuclear medicine imaging.

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