ANALYSIS OF THE GEOMETRICAL AND PHYSICAL FLUCTUATIONS WHILE PERFORMING INTRINSIC UNIFORMITY TEST FOR PHILIPS FORTE GAMMA CAMERA

Ibrahim E. Saad
Department of Radiological Sciences and Medical Imaging, College of Applied Medical sciences,
Salman Bin Abdulaziz University, KSA.

ABSTRACT

Intrinsic flood field uniformity is a fundamental quality control test that is considered as prerequisite for performing clinical routine exams using the gamma camera. Every gamma camera vendor provides recommended geometrical and physical parameters that should be followed while performing this test. Conventional methods using NEMA recommended parameters also can be used as well. ***The aim of the current study*** was to analyze the geometrical and physical fluctuations during performing intrinsic uniformity test for the gamma camera. ***Materials and Methods***: The intrinsic uniformity was tested for one detector of *Philips Forte* dual head gamma camera while changing the following geometrical factors the source distance from the detector face, the point source volume and the off-center in the X axis for the source position. Other physical factors were tested; the numbers of acquired counts and the matrix size used in the acquisition protocol, all tests have been done for both integral and differential intrinsic uniformity. The Tc^{99m} radioactive source was used for performing the tests and it measured using a calibrated dose calibrator. ***Results*** showed that the best intrinsic uniformity was found at 200 cm point source to detector face distance, the source position from the center of the detector face in the x- axis should be at the center (zero shift), the total number of acquired counts during the test should be from 30-60 M count and gives the best results at 30 M counts, the point source volume should be from 0.1 to 0.5 ml and the matrix size used in the acquisition protocol should be adjusted with 512X512 matrix. ***Conclusion:*** There were statistically significant differences between the results for each studied factor which indicates that there is an optimum value that should be used in each test at which the best integral and differential uniformity results were measured, deviation from this value lead to deterioration of the integral and differential uniformity as well, which in turn will affect the clinical image. Also there are acceptable limits by which the results of the test could be accepted for each factor studied according to the NEMA specifications of the studied (Philips, Forte) gamma camera.

Keywords: *intrinsic uniformity, gamma camera, fluctuations.*

1. INTRODUCTION

The performance of nuclear medicine cameras is crucial for the accuracy of clinical diagnostic studies because any malfunction may create image artifacts and alter patient diagnoses. Therefore, special series of quality control (QC) tests have been designed to ensure optimal camera performance. Depending on the objectives, the extent and scope of these tests varies. At camera installation, complete QC assessments (acceptance tests) are performed to ensure the correct performance of the system, verify its compliance with the published (or manufacturers') specifications gamma camera uniformity is usually monitored for quality control of performance **(1).** The uniformity or flood QC procedure checks the response of the detector to a uniform irradiation within defined limits. Uniformity can be checked either without collimator (intrinsic) or with collimator (extrinsic). Intrinsic uniformity is simpler to perform and does not require a flood tank or sheet source. It is preferable to do daily intrinsic uniformity QC test because Tc-99m point source is readily available and also relative sensitivity of the gamma camera (count rate per unit source activity cpm/µci) can be checked simultaneously.**(2)** Uniformity can be quantified in terms of the maximum variation in count density over the entire field-of-view [Integral uniformity (IU)] or in terms of the maximum rate of change in count density over a specified distance [differential uniformity (DU)]. **(3)** To detect gradual deterioration in uniformity it is important that uniformity measurements are performed in a consistent manner (i.e. using same method of performance with same orientation, same number of counts, same count rate, same source to camera distance, same matrix size, etc) and records are kept to allow comparisons over period of weeks or even months. **(4)** Regular analysis of uniformity by a computer can facilitate detection of gradual deterioration prior to any visible change. Many quantitative measurements can be derived from computer analysis of uniformity image**.(5)** A number of organizations have developed test protocols for reference tests, among them the AAPM (American Association Of Physicist in Medicine), the United Kingdom Hospital Physicists 'Association (HPA) and the International Electro technical Commission (IEC) .These tests, along with some acceptance and daily tests, provide the basis of routine testing.**(6)**To standardize these tests, the National Electrical Manufacturers Association (NEMA) regularly compiles documents that describe how to perform, analyze, and report QC tests for scintillation cameras. The latest of the NEMA standards for single-photon emission computed tomography cameras is NU-1 2001.**(2)**

Our aim is to analyze the effect of some geometrical and physical fluctuations during performing intrinsic uniformity test for *Philips, Forte* gamma camera.

2. MATERIALS

1- The study was performed on **Philips Forte dual head gamma camera** that has the following specifications:

- Dual head open gantry.

- [NaI (Tl)] crystal with 3/8 inch thickness.

- The number of photomultiplier tubes is 59.

- The detector UFOV dimensions are (40X55) cm.

2- Point sources: special shape of vials made by the manufacturer for containing the 99mTc-point source. It was used to study all parameters to test the intrinsic uniformity.

3- Atom lab 200 Dose Calibrator from ***Biodex Medical Systems*** was used for measuring the radioactivity of the point source.

3. METHODS

The studied parameters were; point source to detector face distance, center offset in X direction, the total number of acquired counts for the flood image, source volume, and image matrix size.

1) Test for intrinsic uniformity at different distances from the crystal: The collimator was removed from the camera from the detector 2 so that the detector 2 perpendicular to the detector 1and facing the wall of the gamma camera room. The point source of 0.2 mCi of 99mTc filled within the special shape container provided by the company is measured using the dose calibrator. The positioned on a source mounting and fixed at the center of the crystal face in the x and Y axis. The matrix was set at 512x512 matrix size. The total count rate was adjusted at 35 million count/sec, all as per company recommendations. The point source was mounted at different distances which are 20,40,60,80,100,120, 140,160,180,200 and 220 cm from the crystal face. For each distance the count rate was recorded and also the integral and differential uniformity were calculated using the processing program on the processing computer of the gamma camera.

2) Test for intrinsic uniformity at different shifts from the center: The same procedure was followed as in the previous test but the point source was mounted at 200 cm from the crystal face as per company recommendation and the point source was shifted in the X axis by 10,15,20,25 and 30 cm to the right side (+X) and then to the left side (-X) For each distance the count rate was recorded and also the integral and differential uniformity were calculated.

3) Test for intrinsic uniformity at different number of acquired counts: For testing this factor, the previous procedures were repeated but with varying the total acquired counts to be 10, 20, 30,40,50,60 and 70 million count/sec. For each acquired total counts the integral and differential uniformity were calculated.

4) Test for intrinsic uniformity at different volumes: In this test the volume of the used point source was varied to be 0.1,0.5, 1, 1.5, 2, 2.5 and 3ml.liter with the adjustment of the same previous procedures. For each volume the integral and differential uniformity were calculated.

5) Test for intrinsic uniformity at different matrix: The same procedures were followed for intrinsic uniformity testing, but the acquisition matrix size was varied to be 64x64, 128x128, 256x256, 512x512 and 1024x1024. For each matrix size the integral and differential uniformity were also calculated.

Data Analysis:

All data reported in the results were mean and (± SD). One way multivariate analysis of variance (MANOVA) was conducted to test the hypothesis that would be one or more mean differences between levels of different independent variables and the scores of uniformity percents. Series of post hoc analyses (Tukey) were performed to examine individual means differences comparison across all levels of each independent variable and four uniformity subscales. A value of $P < 0.05$ was considered statistically significant.

4. RESULTS

1) <u>Test for intrinsic uniformity at different distances from the center</u>

The intrinsic uniformity recorded at different distances of the point source from 20 to 220 cm at the center of the crystal, Post hoc Tukey's HSD tests on the results shown in table (1).

Table (1): The integral and differential uniformity in relation to different distances from the center.

Source Distance (cm)	CFOV Integral Uniformity%	CFOV Differential Uniformity%	UFOV Integral Uniformity%	UFOV Differential Uniformity%
20	3.33±0.279	1.723±0.152	4.943±0.232	1.977±0.13
40	1.97±0.102	1.467±0.031	3.223±0.298	1.776±0.0223
60	1.9±0.036	1.377±0.015	2.733±0.06	1.517±0.051
80	1.8±0.036	1.233±0.068	2.57±0.061	1.393±0.015
100	1.783±0.040	1.143±0.031	2.44±0.087	1.323±0.048
120	1.736±0.05	1.067±0.046	2.153±0.071	1.223±0.072
140	1.651±0.016	1.002±0.008	2.127±0.015	1.167±0.03
160	1.58±0.01	0.992±0.002	2.03±0.061	1.113±0.023
180	1.53±0.015	0.95±0.026	1.99±0.043	1.082±0.002
200	0.68±0.05	0.75±0.046	1.12±0.071	0.89±0.072
220	1.02±0.75	0.85±0.035	1.2±0.035	0.95±0.04

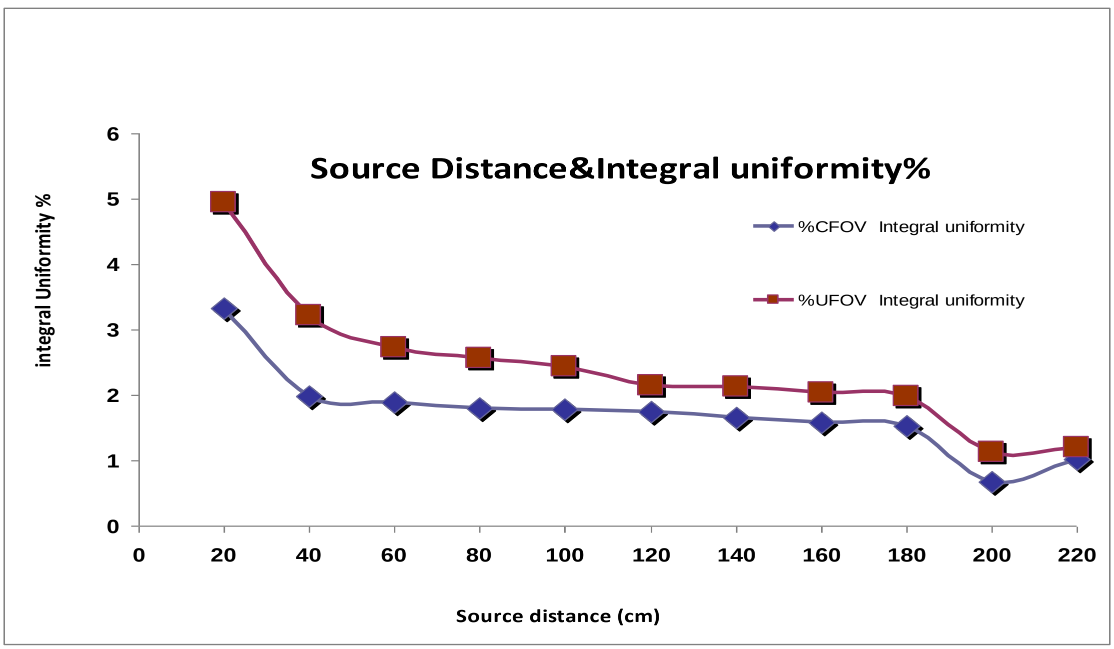

Figure (1) : The integral uniformity versus source to detector distance

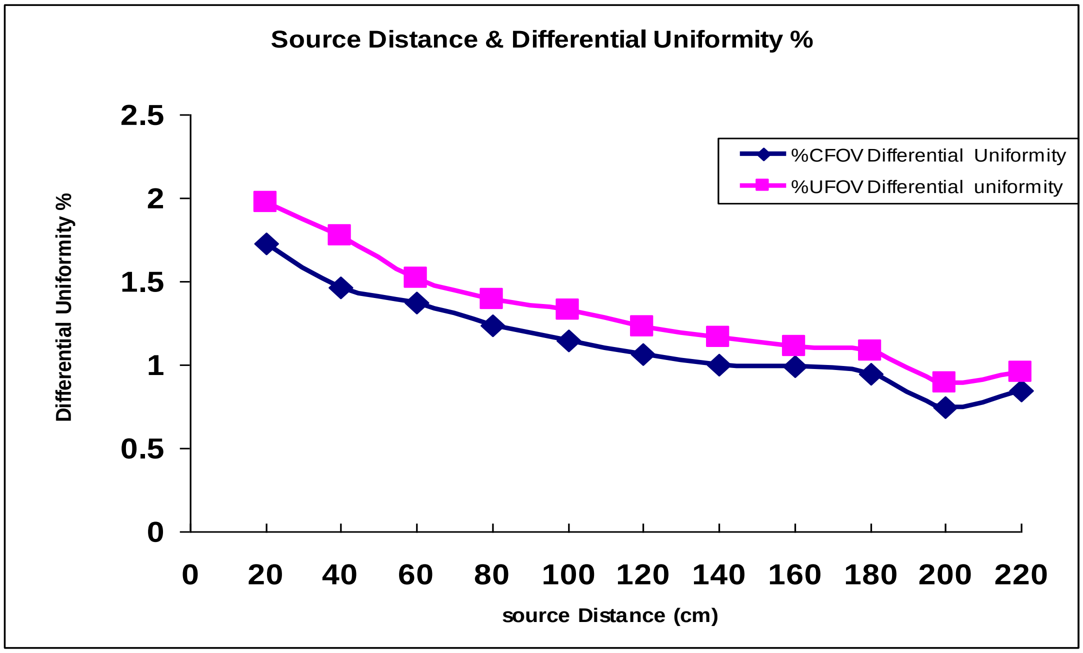

Figure (2): The differential uniformity versus source to camera distance

- The uniformity of the system improved with increasing the source to camera distance. Or by other means improving the flux of the gamma that reaches the crystal.

- MANOVA test was performed and revealed that there was a significant difference between different source distances and subscales of uniformity percents where Wilks' lambda was .0003; F value was 13.3, and $p < 0.05$.

- This indicates that there are significant differences between the results of intrinsic uniformity while changing the distance of the point source from the detector face which is minimum at 200 cm (best uniformity) and maximum at 20 cm (worst uniformity).

2) Test for intrinsic uniformity at different shifts from the center

- The intrinsic uniformity recorded at different shifts from the center from (-30) to (30) cm from the center of the crystal in the x axis , Post hoc Tukey's HSD tests on the results shown in table (2).

Table (2): The integral and differential uniformity in relation to different shifts from the center.

shift from the center (X axis)	UFOV Integral uniformity%	CFOV Integral uniformity %	UFOV differential uniformity%	CFOV differential uniformity%
-30	1.81±0.056	1.53±0.075	1.33±0.01	1.26±0.036
-25	1.7±0.05	1.4±0.03	1.29±0.035	1.2±0.065
-20	1.45±0.14	1.1±0.1	1.22±0.021	1.14±0.05
-15	1.21±0.075	0.79±0.12	1.17±0.01	1.03±0.108
-10	1.19±0.112	0.72±0.112	1±0.0218	0.9±0.1
0	1.12±0.0075	0.68±0.078	0.89±0.072	0.75±0.046
10	1.2±0.011	0.75±0.02	1.1±0.1	0.98±0.08
15	1.23±0.01	0.83±0.15	1.26±0.046	1.093±0.06
20	1.49±0.09	1.15±0.05	1.3±0.085	1.14±0.026
25	1.73±0.091	1.45±0.03	1.42±0.02	1.235±0.018
30	1.8±0.13	1.55±0.03	1.47±0.01	1.317±0.06

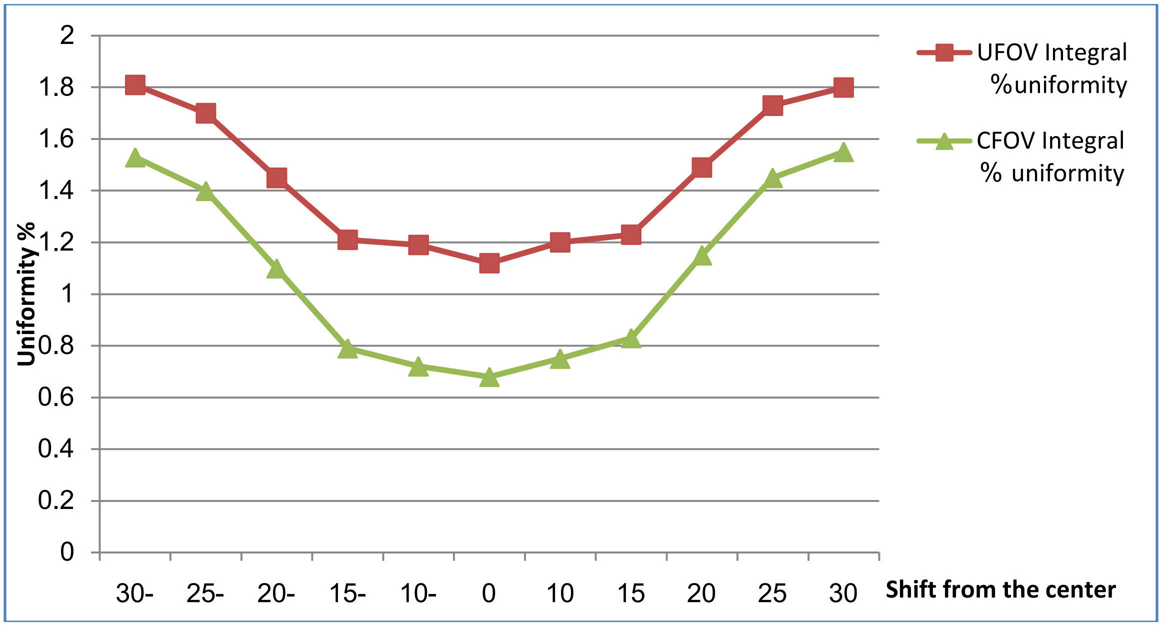

Figure (3): The integral uniformity versus the shift from the center.

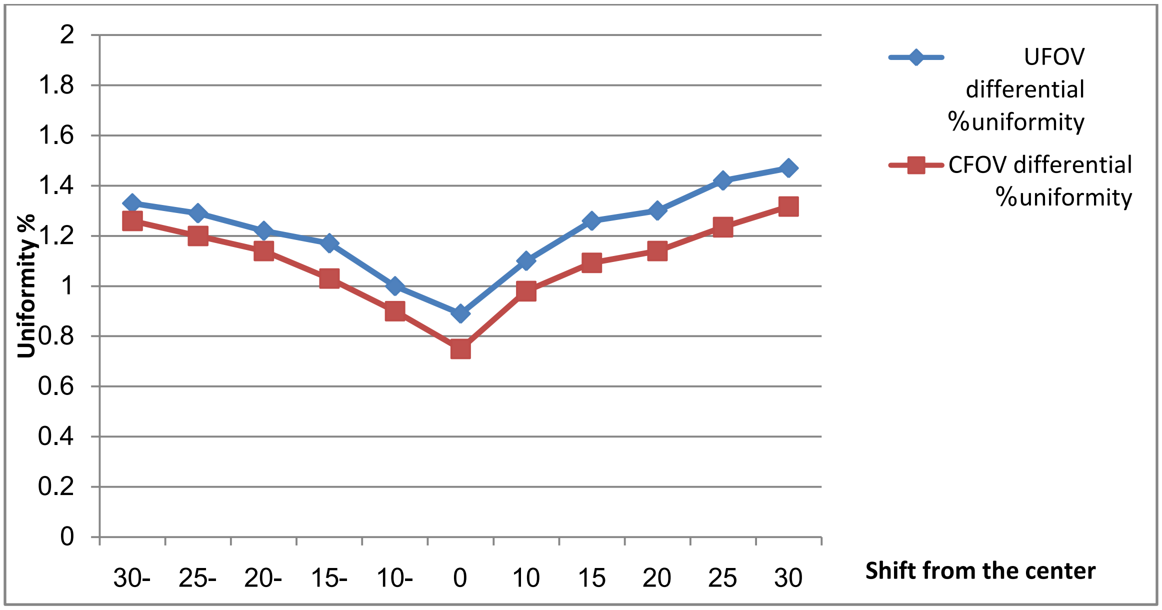

Figure (4): The differential uniformity versus the shift from the center.

- The uniformity of the system degraded with increasing the shift from the center in the x-axis, or by degrading the uniform flux of gamma that reaches the crystal.

- MANOVA test was performed and revealed that there was a significant difference between shifting from centre and subscales of uniformity percents where Wilks' lambda was 0.0002; F value was 15.260, and $p < 0.05$.

- This indicates that there are significant differences between the results of intrinsic uniformity while changing the position of the point source from the center of the detector face in the x- axis, which is minimum at the center (best uniformity) and maximum at 30 and -30 cm (worst uniformity).

3) Test for intrinsic uniformity at different number of acquired count.

-The intrinsic uniformity recorded at different number of acquired Counts from 10 M to 70 M, Post-hoc Tukey's HSD tests on the results is seen in table (3) .

Table (3): The integral and differential uniformity in relation to different number of acquired counts.

Reading Million Count	CFOV Average Integral Uniformity%	UFOV Average Integral Uniformity%	CFOV Average Differential Uniformity%	UFOV Average Differential Uniformity%
10	4.283±0.231	5.85±0.219	2.403±0.424	2,416±0.123
20	2.343±0.030	2.723±0.060	1.55±0.061	2.006±0.025
30	0.68±0.05	1.12±0.046	0.75±0.07	0.89±0.072
40	2±0.075	2.42±0.040	1.1±0.153	1.38±0.056
50	1.836±0.045	2.516±0.025	1.093±0.123	1.14±0.062
60	1.683±0.040	2.12±0.06	0.993±0.065	1.223±0.23
70	1.79±0.062	2.23±0.055	1.037±0.08	1.223±0.095

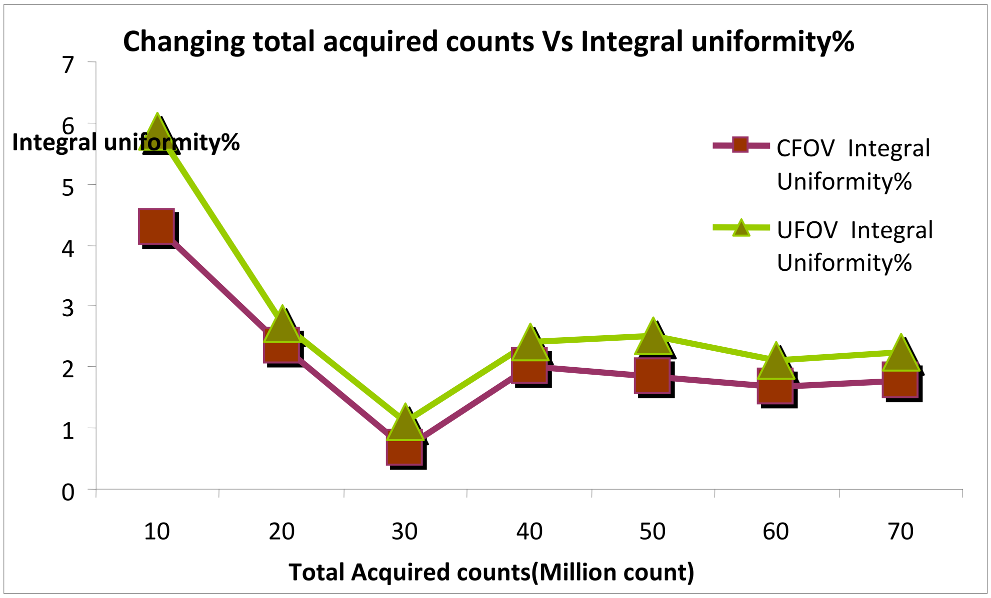

Figure (5): The integral uniformity versus the number of acquired counts.

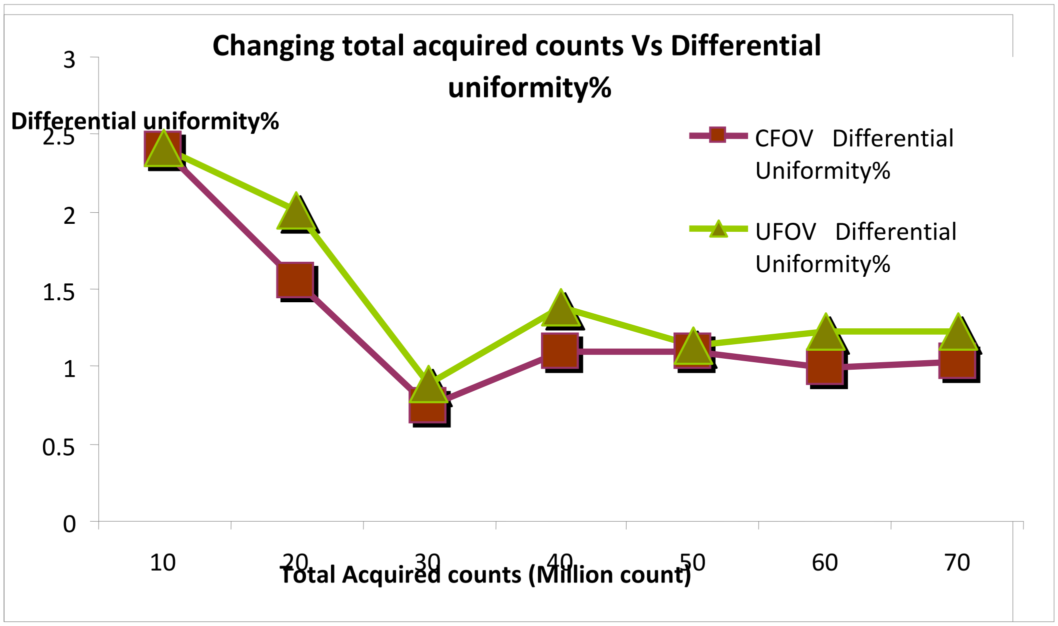

Figure (6): The differential uniformity versus the number of acquired counts.

- The uniformity of the system improved with increasing the number of acquired counts but increasing after 60 M count the uniformity degraded.

- MANOVA test was performed and revealed that there was a significant difference between total count rate and subscales of uniformity percents where Wilks' lambda was 0.003; F value was 30.410, and $p < 0.05$.

- This indicates that there are significant differences between the results of intrinsic uniformity while changing the number of acquired counts used to perform the test, which is minimum at 30 M counts (best uniformity) and maximum at 10 M counts (worst uniformity).

4) Test for intrinsic uniformity at different volume

-The intrinsic uniformity recorded at different volume from 0.1 to3 ml, Post- hoc Tukey's HSD tests on the results is listed in table (4).

Table (4): the integral and differential uniformity in relation to different point source volume

volume(ml)	CFOV Integral Uniformity%	UFOV Integral Uniformity%	CFOV Differential Uniformity%	UFOV Differential Uniformity%
0.1	0.68±0.03	1.12±0.07	0.75±0.046	0.89±0.072
0.5	1.9±0.09	2±0.17	1.13±0.15	1.2±0.1
1	1.873±0.068	2.097±0.058	1.247±0.178	1.4±0.017
1.5	1.753±0.076	2.147±0.126	1.253±0.058	1.38±0.103
2	1.687±0.065	2.03±0.18	1.147±0.05	1.403±0.104
2.5	1.677±0.15	2.217±0.23	1.157±0.03	1.423±0.3
3	1.937±0.13	2.493±0.27	1.263±0.12	1.43±0.119

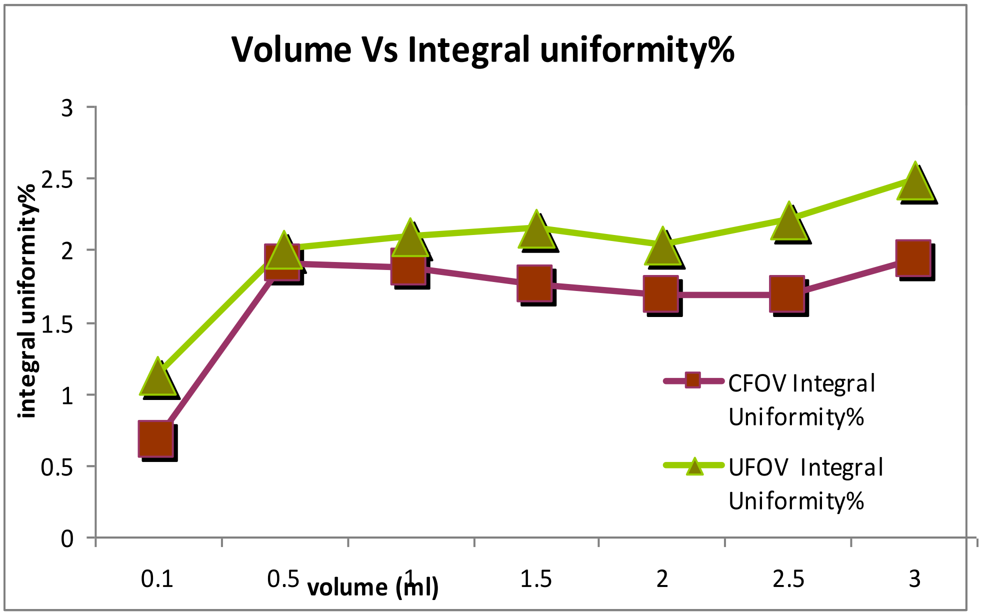

Figure (7): The integral uniformity versus the volume.

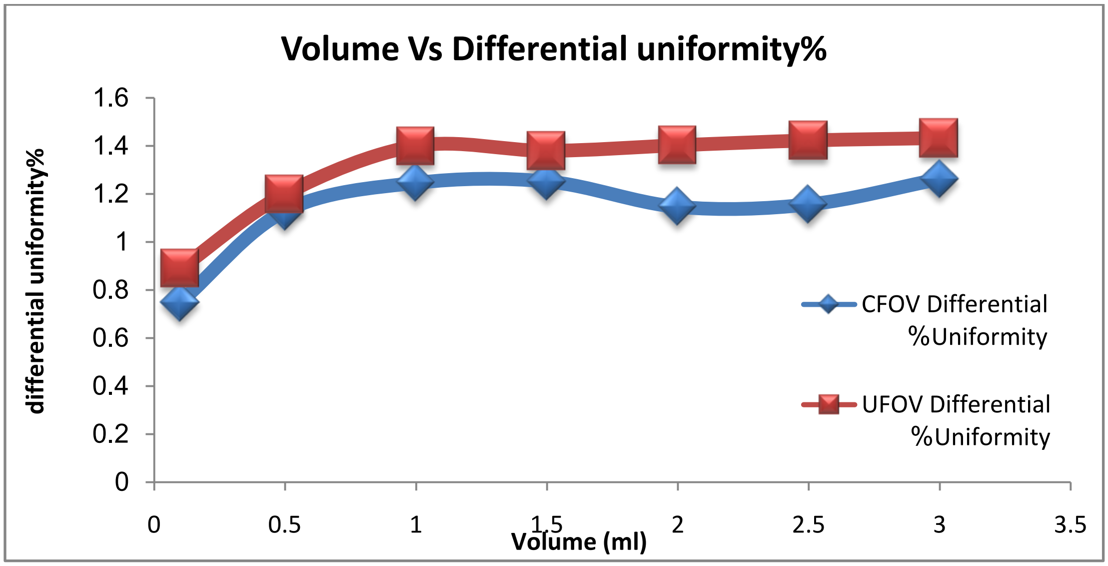

Figure (8): The differential uniformity versus the volume.

- MANOVA test was performed and revealed that there was a significant difference between volume and subscales of uniformity percents where Wilks' lambda was .004; F value was 6.416, and $p < 0.05$.

- This indicates that there are significant differences between the results of intrinsic uniformity while changing the point source volume, which is minimum at 0.1 ml (best uniformity) and maximum at 3 ml (worst uniformity).

5) Test for intrinsic uniformity at different matrix size

- The intrinsic uniformity recorded at different matrix size from 64x64 to1024x1024 , Post hoc Tukey's HSD tests on the results shown in table (6).

Table (5): The integral and differential uniformity in relation to different matrix size.

matrix size	UFOV Integral uniformity%	CFOV Integral uniformity%	UFOV differential uniformity%	CFOV differential uniformity%
64X64	1.74±0.065	1±0.125	1.58±0.105	1.58±0.105
128X128	1.5±0.1	0.85±0.06	1.19±0.0325	1.19±0.0325
256X256	1.62±0.11	1.12±0.068	1.18±0.035	1.18±0.035
512X512	1.12±0.071	0.68±0.05	0.89±0.072	0.89±0.072
1024X1024	1.23±0.153	0.899±0.078	1±0.314	1±0.314

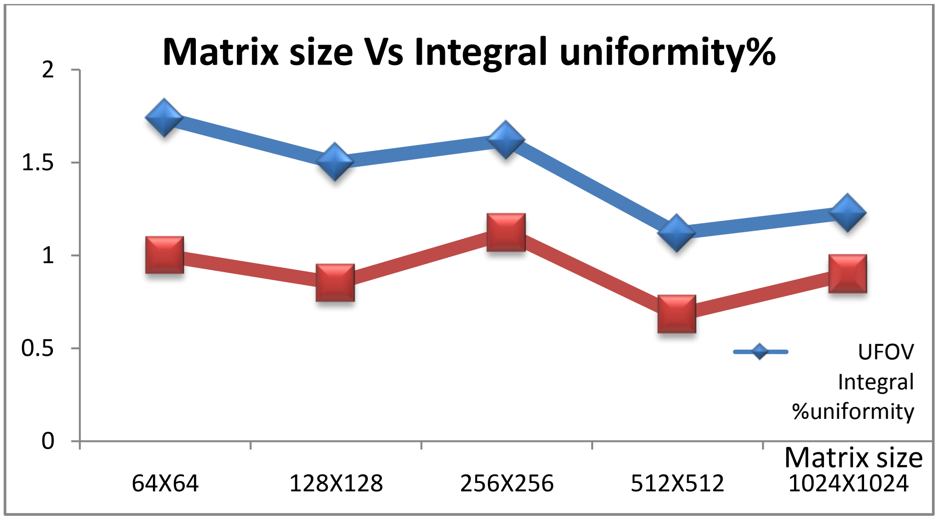

Figure (9): The integral uniformity versus the matrix size.

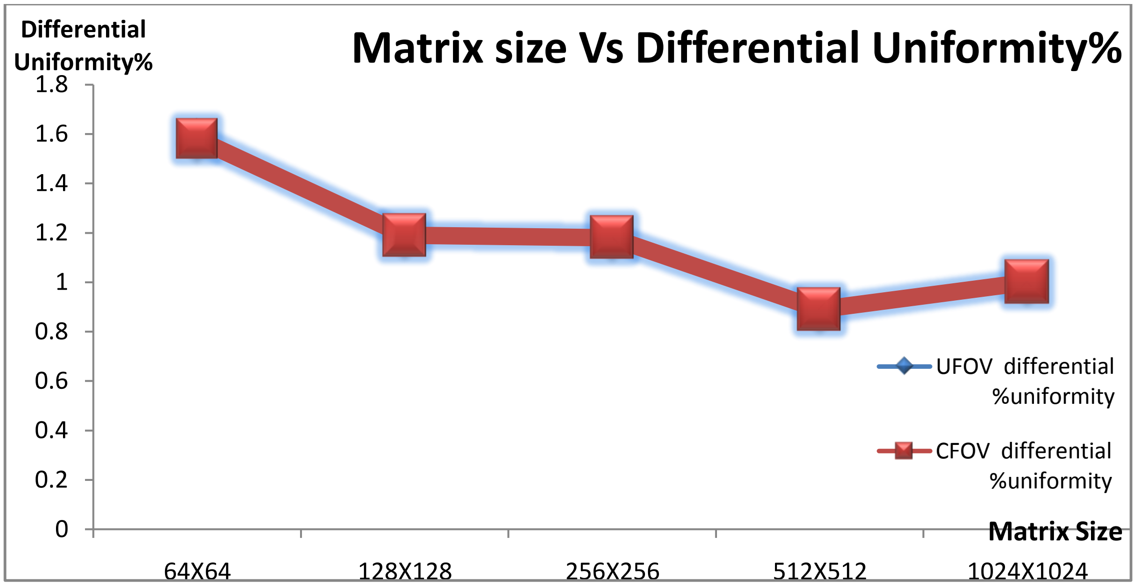

Figure (10): The differential uniformity versus the matrix size.

- MANOVA test was performed and revealed that there was a significant difference between matrix size and subscales of uniformity percents where Wilks' lambda was .006; F value was 10.776, and $p < 0.05$.

- This indicates that there are significant differences between the results of intrinsic uniformity while changing the matrix size, which was minimum at 512 X 512 (best uniformity) and maximum at 64X64 (worst uniformity).

5. DISCUSSIONS

The purpose of quality control (QC) is to detect changes in the performance of a gamma camera system that may adversely affect the interpretation of clinical studies. Clearly, there are a large number of factors that contribute to the final image quality, including uniformity, resolution (both intrinsic and energy), collimation and the hardcopy device. In the present study, different physical factors such as matrix size, total acquired counts and the point source volume. And also geometrical factors such as point source distance from the detector face and the position of the point source in relation to the detector face were studied to evaluate the effect of these factors on the intrinsic uniformity of the gamma camera.

Firstly, the intrinsic uniformity was measured while changing in the distance from the detector face. *Abdelhamid A. Elkamhawy,2000 [3]* found that the integral uniformity of the system improved as the source to camera distance increased by improving the uniformity of the gamma flux reaching the crystal . Ten feet was the maximum distance he could measure. *Sulieman M. S. Zobly, 2010 [7]* found that the integral and differential uniformity of the system improved in source to camera distance in between 95,105 cm. *NEMA ,1994 [2],* stated that the integral and differential uniformity as the source to camera distance increased at 5 times UFOV. These results are matching the result in the present study in which we found that the integral and the differential uniformity improved at a distance 5 times the diameter of the crystal 200 cm.

It was found that the integral and the intrinsic uniformity was improved at the center of the crystal, for both integral and differential uniformity while changing the distance from the center of the detector face in the x- axis.

The intrinsic uniformity parameter was measured against the change of number of acquire count. *E. A. I. Elbeshir;2006[8]* , found that: $4x10^6$ (4 M) counts per image were found to be the lowest number of counts required to define the non- stochastic response of the gamma camera used. *Abdelhamid A. Elkamhawy,2000 [3]* found that The intrinsic flood-field uniformity improved as the number of acquired counts for the flood-field image increased. by increasing the number of acquired counts, the IU improved because there were fewer statistical fluctuations. However, the incremental gain in IU from 30–60 M was minimal.

These results are matching the results in the present study in which we found that the integral and the differential uniformity improved as the number of acquired counts for the flood-field image increased till 60 M counts after which the intrinsic uniformity starts to degrade due to the dead time effect of the crystal [5].

The intrinsic uniformity was measured while changing the source volume. *Abdelhamid A. Elkamhawy, 2000 [3]* found that the integral uniformity of the system slightly degraded as the source volume increased. For source volume up to 0.3ml, the integral uniformity is almost constant (~1.5%). *Sulieman M. S. Zobly,2010 [7]* found that the integral and differential uniformity of the system is constant for the volume between 0.1 and 0.4 ml, then change when volume increased. These results are matching the result in the present study in which it was found that the integral and the differential uniformity improved at the volume of point source from (0.1 to 0.5 ml).

The intrinsic uniformity was measured while changing the matrix size. *Klingensmith et al.[9], Sorensen and Phelps [5]* and *Early and Sodee [10]* suggested that 64 x 64 x 16 matrix size (in which the cardiac SPECT studies are usually performed), whereas one manufacturer *[11]* suggests 512 x 512 x 16 and the *American Society of Nuclear Cardiology [12]* suggested 256 x 256 matrix. *NEMA protocol [2]* suggests image matrix size, which produces pixel sizes with linear dimension of 6.4 mm ±30% (this corresponds to 64 x 64 matrix for large FOV cameras). It is important to ensure that uniformity is acceptable for all clinically used matrix sizes.

NEMA protocol [2], was found to be matching with the present study, that the integral and the differential uniformity improved at the matrix size 512x512, for both the integral and differential uniformity.

6. CONCLUSIONS

Performing the intrinsic uniformity requires special attention to the physical and geometrical adjustments, these adjustments depend on different factors. There were significant differences between the results for each studied factor that indicates that there is an optimum value that should be used in each test that gives the best integral and differential uniformity, deviation from this value lead to deterioration of the integral and differential uniformity as well, which in turn will affect the clinical image. Our results showed that the best intrinsic uniformity results were found at 200 cm point source to detector face distance, the source position from the center of the detector face in the x- axis should be at the center (zero shift), the total number of acquired counts during the test should be from 30-60 M count and gives the best results at 30 M counts, the point source volume should be from 0.1 to 0.5 ml and the matrix size used in the acquisition protocol should be adjusted with 512X512 matrix. Also there are acceptable limits by which the results of the test could be accepted for each factor studied according to the NEMA specifications of the studied (Philips, Forte) gamma camera.

REFERENCES

[1]. (Development of NEMA-based Software for Gamma Camera Quality Control) Andrew Rova, Anna Celler, and Ghassan Hamarneh, Journal of Digital Imaging, Vol 21, No 2 (June), 2008: pp 243Y255

[2]. National Electrical Manufacturers Association: NEMA NU 1-2001: Performance measurements of scintillation cameras. http://www.nema.org/stds/nu1.cfm. Rosslyn: National Electrical Manufacturers Association, 2001

[3]. Abdelhamid A. Elkamhawy, Joseph R. Rothenbach, Srikanth Damaraju, and M. Badruddin. J Nucl Med Technol 28:252-256:2000.

[4]. Groch M, Erwin WD: Single-photon emission computed tomography in the year 2001: instrumentation and quality control. J Nucl Med Technol 29:9Y15, 2001

[5]. Sorenson JA, Phelps ME, Physics in Nuclear Medicine. 2nd ed. Philadelphia, PA; W.B. Saunders Co.; 252-259, 387-390:1987.

[6]. International Atomic Energy Agency [IAEA] (Quality control of nuclear medicine instruments) pub. No. IAEA-TECDOC-602 Vienna, Austria.143: 1991.

[7]. S. S. Zobly & A. Osman : Parameters Affecting on Intrinsic Uniformity Test For MEDISO. The Internet Journal of Nuclear Medicine. 2010 Volume (5) Number (2)

[8]. E. A. I. Elbeshir & A. M. G. Bari : Effect of Counts per Image on the Gamma Camera Uniformity . The Internet Journal of Medical Technology. 2006 Volume (3) Number (2).

[9]. Klingensmith III WC, Eshima D, Goddard J. Nuclear Medicine Procedure Manual. Ingelwood, CA: Wick Publishing; 1998:17-1–18-1

[10]. Early PJ, Sodee DB. Principles and Practice of Nuclear Medicine. 2nd ed. St. Louis, MO: Mosby-Year Book, Inc.; 1995:261–273, 282–285

[11]. Pegasus X Reference Manual. ADAC P/N 9201-0159A. Rev. A. Milpitas, CA: ADAC; November 1995:2–505.

[12]. Garcia EV, ed. American Society of Nuclear Cardiology. Imaging guidelines for nuclear cardiology procedures. J Nucl Cardiol. 1996;3:G6–G8.