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The influence of acquisition parameters on the extrinsic uniformity on SPECT/CT gamma camera

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SUMMARY

Purpuse: The SPECT/CT gamma camera is the most commonly used imaging device in nuclear medicine. It is used to detect photons emanating from radioactive material. For its proper functioning, it is necessary to perform quality control tests regularly. One of the most important tests is extrinsic uniformity, which must be performed every day before starting work. We wanted to determine how extrinsic uniformity varies if we change the number of counts and the matrix size.

Methods: The measurements were carried out on SPECT/CT, where we placed a cobalt flood source between the two detectors. We used the protocol for uniformity where we used the different number of counts (3 million, 4.5 million, and 10 million) and different matrix sizes. Uniformity was calculated with the IAEA application in the program Image.

Results: The uniformity values are improved if we increase the number of counts ($p<0.01$). In most cases was determined that the matrix size does not affect uniformity ($p>0.01$). An exception was shown at integral uniformity with the useful field of view on detector one ($p<0.01$) and detector two ($p<0.01$).

Conclusion: By increasing the number of counts, the uniformity of the detector system improves. The matrix size does not have a significant effect on the uniformity of the detector system.

Key words: uniformity, extrinsic test, gamma camera, matrix size, number of counts, quality control

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INTRODUCTION

The uniformity of a gamma camera is the ability to demonstrate the exact distribution of radioactive origin over a given area. Distribution of radioactivity is most easily achieved by uniform irradiation of the crystal in a gamma camera that can be verified daily by intrinsic or extrinsic uniformity tests [1,2]. Uniformity can be measured qualitatively by visual inspection or quantitatively by calculating integral and differential uniformity within the detector's Central Field of View (CFOV) and Useful Field of View (UFOV). The sensitivity of the detector system is calculated as the number of counts per unit of activity in megabecquerel (cps/MBq) of the imaged radioactive source [3-6].

The main cause of the appearance of artefacts in the image in a gamma camera is non-uniformity [7]. Non-uniformity can occur due to the crystal damage caused by impact or large fluctuations in room temperature and humidity, instability of photomultipliers, or energy window offset [8]. The energy window may be offset because the 57Co-Cobalt (57Co) adjusted window (photopeak at 122 keV) uses the 99mTc-Technetium (99mTc) adjusted window (photopeak at 140 keV) that may have been used in the previous test. Despite an incorrectly set window, a sufficient number of events are produced to create the image, but the duration is greatly extended [9,10]. It can also be affected by the matrix size when the matrix size changes from smaller to larger by more than 30%, as this smooths the number of events per image element [8]. Uniformity can be measured as CFOV or UFOV in two ways, integrally and differentially. CFOV represents 75% of UFOV [11]. Integral uniformity is defined as the maximum variation (maximum/minimum) of counts throughout the entire field of view [7,12] The maximum is the largest number of counts, and the minimum is the smallest number of counts in the pixel located anywhere in the field of view [13,14]. Differential uniformity is a regional parameter that measures contrast in a small number of neighbours (where there is the greatest change in uniformity). The measurement takes five image elements in the x and y directions within the CFOV and UFOV. The program itself automatically determines the largest change in uniformity by verifying the values of the first five pixels, then moving one pixel forward and analyzing the next set [7,13].

Our research aimed to determine how the different number of counts, the matrix size, and their interaction affect the uniformity of the detector system. The analysis was determined for integral and differential uniformity in each detector's useful and central field of view separately.

MATERIALS AND METHODS

An extrinsic uniformity test was performed with 57Co flood source at SPECT/CT, (Siemens Symbia T2 series) at the Department of Nuclear Medicine, Ljubljana. SPECT CT consists of a double-headed gamma camera and a two-slice spiral CT.

The gamma camera detector consists of a sodium iodide crystal (dimension 59.1 × 44.5 cm and 9.5 mm thick) and 59 photomultipliers. Since this is an extrinsic test, we coated the 57Co flood source with a LEHR (Low Energy High Resolution) collimator.

The measurements were performed by placing the camera in the home position. The camera position allowed us to keep the camera always in the same position, so the measurements are comparable. The two detectors were then brought as close together as possible, and a 57Co flood source was placed between the detectors. We used a 57Co flood source (FeatherLite), model MED 3709, size 683 mm × 454 mm, and its active size 610 mm × 419 mm. The initial cobalt activity in the flood was 555 MBq. The 57Co flood source allows a homogeneous radiation field to be used to evaluate the performance of the gamma camera. The typical lifespan of a 57Co board is about two years.

ACQUISITION PROTOCOL

We selected the appropriate protocol on the acquisition computer, changing the number of counts and the matrix size. We started the measurements by collecting 3 million counts per image at all matrix sizes (1024 × 1024, 512 × 512, 256 × 256, and 128 × 128). Then we collected 4.5 million counts per image and finally another 10 million counts per image at all of the previously listed matrix sizes. Thus, we collected ten measurements for each variable.

IMAGE ANALYSES

The standard protocol for performing the measurements is already automatically set in the protocol and recommends to collect 10 million counts per image at a matrix size of 1024 × 1024. If the camera works correctly, the uniformity values should be within the tolerances listed in Table1 [15]. The more inhomogeneity is the image; the worse is uniformity, the higher the error rate. Moreover, if these deviation values exceed the allowable limit, it is necessary to verify the settings and, if necessary, calibrate the detector.

However, because we changed the conditions for the measurements, we used the program in ImageJ, developed by the IAEA (2017), to calculate the uniformity.

The IAEA has followed NEMA standards, which say it is necessary to collect at least 10,000 counts in a pixel located in the centre of the image. This image must then be converted into a matrix such that the pixel size is 6.4 ± 30% mm. It defines two standards for quantification: integral uniformity and differential uniformity [16].

If the pixel size is out of limits, an automatic change of the matrix size is performed (summation method). The program also automatically determines the field of view for any detector's shape and then smoothers the obtained image. It then changes the value of the pixels to zero if they are located outside the CFOV or UFOV, if they are located at the edge of the image, and if at least one of the directly adjacent pixels does not detect any counts. The program determines the UFOV by capturing 98% of the image dimension. The CFOV is a rectangle covering 75% of the dimension of the usable field of view. The program then automatically calculates the integral and differential uniformity for each region of interest (ROI), i.e., CFOVs and UFOVs.

The image also indicates pixels with a maximum and minimum value. The integral and differential uniformity, average and minimum, and maximum value of pixels, are displayed in addition to the image. The image also indicates the UFOV and CFOV (Figure 1)

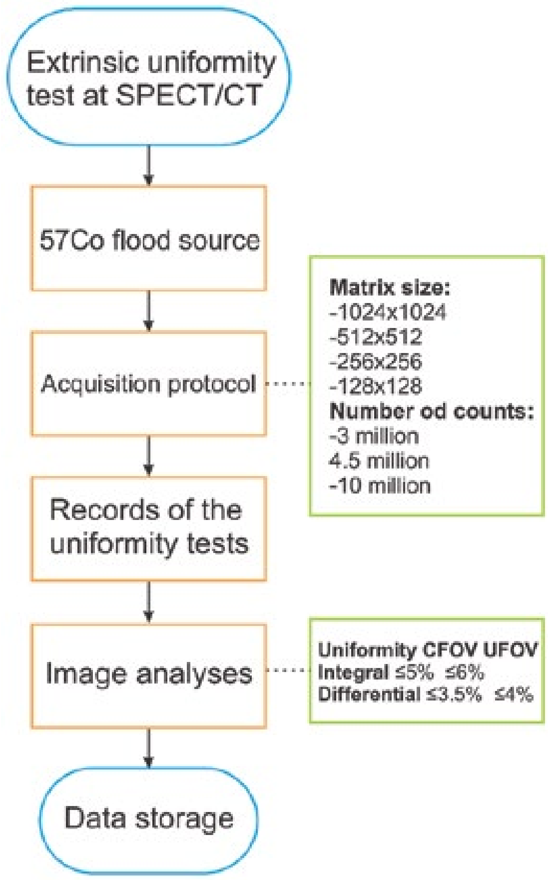

Fig. 1. Flowchart illustrating procedure for extrinsic uniformity test

Tab.1. The permissible tolerances for the extrinsic uniformity test (15)

Uniformity	CFOV	UFOV
Integral	≤ 5 %	≤ 6 %
Differential	≤ 3.5 %	≤ 4 %

STATISTICAL ANALYSIS

The obtained data were statistically processed with SPSS, namely with two-way ANOVA. With SPSS, we verify if the number of counts and the matrix size and their combination affect the image's uniformity. We verified for the CFOV and UFOV separately and separated the data according to the type of detector. With the normality test, we have determined the normality of data distribution. Nevertheless, we performed statistics with a two-way ANOVA and reduced the significant limit from 0.05 to 0.01. With this, we have reached a stricter limit, which means that only what makes significant differences will be significant. In addition, we performed a Post-Hoc analysis to verify which levels were statistically significantly different from the others.

RESULTS

Tables 2 and 3 show the results, which were described as mean and standard deviation. We obtained them by measurements

Tab.2. Measurement results, which were obtained on detector 1. They are described as mean and standard deviation

Number of kilo counts (kcnt) in field of view		Matrix size			
		1024 × 1024	512 × 512	256 × 256	128 × 128
10 000	CFOV integral	(N=10) 5.154 ± 0.131	(N=10) 5.012 ± 0.265	(N=10) 5.161 ± 0.351	(N=10) 5.149 ± 0.285
	CFOV differential	(N=10) 3.553 ± 0.175	(N=10) 3.635 ± 0.318	(N=10) 3.580 ± 0.199	(N=10) 3.570 ± 0.236
	UFOV integral	(N=10) 6.053 ± 0.355	(N=10) 5.979 ± 0.276	(N=10) 5.933 ± 0.320	(N=10) 6.086 ± 0.546
	UFOV differential	(N=10) 3.929 ± 0.412	(N=10) 3..700 ± 0.261	(N=10) 3.665 ± 0.176	(N=10) 3.722 ± 0.316
4 500	CFOV integral	(N=10) 6.750 ± 0.348	(N=10) 6.571 ± 0.434	(N=10) 6.731 ± 0.361	(N=10) 6.662 ± 0.327
	CFOV differential	(N=10) 4.722 ± 0.208	(N=10) 4.880 ± 0.633	(N=10) 4.772 ± 0.325	(N=10) 5.073 ± 0.385
	UFOV integral	(N=10) 8.112 ± 0.539	(N=10) 7.267 ± 0.488	(N=10) 7.622 ± 0.761	(N=10) 7.423 ± 0.319
	UFOV differential	(N=10) 5.173 ± 0.209	(N=10) 5.173 ± 0.595	(N=10) 5.205 ± 0.393	(N=10) 5.275 ± 0.415
3 000	CFOV integral	(N=10) 8.002 ± 0.345	(N=10) 7.699 ± 0.468	(N=10) 7.538 ± 0.342	(N=10) 8.203 ± 0.712
	CFOV differential	(N=10) 6.163 ± 0.503	(N=10) 5.954 ± 0.566	(N=10) 5.780 ± 0.323	(N=10) 5.967 ± 0.506
	UFOV integral	(N=8) 9.486 ± 0.431	(N=10) 8.727 ± 0.785	(N=9) 8.871 ± 0.717	(N=9) 8.761 ± 0.752
	UFOV differential	(N=8) 6.300 ± 0.330	(N=10) 6.375 ± 0.638	(N=9) 6.043 ± 0.508	(N=9) 6.143 ± 0.489

Tab.3. Measurement results, which were obtained on the detector 2. They are described as mean and standard deviation

Number of kilo counts (kcnt) in field of view		Matrix size			
		1024x1024	512x512	256x256	128x128
10 000	CFOV integral	(N=10) 5.058 ± 0.407	(N=10) 5.294 ± 0.332	(N=10) 5.405 ± 0.304	(N=10) 5.202 ± 0.237
	CFOV differential	(N=10) 3.490 ± 0.252	(N=10) 3.515 ± 0.397	(N=10) 3.554 ± 0.318	(N=10) 3.511 ± 0.161
	UFOV integral	(N=10) 6.525 ± 0.379	(N=10) 6.211 ± 0.309	(N=10) 6.447 ± 0.347	(N=10) 6.463 ± 0.352
	UFOV differential	(N=10) 3.674 ± 0.356	(N=10) 3.690 ± 0.306	(N=10) 3.653 ± 0.258	(N=10) 3.756 ± 0.316
4 500	CFOV integral	(N=10) 6.754 ± 0.578	(N=10) 6.613 ± 0.305	(N=10) 6.807 ± 0.581	(N=10) 6.809 ± 0.446
	CFOV differential	(N=10) 4.694 ± 0.294	(N=10) 4.910 ± 0.289	(N=10) 4.818 ± 0.377	(N=10) 4.770 ± 0.272
	UFOV integral	(N=10) 8.414 ± 0.509	(N=10) 7.947 ± 0.615	(N=10) 7.734 ± 0.614	(N=10) 8.005 ± 0.503
	UFOV differential	(N=10) 4.987 ± 0.330	(N=10) 5.213 ± 0.286	(N=10) 4.889 ± 0.368	(N=10) 4.889 ± 0.223
3 000	CFOV integral	(N=10) 8.241 ± 0.881	(N=10) 7.845 ± 0.501	(N=10) 8.153 ± 0.438	(N=10) 7.894 ± 0.482
	CFOV differential	(N=10) 5.787 ± 0.313	(N=10) 6.023 ± 0.271	(N=10) 5.994 ± 0.698	(N=10) 5.844 ± 0.714
	UFOV integral	(N=9) 10.020 ±0.593	(N=10) 8.836 ± 0.588	(N=9) 9.330 ± 0.748	(N=9) 8.828 ± 0.493
	UFOV differential	(N=9) 6.166 ± 0.387	(N=10) 6.271 ± 0.534	(N=9) 6.179 ± 0.592	(N=9) 6.219 ± 0.745

on a gamma camera and then processed them using the ImageJ program. The results are shown for each detector (detector 1 and detector 2) separately.

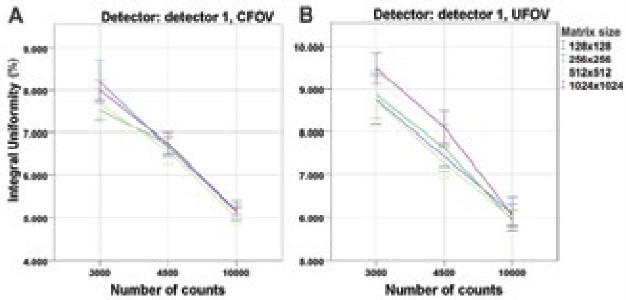

Fig. 2. Differential uniformity expressed in percent at the CFOV (A) and UFOV (B) on detector 1, (In according to oar guideline)

Figure 2 (A) shows the lower deviation in integral uniformity with an increasing number of counts per image. Such results can be expected since the larger the number of counts we have, the better the uniformity and, consequently, the smaller the deviation. Minor differences between the different matrix size are also noticeable at lower counts values. After all, the longer we collect data, the more information we obtain and, consequently, there is less statistical variability.

With ANOVA, we found that the integral uniformity at the central field of view on detector 1 is affected only by the number of counts (F 504.398; p <0.01). While the matrix size (F=2.819; p=0.042) and the interaction between the number of counts and the matrix size (F=1.947; p=0.080) do not affect the integral uniformity. For more detailed findings, we also performed a Post-Hoc analysis. We found that there were statistically significant differences between all three values (p<0.01).

Figure 2 (B) shows the lower deviation in integral uniformity with an increasing number of counts per image. However, the differences between the different matrix size themselves are also visible. Namely, matrix size 1024 × 1024 differs the most from other matrix sizes.

With ANOVA, we found that the number of counts (F=270.271; p<0.01) and the matrix size (F=5.605; p<0.01) affect the integral uniformity in the UFOV. While the interaction between them is not affected (F=1.338; p=0.247). We also performed a Post-Hoc analysis, where we found statistically significant differences in the number of counts between all three values (p<0.01). In terms of matrix size, we found no significant differences between them (p>0.01), although ANOVA showed us that the matrix size affects the uniformity of the image. The discrepancy probably occurred because we looked at a p-value of 0.01 instead of 0.05. However, there was an almost statistically significant difference between the two matrix sizes, namely between a matrix of size 512 × 512 and a matrix of size 1024 × 1024, where the p-value was equal to p=0.015.

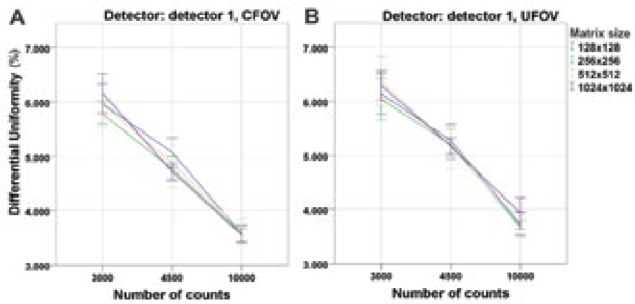

Fig. 3. Differential uniformity expressed in percent at the CFOV (A) and UFOV (B) on detector 1

Figure 3 (A) shows the lower deviation in differential uniformity with an increasing number of counts at the CFOV. However, there are also minimal differences in uniformity at different matrix sizes, which can be neglected.

With ANOVA, we found that the number of counts affects the integral uniformity at the CFOV (F=330.468; p<0.01). However, the matrix size does not affect the uniformity (F=0.965; p=0.412). Also, the interaction between the number of counts and the matrix size does not affect the integral uniformity of the image (F=0.944; p=0.467). Post-Hoc analysis revealed statistically significant differences in the number of counts between all three values (p<0.01).

Figure 3 (B) shows the lower deviation in differential uniformity with the increasing number of counts at the UFOV. However, no significant differences are observed between the matrix size. Even the most minor differences are noticeable at 4.5 million counts.

With ANOVA, we found that the number of counts affects the differential uniformity of the image at the UFOV (F 332.413; p<0.01). While the matrix size (F=0.764; p=0.517) and the interaction between the number of counts and the matrix size (F=0.698; p=0.652) do not affect the uniformity. In the Post-Hoc analysis, we found statistically significant differences between all three values (p<0.01).

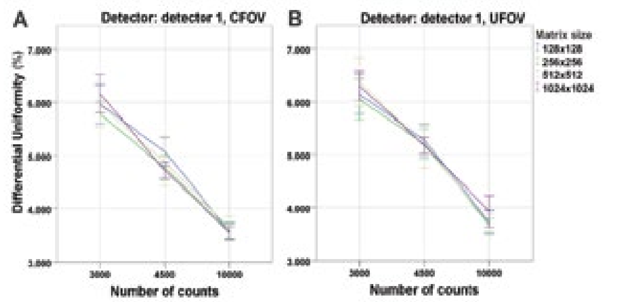

Fig. 4. Integral uniformity expressed in percent at the CFOV (A) and UFOV (B) on the detector 2

Figure 4 (A) shows that the lower deviation in integral uniformity decreases with increasing counts per image. There are also minimal differences in uniformity in different matrix size, which can be neglected.

With ANOVA, we found that the number of counts affects the integral uniformity at the central field of view (F=330.468; p<0.01). However, the matrix size does not affect the uniformity (F=0.965; p=0.412). Also, the interaction between the number of counts and matrix size does not affect the integral uniformity of the image (F=0.944; p=0.467). Post-Hoc analysis revealed statistically significant differences in the number of counts between all three values (p<0.01).

Figure 4 (B) shows the lower deviation in integral uniformity with an increasing number of counts per image. The difference in uniformity is also observed when comparing different matrix sizes. It is most apparent at lower counts values.

With ANOVA, we found that the number of counts (F=292.819; p<0.01) and the matrix size (F=9.207; p<0.01) affect the integral uniformity in the UFOV. While the interaction between them is not affected (F=2.892; p=0.012). Post-Hoc analysis revealed statistically significant differences in the number of counts between all three values (p<0.01). When comparing different matrix size, we also found that there are statistically significant differences between them. The 1024 × 1024 matrix size differs statistically significantly from the matrix size 128 × 128 (p < 0.01), 256 × 256 (p < 0.01) and 512 × 512 (p < 0.01).

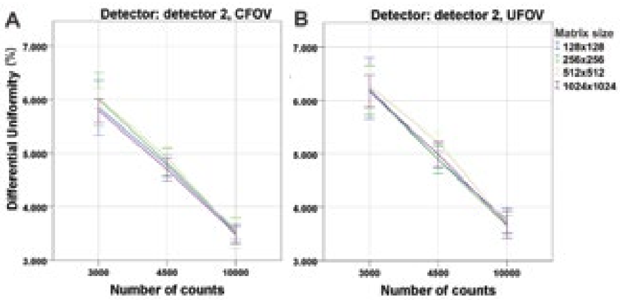

Fig. 5. Differential uniformity expressed in percent at the CFOV (A) and UFOV (B) on detector 2

Figure 5 (A) shows the lower deviation in differential uniformity with an increasing number of counts at the CFOV. The difference in uniformity between the maximum and a minimum number of counts is as much as 3 percent. However, the matrix size does not affect the uniformity, as there are minimal differences between them.

The findings were also verified with ANOVA, which found that the number of counts affects the differential uniformity in the CFOV (F= 362.221; p < 0.01). The matrix size (F=1,004; p=0.394) and the interaction between the number of counts and the matrix size (F= 0.188; p=0.980) do not affect the uniformity of the image. Post-Hoc analysis revealed statistically significant differences in the number of counts between all three values (p < 0.01).

Figure 5 (B) shows the lower deviation in differential uniformity with increasing counts at the UFOV. Different matrix sizes do not affect uniformity, as there are minimal differences between them.

We also verified the findings with the ANOVA test, where we found that the number of counts affects the uniformity of the image in the usable field of view (F=357.062; p < 0.01). While the matrix size (F=0.730; p 0.536) and the interaction between the number of counts and the matrix size (F 0.437; p=0.853) do not affect the uniformity. Post-Hoc analysis revealed statistically significant differences in the number of counts between all three values (p<0.01).

DISCUSSION

In our research, we wanted to confirm whether the number of counts and matrix size affects the uniformity of the image. First, we verified the influence of the number of counts for integral and differential uniformity separately, namely in the UFOV and CFOV. We also separated the data according to the type of detector. With the ANOVA statistical method, we proved that the number of collected counts affects the integral and differential uniformity of the image in the UFOV and CFOV, both on detector 1 and detector 2. In all cases, the statistical characteristic (p-value) was less than 0.01, which means that there is no difference according to the null hypothesis, and it can thus be rejected. In addition to the p-value, we also observed the F-value, since the higher it is, the more significant the specific factor. The F-value was always between 270 and 500, which means that the number of counts strongly affects the uniformity of the image in the extrinsic test. If we compare the size of the field of view Field of View, we can find that the F-values are slightly higher at the CFOV. Such results may be due to more condensed data in the detector centre than at the periphery, where a smaller number of collected counts are obtained due to scattering. In addition, we performed a Post-Hoc analysis, which showed a significant difference in uniformity between all three values of the collected counts.

The larger the number of counts, the more data we have and the integral and differential uniformity. As Rahman et al. [17] and Elkamhawy et al. [18] have already said, the longer we collect data, the more information we obtain and, consequently, less statistical variability [17,18]. However, we found that the uniformity gradually deteriorated linearly with a smaller number of received counts. Elkamhawy et al. [18] wrote that uniformity greatly improved with increasing counts from 1 to 30 million, and between 30 and 60 million counts, uniformity still increased but minimally [18]. A similar conclusion was reached by Elbeshir and Bari [19], but they think that the uniformity increases markedly to 4 million counts, and then the uniformity changes minimally. The difference can be assumed to occur because the images captured only up to 16 million counts in the second case, meaning that the data range was smaller [19]. In our case, we did not have uniform differences between the collected number of counts, so our uniformity increased more than in those who observed one million counts each.

Given that some collected 60 million counts, others 16 million counts, and 10 million counts, this may be due to the use of a gamma camera from different manufacturers or the same manufacturer, only a different type of camera. After all, each manufacturer has its protocols that we must follow to get optimal results. In addition, they did intrinsic uniformity tests, where 20 million counts are collected with our gamma camera.

We also investigated how the matrix size affects the uniformity of the image in the extrinsic test. We calculated integral and differential uniformity in the CFOV and UFOV separately for detector 1 and detector 2. We used the ANOVA statistical method and found that the matrix size did not affect image uniformity in most cases. The deviation occurred only in the case of integral uniformity, where the UFOV was considered. The values deviated from both detectors. Rahman et al. [18] and Elkamhawy et al. [18] explained in their research that matrix size does not affect image uniformity in an intrinsic test. In the study, approximately equal values of uniformity were obtained, regardless of the matrix size [17, 18].

The advantage of a larger number of counts is the better uniformity of the detector system, reducing the statistical variability. In our case, we captured 3 to 10 million counts per image and found that increasing the number of counts improves the uniformity of the detector system. We also proved this statistically using ANOVA in the SPSS program, where a statistically significant difference between the captured counts was given. As for the influence of the matrix size on the uniformity of the image, we found and proved with the same test that the matrix size does not affect the uniformity of the image. Such results can be explained by the fact that no matter the pixel size, the counts still fall to the same surface size, representing the size of the detector.

Limitations are shown by the time use of the cobalt flood source. Due to the half-life of the 57Co isotope, the cobalt flood source needs to be replaced every one or two years because the isotope decay prolongs the data acquisition time. New cobalt flood source usually contains small amounts of 56Co and 58Co, which have a shorter half-life and emit gamma rays with higher energies (> 500 keV) than 57Co. For the first few months, this contamination will affect the operation of the gamma camera (unevenness will be visible in the images obtained) unless the measurements are performed with a medium-energy or high-energy collimator. If it is not possible to use another collimator, it is recommended to measure a greater distance.

CONCLUSION

Our study concluded that uniformity improves with an increase in the number of counts, reducing statistical variability. As for the influence of matrix size on image uniformity, we found and proved with the same test that matrix size does not affect image uniformity [20].

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