TEST OBJECTS AND METHODS FOR VISUAL ASSESSEMENT OF THE GAMMA CAMERA INTRINSIC RESOLUTION DURING QUALITY CONTROL

Trindev, P.

GAMMACHECK, Sofia, Bulgaria

Abstract - **The spatial resolution of a gamma camera may be measured either subjectively or objectively. Objective assessment of resolution are simple to perform and reproducible, but usually give an insight into part of the field, while subjective methods usually cover entire UFOV. A common approach is the visual evaluation of the image of a test pattern that involves recording the smallest features which can be seen on the image. Transmission test patterns have been developed over the years for a simultaneous evaluation of intrinsic resolution of the entire field.**

The present review paper discusses the capabilities of only those phantoms who, on visual inspection, assess resolution in a relatively short time and are suitable to today's cameras with rectangular detector and spatial resolution of 3.8 mm: four quadrant, Hine-Duley, PLES, UB, BRH and LRP phantoms.

Subjective methods should give similar or at least close assessments of these from objective methods. The criteria to choose a particular set, the size of the step between adjacent sets (quadrants) and coefficient for quantification are discussed. A new phantom for visual examination of camera resolution is proposed.

Visual evaluation phantoms offer a convenient and quick way to test a GC performance, but in its current form are not suitable for acceptance or routine testing. Most of the phantoms for visual inspection has been developed almost 30 years ago for the assessment of GC performance of that time. Today's GC has significantly improved features that can't be accurately evaluated with old time phantoms. They need to be updated.

Keywords: **intrinsic resolution, subjective, quality control, phantom**,

INTRODUCTION

The gamma camera detector is a sophisticated complex of a large area scintillation crystal and several dozen PMTs, which must work together so that the detector field (52x39 cm) has the same sensitivity and resolution at each point, as well as a high degree of linearity. In order to keep these three basic parameters under control, appropriate methods are needed (subjective and objective as well) for their assessment. While online correction methods have been developed for sensitivity and linearity throughout the entire field, there is no such method for intrinsic spatial resolution.

Without being explicitly stated, many papers - relating to quality control - note that resolution is probably not the same throughout the field, and therefore it is necessary to evaluate it at more points in the field - or at least in the central field of view (CFOV) and in the useful field of view (UFOV). That's why a lot of attention is paid to phantoms who assess resolution in different parts of the UFOV.

The spatial resolution of a gamma camera may be measured either subjectively or objectively. Objective measures are based on the point or line spread function, spatial resolution often being quoted as the Full width at half maximum (FWHM). Objective assessments of resolution are simple to perform and reproducible, but usually give an insight into part of the field, while subjective methods usually cover entire UFOV. A more common approach is the visual evaluation of the image of a test pattern that involves recording the smallest features which can be seen on the image. Subjective methods should give similar or at least close assessments of these from objective methods.

The purpose of this paper is to make a review and comparative analysis of phantoms and methods of visual evaluation of resolution over the UFOV.

Transmission test patterns have been developed over the years for the simultaneous evaluation of intrinsic resolution of the entire field. By default the width of the lead bars in these patterns is equal to the space between them while the center-to-center spacings of the holes may vary. For such patterns, the spatial frequency of either bars or holes increases as the width of the bars or spacing between holes decreases. The minimum perceptible bar spacing is used as an index of camera spatial resolution. It can be quantified using the following relationship

$$FWHM = 1.75\ B$$

where B is the width of the smallest bar that the camera can resolve.

In assessing the qualities of phantoms for resolution assessment, it is often noted as an advantage the ability to assess linearity as well, since the configuration of holes or bars in most cases allows this. In the context of the quality control (QC) it is better for the phantom to give an accurate assessment of the resolution - which covers the entire field - than to give a good estimate of linearity at the same time. For linearity assessment, there are enough good specialized phantoms – ortho hole transmission phantom (OHTP) (1), parallel line equally spacing (PLES) (2) etc.

Present paper discusses the capabilities of only those phantoms who, on visual inspection, assess resolution in a relatively short time and are suitable to today's cameras with a rectangular detector and 3.8 mm resolution. Anger's first two phantoms were added as a tribute to his invaluable contribution to the creation and development of the gamma camera, a major tool for nuclear- medicine diagnostics.

REVIEW OF VARIOUS PHANTOMS

The ingenious inventor of gamma camera H. Anger created the first phantom (3) to evaluate the resolution of the detector field (Fig. 1). The phantom is a group of 4 tungsten bars with a width of 1/8" to 1/2" (3.2 – 12.7 mm) located symmetrically on the detector. Width of bars is equal to space between them. This phantom gives a good idea of camera resolution and launches development of bar phantoms.

Anger's later development is the so-called Anger "pie" phantom (4) - a lead disc with hexagonal arrays of holes with a diameter of 2, 2.5, 3, 3.5, 4 and 5 mm. (Fig. 2). In each case the hole diameter is one fourth of the center-to-center distance. This configuration is suitable for visual evaluation of the resolution of a circular detector because it allows with 5 rotations of the phantom through 60^o all sectors of the phantom to pass through the entire field of the detector.

In the following years, new phantoms were already created (5), some of which are suitable for assessment of a camera resolution: 90^o Bar Quadrant phantom, Hine-Duley phantom and PLES phantom.

90^o Bar Quadrant phantom (later renamed to 4 quadrant bar phantom) (Fig. 3) consists of four sets of bars arranged so that each set is rotated 90^o with respect to the adjacent set (5). In each set the bar width is equal to the space between bars. The smallest bar width in original pattern is 4 mm while in the present-day commercially available phantoms it is 2 mm. The width of the bar increases in step of 0,5 mm – 2, 2.5, 3 and 3.5 mm. 4 quadrant bar phantom with different bar width and steps are available on the market. The choice of the bar width should be matched to the resolution of the camera.

To obtain a complete evaluation of camera resolution the smallest bar width has to be imaged in all 4 quadrants of the useful-field-of-view (UFOV) i.e. the fantom must be inverted 3 times to achieve this. Note also that for rectangular detector acquired images show the smallest bars only in one direction – X or Y. For older round detectors, it's possible to get images of the smallest bar width in X and Y direction with one phantom that's inverted and rotated (6)**.** In this case 8 images in total are obtained for the final evaluation!

The following images are shown with educational purpose, their sources being cited at each figure.

The Hine-Duley bar phantom (Fig. 4) consists of 5 sets of lead bars (5). In each set the bar width is equal to the space between bars. The widths of the bars are 4 mm, 4,8 mm and 6.4 mm. The center section consists of 8 bars each 4 mm wide. On either side are 2 sets of 6 bars each 4,8 mm wide and the endmost set of 6,4 mm wide. A probable reason why this phantom does not get development is the limited number of sets - 3 that give an estimate of the limited portion of UFOV.

The Parallel Line Equal Spacing (PLES) bar phantom (Fig. 5) consists of an array of lead bars (5). The widths of the bars are equal to their separation being 3,2 mm or 4,8 mm. Later, the PLES phantom undergoes a significant modification and becomes the well-known today's main phantom for quantitative assessment of resolution through FWHM of line spread function (LSF). In addition, the PLES phantom is also known as Slit mask (7) and as Intrinsic spatial resolution and lingearity phantom (1).

The UB Gamma Camera Test Pattern (Fig. 6) developed at University of Buffalo (8) consists of four sets of parallel line equally spaced bars (0.25, 0.19, 0.16, and 0.1 inch) (6.4, 4.8, 4.1 и 2.5 мм) arranged in an "L-shaped" configuration in each of its quadrants (1998). It is attractive because perform routine quality control tests of gamma camera spatial resolution and spatial linearity in approximately one quarter of the time presently spent with four-quadrant phantom.

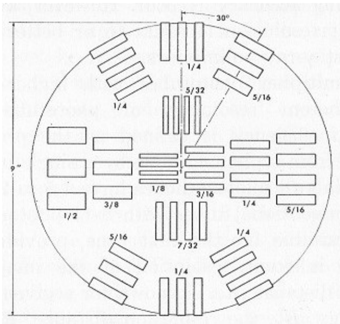

Fig. 1 Anger test pattern

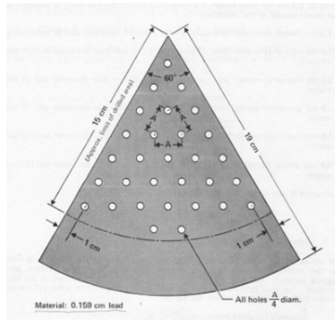

Fig. 2 Anger pie phantom

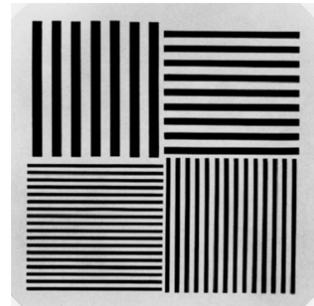

Fig. 3 Four quadrant phantom

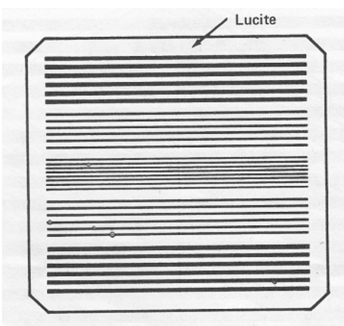

Fig. 4 Hine-Duley phantom

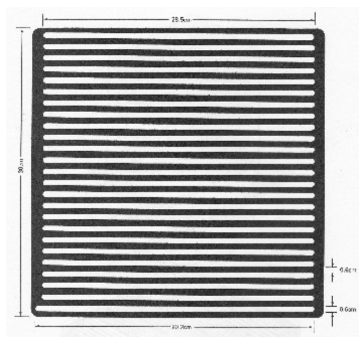

Fig. 5 PLES phantom

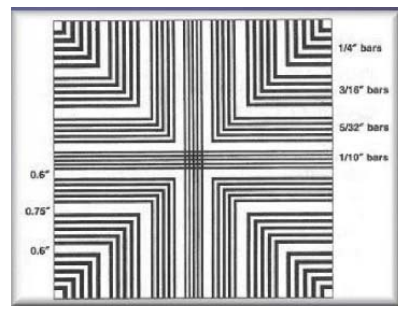

Fig. 6 UB (University of Buffalo)

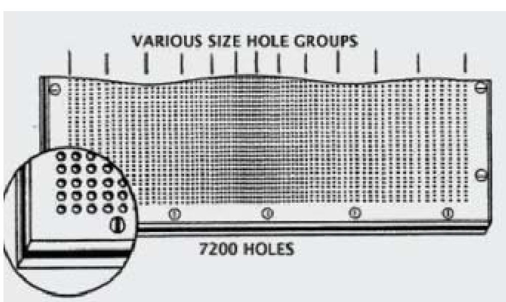

Fig. 7 BRH phantom

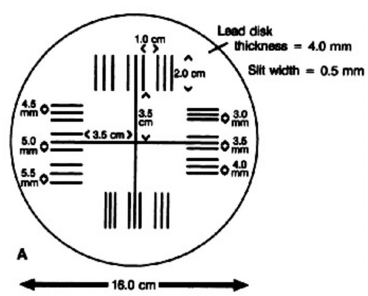

Fig. 8 LRP phantom

Figure 1 is taken from [1] Anger, H. 0., Radioisotope Cameras (1967) In "Instrumentation in Nuclear Medicine, Vol. 1", Academic Press, New York

Figures 2, 3 ,4 and 5 are taken from Quality Control for Scintillation Cameras (1976) Bureau of Radiological Health: HEW Publication (FDA) 76-8046

Figure 6 is taken from www.elimpex.com

Figure 7 is taken from Short M, Elliot A, Barnes J (1983) Performance assessment of the Anger Camera in: Quality Control of Nucl. Med. Instrumentation, The Hospital Physicists' Association, London

Figure 8 is taken from O'Connor M, Oswald W (1988) The Line Resolution Pattern: A New Intrinsic Resolution Test Pattern for Nuclear Medicine J Nucl Med 29:1856-1859

The UB Gamma Camera Test Pattern provides all of the benefits of a four-quadrant bar phantom, with an important added benefit that allows to make direct simultaneous comparison and evaluation of resolution and linearity in each of the 4 quadrants in one image. This makes it particularly effective means of performing routine quality control check of gamma camera. To get closer to the test requirements of modern GC a better choice would be sets of bars 2, 2.5, 3, 3.5 mm.

The BRH Test Pattern (9,14) (Fig. 7) consists of an orthogonal array of 2.5 mm diameter holes in a 3.2 mm thick lead plate (1981). The minimal lead spacing separating adjacent holes is a constant 2,5 mm in the Y direction, but varies along the X axis, in 12 groups of six holes, The spacing separating the holes is constant within each group but differs from one group to another, from 1.5 - 7 mm in steps of 0.5 mm. The group of holes with the closest spacing that appears still resolved on the transmission image of the BRH Test Pattern is a measure of the camera's intrinsic resolution.

As a whole BRH Test Pattern is further growth of the Hine-Duley phantom. Remarkable novelty in the development of BRH Test Pattern is the idea to produce areas of well-resolved, barely resolved, and unresolved groups of holes within a single image.

As in the case of lead-bar transmission images, a fixed relation exists for the minimal lead spacing between the holes that can be resolved and the spatial resolution, expressed as FWHM. On our opinion this relation should be determined experimentally because it depends on the experience of the user and his/her perception of "well-resolved, barely resolved, and unresolved" groups of holes. For a complete analysis of local variations of the intrinsic resolution within the UFOV, several transmission images of the BRH test pattern at various orientations are essential.

An original approach for visual resolution assessment other than that of BAR phantoms was used in Line Resolution Phantom (LRP) phantom (10) (Fig. 8). Its construction is based on the definition that the resolution is the smallest distance at which two small objects become indistinguishable. The object used is a 0.5 mm wide slit. The phantom contains 6 groups of slits with different distances between them 3, 3.5, 4, 4.5, 5 and 5.5 mm. The resolution assessment is the group that is unresolvable.

This phantom clearly cannot be assigned to either bar phantoms or PLES phantoms, but it is a successful combination between them, allowing for both a visual assessment with a step of 0.5 mm and an FWHM assessment. Among phantoms with visual inspection and interpretation of resolution, this phantom is best approached to the quantitative assessment of resolution.

The LPR phantom has four great advantages over BAR phantoms- 1) the resolution is evaluated directly without the need for a correction factor; (2) include in the centre two slits wide 0,5 mm on which FWHM can be assesst in X and Y direction; 3) better accuracy of the assessment due to a smaller step between adjacent sets - 0.5 mm and4, while in bar phantoms the step is 0.5 x 1.75 = 0.875 mm and 4) offers a larger range of choices of the type "well-resolved, barely resolved, and unresolved".

Discussion

Overall, the view is that the advantage of subjective methods for assessment of camera resolution is that they cover the entire field, and the downside is that they are not particularly accurate. In our opinion, a great contribution to inaccuracy is the fact that the process of forming the final assessment involves a series of conditionalities that allow for a broader interpretation and application. We believe that if these conditionalities are refined, the accuracy and repeatability of the assessment can be substantially improved.

An essential component of the subjective method of evaluating resolution is the choice of the set of unresolvable bars. It's a little intimidating when the chosen set of bars or holes turns out to be the endmost in a series of sets. In this case, there is always the suspicion that perhaps the missing next.

This feeling is further reinforced by the vague and varied definition of choice: barely resolved bars (9), just resolved bars (6,11), minimum perceptible bar spacing (12), the smallest resolvable bar (1987), just barely resolvable bar (1988), minimum resolvable line separation (10), the smallest bars visible (13). In the context of the current topic, this concept is uncertain because it depends on a personal perception.

The only definition that points to a more objective choice of a particular set is that "at least one half of the length of the bars will be observed in a portion of a quadrant for that quadrant to be considered visible." (13). An additional condition that would contribute to a more accurate choice of a particular set is to introduce the series "well-resolved, barely resolved, and unresolved" in a single image (9) to facilitate visual evaluation and exclude a moment of hesitation.

An essential element that determines the suitability of phantoms for acceptance and routine testing is the step of change between adjacent bars or holes. A disadvantage of modern bar phantoms is that the step is too large and does not allow for intermediate results.

Table 1 4-quad pattern – step 0,5 mm

Bar width [mm]	FWHM [mm]	3.8 mm referent
2	3.5	-8%
2.5	4.375	15%
3	5.25	38%
3.5	6.125	61%

Table 2 4-quad pattern – step 0,3 mm

Bar width [mm]	FWHM [mm]	3.8 mm referent
2	3.5	-8%
2.3	4.025	6%
2.6	4.55	20%
3.1	5.425	43%

Table 3 4-quad pattern – step 0,25 mm

Bar width [mm]	FWHM [mm]	3.8 mm referent
2	3.50	-8%
2.25	3.94	3.9%
2.5	4.38	15%
2.75	4.81	27%

This statement is illustrated for a 4-quadrant phantom in Tab. 1. In the first column of Table 1, width of bars in all four sets are listed, while in the second column the corresponding FWHM values are calculated. The third column shows what is the deviation of the reported resolution relative to referent resolution - 3.8 mm - when the corresponding quadrant is barely resolvable.

Virtually only the first quadrant of a 4-quadrant phantom is used as barely resolvable one in present day cameras with a resolution of 3.8 mm. (Tab. 1). When the second quadrant becomes barely resolvable - the deviation is 15% and service intervention must be planned. When the third quadrant becomes barely resolvable - the camera has to stop. Therefore the 4th quadrant remains unusable (obsolete). This opens up the prospect of improving the accuracy of the 4-quadrant phantom assessment by changing the step between adjacent quadrants. Tables 2 and 3 provide examples of the results of such a change. The reduced step will make it possible to define more definitively and more objectively the resolution explored in the series, "well-resolved, barely resolved, and unresolved" in a single image. The reasoning outlined so far gives reason to argue that in its current form 4-quadrant phantom was suitable for GC with a resolution of 4.5 – 5 mm, but not for modern GC with resolution of 3.8 mm.

To quantify the result of the visual inspection, the width of the barely resolved bars has to be multiplied by a coefficient. The most popular value of this coefficient is 1,75 (6, 9, 11, 15), while other authors indicate a value of 1,6 (13). Our view is that the value of this coefficient should not be accepted as mandatory but can be determined locally in order to adapt to the perceptibility of the local staff. This can be done this way: suppose the barely resolved bars are in the upper left quadrant of the field. Determine the FWHM in the same location. Calculate the coefficient:

Coefficient = FWHM / bar width

Among the phantoms with a visual score, the best approximation to the actual resolution value is the phantom suggested by O'Connor (10). The main disadvantage of this phantom is that it covers a small area of the field. This flaw can be easily overcome by replicating the phantom in the 4 quadrants of entire UFOV with a central cross of two slits of 0.5 mm width (Fig. 9). Thus, a universal phantom is formed for visual and FWHM assessment of the resolution of modern GC with a rectangular field. The 6 groups of slits with distances from 3 to 5.5 mm and step 0.5 mm create comfortable conditions for working on the criterion "resolvable, barely resolvable, unresolvable".

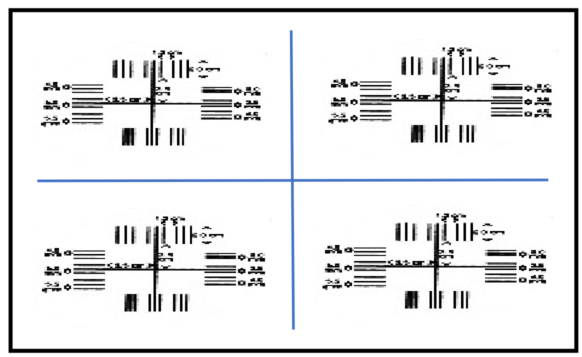

Fig. 9 Proposal for a new quadrant phantom

Conclusions

Bar phantoms, in particular the quadrant bar phantom, has been used widely as a simple, quick method for judging the spatial resolution of a GC. Phantoms for visual evaluation offer a convenient and quick way to test GC performance but in its current form they are not suitable for acceptance or routine testing.

It should not be overlooked that the assessment of resolution with these phantoms is too approximate, as it is generally the view that the variability of resolution is much greater and does not run out of estimates in the four quadrants of the field.

The accuracy of the phantom bar assessment can be improved by reducing the step between adjacent quadrants. Only then they can be used for routine QC.

Taking into account the requirement for visual resolution assessment on both X and Y, the UB phantom is preferable to 4-quadrant bar phantom - only one transmission image to assess resolution and linearity on X and Y directions.

A new phantom based on the LRP test pattern of O'Connor has been proposed, which will give a direct visual assessment of resolution in 4 quadrants and in addition will allow for additional FWHM evaluation in both each quadrant and on UFOV's central X and Y axes.

Most of the phantoms for visual inspection has been developed almost 30 years ago for the assessment of GC performance of that time. Today's GC has significantly improved features that can't be accurately evaluated with old time phantoms. They need to be updated.

References

1. Test of intrinsic spatial resolution (2009) In: Quality Assurance for SPECT, IAEA, Vienna
2. Intrinsic spatial resolution and linearity (2003) In: IAEA Quality Control Atlas for scintillation camera systems. IAEA, Vienna
3. Anger, H. 0. (1967) Radioisotope Cameras In "Instrumentation in Nuclear Medicine, Vol. 1, Academic Press, New York.
4. Anger H. (1973) Testing the performance of scintillation cameras. AEC Contract No. W-7405-eng-48
5. Quality Control for Scintillation Cameras (1976) Bureau of Radiological Health: HEW Publication (FDA) 76-8046, p. 49
6. Computer-aided scintillation camera acceptance testing (1982). AAPM Report No. 9, Chicago: American Institute of Physics.
7. National Electrical Manufacturer's Association (2018), NEMA 1: Standards for performance measurements of gamma cameras, NU 1-2018, Rosslyn, Virginia.
8. Bar Phantoms and Test Patterns - Models 76-802 to 76-890 (elimpex.com)
9. Paras P, Hine GJ, Adams R (1981) BRH test pattern for the evaluation of gamma camera performance. J Nucl Med 22:468 - 470.
10. O'Connor M, Oswald W. (1988) The Line Resolution Pattern: A New Intrinsic Resolution Test Pattern for Nuclear Medicine. J Nucl Med 29:1856-1859
11. Scintillation camera acceptance testing and performance evaluation (1980) AAPM Report No. 6, Chicago: American Institute of Physics.
12. Soni P. (1992) Quality control of imaging devices In: Handbook of nuclear medicine practice in developing countries, IAEA, Vienna
13. Acceptance Testing and Annual Physics Survey Recommendations for Gamma Camera, SPECT, and SPECT/CT Systems (2019) AAPM Report No. 177, Chicago: American Institute of Physics
14. Short M, Elliot A, Barnes J (1983) Performance assessment of the Anger Camera In: Quality Control of Nuclear Medicine Instrumentation, The Hospital Physicists' Association, London
15. Murphy P. (1987) Acceptance Testing and Quality Control of gamma cameras. Including SPECT. J Nucl Med 28:1221-1227

Contacts of the corresponding author:
Author: Peter Trindev, GAMMACHECK
City: 1233 Sofia
Country: Bulgaria
Email: trindev@gmail.com