A NOVEL TEST OBJECT AND METHOD FOR PRECISE ASSESSMENT OF GAMMA CAMERA INTRINSIC SPATIAL RESOLUTION DURING ACCEPTANCE TESTING

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Abstract. **Acceptance testing (AT) is considered a mandatory and particularly important procedure for any newly installed gamma camera because the parameters declared by the manufacturer are verified. Therefore, the AT measurement methods must produce results that are accurate and reproducible.**

Intrinsic spatial resolution (ISR) is one of the most important parameters of the gamma camera detector. Objective methods for the assessment of ISR are preferred because they provide quantitative assessment necessary for tracking the performance of a camera over time. Many authors emphasize the variability of ISR across the detector field. A commonly accepted method of quantification of ISR uses a parallel line equally spacing (PLES) phantom. More than 200 measurements are made on the image of the PLES phantom to compensate for the variability of ISR – approximately 100 in the central field of view (CFOV) and approximately 100 in the useful field of view (UFOV). The results for ISR in CFOV and UFOV are an average of the respective 100 measurements. The problem is that these results differ from the specification.

A new slit phantom - TP-phantom has been developed, that allows for an assessment of ISR at any point and in any direction of the detector field. Based on this TP-phantom's ability, a new method for objective, fast and accurate assessment of ISR is proposed. This method yields results that are reproducible and close to the specification of the gamma camera, which makes it particularly appropriate for acceptance testing. The need for an appropriate selection of reference points for ISR assessment is discussed.

An important advantage of TP-phantom is that it ensures zero radiation hazard for staff. A combination of 2 TP-phantoms can simulate a point source of very small size at a sufficiently high intensity.

Keywords - **phantom, acceptance testing, intrinsic resolution, gamma camera,**

I. INTRODUCTION

Acceptance testing (AT) is considered mandatory and particularly important for any newly installed gamma camera. On the one hand, the parameters declared by the manufacturer are verified until, the true, actual parameters of the apparatus are established, which will be the basis for monitoring the condition of the apparatus during its lifetime of clinical use. Therefore, the AT measurement methods must produce accurate and reproducible results.

The intrinsic spatial resolution (ISR) of a gamma camera is considered one of the most significant parameters of a gamma camera. The ISR may be measured either subjectively or objectively. Subjective methods rely on visual evaluation of transmission images of phantoms. The accuracy of subjective methods depends on both phantom design and the user's perceptivity and experience. Our preliminary study has shown why subjective methods are not suitable for AT of ISR [1].

Objective methods are preferred because they provide quantitative assessment necessary for tracking the performance of a camera over time. They (Objective measures) are based on the point or line spread function (LSF), ISR often being quoted as the full width at half maximum (FWHM). The generally accepted objective method of assessment of ISR uses parallel line equally spacing (PLES) phantom. The procedure with PLES phantom involves more than 200 measurements on the image of the PLES phantom – approximately 100 in CFOV and approximately 100 in UFOV. The result for ISR is quoted as an average of these100 measurements in CFOV and UFOV respectively. The reason to adopt such a complicated and time-consuming approach instead a single measurement is the variability of ISR across the detector field. This variability prevents an accurate assessment of the ISR.

The purpose of the current study was to develop a phantom and method for fast and accurate assessment of ISR during acceptance testing.

II. MATERIALS AND METHODS

At the core of the proposed practical solution to the problem with ISR assessment is the development of a test object (phantom) with flexible slit width. An additional purpose of the current study was to investigate the influence of the slit width on the accuracy of the assessment of the ISR. In conventional PLES phantom, the choice of a 1 mm slit width is a deliberate tradeoff between sensitivity (counting time) and accuracy of the FWHM measurement [2].

The developed slit phantom consisted of 2 lead plates 33x110x5 mm each, which were fixed stationary with 2 additional aluminum tiles (Fig. 1). The slit width between the two lead plates could be adjusted down to a size much smaller than 1 mm. The desired slit width was established

Fig. 1 Slit phantom with encapsulated source.

with an insert, which was gamma radiation transparent - for example, cardboard with corresponding thickness. The next step was to provide appropriate irradiation of the slit.

It is apparent that in the present case the traditional way of irradiation with a point source at a distance of 4-5 times the diameter of the field and closing the rest of the field with lead leaves was too inconvenient and not safe for scintillation crystal. That is why an encapsulated source – vial with 99mTc solution in a container was implemented (Fig. 1). At the bottom of the container, a hole with a diameter of 25 mm was cut. The slit of the phantom was irradiated through this hole. The container fully shields the vial from the environment and provides zero radiation hazard for staff. For convenience, the combination of slit phantom and encapsulated source in a container with an opening at the bottom would be referred to as TP-phantom. While working with the TP-phantom count rate was adjusted by changing the activity in the vial or by placing copper plates under the vial.

The gamma cameras taking part in this study were Philips Meridian, Siemens Intevo, Siemens E.CAM, and GE Millennium. All of them declared intrinsic resolution of 3.8 mm in CFOV and 3.9 mm in UFOV.

All measurements were made under fully calibrated detector and measurement conditions according to the National Electrical Manufacturers Association (NEMA) [2] and American Association of Physics in Medicine (AAMP) [3]: count rate between 10 and 14 kcps, peak of the LSF profile - above 2 000 counts, acquisition matrix 1024x1024. The energy window for 99mTc was the one recommended for clinical use.

The TP-phantom provided an excellent opportunity to easily determine the correlation between slit width and ISR measurement results. Measurements were made in the fixed place on the crystal as slit width was changed from 0.2 mm to 1.2 mm with a step of 0.2 mm. Fig. 2 shows a progressive improvement in ISR result with a decrease in slit width. For

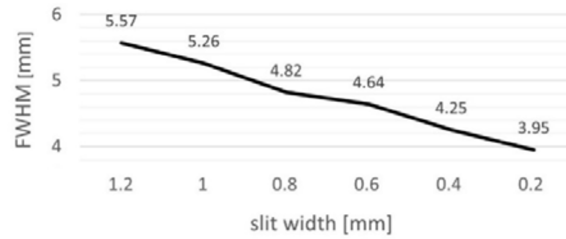

Fig. 2 Effect of slit width on spatial resolution result.

subsequent measurements, a 0.2 mm slot width was established which in camera resolution 3,8 mm meets the requirement [2]:

Camera resolution / slit width > 10

Which, with an expected camera resolution of 3.8 mm yields

3,8 / 0,2 = 19.

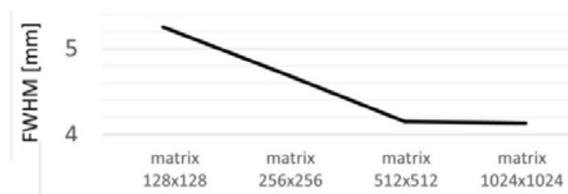

Fig. 3 Effect of pixel size on spatial resolution result

The next step was to determine the impact of the pixel size of the acquisition matrix on the accuracy of the measured spatial resolution. The TP-phantom with 0.2 mm slit width was placed stationary on the crystal and four acquisitions were made at the different sizes of the recording matrix. The result shown in Fig 3 shows that it is advisable to work with matrix 1024x1024. Fortunately, matrix 1024x1024 has been available in all gamma cameras for the last 10 or more years. The pixel size of this matrix is close to 0.52 mm at LFOV cameras and meets the second condition requested [2,3]:

Pixel size / FWHM < 0.2

Which, with an expected camera resolution of 3.8 mm yields

0.52 / 3.8 = 0.14

What remained to be studied was the third condition on which the accuracy of camera ISR measurement depends.

In routine quality control of working with the TP-phantom in the past years, it was very difficult to interpret the paradoxical fact that sometimes spatial resolution in UFOV is better than spatial resolution in CFOV. To find the possible cause of this effect, spatial resolution was measured with the TP-phantom along the small axis of the detector with step 1 cm. The line of measurement included both parts of the field – CFOV and UFOV (Fig. 4). Measurements were only in one direction Y along the dashed line through the

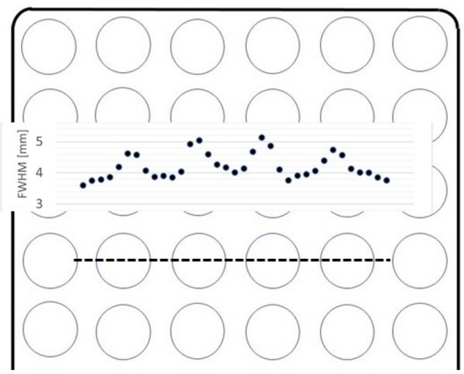

Fig. 4 Stepwise variation of spatial resolution along the line passing through the centers of the PMT

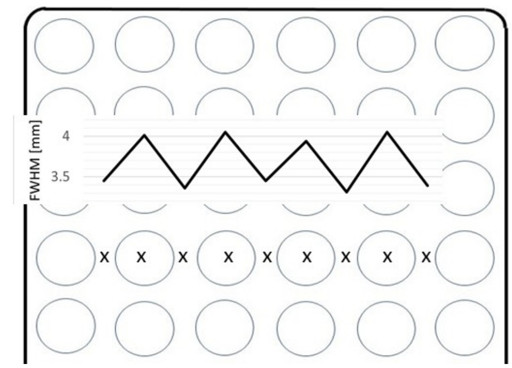

Fig. 5 Graph of spatial resolution at 9 reference points marked with "x" of PMT "matrix-stacking" detector.

PMT centers. There was no reason to expect that the graph of measurements at the same points on (in) the X direction will differ.

The results of the measurements in graphic form showed a change in a form similar to the sinusoid. After thoroughly reviewing relevant studies, we found that this phenomenon was published as early as 2006 [5] and later in 2009 [6], but it was not reflected in the ISR measurement procedure in official documents like NEMA [2] and AAPM [3]. Fig. 4's graph shows that there are specific places of minimum and maximum of ISR - the minimums are invariably at the limit between two PMTs - and the maximums coincide with PMT centers. The average of the minimums in Fig. 4 was 3.74 mm, while the average of the maximums - 4.73 mm was 26.5% higher. The declared ISR for this camera was 3.8 mm in CFOV, which practically corresponded to the average of the minimums.

The main conclusion of this example was that in the AT procedure of ISR, in addition to the requirements set out above for slit width of the line source and pixel size of the acquisition matrix, a third condition - appropriate permanent locations for ISR measurement - which we hereinafter refer to as reference points - must also be included.

Fig. 4's graph unequivocally shows that ISR has clearly localized maximums on the PMT center and minimums halfway between two PMT centers. This is a reason to use these points with a clear fixed location as reference points during acceptance testing and for the annual survey as well to track the state of ISR over time.

The following paragraphs propose sample options for selecting reference points for the objective assessment of ISR as an indicator of the detector's performance.

By arranging PMT in a rectangular detector field, gamma cameras can be conditionally divided into 2 types – those where PMT are arranged in the type "matrix" and those in which PMT are arranged in "chess-board" order.

On a "matrix" type PMT detector measurements of ISR were made (in Y direction only) in a series of 9 points marked with an "x". The results in graphic form are presented in Fig. 5. The average of the minimums was 3.9 mm while the average of the maximums was 4.74 mm. The difference between the max average and the min average was 21%. Apparently, the ISR value in the specification matched the average value of the minimums.

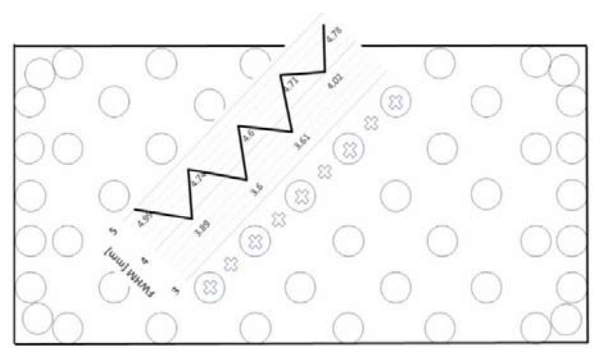

Fig. 6 Graphs of spatial resolution at 9 reference points marked with "x" in chess-board" arrangement of PMT.

In the case of the "chess-board" order of PMT measurements were made on a series of 9 points marked with an "x" (Fig. 6) – 5 measurements on the PMT and 4 measurements half the distance between two adjacent PMT. The selected PMT line passed through the center of the detector field. The average of the minimums was 3.9 mm while the average of the maximums was 4.74 mm. The difference between the max average and the min average was 20.5%. Apparently, the average value of the minimums matched the ISR value in the specification.

A possible extension of the functionality of the TP-phantom is adding a second slit phantom rotated at 90^o. This configuration simulates a well-collimated point source with a very small diameter (0.2 mm in this case). This way a point source of very small size can be realized which is difficult or almost impossible to achieve by drilling a physical hole into a lead plate.

This configuration can be used in a small-field-of-view gamma camera by reducing the size of the TP-phantom - a smaller plastic vessel for 99mTc solution with appropriate shielding and corresponding downsized slit phantom.

WARNING. Intrinsic measurement involves the removal of the collimator with the attendant risk to the crystal. Care must be taken so as to not damage the crystal. The phantom's small dimensions allow it to position itself at any point of UFOV, which is usually done by sliding. Sliding the phantom onto the easily damaged surface of the aluminum foil which covers the scintillation crystal poses a high risk. Therefore, it is strongly recommended to cover the scintillation crystal with transparent foil (1-2 mm) immediately after removing the collimator and then place the TP-phantom on the foil. Additionally, it is recommended to place a pad of soft fabric under the TP-phantom.

III. DISCUSSION

An example of the inhomogeneous distribution of ISR in the detector field, which is always in front of our eyes, is the image of a 4-quadrant phantom with a high resolution starting at 2 mm bar width (Fig. 7). At an appropriate setting of the brightness window blurring of the bars above PMT becomes visible. Apparently, the lower resolution above PMT causes the lines in the quadrant with the narrowest bars to be displayed blurry. Note that blur is only in the areas around the PMT center, while in areas between PMT ISR is partially preserved, which confirms the results of this study.

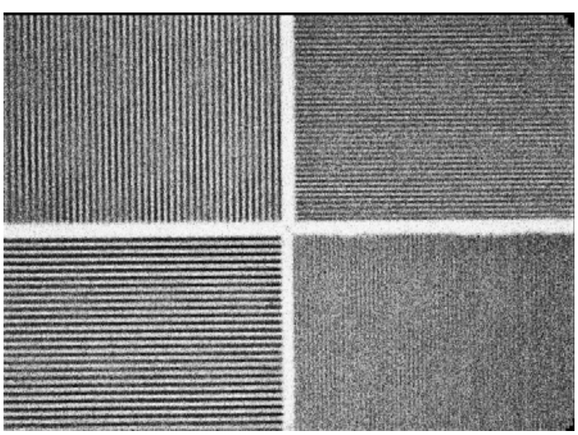

Fig. 7 Transmission image of four quadrant bar phantom.

The variation of the ISR across the detector field has been noticed on the first attempts at its assessment [4, 7]. The different resolution values along PLES phantom slits also confirm the variability of ISR on the detector field. It is therefore accepted to average the assessment of spatial resolution in an interval of 30 mm, which is further replicated in several (not specified exactly how many and where) locations [6]. The additional averaging of the result of X- and Y-direction measurements does not appear to give a consistent result. The reason is that it is made with two PLES phantoms, where the X and Y measurement points do not match.

Fig. 4‘s graph shows that in the interval between minimum and maximum, the intermediate resolution values can be found. In this sense, it can be expected that in a three-dimensional representation, the distribution of ISR across the detector plane will represent a geographical plain with "peaks" (PMTs) and "valleys" between them. It's easy to "get lost" in this huge set of different resolution values, which justifies the need for fixed permanent points of ISR measurement. Moreover - It becomes clear that the division of the detector field of CFOV and UFOV is conditional since "good" and "bad" ISR values can be found in both CFOV and UFOV. Most likely the ISR parameter in gamma camera specification is an average of the lowest points of "valleys"(the minimums).

We can take advantage of the opportunities provided by the TP-phantom to determine objectively and relatively quickly ISR. For PMT “matrix-stacking” detectors (Fig. 5), the average of the intermediate 3 results is an assessment of ISR in the CFOV, while the average of the endmost 2 results is an assessment of ISR in the UFOV.

The same model can be applied to “chess-board” order detectors (Fig. 6) - of the resulting 4 minimums (3.89 mm,3.6 mm, 3.61 mm, and 4.02 mm) the average of the intermediate 2 results is an assessment of ISR in the CFOV, while the average of the endmost 2 results is an assessment of ISR in the UFOV.

For a specific gamma camera, it becomes appropriate to determine a permanent row/s of PMTs to track the state of ISR over time.

TP-phantom allows measuring ISR at the same point in different directions with a simple rotation of the slit in the desired direction. This ability opens up an excellent opportunity to explore whether it is really necessary to measure ISR in both directions X and Y (as is the current rule) or it can be replaced, for example, by a single measurement with a slit of the TP- phantom rotated on 45^{o}.

The reference point selection models mentioned so far are just an example of obtaining consistent ISR assessments - but they by no means limit the creation of other models based on different criteria.

PLES phantom has some disadvantages (weak points) such as:

- The slit width of 1 mm that does not meet the requirement FWHM/slit width > 10
- The slits have a fixed location and restrict access to only certain places on the detector field

- It is necessary to average LSF over 30 mm along the slit in order to reduce the impact of ISR variability alongside the slit
- PLES phantom irradiation time is relatively long to get information with good statistics
- Two PLES phantoms are needed to measure spatial resolution in X and Y directions
- Inevitable staff radiation exposure during preparation and irradiation of the PLES phantom.
- The software of some of the modern gamma cameras does not allow to form ROI with dimensions 55 x 30 mm to perform measurements with the PLES phantom (Siemens, GE)

The proposed new TP-phantom provides some significant advantages over the conventional PLES phantom, the most important of which are:

- Adjustable width of the slit to a very small size
- Well-shielded source in a container, which assures zero radiation hazard for staff
- Ability to provide the required count rate (below 20 kcps) with a change of source activity which facilitates and speeds up the measurement process.
- Short time to collect reliable information (LSF peak > 2000 counts) in a single measurement
- Ability to test ISR at any point of UFOV and in any desired direction with a simple rotation of the TP-phantom
- The TP-phantom is several times lighter than the standard PLES phantom and therefore reduces the risk of crystal damage while complying with recommended safe operation measures.

IV. Conclusions

A new phantom has been developed for rapid and easy quantitative measurement of ISR at any point of the detector field of a gamma camera - the TP-phantom. This confirms the findings of other authors [5, 6] – the presence of pronounced maximums and minimums of ISR, the locations of which in the detector field are unambiguously determined.

Based on this information, it is proposed to introduce an additional requirement to the ones prescribed by NEMA [2] - a specific measurement location of ISR. A criterion for selecting reference points in the detector field is proposed, which meets the requirements of the QC for the unambiguousness of ISR measurement conditions and ensures the replicability of the assessment.

The accuracy of the results obtained with the new TR phantom is confirmed by the fact that they comply with the specification.

The proposed assessment method facilitates acceptance testing, allows to compare objectively gamma cameras in terms of ISR, and tracks the detector's performance over time.

An essential advantage of the TP-phantom is the ability to establish a very small slit width (e.g. 0.1 mm), making it suitable for measuring ISR on a small field of view gamma cameras. An interesting option for the practice is the realization of a point source of radiation of small diameter adding a second slit phantom rotated at 90^{o}.

A practical advantage of the TP-phantom is that reducing the slit width does not result in a loss of time because the count rate can be adjusted with a corresponding change of the activity of 99mTc in the vial while observing the requirement count rate < 20 kcps. This makes measurement with TP-phantom quick and easy.

Last, but not least, working with the TP-phantom ensures zero radiation hazard for staff.

It is envisioned that the TP-phantom will provide fruitful avenues for other applications in the practice of medical physics.

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