
Rapid Evaluation of Weekly Scintillation Camera Resolution and Linearity Using the Orthogonal Tri-Hole Phantom

Edward M. Smith and Kevin T. Hopkins

University of Rochester Medical Center, Division of Nuclear Medicine, Department of Radiology, Rochester, New York

Objective: Both state and federal regulations require weekly monitoring of the resolution and linearity of the scintillation camera. Several phantoms are available to perform this quality control function. These include the quadrant bar, Bureau of Radiological Health (BRH), and orthogonal-hole (OH) phantoms. Each of these phantoms has either functional or temporal limitations on its use. The orthogonal tri-hole phantom (OTHP) was designed to overcome these limitations.

Methods: The OTHP consists of a precision-drilled lead plate sandwiched between two plastic plates. The OTHP has an active area of 15 in. \times 20 in. which contains an orthogonal array of three-hole (2.5-mm, 3.0-mm, and 4.0-mm) clusters. Intrinsic and extrinsic images were acquired for the OTHP, OH phantom, BRH phantom and quadrant bar phantom.

Results: The OTHP test pattern allows resolution, linearity, object shape, and contrast to be evaluated simultaneously, either intrinsically or extrinsically, in a single image over the entire useful field-of-view.

Conclusion: The OTHP provides a more quantitative evaluation of the quality control parameters than any other phantom currently available. The use of the OTHP results in cost savings since both camera and technologist time are reduced because only one image is required instead of the two or four needed for other phantoms.

Key Words: contrast; linearity; object shape; orthogonal; phantom; quality control; resolution; scintillation camera

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Weekly evaluation of the resolution and linearity of a scintillation camera is required by both the NRC (1) and agreement states, such as New York (2). These regulations require that on a weekly basis the following checks must be performed:

1. "With the same frequently used collimator in place, image a parallel-in-line equal-space (PLES), bar, orthogonal-hole (OH), or resolution-quadrant phantom with the flood field as a source."

2. "If a PLES or bar phantom is used, rotate it 90° so that the camera is tested for both vertical and horizontal geometric linearity."
3. "If a resolution-quadrant phantom is used, rotate it so that each quadrant is imaged in each quadrant of the crystal."
4. "Process the images as if they were images of a patient. Mark them clearly to indicate image orientation, source activity, and date."
5. "Retain these images for 2 y (NRC) or 3 y (New York)." New York state requires documentation of the action taken when an image reveals a problem.

Each of the above types of phantoms, as currently designed, has either one or more functional or temporal limitations on its use. The orthogonal tri-hole phantom (OTPH) (manufactured by Nuclear Associates, Inc., Carle Place, NY to specifications provided by Edward M. Smith) was designed to overcome these limitations which are:

1. Excessive time to acquire the required images.
2. Can only be imaged intrinsically.
3. Cannot evaluate resolution and linearity with a single image.
4. Cannot evaluate changes in object shape and contrast over the useful field-of-view (UFOV).
5. The distribution of photons that pass through the phantom are not evenly distributed over the UFOV of the camera.
6. It is difficult to make an objective statement regarding camera performance based on the image obtained.

DESCRIPTION OF THE ORTHOGONAL TRI-HOLE PHANTOM

The OTHP is composed of a precision-drilled lead plate, which is the test object, sandwiched between two plastic plates. The overall phantom dimensions are 20.94 in. \times 16.94 in. \times 0.41 in. thick. The phantom weighs just over 21 lb.

The test object is a lead plate 1/8 in. thick that contains an orthogonal array of three-hole clusters covering a test area 20 in. \times 15 in. The holes in each equilateral triangular cluster are 2.5, 3.0, and 4.0 mm in diameter, with spacing between hole centers of 9 mm. The clusters are spaced at 16-mm intervals

For correspondence or reprints contact: Edward M. Smith, University of Rochester Medical Center, Division of Nuclear Medicine, Department of Radiology, 601 Elmwood Ave., Box 620 Rochester, NY 14642-8648.

along the long axis of the phantom and at 17-mm intervals along the short axis of the phantom.

To simplify positioning the phantom on the scintillation camera, the plastic plates have horizontal and vertical positioning lines which bisect the plate. A 5-mm orientation hole is located in one quadrant of the phantom so it can be positioned in the same relative position each time it is imaged.

IMAGING THE ORTHOGONAL TRI-HOLE PHANTOM

The OTHP may be imaged either intrinsically or extrinsically. Figure 1 illustrates the proper positioning of the phantom on the scintillation camera. It is recommended that the phantom be imaged intrinsically, since the purpose of the weekly check on resolution and linearity is to evaluate the performance characteristics and stability of the scintillation camera detector rather than the overall system performance of the detector and collimator. The phantom may be imaged intrinsically using a point source of ^{99m}Tc located at least five UFOVs from the face of the detector. Alternatively, the OTHP can be imaged extrinsically using a ^{57}Co sheet source or a fillable flood phantom.

Standard planar acquisition parameters should be used. For newer scintillation cameras, late 1980s and on, it is strongly recommended that a 15% energy window be used for imaging to take advantage of the improved energy resolution of the cameras. If the image is to be acquired digitally, it is recommended that a 512×512 acquisition matrix be used. This matrix size will result in a pixel size of approximately 1 mm for most cameras. This is required when trying to resolve a 2.5-mm test object. The zoom must be set at one.

The OTHP has significantly less open space than the quadrant bar, PLES, Bureau of Radiological Health (BRH), or OH phantoms. Therefore, fewer counts need to be acquired to obtain an equivalent count density in the image. The OTHP images should contain between 400,000 and 800,000 counts.

Intrinsic Imaging

The collimator is removed from the camera and the camera is positioned so the detector is facing the ceiling. The back of the camera should be as close as possible to the floor. Care must be taken not to damage the detector while the collimator is removed. A field restricter is placed on the camera, if one is

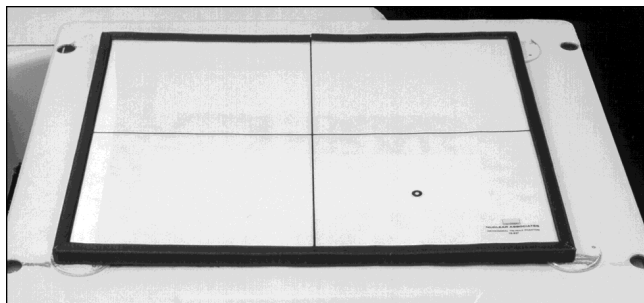


FIGURE 1. The orthogonal tri-hole phantom properly positioned on the scintillation camera. Note the orientation hole in the lower-right corner of the phantom and the alignment lines on the phantom demonstrating proper positioning and orientation of the phantom with the long and short axis of the camera.

available. The purpose of the field restricter is to limit the exposed area of the detector to the UFOV. The phantom may be used without a field restricter.

Plastic-backed absorbent paper should be placed over the detector. The phantom is carefully placed on the detector over the absorbent paper with the orientation marks facing the ceiling. The orientation hole is placed in the same orientation as when the baseline or reference image was acquired. The OTHP is positioned so that the long line on the phantom is parallel with and over the long axis of the detector. The short line on the phantom and short axis of the detector are aligned in the same manner as the long line of the phantom.

A source holder, such as the barrel of a 5-mL syringe, is centered above and securely fastened to the ceiling above the scintillation camera. If the ceiling is acoustical tile, the syringe barrel is tied to the metal acoustical tile supports. An appropriate amount of ^{99m}Tc is placed in a 1- or 2-mL syringe so the counting rate does not exceed 20,000 cps when the source is placed 5 UFOVs from the face of the detector. The syringe is placed in the source holder and it is verified that the camera is centered under the source. Figure 2 is an intrinsic image of the OTHP acquired using a ^{99m}Tc point source.

Extrinsic Imaging

The OTHP may be imaged extrinsically using a ^{57}Co sheet source or a ^{99m}Tc fillable flood phantom. The phantom must not be imaged extrinsically with a point source since the detector cannot be uniformly irradiated with photons at 5 UFOVs with the collimator in place. The low-energy collimator with the highest resolution should be used to image the OTHP extrinsically.

The OTHP is placed carefully on the collimator with the orientation marks facing the ceiling. The orientation hole is placed in the same orientation as when the baseline or reference image was acquired. The OTHP is positioned so that the long line on the phantom is parallel with and over the long axis of the detector. The short line on the phantom and short axis of the detector are aligned in the same manner as the long line of the phantom.

The OTHP is imaged with ^{57}Co by placing the ^{57}Co sheet source on the phantom so the source is oriented with respect to the collimator in the same manner it was imaged when the reference image was obtained. The reason for maintaining the same orientation of the sheet source and the collimator is that there may be small nonuniformities of ^{57}Co activity in the sheet source. The sheet source is centered on the phantom and the image is acquired. Figure 3 is an extrinsic image of the OTHP using a ^{57}Co sheet source.

A fillable flood phantom can be used to image the OTHP extrinsically. The phantom is filled with a quantity of activity so the counting rate does not exceed 20,000 cps and the activity does not exceed 740 MBq (20 mCi). The phantom should not contain air bubbles nor should it be overfilled so that it bulges in the center. Rotate the phantom to ensure the activity is uniformly mixed. Label the phantom with the quantity of activity and time of assay. Place a plastic-backed absorbent paper on the collimator and place the flood phantom on the

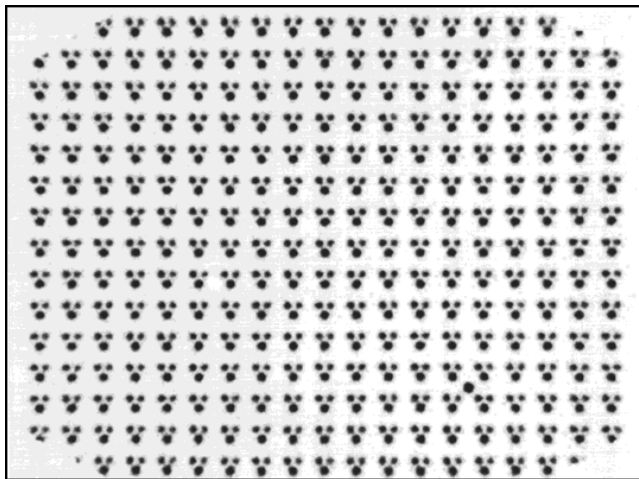


FIGURE 2. A 400,000-count intrinsic image of the orthogonal tri-hole phantom from a camera with a useful field-of-view (UFOV) of 15 in. \times 20 in. using a point source of ^{99m}Tc . A single image provides information to evaluate x-axis and y-axis linearity and spatial resolution over the entire UFOV with a single image. Note the phantom's orientation hole in the lower right-hand quadrant.

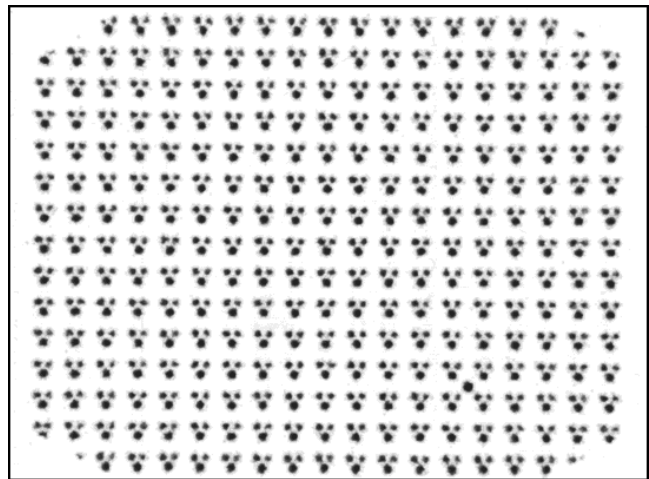


FIGURE 4. A 400,000-count extrinsic image of the orthogonal tri-hole phantom from a camera with a useful field-of-view of 15 in. \times 20 in. using a ^{99m}Tc fillable flood source. The extrinsic image yields significantly poorer system resolution when compared to an image obtained intrinsically with a ^{99m}Tc point source.

OTHP. Center the source on the phantom and image. Figure 4 is an extrinsic image of the OTHP using a fillable ^{99m}Tc flood phantom as source. The use of the fillable flood phantom is the least desirable method of imaging the OTHP.

EVALUATING THE OTHP IMAGES FOR WEEKLY QUALITY CONTROL

Baseline images of the OTHP must be obtained as part of acceptance testing or when the phantom is first used. In the latter case, high-count quantitative floods should be obtained to ensure that both integral and differential flood-field uniformity meet the camera's specifications. In addition, the phantom previously used to evaluate resolution and linearity must be

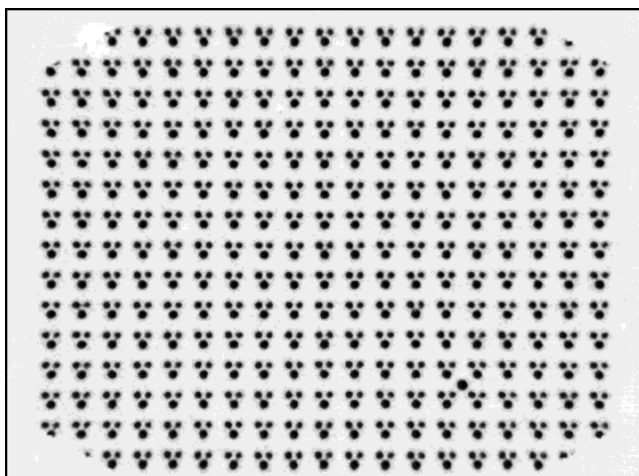


FIGURE 3. An 800,000-count extrinsic image of the orthogonal tri-hole phantom (OTHP) from a camera with a useful field-of-view of 15 in. \times 20 in. using a ^{57}Co sheet source. The extrinsic image yields significantly poorer resolution (system) compared to the resolution (intrinsic) obtained when the phantom is imaged intrinsically. As a result of the unique hole pattern used in the OTHP, no moiré pattern is seen in the extrinsic images. This may be seen on phantoms with other hole patterns when imaged extrinsically.

imaged and compared with the OTHP baseline images for the camera.

If the uniformity is within specifications and if the images of the resolution and linearity phantom previously used are comparable to the baseline images, the initial image of the OTHP can serve as the new baseline image. All of the above images must be saved for future reference.

The following protocol can be used to evaluate the images obtained with the OTHP. Compare the current image obtained with the OTHP with the reference image and evaluate the following characteristics of the image:

1. Do the 4-mm holes in each row and column line up in a straight line along the long and short axes of the UFOV? Note any deviation from a straight line.
2. Are the 2.5-, 3.0-, and 4.0-mm holes of equal contrast and equally resolved over the entire UFOV? Note the location of any variation in contrast and resolution of any hole.
3. Are the shapes of the holes circular over the entire UFOV? Note the location of any variation in shape and hole size.

Figure 5 is a sample quality control log sheet that can be used to monitor weekly resolution and linearity in conjunction with the OTHP.

COMPARISON WITH OTHER PHANTOMS

The OTHP was compared with the OH, BRH and quadrant bar (bar widths of 1/4 in., 3/16 in., 1/8 in. and 1/16 in.) phantoms by imaging the phantoms both intrinsically and extrinsically on the ADAC Argus (Milpitas, CA) scintillation camera. The phantoms were imaged intrinsically with a point source of 29.6 MBq ^{99m}Tc at 5 UFOVs from the face of the detector and extrinsically with a low-energy, high-resolution collimator using a 555-MBq ^{57}Co sheet source. All images were

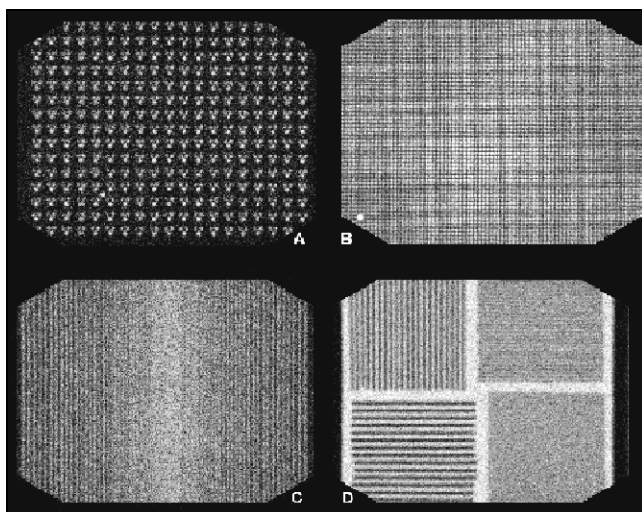


FIGURE 7. Comparison of extrinsic images obtained with a ^{57}Co sheet source of the (A) orthogonal tri-hole phantom (400,000 counts), (B) orthogonal hole phantom (1,000,000 counts), (C) Bureau of Radiological Health Phantom (1,000,000 counts), and (D) quadrant bar phantom (2,000,000).

as the limit of resolution. The OH phantom has only a single-diameter test object. The test pattern of the BRH phantom varies over the UFOV and requires it to be imaged twice if the limit of resolution is to be evaluated along both axes of the camera. The test pattern of the quadrant bar phantom is not uniform over the UFOV and must be rotated four times to evaluate all quadrants of the camera. This results in increased technologist and camera time to obtain quality control images and, therefore, cost. The use of the OTHP, as compared to the quadrant bar phantom, will reduce image acquisition time for the weekly resolution and linearity check by a factor of three (Table 1).

The 4-mm test object in the OTHP aligned horizontally and vertically over the UFOV makes it easy to evaluate linearity. The bars in the quadrant bar phantom do not align horizontally or vertically (Figs. 6D and 7D) making it more difficult to evaluate linearity.

Even though the regulations (1,2) specify that the weekly resolution and linearity evaluation should be performed extrinsically, it is recommended that this procedure be performed intrinsically. The purpose of the weekly resolution and linearity check is to evaluate the performance and stability of the detector. The resolution of the collimator is at least two times less than that of the detector. Compare the intrinsic images in Figure 6 to the extrinsic images in Figure 7. Subtle changes in detector performance will not be detected if extrinsic (system) measurements are made.

The counts in an image of the quadrant bar phantom are concentrated in the center where the four bar segments meet and

between segments resulting in an uneven count distribution (Figs. 6D and 7D). The count density should be relatively uniform so that resolution can be evaluated with the same statistical certainty over the entire UFOV. The uniform test pattern of the OTHP throughout the UFOV provides a relatively constant count density compared to the quadrant bar phantom.

A moiré pattern is quite frequently produced when the OH or BRH phantoms are imaged extrinsically (Figs. 7B and, to a lesser degree, 7C). The moiré artifact appears as interference patterns resulting from the repetition of the hole pattern in the phantom and the collimator on the scintillation camera. The periodic pattern of holes used in the OTHP does not result in the formation of a moiré pattern because the spacing between clusters of holes does not reinforce the hole pattern of the collimator.

CONCLUSION

It is strongly recommended that the weekly resolution and linearity images be acquired intrinsically rather than extrinsically. Compare the intrinsic images in Figure 6 to the extrinsic images in Figure 7. The OTHP covers the entire UFOV of the camera with a repetitive set of three test objects arranged in an orthogonal array. This allows resolution, linearity, contrast, and object shape to be evaluated simultaneously, either intrinsically or extrinsically, over the entire UFOV with one image. This cannot be achieved with any other phantom currently available.

Since there is less open test object area in the OTHP than in other phantoms, a higher count density can be achieved with lower counts per image. The OTHP provides a more quantitative evaluation of quality control parameters than any other phantom. No moiré effect is produced when the OTHP is imaged extrinsically, while this may occur with other phantoms.

Both camera time and technologist time will be saved when the OTHP is used, resulting in quality control cost reduction since only one image is required compared to two images for the BRH phantom and four for the quadrant bar test phantom.

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