# Measurement of Collimator Hole Angulation and Camera Head Tilt for Slant and Parallel Hole Collimators Used in SPECT

E. Busemann-Sokole

*Department of Nuclear Medicine, Academic Medical Centre, University of Amsterdam, Amsterdam, Netherlands*

Collimator hole angulation was measured at 16 locations in three collimators used in SPECT. The parallel hole collimator measured −0.1 ± −0.1 s.d. degrees in the X and −0.2 ± 0.1 s.d. degrees in the Y direction. One 30° nominal slant hole collimator revealed a 0.1 ± 0.3 s.d. degrees angulation in X and 26.5 ± 1.1 s.d. degrees angulation in Y, which was unacceptable. The replacement collimator measured 0.0 ± 0.1 s.d. degrees in X and 29.6 ± 0.2 s.d. degrees in Y. Determination of collimator hole angulation is recommended as an acceptance test for SPECT systems. The net angle of tilt with respect to the orthogonal resulting from a particular collimator and camera head tilt was determined from summed projection images over 360° of a point source placed off the axis of rotation. These measurements were sensitive within a 0.5° tilt angle. The method is suggested as a routine quality control procedure to optimize camera head tilt to a particular collimator. It may also reveal unexpected mechanical misalignments in the camera gantry.

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Single photon emission computed tomography (SPECT) with a rotating scintillation camera presupposes that the collimator holes and septa are directed precisely orthogonal to the axis of rotation throughout rotation. Nonorthogonality in either X (perpendicular to the axis of rotation) or Y (parallel to the axis of rotation) directions may cause deterioration in reconstructed image quality (*1–3*). The effect in the X direction is a center of rotation offset, whereas the effect in the Y direction is equivalent to camera head tilt and a single projection line in Y will view more than one transaxial plane.

The condition of orthogonality may not necessarily be true even for a parallel hole collimator which is carefully leveled with a spirit level to be exactly horizontal at the start of rotation based on the assumption that the axis of rotation is horizontal. When a slant hole collimator, that has parallel holes inclined at some angle, is used to perform brain imaging with a smaller radius of rotation (*4*) the camera head must be tilted to the correct angle so that the collimator holes are aligned orthogonally with respect to the axis of rotation. This angle of tilt needs to be determined for the particular slant hole collimator used.

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For reprints contact: E. Busemann Sokole, MD, Dept. of Nuclear Medicine, Academic Medical Center, Meibergdreef 9, 1105 AZ Amsterdam Zuidoost, Netherlands.

Nonorthogonality in either X or Y may be caused by hole misalignment in the collimator septa construction and by use of an incorrect camera head tilt. Also, incorrect mechanical movement of the detector head may introduce shifts in hole angulation during rotation.

The purpose of this study was twofold: (a) to determine a method for measuring the collimator hole angulation for parallel and slant hole collimators, and (b) to determine a simple, yet sensitive, method to optimize and routinely check the camera head tilt used during SPECT data acquisition when using either type of collimator.

## MATERIALS AND METHODS

### Collimator Hole Angulation

When a radioactive point source is measured at two positions, I and II, separated by D exactly perpendicular to the collimator face, the images will superimpose when the collimator holes are perfectly orthogonal with the detector plane (Fig. 1A). If there is a small angulation of all the holes within a local area, then the images will be separated by a small distance d (Fig. 1B). The hole angulation ($\alpha$) is then given by the relation:

$$\alpha = \tan^{-1} (d/D) \qquad (1)$$

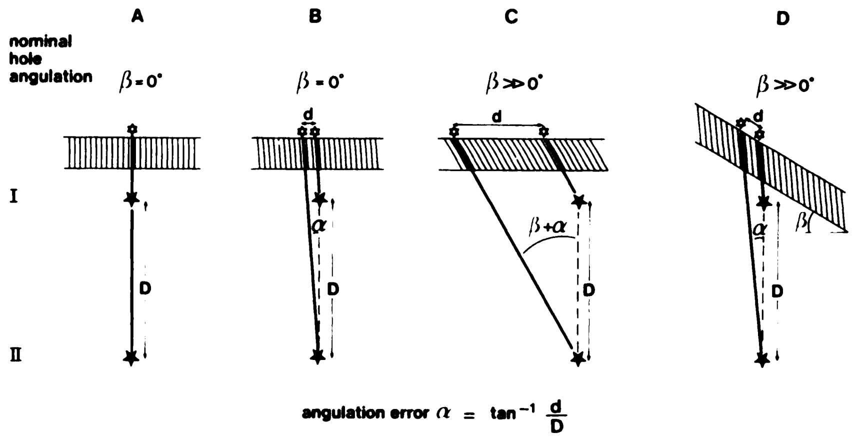


**FIGURE 1**
Method used for measurement of collimator hole angulation of a parallel hole collimator for which nominal hole angulation $\beta = 0°$ (A and B), and a slant hole collimator for which nominal hole angulation $\beta \gg 0°$ (C and D). The large stars indicate $^{99m}Tc$ point source positions, and the small stars indicate resultant images.

The value of $\alpha$ measures the collimator hole angulation over a small local area of the collimator.

When applying this to a slant hole collimator that has a nominal hole angulation ($\beta$) of 30°, the distance d becomes large (Fig. 1C). The measured angle ($\beta + \alpha$) will then no longer measure the hole angulation within a small local area of the collimator, but will be influenced by the angulation at two different locations in the collimator. For a slant hole collimator it is therefore preferable to tilt the camera head to the nominal slant hole angle, that should align the collimator holes perpendicularly, and then measure any residual hole angulation (Fig. 1D).

In order to apply this technique a special support jig was constructed (Fig. 2A and B). It consisted of a Lucite plate in which 16 1-mm-diameter holes had been drilled at 9-cm spacings in order to create a 4 × 4 matrix of point sources spanning a 27 cm square surface area. This plate could be located in one of two slots cut in the side supports exactly 20 cm apart. The jig was carefully constructed so that the holes were exactly perpendicularly aligned when the plate was removed from the one slot to the other. Using a microliter automatic pipette, a drop containing 3 μl of high specific activity technetium-99m ($^{99m}Tc$) solution was pipetted into each hole, ensuring a similar quantity of radioactivity for each radioactive point source.

This jig was used to measure the hole angulation of a high-resolution parallel hole collimator and two 30° nominal slant hole collimators provided by the SPECT system manufacturer*. For the parallel hole collimator the jig was placed centrally on the surface of the collimator (Fig. 2A). For the

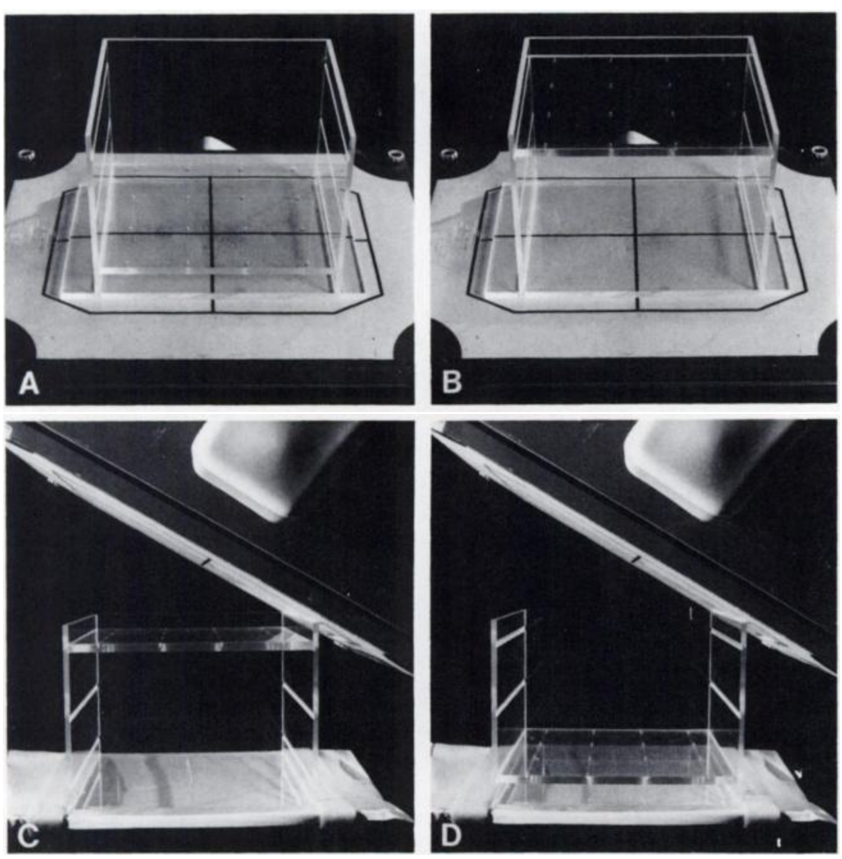


**FIGURE 2**
The jig positioned on the parallel hole collimator with plate containing 16 $^{99m}Tc$ point sources close to collimator (A) then shifted by 20 cm (B); and under the slant-hole collimator with plate close to collimator (C) then shifted 20 cm (D).

slant hole collimators the jig was secured to the imaging couch in a position directly beneath the camera head which was tilted to 30° to the horizontal. In this situation, the jig was very carefully leveled to be exactly horizontal in both X and Y directions, and the camera head was adjusted to be exactly horizontal in the X direction (perpendicular with the axis of rotation) using a spirit level which had an accuracy of 1° in 1 m (Fig. 2B).

With the point sources in the position closest to the collimator face (position I) a static acquisition was obtained in a 256 × 256 matrix using the 1.4 analog magnification of the camera. The plate was then displaced by 20 cm (position II) and a second acquisition obtained. The total time of the second acquisition was adjusted to give maximum count statistics similar to the first acquisition.

The data of the two acquisitions in positions I and II were smoothed then the exact X and Y coordinates of each point source were determined by calculation of the centroids of each image (5). For each of the 16 point sources the shift d in X and Y coordinates between positions I and II was determined. In order to convert d from pixels to mm, the pixel size in both X and Y directions was determined from the parallel hole collimator data. The same pixel size in the X-direction was used for the slant hole collimator whereas the pixel size in the Y-direction was multiplied by a factor 0.866 (i.e., Cos30) to correct for the camera head tilt of 30°.

The angulation error, $\alpha$, was then determined for each point source from Eq. (1) given above. For the particular SPECT system used, the pixel size for the 256 × 256 matrix was measured to be 1.43 mm. Therefore, for a separation between positions I and II of 200 mm and an angulation error of 1°, a shift in d of 2.44 pixels could be expected.

This method was first applied to measuring the collimator hole angulation of the high-resolution parallel hole collimator. The accuracy of the jig was checked by repeating the measurements after rotating the jig through 90° and 180°, but maintaining the same position on the collimator. Also reproducibility was checked by four repeat measurements without rotating or moving the jig. The method was then used as an acceptance test for two high resolution 30° nominal slant hole collimators.

**Camera Head Tilt**

When a radioactive point source is placed at a distance r off the axis of rotation and a SPECT acquisition through 360° around this point source is obtained, this is equivalent to holding the camera stationary and moving the source around a circle radius r. The images resulting from such a motion will describe a sinusoidal pattern in the X-direction, $x(\phi)$, due to the projection of the point source onto the detector as it rotates through 360° (Fig. 3A). The amplitude of this sinusoidal pattern in the X-direction is r, and from these data the center of rotation offset may be calculated.

In the Y-direction, a sinusoidal pattern will also be projected onto the detector as the point source describes a circle (Fig. 3B). However, in this projection, the amplitude of the pattern is dependent upon the angle of tilt, $\theta$, which the collimator holes make with the orthogonal to the axis of rotation. In the special case when the collimator holes are perfectly orthogonal to the axis of rotation, then the angle of tilt is 0 and a pattern of constant Y is described. When the collimator holes are tilted at an angle $\theta$ to the orthogonal then the amplitude of the pattern is $r\sin(\theta)$. The summation of all the projection images produces an ellipse from which the major axis in X direction gives 2r and the minor axis in Y gives $2r\sin(\theta)$ so that the tilt angle $\theta$ can be calculated (Fig. 4). Measurement of angle $\theta$ for a particular combination of camera head tilt and collimator indicates the degree of hole orthogonality achieved in the SPECT acquisition. For a tilt angle $\theta$ equal to 1°, and a distance r of 14 cm, the minor axis $2r\sin(\theta)$ will give a magnitude of 0.5 cm, or ~ 1 pixel in a 64 × 64 matrix normally used for SPECT acquisition.

This technique was used to measure $\theta$ for different collimator and camera head tilt combinations. A $^{99m}$Tc point source was placed at ~ 14 cm off the axis of rotation. After adjusting the camera head to the desired degree of tilt, a 60-view SPECT acquisition over 360° was obtained using a 64 × 64 matrix. The 0° camera head tilt was adjusted with the spirit

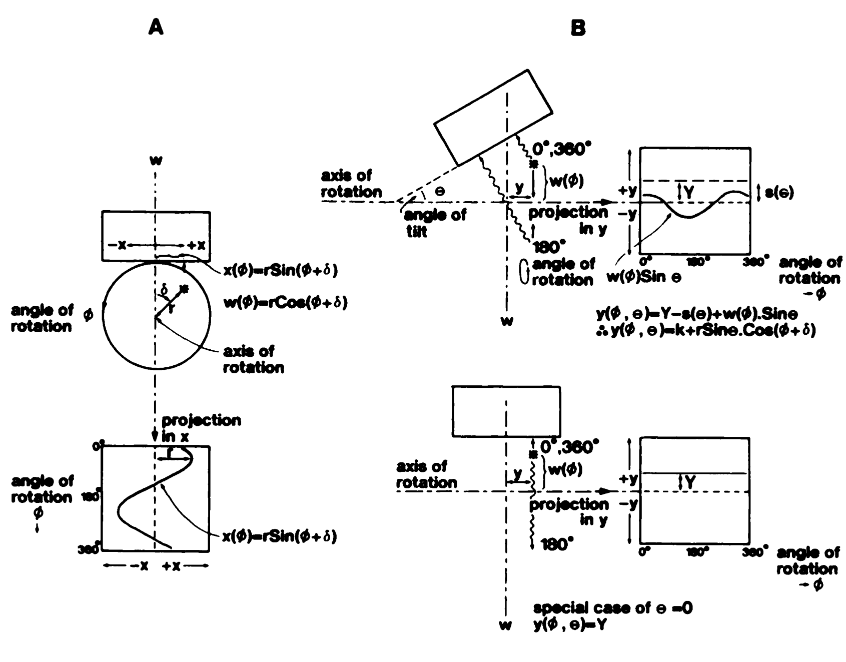


**FIGURE 3**
Schema illustrating projections of image formed by a 360° rotation of a point source at radius r about the axis of rotation. A: Front view, projection in X: image describes locus $x(\phi) = r\mathrm{Sin}(\phi + \delta)$ as source describes circle in plane of page; and B: Side view, projection in Y: image describes locus $y(\phi, \theta) = k + r\mathrm{Sin}(\theta)\mathrm{Cos}(\theta + \delta)$ (upper diagram, B) as source describes circle perpendicular to plane of page. In the special case of $\theta = 0$ (lower diagram, B) then $y(\phi, 0) = Y$ which is constant and gives a horizontal line in Y.

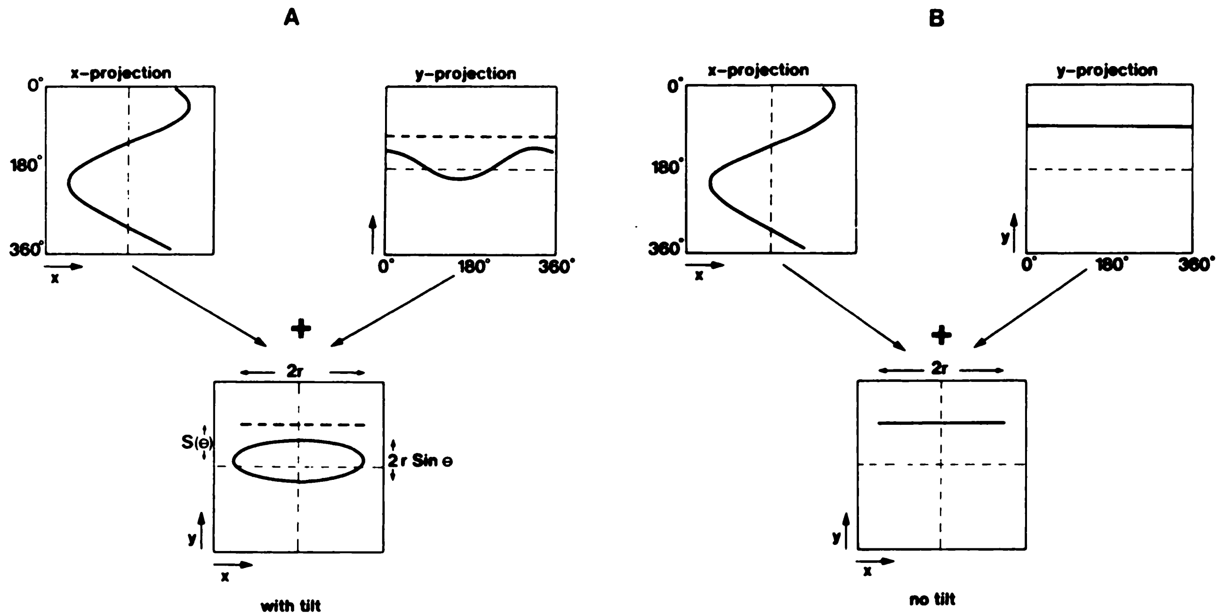


**FIGURE 4**
Schema illustrating summation of all projection images obtained from a 360° rotation around a point source positioned off axis when tilt angle 〈 〉 0 (A) and tilt angle = 0 (B).

level and used as the reference for other desired tilt angles. From the acquired data, the exact X and Y coordinates of the centroid of the point source image in each view were determined (*5*), then the magnitude of the major and minor axes were determined from the summation of views and finally the tilt angle $\theta$ was calculated.

With the parallel hole collimator, measurements were obtained with the camera head tilted to +1°, 0°, and −1° in order to ascertain the sensitivity of this method. Because of the considerable variation in collimator hole angulation found for the first slant hole collimator, tilt measurements were made at different Y locations. In this way the tilt angle $\theta$ was determined at intervals across the Y axis of the collimator.

## RESULTS

### Collimator Hole Angulation

The measurements of collimator hole angulation obtained for the collimators investigated are shown in Figure 5. Repeat measurements for both collimator types including those obtained after rotating the jig gave an s.d. of < 0.1° for each point source.

The parallel hole collimator showed a small variation in hole angulation in both X and Y directions (Fig. 5A). Since the collimator surface was parallel with the detector plane, confirmed by the spirit level, the small offset angle was attributed to the collimator holes themselves. However, the first slant hole collimator (Fig. 5B) showed considerable variation of hole angulation, that also deviated considerably from the nominal 30° angulation specified. A central area indicated an angulation of ~ 25°. This increased to greater than 28° further towards the periphery of the collimator. Because of this unacceptable variation in hole angulation this collimator was replaced. The measurements for the new slant hole collimator are given in Figure 5C.

### Camera Head Tilt

Figure 6 shows the measurements of the tilt angle $\theta$ obtained for the parallel hole collimator. The camera head tilted to +1°, 0°, and −1° gave hole tilt angles $\theta$ of, respectively, +0.5, −0.5, and −1.4°. These corresponded well with the average hole angulation in Y of −0.2° measured using the parallel platform jig. The direction of the path defined by the point source images during the 360° rotation is indicated by an arrow in the figure, and is seen to change direction as the hole tilt angle changes from negative to positive with respect to the orthogonal.

The downward slope in the major axes of the ellipses shown in Figure 6 was unexpected and disturbing. On investigation it was found that, when the camera head was set to zero degrees tilt, the Y coordinate of a point source changed in the same manner as the camera rotated between 0° and 360°. This occurred regardless of the magnitude of the radius of rotation or actual position of the point source in the field-of-view. The shift in Y was ~ 1.3 pixels (64 × 64 matrix) from a higher to a lower coordinate between the 0° and 180° angle of rotation. The detector remained horizontal at these angles as ascertained from the spirit level. On further investigation using a pointer fixed to the center of the collimator it was observed that there was a physical motion of the whole camera head away from the gantry of ~ 7 mm as the camera rotated between 0° and 180°. This corrected itself as rotation continued through to 360°. The measured Y coordinate shift in pixels and the observed physical motion correlated well.

**HR Parallel-Hole Collimator X°**

| | | | |
|---|---|---|---|
| -0.2 | -0.2 | -0.1 | -0.1 |
| -0.2 | -0.2 | -0.1 | 0.0 |
| -0.1 | -0.1 | -0.1 | +0.1 |
| 0.0 | -0.1 | 0.0 | 0.0 |

Average -0.1° ± 0.1° SD

**HR Parallel-Hole Collimator Y°**

| | | | |
|---|---|---|---|
| -0.1 | -0.2 | -0.1 | -0.1 |
| -0.2 | -0.2 | -0.3 | -0.4 |
| -0.2 | -0.3 | -0.2 | -0.3 |
| -0.1 | -0.2 | -0.2 | -0.3 |

Average -0.2° ± 0.1° SD

A

**30° Slant-Hole Collimator X°**

| | | | |
|---|---|---|---|
| +0.2 | +0.3 | +0.2 | -0.1 |
| +0.2 | +0.2 | +0.1 | +0.2 |
| -0.3 | -0.1 | +0.2 | +0.5 |
| -0.5 | -0.3 | +0.3 | +0.6 |

Average +0.1° ± 0.3° SD

**30° Slant-Hole Collimator Y°**

| | | | |
|---|---|---|---|
| +26.5 | +26.5 | +26.6 | +27.0 |
| +25.8 | +24.8 | +24.9 | +26.2 |
| +26.5 | +25.3 | +25.7 | +26.6 |
| +28.2 | +28.2 | +28.2 | +27.5 |

Average +26.5° ± 1.1° SD

B

**New 30° Slant-Hole Collimator X°**

| | | | |
|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 |
| -0.2 | +0.2 | 0.0 | 0.0 |
| -0.1 | +0.1 | 0.0 | 0.0 |
| 0.0 | -0.1 | +0.1 | 0.0 |

Average 0.0° ± 0.1° SD

**New 30° Slant-Hole Collimator Y°**

| | | | |
|---|---|---|---|
| +29.7 | +29.7 | +29.5 | +29.6 |
| +29.7 | +29.5 | +29.5 | +29.6 |
| +29.7 | +29.2 | +29.3 | +29.5 |
| +29.9 | +29.7 | +29.7 | +29.6 |

Average +29.6° ± 0.2° SD

C

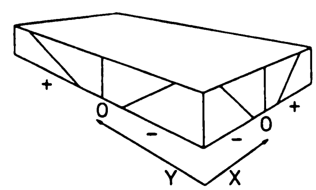


**FIGURE 5**
Collimator hole angulation measured for three collimators. Left side: angulation in X direction. Right side: angulation in Y direction. The direction of angulation is given in the lower figure.

Because of this gantry fault, special care had to be exercised in positioning the point source to avoid introducing errors into the calculation of angle $\theta$ due to the forward motion of the camera head.

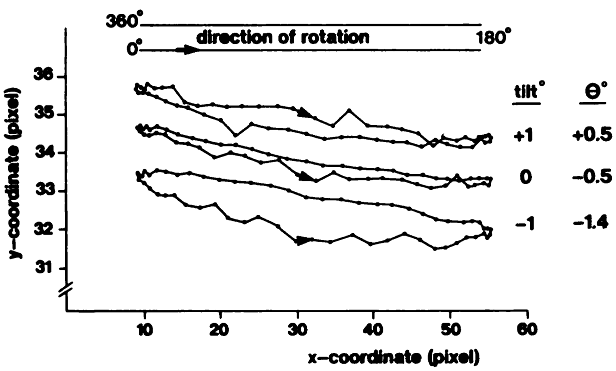


**FIGURE 6**
Ellipses obtained from rotation around a point source placed off axis for the parallel hole collimator tilted to +1°, 0°, and −1°. Note the direction of rotation change as the measured tilt angle $\theta$ changes from a positive to negative value.

Figure 7 shows measurements of tilt angle $\theta$ for the first slant hole collimator at different Y locations obtained with the camera head tilted to a fixed 25°. The camera head tilt of 25° combined with the measured hole tilt angle $\theta$ at each Y location gives the central collimator hole angulation in Y at these locations. These values as well as the actual loop formed by the described path correspond closely with the angulation values in Y found with the parallel platform jig (Fig. 5B).

## DISCUSSION

This study was stimulated by the delivery of a slant hole collimator to be used for SPECT imaging of the brain. Although a nominal value of 30° collimator hole angulation was specified it was deemed desirable to establish methods to confirm this accurately. In addition, the question of how to verify that a particular degree of camera head tilt was indeed correct arose. The digital display on the camera gantry, calibrated in degrees, was not considered sufficiently reliable.

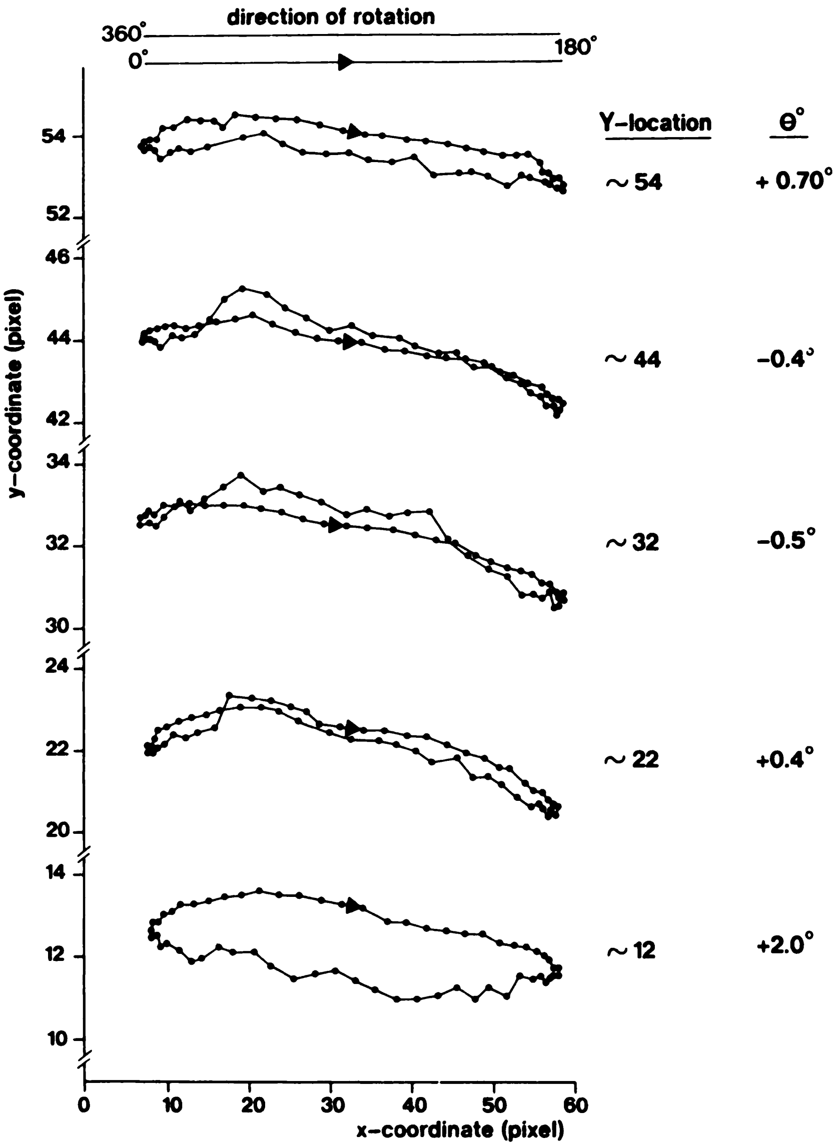


**FIGURE 7**
Ellipses obtained with the first slant hole collimator tilted to a fixed 25° angle for a point source off axis positioned at five different Y levels. The tilt angle θ measured and shape of the ellipses formed are indicative of changes in the effective hole tilt with the orthogonal.

The jig used to measure the hole angulation was simple to construct and to use. It confirmed that the parallel hole collimator holes were close to perpendicular over the area measured. A more thorough mapping of the collimator hole angulation was not considered necessary since the 16 measurements showed close agreement with each other and to the angulation expected. However, other parts of the collimator could easily be also measured by translating the jig several centimeters in the X or Y direction and repeating the measurements. Alternatively, a larger matrix of point sources could be created to map the collimator hole angulation more thoroughly.

The first 30° nominal slant hole collimator indicated a wide variation of hole angulation that ranged between 24.8° and 28.2° over the measured collimator area and, furthermore, bore no resemblance to the nominal value expected. Had a camera head tilt of 30° been adopted for SPECT acquisition without any confirmation that this was the correct tilt angle, then the combined camera head tilt and hole angulation would have resulted in an error of > 5° within the central portion of the collimator, the part most likely to be used for SPECT brain imaging. Such an error would produce considerable loss of reconstructed image quality.

Hole angulation determinations for the parallel and slant hole collimators presented adequate evidence that the slant hole collimator was outside specifications. The new slant hole collimator supplied was similarly tested and was accepted in part on the basis of these hole angulation measurements which were now less variable and were within acceptable limits of the specifications (±0.3°).

The tilt angle θ measured by acquiring a SPECT acquisition of a point source off axis gave the effective residual tilt from the combination of collimator hole angulation and camera head tilt applied. For an accurate setup of the camera head the values of θ corroborated the jig angulation measured in the Y direction. Measurements were sensitive to within 0.5° of tilt. Using this method the camera head tilt was optimized for routine data acquisition for each collimator type and two separate spirit levels attached to the side of the camera head were calibrated accordingly. Recalibration was subsequently performed routinely. Such a simple confirmatory check is particularly important after a service adjustment of the gantry alignment and in addition to monitor any deterioration in mechanical stability. Since the data also provide the center of rotation offset in the X direction an extra quality control procedure does not necessarily need to be carried out.

These measurements may be performed on any SPECT system. The only provision is that software is available to determine exact X and Y coordinates of a point source image (*5,6*). If a jig is not available then the tilt angle $\theta$ provides a measure of the hole angulation in the Y direction combined with the head tilt setup. Determination of tilt angle $\theta$ obtained at different Y locations together with visual interpretation of the pathways of the ellipse formed by the summed projection images provide a good impression of the hole angulation across particular Y projection lines.

During the course of the measurements a gantry construction fault was discovered in the particular model SPECT system used. This problem was confirmed by the manufacturer as a known construction fault. The fault caused a significant displacement of the whole camera head during rotation. This was unrelated to both collimator hole angulation and camera head tilt, and could not be mechanically corrected. Optimizing the camera head tilt to collimator angulation still left a maximum misalignment in Y of ~ 1.3 pixels in a 64 × 64 matrix between 0° and 180° rotation. A "sinogram" obtained in the Y direction of the point source revealed loss of image data from many of the projections thereby leading to incomplete data for reconstruction of any transaxial slice. A suggested solution was to correct each projection image in the Y direction by a fixed calibrated amount (*7*). Other SPECT systems were not tested, but may reveal unexpected problems. Even though a manufacturer might have a stringent method of checking gantry alignment and detector motion integrity, such as the use of laser beams, it is still recommended that this be checked routinely in the clinical environment and throughout the lifetime of the SPECT system.

In conclusion, the measurements of collimator hole angulation and camera head tilt described are simple to perform and sensitive to the level of precision required. It is advisable to test the hole angulation of the collimators used for SPECT at acceptance. This is particularly important for dual or multi-headed systems. A check of camera head tilt should be incorporated as a standard, routine quality control procedure in addition to those normally advocated in order to ensure use of an optimum tilt angle for the collimator used. This will additionally check the integrity of the mechanical motion and stability of the detector head.

## NOTE

SPECT system Technicare Omega 500 scintillation camera with MCS 560 computer. Data analyzed on a Digital Equipment Gamma-11 computer system.


## ACKNOWLEDGMENTS

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## REFERENCES


1. Jaszczak RJ, Greer KL, Coleman RE. SPECT. In: Rao DV, Chandra R, Graham MC, eds. American Association of Physicists in Med. Monograph 10, New York: American Institute Physics, 1984.
2. Farrell TJ, Cradduck TD, Chamberlain R. The effect of collimators on center of rotation offset in SPECT. *J Nucl Med* 1984; 25:632–633.
3. Harkness BA, Rogers WL, Clinthorne NH, et al. SPECT: quality control procedures and artifact identification. *J Nucl Med Technol* 1983; 11:55–60.
4. Esser PD, Alderson PO, Mitnick RJ, et al. Angled-collimator SPECT (A-SPECT): an improved approach to cranial single photon emission tomography. *J Nucl Med* 1984; 25:805–809.
5. Standards for performance measurements of scintillation cameras. NEMA Standards Publication NU1-80, National Electrical Manufacturers' Association, Washington, 1980.
6. Silverstein EA, Spies SM, Spies WG, et al: Quantitative SPECT quality control by error analysis of point source images [Abstract]. *J Nucl Med* 1985; 26:P91.
7. Anderson JE, King SE, Lim CB. Two dimensional spatial correction for angular dependent variations during SPECT imaging. *Eur J Nucl Med* 1985; 11:A36.