Nonisotropic Point Spread Function as a Result of Collimator Design and Manufacturing Defects

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A point spread function (PSF) which was of an unusual form was observed when using a low energy collimator and a ^{99m}Tc point source. A lack of radial symmetry and the detection of events over 20 cm away from the center of the source were noted. The major quantitative effect of this was a variation in the resolution of the system with direction. The consequences of this are likely to be of importance especially for single photon emission computed tomographic (SPECT) imaging. The effect was produced by a combination of faults in the design and manufacture of the low energy collimators. It demonstrates the importance of making quantitative measurements of collimator performance in the quality control assessment of gamma camera systems. For SPECT imaging the replacement of lead foil collimators with cast collimators should be considered.

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During the course of tests carried out as part of a quality control program to assess the performance of a recently installed gamma camera, it was observed that the image of a point source was of an unusual form (Fig. 1). Further enquiries indicated that this phenomenon was not unique to this system, but was present on many other systems produced by the same manufacturer.

The image in Figure 1 was obtained from the camera's persistence monitor using a point source of technetium-99m (^{99m}Tc) placed over the center of the camera's field of view at a distance of 20 cm from the collimator face. A low-energy, general purpose collimator (GP) was used and the whole field of view is shown. The electronic y-axis of the camera points in the vertical direction and the x-axis in the horizontal. As can be seen, there are four lines passing through the center of the source which extend across the whole field of view. The most intense line is almost parallel to the y-axis and has the effect of making the central region of the image elliptical rather than circular. The line perpendicular to this is the least intense. The remaining two lines lie at angles of 35° to the most intense line which again enhances the elliptical shape of the central region.

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MATERIALS AND METHODS

A point source of ^{99m}Tc, of approximate size 0.2 × 0.2 × 0.2 cm, was used to assess the properties of the PSFs of the three low-energy collimators in our possession. The quantitative effects of the nonisotropic nature of the PSF of each collimator were measured by acquiring images of the point source onto a standard nuclear medicine computing system. For all measurements a 15% energy window was used.

Collimator Specifications

From the technical specifications given by the manufacturer the GP collimators had 51,600 hexagonal holes of length 2.36 cm and septal thickness 0.2 mm giving an effective hole diameter of 1.43 mm. For the high resolution (HR) collimator there were 85,400 hexagonal holes of length 2.36 cm and septal thickness 0.16 mm giving an effective hole diameter of 1.11 mm. For all collimators the 5% penetration energy was 160 keV.

RESULTS

Qualitative Assessment

If the point source was moved to different positions within the camera field of view an equivalent translation of the whole PSF was produced (Fig. 2). In fact,

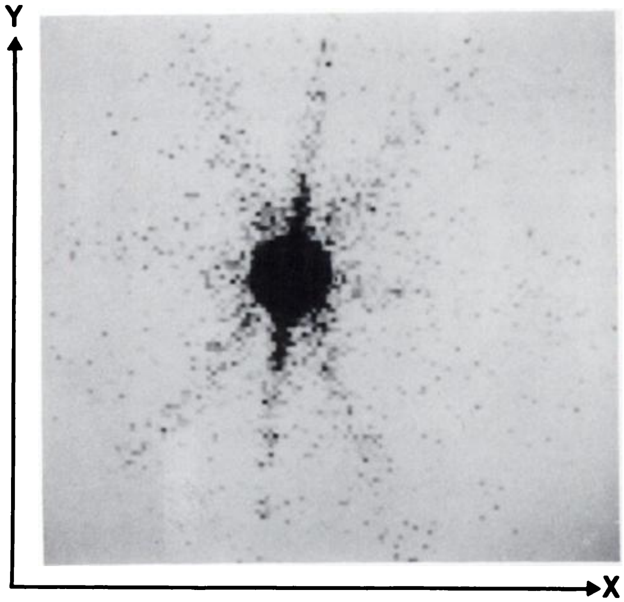

FIGURE 1
Image of a point source of ^{99m}Tc displayed on the gamma camera's persistence monitor. Four lines of apparent activity are observed to pass through the center of the image and extend across the whole of the field of view.

when the source center was outside the field of view the line structure could still be seen (Fig. 2D). Additionally, when the collimator was placed on the camera face and rotated, the whole pattern of the PSF rotated in an identical fashion. This is sufficient to demonstrate that the unusual form of the PSF originates from the collimator and is not produced, for example, by errors in the electronic calculation of the location of detected photons.

These phenomena were also observed with the HR collimator, the PSF of which is shown in Figure 3. A comparison with the PSF of the GP collimator, shows that it has the same general form but a different orientation (Fig. 1).

A newer design of GP collimator was also investigated; the PSF is shown in Figure 4. It has a different form from that of the two older collimators exhibiting a greater degree of rotational symmetry. The major difference appears to be the absence of the most intense line passing through the center of the PSF.

Effect on Resolution

As a consequence of the nonisotropic PSF the resolution of the camera will vary with direction. As the central part of the PSF is elliptical the resolution will be poorer in the direction of the longer axis of the ellipse.

To study the magnitude of this effect, the FWHM of the PSF was measured in directions corresponding to the x and y electronic axes of the camera. For the older design of GP collimator the longer axis of the ellipse is almost parallel to the y axis (Fig. 1). Thus the difference in the FWHM of the PSF when measured in the x and y directions should give a quantitative measure of the effect. The variation of the point source FWHM with

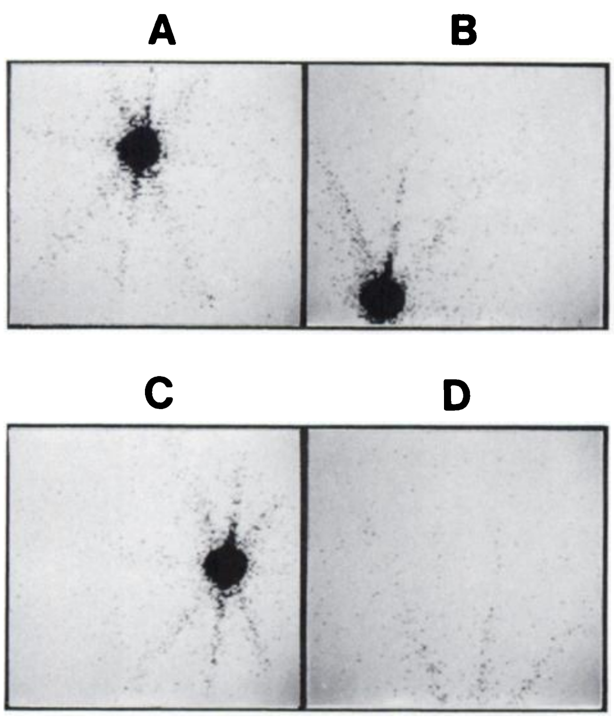

FIGURE 2
Moving the source within the field of view, (A), (B), and (C), produces a translation, without rotation, of the whole image pattern. Even when the source is outwith the field of view the line structure can still be seen (D).

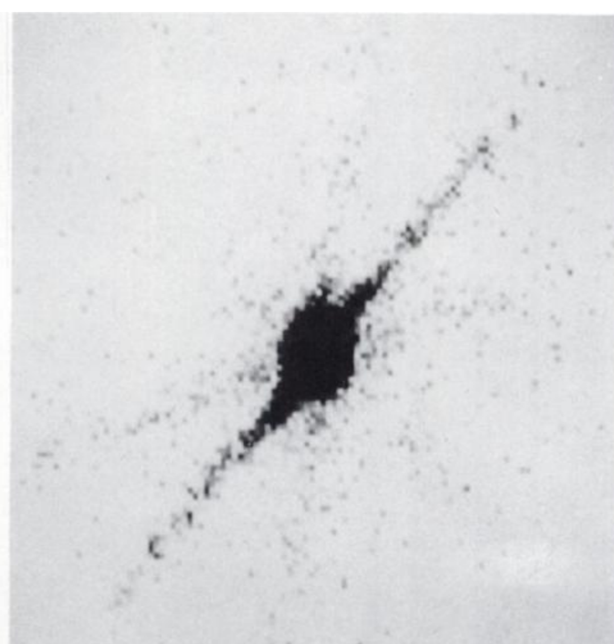

FIGURE 3
When the high resolution collimator was used a similar pattern, but with a different orientation, to that obtained with the GP collimator was observed.

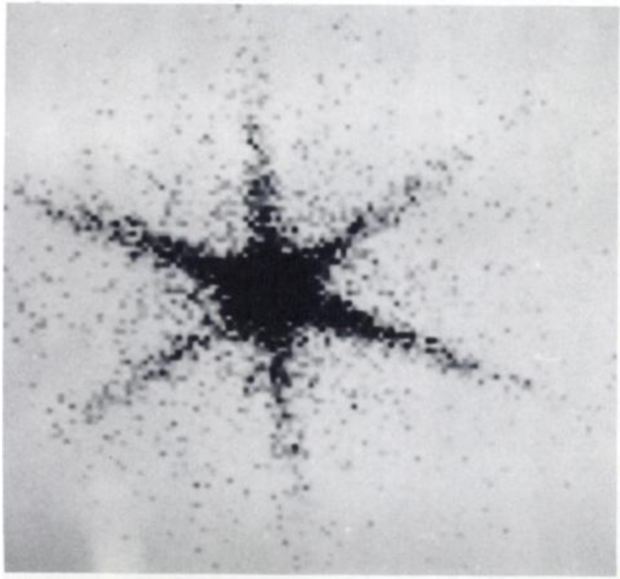

FIGURE 4
A newer design of GP collimator was found to exhibit a different form of PSF. Compared to the previous images, Figures 1–3, the most intense line appears to be absent.

distance from the camera for both x and y directions is shown in Figure 5. As expected, due to the elliptical shape of the PSF and the fact that the longer axis of the ellipse is almost parallel to the y-axis, the FWHM in the y direction was consistently greater than the FWHM in the x direction. It is notable that the smaller of the FWHM values was close to the manufacturer's specification but the FWHM in the orthogonal direction was around 2 mm greater.

For the HR collimator a similar, though less marked, effect was observed. The pattern has a different orientation from that produced by the GP collimator with the most intense line lying at an angle of ~38° to the x direction (Fig. 3). This will mean that its effect will be proportionally greater in the x direction although the magnitude of the increase in the FWHM will not be as pronounced as for the GP collimator. This is shown in Figure 6.

For the newer design of GP collimator there is a less marked variation of resolution with direction (Fig. 7). The FWHM is slightly greater in the x-direction due to the influence of the two oblique lines (Fig. 4). The absence of the most intense line makes the nonisotropic nature of the PSF less pronounced than for the other collimators.

Quantitative Effects

To investigate the quantitative effects of this phenomenon the digitized images obtained with a source to camera distance of 20 cm were used.

The fraction of the total counts in the view found outside the central quadrant of the image was measured. This quadrant was defined to be the 64 × 64 matrix at the center of the whole 256 × 256 view. As the camera field of view is 40 cm in diameter it corresponds to a square of size 10 cm at the center of the field of view. In addition, a 2% isocontour was defined for each image and the counts outside the area defined by it measured.

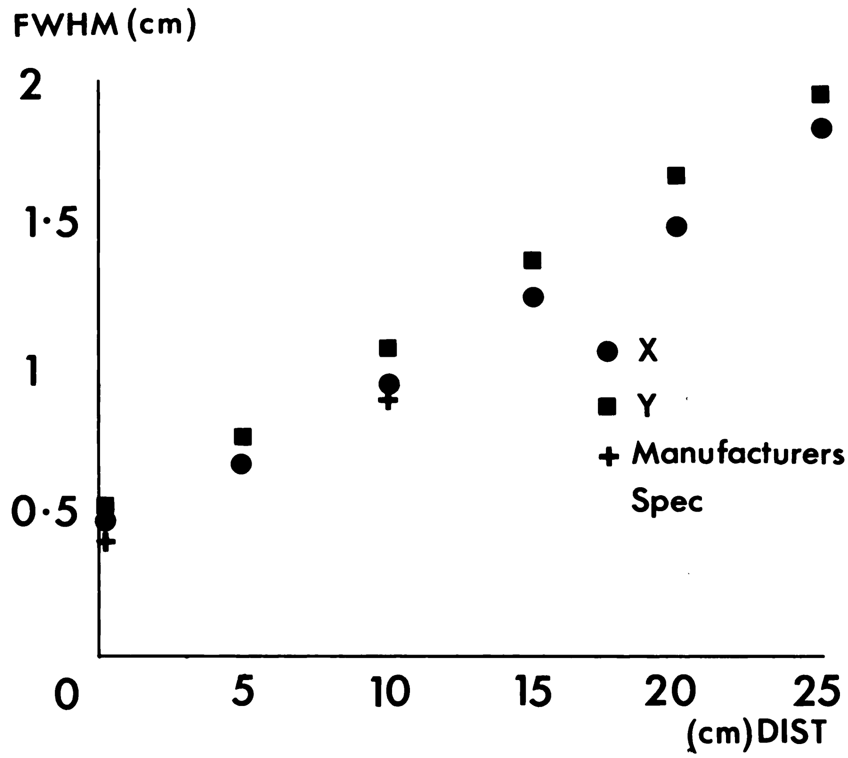

FIGURE 5
FWHM of point source v's distance from older design of GP collimator. The nonisotropic nature of the PSF produces a difference between the FWHM when measured parallel to the x and y electronic axes. The FWHM is larger in the y direction because the longer axis of the elliptically shaped PSF is almost parallel to it.

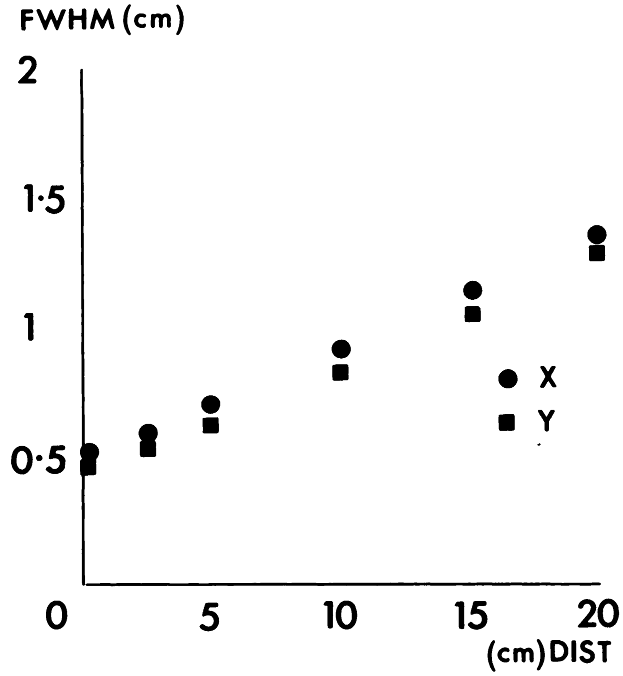

FIGURE 6
FWHM of point source v's distance from the high resolution collimator. For the high resolution collimator the angle between the longer axis of the elliptical PSF and the x-axis is 38° so the FWHM is larger along this direction. The discrepancy between the FWHM is less marked than for the older design of GP collimator.

For the HR collimator 3.1% of the counts in the whole view were outside the central quadrant. For the older GP collimator the figure was 3.6% and, surprisingly, for the newer design of GP collimator, 4.9%. The counts outside the 2% isocontour were respectively 10.2%, 9.9% and 12%.

The relative sensitivity of the three collimators was also measured; taking the HR to be 100%, the sensitivity of the older GP was 140% and the newer GP was 160%.

Thus, there would appear to be a significant level of septal penetration in all three collimators. Between 3% and 5% of the total counts in the field of view lie outside the central quadrant. Between 10% and 12% of the total counts lie outside the central region of the point source image as defined by a 2% isocontour. The largest breakthrough occurs in the newer GP collimator which also has the highest sensitivity. This would imply that in the redesign of the collimators there has been a reduction in the thickness of lead used to form the septa.

DISCUSSION

With the cooperation of the manufacturer it was identified that the previously described phenomena were produced by a combination of defects in both the design and manufacturer of the collimators.

The collimators are constructed by affixing lead foil strips with glue to produce hexagonal holes. If the construction process is less than perfect then gaps in the junction between the lead strips will allow photons to pass through the collimator preferentially along the direction of the strips. This will produce the most intense line in the PSF (*1*).

Photons travelling in a perpendicular direction to this will have to penetrate a double thickness of lead which explains the presence and orientation of the least intense line. Making the segments of lead, used at the junctions between the foil strips, of half thickness will increase the homogeneity of the response.

Furthermore the collimator holes have been stretched during the manufacturing process which explains the lack of hexagonal symmetry in the observed pattern. The magnitude of the stretch introduced appears to be constant as the oblique lines in the pattern are always at the same angle, 35 degrees, to the most intense line.

Redesign of the collimators and correction of errors in the manufacturing process have increased the homogeneity of the camera's response.

In general, the two dimensional structure of the PSF is not examined as part of gamma camera quality control investigations. System resolution is usually assessed by measuring the FWHM or modulation transfer

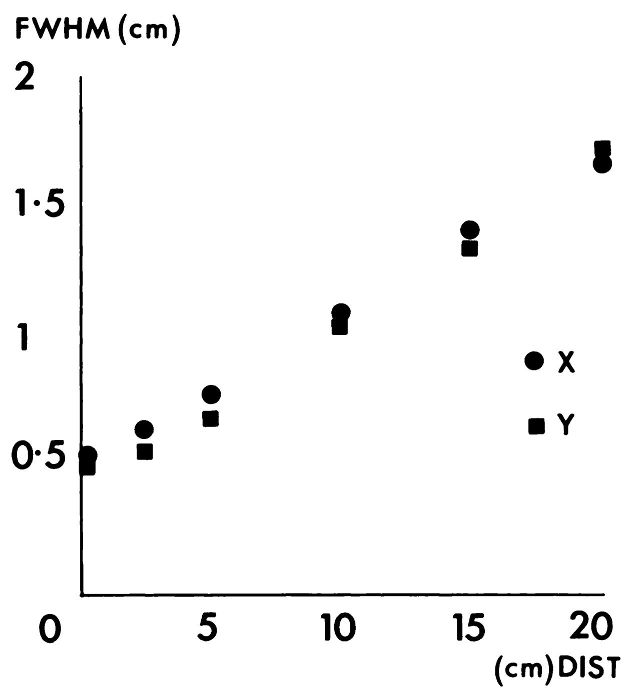

FIGURE 7
FWHM of point source v's distance from the newer design of GP collimator. There has been an improvement in the homogeneity of the PSF from the older design of collimator. The two oblique lines in the PSF, Figure 4, result in a slight increase in the FWHM in the x direction.

function of a line source. We would suggest that using a point source to make these measurements is not only easier in practice but that important information on the directional nature of the camera's response is gained.

Recently, attention has been paid to the improvement of collimator performance for SPECT imaging through the use of alternative designs to the parallel hole, e.g., cone beam and astigmatic, (*2–5*). However, the conventional parallel hole, lead foil, collimator is still by far the most commonly used; if the phenomena described herein are common, and are as severe as reported, there are important consequences for the continued use of lead foil collimators for SPECT imaging (*6*). A promising alternative has recently become available in the form of collimators manufactured by a casting process (*7*).

CONCLUSIONS

A combination of collimator design and manufacturing defects have produced a nonisotropic PSF. The major effect of this was to make the resolution of the system dependent on the direction in which it was measured, and, for the worst cases, outside the manufacturers performance specifications. This is likely to be of importance especially for SPECT.

Improvements in the way in which the lead strips are glued together, and alterations in the design, have increased the homogeneity of the cameras response. Even after redesign, however, significant percentages of the counts from a point source were still found to lie outside the central region of the source image.

This investigation illustrates the importance of making a quantitative assessment of the collimators in gamma camera quality assurance programs, and suggests that for SPECT imaging the replacement of lead foil with cast collimators should be considered.

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