Foil Collimator Defects: A Comparison with Cast Collimators

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Imperfections such as septal tears, improper alignment of channels, and improper seating can be built into collimators at the time of manufacture. The purpose of this study was to compare the collimator uniformity of a high-resolution low-energy foil collimator to that of a similar cast collimator. A 5 mCi point source of technetium-99m (^{99m}Tc) placed 5 m from the collimator face was imaged with both collimators. Line sources were imaged at 5 to 30 cm from the collimator face, both above and below the imaging table. A SPECT phantom filled with 10 mCi of ^{99m}Tc was imaged with both collimators. Transaxial images were reconstructed, and uniformity corrections were obtained, based on data from each collimator. In the distant point-source images, using the foil collimator, linear streaks and a sizeable cold defect were seen. These almost disappeared in the sheet-source images. Linear streaks were also present in the line-source images. The SPECT images showed small ring artifacts in three areas. None of these defects were seen with the cast collimator. These findings illustrate the importance of properly evaluating the uniformity of each collimator purchased with a new system.

A collimator consists of one or more holes in a dense material of high atomic number, such as lead or tungsten, which is almost opaque to the gamma photons encountered in nuclear medicine. Attached to a radiation detector and used for radionuclide imaging, the collimator performs the same function as the lens of a camera, and like a lens affects the sensitivity, spatial resolution, and depth of field of the imaging instrument (*1*).

Unlike the glass lens of a camera, which changes the direction of light rays by refraction to achieve a focussing effect, the collimator passively performs its function by absorbing and stopping most radiation except that arriving almost perpendicular to the detector face. Photons striking the collimator at oblique angles should not be allowed to interact with the camera crystal nor be included in the final image. It is only by careful design and construction of a collimator that reasonable spatial resolution and sensitivity can be achieved.

A number of imperfections may be built into collimators at the time of manufacture; including septal tears, improper alignment of channels, variations in the size of individual channels, nonuniformity in the thickness of septa and improper seating. Although collimator fabrication techniques have improved over the years to yield better performance, some nonuniformity defects still persist at the time of delivery.

New imaging applications such as single-photon emission computed tomography (SPECT) place much more stringent demands on camera system performance. The dual requirements of good uniformity and spatial linearity have been particularly emphasized in the SPECT literature (*2–5*). Modern cameras achieve their improved uniformity and spatial linearity by digital correction techniques (for energy, linearity, and uniformity). However, these corrections may be inadequate for SPECT when the collimator itself introduces a significant degree of nonuniformity. The final uniformity correction should be based on a sheet source imaged with the collimator, but even this may be insufficient in the presence of some collimator defects.

This paper presents several simple quality control procedures for examining collimator performance that can be used during the acceptance testing period. There are many additional quantitative and qualitative collimator performance tests, and the reader is referred to review articles for a more complete coverage of this topic (*4,5*). We will discuss how we examined and compared the performance of a new high resolution foil collimator to that of a similar cast collimator during the acceptance testing period of a new SPECT gamma camera system recently purchased by our institution.

MATERIALS AND METHODS

A new General Electric (GE) AC/T SPECT camera system was used to obtain all the images presented in this study. Images obtained with the high-resolution low-energy foil collimator (Precise G-413 collimator, Precise Corp., Caryville, TN) were compared to similar images obtained with a high-resolution low-energy cast collimator (Nuclear Fields B. V., Boxmeer, The Netherlands). Uniformity correction was per-

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formed using the camera manufacturer's suggested procedures. The linearity and energy maps were intrinsic and constructed without a collimator. The final uniformity map was made with the collimator in place and a sheet source at its face.

Separate uniformity corrections were created for each collimator. All images were corrected with the appropriate uniformity matrices and displayed for examination. Images were visually inspected for regions of nonuniformity and linear defects, and all SPECT images were inspected for ring artifacts.

Initially, planar images of a 5 mCi point source of technetium-99m (^{99m}Tc) placed 5 m from the collimator face were obtained. Additional planar images were obtained of line sources made with 10-ml plastic pipette tubes filled with a solution containing 100 μCi of ^{99m}Tc, diluted with ~10 ml of water. These sources were mounted on a flat sheet of cardboard for support and placed on a patient imaging table. Images of one-million counts were obtained with the camera above the table at distances of 5, 10, 15, 20, 25, and 30 cm from the sources, and again with the camera below the table at distances of 15, 20, 25, and 30 cm from the sources. These distances were chosen as representative of a clinically significant range.

SPECT images were obtained using a Data General SPECT Phantom (Atomic Products Corp., Shirley, NY) (Fig. 1), which was filled to capacity with distilled water containing 10 mCi of ^{99m}Tc and placed on the imaging table. The projection images were acquired in a 128 × 128 matrix for a 40-sec counting period for each of 64 steps, with the phantom at the same distance from the camera for both foil and cast collimators. Transaxial images were reconstructed using a Ramp filter, both with and without prefiltering by a Hann filter with a 1.0 cutoff, and post-processing attenuation correction using a 0.12 attenuation factor. Images from both collimators were displayed as slices of either 1 or 2 pixels thick for visual inspection.

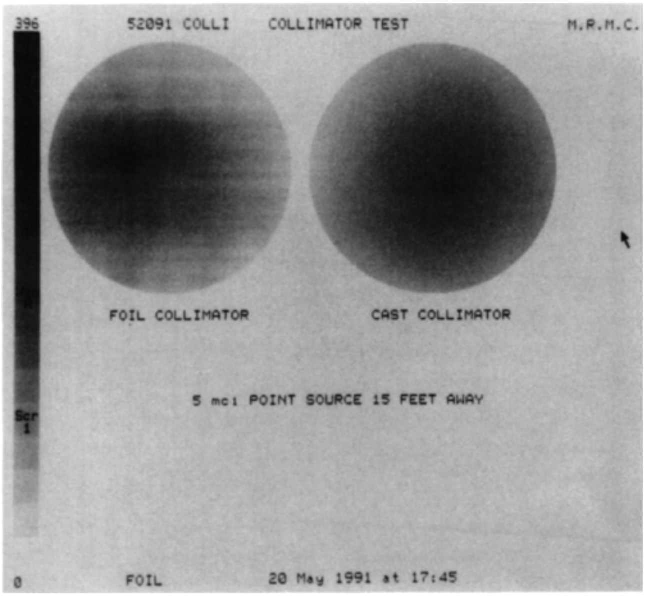

FIG. 2. One-million count planar image of 5 mCi point source of technetium-99m at 5 m (15 ft.) from camera face using a foil collimator and a cast collimator. Note presence of multiple linear defects and large cold spots on foil collimator image and relative lack of linear defects and cold spots on cast collimator image.

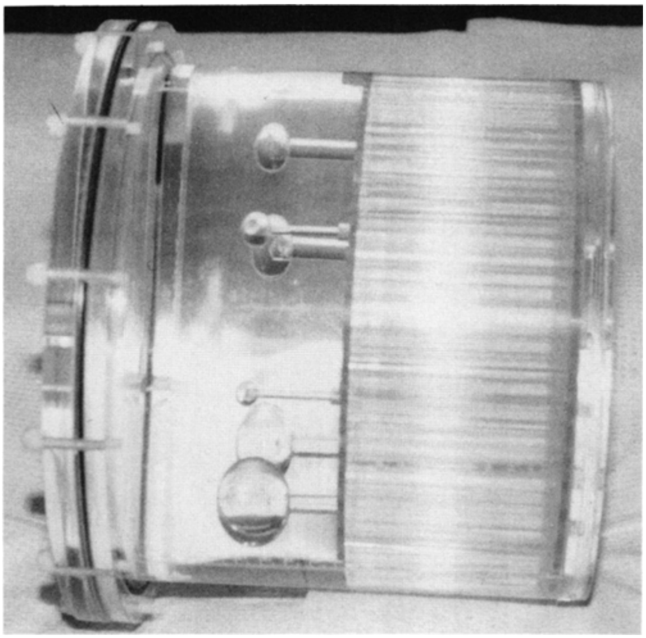

FIG. 1. Data General SPECT phantom used for quality assurance testing.

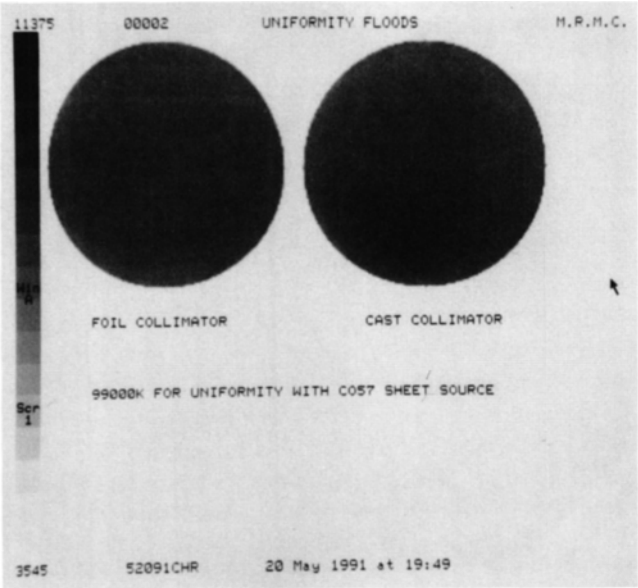

FIG. 3. Two one-million count planar images using sheet source at face of camera. Image at right is formed with use of cast collimator; no defects are noted. Image at left is formed with use of foil collimator and some questionable linear defects can be seen.

RESULTS

Figure 2 shows planar images obtained with the two low-energy, high-resolution collimators and a point source at 5 m from the collimator face. These images represent crude radiographs of the collimators, revealing multiple linear defects in the foil collimator (Fig. 2A) and no defects in the cast collimator (Fig. 2B). The conventional uniformity images obtained with a sheet source at the face of the collimator showed no defects with the cast collimator and only minor or questionable defects with the foil collimator (Fig. 3).

The line sources were set diagonally in the field of view to avoid alignment with the defects. Visual inspection reveals horizontal streak artifacts crossing the diagonal line images at 15, 20, 25, and 30 cm from the camera face with the foil collimator (Fig. 4). No artifacts are seen in the cast collimator images (Fig. 5).

Figures 6 and 7 represent multiple 2-pixel thick transaxial

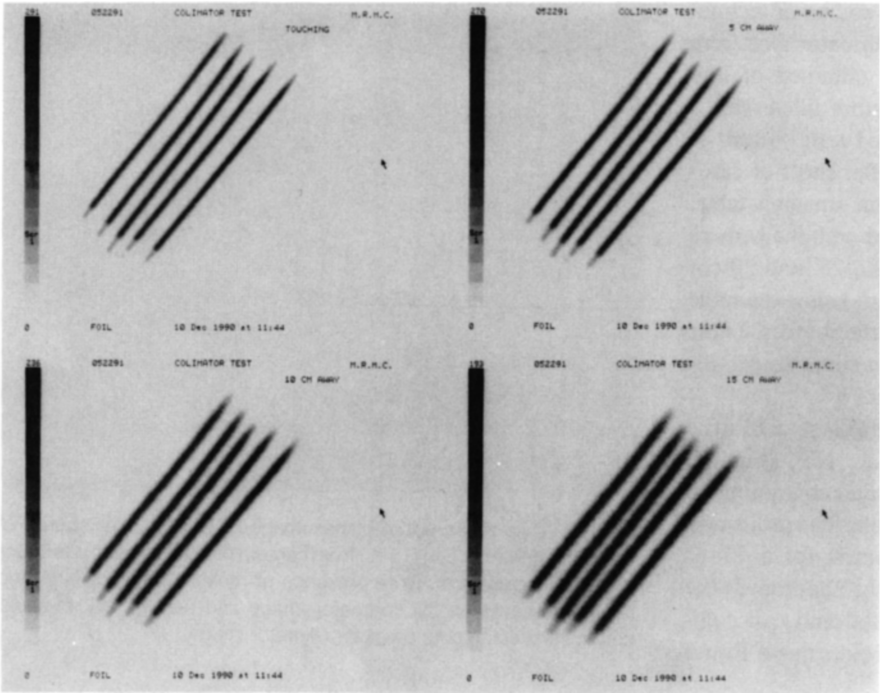

FIG. 4. Multiple planar images of line sources at 0, 5, 10, and 15 cm from face of camera using a foil collimator. Note linear defects in images obtained at 10 and 15 cm from camera face.

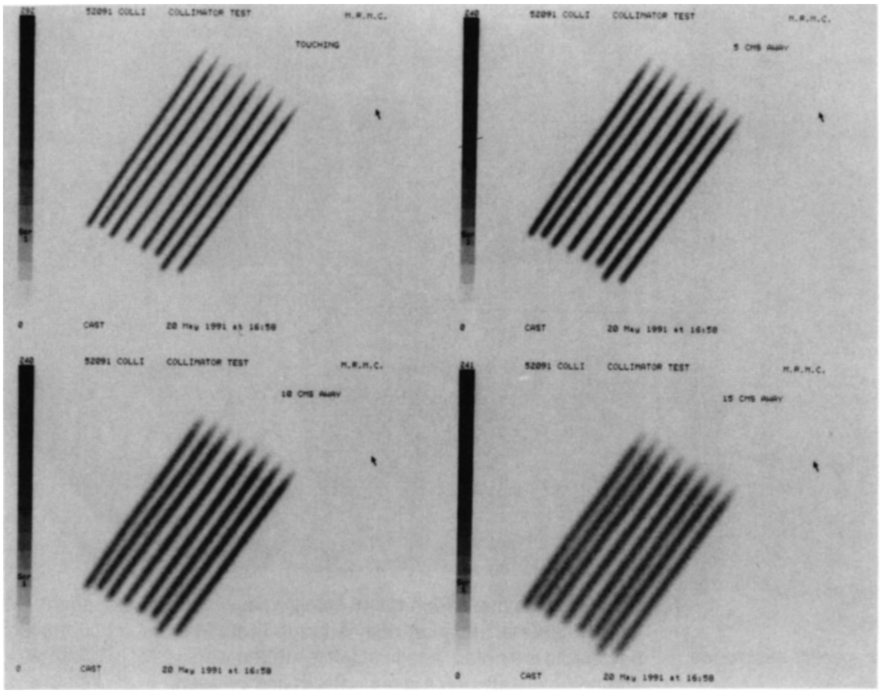

FIG. 5. Multiple planar images of line sources at 0, 5, 10, and 15 cm from face of camera using cast collimator. No defects are seen.

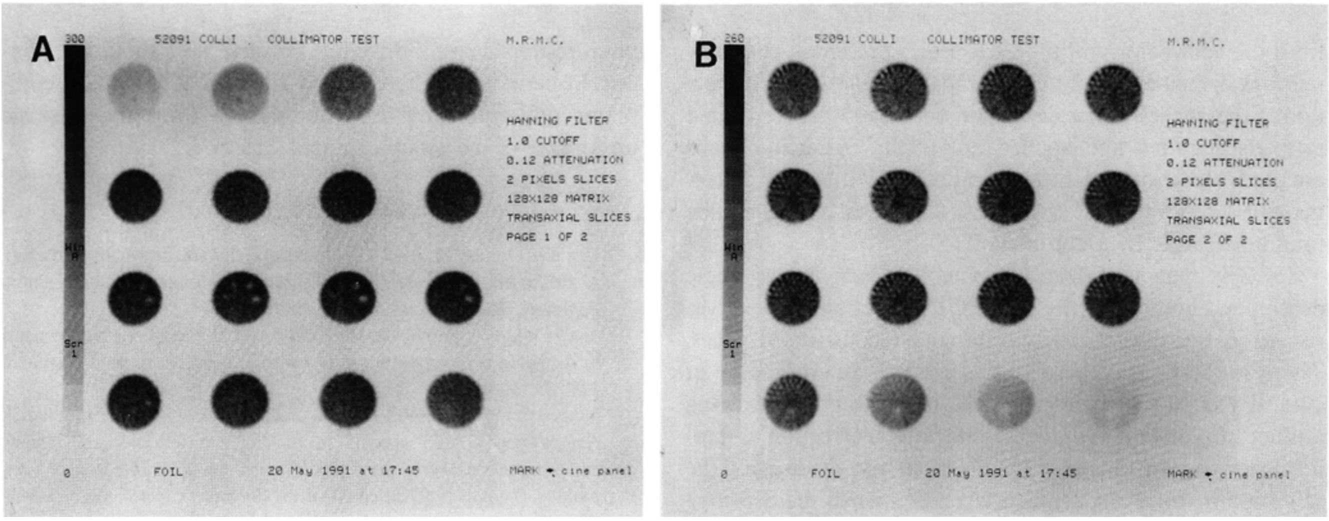

FIG. 6. Multiple reconstructed transaxial slices of SPECT images of phantom, acquired using foil collimator: (A) slices 1–16; (B) slices 17–32. Note ring artifacts in slices 1–3, 22–23, and 26–32.

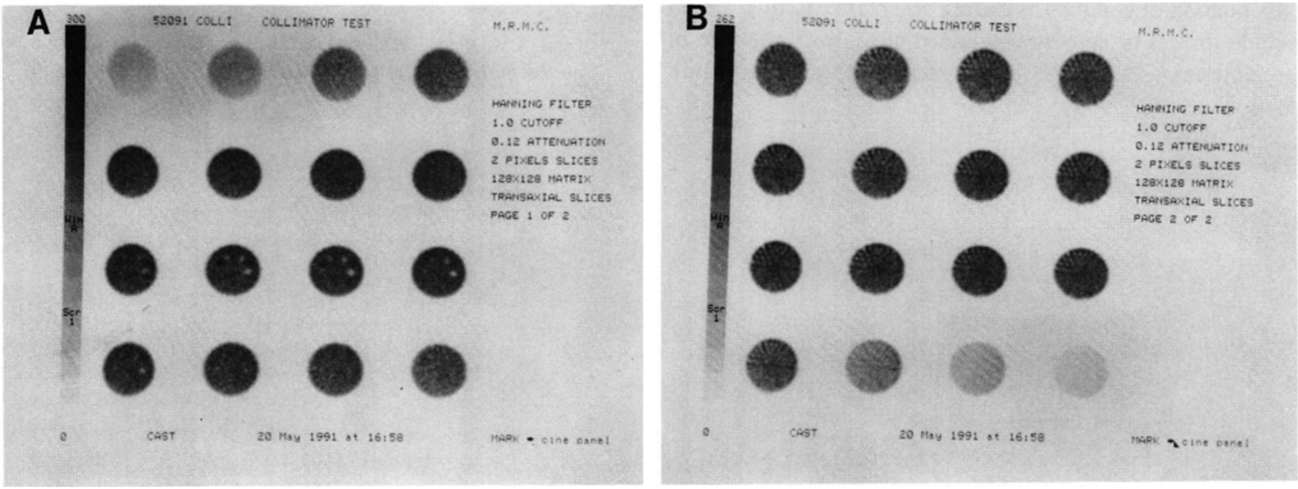

FIG. 7. Multiple transaxial slices of SPECT images using cast collimator. Note absence of ring artifacts.

slices through a SPECT phantom filled with a solution containing 10 mCi of ^{99m}Tc. Note the ring artifacts in slices 1–3, 22–23, and 26–32 in the transaxial sections of the phantom, when using the foil collimator. These artifacts were observed on five separate occasions with two different GE SPECT gamma camera systems. The defects are more apparent on the images reconstructed after prefiltering (Fig. 6). There are no ring artifacts when the cast collimator is used (Fig. 7).

DISCUSSION

The collimator of any radiation detector used for imaging is the first processing layer that photons encounter. Defects in its structure may produce distortions or artifacts in the images.

Collimator-related problems are most easily diagnosed by examination of the collimator for physical damage or foreign objects and by comparison of flood field images obtained with and without the collimator in place. However, these simple tests may not be sufficient to detect septal leaks.

In this study, we found a consistent problem with a high-resolution low-energy foil collimator that was not seen with a similarly designed cast collimator. A simple but "old" test dramatically illustrated this problem. When a point source was placed 5 m from the face of the foil collimator, the image demonstrated a pattern of lines of varying intensity. In 1983, Yeh (*6*) published a description of a similar type of defect in a hexagonal (foil type) collimator, which was reportedly due to small design defects in the foils as they came together to form the hexagonal channels.

Collimators sometimes suffer from defects of construction. These defects may be invisible in a sheet-source image made with the source at the face of the collimator. However, the defects are clearly apparent in a radiograph, or in the image of a distant point source. The resultant artifacts in planar images are more apparent for sources at greater distances from the collimator, but they are clearly present at clinically relevant distances (15–30 cm) through simple visual inspection of the images. These defects do not disappear, even when properly acquired and applied uniformity correction maps are used. More sophisticated quantitative methods for detecting and describing these uniformity and septal defects can be found in a paper by Malmin et al. (*5*).

SPECT imaging, especially, involves activity at these depths, and nonuniformity of SPECT projection images gives rise to ring artifacts in the transaxial reconstructed slices. These artifacts could cause serious errors in interpretation of clinical images (*7*). In our SPECT reconstruction, the ring artifact appears even though uniformity correction is performed using an image of the sheet source made with the same collimator. Ring artifacts were seen when the defective foil collimator was used, but not with the cast collimator.

CONCLUSION

Evaluation of collimators during acceptance testing should include images of activity positioned away from the face of the collimator, e.g., SPECT phantom images or a distant point source. These simple but sensitive tests should be conducted periodically thereafter to assure that (extrinsic) collimator nonuniformity does not detract from the intrinsic uniformity of the gamma camera system.

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