THALLIUM-201: SCINTILLATION CAMERA IMAGING CONSIDERATIONS

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Modulation transfer functions, line spread functions, and energy spectra were obtained for an Anger scintillation camera using three different collimators and commercially produced ^{201}Tl. Images of a thyroid phantom were obtained using these collimators. For each of the three collimators, line spread functions and modulation transfer functions were obtained for both the 75-keV x-ray and 167-keV gamma photon of ^{201}Tl. Although the intrinsic resolution of the scintillation camera is superior when imaging with the 167-keV gamma photon, system performance was superior when the 75-keV x-ray was imaged. Contamination from ^{202}Tl, which emits abundant 439-keV gamma photons, degraded images taken at 167 keV because of septum penetration. At 75 and 167 keV the converging collimator yielded the best system performance. Imaging time was significantly shorter using the 75-keV x-rays.

The introduction of thallium as a radiodiagnostic agent by Kawana et al in 1970 (*1*) and the recent work of Lebowitz et al (*2*) with ^{201}Tl has excited enthusiasm for myocardial perfusion studies using the scintillation camera. Typically, myocardial perfusion studies have been performed using ^{43}K and other high-energy potassium analogs. Because of this, imaging has required the use of scanners or scintillation cameras with specially shielded high-energy collimators (*3,4*). These techniques are cumbersome. Furthermore, when the scintillation camera is used for infarct imaging, as with technetium-tagged diagnostic agents (*5*), it would be advantageous to perform the perfusion studies on that same patient with a camera. The utility of such a combined study for enhanced cardiac diagnosis has been discussed by Lebowitz (*2*).

Thallium-201 is a low-energy gamma emitter, with principal photopeaks at 135 keV and 167 keV and x-rays from the mercury daughter at 69–83 keV (*6*); it is therefore a suitable emitter for imaging with standard low-energy collimators. Furthermore, its biologic properties have been investigated in several laboratories (*2,5*) with indications that the thallous ion (Tl^+) is also a good biologic analog of potassium. Its half-life of 73 hr is convenient and it delivers a smaller whole-body dose to the patient per millicurie than ^{43}K (*2*).

To date, however, there has been a lack of quantitative information regarding the imaging abilities of this nuclide with an Anger scintillation camera, and a study of its imaging properties was therefore conducted. Significant conclusions were reached regarding the performance of ^{201}Tl and the effects of a ^{202}Tl contaminant.

MATERIALS AND METHODS

For this study ^{201}Tl, prepared by the reaction $^{203}\mathrm{Tl(p,3n)}^{201}\mathrm{Pb}^{\beta+\epsilon} \rightarrow {}^{201}\mathrm{Tl}$, was obtained from New England Nuclear Corp. The radiometric purity of the sample was specified as better than 99% and data were recorded within 3–4 hr of the calibration time.

Data were taken with a Searle Radiographics Pho/Gamma HP camera using a Picker thyroid phantom filled with approximately ½ mCi of ^{201}Tl and a line source consisting of a glass capillary tube, 30 cm long with a 1 mm inside diameter, filled with ⅓ mCi of ^{201}Tl. Energy spectra and line spread functions (LSF) were obtained with the aid of a multichannel analyzer, and modulation transfer functions (MTF) were calculated from the LSFs by a minicomputer. Data were taken on the following Searle Radiographics collimators: (A) high resolution (part #821741); (B) 4,000-hole collimator (part #820719); and (C) a specially designed converging collimator (*7*).

Received March 26, 1975; revision accepted July 26, 1975.

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The data for the LSF and energy spectra were taken using the line source at a distance of 12 cm from the collimator face. Images of the thyroid phantom were also taken at this distance. For both the LSF and phantom images, 4 cm of Lucite scattering material was placed between the source and collimator, whereas for the energy spectra no scattering material was used. Line spread functions and phantom images for each collimator were obtained at both 75 keV and 167 keV using a 25% analyzer window. Intrinsic resolution of the scintillation camera was determined by placing a lead sheet containing nine 1-mm-wide slits spaced 3 cm apart directly over the scintillation crystal. A source of 1 mCi of ^{201}Tl was then placed approximately 75 cm from the camera and the average full width at half maximum (FWHM) of the resultant slit pattern was computed.

RESULTS AND DISCUSSION

The energy spectra obtained on the Anger camera through the various collimators are shown in Fig. 1. The x-rays of energy 69–83 keV are most abundant and appear as a single peak centered at 75 keV, while a double peak is present from the 167-keV and 135-keV emissions of ^{201}Tl. A significant 439-keV peak, due to ^{202}Tl contamination, is observed in the spectrum through the high-resolution collimator and to a lesser extent through the converging collimator. The principal radiations from ^{201}Tl and ^{202}Tl and their abundances are given in Table 1.

Although the quantity of ^{202}Tl is minimal (<1%), its 439-keV gamma photon is not attenuated significantly by the collimators, while the lower-energy radiations from ^{201}Tl are attenuated by a factor of approximately 10^4. The number of 439-keV gamma photons within a spectrum taken on the scintillation camera with no collimator is insignificant compared

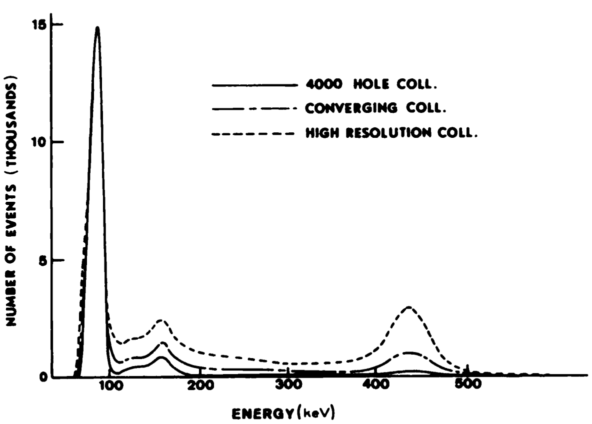

FIG. 1. Energy spectra of ^{201}Tl on Anger scintillation camera through three different collimators in air. Source-to-collimator distance was 12 cm.

TABLE 1. GAMMA PHOTON TRANSITIONS FROM THALLIUM ISOTOPES AND THEIR INTENSITIES

Isotope	Half-life	Principle gamma photon energy (keV)	Gamma photon intensities*
^{201}Tl (6,2)	73 hr	69–83 (Hg x-ray)	98%
		135	2%
		167	8%
^{202}Tl (6)	12 days	439	95%

* Number of transitions per 100 decays of the isotope.

to the number of 167-keV gamma photons. However, the spectrum taken through the high-resolution collimator contains twice as many 439-keV as 167-keV gamma photons. The effect of septum penetration is minimized in the 4,000-hole collimator, which has septa three times as thick as those of the high-resolution collimator. The spectrum through the 4,000-hole collimator contains only one-tenth as many 439-keV as 167-keV gamma photons.

The penetration of large numbers of high-energy gamma photons has a degrading effect on image quality by virtue of Compton scatter within the NaI crystal which deposits events in the window set for lower-energy gamma photons. The data in Fig. 1 indicate that the Compton background for the high-resolution collimator is twice that of the converging collimator, whereas the Compton background with the 4,000-hole collimator is insignificant.

The intrinsic spatial resolution of an Anger scintillation camera at 167 keV is superior to that at 75 keV. Measured values for ^{201}Tl were 7.6 mm for 167-keV gamma photons and 10.6 mm for 75-keV x-rays. The line spread functions for the three collimators imaged at 75 keV and at 167 keV are shown in Figs. 2 and 3, respectively. The LSFs obtained at 167 keV show a high background for the high-resolution and converging collimators. The counts in the wings of the LSF start at 18% of the peak counts for the high-resolution collimator and at 13% for the converging collimator. The background is attributed to the Compton scatter that falls into the 25% window set at 167 keV from the 439-keV gamma photons that penetrated the collimator. In contrast, when the same number of peak counts were obtained using the 75-keV x-ray with the high-resolution collimator, imaging took only one-seventh the time and resulted in less than 1% background. When LSFs were taken on the high-resolution collimator using the 75-keV and 167-keV windows for the same length of time, the backgrounds were nearly equal. A constant background from the Compton scatter of the 439-keV gamma photon is therefore

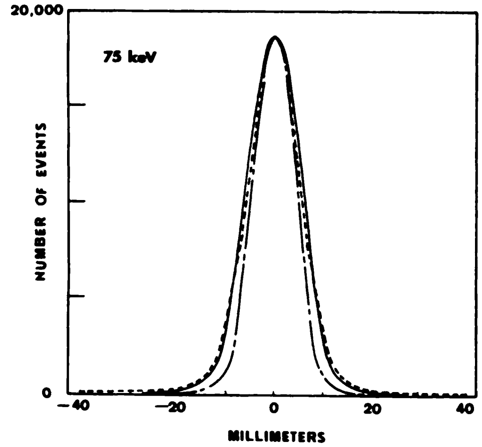

FIG. 2. Line spread functions of ^{201}Tl line source imaged with a 25% window centered around 75 keV, with various collimators. Line source was 12 cm from collimator with 4 cm of Lucite interposed between source and collimator. Continuous line, 4,000-hole collimator; dashed line, high-resolution collimator; dot–dash line, converging collimator.

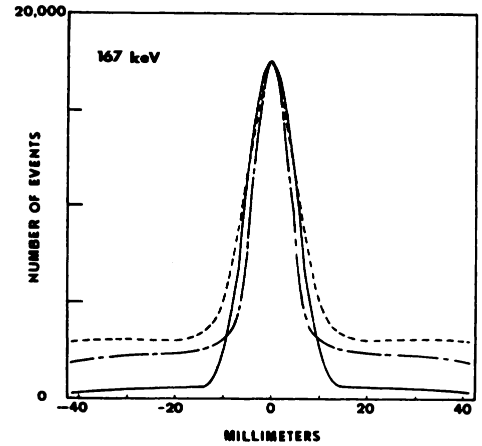

FIG. 3. Line spread functions of ^{201}Tl line source images with a 25% window centered around 167 keV, with various collimators. Line source was 12 cm from collimator with 4 cm of Lucite interposed between source and collimator. Continuous line, 4,000-hole collimator; dashed line, high-resolution collimator; dot–dash line, converging collimator.

present, but its magnitude is less significant than that of the very abundant Hg x-rays. The converging collimator has the best LSF at 75 keV, whereas the 4,000-hole collimator gives the best overall LSF at 167 keV.

The FWHM resolutions for the various collimators are given in Table 2. The converging collimator has the best FWHM for both the 75-keV and 167-keV windows, but its LSF at 167 keV is superimposed upon a significant background. Modulation transfer functions for the three collimators at the 75-keV and 167-keV photopeaks are shown in Figs. 4 and 5. Because of the high background level present for imaging at 167 keV, the MTFs are seriously degraded at low frequencies. The MTFs for the high-resolution and converging collimators are better at 75 keV than at 167 keV, particularly for the low

TABLE 2. RESOLUTION AND IMAGING TIMES FOR THE THREE COLLIMATORS STUDIED

Collimator	FWHM of LSF at 12 cm from collimator face with Lucite scatterer (mm)		Imaging time to accumulate 500,000 counts in 25% analyzer window (min)	
	69–83 keV	135–167 keV	69–83 keV	135–167 keV
High resolution	11.25	11.96	5.85	13.5
Converging	9.26	9.79	4.42	17.1
4,000 Hole	12.19	11.80	3.47	21.25

frequencies. The MTF for the 4,000-hole collimator is superior at low frequencies for 75-keV imaging and better at frequencies over 0.5 cycle/cm for 167-keV imaging. The significance of the sharp drop-off of the MTFs at low frequencies for 167-keV imaging is reduced when photographs are made on Polaroid film because the film's threshold reduces the observable background.

The images of the Picker thyroid phantom obtained with the three different collimators at 75 and 167 keV are shown in Fig. 6. Imaging times to obtain 500,000 total counts are listed in Table 2. The converging collimator's images are superior to those of the high-resolution and 4,000-hole collimators. The superior intrinsic resolution of the scintillation camera at 167 keV is negated by the Compton scatter within the crystal because of the penetration of 439-keV photons from ^{202}Tl. Compton scatter, falling into the window centered at 167 keV, is further illustrated in the imaging times (Table 2). The high-

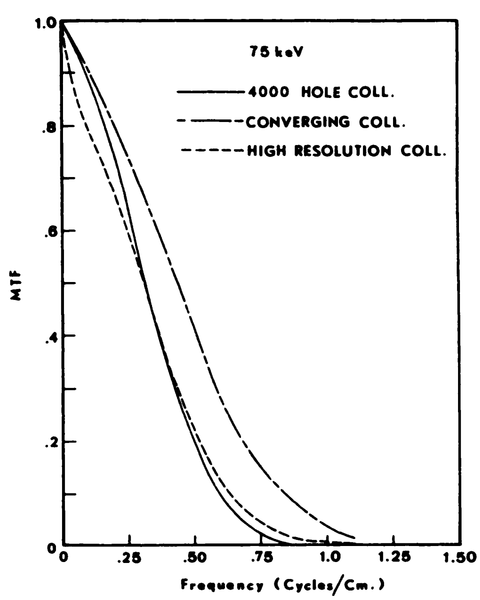

FIG. 4. Modulation transfer functions for ^{201}Tl line source imaged at 75 keV with various collimators.

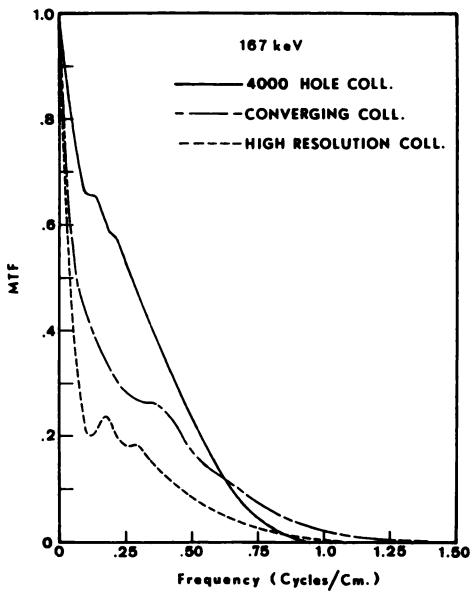

FIG. 5. Modulation transfer functions for ^{201}Tl line source imaged at 167 keV with various collimators.

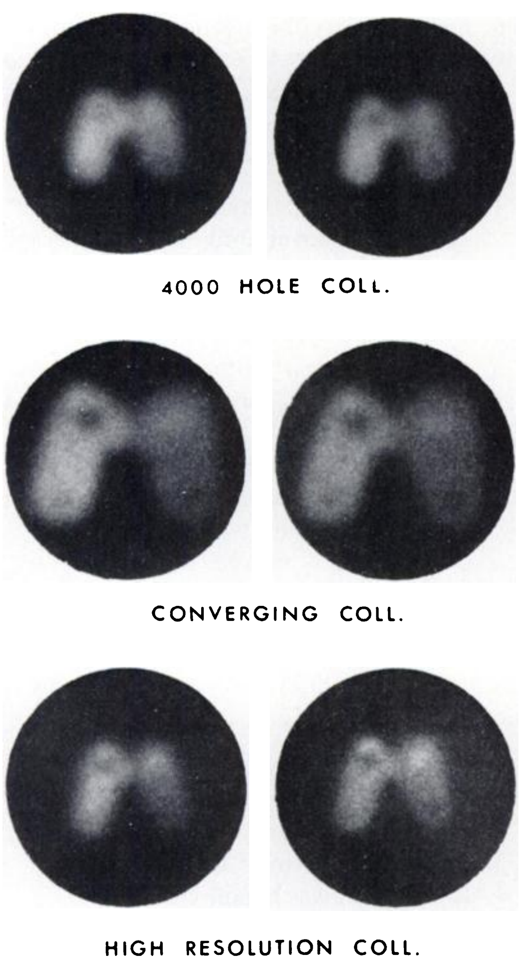

FIG. 6. Images of a Picker thyroid phantom obtained with three different collimators at 12 cm using 75-keV and 167-keV windows. Each image contains 500,000 counts. Left: 75-keV images; right: 167-keV images.

resolution collimator has lower sensitivity than the 4,000-hole collimator, yet the time needed to obtain the same total number of counts using a window centered at 167 keV was less for the high-resolution collimator. With a 75-keV window the imaging times agree with the relative sensitivities of the three collimators. In all three the imaging times were significantly shorter with the window centered at 75 keV.

In conclusion, penetration of 439-keV photons from ^{202}Tl through the thin septa of the high-resolution and converging collimators produces Compton scatter within the NaI crystal, which degrades images obtained at the 167-keV photopeak of ^{201}Tl. Empirical determination noted that one-half of the events within a window centered around 167 keV were not from the 167-keV transition of ^{201}Tl for the high-resolution collimator. Compton scatter is less significant when imaging with the abundant Hg x-rays where empirical measurements for the high-resolution collimator found that only $\frac{1}{25}$ of the events in a 75-keV window resulted from 439-keV Compton scatter. Images of a thyroid phantom did not differ greatly in quality between 75 and 167 keV for the same collimator. However, the imaging time was significantly shorter for the Hg x-rays.

Of the three collimators, imaging with the converging collimator at 75 keV yielded the best LSF and MTF. Septal penetration is least significant for 167-keV imaging with the 4,000-hole collimator. The high-resolution collimator may not produce acceptable images unless the ^{202}Tl contaminant within the source is reduced.

ACKNOWLEDGMENT

The authors wish to acknowledge G. Muehllehner for providing the converging collimator and for his valuable discussions. The authors would also like to thank D. Huard, A. M. Smudde, L. L. Walker, and F. R. Whitehead for their aid in the preparation of this manuscript.

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