OPTIMIZED COLLIMATORS FOR SCINTILLATION CAMERAS

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The use of commercially available tantalum or lead tubes permits convenient fabrication of collimators optimized for specific imaging studies.

Commercially available collimators for scintillation cameras do not necessarily have optimal imaging characteristics. The necessity for mass production and cost control imposes limitations on diversity and design. However, the availability of lead and tantalum tubes of any desired dimensions allows for potentially easy in-house assembly of collimators at costs competitive with those of commercially available collimators.

METHODS

While both lead and tantalum tubes are available, we have found the latter to be the material of choice. The relevant physical characteristics of the two elements are summarized in Table 1. Tantalum offers somewhat greater attenuation. More importantly, the thin lead tubes needed for low-energy collimators are difficult to handle, while tantalum, in contrast, is very rigid. For high-energy collimators, the problems of working with lead are less severe. Offsetting the absorptive and mechanical advantages of tantalum is its higher cost. Two sources of tantalum tubes are Superior Tube Co. (Norristown, Pa.) and Uniform Tube Co. (Collegeville, Pa.).

We report here on a low-energy tantalum collimator and compare its performance with several low-energy Searle Radiographics collimators. Dimensions and tolerances are presented in Fig. 1 (all dimensions are given in inches because the tubes must be ordered in these units). The round tubes (shapes other than round are also available) are supplied cut to length and deburred. The tubes naturally pack into a hexagonal configuration (Fig. 2). While the collimator tested was contained in a 12 × 12-in. frame for a pressurized multiwire proportional chamber, a convenient mounting for the scintillation camera can be obtained by stacking the tubes in the frame that replaces the removable Searle Divergent–Convergent Collimator insert. The tubes are held in place by thin Plexiglas or Mylar covers, and additional rigidity can be obtained by coating the Mylar surface coming into contact with the tubes with an epoxy adhesive. A 10-in.-diam collimator contains approximately 12,000 of the tubes described in Fig. 1.

Comparisons were made with (A) the Searle Radiographics Low-Energy High-Resolution Collimator (LEHR); (B) the Searle Radiographics Low-Energy All-Purpose Collimator (LEAP); and (C) the Searle Radiographics Low-Energy High-Sensitivity Collimator (LEHS). These three collimators are identical except for hole length. Their dimensions are summarized in Fig. 1. The stacking is triangular but does not follow a regular pattern (Fig. 3).

While the comparisons could have been made purely on the basis of calculations, the characteristics (energy and position resolution) and data-readout mode of the imaging instrument are intimately re-

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TABLE 1. PHYSICAL CHARACTERISTICS OF LEAD AND TANTALUM

	Lead	Tantalum
Atomic number Z	Pb = 82	Ta = 73
Density	11.34 g/cm³	16.60 g/cm³
Modulus of elasticity	2×10^6 psi	27×10^6 psi
Linear absorption coefficient:		
Photoelectric, 140 keV	24.9 cm^{-1}	27.4 cm^{-1}
Total, 140 keV	27.8 cm^{-1}	30.7 cm^{-1}

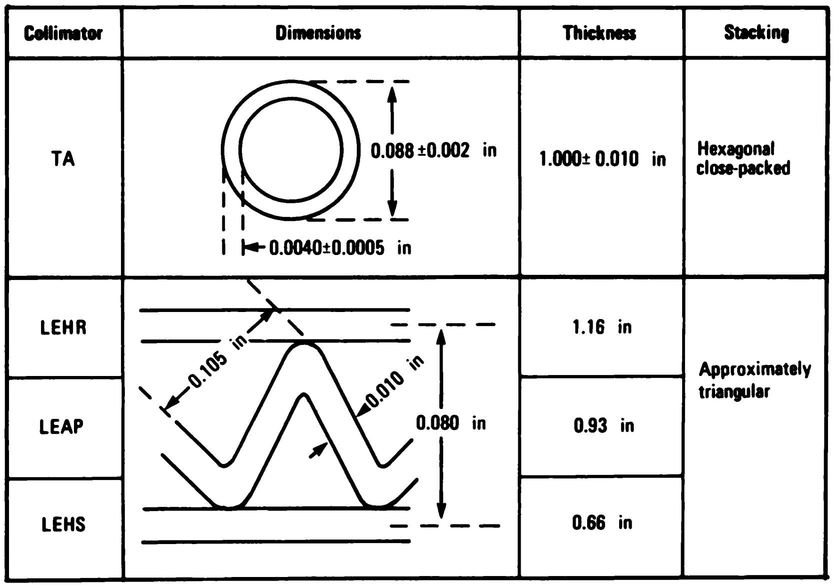

FIG. 1. Dimensions of collimators used in this comparison.

lated to performance. We find it relevant therefore to compare total system response for each collimator. For this purpose, each collimator was tested on a Searle Radiographics Pho/Gamma IV Scintillation Camera, accumulating data in a PDP-11/20 computer. Accordingly, the results given here represent the overall system response using the various collimators and not the resolution or sensitivity parameters for the collimators alone.

Three basic parameters were measured:

1. Spatial resolution was measured as a function of distance from the collimator face. A ^{99m}Tc point source (0.5 mm diam) was placed at distances from 0 to 15.24 cm from the collimator face, in 2.54 cm increments. For each position 100,000 counts were accumulated in a matrix where each element represented a 0.080-mm-square cell, at rates of under 5,000 counts/sec. The full width at half maximum (FWHM) and full width at 10% of maximum (FW0.1M) were then determined.
2. Sensitivity* for a distributed source was measured for each collimator using a ^{99m}Tc source, with the data adjusted for decay between measurement intervals. Absolute sensitivities were obtained by normalizing the data to the published value for the LEHR collimator (*1*), which agreed well with calculated values. This was also checked against the calculated sensitivity for the Ta collimator, with the results closely matching the expected values.
3. Septal penetration, or crosstalk, was measured. The photons which are not stopped by one or more septa and are accepted by the camera as valid events represent the crosstalk, i.e., the contributions by activity over one hole to detected events over the rest of the collimator.

* Sensitivity (to a uniform sheet source) and geometric acceptance are used interchangeably here; they are defined as the absolute fraction of the total number of gamma rays produced by a source that reach the surface of the camera detector.

FIG. 2. Section of Ta collimator with superimposed individual tantalum tubes.

TABLE 2. CROSSTALK AND SENSITIVITY COMPARISON

Collimator	Crosstalk (%)	Sensitivity for a distributed source, 0–15 cm distance
LEHS	8	4.0×10^{-4}
LEAP	6	2.5×10^{-4}
LEHR	6	1.3×10^{-4}
Ta	9	3.4×10^{-4}

FIG. 3. Searle Radiographics Low-Energy High-Resolution Collimator. Low-Energy High-Sensitivity and Low-Energy All-Purpose Collimators differ from this one in thickness only.

Of all parameters, crosstalk is probably the most elusive, both in terms of measurement and of its effects on image quality. Geometric acceptance for a round-hole hexagonal close-packed collimator is given by

$$G = \frac{0.0566(L - S)^4}{L^2T^2},$$

where L is the center-to-center spacing between holes, S is the septal thickness (which for a tube collimator is twice the wall thickness), and T is the thickness of the collimator (or tube length). For a fixed value of spatial resolution (that is, for fixed L and T), acceptance can be traded for crosstalk by changing S, which is easily achieved with the tube construction. The effects of crosstalk can be of importance if a small faint lesion near a hot field is suspected; they are of little significance for hot lesions in cold fields. Thus, its importance varies according to the study.

We define crosstalk as the ratio of counts from a source that fall in areas outside those defined by the spatial dimensions of the source (plus apparent size increases due to system resolution) to the counts under the source. To measure crosstalk, a ^{99m}Tc "point" source (0.5 mm diam) was centered on the collimator surface and the count rate C_1 was obtained. A 1.9-cm-diam 4-mm-thick lead disk was then placed between collimator and detector, concentric with the source, and the count rate C_2 was measured. Background rates C_3 were obtained by taking the source away. Using the corrected count rates $C_1' = C_1 - C_3$ and $C_2' = C_2 - C_3$, crosstalk as defined above is given by the expression $C_2'/(C_1' - C_2')$.

While the choice of 1.9 cm for the masking disk is somewhat arbitrary (it represents the distance over which essentially all events from a point source are localized by the camera), small changes in this disk were shown not to alter the measured results significantly, because penetration varies slowly as a function of distance from the source. Crosstalk was also determined by moving the source away from the collimator face, the small decrease in count rate observed under these conditions being due mainly to the effective increase in path length through the collimator septum as seen by radiation from the source.

RESULTS

Spatial resolution was measured as a function of distance for the four collimators tested (Fig. 4). Table 2 compares sensitivity and crosstalk. As can be seen, the Ta collimator offers a sensitivity over 2.5 times better than that of the LEHR, and 36% better than that of the LEAP, with a spatial resolution comparable to that of the LEAP. The only Searle collimator with better sensitivity than the Ta collimator is the LEHS, but its resolution is considerably less. At distances of 3 cm or more from the collimator face, the versatility provided by tubes for in-house fabrication of collimators is shown by the fact that the spatial resolution response of the Ta collimator could have been made as good as that of the LEHR (by lengthening the tubes or by decreasing their diameter) while maintaining sensitivity comparable to that of the LEAP. Thus, such a collimator would incorporate the best features of

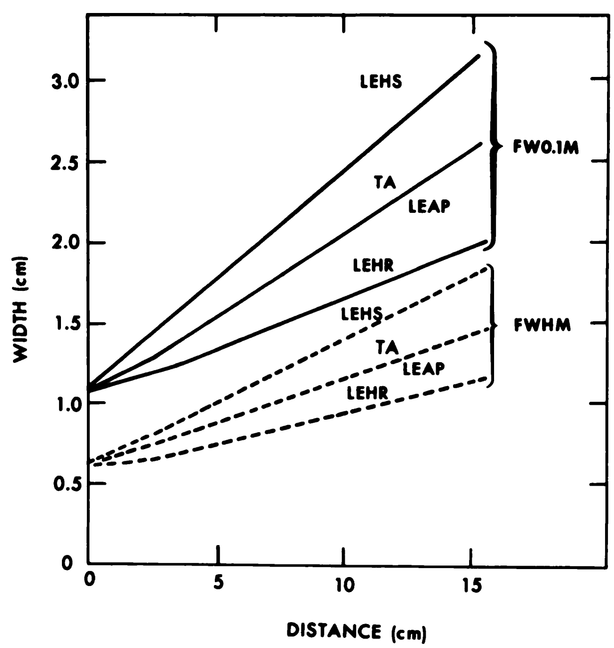

FIG. 4. Measured full width at half maximum (FWHM) and full width at 10% of maximum (FW0.1M) for four collimators tested, using ^{99m}Tc and Pho/Gamma IV camera.

both the LEHR and LEAP. The slight increase in crosstalk observed in the present collimator (some 3% more) is probably insignificant in its effect on image quality (*2*).

DISCUSSION

Collimators optimized with respect to radionuclide, specific studies, sensitivity, etc., can be conveniently obtained by using lead or tantalum tubes of the desired dimensions. The physician can in this manner acquire collimators that maximize the parameters considered most important.

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