A Simple Technique for Determining Basic Collimator Characteristics

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A simple technique for determining some of the geometric characteristics of focusing collimators is described. Data obtained with this technique on 25 different collimators were compared with those given by the manufacturer and in the literature, and many deviations from published parameters were observed. These differences demonstrate the need to evaluate collimators before clinical use, which can be accomplished easily by what we call the contact picture technique.

A thorough understanding of the elementary characteristics of focusing collimators is necessary for the production of optimal clinical scans. Much of the published information on collimator evaluation is so complicated and/or time-consuming that its routine application is discouraged. Consequently, collimators in clinical use are seldom checked to assure the user that even the basic specifications are met. For example, it is not uncommon to find discrepancies between the actual and specified focal lengths of manufactured collimators. Such an error may be sufficient to cause suboptimal clinical scans. Scanning out of the true focal plane of a collimator degrades both spatial resolution and the probability of detecting a lesion. In addition, some collimators may be labeled poorly or not at all and thus are difficult to identify for their proper use. With the contact picture technique described here, one can determine identifying characteristics including number, shape, and spacing of holes, diameter and thickness of collimator, focal length, radius of field of view (geometric radius of resolution), depth of focus, and geometric efficiency.

Intelligent use of focusing collimators requires the selection of the best available collimator for a given study and the placement of the collimator focal plane in the region of interest *(1)*. One then relies on the collimator depth response to permit the detector to *see* slightly above or below the focal plane with nearly equal but maximum efficiency. Hence, understanding basic characteristics such as focal length, radius of field of view, depth of focus, and efficiency of any given collimator and knowing how to apply them are essential. In choosing the proper collimator, one must, of course, be aware of the photon energy for which the collimator was designed. Manufacturers may supply these data if available. A search of the literature reveals a variety of technical data that have been accumulated for various collimators *(2–6)*. Unfortunately, not all collimators in use have been evaluated. In addition, some collimators may vary in construction so that published data may not be applicable to a specific collimator.

The contact picture technique can be applied easily in nearly all laboratories for evaluating focusing collimators. It is not intended to supplant some of the more mathematically rigorous and informative procedures presented elsewhere in the literature *(7-15)*. The technique provides a simple means of determining the geometric properties of collimators and hopefully will encourage the user to identify, evaluate, compare, and, hence, use focusing collimators more intelligently.

The Contact Picture Technique

This technique involves (A) producing contact photographic pictures of a collimator; (B) measuring certain dimensions from the images; and (C) calculating the geometric parameters of the collimator. Materials needed are x-ray film, a light diffuser such as a single-panel diffuser from a view box, black felt (at least the same size as the film), dark room, incandescent light, finely graduated

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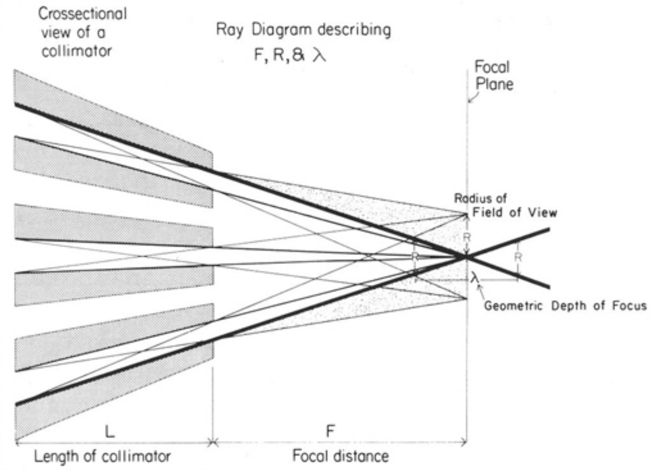

FIG. 1. Axial cross section of multiaperture focusing collimator illustrating collimator length, focal distance, radius of field of view, and depth of focus.

ruler or calipers, and collimator(s). Some manufacturers affix opaque covers over the holes, thus preventing the collimator from being evaluated directly by this method unless the covers can be removed conveniently and without damage to the collimator.

The contact pictures are made in a dark room with a film safety light for convenience of handling the collimator and film. The film is placed on the black felt to prevent blurring of the images. A felt-lined film cassette works well for this purpose. The collimator to be evaluated is placed on the film so there is direct contact with the face of the collimator. Some collimators such as the 3-in.

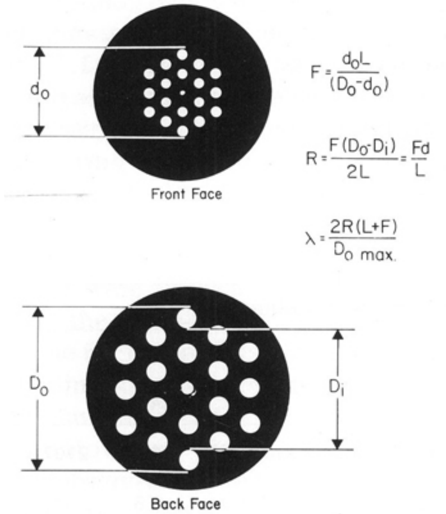

FIG. 2. Contact picture of front and back faces of Ohio-Nuclear model 53538H focusing collimator. Distances D_o and d_o are measured from contact picture between *outside* edges of any pair of holes positioned symmetrically about center hole, whereas D_i is measured from *inside* edges of same holes. D_o and D_i are obtained from back face and d_o is obtained from front face. Measurements are applied in formulas to calculate basic geometric parameters. Single-hole diameter on back face is d.

Picker collimators described in this paper have faces that are recessed, making it necessary to cut the film to fit within the recess. The film is held in contact with the collimator face by an opaque object such as a large rubber stopper. The light diffuser is placed on top of the collimator and the incandescent light is quickly flashed on and then off above the collimator. The light diffuser more evenly disperses the light through the holes, leaving the unexposed shadow of the collimator on the film.

The length of film exposure can be determined easily by trial and error but usually is 1 sec or less. The only requirement is that the exposure should reveal a sharp outline of the collimator holes as they appear on each face. Overexposure will blur the edges of the holes on the image.

A contact picture is made of each face of the collimator. If care is exercised, several collimators may be placed on the same film to produce simultaneous contact pictures. When a collimator is placed on the film, it is necessary to note the position of the collimator with respect to the film because the holes as observed on the front face must be correlated with those on the back face. A coin, for example, may be placed on the film beside the collimator as a mark for a particular hole. As the collimator is turned over, the coin is moved to mark the same hole on the contact picture of the other face. The exposed films are then developed.

Figure 1 illustrates an axial cross section of a multiaperture focusing collimator with indications of some of the geometric parameters to be evaluated. Measurements necessary for calculating the geometric parameters of each collimator are made directly from the contact picture of each face as illustrated in Fig. 2. (The contact picture will be the inverse of what is shown in Fig. 2. The holes will be dark and the lead septa will be light.) The collimator thickness, L (distance between the front and back faces), must be measured also. A finely graduated ruler or calipers may be used to make all the necessary measurements. The distances D_o, D_i, and d_o as indicated in Fig. 2 are determined from any pair of holes that are concentrically symmetrical about the center hole. It is not necessary to choose the outermost ring of holes for the measurements. However, the pair of holes from which D_o and D_i are determined on the back face must represent the same two holes from which c_o is determined on the front face. Several measurements should be made on each collimator using a variety of pairs of holes. These values are used in the following formulas to calculate the focal length, F, radius of field of view, R, and the geometric depth of focus, λ:

$$F = \frac{d_o\ L}{(D_o - d_o)}$$

$$R = \frac{F\ (D_o - D_I)}{2L}$$

$$\lambda = \frac{2R(L + F)}{D_{o\ max}}.$$

In addition, the geometric efficiency, G *(16)*, is determined using the following equation:

$$G = \frac{\pi N R^4 L^2}{64\ F^2\ (F + L)^2}$$

where N is the number of holes.

The focal length is defined as the distance along the collimator axis between the front face of the collimator and the point in front of the collimator where all the lines converge when extended from the surfaces of the tapered holes. This point of convergence is called the focal point. The focal plane, which contains the focal point, is the plane parallel to the collimator face and is separated from the collimator by the focal length. The radius of field of view is the radial distance in the focal plane from the focal point to the perimeter of a circular area from which photons may travel through the collimator without direct interactions with the lead septa.

The geometric depth of focus is based on the collimator having a designed (theoretical) point of focus. The maximum ideal region permitting photons to penetrate the collimator without direct interactions with the lead septa is represented by the heavy solid lines that converge at the focal point in Fig. 1. Penetrating photons from outside this region (shaded area) degrade the point focus capability of the collimator as do the photons within the regions that are above and below the focal point. The detection of such photons contributes to the error or parallax in locating the point of origin of the photons. The geometric depth of focus defines a region above and below the focal point in which the ideal parallax is less than the geometric radius of field of view, R. This parameter can be used to compare the relative focal depths of a series of collimators from a particular manufacturer in order to choose the one more likely to permit detection of a small lesion in a thin internal organ like the thyroid or a large organ like the liver. For consistency, the calculation of λ is applied only when the measurement of D_o (see Fig. 2) is at its maximum value and corresponds to the diameter of the exposed crystal, i. e., the maximum distance across the outermost hexagonal ring of holes. If this distance exceeds the crystal diameter, the actual diameter of the crystal is used to calculate λ.

The geometric efficiency, G, is an expression of the ratio of detected radioactivity to the amount of radioactivity contained in a unit area of an extended uniform sheet source perpendicular to the collimator axis and placed at any distance from the collimator. Photon absorption in air and septal penetration are assumed to be negligible.

Collimator Evaluations Using the Contact Picture Technique

All focusing collimators used in this laboratory were evaluated using the contact picture technique. Several measurements from each collimator contact picture were made to determine the variations in the size and distribution of the tapered holes. Hole diameters, off-axis spacing, and consequently focal length, as well as other parameters, vary somewhat from hole to hole as seen in Table 1. It is evident that all holes in a given collimator are not precisely focused at a common point. Whereas a few collimators are designed for special purposes to have each hexagonal ring of holes focused at a different

TABLE 1. Variations of Focal Distance within Individual Collimators

	Collimators									
	Ohio-Nuclear					Picker				
Focal length	53524-L	55035-L	53517-MT	53538-M	53538-H	2102	2102B(1)	2107	2107A	2114B
Outer ring of holes	8.9	12.6	10.2	8.3	8.9	7.3	9.9	8.5	11.0	8.8
Middle ring of holes	9.1	12.4	10.2	8.3	9.0	7.8	9.8	8.6	10.7	8.7
Inner ring of holes	9.2	12.6	10.0	8.8	8.7	7.8	9.6	8.2	11.1	8.7
Average value*	9.0	12.5	10.1	8.5	8.9	7.6	9.8	8.5	10.9	8.7

All values in centimeters

**Average taken from all collimator holes.*

TABLE 2. Basic Geometric Characteristics of Several Focusing Collimators

Collimator	Design (in.)	Designed maximum energy (keV)	No. holes/hole shape	L (cm)	F_m* (cm)	F_c† (cm)	R_m* (cm)	R_c† (cm)	λ_m* (cm)	λ_c† (cm)	G_m* (x 10^{-2} cm^2)	G_c†
Ohio-Nuclear												
53524-L	5	180	151/Round	7.6	8.9	9.0	1.0	1.0	2.6	2.6	1.4	1.9
55035-L	5	180	163/Round	7.6	12.7	12.5	1.4	1.4	4.7	4.5	2.6	2.9
53517-MT	5	370	163/Round	7.6	8.9	10.1	0.7	0.8	1.8	2.3	0.44	0.5
53538-M	5	370	37/Round	7.6	8.9	8.7	1.5	1.5	4.0	3.8	2.4	2.8
53538-H	5	550	19/Round	7.6	8.9	9.0	1.5	1.6	4.0	4.9	1.2	1.5
Picker												
2114B	5	150	55/Hexagonal	8.3	7.6	8.8	1.3	1.5	NA §	4.0	NA	4.4
2102B(1)	3	150	31/Hexagonal	6.2	7.6	9.8	1.3	1.7	NA	7.6	NA	2.1
2102B(2)	3	150	31/Hexagonal	6.2	7.6	9.3	1.3	1.6	NA	6.9	NA	2.0
2113	3	150	73/Hexagonal	7.1	7.6	8.7	0.6	0.8	NA	3.5	NA	0.4
2116	3	150	73/Hexagonal	8.4	7.0‡	7.8	0.5	0.7	NA	3.0	NA	0.3
2102	3	400	31/Round	10.1	7.6	7.6	0.6	0.6	NA	3.2	NA	0.1
2107	3	400	19/Round	7.7	7.6	8.5	1.3	1.4	NA	6.0	NA	1.0
2107A	3	400	19/Hexagonal	7.6	10.2	10.9	1.6	1.8	NA	9.3	NA	1.4

* *Manufacturer's value.*
† *Calculated value.*
‡ *Picker model 2116 collimator label indicated a 2.75-in. (7.0 cm) focal length but the technical data supplied in advertisements claim this collimator has a 2.5-in. (6.4 cm) focal length.*
§ *Not available.*

point on the collimator axis *(8)*, an ordinary collimator with holes of widely varying focal lengths would appear to be poorly constructed.

The geometric parameters of 12 types of collimators that were evaluated using the contact picture technique are listed in Table 2. Actually, 25 different collimators were checked but several were of the same types illustrated in Table 2. The data include average values for a given collimator type unless individual collimators differed in their focal lengths by at least 0.5 cm. Such a difference (5%) was observed between two Picker model 2102B collimators. The individual collimator data were included in Table 2 for this example. All other differences between individual collimators of a given type were less than 5%. The parameters supplied by the manufacturer were included whenever available for comparison with observed results.

Most collimator data provided by Ohio-Nuclear compared favorably with those calculated (see Table 2). However, the model 53517-MT collimator was observed to have a focal length 1/2 in. greater than that specified. Other properties of this collimator also were found to be different from those specified by the manufacturer. The 13% greater focal length was verified by several alternate methods. The line-source response *(8)* was measured at various distances from the collimator face and the results indicated that the 53517-MT collimator had a 10-cm focal length. This focal length was confirmed again by scanning a 45-deg line source *(17)* and also by a visual check in a manner similar to that described by Harris, et al *(18)*. A cross-hair indicator was moved in front of the collimator along its axis until the cross hair could be seen through all the collimator holes from the back face. At that point, the indicator was in the focal plane of the collimator. These methods were not as accurate in determining the geometric focal length as the contact picture technique but helped to verify the results.

The values for geometric efficiency from Ohio-Nuclear were originally supplied to this laboratory in a technical pamphlet on collimators *(19)*. The contact picture technique revealed that these values from the manufacturer were in error by a factor of 10. A later revision of the technical pamphlet (Rev. D, May 1974) was provided with correct values. The later efficiency values are listed in Table 2. The geometric efficiency can be used to compare similar collimators. For example, one would expect (see Table 2) the 53538-M collimator to provide between five and six times the counting rate compared to the 53517-MT for the same counting situation and assuming no septal penetration. Beck *(16)* described how G can be used to calculate the expected counting rate.

Table 2 includes a comparison of the depth of focus for several Ohio-Nuclear and Picker collimators. Only Ohio-Nuclear supplied data for this parameter. Most of the calculated values were only slightly different from those listed by the manufacturer with the exceptions of the 53517-MT and 53538-H collimators for which λ was greater by 28% and 23%, respectively. This is expected, at least in the case of the 53517-MT collimator, since F was found to be considerably greater than the specified value. The value of $D_{o\ max}$ also affects the determination of λ. The published specifications from Ohio-Nuclear do not include such values; thus it was not possible to critically compare the observed and specified values of depth of focus such as that observed in the 53538-H collimator. The data for this collimator appear to indicate that the depth of focus provided by the manufacturer was based on the 5-in. crystal diameter rather than the actual exposed crystal diameter determined by $D_{o\ max}$.

The 3-in. Picker collimators in general have larger depths of focus than the 5-in. collimators. This is consistent with the equation for λ. Whereas F, R, and L for 3-in. collimators may differ only slightly from the group of 5-in. collimators, the maximum value for D_o is smaller for all 3-in. collimators. This results in longer focal depths for most 3-in. collimators as observed in Table 2. In fact, the 2107A collimator has a geometric depth of focus nearly equal to the focal length.

Comparisons between manufacturer and observed geometric specifications for the Picker collimators indicated many apparent differences. Of the seven collimator types, five types were observed to have focal lengths over 10% greater than the specified values. The 2102B collimators had focal lengths over 20% greater than that specified. Only 2107A and 2102 collimators had geometric focal lengths within 10% of their design. The radius of field of view, R, was observed to be greater than 10% over the specified values for all but the 2102 and 2107 collimators.

The fine-focus, low-energy collimators (models 2113 and 2116) were purchased by this laboratory as potential ^{99m}Tc thyroid-scanning collimators in place of the 2102 medium-energy collimators. The plane-source sensitivity data from Hine *(2)* (Table 3) indicate that the two low-energy collimators should provide better than a threefold increase in counting rate. According to the data from the manufacturer, this greater efficiency could be accomplished with no sacrifice in spatial resolution. However, the calculations from the contact picture technique revealed that the radius of field of view for both collimators was observed to be over 30% greater than the designed specifications. Phantom scans comparing the three collimators verified that the low-energy collimators have noticeably poorer resolution than the 2102 collimator.

The contact picture technique frequently demonstrated that there were significant differences between actual and specified geometric parameters of commercially available collimators. In addition, there were observed differences between individual collimators of the same type. Geometric properties of several Picker collimators evaluated in this laboratory and by Hine *(2)* are given in Table 3 for comparison. The focal lengths determined by the contact picture technique compared closely with those of Hine for the 2114B, 2102B(2), and

TABLE 3. Comparison of Geometric Properties of Picker Collimators

		Contact picture technique				Data from Hine *(2)*					Manufacturer data‡	
Model no.	No. holes/hole shape	L (cm)	F (cm)	R (cm)	G (x 10^{-2} cm^2)	L (cm)	F (cm)	R (cm)	G* (x 10^{-2} cm^2)	S†	F (cm)	R (cm)
2114B	55/Hexagonal	8.3	8.8	1.5	4.4	8.4	8.9	1.65	6.0	5.6	7.6	1.3
2102B(1)	31/Hexagonal	6.2	9.8	1.7	2.1	6.2	9.3	1.5	1.4	2.1	7.6	1.3
2102B(2)	31/Hexagonal	6.2	9.3	1.6	2.0	6.2	9.3	1.5	1.4	2.1	7.6	1.3
2113	73/Hexagonal	7.1	8.7	0.8	0.4	7.3	7.8	0.75	0.4	0.4	7.6	0.6
2116	73/Hexagonal	8.4	7.8	0.7	0.3	8.3	7	0.55	0.2	0.3	7.0 §	0.5
2102	31/Round	10.1	7.6	0.6	0.1	10	6.3	0.45	0.1	0.1	7.6	0.6
2107	19/Round	7.7	8.5	1.4	1.0	7.8	8.2	1.3	0.9	1.0	7.6	1.3
2107A	19/Hexagonal	7.6	10.9	1.8	1.4	7.7	8.2	1.4	1.3	1.4	10.2	1.6

* *G was calculated from the geometric data provided by Hine (2).*

† *S is ^{99m}Tc plane source sensitivity relative to collimator 2107 as provided by Hine (2).*

‡ *Manufacturer data do not include values for L and G.*

§ *Collimator label indicated a focal length of 2.75 in. (7.0 cm) whereas collimator specifications given in advertisements list the focal length as 2.5 in. (6.4 cm).*

2107 collimators, whereas they were closer to the values of the manufacturer for the 2102 and 2107A collimators. The 2113 and 2116 collimators evaluated by Hine had geometric focal lengths nearer those given by the manufacturer.

The geometric efficiencies determined in this laboratory were in very close agreement with the relative plane source sensitivity given by Hine *(2)* for all the Picker collimators evaluated except the 2114B collimator. The geometric efficiencies also were comparable to those calculated from the data provided by Hine *(2)*.

It is apparent from these collimator evaluations that geometric parameters may vary not only from those provided by the manufacturer but also from those documented in the literature. The data in Table 3 illustrate the need for checking individual collimators prior to clinical use.

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