Collimator Comparisons Made Easy

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One of the most important components of any nuclear imaging system is the collimator where the positional and quantitative information of the image is acquired. The final image can be no better than the primary information obtained by the collimator.

Several approaches to collimator comparisons will be shown, including a simple technique for correlating information from a 45-deg line-source scan with the more refined data obtained by conducting line-spread function determinations. Collimation is complex, and it is the purpose of this paper to present information to the technologist to assist him in understanding this important part of imaging.

In making evaluations of any kind, there is no perfect model or phantom to duplicate the clinical nuclear imaging situation. Clinical imaging problems can be simulated only by the use of extended sources. All organs imaged are extended sources with large volume and depth components. A line source placed 45 deg to the collimator axis (Fig. 1) provides a simple method of evaluating collimator performance (*1*). As the line source is imaged, the resolution of the line at all distances from the collimator face is presented as the image on the film.

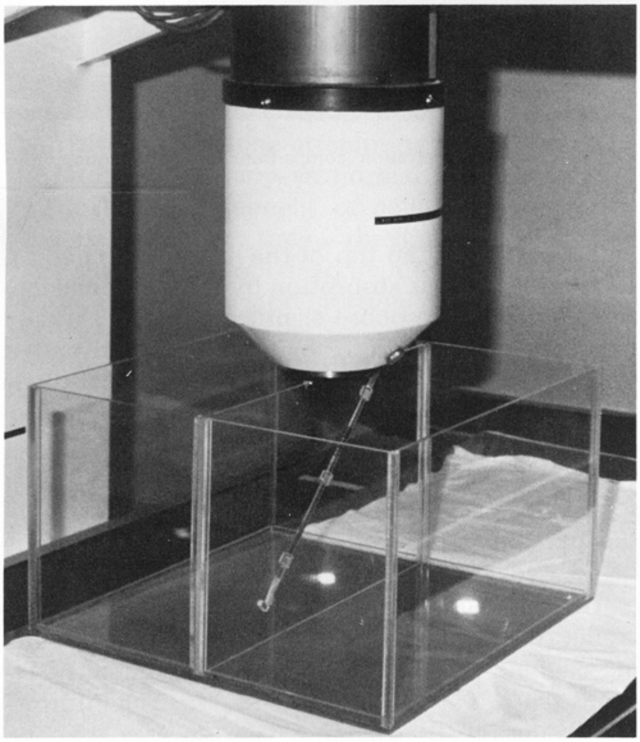

FIG. 1. 45-deg line source used for collimator comparisons.

This technique is very useful for comparing collimators with regard to resolution, depth and uniformity of resolution, and septal penetration. The influence of tissue absorption and scatter of gamma rays can be simulated by surrounding the line source with water.

Focusing Collimator Comparisons

We compared three focusing collimators—the Ohio-Nuclear 17M, 24L, and 38M collimators—for a 5-in. detector (Fig. 2). The collimator characteristics derived from Ohio-Nuclear data sheets are given in Table 1.

Figure 3 shows how a 45-deg line source is used to compare the three collimators' resolution and depth of resolution around the focal plane. A line-source scan comparison correlates well with the listed collimator data. Notice that the greater the resolution the less the uniformity of resolution around the focal plane. The line source contained ^{99m}Tc to eliminate the interference of septal penetration in the resolution comparison.

Image degradation due to septal penetration can be demonstrated by using the 45-deg line source filled with ^{131}I (364-keV photopeak) (Fig. 4). The 17M and 38M collimators which are designed for up to 370-keV energy show no septal penetration, but the 24L which is designed for up to 180 keV shows a great deal of penetration, demonstrated by the loss of line definition and increased background.

The effects of absorption and scattering of gamma rays by tissue can be demonstrated by

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comparing images of the line scan in air and water. These effects and the determination of the best level at which to place the focal plane while imaging can be demonstrated by scanning the 45-deg line source with the focal plane at the surface, 1, 2,

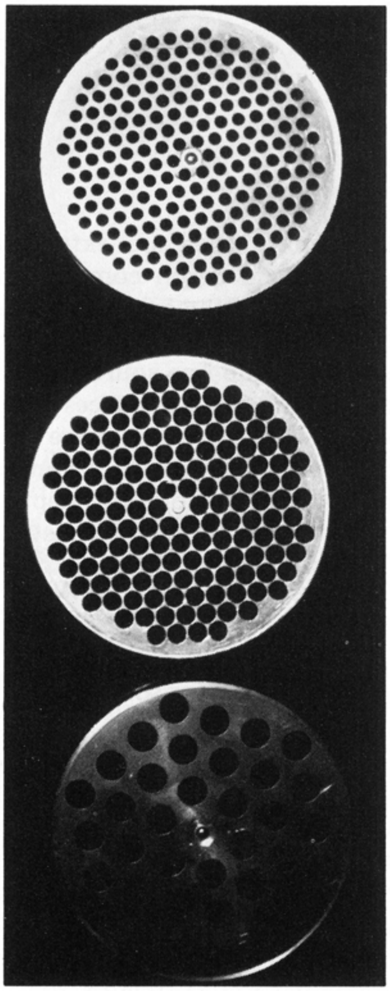

FIG. 2. Ohio-Nuclear 17M (top), 24L (middle), and 38M (bottom) collimators used in focusing collimator comparisons.

Table 1. A Comparison of Collimator Characteristics

	Collimator		
	17 M	24 L	38 M
Maximum energy	370 keV	180 keV	370 keV
No. of holes	191	151	37
Focal length	3.5 in. (8.9 cm)	3.5 in. (8.9 cm)	3.5 in. (8.9 cm)
Resolution at focal plane (FWHM)	7 mm	10 mm	15 mm
Sensitivity factors to plane source regardless of depth	5.2	18	24
Uniformity of resolution around focal plane	18 mm	26 mm	40 mm

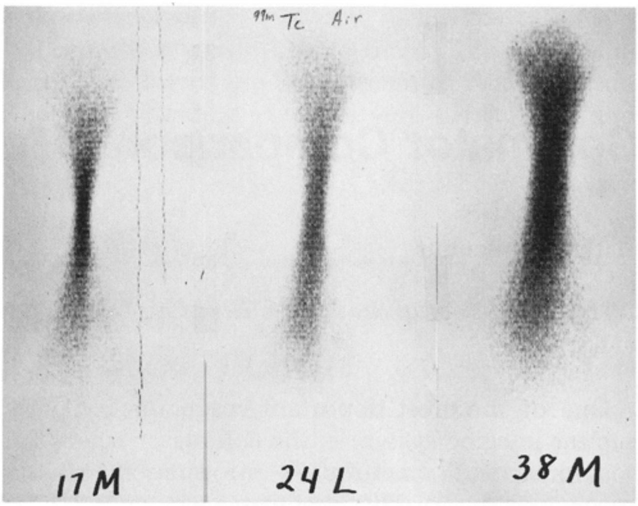

FIG. 3. Resolution and depth of resolution comparisons using line-source scan method.

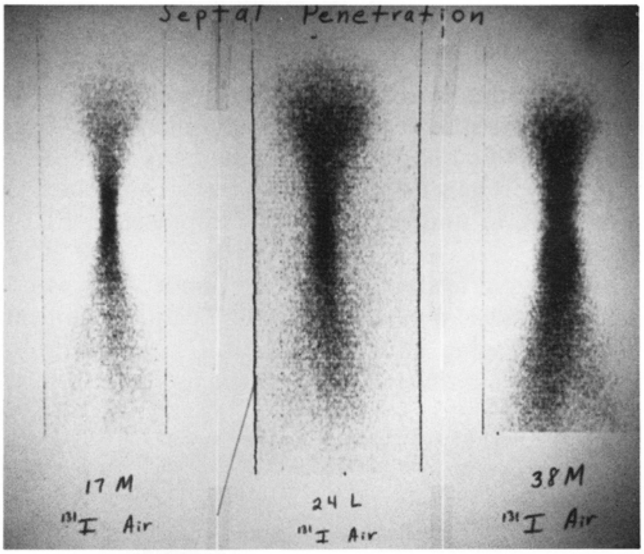

FIG. 4. Septal penetration comparisons using line-source scan method.

and 3 in. below the top of the line source (Fig. 5). It can be seen that absorption by the water changes the collimator response significantly and actually improves the response by absorbing unwanted information coming from beneath the focal plane (2). It should be noted that the collimator response with the best resolution occurs when the focal plane is located 1 in. below the top of the line source. The scan at 1 in. in water shows that only the best resolution found about the focal plane is being used.

The comparison in Fig. 5 identifies the fact that trying to focus in depth is not possible and results in scanning with a portion of the collimator response shown at depths of 2 and 3 in. The information being recorded comes from an area of poor resolution because the sensitivity of a focusing col-

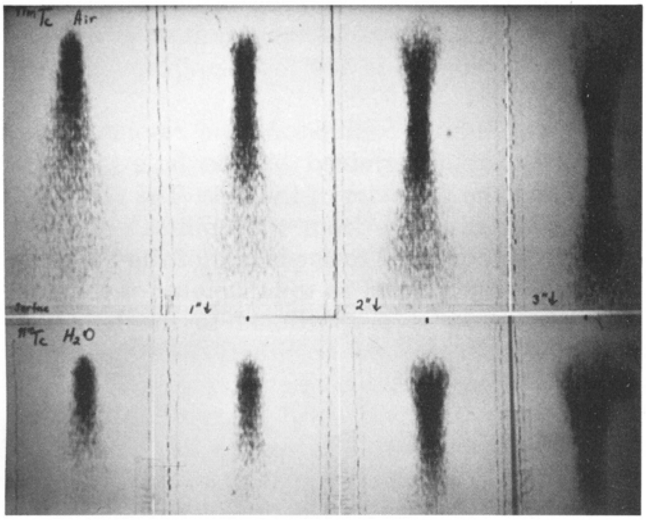

FIG. 5. Determination of best depth for focal plane and observation of effect of tissue equivalent water on collimator response to 45-deg line source.

limator is constant for a plane or volume source regardless of the collimator-to-source distance; this is true only if the source is larger than the collimator field of view (*2*). An easy way to show collimator sensitivity to a large volume source is to raise or lower a detector with a focusing collimator above a lung or liver and observe the lack of variation in counting rate.

Figure 6 illustrates the focal depth and collimator sensitivity relationship by showing that normal tissue overlying a lesion can "mask" the lesion since counts from the normal tissue are recorded even if the "cold" lesion is in the focal plane. This is due to the sensitivity relationship just described. The anterior liver scan shows a large lesion in the inferior portion of the right lobe while the right lateral, done attempting to focus deep on the known lesion, appears normal.

The basic component of collimator evaluation used at the present time is the line-spread function (LSF). An LSF is obtained by moving a line source longer than the widest portion of the collimator field of view in a plane perpendicular to the collimator axis or parallel to the collimator face. The resulting curve of counting rate as a function of distance is an LSF. This can be performed at various distances and gives the collimator response or performance at different depths. The sharpness of the LSF curve is a function of resolution and the total area under the curve is a function of sensitivity. The full width at half maximum (FWHM) determination is commonly derived from the LSF to describe resolution. The modulation transfer function (MTF) is a more accurate method of evaluation since it analyzes all of the points on the curve, not just a portion of the curve as with the FWHM determinations. This is most critical when septal penetration is a factor and the LSF is spread out at the edges. A further discussion of MTFs is beyond the scope of this paper.

The 45-deg line-source method previously described can be easily compared and correlated with the LSF determinations for different radionuclide energies in air and in water. The resolution at all depths is seen on the 45-deg line-source scan. The width on the scan represents resolution, and the total film density integrated for each scan line would represent the sensitivity.

By displaying a 45-deg line-source scan and LSFs side by side, looking directly across, and comparing the two, a useful correlation is obtained between a simple technique of collimator evaluation everyone can do and LSF data obtainable in specially equipped laboratories.

For the comparisons, illustrated in Figs 7 and 8 the LSFs were obtained using the 364-keV gamma rays of ^{131}I and the 145-keV gamma rays of ^{141}Ce. The solid lines are ^{131}I and the broken lines are ^{141}Ce.

Figure 7 is an evaluation of the 38M collimator using the 45-deg line-source scan and LSFs. Direct cross comparison shows the LSF that would have been obtained at the time the line source was scanned. The sharpest LSF corresponds directly across to the best resolved portion of the line source scan. Figure 7A shows that the results for the two energies are the same because of the absence of septal penetration or scattering and absorbing medium. Figure 7B shows how water alters the LSFs at the greater depths due to in-

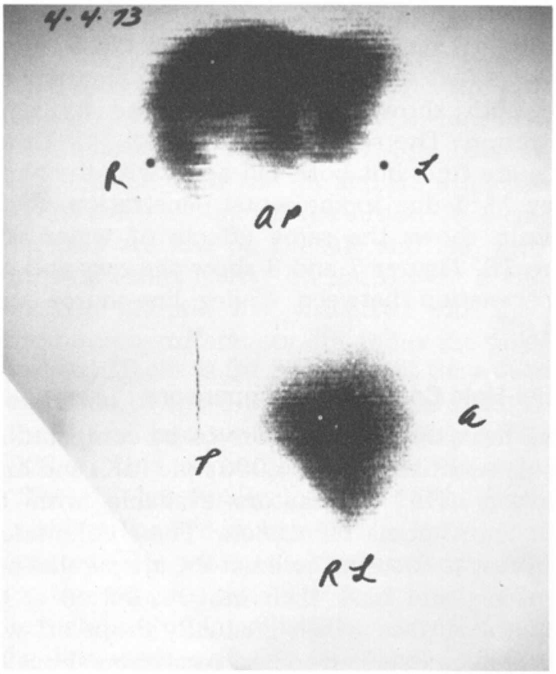

FIG. 6. Liver scan shows inability to focus on "cold" lesion when normal tissue overlies lesion on right lateral view.

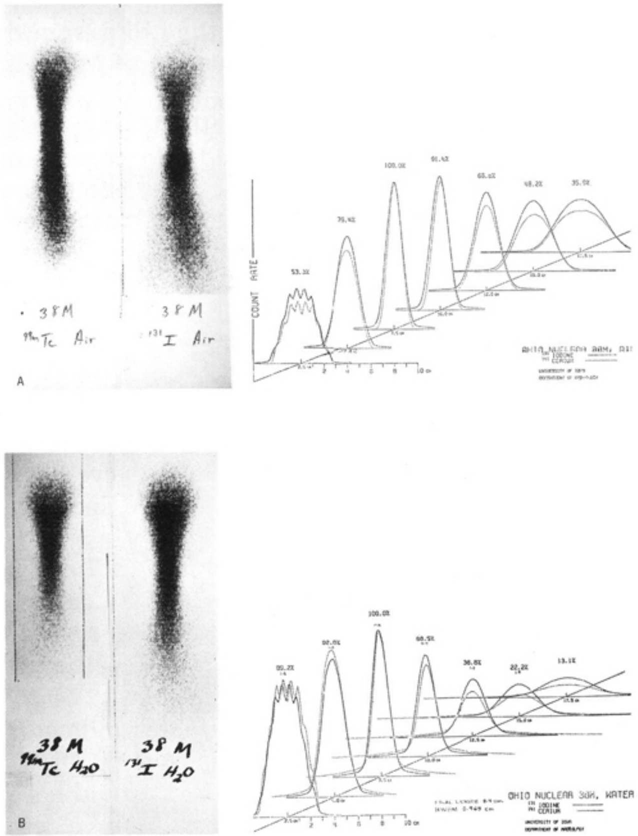

FIG. 7. Correlation of information from 45-deg line source scans and line spread functions for 38M collimator. In A no differences occur due to lack of septal penetrations. In B, effect of water scatter and absorption on scans and line-spread functions.

creased absorption. Also, the LSF of the lower energy ^{141}Ce is affected to a greater degree than the LSF using the higher energy ^{131}I gamma rays.

An evaluation of the 24L collimator designed for 180-keV gamma rays is shown in Fig. 8. Figure 8A shows that the 45-deg line-source scan and the LSFs both show degradation caused by septal penetration. The scan and LSFs with ^{99m}Tc and ^{141}Ce are fine, but both fall apart with the higher energy ^{131}I due to the septal penetration. Figure 8B again shows the same effects of water as in Figure 7B. Figures 7 and 8 show the easy and useful correlation between 45-deg line-source scans and LSFs.

Parallel-Hole Collimator Comparisons

The next three collimators to be compared are the high sensitivity (HS), 4,000 hole (4K) and high-resolution (HR) collimators available with the Searle Pho/Gamma HP camera. These collimators, in contrast to focusing collimators, are parallel-hole collimators and have their best resolution at the collimator surface which gradually drops off with distance in comparison to best resolution about the focal plane for focusing collimators. The sensitivity is best at the surface but decreases very little with increased collimator-source distance. The greatest advantage of the parallel-hole collimator over the focusing collimator is the more uniform depth of resolution.

In parallel-hole collimators, the resolution and sensitivity are determined by the hole length or depth and the diameter of the hole. The resolution at a given distance from the collimator face is directly proportional to the length of the holes and inversely proportional to the diameter of the hole. The resolution is proportional to the length-to-diameter ratio and the sensitivity is inversely proportional to the length-to-diameter ratio.

The high-sensitivity and high-resolution collimators both have 15,000 holes with a diameter of 0.19 cm. The only difference is that the hole length is 1.6 cm for the HS and 3.2 for the HR. As a result, the length-to-diameter ratio is twice as good for the HR as the HS, and consequently the depth of resolution is much better for the HR collimator. As with all types of collimators, the increased resolution costs a great deal in loss of sensitivity.

The 4,000-hole collimator has fewer and larger holes than the HS and HR collimators with a hole diameter of 0.28 cm and length of 4.5 cm. In resolution and sensitivity it falls between the HS

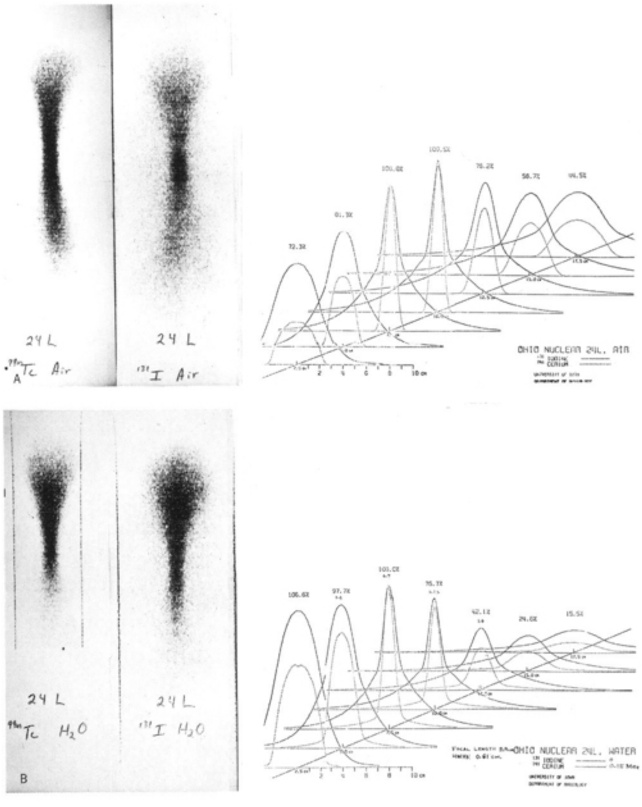

FIG. 8. Correlation of information from 45-deg line-source scans and line-spread functions for 24L collimator. A shows effect of septal penetration using ^{131}I on both scan and line-spread functions. B, as in Fig. 7B, shows effect of water.

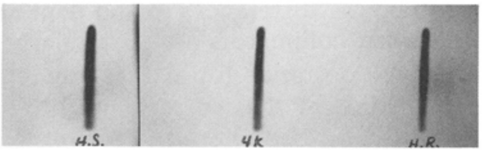

FIG. 9. Comparative images of 45-deg line source filled with ^{99m}Tc obtained by high-sensitivity, 4,000-hole, high-resolution collimators for Nuclear-Chicago cameras.

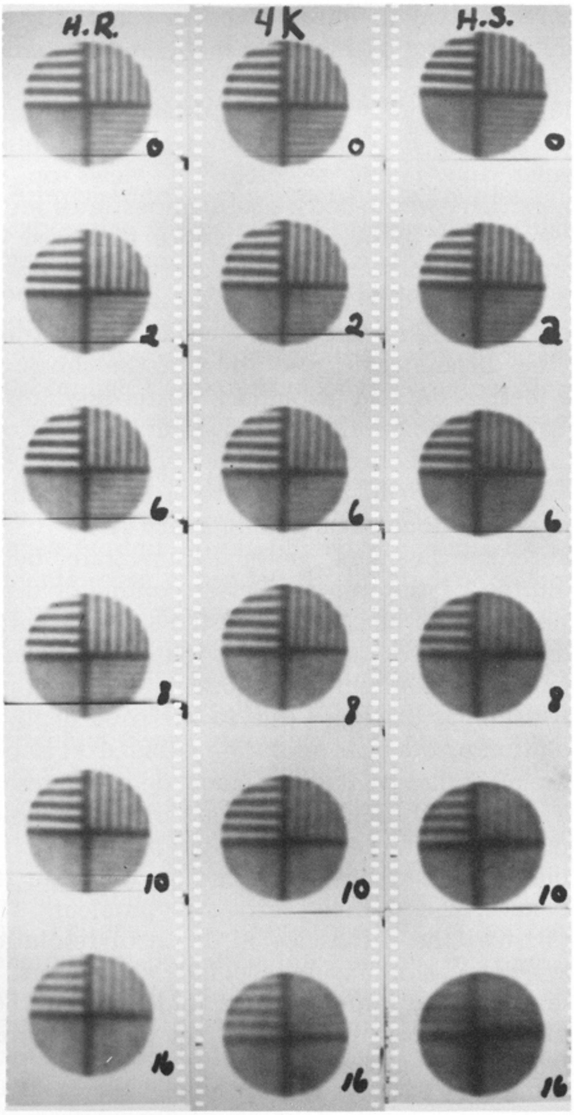

FIG. 10. Bar phantom resolution comparisons of high-resolution, 4,000-hole, high-sensitivity collimators at different collimator-to-phantom distances.

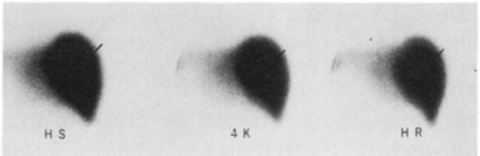

FIG. 11. Significant differences in depth of resolution between three camera collimators demonstrated on posterior liver images.

and HR collimators. The increased hole length compensates for some of the resolution loss due to the increased hole size.

The following summarizes the hole diameter and length relationships. Given the same hole diameter, the greater the length the better the depth of resolution or depth response, with a decrease in sensitivity. Given the same hole length, an increase in hole diameter will decrease the depth of resolution and increase the sensitivity. The following examples will clarify these relationships.

The 45-deg line source can also be used in parallel-hole collimator comparisons. The depth of resolution is much better for the HR than the HS with the 4K falling in between (Fig. 9). The hole length is the factor making the HR superior to the HS. The greater hole length of the 4K over the HS and HR partially compensates for the resolution loss due to the larger hole diameter of the 4K collimator.

Another simple comparison can be made by using the standard bar phantom at different distances. It must be kept in mind that clinical resolution will not be as good as bar phantom resolution. The reason is that with the bar phantom an image is made using a precollimated source; only gamma rays coming straight up between the lead bars are being detected, and the collimator does not have to select from gamma rays coming from all 360-deg as it must do in the clinical situation. As a result, bar phantom resolution will be better than that actually obtained.

A comparison of the three collimators shows obvious differences in resolution when using the bar phantom at collimator-to-phantom distances of 0, 2, 6, 8, 10, and 16 cm (Fig. 10). At 0 and 2 cm, the 1/2, 3/8, and 1/4-in. bars are all seen with the sharpest 1/4-in. bars resolved by the high-resolution collimator. At 6 cm, the 1/4-in. bars are becoming less sharp for the 4K and HS while the HR maintains sharp 1/4-in. bar resolution. At 8 cm, the 1/4-in. bars are lost on the 4K and HS, with the 3/8-in. bars losing clarity on the HS. At 8 cm, the 1/4-in. bars are still well visualized with the HR. The resolution differences are about the same for all three at 10 cm as for 8 cm except for a decrease in resolution of the 3/8-in. bars for the HS. At 16 cm the 3/8-in. bars are lost on the 4K and HS with the 1/2-in. bars almost lost completely with the HS. The HR has finally lost the 1/4-in. bars but still resolves the 3/8-in. bars lost by the 4K and HS collimators. The previous example clearly demonstrates the superior resolution and depth response of the high-resolution collimator.

The importance of the difference in depth of resolution between collimators is clearly illustrated in Fig. 11. The lesion in the posterior liver image is

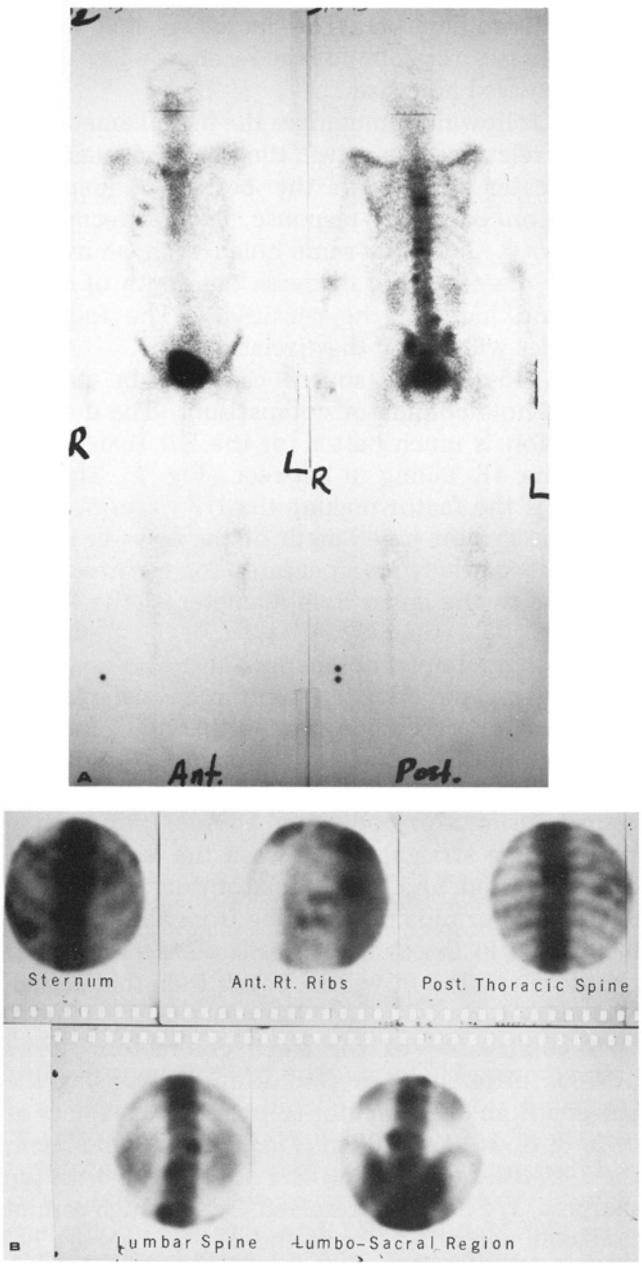

FIG. 12. Comparison of focusing and parallel-hole collimation on ^{99m}Tc polyphosphate bond study. A is 5:1 whole-body rectilinear scan and B contains selected camera views over some of abnormalities seen on whole-body scan.

faint to nonexistant with the HS collimator. The lesion is moderately well defined with the 4K collimator, and the lesion is clearly seen when the HR collimator is used. In this comparison, as with all others in this paper, all information densities in a comparison have been identical to avoid any introduction of bias by different IDs. (information densities).

These dramatic differences in the depth of resolution between collimators are particularly critical in imaging the posterior fossa. It is inherently difficult to maintain the correct head-to-detector angle and still be close enough to the collimator surface for satisfactory resolution. This is where the collimator with the best depth of resolution plays its most important role.

The difference in the depth of resolution response for focusing and parallel-hole collimators is an important consideration when selecting the imaging system to be used and in comparing and correlating the results of camera and rectilinear scanner images.

Figure 12 is a ^{99m}Tc-polyphosphate bone study done using a 5:1 minification technique on the scanner and taking selected 1:1 views on the camera. The whole-body scan demonstrates multiple metastatic bone lesions. Notice how well the anterior and posterior views are separated with regard to anterior and posterior structures. The effect of being in or out of focus is demonstrated by the difference in resolution of the shoulders. The better defined shoulders posteriorly are in focus while the poorly defined shoulders anteriorly are out of focus because of the necessity of keeping the detector high enough to clear the patients head as the shoulders are coming into view.

Selected camera views demonstrate better resolution of the lesions. Better collimator depth of resolution is one reason for the superior definition. One disadvantage noted is that in the anterior view of the sternum the thoracic spine lesion is seen "shining through" due to the good depth of resolution of the high-resolution collimator. Here is an isolated disadvantage of good depth of resolution in that difficulty in location of the lesion might be introduced. The anterior view on the whole-body scan using a focusing collimator did not have the "shine through" problem. This emphasizes the difference in depth of resolution between focusing and parallel-hole collimators. In conclusion, the importance of understanding collimators and how they affect the final diagnosis cannot be overemphasized.

References

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