# RELATIVE IMPORTANCE OF RESOLUTION AND SENSITIVITY IN TUMOR DETECTION

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The optimum compromise between sensitivity and spatial resolution in a scanning system designed to detect small regions of abnormal radioisotope concentration *in vivo* is still a controversial subject. Some workers assume that smaller resolution diameters will necessarily result in better detection, provided that the resulting loss of sensitivity is not excessive.

Lack of proper appreciation of these factors can lead to the inefficient use of a device in practice. The purpose of this paper is to present an important example of this, involving the relative merits of collimators for the detection of small abnormal volumes.

## MATERIALS AND METHODS

At least two collimators are commercially available for scintillation-camera use with low-energy gamma rays. One collimator is designed specifically for $^{99m}$Tc (1.75 in. thick, 4,500 square holes). The other is for isotopes emitting gamma-ray energies up to about 280 keV (1.5 in. thick, 1,090 round holes). The resolution diameter of the technetium collimator is 1.5 cm (full width at half maximum, FWHM, for a point-source distribution of $^{99m}$Tc at 2.5 cm depth in water); that of the 1,090-hole coarse collimator is 2.2 cm for $^{99m}$Tc under the same conditions. The point-source sensitivity of the technetium collimator is smaller by a factor of four. The point-source sensitivity includes counts recorded from the entire photopeak and over the full diameter of the image instead of four and not just the area included within the FWHM or at 80% of maximum height. These latter measurements, however, are more relevant for the detection of abnormal areas in the presence of background counts.

It is generally accepted that a collimator will be most efficient for the detection of small regions of abnormal isotope concentration if the size of the abnormal region is approximately equal to its resolution diameter (*1*). This suggests that the high-resolution 4,500-hole collimator should be more useful for $^{99m}$Tc brain scans where detection of small lesions is of interest, and many workers believe this to be so.

However, our measurements made with both collimators using the figure-of-merit theory developed by Matthews (*2*) showed that the coarser-resolution 1,090-hole collimator was considerably more efficient for detecting abnormal regions with diameters as small as 1.4 cm although its FWHM is considerably greater than this. These results are published elsewhere (*3*).

Because some surprise was expressed at this result, we investigated this prediction further by carrying out tests using bulbs of 1.1-, 1.4- and 2.3-cm diameter immersed at various depths in a $20 \times 20 \times 12.5$-cm deep tank in contact with the collimator face. The concentration of $^{99m}$Tc in the bulbs was 1.0 $\mu$Ci/ml and that in the background tank 0.1 $\mu$Ci/ml, giving a tumor-to-background concentration ratio of 10:1. A series of pictures was taken using the scintillation camera with increasing exposure times under identical conditions with each of the two collimators in place. The camera single-channel analyzer was set to include the whole photopeak of $^{99m}$Tc. In addition to recording the results on Polaroid film, the data were analyzed quantitatively by feeding the x- and y-position pulses into a multichannel analyzer used in the bidimensional mode (*4*).

## PHYSICAL RESULTS

The Polaroid photographs clearly confirmed that in each case the 1.1-, 1.4- and 2.3-cm diameter bulbs were all detected in a shorter time using the 1,090-hole collimator. Figure 1 shows an example of these results in which the 1.4-cm diameter bulb is clearly shown in 13 sec using the 1,090-hole coarse collimator, although it is not visible in the picture taken with the same exposure time using the 4,500-hole technetium collimator.

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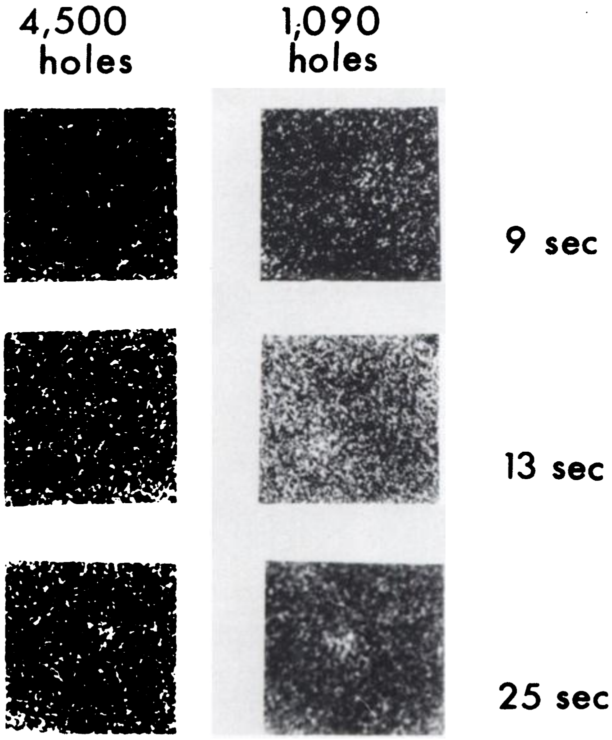


**FIG. 1.** Polaroid photographs of different exposure times taken with scintillation camera to compare performance of two collimators. Target, a bulb of 1.4-cm diameter containing $^{99m}$Tc at 10 times background concentration, is clearly seen after 13-sec exposure with 1,090-hole collimator. However, 25-sec exposure is required using 4,500-hole collimator.

## DISCUSSION

The times required for threshold visual detection were in good agreement with those predicted by our previous figure-of-merit measurements (*3*) assuming that a difference of about 3 standard deviations between bulb and background must be achieved, for an area corresponding to 80% of the height of the point source distribution function. The multichannel analyzer counts which were simultaneously recorded also showed that a difference of 2–3 standard deviations between bulk and background corresponded to threshold visualization. This is an approximate check that n = 3 standard deviations is a reasonable choice in these circumstances. For the detection of a given abnormality, a difference of at least n = 3 standard deviations above background must be achieved in the image either by a high concentration in the abnormality or by sacrificing resolution to gain sensitivity.

Matthews and Kibby (*5*) have recently carried out a similar experiment by comparing the detecting ability of rectilinear-scanner collimators with different resolution diameters. Their result was similar to ours; they found that when resolution was sacrificed to improve the sensitivity, the detecting ability of the collimator was greatly improved even when the abnormal region was smaller than the FWHM of the point-source distribution.

The conclusion from the present result is that the technetium camera collimator is inferior to the alternative, coarser, collimator for detecting abnormal regions even as small as 1.1 cm diameter; and even using $^{99m}$Tc. The broader conclusion is that in the attempt to design high-resolution collimators, the loss of sensitivity may more than cancel out any improvement due to the smaller resolution diameter.

It is likely that FWHM is a misleading index of resolution; a smaller diameter such as the full width at 75% maximum might be more relevant; certainly the latter dimension has been shown to be nearer to the distance apart at which two point sources can be visually distinguished (*4*).

In applications where the visualization of fine detail is essential, a collimator with fine resolution must of course be used. The important point is that it will require a *much longer time than a coarser collimator,* or the results will be worse both for visualization of detail and for detection of abnormal regions. There must be a very high concentration of radioactivity present in the target region compared with body background for fine resolution to be useful. Such concentration ratios are rarely found except in the thyroid.

In these two gamma-camera collimators the reduc-

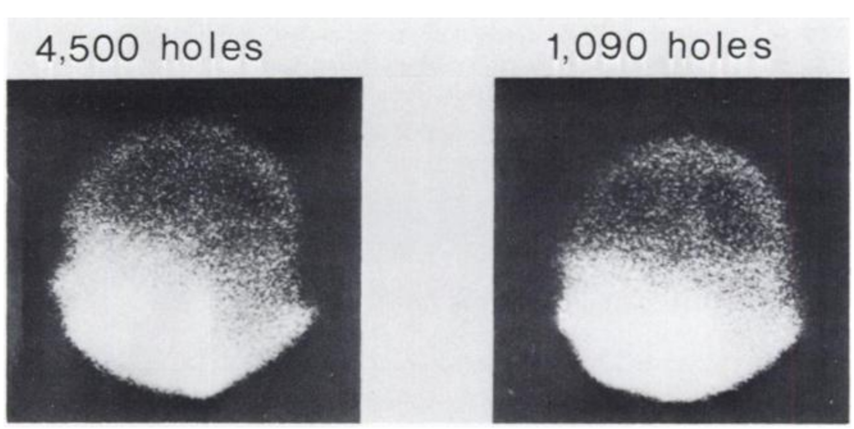


**FIG. 2.** Left lateral brain study using 4,500-hole collimator with $^{99m}$Tc is shown at left. Picture consists of 200,000 counts with exposure of 2 min. Presence of abnormal area in parietal region is equivocal. At right is result obtained with same patient but using 1,090-hole collimator. 400,000 counts were recorded with exposure time of 1 min, and region of abnormal uptake can be clearly seen.

tion in resolution diameter in the ratio 2.2:1.5 was found to require an increase in counting time by a factor of 2–2.5 to give the *same* chance of detecting small bulbs (Fig. 1). This is in agreement with the ratio of resolution areas, 2.2, as would be expected for nonfocusing collimators. If the finer resolution of the technetium collimator is going to be successful in visualizing finer detail, then its counting time must be longer than for the coarse collimator by a factor of at least 2.2.

If these facts are not appreciated, the use of fine-resolution collimators could well give worse results than the coarser collimators.

## CLINICAL RESULTS

Figure 2 shows two camera pictures of the same patient taken a few minutes apart 1 hr after injection of 5 mCi of $^{99m}$Tc-pertechnetate. The 4,500-hole technetium collimator recorded about 200,000 counts (in 2 min), and the visualization of the abnormality is doubtful. The 1,090-hole collimator, however, recorded about 400,000 counts in a shorter time (1.5 min), and a clearer diagnostic picture was obtained.

It is now routine in our laboratory to allow a sufficiently long counting time for the accumulation of at least 400,000 counts for a brain tumor localization when the technetium collimator is used.

## ACKNOWLEDGMENTS

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