CONVERGING COLLIMATION AND A LARGE-FIELD-OF-VIEW SCINTILLATION CAMERA

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Three low-energy multihole converging collimators were evaluated in reference to accepted imaging parameters using a prototype large-field-of-view scintillation camera. A substantial improvement in resolution and/or sensitivity with depth was observed. Because of the large detector, the inherent reduction in field size due to convergence was not detrimental to satisfactory imaging of most target volumes. Such collimation should prove to be of significant clinical value.

The potential benefits of converging collimation for radionuclide imaging with a scintillation camera have been previously described (*1–7*). The degree of convergence required to obtain satisfactory image magnification restricts the field of view of a 10-in. camera to the point where application is limited.

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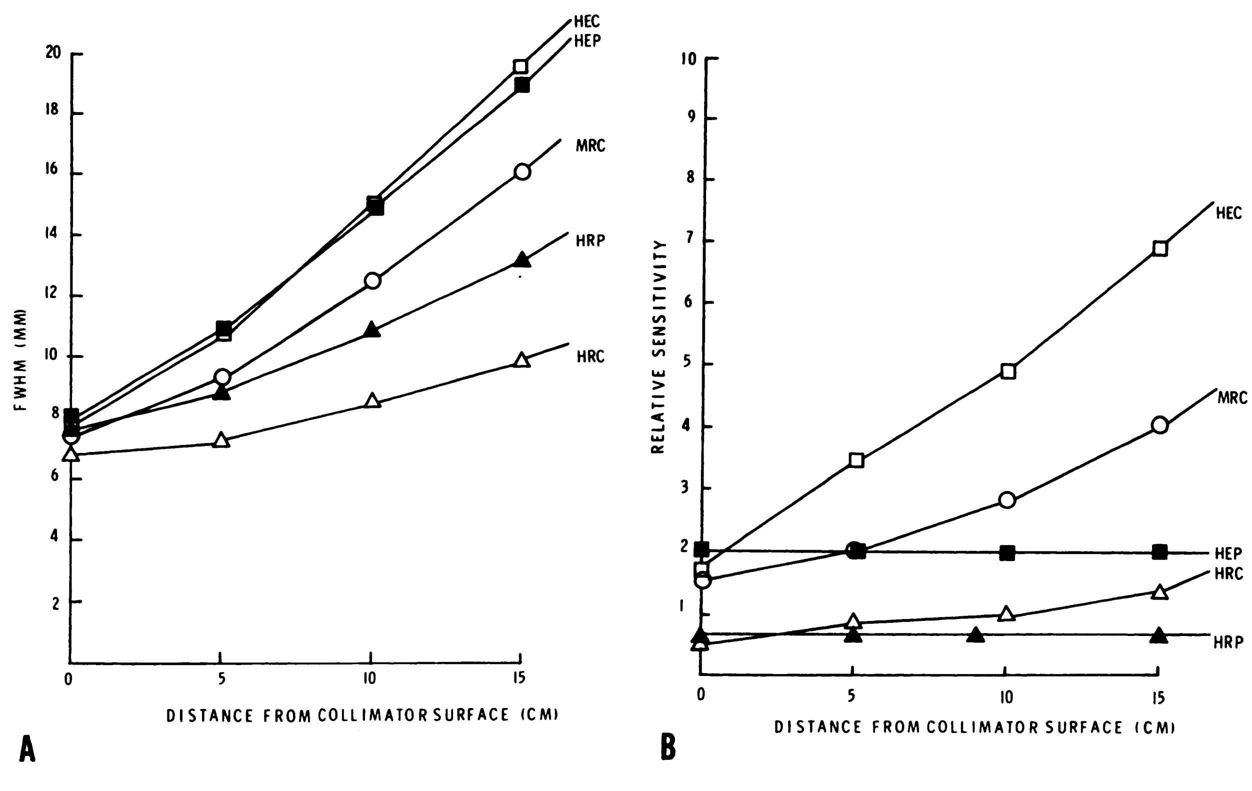

FIG. 1. (A) System resolution (FWHM) for ^{99m}Tc versus distance from collimator surface for high-resolution converging (HRC), medium-resolution converging (MRC), high-efficiency converging (HEC), high-resolution parallel (HRP), and high-efficiency parallel (HEP) collimators. (B) Relative mean point-source sensitivities for LFOV collimators versus distance from collimator surface.

Seeking improved resolution of deeper structures and more general clinical utility, an investigation was undertaken to evaluate the use of low-energy multihole converging collimation with a prototype large-field-of-view scintillation camera (LFOV) (7) (manufactured by Searle Radiographics). The useful viewing area of this instrument is 15.25 in. in diameter with parallel-hole collimation. Three collimators were designed to span the opposing limits of high resolution and high sensitivity with a field size at 10 cm equal to that of the standard size camera with parallel-hole collimation. This report summarizes the physical and performance characteristics of the collimators and the influence of their unique properties on image quality.

MATERIALS AND METHODS

Each of the three collimators was designed for optimum performance at the 140-keV photon energy of ^{99m}Tc, having approximately 23,000 triangular holes, with a septal thickness of 0.25 mm. Focal lengths of 15.13, 15.71, and 15.92 in. correspond, respectively, to the high-resolution con-

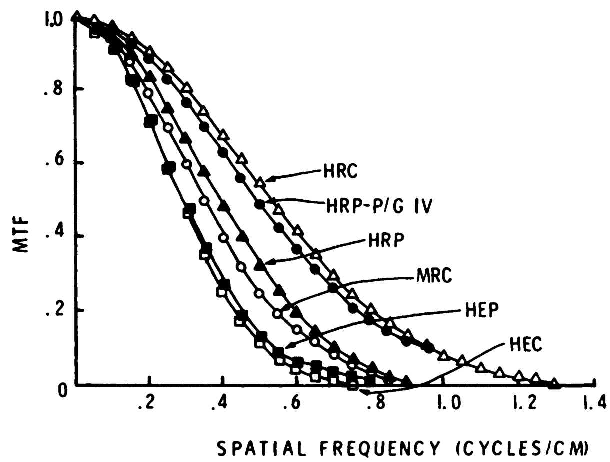

FIG. 2. Modulation transfer functions at 10-cm object distance for LFOV collimators and PG/IV with high-resolution collimator. MTFs obtained from Fourier transform of line-source response function for ^{99m}Tc in air.

verging, medium-resolution converging, and high-efficiency converging collimators. Using parallel-hole collimation for standard size cameras [Searle Radiographics Pho/Gamma HP (PG/HP) and Pho/

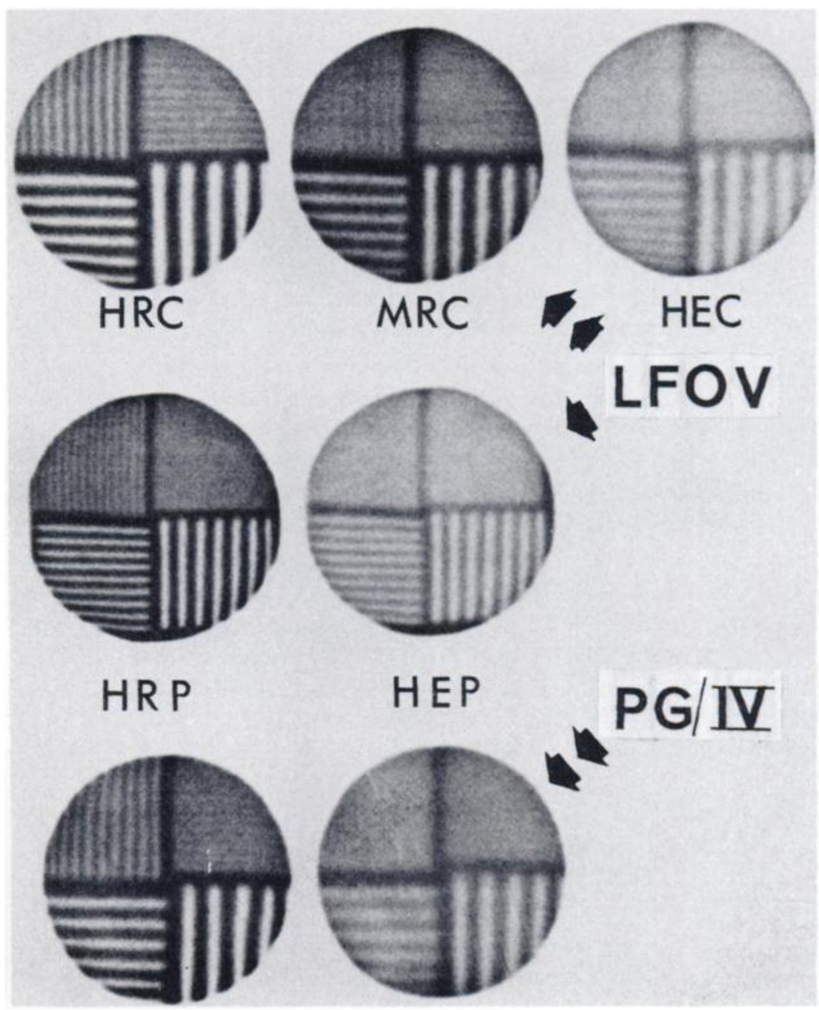

FIG. 3. Bar phantom images at 10 cm from collimator surface for LFOV converging collimators and high-resolution and high-efficiency parallel-hole collimators on LFOV and PG/IV. Bar phantom spacings are 3/16, ¼, ⅜, and ½ in.

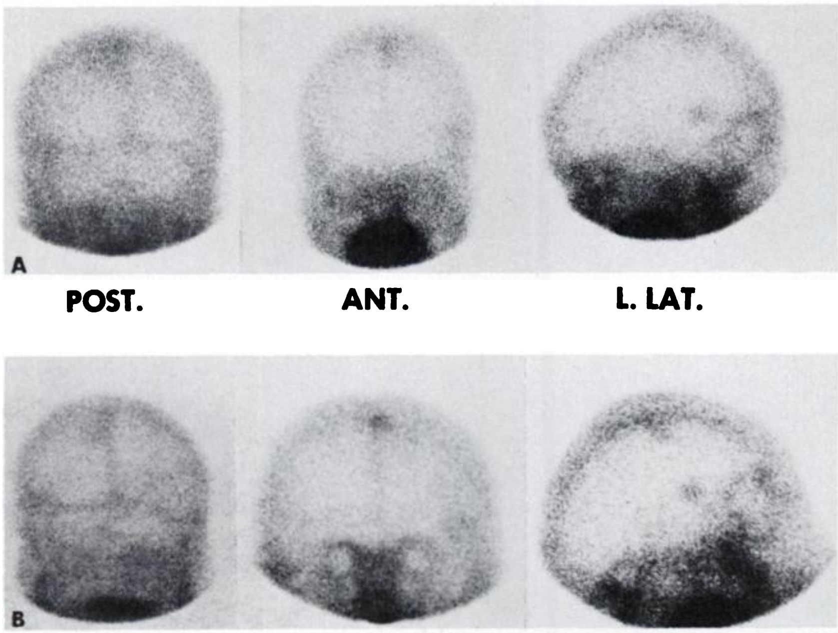

FIG. 4. Metastatic carcinoma of lung in 67-year-old woman. Delayed static images of 400K count obtained with PG/IV and high-resolution collimator (A), and with LFOV and HRC collimator (B).

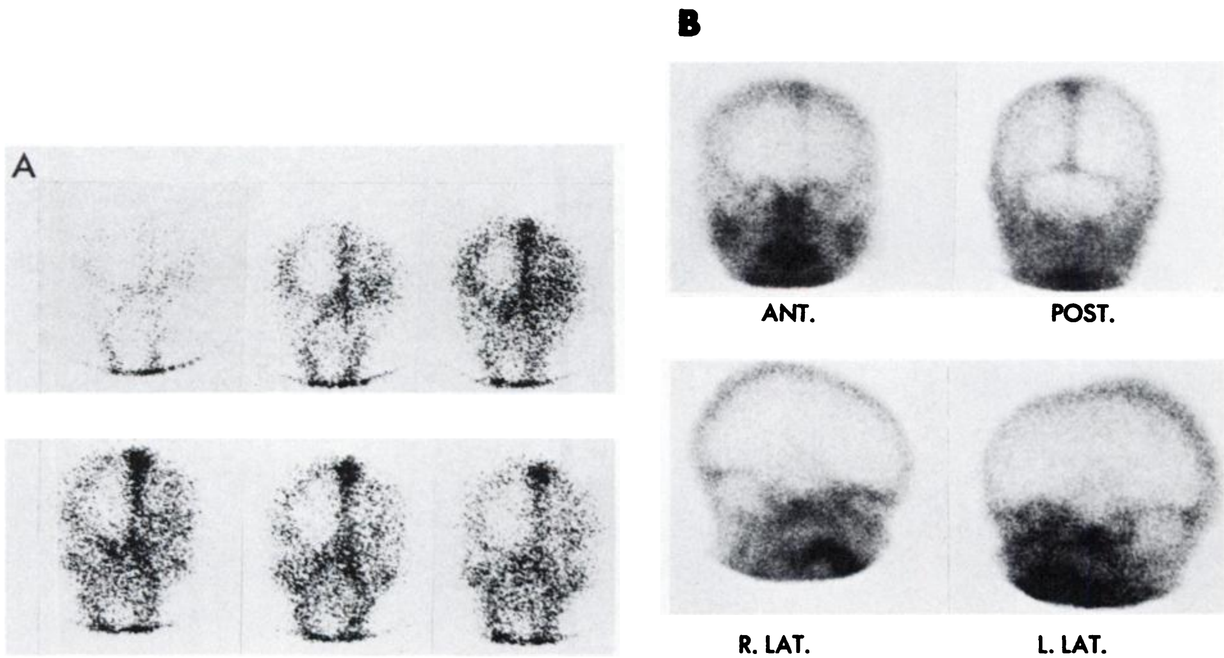

FIG. 5. Porencephalic cyst in 3-year-old boy. (A) Sequential 2-sec frames of cerebral scintiangiogram performed with 6.1 mCi of ^{99m}Tc-pertechnetate. Although comparison images with standard camera are not feasible in dynamic studies, overall improvement in vascular detail is consistently observed in HEC collimator scintiangiograms. (B) Static images of 400K count with HRC collimator. Note relative lucency of right hemisphere seen in lateral as well as anterior and posterior views.

Gamma IV (PG/IV)] as a reference, the high-efficiency converging collimator (HEC) was intended to mimic the resolution of the high-efficiency parallel-hole collimator (HEP), while the high-resolution converging collimator (HRC) was designed to be no less sensitive than the high-resolution parallel-hole collimator (HRP).

The spatial resolving capabilities and relative sensitivities of the collimators were determined in comparison with similar parallel-hole collimators for the LFOV and equivalent collimation for the most recent model of the standard camera (PG/IV). The parameters of resolution measured were full width at half maximum of the line-source response function

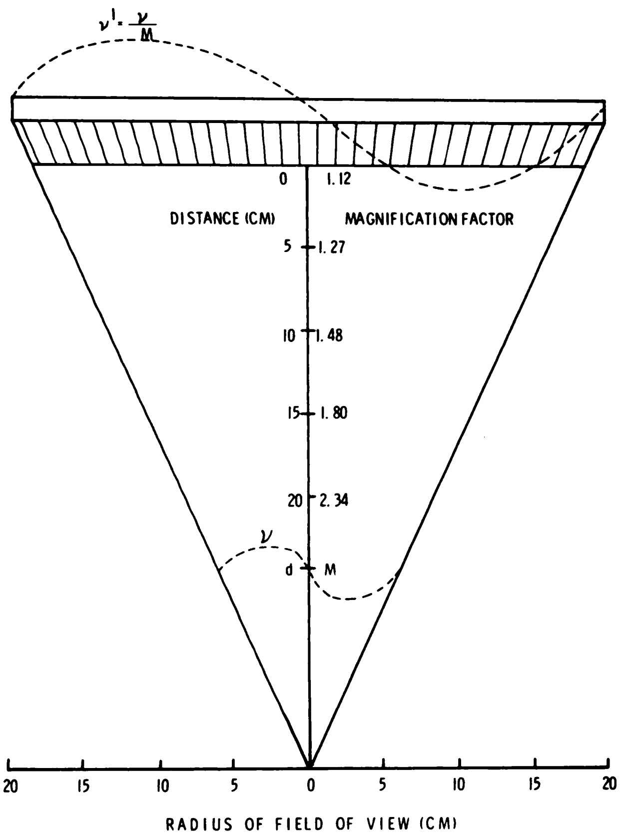

FIG. 6. Schematic diagram of HRC collimator indicating field-of-view and magnification factors as functions of distance from collimator surface. Apparent decrease in spatial frequency ν of object as it appears in image ν' is related to magnification factor M at depth d of object.

(FWHM) for ^{99m}Tc in air, modulation transfer functions (MTFs), and phantom images. Sensitivities were compared by recording the response of the camera to a plane source of ^{99m}Tc covering the field of view. The mean point-source sensitivities were subsequently derived by normalizing this measurement per unit area of the field size at a given depth. Patient studies were also performed to determine the combined influence of collimator resolution and sensitivity on clinical images.

RESULTS

System resolution for ^{99m}Tc as a function of distance from the surface of the collimators is shown in Fig. 1A by the FWHM. In Fig. 2, MTFs illustrate the resolving capabilities at depth (10 cm) in relation to object spatial frequency. The high-resolution converging collimator exhibits spatial resolution superior to that of the other collimators. In Fig. 3, bar phantom images provide visual confirmation of these findings.

The mean point-source sensitivities for the LFOV collimators are shown in Fig. 1B. Note that with the converging collimators the sensitivity increases with depth and that each demonstrates greater sensitivity than the corresponding parallel-hole counterpart for either the LFOV or the PG/IV. The patient studies in Figs. 4 and 5 illustrate the enhanced image quality resulting from converging collimation.

DISCUSSION AND CONCLUSIONS

Theoretically, images recorded with converging collimation contain inherent distortion because of nonuniform image magnification. The magnification factor increases as the field of view decreases with distance from the collimator surface (Fig. 6), which results in projections of different relative size for objects that do not lie in the same plane parallel to the surface of the collimator. In addition, distortion of relative position also occurs due to the projection onto different locations of the detector of objects lying in different planes but at the same displacement from the axis. The net effect is that deeper structures appear larger in the image than those of the same size but nearer the detector, and the object being imaged tends to "balloon" away from the point nearest the detector (Fig. 7). Alternatively, distortion may be defined as the result of varying magnification factors for different regions of the same object. These effects are more pronounced near the collimator focal

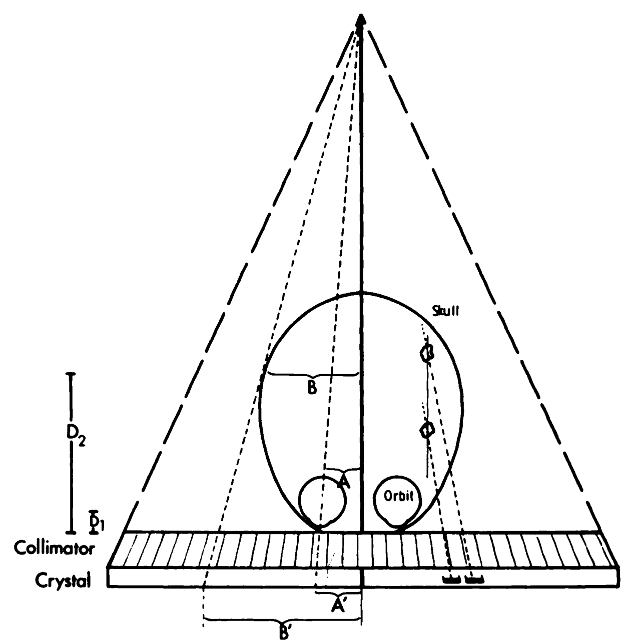

FIG. 7. Schematic representation of positioning for anterior brain view illustrates potential for distortion in imaging thick objects. Two lesions represented in left hemisphere at different depths are projected onto different locations of scintillation crystal although they are at equal distances from midplane. Ballooning effect is produced by converging collimation because magnification increases with depth. Ratio of distances from midline to orbit and to lateral aspect of brain (A/B) is greater than ratio of equivalent distances in image (A'/B') because magnification factors at distances D_1 and D_2 (M_1 and M_2) are not equal. Thus, $A'/B' = (A \times M_1)/(B \times M_2) \neq A/B$ since $M_2 > M_1$.

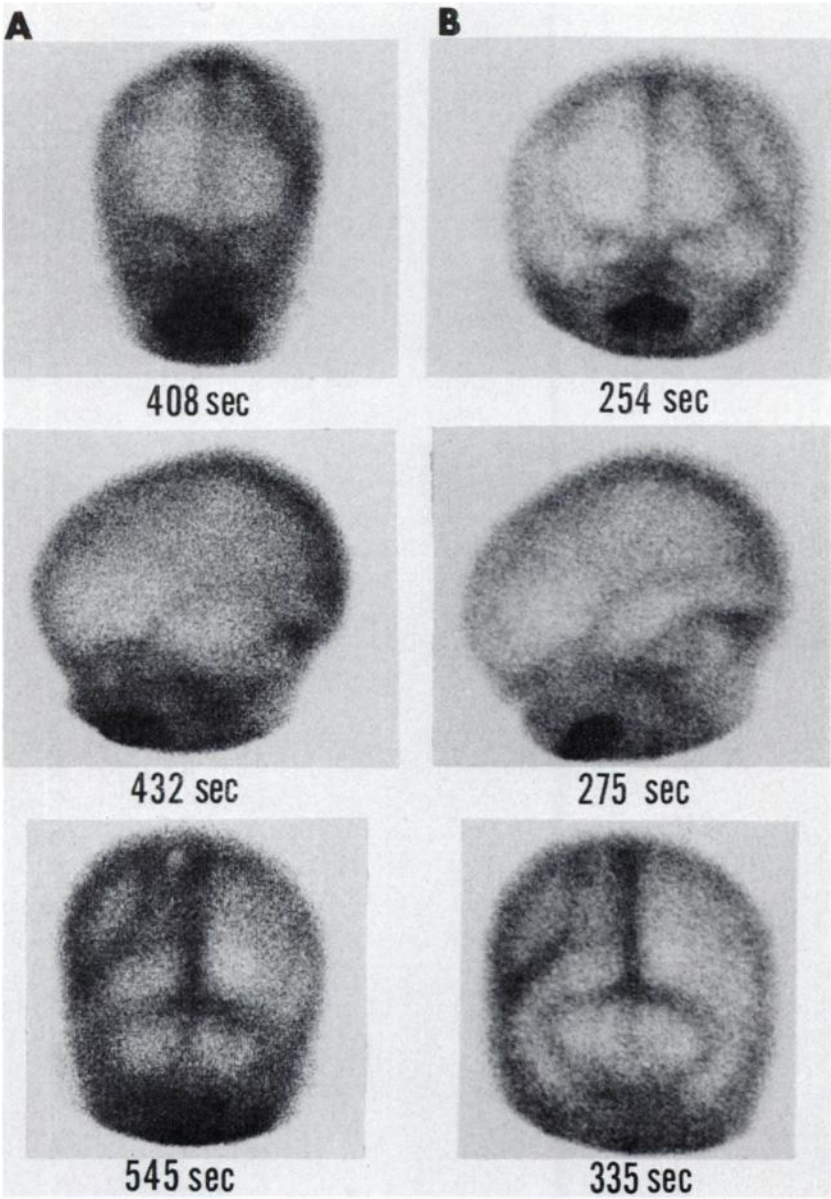

FIG. 8. Brain images from 5-year-old boy with hydrocephalus and subdural hematoma. PG/IV and high-resolution collimator (A); LFOV and HRC collimator (B). Ballooning effect described in Fig. 7 is readily apparent, but does not adversely influence projection of lesion.

point. Although some distortion can be readily noted in the clinical images by comparing the relative position and size of surface and deeper structures, no adverse influence has been detected in more than 2,000 patient images (Figs. 8 and 9). The discrepancy between the theoretical and the observed may be related in part to the considerably greater distance of the collimator focal point in relation to the thickness of the object of clinical interest.

The benefits of converging collimators include improvements in both spatial resolution and sensitivity in comparison with equivalent parallel-hole collimators, but there is an inherent sacrifice in the field of view with depth. The enhanced spatial resolution is caused by an apparent decrease in the spatial frequencies of an object because of magnification before incidence upon the scintillation crystal (Fig. 6). In essence there is a translation to higher frequencies of the modulation transfer function along the frequency axis. One consequence of these effects is the possibility of improving upon the intrinsic resolution of a scintillation camera (Fig. 10). Also, the magnification increases with distance from the collimators, partially compensating for the usual geometric degradation of resolution which is observed with equivalent parallel-hole collimators.

Sensitivity increases along the axis of the detector due to an increase in the fraction of the collimator ports viewing the source. Since a larger fraction of the detector is thereby exposed to the source, more photons emanating from the object can be used for imaging. In a fashion analogous to that with resolution this increase in sensitivity with depth partially counteracts the attenuation of photons by over-

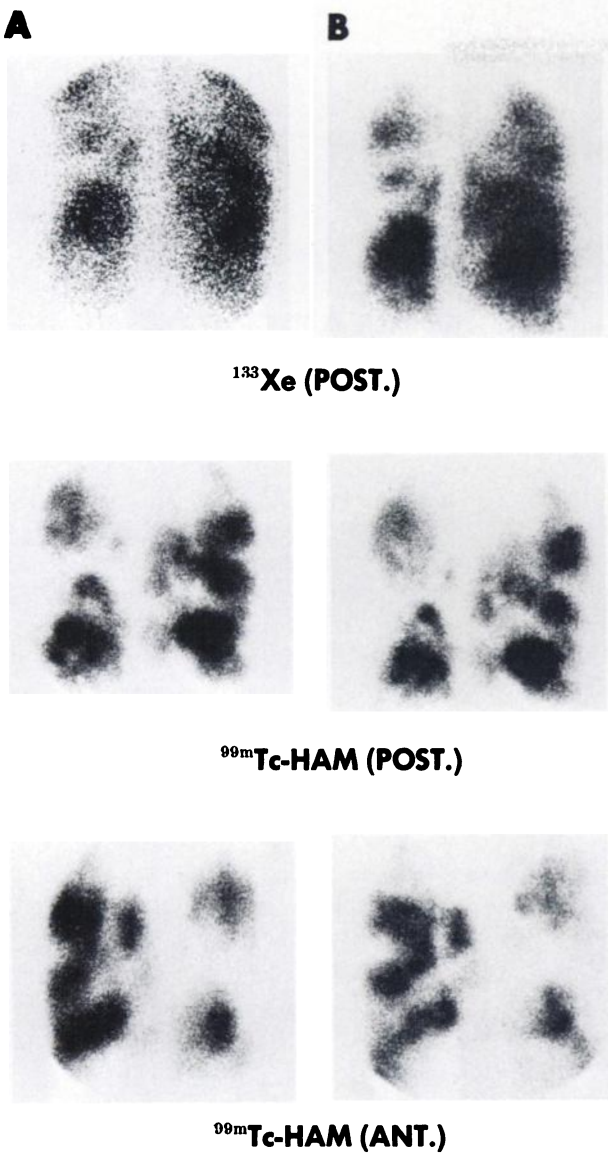

FIG. 9. Cystic fibrosis in 11-year-old girl. Pulmonary ventilation and perfusion images with PG/IV (A) and LFOV (B). LFOV with HEC collimator for ^{133}Xe ventilation and HRC collimator for ^{99m}Tc-HAM perfusion images. PG/IV with equivalent parallel-hole collimation. (Imaging times approximately 40% less with converging collimators.) Potential for distortion with converging collimators should be most evident in imaging lesions at depth in thick objects. In spite of lesions being distributed through large target volume, no significant distortion is noted in LFOV images.

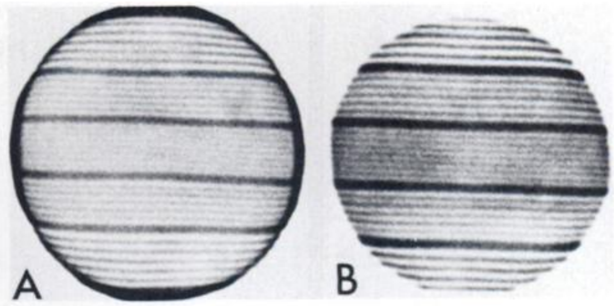

FIG. 10. Comparison of LFOV images of Hine–Duley phantom at 0 cm. (A) Without collimation (intrinsic resolution), and (B) with HRC collimator. Converging collimation creates potential for improving upon intrinsic resolution of scintillation camera.

lying tissues. The option of converging collimation for a scintillation camera allows more efficient use of the total crystal through application of a collimator with a degree of convergence which is matched to the object size at the depth in question.

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