INSTRUMENTATION

Improved Intrinsic Resolution: Does it Make a Difference?

Concise Communication

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The purpose of this study was to determine what effect further improvement in an Anger camera's intrinsic resolution has on lesion detection. We studied 52 patients undergoing bone imaging and 58 undergoing liver imaging. All patients had images performed in rapid sequence on ZLC-75 and ZLC-37 Anger cameras, both by Siemens. The two imaging systems are virtually identical except for the number of photomultiplier tubes and crystal thickness; these resulted in differences in intrinsic resolution (ZLC-75 <3.8 mm FWHM at 140 keV, ZLC-37 <4.9 mm) and sensitivity (ZLC-75 ~0.91 of ZLC-37 at 140 keV). Observer performance, measured by ROC curves, for detection of abnormalities was virtually identical with the two instruments. Subjectively, there was a trend toward preference of the ZLC-75 images, but this was not associated with any significant improvement in lesion detectability even in the subgroup in which a preference for one or the other instrument was noted.

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The purpose of this study was to determine whether slight improvement in intrinsic resolution (~20%) in an Anger camera, obtained at the sacrifice of economy (~10% increase in price) and sensitivity (~10% loss), results in improved lesion detection. The study was carried out prospectively on a group of patients undergoing clinically indicated bone and liver imaging.

METHODS

All studies were performed on two Siemens cameras, the large-field ZLC-37 and the large-field ZLC-75. Both were of similar vintage (1980–1981) and differed only in the crystal thickness and number of photomultiplier tubes. The ZLC-37 has 37 photomultiplier tubes and a 3/8-in.-thick thallium activated NaI crystal. The ZLC-75 camera has 75 phototubes and a 1/4-in.-thick crystal. These component differences result in the following performance differences: the spatial resolution of the ZLC-75 is specified by the manufacturer to be approximately 1 mm better than the ZLC-37 (3.8 mm compared with 4.9 mm FWHM at 140 keV). This difference was confirmed in the cameras used in this study by an Anger phantom with a photogenic focus, which demonstrated resolution with the ZLC-37 to lie between 5.0 and 4.5 mm, and the ZLC-75 between 4.0 and 3.5 mm. The sensitivity of the ZLC-37 camera was ~10% better than that of the ZLC-75, as measured with a 140-keV source using identical 20% symmetric energy windows. The energy resolution of the two cameras was ~12% FWHM at 140 keV.

Field uniformity and resolution were periodically checked during the course of the study, and comparison studies were performed only when both instruments were operating acceptably. Both were used in conjunction with identical readout systems and recorded on Kodak NMB film. The Microdot systems were calibrated periodically to ensure similar image density. Studies with obvious instrument artifacts or differences in density were eliminated from comparison. Such studies constituted less than 10% of the total performed.

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PHYSICAL MEASUREMENT OF RESOLUTION

The modulation transfer functions of the two cameras were determined at various distances from the face of the collimator in the following manner. A thin plastic tube with (i.d. 1 mm) was filled with 150 μCi of Tc-99m as pertechnetate. Each camera was equipped with the same high-resolution, low-energy collimator for the measurement. A symmetric 20% energy window was used, and all data were recorded and processed using a computer interfaced to both cameras.

The line source was placed across the center of the face of the collimator and the modulation transfer functions determined for the center of the camera at the following source-to-collimator distances: in contact, and at 2.5, 5, and 7.5 cm. For all distances greater than 0 cm, tissue-equivalent scattering material (pressed wood) was interposed in the space between source and collimator.

BONE-IMAGING STUDIES

Fifty-two patients were studied following informed consent. Selection of patients was random, no more than one per day, from the patients referred to the nuclear medicine section of our hospital for clinically indicated bone imaging. The indications included malignancy (initial staging or follow-up) of the breast (*12*), prostate (*9*), lung (*5*), or other primary site (*14*), or nonmalignant disease including infection (*3*), pain (*2*), or other condition (*7*). Patients were imaged 2 to 3 hr after intravenous injection of approximately 20 mCi Tc-99m MDP. Examination consisted of several Anger-camera images of either the total body (excluding distal extremities) or a specific region (depending on clinical indication) performed first with one camera and immediately thereafter with the other camera. The sequence of camera use was based on a random order list. The same high-resolution, low-energy collimator was used and time was preset for 180 sec.

LIVER IMAGING STUDIES

The protocol used for performance of the liver images was similar to that used for the bone images except for the following details. A total of 62 patients were imaged, but adequate data for only 58 were available for follow-up analysis. Indications for scintigraphy in these 58 patients included malignancy of the breast (*13*), colon (*11*), skin (melanoma) (*6*), lung (*3*), or other primary site (*10*), or nonmalignant disease including cirrhosis (*11*), infection (*2*), or other condition (*2*).

Imaging was performed starting 15 min after intravenous injection of 6 mCi of Tc-99m sulfur colloid. Images were obtained in anterior, right and left anterior oblique, right and left lateral, and posterior positions. The initial time for a 750K count anterior view was recorded, and all subsequent images used this time unless 750K counts were achieved first. The predicted count densities for both liver and bone images should have been well within the range that would allow detection of differences in lesions if resolution were a factor (*1*).

IMAGE EVALUATION

For this purpose patient and instrument identification were covered with opaque tape and each pair of films identified by number and letter (A or B) only, so that the observers could identify neither the patient nor the instrument used.

The A and B sets (refers to the set of images associated with a single examination) for a specific patient were presented sequentially and at the same sitting. Two experienced observers were shown the A set first and were asked to rate it independently on a probability scale of 1 to 5 as to the following abnormalities: for bone images, (a) the presence of any abnormality and (b) the presence of a pathologically significant abnormality; for liver images, (c) the presence of diffuse disease and (d) the presence of focal lesions. A score of 1 indicated almost definitely normal, 2 probably normal, 3 possibly abnormal, 4 probably abnormal, and 5 almost definitely abnormal. The A set was then removed, the B set presented, and a similar rating performed. The A set was then presented alongside the B set and the observer was asked to state a preference, if any, based on a diagnostically significant feature, e.g., ability to discern whether a lesion was solitary or a combination of two adjacent lesions, or ability to establish the cause of the lesion. After the A + B sets had been compared by each observer independently, the two observers discussed their findings. If their ratings were identical they were entered as a consensus rating, otherwise each observer discussed the reasons for his rating. A comparison rating that both would agree upon was then arrived at.

The numerical ratings for each observer were evaluated by the receiver operating characteristic curve method (*2–4*). The combined preference data of the observers were analyzed by the chi-squared method for paired samples (*5*).

METHOD OF CONFIRMATION OF DIAGNOSIS

The 52 bone-image evaluations were confirmed by surgery or biopsy (*2*), radiologic correlation (*33*), information derived from previous or subsequent bone images (*5*), laboratory data (*3*), or clinical follow-up only (*9*). Follow-up evaluation was performed between 6 mo and 1 yr following the procedure.

The 58 liver images were evaluated based on either biopsy, surgery, or autopsy (15), or on a combination of laboratory data (including previous liver images, other imaging examinations, liver function tests) *and* at least a 3-mo clinical follow-up (*43*).

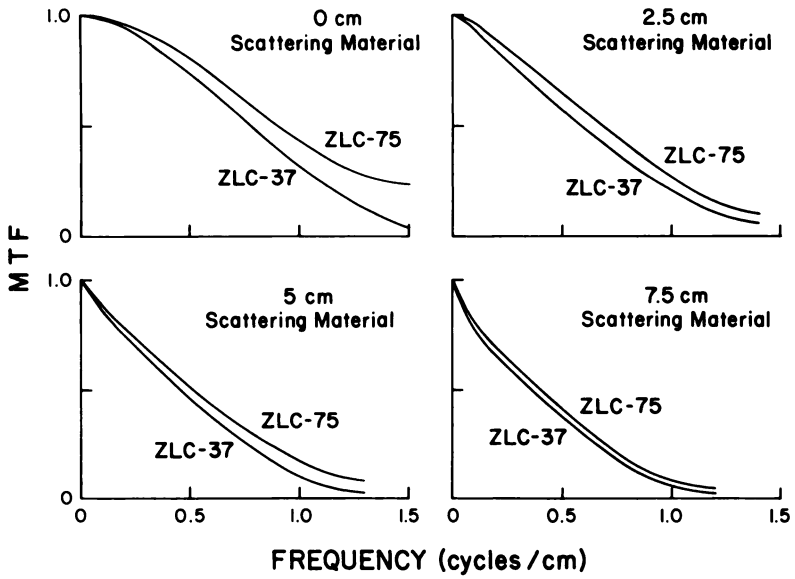


FIG. 1. Modulation transfer functions (MTFs) measured at various distances from collimator, using indicated camera, high-resolution, low-energy collimator, and 20% symmetric energy window. For all distances greater than 0 cm, region between collimator and source was occupied by tissue-equivalent scattering material. Note progressive diminuation in difference in resolution between two cameras with progressive increase in distance from collimator.

RESULTS

Measurement of resolution as a function of distance from the collimator. The modulation transfer functions (MTFs) for the two cameras are presented in Fig. 1. The difference in MTF varied as a function of distance from the collimator. At the face of the collimator, the difference in resolution was clearly apparent whereas at a depth of 7.5 cm it was barely detectable.

DIAGNOSES

Forty of 52 patients undergoing bone imaging had at least one site of confirmable abnormality. In 22 patients, the abnormalities were established to be pathologically significant. These included metastases (*15*), fracture (*3*), osteomyelitis (*2*), Paget's disease (*1*), and symptomatic degenerative joint disease (*1*). Eighteen patients had some abnormality that was deemed to be not pathologically significant, e.g., minor asymptomatic degenerative changes.

Twenty-two of the 58 patients undergoing liver imaging had a confirmable hepatic abnormality, including metastases (*15*), cirrhosis (*5*), active hepatitis (*1*), and sarcoidosis (*1*). The remaining 36 patients had no confirmable abnormality.

INTEROBSERVER CORRELATION

There was excellent interobserver agreement in the rating of all categories. It ranged from 99% agreement to within one scoring unit for "any bone lesion", to 89% agreement to within one scoring unit for parenchymal liver lesions. The exact magnitude of interobserver agreement for each category is summarized in Fig. 2.

CORRELATION BETWEEN IMAGE FINDINGS AND FINAL DIAGNOSES

Because of the small number of patients with parenchymal hepatic disease alone (seven of 58), the obvious difficulty in diagnosing parenchymal hepatic disease in the face of widespread liver metastases, and the difficulty in pathologically confirming hepatic parenchymal disease in patients with proven metastatic disease, the parenchymal and focal lesion categories for liver images were grouped into a single category of "any abnormality." The highest numerical rating of the probability of any disease was used for scoring this combined category. A separate category of "focal lesion" was subdivided from this overall "any abnormality" group and included only the observer rating for presence of a focal hepatic lesion.

Thus, for both liver and bone images two diagnostic categories were created. In the case of the bone-image group the categories were (a) any abnormality and (b) a pathologically significant abnormality. In the case of the liver-image group, the categories were (a) any abnormality and (b) focal hepatic lesion.

Receiver operating characteristic curves comparing observer diagnostic performance were plotted for each observer for each instrument in each diagnostic category, as defined above. In three cases no accurate curve could be plotted. In these cases the data points are presented with no curve. The plots of the five cases in which the data could be fitted to curves revealed virtually identical curves. In the three cases in which no accurate curve could be plotted, there are still virtually complete overlap of the data points. These data are presented in Fig. 3 (top and bottom). Thus no difference was observed in any category between performance using the ZLC-37 compared with ZLC-75.

The results of the subjective comparison of the images obtained from the two instruments are illustrated in Fig. 4. In most cases (73 of 110) no preference was noted. When a difference was noted, the images from the ZLC-75 were preferred almost twice as often as those from the ZLC-37 (24 compared with 13). This differ-

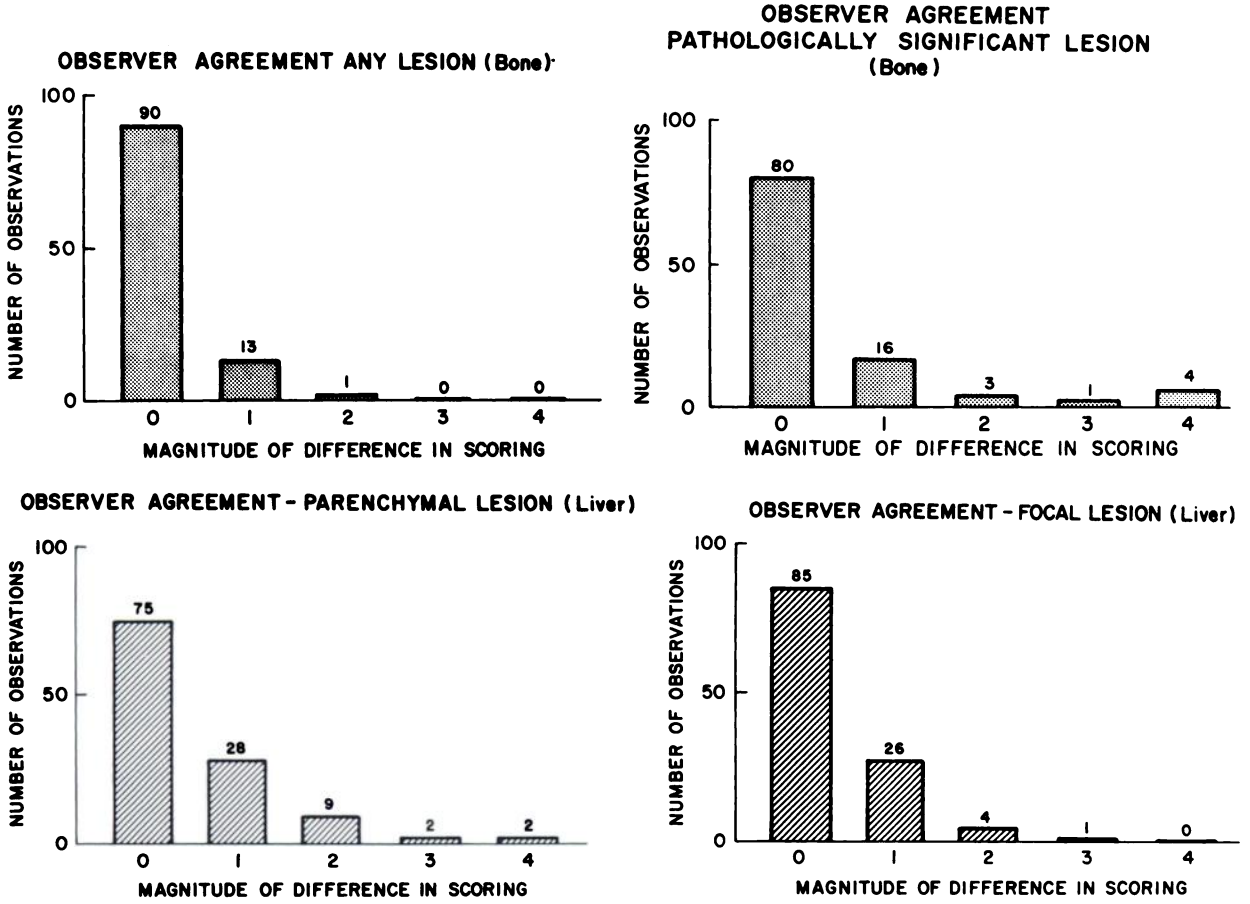


FIG. 2. Interobserver agreement by two observers in rating bone and liver images; bone images, any lesion (upper left), bone images, pathologically significant lesion (upper right), liver images, parenchymal lesion (lower left), and liver images, focal lesion (lower right).

ence was not statistically significant ($p = 0.10$), but did suggest a trend.

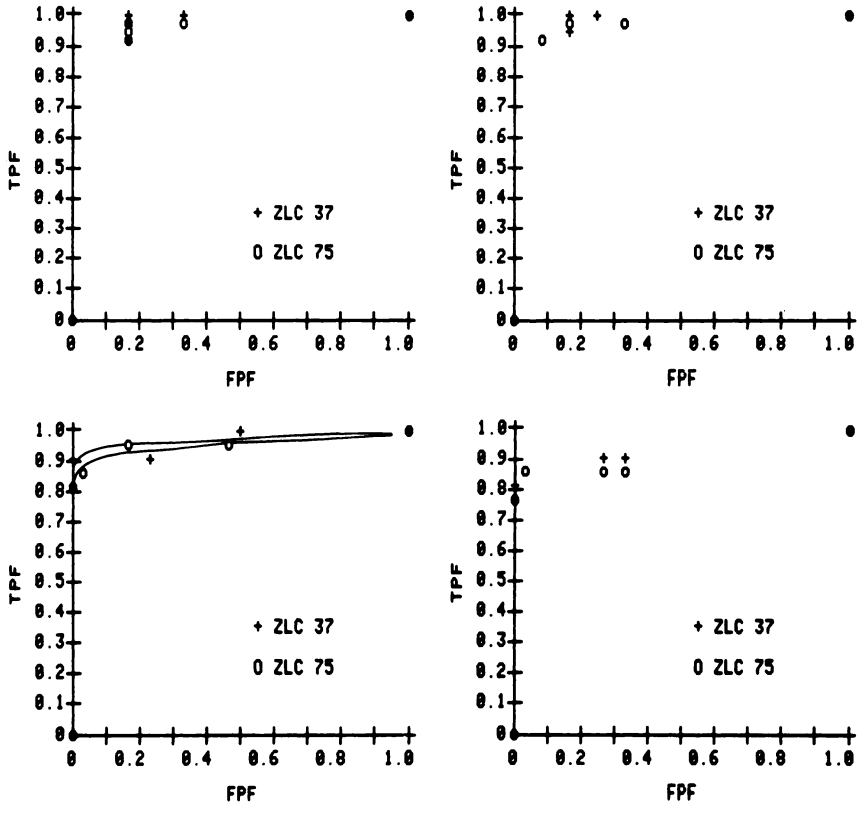
The studies in which an instrument preference was stated were reanalyzed separately to determine whether, within this subgroup, the image preference was associated with improved diagnosis. However, even within this subgroup the rating for the probability of pathologically significant disease was identical for both instruments in about 70% of the situations, and not even a trend was noted for the preference of either instrument ($p > 0.10$).

DISCUSSION

Improvements in electronics and detector design have resulted in significant improvement in Anger-camera performance. This improvement includes availability of cameras with larger field of view, shorter dead time, better energy resolution, improved uniformity and linearity, and better intrinsic resolution. Most of these improvements are of obvious clinical benefit.

However, the value of improved intrinsic resolution is controversial (*6,7*). Since intrinsic resolution can easily be compared from camera to camera using various simple phantoms, and since it implies improvement in detectability of lesions, it is often a major "selling point" in instrument selection. Unfortunately, improvements in this parameter are currently achieved at the sacrifice of increased expense (the cost of additional photomultiplier tubes and electronic circuitry) and sensitivity (due to use of a thinner scintilation crystal). Intrinsic resolution is but one factor in overall system resolution. Other factors include scatter rejection, septal penetration, and collimator (geometric) resolution. These resolution factors must, in turn, be balanced against their influence on sensitivity to determine effects on actual lesion detectability (*8,9*). In general, as one parameter in the resolution chain improves significantly beyond the others, its overall influence on system resolution diminishes. This is of particular consequence when the improvement is achieved at some sacrifice in other aspects of system performance, e.g., sensitivity.

We attempted to compare the clinical performance of two instruments that are virtually identical except for modifications made in one (ZLC-75) resulting in slight improvement in intrinsic resolution at the expense of modest increase in cost (~10%) and loss of sensitivity (~10% at 140 keV). We chose to study these effects on



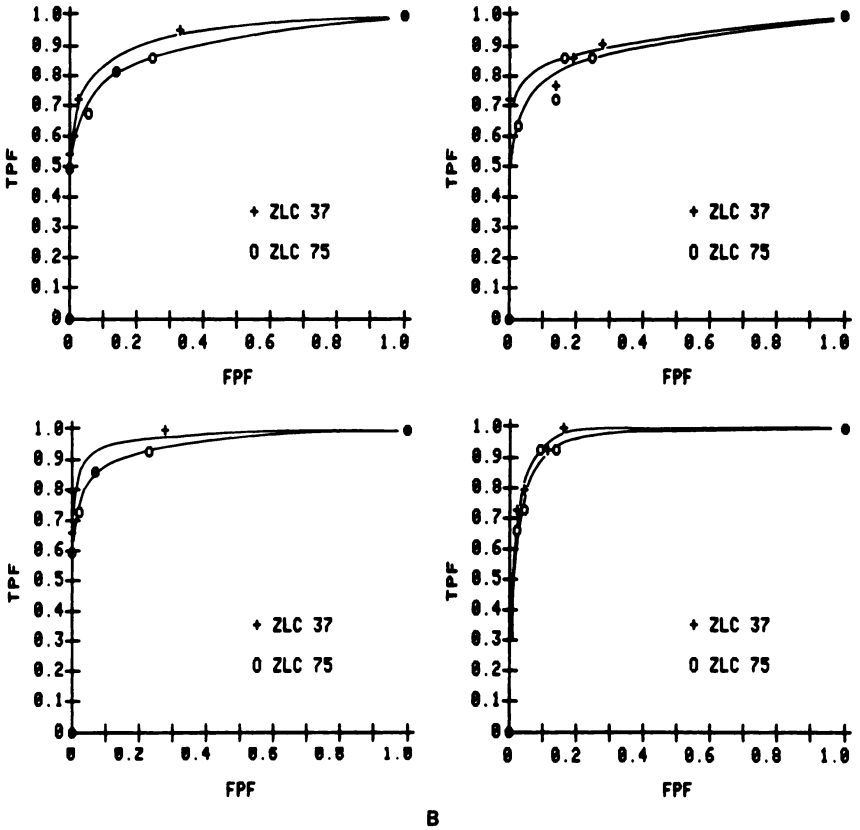


FIG. 3.(A) Receiver operating characteristic curves based on observer performance. Bone image, any lesion (upper left), Observer 1; Bone image, any lesion (upper right), Observer 2; Bone images, pathologically significant lesion (lower left), Observer 1; Bone image, pathologically significant lesion (lower right), Observer 2. In cases where no accurate curve could be fitted to data, the points are plotted alone. (B) Liver image, any abnormality (upper left), Observer 1; Liver image, any abnormality (upper right), Observer 2; Liver image, focal lesion (lower left), Observer 1; Liver image, focal lesion (lower right), Observer 2.

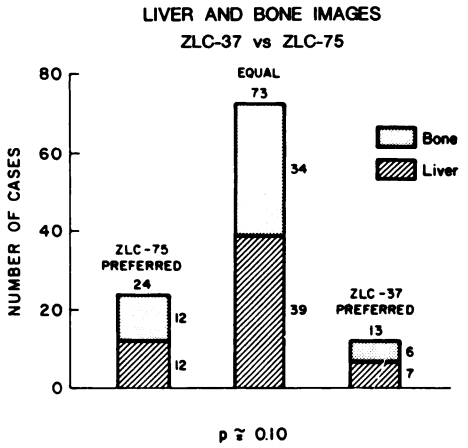


FIG. 4. Subjective comparison of images acquired with ZLC-37 compared with ZLC-75 (concurrence decision of both observers). Although these data show trend for preference of images acquired with ZLC-75, further analysis of 37 sets of images in which some preference was stated revealed no significant difference in scoring for probability of abnormality or disease. It is possible, however, that this trend reflects some subtle observational preference in terms of differential diagnosis, parameter that we did not measure.

lesion detection involving foci of hyperactivity for bone images and foci of hypoactivity for liver images. The bone- and liver-image examples were also selected because they allowed collection of a relatively large data base over a short interval of time, follow-up information on patients undergoing such studies is usually available and, finally, these studies constitute a large fraction of all studies performed using the Anger camera.

Our results indicate that there was no difference in clinical detectability of lesions between the two instruments. Viewing of the sets of images from each patient in sequence at the same sitting would tend to prejudice the interpretations somewhat, mitigating against finding such a difference. This problem occurred because it was necessary to use original films for comparison. We did not wish to remove the original studies from the patient's record for long periods of time, and thus usually viewed only about ten studies per sitting. Subjectively, there was a trend to prefer the images obtained with ZLC-75 to those obtained with the ZLC-37. Even in the subgroup in which a preference was stated, however, there was no indication that lesion detectability improved.

Certain limitations of the study should be considered. First, the results do not necessarily indicate that improved system resolution does not improve diagnosis. As previously stated, intrinsic resolution is but one component of system resolution. This point is emphasized by the progressive decrease in difference in MTF for the two systems with increase in distance from the collimator. The results indicate that at intrinsic resolution levels of less than 5 mm FWHM, the intrinsic resolution becomes only a minor component in determining overall lesion detectability. Second, this study was primarily concerned with lesion detection. The only aspect of the study to deal with specificity involved the ability to designate bone lesions as pathologically significant. It is possible that at the more subtle level of differential diagnosis, differences in performance do exist. This might explain the trend toward preference for the ZLC-75 images. However, no simple methods of evaluating such subtle differences in small groups of studies with mixed diagnoses exist.

Finally, there are other methods of improving system resolution at a sacrifice in sensitivity. A collimator could be designed with either slightly smaller holes or longer holes that would achieve slightly improved resolution at depth for an equal loss in sensitivity. Asymmetrical window setting to reduce scatter can also be used. Ideally, all of these methods should have been tested but such a test was not clinically feasible.

SUMMARY

Our study indicates that slight improvements in intrinsic resolution of an Anger camera, achieved at modest loss of sensitivity and increase in cost, do not result in observable improvement in lesion detection in liver or bone images. These results suggest that either current resolution is adequate for optimal lesion detection or, equally likely, intrinsic resolution has improved to the point where it is no longer a limiting factor in overall system resolution at lesion depth.

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Southwestern Chapter
Society of Nuclear Medicine
29th Annual Meeting

March 22–25, 1984 **Astrovillage Hotel** **Houston, Texas**

Announcement

The Southwestern Chapter of the Society of Nuclear Medicine will hold its 29th Annual Meeting March 22–25, 1984 at the Astrovillage Hotel in Houston, Texas.

The program will include submitted scientific papers, invited speakers, and teaching sessions covering areas of current interest in nuclear medicine. The program will be approved for credit toward AMA Physicians Recognition Award under Continuing Medical Education Category 1 through the Society of Nuclear Medicine.

The Southwestern Chapter 6th Annual Nuclear Medicine refresher course will be held March 22–23, 1984. The course will include reviews of basic science, instrumentation, radiopharmaceuticals, and in vitro and diagnostic imaging techniques. Nuclear Medicine Scientists, Technologists, and Physicians interested in a state of the art review are invited to attend.

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The next examination of the American Board of Science in Nuclear Medicine will be held June 4, 1984, in conjunction with the 31st Annual Meeting of the Society of Nuclear Medicine.

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Completed applications must be received by May 15, 1984.