Tomographic Thyroid Scintigraphy: Comparison with Standard Pinhole Imaging: Concise Communication

W. W. Resinger, E. A. Rose, J. W. Keyes, Jr., K. F. Koral, W. L. Rogers, T. J. Brady, R. C. Kline, J. C. Sisson, and J. H. Thrall

University of Michigan Medical Center, Ann Arbor, Michigan

Coded-aperture imaging (CAI) and multiple-view pinhole imaging (PI) of the thyroid were compared in a prospective study in 136 consecutive patients. Following 10 mCi of pertechnetate, 200K-count pinhole images were obtained in the anterior, RAO, and LAO projections, and CAI data were obtained in the anterior position. Four coronal tomographic sections were reconstructed by computer. Five observers read the studies separately, and ROC curves were constructed. Based on 109 pairs of studies, the ROC curves revealed similar performance for all observers for both techniques. When four observers compared the studies subjectively they rated the CAI more useful in 36% of cases, the PI in 6%, and the two equal in 58%. The advantages offered by the tomograms included improved contrast, accurate size representation of the gland at all depths, freedom from pinhole-type distortion, and faster data acquisition. The major disadvantage to tomography was the 2-hr computer-processing time required. If this can be reduced, CAI offers sufficient advantages over conventional pinhole imaging to warrant its routine use.

J Nucl Med 22: 638–642, 1981

Abnormalities of the thyroid may be quite small, and normal variations of structure and function may mask their presence. The ideal thyroid-imaging technique should provide high resolution and high lesion-to-normal contrast and permit easy correlation with palpatory findings. Coded-aperture imaging (CAI) provides better resolution and higher efficiency than conventional pinhole scintigraphy, along with freedom from the geometric distortion characteristic of pinhole images. The tomograms can be accurately scaled, so that useful size measurements can be made directly from the images, and the inherently high contrast of tomography produces a greater lesion-to-normal ratio.

In our laboratory a preliminary study comparing coded-aperture tomography with conventional pinhole scintigrams suggested that tomography provides significant advantages (*1*). We now report a prospective evaluation of tomographic scintigraphy of the thyroid, discuss its usefulness in various types of thyroid disease, and further compare its advantages and disadvantages with those of pinhole scintigraphy.

METHODS

The technique of coded-aperture imaging of the thyroid has been discussed previously (*1*). The aperture used in this study is the same one used in the previous study and consists of a reinforced lead plate containing 3.6-mm pinholes arranged in a pseudorandom code sequence. The code sequence used is 121 elements long with 33% mean transmission.

Consecutive patients (136) undergoing thyroid scintigraphy for a variety of clinical indications were studied. Each patient was given 10 mCi of pertechnetate intravenously. Imaging was begun 20–30 min later. First, 200,000-count pinhole images were obtained in the an-

Received July 31, 1980; revision accepted March 10, 1981.

For reprints contact: John W. Keyes, Jr., MD, Div. of Nuclear Medicine, Univ. Hospital, Box 21, Ann Arbor, MI 48109.

terior, 35° left anterior oblique, and 35° right anterior oblique projections using a commercial 5-mm pinhole collimator and a standard scintillation camera. Immediately following this, coded-aperture data were obtained in the anterior projection using the same camera.

The field of view of this aperture is sufficiently large that it could be located 1 cm from the neck of all patients. In comparison, the single pinhole was positioned so that the projected image on the persistence scope filled about 75% of the camera field. This usually required a pinhole-to-neck distance of between 3 and 4 cm. A signal-to-noise analysis based on these distances and the relative sizes of the pinholes led to the choice of a tomographic data-collection period twice that required for the anterior single-pinhole image.

Tomograms were reconstructed to yield four sections passing through the thyroid in the coronal plane at depths of 1.2, 1.65, 2.3, and 3.3 cm beneath the surface of the skin. In a few cases a fifth section at 4.3 cm was required to encompass the entire thyroid gland. All tomograms were scaled to a standard reference size. Reconstructions were all accomplished on a commercial nuclear medicine computer system and required 2 hr of computing time for the four standard sections.

All of the images, standard-pinhole and tomographic, were redisplayed on a carefully calibrated, high-quality video computer display and were photographed onto transparency film under uniform conditions using a video-type multiformat imaging device. All studies were read from the photographic transparencies. A transparent "ruler" overlay (Fig. 1) was provided for use in measuring the tomograms.

The pinhole images and the tomograms were read separately from each other by five observers working independently. A brief clinical summary was provided with each set of images, and the observers were asked to rate the images on a scale of one (definitely normal) to five (definitely abnormal) and to note as comments the location and character of any abnormalities seen. The five observers consisted of one nuclear medicine fellow with 4 mo of training, one fellow completing his second year of training, and three experienced nuclear medicine physicians.

In order to familiarize themselves with the appearance of different abnormalities in the tomographic images, all the readers, before they read the study cases, reviewed a series of seven "teaching" cases that were representative of a variety of clinical problems.

Receiver operating characteristic (ROC) curves were constructed, based on the separate readings by the five individuals. The "true" diagnosis in each case was determined by the most reliable diagnostic methods available, including surgery, ultrasound, needle biopsy, laboratory tests, and/or clinical evaluation and followup.

In addition to the ROC analysis, a subjective assessment of the clinical usefulness of each technique was obtained by having four separate readers compare the pinhole and tomographic images side by side several months after the initial readings. This was done with knowledge of the final diagnoses, and the readers were asked to state their subjective impressions as to whether the CAI study was more useful than, equal to, or less useful than the pinhole images in the management of each patient. A weighted average rating was then calculated for each study. For example, if one observer judged the CAI more useful and another observer less, these opinions were considered to cancel each other and the studies rated equal. If at least one observer deemed the CAI more helpful while the others found the procedures of equal merit, the CAI was considered better.

RESULTS

There were 137 studies performed on the 136 patients. Problems, such as aperture malfunction, patient movement, positioning errors, and poor thyroid function, rendered 17 studies unusable. Seven cases were used as the "teaching file" for observers. Four were deleted from the study because of an indeterminate final diagnosis. The 109 remaining patients, exhibiting a variety of problems, formed the basis for our final analysis.

There were 33 normal studies. In general there was no special advantage to tomography when the study was normal, but it was easier to appreciate that the gland was not enlarged with tomograms.

FIG. 1. 38-year-old male with firm 2-cm nodule palpable in lower portion of right lobe. At surgery a 2-cm colloid nodule was found, with a small adjacent focus of papillary carcinoma. In this and other figures pinhole images are on the left and coded-aperture tomograms on the right. Note overlay of a 2-cm "ruler" on tomograms, showing how accurate size measurements can be made from these scaled images.

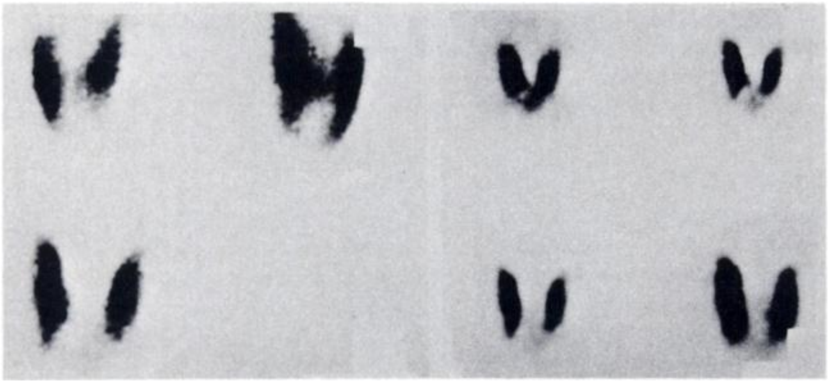

FIG. 2. 37-year-old female with small palpable nodule in the isthmus. Note that tomograms accurately place nodule anteriorly, in isthmus.

A number of studies were done to evaluate palpable nodules. In some cases, such as that illustrated in Fig. 1, nonfunctioning nodules were demonstrated equally well by the two techniques, although again the value of tomograms for determining size was apparent. Several cases of poorly functioning nodules were better demonstrated on the tomograms. In general this occurred when the nodule was small and buried in the substance of the thyroid, or was located in the isthmus (Fig. 2). In such cases the improved contrast afforded by the tomograms increased the detectability of the nodules.

Functioning nodules associated with partial or complete suppression of function in the remainder of the gland were demonstrated equally well by the two techniques. This is because these lesions are inherently high in contrast and thus quite easily demonstrated.

Multinodular goiters were usually well demonstrated by both techniques. There were some notable exceptions, such as the case shown in Fig. 3, in which the greater contrast of the tomographic approach is apparent. Again, the magnitude of enlargement in such glands was better appreciated from the tomograms.

ROC analysis of the data generated by the five observers is shown in Fig. 4. Visual inspection of the curves suggests little difference in diagnostic performance for observers using either of the two imaging techniques. Note particularly that performance is not worse using CAI. In the subjective side-by-side evaluation of the pinhole and tomographic images, the observers felt that, on the average, the tomograms were more useful in 36% of cases, the pinhole images in 6%, and that the two studies were of equal value in 58%. The results are summarized in Table 1.

DISCUSSION

Coded-aperture tomography of the thyroid demonstrates several potential advantages when compared with conventional pinhole imaging. Apparent from the images themselves is the improved lesion-to-normal contrast and the freedom from geometric distortion, which permits the better determination of gland and lesion size. Related to these is the ability to portray the entire three-dimensional anatomy of the gland from a set of tomograms obtained from a single anterior view. To obtain a comparable evaluation of anatomy by pinhole imaging requires oblique views as well as the anterior view (*2,3*).

The efficiency of the coded-aperture technique represents another advantage. Because only a single view of the thyroid is needed with the coded aperture, there is an absolute increase in the efficiency of data collection. A signal-to-noise analysis similar to that described elsewhere (*4*) showed that, for a thyroid of 16 cm^2 projected area, the coded aperture at 1 cm from the gland has roughly 12 times the efficiency of a pinhole of equal diameter at 3 cm distance. In the present study, half of this added efficiency was used to improve resolution by

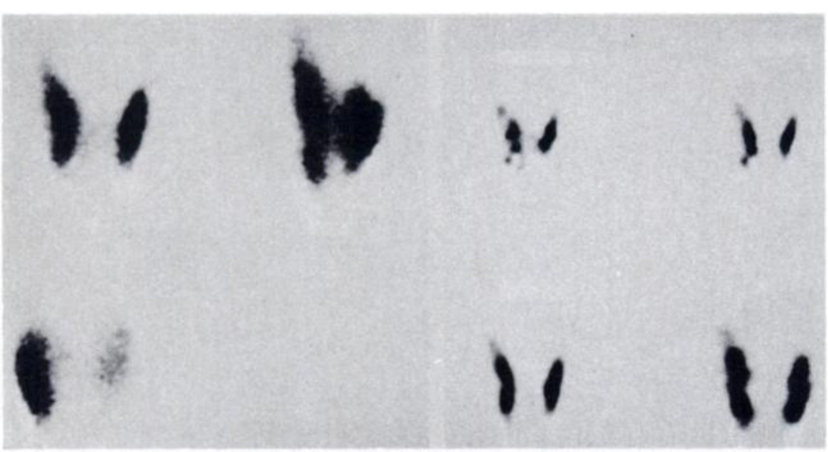

FIG. 3. 22-year-old woman with single 1-cm nodule palpable in mid portion of right lobe. Normal thyroid function. Tomograms show much better delineation of the multinodular character of this gland, reflecting improved lesion-to-normal contrast inherent in tomographic imaging.

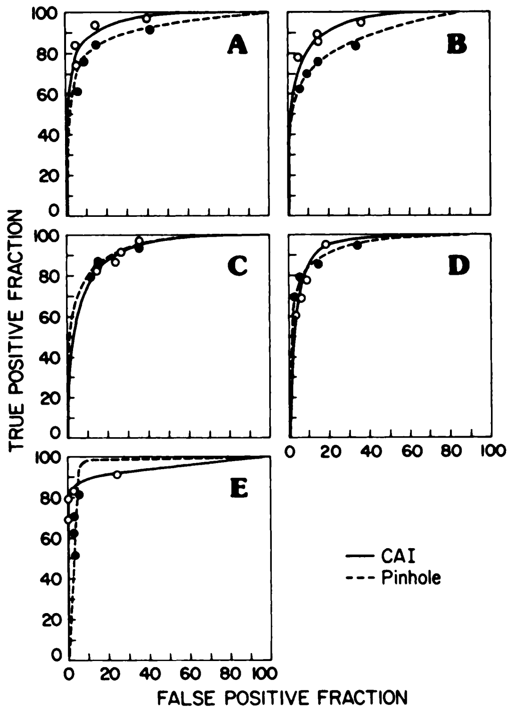

FIG. 4. ROC curves A–E represent readings of five individual observers.

using 3.6-mm diameter pinholes in the code plate compared with the 5-mm conventional pinhole. Since reconstructed tomographic images are inherently noisier for a given total count than are conventional projection images, the remaining efficiency advantage was used in part to improve the total counts in the tomograms and in part to reduce the total imaging time of the study. The total data-collection time for the coded-aperture portion of the study was two thirds of that for the pinhole imaging. If patient positioning time is considered, the total study time for the coded aperture was about half of that required for the pinhole study.

Pinhole imaging and CAI were compared in two different ways in order to test the actual value of these potential advantages. The ROC analysis, as performed, evaluated the ability of different observers to diagnose the presence or absence of abnormalities using each of the methods. This is not a particularly stringent test of the relative usefulness of the two techniques because, in many instances, the study is performed not to detect the presence of disease but to characterize abnormalities, which are already known to be present. For example, a frequent reason for imaging the thyroid is to determine the functional status of a nodule detected by physical examination. Thus, the subjective assessment of the clinical usefulness of each technique was also obtained. This evaluation reflects how the information from each study might have affected the actual management of the patient, and from a clinician's viewpoint is probably more meaningful than the ROC analysis.

TABLE 1. SUBJECTIVE EVALUATIONS: SUMMARY AND INDIVIDUAL-OBSERVER BREAKDOWN

Composite rank	Individual rankings of 4 observers: CAI better	CAI equal	CAI worse	No. of patients
CAI better	4	0	0	2
	3	1	0	3
	2	2	0	7
	1	3	0	26
	2	1	1	1
				39 = 36%
CAI equal	0	4	0	59
	1	2	1	4
				63 = 58%
CAI worse	0	0	4	1
	0	2	2	2
	0	3	1	4
				7 = 6%

The ROC evaluation demonstrated little or no difference in the ability of the two techniques to classify patients as having normal or abnormal thyroid glands. On this basis then, there is no reason to choose one test over the other. Any conclusions as to which procedure is best must be based on other grounds.

The principal advantages to CAI over pinhole imaging appear to be its better performance in the subjective evaluation and the simplified and shortened imaging procedure. These must be contrasted with demonstrated shortcomings of CAI.

A definite problem with CAI is the difficulty encountered in marking landmarks and palpable abnormalities accurately on the tomograms. This problem is also present with pinhole images and must be worked around with either technique.

The most serious problem with CAI is the long computer processing time required. This problem appears to be solvable, since software modifications have already cut the computing time in half since our previous study (*1*). Other approaches have also been discussed (*5*), such as special-purpose reconstructors and/or modifications to the aperture, and they show promise of being able to reduce reconstruction times to a few minutes. At present, nevertheless, this problem more than offsets the advantages gained by shortened imaging times and probably renders the technique impractical for routine clinical use.

Based on our present experience, we feel that tomographic scintigraphy of the thyroid could offer an advantageous alternative to conventional pinhole scintigraphy. If the long processing times can be reduced, coded-aperture imaging would be our preferred method for scintigraphic evaluation of the thyroid gland.

ACKNOWLEDGMENTS

This work was supported in part by NIH Grant No. GM 16188.

The authors thank Dr. Norman Thompson of the surgery department for his help in the followup of surgical cases; Michael Tuscan, Richard Zahler, Laura Myers, Nancy John, Donna Reeder, Debra Hack, and Jean Van Wagner for technical assistance; Mercy Shook and Elaine Smith for clerical help; and Diane Vecellio for secretarial assistance.

REFERENCES

1. KORAL KF, FREITAS JE, ROGERS WL, et al: Thyroid scintigraphy with time-coded aperture. *J Nucl Med* 20:345-349, 1979

2. KARELITZ JR, RICHARDS JB: Necessity of oblique views in evaluating the functional status of a thyroid nodule. *J Nucl Med* 15:782-785, 1974

3. BLUM M, GOLDMAN AB: Improved diagnosis of "nondelineated" thyroid nodules by oblique scintillation scanning and echography. *J Nucl Med* 16:713-715, 1975

4. ROGERS WL, ADLER R, KORAL KF: A rationale for optimal coded aperture design. *Proc. 1980 International Optical Computing Conference Book I*, Vol. 231. Bellingham, Wash., SPIE, 1980, pp 120-128

5. ROGERS WL, KORAL KF, MAYANS R, et al: Coded-aperture imaging of the heart. *J Nucl Med* 21:371-378, 1980