Clinical Evaluation of Thallium-201 Emission Myocardial Tomography Using a Rotating Gamma Camera: Comparison with Seven-Pinhole Tomography

Nagara Tamaki, Takao Mukai, Yasushi Ishii, Yoshiharu Yonekura, Hirofumi Kambara, Chuichi Kawai, and Kanji Torizuka

Kyoto University Medical School, Kyoto, Japan

Single-photon emission computed tomography (SPECT) for thallium-201 myocardial imaging with a rotating gamma camera was evaluated in comparison with planar imaging and seven-pinhole tomography (7P). Cardiac phantom studies indicated that defects 2 cm in diameter can be visualized by both tomographic methods, but the 7P method showed propagation of the image into nearby planes, with lower image contrast. In a clinical study of 47 patients with myocardial infarction, both sensitivity and specificity for the SPECT system were high (96 and 89%, respectively); the 7P system, on the other hand, showed good sensitivity (93%) but poor specificity (68%), while planar imaging performed conversely (75 against 89%). The overall accuracy was not significantly improved in the 7P method (planar: 81%, 7P: 83%, and SPECT: 94%). Our study indicates that SPECT, which can reconstruct reliable tomographic sections in either the transaxial, frontal, or sagittal planes, will result in a remarkable improvement in the clinical evaluation of ischemic heart disease.

J Nucl Med 22: 849–855, 1981

Myocardial perfusion imaging using thallium-201 provides useful information for the noninvasive evaluation of coronary artery disease (*1–3*). Myocardial imaging with a standard gamma camera, however, suffers from limited sensitivity because of the superimposition of the activity of the adjacent myocardial wall as well as background activity. Vogel and Kirch (*4*) introduced the seven-pinhole collimator with its associated computer algorithm for emission tomography of the myocardium. Clinical evaluations have been attempted by several investigators and some have reported that the sensitivity of seven-pinhole tomography for the detection of ischemia is superior to that of the conventional planar technique (*4, 5*); others, however, found the 7P system to have less specificity (*6, 7*).

Recently a method of single-photon transaxial emission computed tomography (SPECT) using rotating or multicrystal cameras became available and myocardial perfusion imaging using this approach has been described (*8–10*). However, a precise clinical evaluation of myocardial SPECT has not yet been made.

Last year, a rotatable gamma camera became commercially available and a clinical evaluation of SPECT using this system was undertaken at our institution (*11*). This report describes a comparison of the rotating camera with the planar and seven-pinhole imaging systems: Clinical subjects are used as well as a cardiac phantom.

MATERIALS AND METHODS

Description of system. The single-photon emission computed tomograph (SPECT) used in this study consisted of a large-field-of-view gamma camera with a high-resolution, parallel-hole collimator, supported by

Received Jan. 30, 1981; revision accepted April 6, 1981.

For reprints contact: Nagara Tamaki, MD, Dept. of Radiology and Nuclear Medicine, Kyoto Univ. Hospital, Kawara-cho, Shogoin Sakyo-ku, Kyoto, 606, Japan.

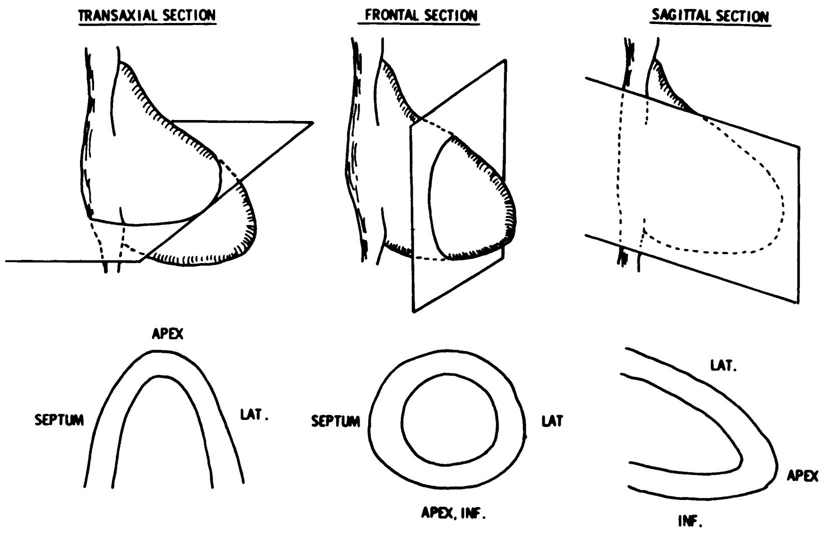

FIG. 1. Transaxial, frontal, and sagittal sections of myocardium available with SPECT.

a gantry in a tunnel configuration.* The gantry rotates 360° around the long axis of the patient. After intravenous injection of 2 mCi of thallium chloride, data were collected from 64 views, requiring 22 min for myocardial imaging. Filtered back-projection used Chesler's filter (*12*). The computer processing time was 20 sec/slice to reconstruct 12-mm-thick sections in the transaxial, frontal, or sagittal planes. Each reconstructed slice contained 150,000–250,000 counts. The spatial resolution is 17 mm FWHM and is nearly independent of the position in the section. Attenuation correction was performed by Sorenson's method (*13*). Data collection was started from the left anterior oblique projection, so that the frontal and sagittal tomograms nearly correspond to transverse and longitudinal sections in relation to the cardiac axis (Fig. 1). Our reconstruction method has been fully described elsewhere (*11*, *14*).

Seven-pinhole tomography used pinholes 5.5 mm in diameter and a large-field-of-view gamma camera positioned for 45° left anterior oblique projection. The raw data for reconstruction required about 10 min of counting time, during which two images, each containing 375,000 counts, were stored in computer. A series of ten reconstructed tomograms were obtained by the commercial algorithm (CMS). Enhanced digital images were used for evaluation of these tomograms by subtracting 30–40% of the background.

Phantom study. A cone-shaped, plastic cardiac phantom was constructed. The wall thickness of its chamber was 1.0 cm; the maximum external diameter and the long axis measured 6 and 12 cm, respectively. Two hundred microcuries of thallium-201 were dissolved in 200 cc of water to make a standard solution, which was used to fill the walls of the phantom. To simulate transmural perfusion defects, cylindrical nonradioactive plastic materials of 1, 2, 3, and 4 cm in diameter were inserted into the inferior wall of the phantom. The long axis of the phantom was placed in the 45° left anterior oblique position, with 30° caudad tilt, in a water tank 30 cm in diameter by 30 cm high. In order to determine the defect-to-normal-wall ratio in each image, the long axis of the phantom, with a 3- by 3-cm wall defect, was placed perpendicular to the detector plane (Fig. 3, top) and tomograms were reconstructed. Then, 2–4 pixels were flagged on the peaks for the normal wall and the defect, and the peak defect-to-normal count ratios were used for least-square fitting as a measure of imaging performance for comparison between the SPECT and the 7P methods (*15*).

Clinical study. For this we selected 19 noncardiac patients (Group 1: 12 men and 7 women, ages 15–64 yr) and 28 patients with evidence of myocardial infarction (Group 2: 25 men and 3 women, ages 31–80 yr). Each case in Group 1 either had no disease or complained only of inconsistent chest discomfort, with cardiac enzymes or electrocardiogram failing to reveal any abnormality at rest and during exercise. None had a history of myocardial infarction. All cases in Group 2 satisfied all of the following criteria: (a) anterior chest pain lasting 1 hr or longer, (b) typical changes in serum cardiac enzymes, and (c) ECG changes indicative of myocardial infarction. The imaging was undertaken 3 wk to 6 yr after the most recent episode of myocardial infarction.

Ten minutes after intravenous administration of 2 mCi of thallium-201 at rest, planar myocardial images were obtained in the anterior, 30, 45, 60° left anterior oblique, and left lateral views using a large-field-of-view gamma camera with a low-energy, high-resolution, parallel-hole collimator. Immediately after the planar imaging, 7P tomography was performed, and then SPECT. It took less than an hour after Tl-201 injection to complete all of the imaging. The 7P method required 10 min for data acquisition and 1 min for image reconstruction, whereas the SPECT took 22 min for sampling and 3 min for reconstruction of the series of myocardial images.

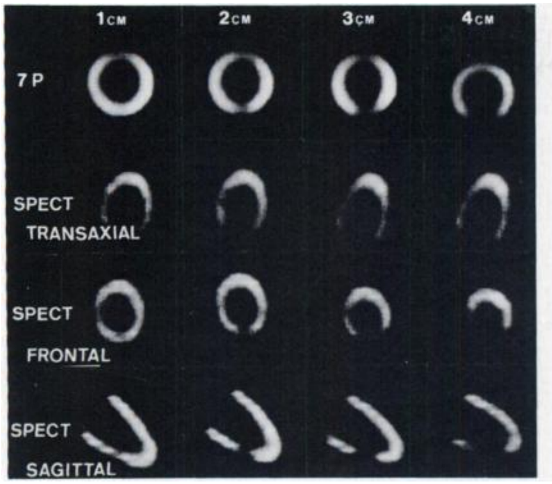

FIG. 2. Seven-pinhole and SPECT images of cardiac phantoms with defects 1–4 cm in diameter in inferior region. Both methods can visualize defects larger than 2 cm in diameter.

Images were evaluated by three experienced physicians, who interpreted them independently without knowledge of other laboratory data. The SPECT images were considered abnormal when more than two tomographic sections revealed a perfusion defect.

RESULTS

Phantom study. Figure 2 shows SPECT and 7P tomographic images of the cardiac phantom with various-sized defects in the inferior wall. The images in each series showing the defect most clearly were selected for examination. SPECT as well as 7P tomography can detect defects 2 cm in diameter, whereas neither system can visualize 1-cm defects.

Figure 3 summarizes the results of a quantitative study using the phantom with a 3- by 3-cm defect, in a water tank. The 7P method gives a slightly higher ratio for defect to normal wall, indicating lower image contrast, and also marked propagation at shallower and deeper levels compared with SPECT. Especially, the deeper propagation is greater than the shallower, probably due to reduction in spatial resolution with distance from the collimator plane with the 7P method. The SPECT method, on the other hand, showed higher image contrast without significant image propagation.

Clinical study. The results of interpretation in the 47 cases in Groups 1 and 2 are shown in Table 1. In Group 2 the planar imaging method showed perfusion defects in 21 of the 28 cases (sensitivity 75%), whereas 7P tomography revealed defects in 26 of the 28 (sensitivity 93%), and SPECT showed perfusion defects in all but one case (sensitivity 96%). In the study of Group 1, planar imaging and SPECT gave only two false-positive findings (specificity 89%), whereas the 7P method gave six false positives among the 19 cases, indicating low specificity (68%) in comparison with other two systems.

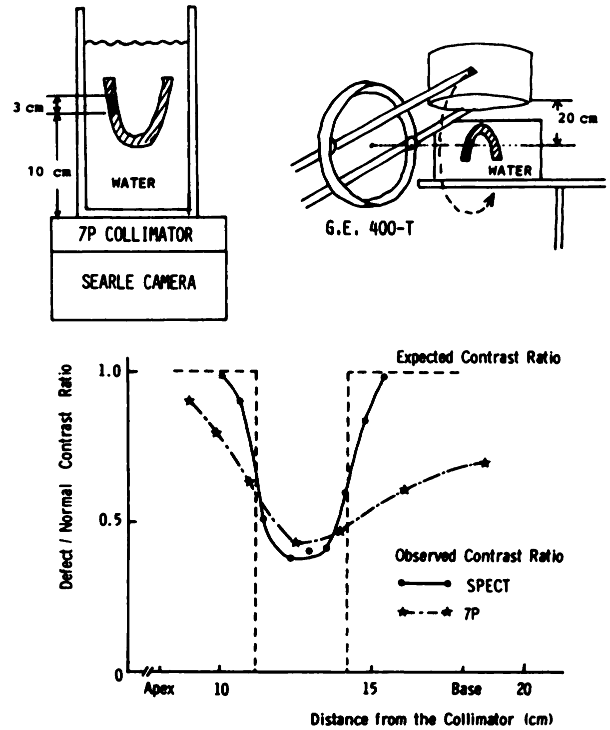

FIG. 3. Quantitative analysis of both tomographic methods using cardiac phantom with 3- by 3-cm defect. Minimum contrast ratio for reconstructed plane is 0.44 in 7P tomography and 0.38 in SPECT. 7P method reveals marked propagation of image above and below plane of interest.

The overall accuracy was 81% for planar imaging, 83% for the 7P, and 94% for SPECT. Compared with planar imaging, 7P tomography had higher sensitivity but less specificity, so its overall usefulness was not significantly improved for the evaluation of myocardial infarction. SPECT, on the other hand, improved both the sensitivity and specificity (Table 2). Thus, the higher accuracy of SPECT was well demonstrated in comparison with planar imaging and 7P tomography.

Tomographic images of some of the cases with myocardial infarction are shown in Figs. 4 and 5. Figure 4 is from a patient with inferior-wall infarction. 7P tomography clearly reveals a perfusion defect. The transaxial section in SPECT hardly shows any perfusion defect, whereas the frontal and sagittal sections, by

TABLE 1. RESULTS OF INTERPRETATION IN 19 NORMAL SUBJECTS (GROUP 1) AND 28 PATIENTS WITH MYOCARDIAL INFARCTION (GROUP 2) USING VARIOUS THALLIUM IMAGING METHODS

	Group 1		Group 2	
	normal	abnormal	normal	abnormal
Planar imaging	17	2	7	21
7P tomography	13	6	2	26
SPECT	17	2	1	27

TABLE 2. COMPARISON OF RESULTS OF VARIOUS IMAGING METHODS

	Planar	7P	SPECT
Sensitivity = $\frac{TP^*}{TP + FN}$	75%	93%	96%
Specificity = $\frac{TN}{TN + FP}$	89%	68%	89%
Overall accuracy = $\frac{TP + TN}{TP + TN + FP + FN}$	81%	83%	94%

* Abbreviations: TP = true positive; TN = true negative; FP = false positive; FN = false negative; and 7P = seven-pinhole tomography.

which one can view the lesion transversely, show the defect clearly. Figure 5 shows a case with anterior-wall infarction. The planar images yield no apparent perfusion defect because of increased background activity. No defect can be seen in the 7P tomogram in the LAO projection either, but in this case, 7P tomography in the 30° RAO projection was attempted, and it revealed a defect in the apical region, as indicated by arrows. As for SPECT, this perfusion defect is most clearly shown in the transaxial section. The sagittal tomogram also shows it.

Figure 6 shows the tomograms by the 7P method and SPECT, in a case with nodular goiter (Group 1). Myocardial imaging was performed immediately after thallium thyroid imaging. In this case there was no history of myocardial infarction, and laboratory data gave no indication of cardiac disease. The 7P tomogram shows decreased uptake in the anteroseptal region, which might suggest myocardial infarction. SPECT, however, reveals almost homogeneous distribution of thallium with no perfusion defect in any tomographic section. We considered these to be normal myocardial images. False-positive findings observed in 7P tomography are considered to result from the forward propagation of the left-ventricular outflow tract.

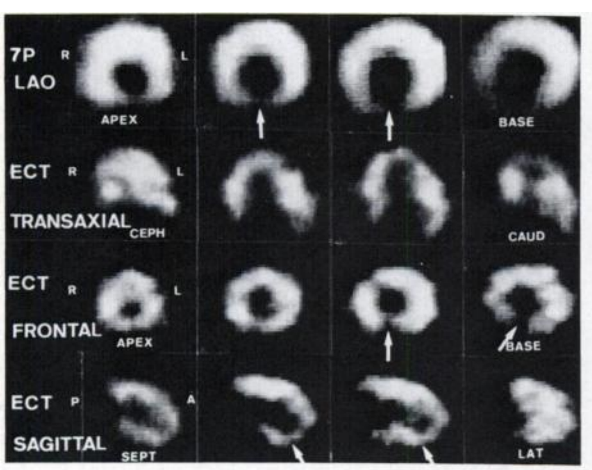

FIG. 4. 7P and SPECT images in patient with inferior-wall myocardial infarction. Sections in 7P proceed from apex to base. In SPECT, transaxial sections proceed from head to foot, frontal sections from apex to base, and sagittal sections from septal to lateral region. Perfusion defect in inferior wall is clearly seen (arrows)

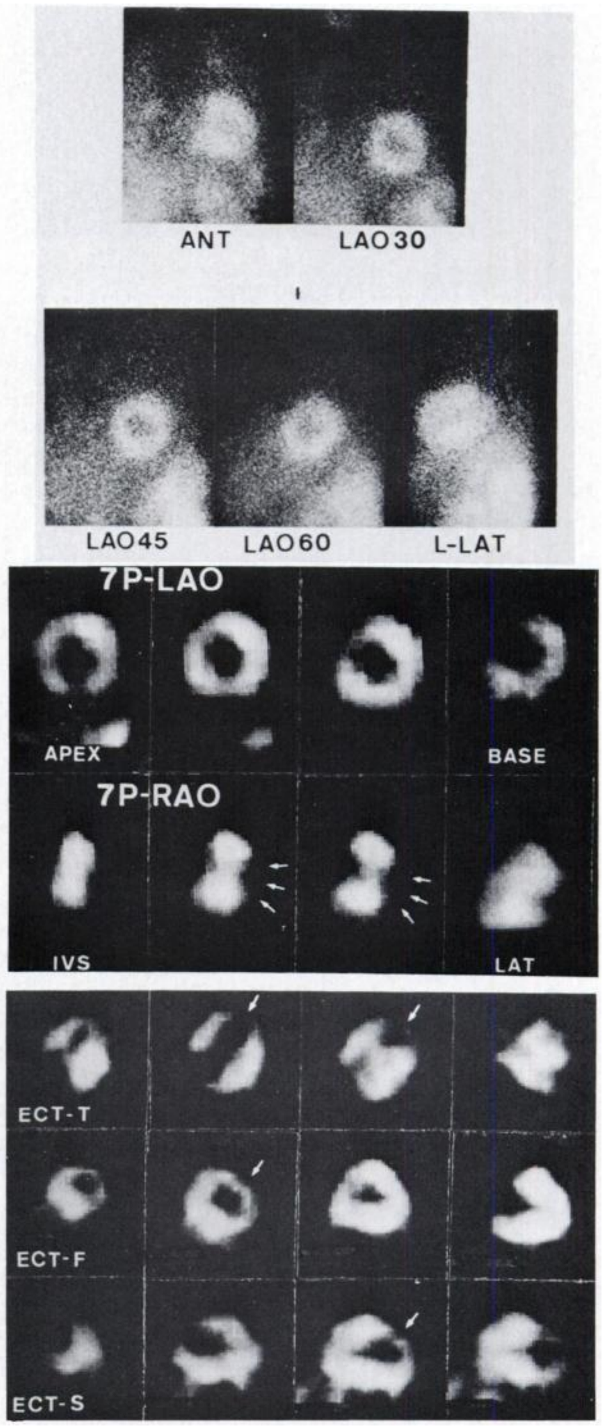

FIG. 5. Planar (top), 7P (middle), and SPECT (bottom) images from patient with anterior-wall infarction. Perfusion defect, not seen in planar or 7P images in LAO projection, is clearly seen in 7P tomography in RAO and in SPECT (arrows).

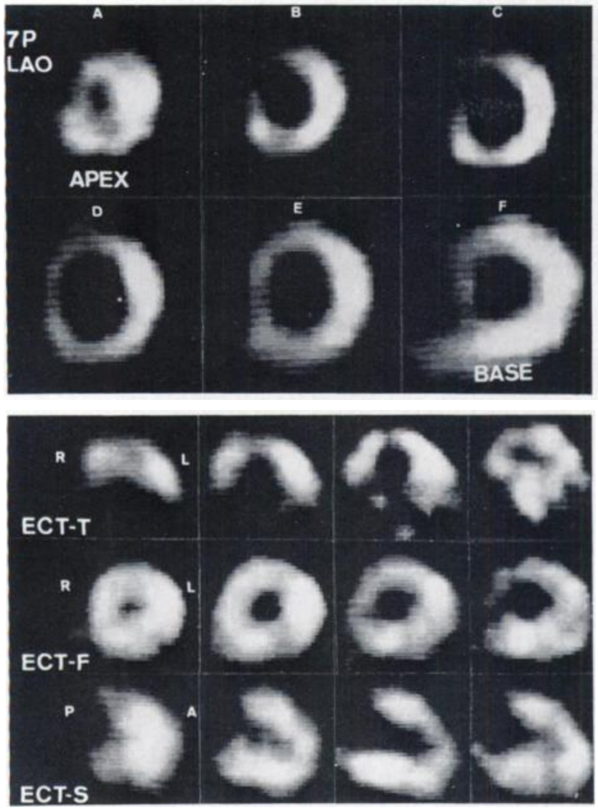

FIG. 6. 7P and SPECT images in patient with no evidence of myocardial infarction. Perfusion defect in anteroseptal wall is falsely suggested by 7P tomography; this results from anterior propagation of left-ventricular outflow tract.

DISCUSSION

Single-photon emission tomography can be divided into two versions: (a) longitudinal tomography, in which the plane through the patient is parallel to the long axis of the body; and (b) transaxial tomography, in which the plane is transverse to the long axis of the body (*16*). The seven-pinhole method belongs to the former and emission CT using a rotating camera belongs to the latter. Both tomographic approaches have advantages as well as disadvantages. The purpose of our study was to compare these two tomographic methods for thallium-201 myocardial imaging using clinical materials as well as a cardiac phantom.

The phantom study showed that both tomographic methods were able to detect defects as small as 2 cm in diameter. However, the 7P system showed marked propagation of a small defect into neighboring sections, and image contrast was reduced.

Budinger precisely described the physical properties of emission tomography with collimators or with the coded-aperture system (*17*). His paper discussed the distortion problem produced by data collection over a limited angular range. An additional problem produced by the limited-angle data collection was the remarkable reduction in spatial resolution with increasing distance from the central axis (*18*). For these reasons, with the 7P method the reconstructed images do not always show accurately the distribution of cross-sectional activity in the phantom, and a number of artifacts have been observed in the reconstructed images (*15*, *18*). Several investigators (*7*, *19*, *20*) have described the artifacts from propagation with the 7P method as being worse than with the slant-hole collimator, which has a larger field of view and better depth or z-axis resolution. However, slant-hole tomography is still an unsatisfactory method for the reconstruction of a reliable tomogram, since it is also a limited-angle technique (*12*). We consider SPECT to be better in this respect (wider than 180° data collection). Limited-angle tomography, such as 7P method with its severe quantitative limitations, should be used only for qualitative evaluation.

The choice of tomographic sections is limited with the 7P method, whereas our SPECT can reconstruct either the transaxial, frontal, or sagittal section of the myocardium because of extensive data collection. In order to improve sensitivity, we examined the myocardial perfusion image in the most appropriate section that viewed the defect transversely. In order to maintain high specificity, we interpreted the image to be abnormal only when more than two tomographic sections revealed the perfusion defect.

In the clinical study of 47 cases, SPECT showed high sensitivity as well as high specificity, whereas the 7P system showed high sensitivity but low specificity, the latter probably due to the artifacts as well as image distortion in limited-angle data collection. In comparison with planar imaging, overall accuracy was improved with SPECT, whereas it was not significantly improved with the 7P method. These findings were compatible with other reports describing the clinical efficacy of the 7P method (*6*, *7*). If redistribution of thallium is taken into consideration in myocardial imaging at rest, it is theoretically conceivable that as compared with the previously performed planar and 7P methods, the efficacy of the subsequently performed SPECT should be worse, but actually our SPECT proved to be more effective, as described above. Thus, our study suggests that myocardial tomography using SPECT is a most reliable method, yielding quite accurate information for the evaluation of myocardial infarction.

SPECT requires a longer time for data collection because of wider sampling. In our institution, SPECT required 22 min for 360° data collection, whereas the 7P method took 10 min. In spite of its faster data collection, the 7P demands more care in patient positioning, since improper positioning may lead to false interpretation. The increased setup time lessens the advantage of rapid data collection.

As for SPECT, the 180° rotation mode (from LPO to RAO), which we also use in our institution, will reduce the sampling time without deterioration of image quality.

FIG. 7. SPECT images in a single transaxial plane, reconstructed from 180 and 360° data collection, is in patient with anteroseptal infarction. Perfusion defect is seen more clearly in 180° projection, with greatly reduced background noise.

Figure 7 shows ECT images in almost the same transaxial plane, reconstructed from 180 and 360° data collection in a patient with anteroseptal infarction. The former image, although requiring only 11 min for acquisition, revealed a clearer perfusion defect, due to less background noise in comparison with the 360° image. Thus this current procedure improves image quality and makes SPECT more practical.

In the case of gated myocardial tomography, the 7P method required only about 20 min for sampling (*21*), whereas SPECT took as long as 1 hr (*11*) due to the limited photon yield of thallium. In this connection the new radiotracers with higher proton yields may be desirable—for example the cationic Tc complexes (*23*).

In attempts at quantitative analysis with emission CT, photon attenuation through the body must be considered. In positron CT, attenuation is a function of the total body thickness, whereas in SPECT attenuation varies with location, and thus with the distribution of the radionuclide. Accurate attenuation correction is therefore much more difficult with SPECT, and accurate quantitative results would be possible only with positron CT. Nevertheless, Sorenson's method (*13, 14*), based on the assumption of uniform attenuation loss, permits acceptable attenuation correction without significant image distortion. Murphy et al. point out that the inability of the SPECT system to correct fully for attenuation does not appear to be a significant drawback (*22*), especially in the case of such a small organ as the heart. On the other hand a major advantage of SPECT is the applicability of widely available low-energy radiopharmaceuticals as compared with cyclotron-produced positron emitters. We consider our SPECT to be clinically practical for geometric assessment of an ischemic region, such as quantitative determination of infarct size, as well as the detection of ischemic regions.

In conclusion, 7P tomography, though requiring less time for data collection, has quantitative limitations creating several artifacts because of limited-angle data collection. On the other hand, emission computed tomography using a rotating gamma camera, which reconstructs reliable tomographic sections, can result in remarkable improvement of the clinical efficacy and has potential for the quantitative assessment of ischemic heart disease.

FOOTNOTE

* General Electric Maxi 400-T.

REFERENCES

1. WACKERS FJ, SOKOLE EB, SAMSON G, et al: Value and limitations of thallium-201 scintigraphy in the acute phase of myocardial infarction. *N Engl J Med* 295:1-5, 1976
2. HAMILTON GW, TROBAUGH GB, RITCHIE JL, et al: Myocardial imaging with intravenous injected thallium-201 in patients with suspected coronary artery disease. Analysis of technique and correlation with electrocardiographic, coronary anatomic and ventriculographic findings. *Am J Cardiol* 39:347-354, 1977
3. STRAUSS HW, HARRISON K, LANGAN JK, et al: Thallium-201 for myocardial imaging. Relation of thallium-201 to regional myocardial perfusion. *Circulation* 51:641-645, 1975
4. VOGEL RA, KIRCH D, LEFREE M, et al: A new method of multiplanar emission tomography using a seven pinhole collimator and an Anger scintillation camera. *J Nucl Med* 19: 648-654, 1978
5. BERMAN D, FREEMAN M, GARCIA E, et al: Clinical comparison of multiple pinhole tomography with planar imaging for thallium-201 stress myocardial scintigraphy. *J Nucl Med* 21:P70, 1980 (abst)
6. HENKIN RE, HALE DJ, SALO BC, et al: 7-pinhole tomography. Is it worth it? *J Nucl Med* 21:P69, 1980 (abst)
7. GOTTSCHALK SC, SMITH KA, WAKE RH: Comparison of seven pinhole and rotating slant tomography of a cardiac phantom. *J Nucl Med* 21:P27, 1980 (abst)
8. HOLMAN BL, HILL TC, WYNNE J, et al: Single-photon transaxial emission computed tomography of the heart in normal subjects and in patients with infarction. *J Nucl Med* 20:736-740, 1979
9. TREVES S, HILL TC, VANPRAAGH R, et al: Computed tomography of the heart using thallium-201 in children. *Radiology* 132:707-710, 1979
10. MAUBLANT J, JOURDE M, VEYRE A, et al: Transverse CAT of the myocardium with 201 Tl. *Eur J Nucl Med* 4:457-459, 1979
11. MUKAI T, MINATO K, TORIZUKA K, et al: Characteristic of ECT by a rotating gamma camera. 3rd symposium on physical and technical aspects on transmission and emission computed tomography jointed with 7th ICCR, Tokyo. 1980, p 86
12. CHESLER DA, RIEDERE SJ: Ripple suppression during reconstruction in transverse tomography. *Phys Med Biol* 20: 632-636, 1974
13. SORENSON JA: Quantitative measurement of radioactivity in vivo by whole body counting. In *Instrumentation in Nuclear Medicine.* Hine GJ, Sorenson JA, Eds. Vol. 2, New York, Academic Press, 1974, p 311
14. MUKAI T, ISHII Y, YONEKURA Y, et al: Radionuclide emission tomography using gamma camera. In *Proceedings of the 2nd International Congress of World Federation of Nuclear Medicine and Biology.* Washington, 1978, p 13
15. WILLIAMS DL, RITCHIE JL, HARP GD, et al: In vivo simulation of thallium-201 myocardial scintigraphy by seven-pinhole emission tomography. *J Nucl Med* 21:821-828, 1980

16. GOODWIN PN: Recent developments in instrumentation for emission computed tomography. *Semin Nucl Med* 10:322-334, 1980
17. BUDINGER TF: Physical attributes of single-photon tomography. *J Nucl Med* 21:579-592, 1980
18. ROLLO FD, PATTON JA: Perspectives on seven pinhole tomography. *J Nucl Med* 21:888-890, 1980
19. SHOSA DW, O'CONNELL JW, HATTNER RS: Motivation for the rotating slant hole approach to scintillation camera tomography. *J Nucl Med* 21:P27, 1980 (abst)
20. CHANG W, LIN SL, HENKIN RE, et al: A multisegmental slant hole tomographic collimator (MUST): A new tomographic gamma camera system. *J Nucl Med* 21:P28, 1980 (abst)
21. YONEKURA Y, MUKAI T, YAMAMOTO K, et al: Myocardial perfusion tomography with 7-pinhole collimator. *Jpn J Nucl Med* 17:1267-1278, 1980
22. MURPHY PH, THOMPSON WL, MOORE ML, et al: Radionuclide computed tomography of the body using routine radiopharmaceuticals. I. System characterization. *J Nucl Med* 20:102-107, 1979
23. DEUTSCH E, GLAVAN KA, FERGUSON DL: Development of a Tc-99m myocardial imaging agent to replace Tl-201. *J Nucl Med* 21:P56, 1980 (abst)

ANNOUNCEMENT OF THE PAUL C. AEBERSOLD AWARD FOR OUTSTANDING ACHIEVEMENT IN BASIC SCIENCE APPLIED TO NUCLEAR MEDICINE—1982

Nominations are invited for this award, which commemorates the contributions of Dr. Paul Clarence Aebersold to the applications of nuclear physics to nuclear medicine and radiation biology, and his contributions to the Society of Nuclear Medicine. Dr. Aebersold contributed greatly to the emergence of nuclear medicine as a discipline by his energetic leadership in the provision of cyclotron-generated and reactor-produced radionuclides, and by his numerous publications and lectures.

In giving this award, the Society thus symbolically signifies its appreciation of the warm and vital person who became our first Honorary Member and whose enthusiastic encouragement and support contributed importantly to the formation and success of the Society of Nuclear Medicine.

Nominations should be supported by the curriculum vitae of the nominee and at least two letters supporting the nomination. These letters should describe briefly the contributions in basic science for which the nominee is proposed. The nominee need not be a member of the Society of Nuclear Medicine.

Please submit nominations and supporting documents to:

William H. Blahd, M.D.
c/o Society of Nuclear Medicine
475 Park Avenue South
New York, NY 10016
Deadline for nominations: December 31, 1981.

7th ANNUAL SCIENTIFIC MEETING GREATER NEW YORK CHAPTER SOCIETY OF NUCLEAR MEDICINE

October 23-25, 1981 **Bellevue Stratford Hotel** **Philadelphia, Pennsylvania**

The 7th Annual Scientific Meeting of the Greater New York Chapter of the Society of Nuclear Medicine will be held Friday through Sunday, October 23-25, 1981 at the Bellevue Stratford Hotel in Philadelphia, Pennsylvania.

Topics will include cardiovascular nuclear medicine in patients with valvular heart disease and with hypertension, phase analysis of gated blood pool studies, current concepts in liver-spleen scintigraphy, cancer therapy with labeled immunoglobulins, and pediatric nuclear medicine.

A technologist program will be presented on Saturday, October 24, at the same location.

For information concerning registration or commercial exhibits please contact:

Mitchell H. Stromer, M.B.A.
Greater N.Y. Chapter, SNM
100-1 Einstein Loop
Bronx, NY 10475
Tel: (212) 671-1325

The program has been approved for 13 credit hours toward the AMA Physicians Recognition Award under Continuing Medical Education Category 1 through the Society of Nuclear Medicine and for VOICE credit for technologists.