EVALUATION AND CLINICAL USE OF EARLY WASHOUT RATIO OF THALLIUM-201 IN NORMAL AND ISCHEMIC MYOCARDIUM AFTER DIPYRIDAMOLE-INDUCED VASODILATION USING RING-TYPE EMISSION COMPUTED TOMOGRAPHY

MASATAKA HAYASHI, M.D., HIROFUMI KAMBARA, M.D., RYUJI NOHARA, M.D.
TETSURO FUDO M.D., TETSUO HASHIMOTO, M.D., CHUICHI KAWAI, M.D.
NAGARA TAMAKI, M.D.*, YOSHIHARU YONEKURA, M.D.*
AND JUNJI KONISHI, M.D.

Using newly developed ring-type emission computed tomography (SPECT), we investigated the washout ratio (WR) of Tl-201 in the myocardium quantitatively with fast dynamic scanning after infusion of dipyridamole (0.57 mg/kg), and assessed the feasibility of early WR as a marker to detect coronary artery disease. Twenty-three patients with and 8 patients without coronary artery disease had serial SPECT images obtained every 5 min for 45 min and at 180 min after dipyridamole and subsequent Tl-201 injection. The best appropriate transaxial slice was selected for WR analysis. Most appropriate diagnostic time was 25 min after infusion of Tl-201 (WR-25). Normal WR-25 was $7.1 \pm 4.0\%$, $5.9 \pm 3.1\%$ and $7.1 \pm 2.3\%$ at the septum, anterior and lateral wall, respectively. Sensitivity, specificity and accuracy to identify coronary stenosis $>50\%$ with a usage of abnormal WR-25, defined as $\text{WR-25} < (\text{mean of normals} - 1 \text{ SD})$ in each region of interest of the left ventricle (LV), were 96%, 100% and 97%, respectively. These results were better than those achieved by visual analysis (sensitivity 78%, specificity 100%, accuracy 84%). In patients with single as well as multivessel disease, the regional accuracy in assessing stenosis of more than 50% in the left anterior descending artery (LAD) and left circumflex artery (LCX) by WR-25 was 94% and 83%, respectively, which was significantly better than using visual methods (LAD 72% and LCX 50%; $p < 0.05$). Thus, evaluation of early washout ratios (WR-25) after dipyridamole injection is a valuable method to increase sensitivity in assessing regional myocardial perfusion abnormality and is helpful in detection of ischemic heart disease, even with multivessel disease.

DIPYRIDAMOLE is a potent vasodilator, primarily of the coronary arteries, with minor systemic effects. This potent coronary vasodilator enhances regional myocardial

blood flow in zones supplied by normal coronary arteries but not in the myocardium perfused by obstructed vessels, producing an inhomogeneity of blood flow. Since the initial myocardial distribution of intravenous administration of Tl-201 is proportional to blood flow^{1,2} scintigraphic defects are observed demonstrating this relative

Key words:

Ischemic heart disease
Dipyridamole
Ring-type single photon emission CT
Thallium-201 washout ratio

(Received February 16, 1990; accepted April 23, 1990)

Third Division, Department of Internal Medicine, and Department of Nuclear Medicine*, Kyoto University Hospital, Kyoto, Japan

Mailing address: Masataka Hayashi, M.D., Third Division, Department of Internal Medicine, Kyoto University Hospital, 54 Kawaracho, Shogoin, Sakyo-ku, Kyoto 606, Japan

Fig.1. Protocol of thallium-201 dipyridamole imaging used for this patient study. Total dose of dipyridamole was 0.568 mg/kg over 4 min. BP=blood pressure, HR=heart rate, IV=intravenously

Fig.2. Schematic representation of left ventricular transaxial imaging by ring type SPECT and the ROI used for this study analysis. 1: septum, 2: anterior wall, 3: lateral wall

hypoperfusion. Intravenous infusion of dipyridamole has been suggested as an alternative to physical exercise for myocardial perfusion imaging³⁻⁸. This pharmacologic method is particularly useful in patients who are physically unable to perform adequate exercise, such as aged patients with peripheral vascular or musculo-skeletal disease, or those with chronic pulmonary disease. Gould et al³⁻⁵ and Albro et al⁶ showed that the quality of Tl-201 myocardial perfusion imaging obtained during coronary vasodilation after dipyridamole injection was equal to, or better than, that of images acquired during maximal exercise. This method is also safe because its pharmacologic effect can be completely blocked within a

few seconds by intravenous administration of aminophylline³⁻¹⁰.

Beller^{11,12}, Schmoliner¹³, Leppo^{14,15} and Okada^{16,17} have demonstrated that under conditions of coronary stenosis in canine preparations, dipyridamole results not only in diminished Tl-201 uptake but also in subsequently delayed redistribution similar to that observed with exercise scintigraphy. Redistribution has also been demonstrated on serial myocardial scintigrams in patients with coronary artery disease receiving dipyridamole before Tl-201 administration^{11-15,18}. However, the sequential process and clinical significance of Tl-201 redistribution after dipyridamole imaging are not fully elucidated. We used a ring-type emission computed tomography (SPECT) in which detectors were arranged in a circular array to achieve better counting and fast dynamic scanning^{18,19} and measured the early washout ratio after dipyridamole-induced vasodilation. The purpose of the study is to assess dynamic changes of Tl-201 washout and its clinical usefulness in detecting coronary artery disease with dipyridamole administration.

MATERIAL AND METHOD

Study patients: Thirty-one consecutive patients (21 males and 10 females, mean age 57 ± 10 years, ranging from 20 to 71 years) referred for cardiac catheterization and cor-

TABLE I CLINICAL BACKGROUNDS AND FINDINGS OF THALLIUM-201 RING TYPE SPECT IN 31 PATIENTS

No.	Age & Sex	Coronary angiography (% of diameter narrowing)			Diagnosis	Finding of dynamic SPECT
		LAD	LCX	RCA		
1.	20M	0	0	0	Normal	Homogenous
2.	62F	0	0	0	Normal	Homogenous
3.	45F	0	0	0	Normal	Homogenous
4.	54F	0	0	0	Normal	Homogenous
5.	57F	0	0	0	Normal	Homogenous
6.	29M	0	0	0	Synd X	Homogenous
7.	70F	0	0	0	Synd X	Homogenous
8.	63F	0	0	0	Synd X	Homogenous
9.	62M	7—90	0	0	AP	Hypoperfusion (Antero-septal)
10.	72F	90	0	90	AP	Hypoperfusion (Antero-septal)
11.	59M	99	90	0	AP	Hypoperfusion (Antero-septal)
12.	55M	50	0	0	AP	Homogenous
13.	57M	50	50	0	AP	Hypoperfusion (Postero-lateral)
14.	59M	90	99	25	AP	Hypoperfusion (Anterior)
15.	60M	0	90	75	AP	Hypoperfusion (Postero-lateral)
16.	69F	0	90	0	AP	Homogenous
17.	66F	75	75	75	AP	Homogenous
18.	59M	50	0	0	AP	Homogenous
19.	40M	99	0	0	AP	Hypoperfusion (Antero-septal)
20.	55M	50	90	75	MI	Homogenous
21.	71M	90	0	50	MI	Perfusion defect (Antero-septal)
22.	46M	99	90	50	MI	Perfusion defect (Antero-septal)
23.	57M	99	100	99	MI	Perfusion defect (Postero-lateral)
24.	64M	90	100	75	MI	Perfusion defect (Postero-lateral)
25.	63M	99	99	50	MI	Perfusion defect (Antero-septal)
26.	65M	90	0	0	MI	Perfusion defect (Antero-septal)
27.	59M	90	50	0	MI	Perfusion defect (Antero-septal)
28.	57M	90	50	25	MI	Perfusion defect (Antero-septal)
29.	63F	99	25	25	MI	Perfusion defect (Antero-septal)
30.	53M	0	90	0	MI	Perfusion defect (Postero-lateral)
31.	55M	50	0	100	MI	Homogenous

AP=angina pectoris, MI=myocardial infarction, LAD=left anterior descending artery, LCX=left circumflex artery, RCA=right coronary artery, Synd=syndrome

nary angiography for evaluation of chest pain were studied. They were classified into two subgroups: 8 patients with no coronary artery disease (2 males and 6 females, mean age 50 ± 18 years) and 23 patients with coronary artery disease (19 males and 4 females, mean age 59 ± 7 years). Of 23 patients with coronary artery disease, 12 had a history of myocardial infarction.

Coronary angiography: Coronary artery disease was defined as $>50\%$ luminal narrowing in diameter of one or more major coronary arteries or their major branches. The finding had to be confirmed by more than 5 experienced observers who were unaware of the thallium scintigraphic findings. The major branches included 1) the first diagonal branch of the left anterior descending

Fig. 3. Serial uptake counts at the ROI of left ventricular slice of normal patients. Initial uptake counts (5-10 min) of the normal ROI were the highest and decreased gradually with time.

TABLE II SERIAL WASHOUT RATIO OF THALLIUM-201 OVER THE LEFT VENTRICLE IN 8 NORMAL PATIENTS

	$t = 10$ (10-15)	$t = 15$ (15-20)	$t = 20$ (20-25)	$t = 25$ (25-30)	$t = 30$ (30-35)	$t = 35$ (35-40)	$t = 40$ (40-45)	$t = 180$ (180-190)
Septum								
mean $\pm$ SD	1.8 ± 3.3	3.8 ± 1.8	5.7 ± 2.5	7.1 ± 4.0	10.1 ± 3.3	10.7 ± 5.8	12.7 ± 6.5	44.0 ± 6.4
mean - SD	-1.5	2.0	3.2	3.0	6.8	4.9	6.2	37.6
Anterior wall								
mean $\pm$ SD	1.4 ± 4.4	2.8 ± 3.0	6.5 ± 3.7	5.9 ± 3.1	8.3 ± 4.6	9.7 ± 8.6	10.6 ± 7.9	43.5 ± 7.1
mean - SD	-3.0	-0.3	2.8	2.8	3.7	1.1	2.7	36.4
Lateral wall								
mean $\pm$ SD	1.1 ± 1.6	3.5 ± 4.3	6.1 ± 2.8	7.1 ± 2.3	7.3 ± 4.5	9.3 ± 5.2	8.7 ± 4.0	42.8 ± 4.2
mean - SD	-0.5	-0.8	3.3	4.8	2.8	4.1	3.7	38.6
Global								
mean $\pm$ SD	1.5 ± 3.1	3.4 ± 3.1	6.1 ± 3.0	6.7 ± 3.1	8.6 ± 4.1	9.9 ± 6.5	10.7 ± 6.2	43.4 ± 5.9
mean - SD	-1.6	0.3	3.1	3.6	4.5	3.4	4.5	37.5

t = Starting time of acquisition, () = (interval)

artery, 2) obtuse marginal branch of the left circumflex artery, and 3) posterior descending branch of the right coronary artery with right dominant system, or left circumflex artery with left dominant system.

Ring-type emission computed tomography: The ring-type emission computed tomography scanner (SET-030W, Shimazu) had 128 detectors of $14 \times 24 \times 30$ mm NaI crystal arranged in a circular array of 660 mm in diameter. There were three detector rings at 30 mm intervals and total of 384 detectors in a gantry. A high resolution collimator was used. Spatial resolution at the center of the eye field was 14.2 mm and slice thickness

was 24 mm. The sensitivity was measured using cylindrical phantoms containing ^{99m}Tc . The sensitivity for a 20 cm diameter phantom was 5700 cps/mCi/ml. Acquisition was performed for 5 or 10 min. Image reconstruction was made using the back projection method with a Shapp-Logan filter using a convolution reconstruction algorithm. Acquisition time correction was performed without attenuation correction.

Thallium-201 imaging with dipyridamole administration: The imaging protocol (Fig. 1) is a modification of the technique described by Albrow et al.⁴ At the beginning of the study, the patient laid supine on a tilt

Fig. 4. Serial washout ratio of thallium-201. Serial change of washout ratio in each segment was essentially similar with a linear relationship.

Fig. 5. Serial washout ratio of thallium-201. Hatched part is an area defined as abnormal washout ratio.

table. A 23-gauge plastic cannula was placed in a large antecubital vein to avoid pain due to dipyridamole injection into the small vein.

A 12-lead ECG was recorded during the study. Blood pressure by a cuff method and heart rate were monitored every minute during the study period. Dipyridamole (Boehringer Ingelheim Co.) was then infused with a total dose 0.568 mg/kg over 4 min. Side effects due to dipyridamole injection, such as chest pain, nausea or vomiting were suppressed with 125 mg of intravenous aminophylline. Seven minutes after starting dipyridamole infusion, 3 mCi of thallium-201 (JAPAN Medipysics Co.) was injected through the 23-gauge plastic cannula. Data acquisition was performed from 5 to 45 min after injection, followed by additional scan at 180 min after injection. Each acquisition time was 5 min from the first to the eighth acquisition and 10 min in the ninth acquisition. Body positioning in the gantry was carefully set with a marker on the body and a light beam from the gantry to avoid mispositioning. All patients were in a fasting state until delayed imaging was taken.

TABLE III COMPARATIVE ANALYSIS OF SERIAL WASHOUT RATIO

	WR-20	WR-25	WR-30	WR-35	WR-40
Sensitivity (%)	96	96	96	78	91
Specitivity (%)	75	100	100	100	87
Accuracy (%)	90	97	97	84	90

The sensitivity specificity and accuracy of WR-25 were 96%, 100% and 97%, respectively, and WR-25 was more accurate than the WR of other reference times.

WR-t: Washout ratio during t to t+5 min.

TABLE VI COMPARISON BETWEEN VISUAL ASSESSMENT AND ANALYSIS OF WASHOUT RATIO

	LAD		LCX		LAD+LCX	
	Visual	WR-25	Visual	WR-25	Visual	WR-25
Sensitivity (%)	72	94	50	93	78	96
Specificity (%)	100	85	100	82	100	100
Accuracy (%)	84	90	84	87	84	97

Sensitivity, specificity and accuracy of washout ratio analysis were better than those of visual analysis.

WR-25: Washout ratio during 25 to 30 min.

Qualitative analysis of serial Tl-201 images: Serial transaxial thallium-201 images were displayed on a computer screen for comparison. The visual analysis was carried out by more than three independent investigators who were unaware of the findings of cardiac catheterization or the patient's clinical history. The myocardial segments were matched according to the coronary artery distribution as follows: septum and anterior segments corresponded to the left anterior descending coronary artery and a lateral segment to left circumflex artery or diagonal branch. Because only transaxial images were reconstructed, an inferior segment was not evaluated. The visual results were interpreted by the consensus of all investigators.

Quantitative analysis of serial Tl-201 images: We analyzed a tomographic slice of most appropriate transaxial image in each patient. The left ventricular wall of this image was divided into 3 segments (Fig. 2). A region of interest (ROI) was set at the septum, anterior wall and lateral wall of the left ventricle. Each ROI contained 81 pixels. A washout ratio at each time interval was calculated as follows:

$$\text{Washout ratio (WR-t)} = \frac{C_i - C_t}{C_i} \times 100 (\%)$$

where t is the starting time of acquisition, Ct is the counts of each ROI at the time of acquisition and Ci is the counts of the ROI at initial time of acquisition. The abnormal range of thallium washout ratio was defined as less than 1 SD from the mean value obtained from normal patients group.

Statistical analysis: Sensitivity was defined as the (true positive $\times$ 100) / (true positive + false negative); specificity as (true negative $\times$ 100) / (true negative + false positive); and accuracy as (true positive + true negative) / (total number of cases). A p value less than 0.05 was considered to be statistically significant with Student's t test, and all values were expressed as mean $\pm$ 1 SD.

RESULTS

Coronary angiographic findings (Table I): Angiographically significant coronary artery stenosis of at least one major coronary artery was present in 23 of the 31 patients. Eight patients had angiographically normal coronary arteries without any provocative spasm. Of the 23 patients with significant coronary artery disease, 8 had single vessel disease, 9 had double vessel disease and 6 triple vessel disease.

Fig. 6. A representative serial thallium scintigraphy of ring type SPECT. An antero-septal hypoperfusion is recognizable in the initial image (5-10 min: arrow) and persists until the 8th imaging (40-45 min) with slight reperfusion. However, complete reperfusion was seen in the last imaging (180-190 min).

Hemodynamic response to dipyridamole: Changes in heart rate, systolic blood pressure and diastolic blood pressure after dipyridamole infusion were significant but small. The heart rate before infusion of dipyridamole was 67 ± 12 beats/min and increased to 77 ± 14 beats/min in 4 min after dipyridamole ($p < 0.001$), and to 81 ± 14 beats/min in 7 min ($p < 0.001$). The systolic blood pressure before infusion of dipyridamole was 126 ± 18 mmHg and fell to 113 ± 20 mmHg in 4 min after dipyridamole ($p < 0.001$) and 111 ± 20 mmHg in 7 min ($p < 0.001$). The diastolic blood pressure before dipyridamole was 77 ± 13 mmHg and fell to 68 ± 13 mmHg in 4 min after dipyridamole ($p < 0.001$) and 66 ± 12 mmHg in 7 min ($p < 0.001$).

Adverse effects of dipyridamole: Eight of 31 patients experienced some complaints or adverse effects. Three patients complained of chest pain, usually mild to moderate in intensity and of quality similar to that of angina previously experienced on effort. The chest pain was promptly relieved by the intravenous administration of aminophylline (average dose 125 mg) in all patients. Ischemic ECG changes occurred in 3 patients, and only 1 of 3 patients had chest pain. Other

symptoms included palpitation (1 patient), dizziness (1 patient) and dyspnea (1 patient).

Serial washout ratio of thallium-201: Fig. 3 shows serial uptake counts after Tl-201 injection in the normal ROI. The initial uptake counts (5-10 min) of the normal ROI were the highest counts and decreased gradually. In Table II, the serial washout ratio of Tl-201 over the left ventricle in 8 normal patients is shown. The mean washout ratios of the septum, anterior wall and lateral wall at each time were calculated. A serial change of washout ratio in each segment was essentially identical with a linear relationship (Fig. 4), so that we used the global mean washout ratio to assess ischemia. Abnormal washout ratio defined as $WR < (\text{mean of normal} - 1 \text{ SD})$ at each time period (Fig. 5) gave the sensitivity, specificity and accuracy to detect coronary stenosis $> 50\%$ as summarized in Table III. The sensitivity, specificity and accuracy of washout ratio at 25 min (WR-25) were 96%, 100% and 97% (Table III), respectively. Because accuracy at 25 min was better than that at any other reference time, WR-25 was selected to diagnose ischemic heart disease. Table IV showed a comparison between visual assessment and analysis

of washout ratio. Sensitivity, specificity and accuracy in the assessment of stenosis of the left anterior descending artery by WR-25 were 94%, 85% and 90%, respectively, which was significantly better than visual analysis (sensitivity 72%, specificity 100% and accuracy 84%). Sensitivity, specificity and accuracy in assessment of stenosis of the left circumflex artery by WR-25 were 93%, 82% and 87%, respectively, which was significantly better than visual analysis (sensitivity 50%, specificity 100% and accuracy 84%). Sensitivity, specificity and accuracy in assessment of stenosis of combined LAD and LCX artery by WR-25 were 96%, 100% and 97%, respectively, which was significantly better than visual analysis (sensitivity 78%, specificity 100% and accuracy 84%).

A representative case of angina pectoris: Thallium-201 scintigraphy with the ring-type SPECT in a 40 year old man is shown in Fig. 6. The patient had effort angina and single vessel disease of the left anterior descending coronary artery. An antero-septal hypoperfusion is recognizable in the initial imaging (5–10 min) and persisted until the 8th imaging (40–45 min) with minimal reperfusion, but complete reperfusion was seen in the last imaging (180–190 min).

DISCUSSION

A ring-type emission CT: Emission computed tomography is more reliable than planar imaging. However, conventional emission computed tomography using a rotating gamma camera has a relatively low count sensitivity, and requires a substantial amount of time for acquisition. For this reason, it is not suitable for evaluating the early distribution of Tl-201 and time course of washout after tracer injection. With ring-type emission computed tomography, multiple detectors are placed in a circular array, giving a better counting rate so that it is possible to acquire data in a short time and to perform dynamic studies. In our current study, one scan could be performed in five minutes by rotating the detector 360°.

Kinetics of the thallium-201 with dipyridamole: The regional myocardial uptake of Tl-201 has been shown to be an accurate representation of regional perfusion^{1,20–22} and the quantitative relationship between global

left ventricular Tl-201 uptake and blood flow has been examined by Melin et al and Beller et al^{11,12,23}. In a canine model, intravenous dipyridamole causes a disparate rate of thallium uptake in normal vessels and stenosed vessels^{11,12}. Myocardial thallium uptake is related to the regional and transmural difference in the coronary blood flow. In the normal zone, there is a fourfold increase in both endocardial and epicardial coronary blood flow, while in the stenosed vessel the total flow may not change although the epicardial flow may increase slightly while the endocardial flow decreases. The relative decrease of thallium uptake in the area of the stenosed vessel correlates well with the decrease of coronary flow relative to the peak flow in the normal area. In addition to initial differences of thallium activity, there are also differences in washout rates between the area perfused with normal vessels and stenosed vessels. The washout is much slower in the area perfused with stenosed vessels. The average time of maximal thallium uptake obtained from the biopsies was 8.4 ± 1.4 min after dipyridamole injection in a canine model^{11,23}. In our current study, the average time of maximal thallium uptake obtained from the dynamic SPECT was 5–10 min in the normal coronary myocardium, but was delayed to 30 min in the myocardium with the stenosed coronary artery. The counts at regions of myocardial infarction were lower than those of angina pectoris. This may suggest that the low thallium-201 uptake in an infarcted region is associated not only with the severity of coronary artery stenosis but also with low viable myocardium. On the other hand, the washout ratios of both myocardial infarction and angina pectoris with severe stenosis were slower than those of normal regions according to our data. The disparate rates of washout between normal and abnormal zones account for the differences in redistribution of thallium uptake between these two areas. Similar findings have been reported when the intrinsic washout was studied by direct intracoronary injection of Tl-201¹². A few of the stenosed areas showed no hypoperfusion on the early visual imaging, especially in patients with multivessel disease, but the serial washout ratio was lower than that of the normal area, so that the washout analysis provided better

accuracy than visual analysis.

Sensitivity and specificity: Previous clinical studies have suggested the value of thallium-201 imaging for evaluating regional blood flow during pharmacological vasodilation.^{7,15,17} Sensitivities of 67–91% and specificities of 80–100% have been reported. In our study, we obtained a sensitivity of 78% and specificity of 100% by visual analysis of dipyridamole loading thallium-201 imaging. This result is similar to that reported in previous clinical studies. We also performed the WR-25 to estimate the ischemic heart disease, and obtained a regional sensitivity of 96% and specificity of 100%, which were significantly better than visual analysis. In this study, we defined an abnormal washout ratio (WR) as $WR < (\text{mean of normals} - 1 \text{ SD})$ instead of 2 SD, since the latter gave lower accuracy (58%) than that of 1 SD (97%) due to relatively large SD.

Since the left circumflex area may be distant from the gamma camera, it is often difficult to assess regional uptake accurately in this area. However, thallium-201 washout ratio analysis may enhance detection of perfusion abnormality in this area as reported previously²⁸ and appears to give a better result than that achieved using visual analysis.

Clinical implication: Intravenous infusion of dipyridamole has been suggested as an alternative to physical exercise for myocardial perfusion imaging with Tl-201.^{3–8} It is presumed that the powerful coronary vasodilatory effect of this drug will greatly increase the myocardial blood flow in a region served by normal coronary vessels but not in myocardial regions served by diseased vessels, producing an inhomogeneity of blood flow that would be made evident by thallium scintigraphy. This pharmacological method to induce maldistribution of blood flow may be most useful in patients who are physically unable to perform adequate exercise.

Hemodynamic effects and adverse effects of dipyridamole: Heart rate and blood pressure changes after infusion of dipyridamole have been reported by others.^{6,8,24–26} All reported values were similar; 20 to 40 percent increase in heart rate and 4 to 10 percent decrease in blood pressure. In our study, heart rate increased by 14 beats/min (21%) on the average, whereas systolic and diastolic blood

pressure decreased by 15 (12%) and 11 mmHg (14%) on the average, respectively.

Serious adverse effects of dipyridamole are rare and there have been no reports of death or myocardial infarction, although one patient is reported to have had ventricular fibrillation.²⁷ Other adverse effects included chest pain, ST segment depression, arrhythmias, headache, gastric discomfort, nausea, vomiting and dizziness. Most of these side effects do not require treatment. In our current study only one patient who had ST segment depression with chest pain needed to be treated with aminophylline (125 mg), and pain was completely relieved within a few seconds. Thus, intravenous dipyridamole-loading scintigraphy is safe for nonexercise stress testing.

Advantages and limitations of dynamic SPECT: Although a rotating gamma camera has been popularly used as a SPECT device in many institutes, it is not suitable for fast dynamic scanning due to the low count sensitivity and the physical limitations of mechanical rotation of the detector. The new ring-type SPECT scanner consists of 3 detector rings with 128 NaI crystals in each ring. It has been developed for high resolution dynamic SPECT imaging of the heart with high sensitivity and good spatial resolution. This is useful to evaluate the kinetics of Tl-201. The major disadvantage of this dynamic SPECT for clinical imaging is the lack of fine axial imaging. Furthermore, currently we can only obtain the transaxial images, and can not reconstruct the long axial images, which means we are unable to evaluate the inferior wall of left ventricle.

Acknowledgment

We acknowledge the technical assistance of T. Fujita and the secretarial assistance of S. Hanabuchi and N. Takemoto.

REFERENCES

1. STRAUSS HW, HARRISON K, LANGAN JK, et al: Thallium-201 for myocardial imaging: relation of thallium-201 to regional myocardial perfusion. *Circulation* **51**: 641, 1975
2. POHOST GM, ZIR LM, MOORE RH, et al: Differentiation of transiently ischemic from infarcted myocardium by serial imaging after a single dose of thallium-201. *Circulation* **59**: 294, 1977
3. GOULD KL: Noninvasive assessment of coronary

- stenoses by myocardial perfusion imaging during pharmacologic coronary vasodilation. I. Physiologic basis and experimental vasodilation. *Am J Cardiol* **41**: 267, 1978
4. GOULD KL, WESTCOTT RJ, ALBRO PC, et al: Noninvasive assessment of coronary stenoses by myocardial imaging during pharmacologic coronary vasodilation. II. Clinical methodology and feasibility. *Am J Cardiol* **41**: 279, 1978
 5. GOULD KL: Assessment of coronary stenoses with myocardial perfusion imaging during pharmacologic coronary vasodilation. IV. Limits of detection of with idealized experimental cross sectional myocardial imaging. *Am J Cardiol* **42**: 761, 1978
 6. ALBRO PC, GOULD KL, WESTCOTT RJ, HAMILTON GW: Noninvasive assessment of coronary stenoses by myocardial imaging during pharmacologic coronary vasodilation. III. Clinical Trial. *Am J Cardiol* **42**: 751, 1978
 7. GOULD KL, SCHELBERT HR, PHELPS ME, HOFFMAN EJ: Noninvasive assessment of coronary stenoses with myocardial perfusion imaging during pharmacologic coronary vasodilation. V. Detection of 47 percent diameter coronary stenosis with intravenous nitrogen-13 ammonia and emission-computed tomography in intact dogs. *Am J Cardiol* **43**: 200, 1979
 8. SCHELBERT HR, WISENBERG G, PHELPS ME, et al: Noninvasive assessment of coronary stenoses by myocardial imaging during pharmacologic coronary vasodilation. VI. Detection of coronary artery disease in human being with intravenous N-13 ammonia and positron computed tomography. *Am J Cardiol* **49**: 1197, 1982
 9. HOMMA S, GILLILAND Y, GUINEY TE, et al: Safety of intravenous dipyridamole for stress testing with thallium imaging. *Am J Cardiol* **59**: 152, 1988
 10. PEARL JD, BOUCHER CA: Diagnostic value for coronary artery disease of chest pain during dipyridamole-thallium stress testing. *Am J Cardiol* **61**: 43, 1988
 11. BELLER GA, HOLZGREFE HH, WATSON DD: Effects of dipyridamole induced vasodilation on myocardial uptake and clearance kinetics of thallium-201. *Circulation* **68**: 1328, 1983
 12. BELLER GA, HOLZGREFE HH, WATSON DD: Intrinsic washout rates of thallium-201 in normal and ischemic myocardium after dipyridamole-induced vasodilation. *Circulation* **71**: 378, 1985
 13. SCHMOLINER R, DUDOZAK R, KRONIK G, et al: Thallium-201 imaging after dipyridamole in patients with coronary multivessel disease. *Cardiology* **70**: 145, 1983
 14. LEPPA JA, ROSENCRAFTZ J, BONTEMPS R, YIPINTSOI IT: Quantitative thallium-201 redistribution with a fixed coronary stenosis in dogs. *Circulation* **63**: 632, 1981
 15. LEPPA J, BOUCHER CA, OKADA RD, et al: Serial thallium-201 myocardial imaging after dipyridamole infusion: diagnostic utility in detecting coronary stenosis and relationship to regional wall motion. *Circulation* **66**: 649, 1982
 16. OKADA RD, LEPPA JA, BOUCHER CA, POHOST GM: Myocardial kinetics of thallium-201 after dipyridamole infusion in normal canine myocardium and in myocardium distal to a stenosis. *J Clin Invest* **69**: 199, 1982
 17. OKADA RD, LIM HL, ROTHENDLER J, et al: Split dose thallium-201 dipyridamole imaging: A new technique for obtaining thallium images before and immediately after an intervention. *J Am Coll Cardiol* **5**: 1302, 1983
 18. YONEKURA Y, FUJITA T, NISHIZAWA S, et al: Multidetector SPECT scanner for brain and body: System performance and application. *J Comput Assist Tomogr* **13**(4): 732, 1989
 19. YONEKURA Y, KOIDE H, MUKAI T, et al: Dynamic single photon emission computed tomography of thallium-201 with exercise loading. *J Nucl Med (Abstr.)* **27**: 999, 1986
 20. NIELSEN AP, MORRIS KG, MURDOCK R, et al: Linear relationship between the distribution of thallium-201 blood flow in ischemic and non-ischemic myocardium during exercise. *Circulation* **61**: 797, 1980
 21. POHOST GM, OKADA RA, O'KEEFE DD, et al: Thallium redistribution in dogs with severe coronary artery stenosis of fixed caliber. *Circ Res* **48**: 439, 1981
 22. CHU A, MURDOCK RH, JR, COBB FR: Relation between regional distribution of thallium-201 and myocardial blood flow in normal acutely ischemic, and infarcted myocardium. *Am J Cardiol* **50**: 1141, 1982
 23. MELIN JA, BECKER LC: Quantitative relationship between global left ventricular thallium uptake and blood flow: Effect of propranolol, quabain, dipyridamole and coronary artery occlusion. *J Nucl Med* **27**: 641, 1986
 24. BROWN BG, JOSEPHSON MA, PETERSEN RB, et al: Intravenous dipyridamole combined with isometric handgrip for near maximal acute increase in coronary flow in patient with coronary artery disease. *Am J Cardiol* **48**: 1077, 1981
 25. JOSEPHSON MA, BROWN BG, HECHT HS, et al: Noninvasive detection and localization of coronary stenoses in patients: Comparison of resting dipyridamole and exercise thallium-201 myocardial perfusion imaging. *Am Heart J* **103**: 1008, 1982
 26. BONADUCE D, MUTO P, MORGANO G, et al: Effect of betablockade on thallium-201 dipyridamole myocardial scintigraphy. *Acta Cardiol* **39**: 399, 1984
 27. BAYLISS J, PEARSON M, SUTTON GC: Ventricular dysrhythmias follow intravenous dipyridamole during "Stress" myocardial imaging. *Br J Radiol* **56**: 686, 1983
 28. TAMAKI N, YONEKURA Y, MUKAI T, et al: Stress thallium-201 transaxial emission computed tomography: Quantitative versus qualitative analysis for evaluation of coronary artery disease. *J Am Coll Cardiol* **4**: 1213, 1984