QUANTITATIVE EVALUATION OF STRESS THALLIUM-201 MYOCARDIAL PERFUSION IMAGING FOR DETECTION OF THE SEVERITY OF CORONARY ARTERY DISEASE

HITOMI SUZUKI, M.D., YOSHIHIKO WATANABE, M.D., ISAO KUBOTA, M.D.
KAI TSUIKI, M.D., AKIO KOMATANI, M.D.*, AND SHOJI YASUI, M.D.

This study was done to evaluate the quantification of thallium-201 myocardial perfusion imaging (MPI) for the detection of coronary artery disease (CAD). Segmental analysis of stress and delayed MPI was performed in 33 patients with angiographically proved CAD. They were divided into two groups: 22 patients without previous infarction (Group 1) and 11 patients with prior myocardial infarction (Group 2).

Using computer analysis of MPI, 9 region-of-interests (ROIs) were set on the left ventricular image. We defined 3 indices as follows: initial uptake (%) = a ratio of ROI counts to the highest ROI counts on the exercise image; washout rate (WR) = a ratio of [(ROI counts on the exercise image) – (those on the delayed image)] to those on the exercise image; redistribution index (ROI) = a ratio of the maximal WR to WR. Coronary arteriograms were evaluated according to Pujadas' method.

In group 1, the region supplied by the coronary artery with significant stenosis showed a lower initial uptake ($p < 0.005$) and a higher ROI ($p < 0.001$) than the region supplied by the coronary artery without significant stenosis. If an initial uptake less than 83% and/or a RDI greater than 1.15 are defined as abnormal, the sensitivity for detecting CAD, including the detection of a stenosis site, was 76% and the specificity was 84%. In group 2, the sensitivity was 76% and the specificity was 80%. The mean WR could also indicate the severity of CAD. In all patients studied, the average of mean WR was 0.451 in one-vessel disease ($n = 18$), 0.446 in two-vessel disease ($n = 6$) and 0.305 in three-vessel disease ($n = 8$).

In conclusion, the quantitative evaluation of stress MPI using initial uptake, RDI and WR appear to be useful for noninvasive and objective diagnosis of CAD, particularly in detecting the severity and location of stenotic coronary arteries.

Key Words:

Stress myocardial perfusion imaging
Washout rate
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Coronary artery disease

METHODS of noninvasive diagnosis and estimation of coronary artery disease (CAD) have been dramatically advanced with the development of a myocardial perfusion imaging

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The First Department of Internal Medicine and *The Department of Radiology, Yamagata University School of Medicine, Yamagata, Japan

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Mailing address: Shoji Yasui, M.D., The First Department of Internal Medicine, Yamagata University School of Medicine, Nishinomae, Zao-iida, Yamagata 990-23, Japan

(MPI) technique. Exercise thallium-201 MPI has been used extensively for the diagnosis of CAD. Thallium-201 is a cyclotron-produced radionuclide with a low energy emission and a 73-hour physical half-life. The intramyocardial distribution of thallium-201, similar to that of other intracellular cations or potassium ion, has been shown to correlate well with coronary blood flow.¹

Beller et al.² demonstrated that the thallium-201 redistribution after transient myocardial ischemia is related to both a delayed accumulation of thallium-201 into ischemic myocardial segments and to a more rapid washout of the radionuclide from normal segments. Using these characteristics, we performed stress MPI on patients with CAD. Most studies have shown that stress MPI is superior to stress ECG in accuracy for detecting CAD.³⁻⁵ MPI is usually estimated by a visual identification of the areas with abnormally reduced activity. Such an estimation of MPI is inevitably influenced by the observer's bias. We have devised a computer-assisted technique for analysing thallium images; it is objective, reproducible and independent of the observer's bias. The purpose of this study is to detect the region and severity of coronary artery stenosis by stress MPI using this quantitative method.

MATERIALS AND METHODS

Exercise thallium-201 MPI was performed in 33 patients with CAD. They were 30 men and 3 women, ranging in age from 29 to 68 years with

an average of 55. All patients underwent left ventriculography (LVG) and coronary arteriography (CAG). In 10 patients, the 12-lead electrocardiograms at rest revealed the presence of Q waves indicating transmural infarction. In the remaining 23 patients, one had prior subendocardial infarction associated with an enzymatic manifestation. The patients were divided into two groups: Group 1 was composed of 22 patients (from No.1 to No.22) without prior myocardial infarction. Group 2 was composed of 11 patients (from No.23 to No.33) with prior myocardial infarction. All of them had significant ST changes on exercise electrocardiograms (Table I).

Left Ventriculography and Selective Coronary Arteriography

Left ventriculography was performed in 30-degree right anterior oblique and 60-degree left anterior oblique projections. These ventriculograms were assessed visually by experienced cardiovascular radiologists. Wall motion abnormalities were assessed according to the classification recommended by the American Heart Association. "Abnormal wall motion" used in this report implies aneurysmal, dyskinetic or akinetic wall motion.

Selective coronary arteriography was performed in multiple projections using Judkins' technique, and these arteriograms were evaluated according to Pujadas' classification⁶ without any knowledge of the exercise ECG and stress MPI test findings. The maximal stenosis in each of the 4 main coronary arteries (right coronary

Fig.1. Regional assignment of left ventricular wall segments in thallium-201 myocardial perfusion images. Six segments (anterior, lateral, apical, inferior, posterior and septal) are shown at four views.

TABLE I CLINICAL DATA

No.	Age	Sex	Stress Myocardial Perfusion Imaging (MPI)												mean WR
			Initial uptake (%)						Redistribution index (RDI)						
			ANT	SEP	LAT	INF	POST	APEX	ANT	SEP	LAT	INF	POST	APEX	
Group 1															
1	61	F	—	—	—	—	81.0	—	—	—	—	—	—	—	0.526
2	56	M	—	—	—	83.0	78.0	—	—	—	—	—	—	—	0.574
3	59	M	—	—	—	74.4	69.4	82.5	—	—	—	—	—	—	0.533
4	65	M	—	—	80.3	79.4	74.7	79.9	—	—	—	1.31	1.23	—	0.440
5	56	M	—	—	—	—	79.3	—	—	—	—	—	1.15	—	0.530
6	55	M	—	—	—	73.8	69.4	76.7	—	—	—	1.35	—	1.36	0.332
7	66	M	—	—	—	78.4	—	82.4	—	1.27	1.17	1.46	1.27	—	0.349
8	55	F	—	—	—	—	—	—	—	—	—	—	—	—	0.553
9	48	M	—	—	—	—	79.3	75.8	—	1.20	—	1.18	1.21	1.27	0.393
10	45	M	—	—	79.1	—	81.3	—	1.19	1.22	1.29	—	1.19	—	0.419
11	54	M	—	74.2	—	—	—	76.4	1.44	1.34	1.31	1.20	—	1.19	0.398
12	44	M	—	—	—	—	—	—	1.19	1.18	—	—	1.18	1.21	0.455
13	51	M	74.3	76.0	82.1	—	—	80.7	1.29	1.83	—	—	—	1.27	0.390
14	41	M	—	—	82.8	—	82.7	—	1.16	1.19	1.28	1.26	1.26	1.17	0.328
15	68	M	—	—	—	—	76.1	—	—	—	—	—	—	—	0.625
16	63	M	—	—	81.2	—	—	—	1.32	—	1.26	—	—	—	0.439
17	56	M	—	—	—	75.8	64.9	73.2	—	1.19	—	1.20	1.63	1.23	0.440
18	60	M	—	—	—	79.3	77.4	—	—	—	—	1.18	—	1.16	0.460
19	66	M	—	76.9	—	—	81.0	78.8	1.52	1.71	1.29	1.24	—	1.94	0.255
20	54	M	—	—	—	79.1	67.0	78.5	1.30	—	1.22	1.35	2.20	1.80	0.252
21	53	M	82.7	71.0	—	—	81.5	—	1.22	1.66	—	—	—	—	0.431
22	68	M	—	—	—	—	82.0	—	1.74	1.17	1.55	1.28	1.17	1.59	0.280
Group 2															
23	41	M	59.4	51.1	73.3	—	—	55.9	1.29	—	—	—	1.30	—	0.584
24	51	M	71.4	—	77.1	—	—	—	—	—	—	—	—	—	0.581
25	54	M	52.6	82.7	61.8	—	—	72.7	1.31	—	1.62	1.20	—	1.29	0.384
26	55	M	75.8	81.0	—	—	80.9	48.1	—	—	—	—	1.17	1.27	0.482
27	61	M	—	—	82.7	—	—	—	1.20	1.39	—	1.17	1.25	—	0.392
28	29	M	80.9	—	—	—	—	—	1.22	1.18	—	—	—	1.16	0.481
29	58	M	—	—	74.7	74.4	65.7	69.9	—	—	1.15	1.40	1.35	1.76	0.341
30	47	M	71.3	71.2	75.2	74.8	82.7	61.7	2.19	5.60	1.56	2.50	1.49	1.64	0.297
31	62	F	53.9	—	50.6	63.6	80.2	54.8	1.34	1.20	1.37	1.36	1.19	1.38	0.455
32	64	M	—	—	—	71.2	—	74.2	1.26	—	1.23	—	—	—	0.381
33	49	M	—	—	—	80.2	79.9	—	4.19	3.25	—	2.97	4.61	2.85	0.193

In MPI, the values of initial uptake and RDI were given only when they exceeded the diagnostic threshold (initial uptake $\leq 83\%$, RDI ≥ 1.15).

The name of the vessels toward which the collateral circulation moved is shown in parenthesis.

Coronary arteriography (Pujadas' Grade)					Abnormal wall movement	Collateral channels	Electrocardiography		
RCA	LMT	LAD	LCX	ΣGrade			Abnormal Q waves	Exercise Induced	
								ST-depression	ST-elevation
0	0	2	0	2	—	—	—	+	—
3	0	0	0	3	—	—	—	+	—
3	0	1	0	4	—	—	—	+	—
4	0	0	0	4	—	—	—	+	—
4	0	0	0	4	—	—	—	+	—
4	0	0	2	6	Inf. Post.	+(RCA)	—	+	—
4	0	2	0	6	Inf.	+(RCA)	—	+	—
4	0	2	0	6	—	—	—	+	—
5	0	2	2	9	—	+(RCA, LCX)	—	+	—
0	0	3	0	3	—	—	—	+	—
0	0	4	0	4	—	+(LAD)	—	+	—
0	0	4	0	4	—	—	—	+	—
1	0	5	0	6	—	+(LAD)	—	+	—
0	0	0	4	4	—	—	—	+	—
0	0	0	4	4	—	—	—	+	—
3	0	3	0	6	—	—	—	+	—
4	0	3	2	9	—	—	—	+	—
3	0	1	5	9	Inf.	+(LCX)	—	+	—
3	0	5	3	11	—	+(LAD)	—	+	—
4	0	4	4	12	—	—	—	+	—
4	0	4	4	12	—	—	—	+	—
4	0	4	4	12	Sep.	+(LAD)	—	+	—
0	0	4	0	4	Ant. Ape.	+(LAD)	+	+	+
0	0	4	0	4	—	—	+	+	—
0	0	5	0	5	Ant. Ape. Sep.	+(LAD)	+	—	+
1	0	5	0	6	Ape. Sep.	—	+	—	+
4	0	3	0	7	Ant. Ape. Inf.	—	+	—	+
3	0	5	1	9	Ape.	+(LAD)	—	+	—
4	0	0	5	9	Lat. Inf.	+(LCX)	+	+	—
3	3	4	0	10	Ant. Ape.	—	+	+	+
3	0	4	4	11	Ant. Ape. Inf.	+(LAD)	+	+	+
5	0	4	3	12	Ape.	+(RCA)	+	+	—
5	0	4	5	14	—	+(RCA)	+	+	—

Abbreviations: ANT = anterior segment; SEP = septum; LAT = lateral segment; INF = inferior segment; POST = posterior segment; APEX = apical segment; mean WR = mean washout rate; RCA = right coronary artery; LMT = left main trunk; LAD = left anterior descending coronary artery; LCX = left circumflex coronary artery; + = present; — = absent; M = male; F = female; Inf = inferior; Post = posterior; Sep = septum; Ant = anterior; Ape = apex; Lat = lateral

Fig.2. Abnormal stress MPI (Case 13). Stress images (upper) and delayed images (lower). Low initial uptake and remarkable redistribution of anteroseptal segments are observed.

Fig.3. Relationship between initial uptake and RDI in group 1. The two segments (anterior and inferior) of the same case are connected by straight lines (one or two vessel disease) or broken lines (three vessel disease). □ = grade 0-2, △ = grade 3, ● = grade 4, 5

artery, RCA; main trunk of the left coronary artery, LMT; left anterior descending artery, LAD; left circumflex artery, LCX) was graded as follows:

Grade 0: normality of the arterial lumen

Grade 1: slight irregularity of the arterial

TABLE II PUJADAS' METHOD FOR THE EVALUATION OF THE CORONARY NARROWING

Grade	Length of narrowing	Diminution of lumen diameter
0		normal
1		irregular
2	short long tubular	< 40% < 20% < 10%
3	short long tubular	40-85% 20-60% 10-50%
4	short long tubular	85% < 60% < 50% <
5		total occlusion

short: shorter than 5 mm; long: between 5 and 10 mm; tubular: over 10 mm

- Grade 2: lumen without localized stenosis
- Grade 2: localized stenosis which does not hinder the maximal coronary flow
- Grade 3: stenosis which compromises the coronary reserve (maximum flow) significantly but does not alter the rest flow
- Grade 4: a subocclusion which inhibits even the rest flow

Fig. 4. Relationship between initial uptake and RDI in group 2. Symbols are the same as in Fig. 3.

Grade 5: total occlusion

These grades are given in Table II. Σ grade, expressed by adding the grade number of all 4 main coronary arteries, was used as an index of the severity of coronary artery disease. Grades 3, 4 and 5 were considered significant stenosis.

Exercise Thallium-201 MPI

A catheter was inserted into the basilic vein of the forearm and patients underwent submaximal graded stress test using a bicycle ergometer according to the standard protocol. Exercise was terminated when chest pain or ischemic ST changes occurred, or the patient became exhausted. Two mCi of thallium-201 was injected intravenously one min before the end of exercise, and the patient was imaged 5 min later (exercise image). The imaging was performed at 30-degree right anterior oblique (RAO), anterior (ANT), 45-degree left anterior oblique (LAO) and left lateral (LL) views using an Ohio Nuclear Sigma 410S scintillation camera with a high resolution parallel hole slant collimator. The window was set 20% at 80 keV. Images contained 1000 counts per cm^2 fields and were stored on magnetic disk in a 64×64 matrix (DEC, Gamma

11 Processing System, PDP 11/34). Three hours after thallium-201 administration, delayed imaging was performed to evaluate the redistribution of thallium activity in the myocardium at the same 4 views (delayed image).

Quantitation of Stress MPI

Data processing was carried out as follows: 1) The background subtraction from the original data was done interpolatively (Goris' method⁷). 2) Nine region-of-interests (ROIs) were set on each left ventricular muscle image automatically using a computer system (Fig. 1). Thus, the center of the myocardial image and the center ROI of 7×7 cells were determined, and 8 ROIs were also determined around the center ROI at 45 degree intervals. The defect or hypoperfused ROIs due to valvular structure or atrium were excluded from the following data processing. The uptake counts per minute were obtained for each ROI. Three indices at the respective views were defined as follows:

- 1) initial uptake (%)
= counts of ROI / counts of the highest ROI count $\times 100$
- 2) washout rate (WR)
= $(C_{ex} - C_d) / C_{ex}$
where C_{ex} is counts of a ROI in exercise image and C_d is counts of the same ROI in delayed image
- 3) redistribution index (RDI)
= the maximal WR / WR

Initial uptake and RDI in each left ventricular segment were constructed from these indices at the 4 views as described in Fig. 1. In the present study, we divided the left ventricle into the following 6 segments: anterior, lateral, inferior, posterior, septal and apical.

Exercise Electrocardiography

On exercise electrocardiograms, ischemic ST changes were defined as ≥ 1 mm of horizontal or downsloping ST segment depression at 0.08 sec from the J point, or as ≥ 1 mm of ST segment elevation at J point as compared to the preexercise ST level, lasting for 0.06 sec from the J point.

Data Analysis

Statistical analysis was performed using the t -test and linear correlation analysis. Sensitivity was defined as the number of true-positive responses divided by the number of true-positive and false-negative responses. Specificity was defined as the number of true-negative responses

Fig.5. Relationships between the grade of coronary narrowing and the initial uptake (left), and between the grade of coronary narrowing and the RDI (right) at 22 anterior segments and 22 inferior segments. The symbol (<) represents a three-vessel disease.

Fig.6. Detection percentage of coronary arterial narrowing in group 1 (left) and in group 2 (right) in the anterior and inferior segments. In group 1, the sensitivity was 76% and the specificity was 84%. In group 2, it was 76% and 80%, respectively.

divided by the number of false-positive and true-negative responses.

RESULTS

Classification of Coronary Arteriograms

Thirty-two out of the 33 patients studied had stenosis of grade 3 or more in one or more major coronary arteries. In group 1, there were 15 RCA, 10 LAD and 7 LCX diseases. In group 2, there were 7 RCA, 10 LAD and 4 LCX diseases (Table I). The grade 3 or more was considered to have significant coronary narrowing, and there were 18 patients with one-vessel disease, 6 with two-vessel disease and 8 with three-vessel disease. One patient in group 1 had insignificant coronary stenosis. Σ grade was less than 6 in 13 patients, 6 to 10 in 13 and larger than 10 in 7. The presence of collateral vessels were assumed if a vessel distal to the stenosis was opacified through other vessels. Collateral channels were present in 15 patients. Fourteen of these 15 patients were not protected against exercise-induced ischemia

Fig. 7. Relationship between Σ grade and mean WR in 33 patients with coronary artery disease. The patients with high Σ grade have a tendency to show low "mean WR".

(Table I).

Analysis of Scintigraphic Imaging

Figure 2 shows a scintigraphic study in one patient (Case 13) with stress-induced abnormalities of the left ventricular wall, including the anterior, septal and apical walls. RDI was 1.29 at the anterior wall, 1.83 at the septum and 1.27 at the apex. The initial uptakes of anterior wall, septum and apex were 74.3%, 76.0% and 80.7%, respectively. The exercise electrocardiograms showed significant ST segment depression. Coronary arteriograms revealed a severe lesion (grade 5) of LAD. In this case, the ischemia of the anteroseptal wall and the apex could be identified by stress MPI.

The area without thallium accumulation corresponds to the location of the diseased coronary artery^{8,9}. Exercise-induced abnormalities involving the anterior wall and the septum are considered to be induced by LAD disease and the inferoposterior wall abnormalities are related to RCA disease. The lateral and posterior wall abnormalities are related to LCX disease. Apical abnormalities may be induced by distal lesions of any of the three vessels. Figure 3 shows the relationship between the initial uptake and the RDI in group 1 ($n = 22$). The solid line (1 or 2 vessel disease) and the broken line (3 vessel disease) show the relationship between RDI at the anterior wall and that at the inferior wall in individual cases. Note that the region supplied

by the more stenotic coronary artery tended to show a lower initial uptake and a greater RDI than the region perfused by the less stenotic or by the normal coronary artery in individual cases.

Figure 4 shows the relationship between the initial uptake and the RDI in group 2. The initial uptake showed a low value in the areas supplied by the severely stenotic coronary arteries as similarly observed in group 1 (except Case 27). The segments with high RDI were observed in 3 patients with three-vessel disease.

In group 1, the relationships of the initial uptake and the RDI to the grade of coronary narrowing in the anterior and inferior segments are illustrated in Fig. 5. The initial uptake (mean $\pm$ SEM) was $89.6 \pm 0.88\%$ in grade 0–2, $85.8 \pm 2.27\%$ in grade 3 and $84.1 \pm 1.59\%$ in grade 4, 5. Significant differences were observed between grade 0–2 and grade 4, 5 ($p < 0.005$). The RDI (mean $\pm$ SEM) was 1.11 ± 0.01 in grade 0–2, 1.17 ± 0.03 in grade 3 and 1.31 ± 0.04 in grade 4, 5. There were significant differences between grade 0–2 and grade 3 ($p < 0.05$) and between grade 0–2 and grade 4, 5 ($p < 0.001$).

If an initial uptake less than 83% or a RDI greater than 1.15 are defined as abnormal, the sensitivity in detecting coronary artery stenosis of grade 3 or more was 76% and the specificity was 84% in group 1. In group 2, the sensitivity was 76% and the specificity was 80% (Fig. 6).

Washout rate was also calculated to estimate the severity of CAD. In group 1, the average of mean WR was 0.451 in one-vessel disease, 0.405 in two-vessel disease, and 0.332 in three-vessel disease. In group 2, it was 0.508, 0.405 and 0.332, respectively. All 5 patients with mean WR less than 0.3 had three-vessel disease. There was a significant negative correlation ($r = -0.664$, $p < 0.001$) between the Σ grade and the mean WR (Fig. 7).

DISCUSSION

The present study indicates that the quantitation of stress MPI highly improves sensitivity for detecting coronary artery disease. Usually thallium-201 myocardial imaging has been evaluated subjectively by multiple observers^{4,8,10,11}. Using quantitative approach, there have been a thallium-201 redistribution analysis by Kanemoto et al.¹² and a circumferential profile analysis by Burow et al.^{13,14}. Employing these methods, thallium-defects were identified and scored in comparison to the profile curve

with normal limits, and CAD was finally diagnosed. However, it is difficult to recognize the location of the ischemic regions in the left ventricle exactly, especially in the heart whose axis has been rotated or in cardiomegaly. Rigo et al.⁸ have reported that the segmental analysis of MPI identified the lesions of the individual coronary arteries, but they could not estimate the grade of the severity of coronary artery disease. In the present report, the grade of coronary arterial narrowing and the location of the myocardial ischemic region could be detected using the initial uptake and RDI indices. A myocardial segment supplied by the stenotic coronary artery may receive an adequate resting flow, but an adequate increase in flow cannot occur during exercise. Thus, in the initial distribution phase, focal defects in the thallium-201 uptake will be observed in these relatively underperfused segments. During 2 or 3 hours in the postexercise resting phase, underperfused segments with initially observed thallium-201 defects may accumulate thallium-201, whereas normal segments will lose more thallium-201 than abnormally perfused segments. Thus, normally perfused and underperfused myocardial segments may show images with equal thallium-201 concentrations.¹⁵ Considering the above-mentioned phenomenon, it is expected that normally perfused segments have high WR, whereas the segments supplied by stenotic coronary arteries have low WR. However, the WR at each view showed wide variations due to the inequality of the distance between the heart and a collimator or due to the non-homogeneity of the surrounding tissues. Therefore, we devised a new index, RDI, to eliminate the variations in the WR. The RDI is defined as maximal WR, which is obtained in the normally perfused ROI, divided by the WR at each view. Therefore, the RDI in normally perfused ROI is approximately 1.00, and the areas with decreased washout rate have a high RDI. By this study, we concluded that the regions with an initial uptake of less than 83% and/or with an RDI of greater than 1.15 were supplied primarily by stenotic coronary arteries of ≥ 3 in Pujadas' grade. We also found a linear relationship between Σ grade and mean WR as shown in Fig. 7. As the number and severity of coronary arterial narrowing increased, the mean WR of the whole left ventricular muscle diminished significantly. Therefore, the approximate severity of CAD could also be predicted by the mean WR.

In the case of myocardial infarction, the regions supplied by stenotic coronary artery had a low initial uptake, while they had variable RDIs. It is suggested that a high RDI shows the exercise-induced ischemic response in the surrounding area due to an insufficient development of collateral channels, and that a low RDI in the necrotic area is due to an intrinsic washout of thallium-201 accumulated in the interstitial tissue rather than in the myocardium *per se*. Pohost et al.¹⁶ also have reported that in several patients with old infarction, redistribution of thallium-201 into the early defect areas was not observed during the 4–6 hour imaging period.

There have been various reports concerning the effects of coronary collateral circulation on regional myocardial perfusion. Rigo et al.¹⁷ evaluated myocardial perfusion during exercise using thallium-201, and found that areas subserved by noncompromised coronary collateral channels were much less likely to show perfusion defects on scintigrams than areas that were perfused by compromised collateral channels. Cohn et al.¹⁸ have reported that high grade noncompromised coronary collateral vessels were able to implement flow to regions subserved by stenotic native vessels to a significantly greater extent than areas with less well-developed collateral vessels. On the other hand, Haaz et al.¹⁹ and Berger et al.²⁰ found that collaterals neither protect the myocardium from exercise-induced hypoperfusion, nor affect the occurrence of redistribution. In the present study, sufficient collateral channels were present in 15 patients. In one of them, the coronary collateral vessels had protected the myocardium from exercise-induced regional hypoperfusion. In the remaining 14, however, there was no such effect of the collateral channels. Therefore, it may be concluded that regional myocardial perfusion during exercise cannot be maintained sufficiently by the collateral channels.

Patients with significant ST changes on exercise electrocardiograms were selected for the present study. Therefore, comparative study between stress MPI and exercise electrocardiography could not be achieved. Iskandrian et al.¹⁰ and Bodenheimer et al.²¹ have reported a high sensitivity of a combined method of stress MPI and electrocardiography for detecting CAD.

In conclusion, this study emphasized the significance of the quantitative evaluation of stress MPI in diagnosing CAD non-invasively and objectively, especially in detecting the severity

and location of stenotic coronary arteries.

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