## DIAGNOSTIC NUCLEAR MEDICINE

# Exercise Thallium Imaging: Location of Perfusion Abnormalities in Single-Vessel Coronary Disease

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**Exercise-induced thallium defects were segmentally analyzed in four standard views (anterior, 40° left anterior oblique, 60° left anterior oblique, and left lateral) and correlated with the arteriographic findings in 49 patients with single-vessel disease (>70% diameter narrowing). Defects in the septal (SEPT), anteroseptal (ANT SEPT), and anterior (ANT) segments correlated ($p < 0.0005$) with stenosis of the left anterior descending coronary artery (LAD). For LAD disease the ANT SEPT segment had the highest sensitivity (84%) and specificity (100%). Defects in the inferior (INF), posteroinferior (POST INF), and posterior (POST) segments correlated ($p < 0.0005$) with either right (RCA) or circumflex (LCX) stenosis. For RCA or LCX disease, the POST segment had the highest sensitivity (82%) and specificity (100%).**

**The site of single-vessel coronary artery disease can be accurately predicted noninvasively by segmental analysis of thallium images in four anatomical projections.**

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Thallium-201 myocardial perfusion imaging following exercise is a reliable noninvasive method of detecting coronary artery disease (*1–3*), but its value in locating the diseased artery has not been determined (*4–7*). The aim of our study was to analyze exercise thallium images segmentally in patients with single-vessel coronary artery disease in order to establish patterns that would identify the diseased vessel.

## METHODS

**Patient population.** Forty-nine patients with angiographically proven significant obstruction of a single coronary artery (>70% diameter narrowing) underwent exercise thallium-201 myocardial perfusion imaging between January 1978 and March 1979. There were 48 males and one female, with a mean age of 50 yr (range 32–61). Forty of the 49 patients complained of angina pectoris. In 22 of the 49 there was a history of previous myocardial infarction, and in 14 of the 22, ECG evidence of previous infarction was present.

Selective coronary arteriography was performed in multiple projections using the Judkins or Sones technique. Each study was reviewed by two independent observers who agreed that coronary artery narrowings of 70% or greater of the luminal diameter were present in only one major coronary artery. Patients with stenoses between 50–70% in a second artery were excluded from the study. There were 22 patients with stenoses between 30–50% in other arteries, and 27 with stenoses <30%, or normal arteriograms, in the other vessels.

**Exercise myocardial perfusion imaging.** Within a mean time of 10 days from arteriography, patients performed symptom-limited exercise on a bicycle ergometer using a protocol previously described (*3*). Thallium-201 (1.5–2 mCi) was injected at peak exercise through an i.v. cannula previously inserted. Patients continued exercising for a further 60 sec to enable adequate blood clearance and myocardial uptake of the thallium during

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conditions of stress. Medications for angina were not altered before testing, and patients were not exercised within 3 mo of myocardial infarction. Imaging was begun in the exercise laboratory 5 min after the thallium injection (exercise image). With the patient supine, three views were taken with a mobile camera as previously described (*3*)—anterior, 40° left anterior oblique (LAO), and 60° LAO—and a left lateral was added with the patient in right decubitus position.

Three observers interpreted the original Polaroid scintigrams, without computer enhancement, background subtraction, or knowledge of the patient's data. A thallium defect was considered to be present if there was a discrete reduction of tracer activity involving at least 15% of the left-ventricular circumference. A consensus of three observers was taken, and if any defect were thought equivocal, this was reported as negative. The interobserver variability for this technique was 7% (CV). Each of the four views of the exercise image was divided into three segments as shown in Fig. 1, and analyzed for the presence or absence of a thallium defect. Defects in each segment were then correlated with the location of coronary artery disease. There were no complications from any of the procedures.

**Data analysis.** Data were analyzed using the Yates corrected chi-square test or the exact test of Fisher, Irwin, and Yates for the 2 × 2 contingency table (*8*). Each segment of the exercise image showing a thallium defect was correlated with the location of coronary artery disease in the 49 patients with single-vessel disease. The sensitivity, specificity, and predictive accuracy of each segment of the exercise image for locating the site of coronary artery obstruction were calculated.

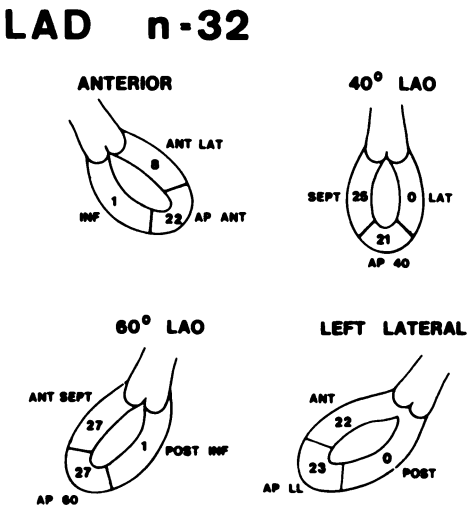


**FIG. 1.** Showing distribution of Tl-201 defects in 32 patients with LAD disease. Numbers refer to frequency of defects for each segment. Abbreviations: LAO = left anterior oblique; ANT LAT = anterolateral; AP ANT = apical segment, anterior view; INF = inferior; SEPT = septal; AP 40 = apical segment, 40° LAO view; LAT = lateral segment; ANT SEPT = anteroseptal; AP 60 = apical segment, 60° LAO view; POST INF = posteroinferior; ANT = anterior; APLL = apical segment, left lateral view; POST = posterior.

$$\text{sensitivity} = \frac{\text{true positives}}{\text{true positives} + \text{false negatives}}$$

$$\text{specificity} = \frac{\text{true negatives}}{\text{true negatives} + \text{false positives}}$$

$$\text{predictive accuracy of positive test} = \frac{\text{true positives}}{\text{true positives} + \text{false positives}}$$

**TABLE 1. SENSITIVITY, SPECIFICITY, AND PREDICTIVE ACCURACY OF THALLIUM DEFECTS IN THE 12 SEGMENTS FOR LAD* AND RCA/LCX DISEASE**

| | Site of thallium defects | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ANT LAT | AP ANT | INF | SEPT | AP 40 | LAT | ANT SEPT | AP 60 | POST INF | ANT | APLL | POST |
| LAD disease N = 32 | | | | | | | | | | | | |
| Number of patients with defects | 8 | 22 | 1 | 25 | 21 | 0 | 27 | 27 | 1 | 22 | 23 | 0 |
| Sensitivity (%) | 25 | 69 | 3 | 78 | 66 | 0 | 84 | 84 | 3 | 69 | 72 | 0 |
| Specificity (%) | 94 | 53 | 35 | 88 | 35 | 88 | 100 | 41 | 41 | 100 | 76 | 18 |
| Predictive accuracy (%) | 89 | 73 | 7 | 93 | 66 | 0 | 100 | 73 | 9 | 100 | 85 | 0 |
| RCA/LCX disease N = 17 | | | | | | | | | | | | |
| Number of patients with defects | 1 | 8 | 13 | 2 | 11 | 2 | 0 | 10 | 10 | 0 | 4 | 14 |
| Sensitivity (%) | 6 | 47 | 77 | 12 | 65 | 12 | 0 | 59 | 59 | 0 | 24 | 82 |
| Specificity (%) | 75 | 31 | 97 | 22 | 34 | 100 | 16 | 16 | 97 | 31 | 28 | 100 |
| Predictive accuracy (%) | 11 | 27 | 93 | 7 | 34 | 100 | 0 | 27 | 91 | 0 | 15 | 100 |

* Abbreviations: LAD = left anterior descending coronary artery; RCA = right coronary artery; LCX = left circumflex coronary artery; N = number of patients; for segment abbreviations see Fig. 1.

**TABLE 2. RELATION BETWEEN SEGMENTAL THALLIUM DEFECTS AND LAD* DISEASE**

| Site of thallium defects† | Incidence of defects in LAD disease (N = 32) | Incidence of defects in RCA/LCX disease (N = 17) | P value† |
|---|---|---|---|
| ANT LAT | 8 (25%) | 1 (6%) | NS |
| AP ANT | 22 (69%) | 8 (47%) | NS |
| SEPT | 25 (78%) | 2 (12%) | <0.0005 |
| AP 40 | 21 (66%) | 11 (65%) | NS |
| ANT SEPT | 27 (84%) | 0 (0%) | <0.0005 |
| AP 60 | 27 (84%) | 10 (59%) | NS |
| ANT | 22 (69%) | 0 (0%) | <0.0005 |
| APLL | 23 (72%) | 4 (24%) | <0.005 |

* Abbreviations: LAD = left anterior descending coronary artery; RCA = right coronary artery; LCX = left circumflex coronary artery; for segmental abbreviations see Fig. 1; NS = not significant; N = number of patients.

† The incidence of defects in each of the eight segments that best detects LAD disease is compared with its incidence in RCA/LCX disease.

## RESULTS

In the 49 patients with single-vessel disease, LAD disease was present in 32 (proximal to the first perforator in 19), RCA disease was present in 13, and LCX disease in 4. A Tl-201 defect on the exercise image was present in 46 (92%), in 29 of the 32 with LAD disease, and in all 17 with RCA or LCX disease.

Figure 1 shows the distribution of thallium defects in each of the 12 segments in patients with LAD disease. Table 1 shows the sensitivity, specificity, and predictive accuracy of each segment for detecting LAD disease. The sensitivity was highest in the ANT SEPT (84%), apical segment 60° LAO view (AP 60) (84%), and SEPT (78%) segments. The specificity was highest in the ANT SEPT (100%), ANT (100%), and SEPT (93%) segments. Thallium defects in the ANT SEPT and ANT segments accurately predicted (100%) LAD disease, and the ANT SEPT segment was the more sensitive. Table 2 shows that defects in SEPT, ANT SEPT, and ANT segments correlated strongly ($p < 0.0005$) with LAD disease. A representative exercise image of a patient with single LAD disease is shown in Fig. 2.

A thallium defect in the SEPT was present in 16 of the 19 patients with obstruction of the LAD proximal to the first perforator, and in eight of the 13 patients with distal LAD obstruction (P = NS).

Figure 3 shows the distribution of thallium defects in each of the 12 segments in patients with RCA or LCX disease. Table 1 shows the sensitivity, specificity, and predictive accuracy of each segment for detecting RCA or LCX disease. The sensitivity was highest in the INF (77%) and POST (82%) segments. The specificity was

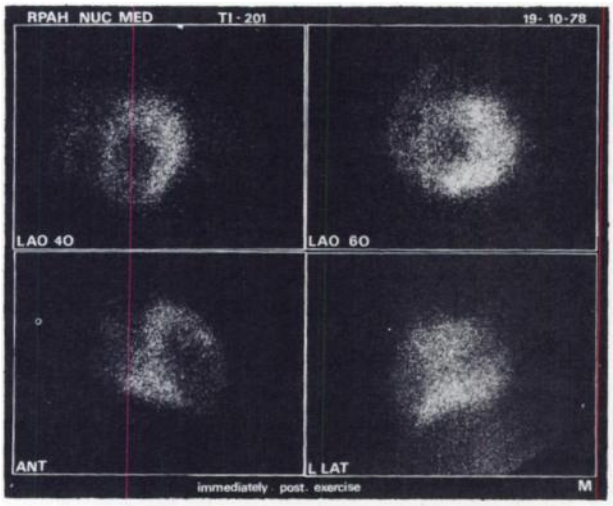


**FIG. 2.** Exercise images of 43-year-old man with 100% LAD obstruction and no lesions >30% in other arteries. There are defects in SEPT, AP 40, ANT SEPT, AP 60, ANT LAT, AP ANT, ANT, and APLL segments.

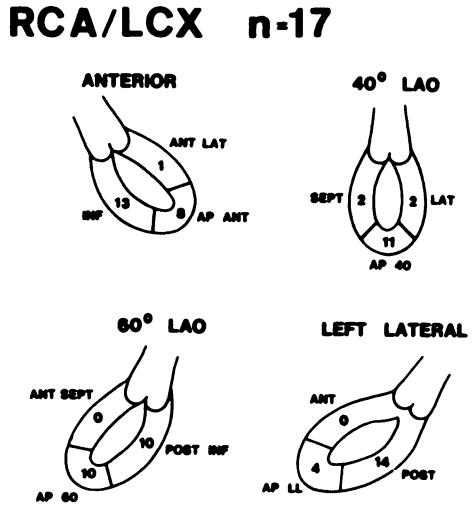


**FIG. 3.** Showing distribution of Tl-201 defects in 17 patients with RCA or LCX disease. Numbers refer to frequency of defects for each segment.

**TABLE 3. RELATION BETWEEN SEGMENTAL THALLIUM DEFECTS AND RCA/LCX* DISEASE**

| Site of thallium defects† | Incidence of defects in RCA/LCX disease (N = 17) | Incidence of defects in LAD disease (N = 32) | P value† |
|---|---|---|---|
| AP ANT | 8 (47%) | 22 (69%) | NS |
| INF | 13 (77%) | 1 (3%) | <0.0005 |
| AP 40 | 11 (65%) | 21 (66%) | NS |
| LAT | 2 (12%) | 0 (0%) | NS |
| AP 60 | 10 (59%) | 27 (84%) | NS |
| POST INF | 10 (59%) | 1 (3%) | <0.0005 |
| POST | 14 (82%) | 0 (0%) | <0.0005 |

* Abbreviations: LAD = left anterior descending coronary artery; RCA = right coronary artery; LCX = left circumflex coronary artery; for segmental abbreviations see Fig. 1; NS = not significant; N = number of patients.

† The incidence of defects in each of the seven segments that best detects RCA/LCX disease is compared to its incidence in LAD disease.

highest in POST (100%), LAT (100%), INF (97%), and POST INF (97%) segments. Thallium defects in the LAT and POST segments accurately predicted (100%) RCA or LCX disease, and of these the POST segment was the more sensitive. Table 3 shows that thallium defects in the INF, POST INF, and POST segments correlated strongly ($p < 0.0005$) with RCA or LCX disease. A representative exercise image of a patient with single LCX disease is shown in Fig. 4.

Table 4 compares the sensitivities and specificities of the best segments for detecting RCA and LCX disease. Defects in the LAT segment predicted LCX disease (100%), but did not reach statistical significance in distinguishing disease in this vessel from RCA disease. The sensitivity of this segment for LCX disease was only 50%. No segment reliably predicted RCA disease.

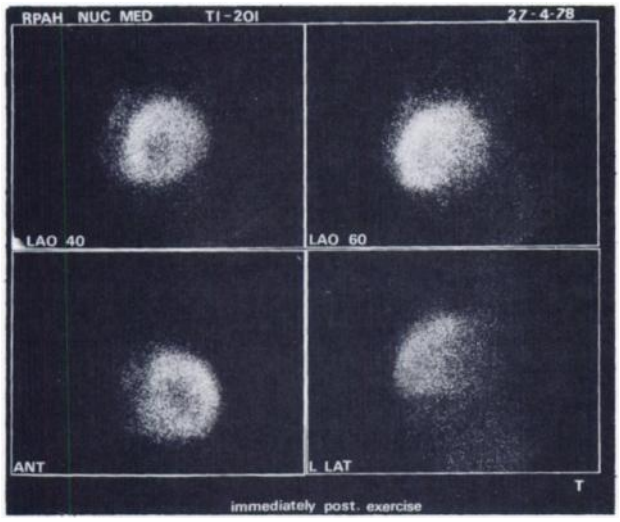


**FIG. 4.** Exercise images of 51-year-old man with 80–90% obstruction of a dominant LCX but no lesions >30% in other arteries. There are defects in AP 40, LAT, POST INF, AP ANT, INF, and POST segments.

Using the above data, three specific vascular areas and one nonspecific vascular area were defined, as shown in Fig. 5. The ANT LAT, SEPT, ANT SEPT, and ANT segments represent the LAD vascular area; the INF, POST INF, and POST segments represent the RCA/LCX vascular area; the LAT segment represents the LCX vascular area. The four apical segments represent the nonspecific vascular area. Table 5 shows the thallium defects in patients with LAD, RCA, and LCX disease localized to these vascular areas. In 40 of the 49 patients (82%), the thallium image correctly predicted the presence and site of the single obstructed coronary artery. In 5 patients (10%) the scan suggested incorrectly that multivessel disease was present, and localization was not possible in four patients (8%): three with no thallium defects and one with only an apical defect. A thallium defect in a second vascular area was found in three of the 22 patients with coronary stenoses of 30–50% in a second coronary artery, and in two of the 27 patients with no other stenosis of 30% or greater (P = NS).

## DISCUSSION

This study shows that a simple geographical analysis of Tl-201 exercise-image defects, which may be related to either myocardial ischemia or infarction, can accurately locate single-vessel coronary artery disease. Thallium defects in the ANT SEPT segment (60° LAO view) most reliably identified LAD coronary disease, and defects in the POST segment (left lateral view) most reliably identified RCA or LCX disease. Patients with LCX disease appeared to be distinguished from patients with RCA disease only if the LAT segment (40° LAO view) was involved, but this did not reach statistical significance. Since the posteroinferior part of the left ventricle can be supplied by either the right coronary or the left circumflex artery, defects in the INF, POST

**TABLE 4. COMPARISON OF SENSITIVITIES, SPECIFICITIES, AND PREDICTIVE ACCURACIES OF THE BEST SEGMENTS FOR DETECTING RCA* AND LCX DISEASE**

| | Site of thallium defects | | | |
|---|---|---|---|---|
| | INF | LAT | POST INF | POST |
| RCA disease N = 13 | | | | |
| Number of patients with defects | 10 | 0 | 6 | 10 |
| Sensitivity (%) | 77 | 0 | 46 | 77 |
| Specificity (%) | 89 | 94 | 86 | 89 |
| Predictive accuracy (%) | 77 | 0 | 60 | 71 |
| LCX disease N = 4 | | | | |
| Number of patients with defects | 3 | 2 | 4 | 4 |
| Sensitivity (%) | 75 | 50 | 100 | 100 |
| Specificity (%) | 76 | 100 | 84 | 78 |
| Predictive accuracy (%) | 23 | 100 | 40 | 29 |
| p value† | NS | NS | NS | NS |

* Abbreviations: RCA = right coronary artery; LCX = left circumflex coronary artery; N = number of patients; for segment abbreviations see Fig. 1; NS = not significant.

† The incidence of defects in each segment in patients with RCA disease is compared with its incidence in LCX disease.

INF, and POST segments could not distinguish between the two arteries.

Although thallium defects were frequently present in the apical segments, these defects did not accurately locate the site of coronary artery disease in any of the four views except the left lateral, which correlated with LAD disease. The apex was thus considered a nonspecific vascular area. This lack of specificity of apical defects for disease in any one vessel may be related to the variable blood supply to this region, which may be the true apex of the heart or, in the 40° LAO view, may include part of the inferior wall in a horizontally oriented heart. The lack of specificity of apical defects may also be related to a misinterpretation of normal apical thinning. On the other hand, apical defects rarely occurred alone and identified specific vessel disease when associated with contiguous or separate defects in other segments.

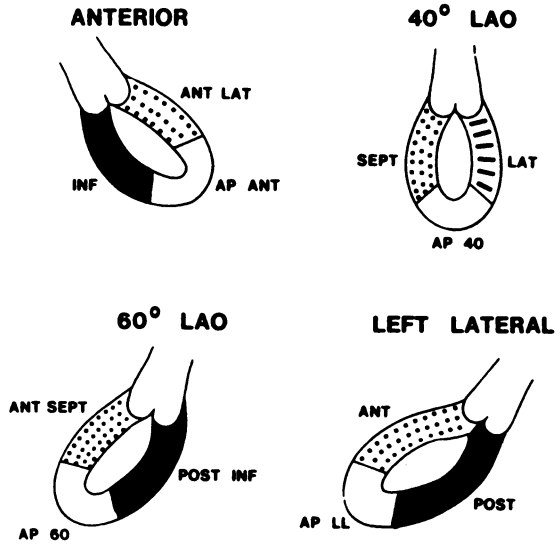


**FIG. 5.** Showing distribution of the four vascular areas. Dotted segments represent LAD vascular area; blackened segments represent RCA/LCX vascular area; striped segment represents LCX vascular area; and unshaded apical segments represent nonspecific vascular area.

Four previous studies (*4–7*) have correlated the site of thallium defects with coronary artery anatomy, but our study analyzes individual patients with single-vessel disease only. Patients with single-vessel disease were studied because the influence of multivessel disease on the distribution of thallium defects is unknown. In a study similar to ours, Lenaers et al. (*4*) found that the site of thallium defects correlated with coronary artery obstruction, but included patients with single- and multivessel disease. Bailey et al. (*5*) studied thallium scans in three views (anterior, 40° LAO, and 60° LAO) in patients with single-vessel disease but did not include a detailed analysis of the patients. In our study four views were used because the left lateral identifies RCA or LCX disease when the POST segment is involved. Other investigators (*6,7*) use the anterior, 45° LAO, and the left lateral as their three views and omit the 60° LAO view with the ANT SEPT segment, which in our study identifies LAD disease best.

A thallium defect in the SEPT segment in the 40° LAO view is reported to distinguish between LAD obstruction proximal and distal to the first perforator (*9*). Patients with proximal LAD disease may have a worse prognosis than those with distal disease (*10*), and noninvasive differentiation would aid management. In our 32 patients with LAD obstruction, proximal and distal

**TABLE 5. COMPARISON OF SCINTIGRAPHIC AND ARTERIOGRAPHIC LOCATION OF CORONARY ARTERY DISEASE**

| | Finding by thallium image | | | | |
|---|---|---|---|---|---|
| | LAD vascular area* alone | RCA/LCX vascular area* alone | LCX† + RCA/LCX vascular areas* | LAD + RCA/LCX vascular areas* | Apical defects alone |
| LAD (N = 32)‡ | 26 | 0 | 0 | 2 | 1 |
| RCA (N = 13) | 0 | 11 | 0 | 2 | 0 |
| LCX (N = 4) | 0 | 2 | 1 | 1‖ | 0 |

* With or without apical defects.

† LCX vascular area was not involved alone.

‡ Three of the 32 patients did not have thallium defects.

‖ This patient also had a defect in the LCX vascular area.

disease could not be distinguished by thallium defects in the SEPT segment, or by any other scan pattern of defects.

In five of our patients, segmental defects on the exercise thallium image were present in a second vascular area unrelated to the site of coronary artery obstruction. One explanation is that the involved segment has a variable blood supply. This was seen in at least one of our patients, whose ANT LAT defect was associated with a LAT defect and dominant LCX disease, rather than with LAD disease, which was present in other patients with ANT LAT defects. In some patients the degree of other coronary artery disease may be underestimated, or a 30–50% narrowing may be sufficient to produce myocardial hypoperfusion on maximal exercise. Although this may be the explanation for defects in a second vascular area in three of our patients, in two of them the second defect was a constant SEPT defect continuous with a constant AP 40° defect and associated with total RCA obstruction plus 30–50% obstruction in the LAD and LCX, respectively. In these two patients the SEPT defects may not reflect minor disease in other vessels, since SEPT defects in patients with RCA disease may be related to a change in orientation of the heart so that an inferior defect (anterior view) extends into the SEPT segment when the heart rotates vertically during exercise. INF or POST INF defects in patients with LAD disease may be due to a dominant LAD coronary artery supplying the apex and part of the inferior wall of the heart, or may be due to tissue attenuation by the diaphragm. Further apparent defects in the second vascular area may be due to observer misinterpretation.

In our patients with single-vessel disease, the identification of thallium defects on the exercise image with three specific and one nonspecific vascular areas predicted the site of coronary artery obstruction that caused either myocardial infarction or ischemia. Although myocardial perfusion imaging can accurately locate the site of coronary artery obstruction in patients with both single- and multivessel disease, this technique is limited, since some patients with single-vessel disease may have thallium defects in the distribution of two vascular areas. Conversely, patients with multivessel disease may have defects in only one vascular area.

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