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DEPARTMENT OF THE AIR FORCE
DAVID GRANT USAF MEDICAL CENTER (MAC)
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14 September 1976

Final Report On The Incorporated Clinical Investigation Proposals #389, Noninvasive Assessment of Coronary Artery Disease, and #499, Noninvasive Assessment Of Coronary Artery Disease: Myocardial Imaging With Rubidium-81 And The Scintillation Camera.

USAF/SGPR

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1. Investigators:

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2. Studies to completion of research proposal:

a. Through 31 June 1975, 407 potassium-43 studies and 326 rubidium-81 studies were accomplished at rest or exercise on 411 patients. Six hundred seventy-five studies were accomplished using the rectillinear scanner and 58 with scintillation camera. Patients studied have included those with the following diagnoses:

(1) Normal subjects
(2) Myocardial infarction
(3) Post myocardial angina pectoris
(4) Angina pectoris without myocardial infarction
(5) False-positive electrocardiographic interpretations
(6) Cardiomyopathy
(7) Barlow's syndrome
(8) Conduction abnormalities including left bundle branch block, right bundle branch block, hemiblocks and atrial ventricular blocks
(9) Pre-excitation syndromes including Wolff-Parkinson-White and Lown-Genonge-Levine
(10) Pericarditis
(11) Postoperative aortocoronary saphenous vein bypass graft in patients with and without postoperative angina pectoris.

3. Results and conclusions:

a. As a direct result of this project, noninvasive myocardial imaging with potassium-43 in the assessment of patients with coronary artery disease at rest and with exercise was initiated as a new technique for the evaluation of heart patients. Our initial publications on this subject were met with a great deal of interest and enthusiasm. Following our initial reports several other major medical centers began their own investigations utilizing this technique. Although noninvasive myocardial imaging for myocardial infarction had been well established, this technique

developed at the David Grant USAF Medical Center created a method for the evaluation of patients for coronary ischemia without resorting to coronary angiography. Extensive international research has followed the introduction of this new technique and the results are reflected in the radiologic and cardiovascular literature.

b. Because of the prolonged half-life, difficult imaging characteristics, high cost and limited availability, investigation was directed toward substituting rubidium-81 for potassium-43 for the purposes of myocardial imaging at rest and with exercise. We found rubidium-81 to be comparable to potassium-43 in the quality of images obtained. Because of its improved imaging characteristics, rubidium-81 permitted rapid sequential studies, shorter imaging time and adaptability of the technique to the scintillation camera. Combined with a reduced cost and more ready availability, these characteristics caused us to convert from potassium-43 to rubidium-81 as our primary imaging agent at this facility. The demonstration that rubidium-81 and potassium-43 were comparable also allowed more widespread use of this technique and prompted even further investigation into noninvasive myocardial imaging by other research centers.

c. The adaptability of the technique to the scintillation camera, which is the standard imaging device used by departments of nuclear medicine, made possible computer analysis of imaging results. This in turn permitted an objective analysis of myocardial perfusion at rest and with stress. As a result, major university departments of nuclear medicine have become interested in the technique and made further investigation into improved imaging agents and techniques. At present, thallium-201 has become the standard imaging agent, having replaced both rubidium-81 and potassium-43. Since our request for continued investigation in noninvasive myocardial imaging utilizing these newer agents was disapproved by Headquarters USAF for FY 1976, we have found it necessary to terminate further research in this area.

d. One hundred sixty of the subjects studied by noninvasive myocardial imaging at rest and with exercise had been evaluated with coronary angiography. In the 98 patients with angiographically significant coronary artery disease, there were 81 positive imaging studies for a sensitivity of 83%. Fifty-one of the 62 patients with angiographically insignificant coronary artery disease had negative imaging studies for a specificity of 82%. Excluding those patients with myocardial infarction, the sensitivity of myocardial imaging was 75% while that of standard electrocardiographic exercise testing was 72%. In this same group of patients the overall specificity of electrocardiographic testing was 50%. Utilizing a combination of myocardial imaging and exercise, ECG testing resulted in a sensitivity of 92% in identifying significant coronary artery disease and 88% sensitivity identifying angiographically significant coronary artery disease. Thus, the diagnostic accuracy of noninvasive myocardial imaging for coronary artery disease shows excellent angiographic correlation and a clearly superior diagnostic specificity to standard stress electrocardiographic testing. Details are specified in the attached report.

e. Patients with left bundle branch block were found to represent a sub-group with very specific imaging characteristics. All patients with left bundle branch block, whether associated with coronary heart disease or angiographically normal coronary arteries, had image defects in the region of the interventricular septum with potassium-43 and rubidium-41. When imaged with exercise, left bundle branch block patients with normal coronary arteries were found to have normal studies, while those with significant coronary artery disease showed an increase in the abnormality found in all left bundle branch block patients at rest. This special group resulted in a separate report which is attached. Patients with right bundle branch block and other conduction abnormalities, including pre-excitation, showed none of the changes found with left bundle branch block patients.

4. Data presentation in conjunction with protocols #389 and #499:

a. Publications:

(1) H. William Strauss, Barry L. Zaret, Neil D. Martin, Harry P. Wells, Jr., and M.D. Flamm, Jr.: Noninvasive evaluation of regional myocardial perfusion with potassium-43: Technique in patients with exercise-induced transient myocardial ischemia. Radiology, Vol. 108, No. 1, Pages 85-90, July 1971.

(2) Barry L. Zaret, H. William Strauss, Neil D. Martin, Harry P. Wells, Jr., and M.D. Flamm, Jr.: Noninvasive regional myocardial perfusion with radioactive potassium: Study of patients at rest, with exercise and during angina pectoris. NEJM 288:809-812, April 19, 1973.

(3) Barry L. Zaret, Robert E. Stenson, Neil D. Martin, H. William Strauss, Harry P. Wells, Jr., Ronald L. McGowan, and M.D. Flamm, Jr.: Potassium-43 myocardial perfusion scanning for noninvasive evaluation of patients with false-positive exercise tests. Circulation, Vol. XLVIII, pages 1234-1241, Dec 1973.

(4) Barry L. Zaret, Neil D. Martin, Ronald L. McGowan, H. William Strauss, Harry P. Wells, and M.D. Flamm, Jr.: Rest and exercise potassium-43 myocardial perfusion imaging for the noninvasive evaluation of aortocoronary bypass surgery. Circulation, Vol. XLIX, pages 688-695, April 1974.

(5) Neil D. Martin, Barry L. Zaret, Ronald L. McGowan, Harry P. Wells, Jr., and M.D. Flamm, Jr.: Rubidium-81, a new myocardial scanning agent: Noninvasive regional myocardial perfusion scans at rest and exercise, and comparison with potassium-43. Radiology, pages 651-656 June 1974.

(6) Martin, N.D., Zaret, B.L., Strauss, H.W., Wells, H.P., Albers, J.: Myocardial imaging using ^{43}K and the gamma camera. Radiology 112:446-448, Aug 1974.

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(8) McGowan, R.L., Welch, T.G., Zaret, B.L., Bryson, A.L., Martin, N.D., and Flamm, M.D. Noninvasive myocardial imaging with potassium-43 and rubidium-81 in patients with left bundle branch block. American Journal of Cardiology, October 1976.

(9) McGowan, R.L., Martin, N.D., Hall, R. R., Bryson, A.L., Zaret, B.L., Strauss, H.W. and Flamm, M.D.: The diagnostic accuracy of noninvasive myocardial imaging for coronary artery disease: An electrocardiographic and angiographic correlation. (Accepted with revision by the American Journal of Cardiology)

b. Data from various segments of clinical investigation proposals #389 and #499 presented at the following meetings.

(1) Fourth Annual Meeting of the Northern and Southern California Chapters, Society of Nuclear Medicine, San Francisco, California, September 1972.

(2) 45th Annual Scientific Session, The American Heart Association, Dallas, Texas, November 1972.

(3) Western Section, American Federation of Clinical Research, Carmel, California, February 1973.

(4) Annual Scientific Session of the Society of Nuclear Medicine, Miami, Florida, June 1973.

(5) 46th Annual Scientific Session of the American Heart Association, Atlantic City, New Jersey, November, 1973.

(6) Advances in Heart Disease 1974, American College of Cardiology, 6th Annual Symposium On Clinical Cardiology, San Francisco, California, December 1973.

(7) Institute of Medical Research of Pacific Medical Center, San Francisco, California, January 1974.

(8) Nuclear Medicine Institute, Cleveland, Ohio, January 1974.

(9) Seminars on "Myocardial Scanning With Potassium-43" have been presented by the David Grant USAF Medical Center staff at several university medical centers, both locally and throughout the country.

(10) 23rd Annual Scientific Session of the American College of Cardiology, New York City, February 1974.

(11) Society of Air Force Physicians (American College of Physicians Regional Meeting), March 1974.

(12) 47th Annual Scientific Session of the American Heart Association, Dallas, Texas, November 1974.

(13) 48th Annual Scientific Session of the American Heart Association, Anaheim, California, November 1973.

(14) Society of Air Force Physicians (ACP), San Antonio, Texas, February 1976.

5. This is an important new diagnostic test for the assessment of patients for coronary artery disease; clearly superior to standard ECG testing. The USAF in its effort to accurately screen personnel for the presence or absence of significant coronary artery disease should continue its efforts to perfect this noninvasive procedure and make it readily available for clinical applications.

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THE DIAGNOSTIC ACCURACY OF NONINVASIVE MYOCARDIAL IMAGING FOR CORONARY ARTERY DISEASE: AN ELECTROCARDIOGRAPHIC AND ANGIOGRAPHIC CORRELATION

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ABSTRACT

From 1972 through 1975, 781 noninvasive myocardial imaging studies were performed at rest and with exercise in 345 patients using potassium-43 and/or rubidium-81. The tracer was given intravenously at rest or after submaximal exercise on a motorized treadmill and the myocardium imaged in the anterior and left anterior oblique positions using a five inch rectilinear scanner or acintillation camera. Resultant images were interpreted by three observers unaware of the clinical data on each patient. One hundred-sixty of these patients had coronary angiography performed and were arbitrarily divided into those with coronary obstructions of 70% or greater (significant disease) or less than 70% obstructions (insignificant coronary artery disease) for the purposes of determining sensitivity and specificity of noninvasive myocardial imaging. In the 98 patients with angiographically significant coronary artery disease there were 81 positive imaging studies for a sensitivity of 83%. Fifty-one of the 62 patients with angiographically insignificant coronary artery disease had negative imaging studies for a specificity of 82%. Excluding those patients with myocardial infarction the sensitivity of myocardial imaging was 75%, while that of standard electrocardiographic exercise tolerance testing was 72%. In this group of patients the overall specificity of electrocardiographic testing was 50%. Utilizing a combination of myocardial imaging and exercise ECG testing resulted in a sensitivity of 92% in identifying significant coronary artery disease and 88% sensitivity in identifying angiographically significant coronary artery disease in non-infarcted vascular beds.

INTRODUCTION

Non-invasive myocardial imaging following the intravenous injection of radioactive tracers is becoming more frequently utilized as a procedure for the evaluation of patients for the presence or absence of coronary artery disease.[1-6] When patients are studied at rest a reduction in regional tracer activity in the resultant myocardial images corresponds to areas of fibrinous scar due to myocardial infarction and evidence for occlusive rather than obstructive coronary artery is obtained. When patients are exercised and radioactive tracers injected intravenously after the onset of angina pectoris, regions of decreased radioactivity in subsequent myocardial images identify ischemic vascular beds beyond hemodynamically significant coronary artery obstructions (Figure 1). Because of an extremely rapid myocardial extraction, a high intracellular accumulation, and a relatively short half life potassium-43 and rubidium-81 have been utilized for this purpose. Since 1972 we have used these agents to perform 781 imaging studies at rest and exercise on 345 patients. In order to evaluate the sensitivity and specificity of this technique in assessment of patients for coronary artery disease, noninvasive myocardial imaging was correlated with the electrocardiographic findings in the 160 of these patients studied angiographically.

METHODS

The results of myocardial imaging and stress electrocardiography were assessed in patients who were also studied angiographically as part of a clinical evaluation for coronary artery disease. Included in this study was a proportional finding of all patients evaluated angiographically at this medical center from September 1972 through October 1975. Patients

with left bundle branch block were excluded because of the unique imaging characteristics of these subjects reported elsewhere.[7] No correlations were attempted in patients who had prior aortocoronary bypass surgery. Stress electrocardiography was performed utilizing a maximal graded treadmill exercise test and continuous electrocardiographic monitoring with a standard multilead system. A positive exercise ECG test was established by flat or downsloping ST depression of 1 mm for at least 0.08 seconds on three or more consecutive beats. Abnormalities of the ST segment of T waves on the control electrocardiogram resulted in an equivocal interpretation of the exercise ECG and were considered negative for correlation purposes. Patients were exercised to the point of fatigue or chest pain, at which time one mCi of potassium or 2 mCi of rubidium-81 was injected intravenously. Exercise was continued for an additional 30 to 45 seconds after which the patient was promptly transported to the adjacent nuclear medicine laboratory where duplicate images were obtained in the anterior and 45° left anterior oblique positions using a standard rectilinear scanner with a 5 inch crystal and both 3 inch and 5 inch focused high energy collimators. Scintillation camera imaging was performed using a pin-hole collimator and a 3 mm insert to obtain unprocessed Polaroid scintiphotos. Additional lead shielding was utilized as previously described.[8] Detailed methodology concerning imaging techniques and dosimetry has been published elsewhere.[4,9] Rest images were obtained three to six days later following a 12 to 14 hour fast and standing for 10 - 15 minutes in the erect position to reduce gastric and hepatic tracer uptake and background interference. Interpretation of the resultant images was accomplished by three experienced observers in a blinded manner. Selective coronary cineangiography and left

ventriculography was performed by the brachial arteriotomy or percutaneous femoral artery approach, usually within two weeks of the imaging studies. Coronary arteriograms were filmed at 60 frames per second on 35 mm film using both the six and nine inch fields of a variable field image intensifier. Biplane left ventricular cineangiography was accomplished following the intracavitary injection of 45 cc of contrast medium over three seconds. Angiograms were reviewed by at least three staff cardiologists and an average luminal narrowing was obtained for each angiographic lesion. For purposes of this study an average luminal narrowing of 70% or greater was arbitrarily considered hemodynamically significant.[10] A diagnosis of myocardial infarction was accepted only when regional akinesis or dyskinesis was noted on left ventriculography in the distribution of a totally occluded coronary artery.

Angiographic interpretation resulted in five patient groups: Group I - normal coronary arteries, Group II - hemodynamic insignificant coronary artery disease, Group III - significant coronary artery disease without myocardial infarction, Group IV - significant coronary artery disease with myocardial infarction, and Group V - significant coronary artery disease with myocardial infarction plus additional coronary disease involving non-infarcted myocardium. (Table I)

Significant obstructive coronary artery disease was defined by a prior myocardial infarction, an angiographically significant coronary obstruction, or both. Those subjects not meeting these criteria were considered normal. Using these criteria the following formulae were utilized to determine the sensitivity and specificity of myocardial imaging and stress electrocardiography in identifying the presence of angiographically significant obstructive

coronary artery disease.

DECISION MATRIX

	Coronary Artery Disease	Normal
Positive test =	a	c
Negative test =	b	d

$$\text{Sensitivity} = \frac{a}{a+b}$$

$$\text{Specificity} = \frac{d}{c+d}$$

a = True positive results

b = False negative results

c = False positive results

d = True negative results

RESULTS

Myocardial Imaging:

Diagnostic studies were obtained in all patients and no untoward side effects were encountered in the course of this study. Patients fell into one of four categories based upon a comparison of the rest and exercise images: Normal homogeneous tracer distribution at rest and with exercise; normal images at rest and a regional defect with exercise; an abnormal defect at rest unchanged with exercise; and an abnormal image defect at rest but an additional regional defect observed when imaging with exercise. (Table II) Of the 50 patients with angiographically normal coronary arteries in Group I, eight had abnormal images with exercise and 42 were normal. There were 12 patients in Group II with angiographically insignificant coronary artery disease and of these, nine had negative and three had positive

studies with exercise. All Group I and II patients were normal when imaged at rest. Those 50 patients included in Group II had one, two or three vessels demonstrating obstructions of equal to or greater than 70% luminal narrowing without prior myocardial infarction. All were normal at rest but with exercise imaging 36 of the 50 were abnormal. Fifteen studies remained normal with exercise and were interpreted as negative for significant coronary artery disease. Twenty-four of the 27 Group IV patients with myocardial infarction had abnormal images which were unchanged when rest and exercise studies were compared. Three demonstrated normal studies at rest and with exercise. All 21 angiographic Group V patients with myocardial infarction and significant obstructive lesion(s) in noninfarcted bed(s) had abnormal images both at rest and with exercise in the area of infarction. Seventeen of these 21 patients had image defects with exercise additional to those regions of infarction demonstrated at rest. (Table III).

Using the specified formulae, the sensitivity and specificity in determining the presence or absence of angiographically significant coronary artery disease was analyzed. The overall sensitivity in identifying significant coronary disease was 83% (81/81+17) and the specificity in excluding coronary artery disease was 82% (51/51+11). The greatest diagnostic accuracy (94%) was in identifying a prior myocardial infarction (Groups IV and V) and the test was least accurate (72%) in identifying patients with coronary obstructions of greater or equal to 70% luminal narrowing without prior myocardial infarction (Group III). The sensitivity in determining the presence of additional regions of ischemia in patients with prior myocardial infarction was 81% (Group V) and when combined with those patients with coronary obstructions without infarction, the sensitivity in identifying coronary

luminal narrowings greater than or equal to 70% in noninfarcted vascular beds by noninvasive myocardial imaging was 75% (Groups III and V). Noninfarcted vascular beds with angiographic obstructions of greater than or equal to 70% in the 71 Group III and V patients numbered 127. Of these, 41% were correctly localized by imaging with the greatest accuracy in identifying left circumflex lesions. Regions of myocardial infarction of the 48 patients in Groups IV and V were correctly localized in 85%.

Of singular importance are nine patients from Group III with stable angina pectoris subjected to one rest and four exercise studies over a 13 week period. Total defect areas were outlined and planed in a blinded manner to assess the reproducibility of results in repetitive studies performed on each individual patient. Analysis was confined to the left anterior oblique image where the average central cavity defect area at rest was 11.35cm^2. After exercise the defects enlarged incorporating an exercise induced area with the central cavity for an average total defect area of 21.87cm^2 or an average 92% change from rest to exercise. Subjecting this data to two way analysis of variance, it was found that the experimental error (chance) was 10%, the variance between patients studied was 87%, and the percent of total variance observed between exercise studies on each individual was 3%. (Table IV).

Camera Imaging:

Because of the thin crystal and resultant poorer detection efficiency when using higher energy photons, the feasibility of using ^{81}Rb and ^{43}K with the scintillation camera was tested in 27 of the 160 patients in this study. Previous work revealed that a high energy parallel hole collimator was unsatisfactory because of lateral penetration, but that satisfactory

images could be obtained using a pin-hole collimator which was in turn provided with additional lead shielding. (Figure 2)

Eight of the 27 patients had normal coronaries and seven were correctly identified as normal using the scintillation camera. The two angiographic Group II patients also had normal images at rest and with exercise. Two patients from Group V were correctly identified as having had a prior myocardial infarction and an additional region of stress induced ischemia. The two Group IV patients demonstrated a region of infarction but no additional stress induced defects. Images obtained on 12 of the 13 patients from Group III correlated with the angiographic findings with only one false negative result. The capability of obtaining diagnostic scintiphotos without contrast enhancement is demonstrated by the results on these 27 patients and diagnostic accuracy was comparable to imaging these same patients with the scanner. We continue to prefer the scanner because the contrast enhancement has made image interpretation easier and more consistent and the additional lead shielding required for satisfactory camera imaging with these agents has been cumbersome.

Electrocardiography:

Four electrocardiographic groups comparable to the four imaging groups can be identified: a normal resting electrocardiogram with no significant ST changes with exercise, a normal resting electrocardiogram with significant exercise induced ST changes, an electrocardiogram with diagnostic Q waves at rest and no ST changes with exercise, and Q waves at rest but the additional development of ST changes with exercise. Equivocal or non-diagnostic electrocardiographic alterations were considered negative for purposes of this study. (Table II). Applying the same criteria for sensitivity and

specificity to electrocardiographic interpretation, the overall sensitivy in identifying significant coronary artery disease was 80%. The specificity of the electrocardiogram in excluding significant coronary artery disease, a normal resting twelve lead electrocardiogram and the absence of exercise induced ST abnormalities was 50%. As with imaging, the greatest electrocardiographic accuracy (94%) was in identifying the presence of a myocardial infarction (Groups VI and V) and was least accurate (66%) in identifying coronary obstructions in the absence of a prior myocardial infarction. (Group III). The sensitivity in determining the presence of ischemia in patients with prior infarction was 86% and when these patients were combined with those with ischemia but no prior infarction, the sensitivity in identifying coronary artery narrowings of greater or equal to 70% by stress electrocardiographic testing was 72%. (Table V).

Combined Studies:

Although the sensitivity achieved using either myocardial imaging or electrocardiographic testing was comparable, the electrocardiographic standards required to obtain this degree of sensitivity resulted in a low specificity. On the other hand, imaging standards resulted in a specificity commensurate with its sensitivity. Since imaging with exercise was performed in conjunction with a stress electrocardiogram, these tests were assessed for a possible complementary value in the identification of coronary artery disease in patients. Using an abnormal exercise image or stress electrocardiogram as a positive test and requiring both the exercise images and stress electrocardiogram to be normal for an interpretation of negativity, we found an 88% sensitivity in the identification of coronary occlusive disease of greater or equal to 70% in non-infarcted vascular beds (Groups III and V). A sensitivity of 97% in the identification of myocardial

infarction was obtained when either abnormal rest scans or classic Q waves on the resting ECG were utilized (Groups IV and V). The overall sensitivity in identifying significant coronary artery disease was 92%, but because of the number of false positive stress electrocardiograms, the specificity of 45% was little different from that of exercise tolerance testing alone in identifying patients with coronary artery disease. (Table VI).

DISCUSSION

We have attempted to demonstrate the sensitivity and specificity of myocardial imaging at rest and with exercise in the identification of hemodynamically significant coronary artery disease. Although the degree of anatomical luminal narrowing as determined by coronary angiography is imperfect in the quantitative assessment of myocardial perfusion, it is presently the most acceptable standard available. Realizing that defining a greater or equal to 70% angiographic luminal narrowing of a coronary artery as hemodynamically significant is arbitrary, we have used this standard as the most likely to be accepted. Out of interest, we did identify those patients with coronary lesions of approximately 50% as a separate group, but for purposes of this study they were included with patients considered to be angiographically normal. The angiographic standard is also defined on the basis of a clinical assessment rather than a precise measurement of luminal narrowing in multiple planes. It is also understood that in assessing coronary artery disease the angiogram defines an anatomic alteration. Myocardial imaging with the tracers utilized in this study are primarily dependent upon changes in cellular physiology secondary to ischemia. This is also the case with stress induced electrocardiographic abnormalities

where a physiologic alteration in myocardial cell membrane potential resulting from myocardial ischemia is used to identify the presence of hemodynamically significant coronary artery disease. We propose the use of noninvasive imaging as an objective screening test for identifying significant coronary artery disease, confirming suspected myocardial infarction, following patients subjected to saphenous vein bypass surgery, and evaluating the long term disease process in patients with established coronary artery disease. The sensitivity and specificity of this technique are quite good and clearly superior to any other presently available noninvasive tests for the purposes noted above. The reproducibility has been excellent in the small number of patients subjected to multiple studies using identical techniques. The additional benefit of localizing the involved vascular beds has at times been helpful, but the accuracy in localizing and quantitating obstructive lesions has been disappointing. In December 1973 rubidium-81 was substituted for potassium-43 as our primary imaging agent and concurrently a five inch focused high energy collimator was substituted for the previously utilized three inch high energy focused collimator for imaging in the left anterior oblique projection. These changes in technique and radionuclide improved the overall sensitivity from 80% to 90%. This improvement is significant since the earlier studies were more likely to be performed on patients with well defined disease in order to establish the accuracy of the technique. Later tests were performed for diagnostic purposes as part of the clinical evaluation of patients when the presence or absence of significant coronary artery disease was in question. Of considerable importance is that the number of coronary angiographic studies for diagnostic purposes have been reduced since myocardial imaging has been

made a readily available clinical test in our medical center. Preliminary reports by others on the use of rubidium-81 [11] and thallium-201,[12] utilizing the scintillation camera have shown equally satisfactory results. The further development of more ideal myocardial imaging agents hopefully would permit even greater sensitivity and specificity in the clinical assessment of patients for coronary artery disease.

Noninvasive myocardial imaging is safe, with no untoward side effects and a low radiation dose. The overall sensitivity has been quite good at 83% and comparable to the 80% sensitivity using electrocardiographic testing. The specificity associated with these comparable sensitivities was 82% for myocardial imaging but only 50% when relying upon the electrocardiogram alone. The sensitivity in identifying significant coronary artery disease when combining the results of noninvasive myocardial imaging with electrocardiographic findings was 88% but the frequent occurrence of false-positive stress electrocardiographic tests held the specificity to less than 50% when combining results. Recent changes in technique have improved the diagnostic accuracy of noninvasive myocardial imaging and newer tracers promise to make the procedure more readily available.

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LEGEND

Figure 1. Rubidium-81 myocardial scans obtained at rest (upper panels) and after exercise to angina pectoris (lower panels). The central defect noted at rest in both positions is somewhat more well defined than usual. The extensive posterolateral defect seen after exercise is consistent with the 90% proximal obstruction of the circumflex artery demonstrated by coronary angiography.

Figure 2. Rubidium-81 scintillation camera images recorded on Polaroid film (upper panels) and exercise (lower panels) in a patient with severe angina pectoris. The central defect corresponding to the left ventricular cavity in both views at rest is typical of that seen in normal camera images. With angina pectoris a large anterior defect is noted in both the anterior and the left anterior oblique positions. Coronary arteriograms revealed a subtotal obstruction of the proximal left anterior descending artery commensurate with these findings.

TABLE I

ANGIOGRAPHIC PATIENT GROUPS

GROUP I	NORMAL CORONARY ARTERIES	50
GROUP II	CORONARY NARROWING < 70%	12
GROUP III	CORONARY OBSTRUCTION(S) ≥ 70% WITHOUT MYOCARDIAL INFARCTION	50
GROUP IV	MYOCARDIAL INFARCTION WITHOUT ADDITIONAL CORONARY OBSTRUCTION(S) ≥ 70%	27
GROUP V	MYOCARDIAL INFARCTION WITH ADDITIONAL CORONARY OBSTRUCTION(S) ≥ 70%	21

TABLE II

COMPARATIVE INTERPRETATION
OF REST AND EXERCISE STUDIES

IMAGING		ECG		INTERPRETATION
REST	EXERCISE	REST	EXERCISE	
NORMAL	NORMAL	NORMAL	NORMAL	NO SIGNIFICANT OBSTRUCTIVE CAD
NORMAL	ABNORMAL	NORMAL	ST ABNORMALITY	STRESS INDUCED MYOCARDIAL ISCHEMIA
ABNORMAL	ABNORMAL	ABNORMAL Q'S	ABNORMAL Q'S	MYOCARDIAL INFARCTION
ABNORMAL	ABNORMAL WITH ADDITIONAL REGIONAL DEFECT(S)	ABNORMAL Q'S	ABNORMAL Q'S WITH ADDITIONAL ST ABNORMALITY	MYOCARDIAL INFARCTION WITH AREA(S) OF STRESS INDUCED MYOCARDIAL ISCHEMIA

TABLE III

RESULTS OF MYOCARDIAL IMAGING
IN TERMS OF ANGIOGRAPHIC FINDINGS

	ANGIOGRAPHIC* GROUP	NO. OF PATIENTS IN GROUP	POSITIVE STUDIES	NEGATIVE STUDIES
Non-Disease	I	50	8	42
	II	12	3	9
Disease	III	50	36	14
	IV	27	24	3
	V	21	21	0

* Angiographic groups, disease, and non-disease are defined in "Methods". Positive studies with rest and/or exercise images interpreted as abnormal. Negative studies = rest and exercise images interpreted as normal.

TABLE IV

REPRODUCIBILITY OF
EXERCISE INDUCED IMAGE DEFECTS,
PLANED AREA AND TWO WAY ANALYSIS OF VARIANCE

NUMBER OF SUBJECTS STUDIED	9
STUDIES PERFORMED PER PATIENT	1 REST 4 EXERCISE
AVERAGE REST DEFECT AREA	11.35cm^2
AVERAGE EXERCISE DEFECT AREA	21.87cm^2
AVERAGE CHANGE REST TO EXERCISE	92% (p .001)
VARIANCE BETWEEN SUBJECTS	87% *
VARIANCE BETWEEN STUDIES	3% *
EXPERIMENTAL ERROR (CHANCE)	10% *

* Percent of total variance observed in exercise studies in 9 patients.

TABLE V

RESULTS OF ELECTROCARDIOGRAPHIC INTERPRETATION IN TERMS OF ANGIOGRAPHIC FINDINGS

	ANGIOGRAPHIC* GROUP	NO. OF PATIENTS IN GROUP	POSITIVE STUDIES	NEGATIVE STUDIES
Non-Disease	I	50	26	24
	II	12	5	7
Disease	III	50	33	17
	IV	27	25	2
	V	21	20	1

* Angiographic groups, disease, and non-disease are defined in "Methods". Positive studies = 12 lead rest ECG and/or exercise ECG abnormal. Negative studies = ECG normal at rest and with exercise.

TABLE VI

COMPARISON OF ECG TESTING (ECG)
WITH NON-INVASIVE MYOCARDIAL IMAGING (NIMI)
IN IDENTIFYING ANGIOGRAPHICALLY INSIGNIFICANT
CORONARY ARTERY DISEASE

TEST	SENSITIVITY (MI Only)	SENSITIVITY (Excl. MI)	SENSITIVITY (Overall)	SPECIFICITY (Overall)
NIMI	94%	75%	83%	82%
ECG	94%	72%	80%	50%
NIMI + ECG	97%	88%	92%	45%

NIMI = Non-invasive myocardial imaging at rest and with exercise.
ECG = Electrocardiography at rest and with stress testing.
MI = Myocardial infarction.

NONINVASIVE MYOCARDIAL IMAGING WITH POTASSIUM-43 AND RUBIDIUM-81 IN PATIENTS WITH LEFT BUNDLE BRANCH BLOCK

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ABSTRACT

Noninvasive myocardial imaging with potassium-43 and rubidium-81 has been used successfully to identify areas of infarction and exercise induced ischemia as regions of decreased radioactivity. These image defects are felt to be due to a lack of isotope uptake by the scar of myocardial infarction or impaired tracer accumulation in ischemic vascular beds. Of 27 patients with left bundle branch block studied with noninvasive imaging at rest and exercise, 23 demonstrated reduced radioactivity at rest in the region of the intraventricular septum similar to the pattern seen with anteroseptal myocardial infarction. Clinically, only two of these patients had evidence for an antecedent myocardial infarction. Of the 23 patients without clinical evidence for coronary artery disease, 14 were studied angiographically. Eleven patients had normal coronary arteries, two had hemodynamically insignificant atherosclerotic lesions and one demonstrated a significantly obstructed left circumflex artery. Two additional left bundle branch block patients had clinical evidence for coronary artery disease confirmed angiographically. Although resting anteroseptal defects were routinely demonstrated in patients with left bundle branch block, a larger, more distinct defect with exercise correctly identified the presence of significant coronary artery disease. In the clinical application of noninvasive myocardial imaging, these rest image defects can lead to the false-positive interpretation of anteroseptal myocardial infarction. An increase in defect definition and size with exercise imaging suggests associated coronary obstructive disease.

Bundle Branch Block | Myocardial Imaging | Rubidium-81

Coronary Angiography | Potassium-43

INTRODUCTION

Although coronary artery disease and hypertension were formerly considered to be the most frequent causes of left bundle branch block,[1,2] recent evidence suggests caution in the diagnosis of coronary atherosclerosis on the basis of this electrocardiographic finding alone.[3] Not only have other etiologies been associated with this conduction disturbance, but it has frequently been found in subjects with no anatomic cardiac disease.[3-7] In addition, recent data also suggests that in the absence of angiographically demonstrable coronary artery disease, morbidity and mortality in left bundle branch block patients is no different than in a general age matched population.[8-9] It is important, therefore, to separate left bundle branch block associated with coronary artery disease from that resulting from other less compromising causes. Unfortunately, in this conduction disturbance, the QRS abnormalities interfere with the recognition of most infarction patterns, and the associated ST-T wave abnormalities preclude the identification of those stress induced electrocardiographic changes usually considered diagnostic of coronary artery disease. Coronary angiography has usually been required to establish or exclude an atherosclerotic etiology for left bundle branch block.

We have utilized noninvasive myocardial imaging with potassium-43 or rubidium-81 in the evaluation of more than 400 patients with coronary artery disease and have demonstrated that this technique is successful in the identification of myocardial infarction and ischemia.[10-13] When patients with angina pectoris and normal conduction are studied at rest, rubidium-81 and potassium-43 accumulation is homogeneous and myocardial images are normal. During exercise induced angina pectoris a relative reduction in both

myocardial cation uptake and tracer delivery may occur in vascular beds supplied by obstructed coronary arteries and a regional image defect may define the ischemic vascular bed (Figure 1). Normal patients and those with hemodynamically insignificant coronary lesions manifest normal images both at rest and exercise (Figure 2). In patients with myocardial infarction, coronary occlusion impairs isotope delivery and uptake is minimal by the physiologically inert scar. The resultant image defects conform to the area of infarction with little or no change noted when comparing rest and exercise studies on the same patient (Figure 3). Because of these favorable results in the study of patients with coronary artery disease, this technique was applied to the evaluation of 27 patients with left bundle branch block in an attempt to establish the presence or absence of coronary artery disease without resorting to coronary angiography.

METHODS

Myocardial imaging was performed on 27 patients with documented left bundle branch block evaluated between December 1973 and May 1975. Electrocardiographic criteria were those of the New York Heart Association. The clinical characteristics of these patients with left bundle branch block, as well as their angiographic data when obtained, are described in Table I. Patient age ranged from 18 to 57 years. Eighteen patients were males and nine were females. In eight patients left bundle branch block was intermittent, of which three were heart rate related. Five patients were experiencing chest pain, however, only one was felt to have angina pectoris. Two had sustained a well documented myocardial infarction. Four patients manifested arrhythmias; two demonstrated paroxysmal supraventricular tachycardia and two had exercise induced ventricular ectopy. Three left bundle branch block patients demonstrated the auscultatory and echocardiographic

findings of mitral valve prolapse. The remaining 13 patients were free from any clinical suggestion of organic heart disease. None of the 27 patients were known to have been hypertensive. During the same period of time 20 patients with electrocardiographic conduction abnormalities other than left bundle branch block were similarly studied with myocardial imaging. These control subjects included nine patients with right bundle branch block, eight patients with the Wolff-Parkinson-White pre-excitation syndrome, and three patients with left anterior hemiblock. Except for the two right bundle branch block patients with non-anginal chest pain and the two Wolff-Parkinson-White patients with documented paroxysmal tachycardia, this group of 20 subjects were asymptomatic and had no evidence to suggest clinically significant heart disease.

All 47 patients were evaluated by noninvasive myocardial imaging at rest and after maximal exercise on a motorized treadmill using either rubidium-81 or potassium-43 as the radioactive tracer. Utilizing a graded maximal treadmill protocol, patients were exercised to an end-point of fatigue or well established chest pain at which time 1.0 mCi of potassium-43 or 2.0 mCi of rubidium-81 was injected intravenously. Exercise was continued for an additional 30-45 seconds after which the patient was promptly transported to the adjacent nuclear medicine laboratory where duplicate images were obtained in the anterior and 45° left anterior oblique positions using a rectilinear scanner (Picker Magnascanner 500 with a five inch crystal) and both three inch and five inch focused high energy collimators. Rest images were obtained three to six days later following a 12-14 hour fast and standing 10 minutes in the erect position to reduce gastrointestinal and hepatic tracer uptake. Initial interpretation of the resultant images

was accomplished by at least two of the authors who were not present at the time of imaging and were not aware of the clinical diagnosis or laboratory findings of the patients.

Sixteen of the 27 left bundle branch block patients and the two right bundle branch block patients with chest pain underwent selective coronary cineangiography and left ventriculography by the brachial arteriotomy or percutaneous femoral artery approach. Coronary arteriograms were filmed at 60 frames/second on 35 mm film using both the six and nine inch fields of a variable field image intensifier. Biplane left ventricular cineangiography was performed in all patients following the intracavitary injection of 45 cc of contrast medium over three seconds. Angiograms were independently reviewed by three of the authors.

Four left bundle branch block patients with angiographically normal coronary arteries were studied by myocardial perfusion imaging with technetium-99m labeled particles injected directly into the coronary circulation according to the technique of Ashburn, et al.[14] The bolus of particles was injected immediately following an injection of 0.5 - 1.0 cc contrast material to assure an accurate intracoronary delivery of tracer.

RESULTS

Of the 16 left bundle branch block patients subjected to selective coronary angiography, 11 presented no clinical evidence of atherosclerotic heart disease and had angiographically normal coronary arteries and left ventricles. Two left bundle branch block patients without historical or laboratory evidence of cardiovascular disease demonstrated angiographically insignificant coronary artery disease and normal biplane left ventriculograms. Three patients with left bundle branch block demonstrated severe obstructive lesions on angiography, two of whom had significant obstruction

of the left anterior descending artery. Of these patients one was asymptomatic, one manifested classic angina pectoris, and the third developed paroxysmal ventricular tachycardia on exercise. None of the three had evidence for myocardial infarction. Selective coronary angiography and left ventriculography on the two right bundle branch block patients so studied were normal.

In 23 of 27 patients with left bundle branch block, potassium-43 or rubidium-81 rest imaging demonstrated decreased septal cation uptake consistent with anteroseptal myocardial infarction. The abnormality was present irrespective of the presence or absence of coronary artery disease. In subjects with intermittent or rate related left bundle branch block, these image defects were demonstrated whether or not the electrocardiographic conduction disturbance was present at the time of study. (Figure 4). The eleven patients with angiographically normal coronary arteries and seven patients without clinical evidence for coronary artery disease manifest anteroseptal defects at rest. When these eighteen subjects were studied with exercise, six had normal images, seven were equivocal and five were less well defined than at rest (Figure 5). Patient two was equivocal at rest and normal with exercise, while patient twenty was normal both at rest and with exercise. These were the only two subjects in which a resting anteroseptal defect was not observed.

The two asymptomatic patients who had developed left bundle branch block in conjunction with an anterior myocardial infarction were not subjected to coronary angiography. Each demonstrated the typical image defect associated with an anterior myocardial scar but also seen in patients with left bundle branch block in the absence of infarction. Both patients

when studied with exercise developed a more distinct anteroseptal defect but no significant change in the area of the defect was observed when comparing these images with those obtained at rest. The results of the rest to exercise comparison in these two patients was clearly different from the results observed in the twenty comparison studies above. (Figure 6).

Three left bundle branch block patients with severe obstructive coronary artery disease without a prior myocardial infarction demonstrated the usual image defects of left bundle branch block at rest. With exercise, patient four who had a significant obstructive disease of the left anterior descending artery manifest an increased area and more clear definition of the anteroseptal defect. Patient six with significant obstructive disease of the circumflex marginal artery manifest a posterolateral defect with exercise, while the high septal defect seen at rest was no longer identified. In the presence of three vessel disease (patient sixteen), exercise images demonstrated an extensive anteroseptal defect as well as an inferior defect. Only a small anteroseptal defect had been present at rest. (Figure 7). Two asymptomatic patients with hemodynamically insignificant coronary artery disease by angiography (obstruction < 50%) also demonstrated anteroseptal defects at rest, less pronounced with exercise, similar to findings on left bundle branch block patients with normal coronaries. Subsequent to a traumatic death resulting from a head injury, one of these latter patients was subjected to postmortem examination. Meticulous gross and microscopic examination of the heart found the interventricular septum to be normal without evidence of circulatory, microcirculatory or fibrotic disease sufficient to cause either the conduction abnormality or the image defect previously manifest in this patient.

All four patients with left bundle branch block and angiographically normal coronary arteries subjected to imaging after selective right and left intracoronary injections of technetium-99m labeled microspheres demonstrated a homogeneous distribution of radioactive particles throughout the septal myocardium in contrast to the abnormal anteroseptal uptake noted when imaging these same patients with either rubidium-81 or potassium-43. (Figure 8). The 20 patients with conduction disturbances other than left bundle branch block (right bundle branch block, Wolff-Parkinson-White, left anterior hemiblock), when studied noninvasively with rubidium-81 or potassium-43, had normal images at rest and with exercise. (Figure 2).

DISCUSSION

The etiologies of left bundle branch block have been reported to be coronary artery disease, hypertension, valvular heart disease and cardiomyopathy in the majority of instances.[1,2,6,7,16] In addition, congenital heart disease,[2] a "primary" sclero-degenerative process,[17,18,19] myocarditis,[16] and congenital left bundle branch block,[20,21] have also been documented as etiologies.

The early reports on left bundle branch block etiology showed arteriosclerotic heart disease to be present in 35% to 68% of the patients,[1,2] but a number of early case reports[3-5] documented that left bundle branch block could occur in the absence of heart disease. Pathologic studies in patients with left bundle branch block also were reported as showing localized fibrosis of bundle branches in the absence of obstructive coronary artery disease.[17,18,19] Lewis, et al.,[6] reported on 12 patients with left bundle branch block eight of whom had normal coronary angiograms. Haft, et al.,[7] described angiographic data on 24 patients with left bundle branch block, of whom seven had severe coronary disease, while the remainder had angiographically normal coronary arteries. In addition, the prognosis of patients

with left bundle branch block without any demonstrable cardiovascular disease has been excellent, as shown by the study of Lewis, et al.,[6] and other epidemiologic studies.[1,2,8,9] Interestingly, although the etiologic factors in both transient and fixed forms of left bundle branch block were thought to be the same, in the study of Lewis, et al. the patients with the transient form of block were equally divided between those with significant coronary disease and those without.

Of our 27 patients with left bundle branch block, eleven had angiographically normal coronary arteries and all but five were free of any clinical evidence of significant coronary atherosclerosis. Although three have been diagnosed clinically as having mitral valve prolapse, none of the patients with left bundle branch block had rheumatic valvular heart disease or congenital heart disease. None of the 27 had a history to support a diagnosis of hypertension or myocarditis. The absence of x-ray evidence for left ventricular hypertrophy, the lack of clinical data to suggest cardiac decompensation and, when performed, normal left ventricular performance by left ventricular end diastolic pressure and angiography, precludes the presence of any significant degree of cardiomyopathy. The pathologic examination of the single patient coming to autopsy did not find small vessel disease of the left ventricle and no fibrotic replacement of the myocardium was identified.

Regardless of the presence or absence of coronary artery disease, patients with left bundle branch block demonstrate image defects at rest similar to those seen in patients with anterior myocardial infarction. Although the definition of this anteroseptal defect has been variable, the abnormalities other than left bundle branch block have not demonstrated any

regional image defects. Thus left bundle branch block must be added to the list of conditions which can produce false-positive myocardial images.

Of equal clinical relevance is the ability to identify the presence of significant obstructive coronary artery disease in patients with left bundle branch block by comparing the rest and exercise images on each patient studied. There is a clear increase in defect definition with exercise imaging in patients with left bundle branch block and obstructive coronary artery disease. In addition, left bundle branch block patients with significantly obstructed coronary arteries supplying non-infarcted vascular beds demonstrate an increase in the defect area appropriate to the distribution of the obstructed vessel. Images obtained on patients with left bundle branch block in the absence of coronary obstructive disease typically show an abnormal septal uptake of tracer at rest which is less well defined or even normal with exercise. To date we have seen this tendency to normalize a rest defect with exercise only in patients with left bundle branch block and normal coronaries.

Comparative myocardial imaging with intracoronary tracer labeled particles and intravenous rubidium-81 and potassium-43 has demonstrated excellent correlation of these techniques in the identification of patients with normal and abnormal coronary circulation. Although performed in only four of the patients with normal coronaries and left bundle branch block, imaging after selective right and left intracoronary injections of technetium-99m labeled microspheres demonstrated a homogeneous distribution of particles in contrast to the abnormal anteroseptal tracer uptake noted when imaging noninvasively with rubidium-81 and potassium-43 in these same patients. Unlike technetium-99m microspheres, rubidium-81 and potassium-43 are physiologically active and regional tracer accumulation is dependent upon the

functional integrity of the myocardial cell membrane. The results of this study allow us to theorize that the defects noted with noninvasive imaging of subjects with left bundle branch block are not the result of impaired perfusion, but rather a cellular abnormality resulting in the altered intracellular accumulation of monovalent cations.

Wackers, et al.,[15] reported that nine patients with left bundle branch block, but without evidence for acute myocardial infarction, had normal scintiscans with thallium-201, while those left bundle branch block patients with acute myocardial infarction manifest defects which localized the region of myocardial damage. One can only speculate as to the reason for normal images in left bundle branch block patients when using thallium-201. Perhaps the difference in technique was sufficient to disallow identification of the anteroseptal defects so consistently demonstrated with potassium-43 and rubidium-81 at rest. It is attractive, however, to hypothesize a physiological difference between thallium-201 and the tracers utilized in this study. If true, this would support the theory that left bundle branch block image defects observed when potassium-43 and rubidium-81 are used as tracers originates at the cellular level.

In summary, 22 of this series of 27 patients with left bundle branch block did not have any of those conditions considered to be responsible for the conduction disturbance and most would be classified as idiopathic. In performing noninvasive myocardial imaging with rubidium-81 and potassium-43 on these patients with left bundle branch block, we have found that anteroseptal image defects at rest not observed in normal subjects or in patients with other selected conduction abnormalities, are routinely demonstrable regardless of the presence of absence of organic heart disease. These image

defects can lead to the false-positive interpretation of anteroseptal myocardial infarction and only the demonstration of larger or more distinct regions of reduced tracer uptake with exercise can correctly identify the presence of obstructive coronary artery disease. In addition, this abnormal uptake of physiologically active radionuclides in the region of the ventricular septum suggests a cellular metabolic abnormality which may in some way be responsible for the conduction disturbance in left bundle branch block.

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LEGEND

Figure 1. These images demonstrate the rubidium-81 findings on a patient with angina pectoris resulting from an isolated 90% obstruction of the left anterior descending artery. The rest images (upper panels) are normal but after exercise to angina pectoris the images (lower panels) demonstrate reduced tracer activity in the anteroseptal region in the left anterior oblique projection. This defect is not defined in the anterior projection. This patient had no electrocardiographic conduction disturbance.

Figure 2. This patient with right bundle branch block (RBBB) and angiographically normal coronary arteries demonstrates a homogeneous distribution of rubidium-81 throughout the myocardium The myocardial images are normal both at rest and exercise

Figure 3. Rest and exercise potassium-43 images obtained on this asymptomatic patient with a remote anteroseptal myocardial infarction demonstrate this abnormality as a region of reduced tracer activity. This anteroseptal defect is somewhat more well defined with exercise. The patient did not manife t any form of bundle branch block.

Figure 4. Myocardial images obtained at rest on patient twenty-six in the anterior (ANT) and left anterior oblique (LAO) projections with the patient in left bundle branch block (LBBB) upper panels, and normal conduction, lower panels. The same anteroseptal defect is noted whether the conduction disturbance is present or not when imaged noninvasively with rubidium-81.

Figure 5. Rest and exercise myocardial scans in the anterior (ANT) and left anterior oblique projections (LAO) in a patient with left bundle branch block (LBBB). These images obtained on patient eleven utilizing potassium-43 demonstrate the typical anteroseptal defect associated with this conduction disturbance. Note that the defect is more prominent at rest than with exercise.

Figure 6. Myocardial images obtained at rest and with exercise on patient 9. This patient had developed left bundle branch block (LBBB) in conjunction with a remote (location) myocardial infarction. Like patients with myocardial infarction but without left bundle branch block (Figure 3) the defect observed at rest is more clearly defined with exercise.

Figure 7. Patient sixteen with left bundle branch block (LBBB) and angina pectoris was imaged at rest (upper panels) and exercise (lower panels). The rest scans show the anteroseptal defect typical of LBBB but with exercise to angina pectoris an additional inferior wall defect is observed. These scans demonstrate how significant coronary artery disease can be identified in the presence of the LBBB associated image defect.

Figure 8. Patient eighteen was imaged after an intracoronary injection of technetium-99m labeled microspheres. A left anterior oblique (LAO) microsphere scan is shown (left panel) in comparision with an LAO scanner image obtained on this same patient noninvasively with potassium-43.

TABLE I

LEFT BUNDLE BRANCH BLOCK PATIENTS IMAGED WITH RUBIDIUM-81 AND POTASSIUM-4

PATIENT	AGE	SEX	ECG	CLINICAL CARDIOVASCULAR STATUS	ANGIOGRAPHI FINDINGS
1 JA	47	F	Int LBBB	Normal	-
2 RA	31	M	Int LBBB	Normal	Normal
3 DA	46	F	LBBB	Barlow's Syndrome	Normal
4 RC	39	M	Int LBBB	Exercise Induced Ventricular Tachycardia	80% LAD Obs
5 CC	57	M	LBBB, Q's in lateral leads	Post-myocardial infarction	-
6 JG	52	M	LBBB	Normal	90% LCA and LAD Obst.
7 LJ	26	F	Int LBBB	Normal	Normal
8 CH	39	M	LBBB	Normal	Normal
9 KH	44	M	LBBB, Long PR interval	Post-myocardial infarction	-
10 GH	37	M	LBBB	Normal	50% LCA and LAD Obst.
11 CH	48	F	LBBB	Barlow's syndrome/PAT	Normal
12 JK	42	M	LBBB	Barlow's Syndrome/PVC's	Normal
13 BK	39	M	LBBB	Normal	-
14 BM	35	F	LBBB	Normal	-
15 JM	38	M	LBBB	Normal	Normal
16 BM	55	M	LBBB	Angina Pectoris	90% LAD, 75% 85% RCA Obst
17 MO	42	F	LBBB	Normal	Normal
18 WP	50	M	LBBB, Long PR interval	Normal	Normal
19 AP	15	M	Int LBBB	Normal	Normal
20 AP	18	M	Int LBBB	Paroxysmal atrial fibrillation	-

TABLE I (Cont'd)

PATIENT	AGE	SEX	ECG	CLINICAL CARDIOVASCULAR STATUS	ANGIOGRAPHIC FINDINGS
21 MP	25	M	LBBB	Normal	Normal
22 FB	46	M	Int LBBB	Normal	50% Obst. 1st diagonal branch of LAD
23 MT	44	F	LBBB	Normal	-
24 JW	33	M	LBBB	Normal	-
25 BW	39	F	LBBB	Normal	-
26 JW	50	M	Int LBBB	Normal	Normal
27 BW	49	F	LBBB	Normal	-

Int LBBB = Intermittent left bundle branch block

LAD = Left anterior descending coronary artery

LBBB = Non-intermittent left bundle branch block

LCA = Left circumflex coronary artery

OBST = Obstruction

PAT = Paroxysmal atrial tachycardia

PVCS = Premature ventricular contractions

RCA = Right coronary artery