Assessment of diagnostic value of technetium-99m pyrophosphate myocardial scintigraphy in 80 patients with possible acute myocardial infarction

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The diagnostic value of technetium-99m-pyrophosphate (Tc-pyrophosphate) myocardial scintigraphy was determined in 80 consecutive patients who had been admitted to the coronary care unit in order to rule out an acute myocardial infarction. Scintigraphic findings obtained within 5 days of admission were correlated with the final cardiac diagnosis determined for each patient.

Significant myocardial uptake of Tc-pyrophosphate (positive scans) occurred in 13 of 22 patients (59%) who had enzyme and/or electrocardiographic proven acute myocardial infarction: 3 out of 5 with transmural myocardial infarct, 9 of 16 with nontransmural myocardial infarct, and 1 patient with left bundle-branch block. Of 58 patients who showed no evidence of acute myocardial infarction, positive scans occurred in 14 of 33 patients who had unstable angina pectoris (43%), 0 of 6 who had congestive heart failure, 6 of 9 who had other acute cardiac syndromes, and in 0 of 10 who had noncardiac chest pain. In the patients with unstable angina pectoris positive scans could not be predicted on the basis of the history, electrocardiographic findings, or the arteriographically determined severity of the coronary artery disease. Blood levels of Tc-99m activity measured in 21 cardiac patients and in 6 volunteers did not correlate with the uptake intensity of Tc-pyrophosphate. These findings suggest caution in the use of this imaging method for the diagnosis of acute myocardial infarct in patients admitted with ‘rule out myocardial infarction’.

In 1973 technetium-99m pyrophosphate myocardial scintigraphy was introduced by Bonte and co-workers as a noninvasive method of visualising acute myocardial infarction (Bonte et al., 1974; Parkey et al., 1974). Since that time there have been a number of clinical and experimental studies which have confirmed the uptake of labelled pyrophosphate by acutely infarcted myocardium (Fink/Bennett et al., 1974; Bonte et al., 1975; Buja et al., 1975; Willerson et al., 1975a). These studies suggest that myocardial imaging using Tc-pyrophosphate may be of value in the investigation of patients admitted to the coronary care unit in whom the diagnosis of acute myocardial infarction is uncertain.

Subjects and methods

Patient population

Eighty patients (mean ages: men 50 years, women 30 years, whole group 57 years), who had been admitted to the coronary care unit (CCU) in order to rule out an acute myocardial infarction, were investigated. Seventy-six were admitted with chest pain thought to be cardiac in origin, and 4 after either syncope or an episode of acute dyspnoea. In all cases a definite cardiac diagnosis had not been established at the time of the initial imaging study.

Imaging procedure

Myocardial scintigraphy was performed between
12 hours and 5 days after admission to the CCU (mean 48 hours). After obtaining informed consent, patients were imaged at their bedside using a mobile gamma camera (Searle Radiographics Pho-Gamma HP or IV) equipped with a 16000 parallel hole, high resolution collimator, and interfaced to a mobile digital acquisition unit (Ohio Nuclear 150 System) with tape storage facilities. Fifteen milli-curies of Tc-pyrophosphate (Mallincrodt/Nuclear) were injected intravenously, and 60 to 180 minutes later (mean 102 minutes) analogue and digital images containing 800000 counts were collected in both the anteroposterior and left anterior oblique 30° projections. Analogue images were recorded on Polaroid film and the digital images stored on magnetic tape for subsequent image processing. No complications resulting from the administration of the Tc-pyrophosphate occurred in any of the patients studied.

SCAN INTERPRETATION
Myocardial scans were interpreted by one of the authors (H.F.) who was unaware of the clinical findings or the presumed diagnosis. The intensity of the myocardial uptake of Tc-pyrophosphate was visually graded on a 0 to III scale: 0, being no visible uptake of the agent in the region of the heart; grade I, faint diffuse uptake; grade II, definite but moderate uptake, either localised or diffuse in distribution; and grade III, intense localised uptake approximately equal to the intensity of the sternum (Fig. 1). Because of doubt about the significance of grade I uptake, only grade II and III were regarded as abnormal and as representing positive scans.

MEASUREMENT OF \(^{99}\text{Tc}\) BLOOD ACTIVITY
In 21 cardiac patients and in 5 normal volunteers, blood samples were taken both at the beginning and at the end of the imaging procedure. All 26 subjects were imaged 120 minutes or more after injection. The blood samples were counted for \(^{99}\text{Tc}\) activity, and using injection standards the percentage of the injected dose in the blood was calculated, which was normalised to the estimated whole blood volume of the patient.

CARDIAC CATHETERISATION
Of the 80 patients, 28 underwent cardiac catheterisation during the study admission as part of the investigation of their chest pain. After informed consent was obtained, bilateral selective coronary arteriography using the Judkins technique and biplane left ventricular cineangiography were performed. The coronary angiograms and left ventriculograms were interpreted by at least two observers. The degree of obstruction of lesions in the left anterior descending, left circumflex, and right coronary arteries, and in their branches, was subjectively assessed, and left ventricular function, ejection fraction, and segmental contractility were defined.
myocardial infarction. Eight had both electrocardiographic and enzymatic evidence of infarction, 7 had enzymatic evidence, and 1 patient, who was admitted 4 days after his main episode of chest pain, had electrocardiographic evidence only. Of these 16 patients, 7 had positive scans (44%), of whom 5 showed a localised uptake pattern and in 2 a diffuse uptake pattern occurred. Nine patients (56%) had negative or doubtful scans (grade 0–1). One patient, who had chronic left bundle-branch block and an enzyme rise indicative of infarction, had a grade III positive scan.

Peak enzymes, electrocardiographic abnormalities, and the time interval between admission and scanning did not distinguish between those patients with positive scans and those with negative or doubtful scans (Table).

**Table Time interval before admission and study, electrocardiographic findings, peak CK level, and scan findings in 22 patients with acute myocardial infarction**

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<th>Case No.</th>
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Ant, anterior; Inf, inferior; LBBB and RBBB, left and right bundle-branch block; LAFB, left anterior fascicular block; (T), transmural; (NT) nontransmural.

**Results**

The available findings and the results of all laboratory and angiographic investigations were reviewed to determine the definitive diagnosis of each patient. Based on this information, the 80 patients were divided into 5 clinical groups: (1) acute myocardial infarction, (2) unstable angina pectoris, (3) congestive heart failure, (4) other acute cardiac syndromes, and (5) noncardiac chest pain. The scan findings were correlated with the final clinical diagnosis (Fig. 2).

**Acute Myocardial Infarction**

Twenty-two patients (mean age 58 years; 15 men, 7 women) were diagnosed as having acute myocardial infarction (Table). Criteria for diagnosis were the triad of; (1) prolonged chest pain, (2) evolutionary ST and T wave changes on the electrocardiogram, and/or (3) a transient rise and fall in the serum levels of the enzymes creatinine kinase (CK) and lactic dehydrogenase (LDH). Development of new deep Q waves of greater than 0.04 s duration indicated a transmural infarction.

Five patients met the diagnostic criteria for acute transmural infarction, of whom 3 had grade II positive scans, and 2 had grade I scans.

Sixteen patients sustained acute nontransmural myocardial infarction. Eight had both electrocardiographic and enzymatic evidence of infarction, 7 had enzymatic evidence, and 1 patient, who was admitted 4 days after his main episode of chest pain, had electrocardiographic evidence only. Of these 16 patients, 7 had positive scans (44%), of whom 5 showed a localised uptake pattern and in 2 a diffuse uptake pattern occurred. Nine patients (56%) had negative or doubtful scans (grade 0–1). One patient, who had chronic left bundle-branch block and an enzyme rise indicative of infarction, had a grade III positive scan.

Peak enzymes, electrocardiographic abnormalities, and the time interval between admission and scanning did not distinguish between those patients with positive scans and those with negative or doubtful scans (Table).

**Fig. 2 Distribution of Tc-99m pyrophosphate uptake grades (0 to III) in 22 patients with acute myocardial infarction, 33 patients with unstable angina pectoris, 6 patients with congestive heart failure, 9 patients with other acute cardiac syndromes, and 10 patients with noncardiac chest pain. TMI = transmural myocardial infarction (3 of the 22 patients).**
Tc-99m-pyrophosphate myocardial scintigraphy

positive scans, of which 2 remained grade II positive 48 hours later, and 2 showed grade I uptake, 6 and 8 days, respectively, after the initial study. One of these latter 2 patients had undergone myocardial revascularisation surgery during the interval between scans.

In view of the intriguing occurrence of positive scans in a high proportion of patients with unstable angina pectoris, the clinical data of the 33 patients were examined retrospectively to ascertain whether there were any specific features that might have predicted the occurrence of a positive scan. There were no features in the history and no specific electrocardiographic abnormalities which correlated with the presence of a positive scan. In order to determine if the significant uptake of Tc-pyrophosphate was related to the severity of the coronary artery disease, a study was made of the coronary arteriographic findings in the 22 patients (67%) who underwent cardiac catheterisation during the acute phase of unstable angina pectoris. Fig. 4 shows that while the majority of these patients had significant two or three vessel coronary artery disease, there was no relation between the number of vessels with obstructive disease of greater than 70 per cent, and the occurrence of a positive scan, assuming that grade 0 and grade I do not represent any significant myocardial uptake.

CONGESTIVE HEART FAILURE
Six patients (mean age 69; 3 women, 3 men) were diagnosed as having had an exacerbation of cardiac failure, with no evidence of recent myocardial infarction. Five had underlying coronary artery disease, and one a primary congestive cardiomyopathy. Four of these patients had zero uptake of Tc-pyrophosphate and 2 had grade I uptake.

during pain, 11 had stable nonspecific electrocardiographic abnormalities, 7 had electrocardiographic evidence of old transmural myocardial infarction and 3 patients had normal electrocardiograms.

Despite the absence of evidence of recent infarction, 14 patients (42%) had positive scans, of whom 8 had a localised uptake pattern and 6 had a more diffuse pattern (Fig. 3).

Seven patients with unstable angina pectoris had follow-up scans performed 1 to 8 days after the first study. Four of these patients initially had grade II

Fig. 3 Positive anteroposterior and left anterior oblique scintigrams occurring in patients with (a) acute nontransmural myocardial infarction, (b) unstable angina pectoris, (c) angina pectoris with normal coronary arteries, and (d) chest pain and mitral valve prolapse.

Fig. 4 Relation between the angiographically determined severity of the coronary artery disease and the uptake grades (0 to II) in 22 patients with unstable angina pectoris. V = coronary artery.
OTHER CARDIAC SYNDROMES

Nine patients comprised this clinical group (mean age 53 years; 5 men and 4 women). Three patients had angiographically documented mitral valve prolapse with normal coronary arteries, of whom 1 had a grade III positive scan, 1 a grade I, and the third a grade 0 scan. Three female patients who presented with typical angina pectoris had normal epicardial coronary arteries, as shown by selective coronary arteriography. Of these 3 patients, 2 had grade II positive scans, including 1 patient who had a positive treadmill exercise test and whose myocardium produced lactate when subjected to the stress of atrial pacing. Two patients who presented with recurrent ventricular arrhythmias without cardiac pain had grade II positive scans. One had undergone electroversion (250 joules) 24 hours before the imaging procedure. The sixth patient who had ulcerative colitis with a probable toxic myocarditis had a negative scan.

NONCARDIAC CHEST PAIN

Ten patients (mean age 44 years; 6 women, 4 men) were admitted with chest pain, whose symptoms upon careful review of the history and all investigations were not considered to be cardiac in origin. In 7 the pain was thought to be musculoskeletal. The other 3 patients were diagnosed as reflux oesophagitis, biliary colic, and viraemia, respectively. Six patients in this noncardiac group had zero uptake scans and 4 had grade I scans. Thus no patient with non-cardiac chest pain had a definitely positive scan.

RELATION BETWEEN SCAN GRADE AND BLOOD ACTIVITY OF $^{99m}Tc$

The relation between the visually graded uptake of Tc-pyrophosphate and the residual $^{99m}Tc$ blood pool activity at the time of the imaging study was investigated in 21 cardiac patients and in 5 normal control subjects. Fig. 5 shows the residual blood activity for each of the 26 subjects classified according to the scan uptake grade reading. These measurements were all made at least 120 minutes after administration of Tc-pyrophosphate in order to allow time for adequate clearance of the agent from the circulation. The mean percentage of the injected dose per whole blood volume for the patients with grade 0 scans was 12-2 per cent ($\pm 0.9$ SE); grade I, 13-8 per cent ($\pm 1.5$); grade II, 16-4 per cent ($\pm 1.2$), and grade III, 13-8 per cent ($\pm 2.4$). Using a one-way analysis of variance no significant differences in blood pool activity were found between the two groups. Frequently subjects with 0 or grade I scans had higher blood pool levels of $^{99m}Tc$ activity than patients with grade II activity. Thus, no qualitative or quantitative relation could be shown between the uptake grade of Tc-pyrophosphate and the blood pool activity.

Discussion

Both animal and clinical studies have shown that the bone scanning agent technetium-99m-pyrophosphate concentrates in acutely infarcted myocardium and can be imaged with a standard scintillation camera (Fink/Bennett et al., 1974; Bonte et al., 1975; Buja et al., 1975; Willerson et al., 1975a). Morphological animal studies have shown that uptake of labelled pyrophosphate, being in part flow dependent, tends to be confined to the more peripheral segments of an acute infarct where residual perfusion is greater (Buja et al., 1975; Zaret et al., 1975). Little uptake of Tc-pyrophosphate can be detected in the adjacent histologically normal, but presumably ischaemic, tissue surrounding an infarct. The time course and
the distribution of pyrophosphate uptake has been observed to parallel the accumulation of ionised calcium by necrotic tissue (Buja et al., 1975, 1976). It has, therefore, been suggested that pyrophosphate is fixed intracellularly by binding with mitochondrial calcium deposits (Buja et al., 1975).

The experimental data suggest that Tc-pyrophosphate myocardial scintigraphy may provide a specific diagnostic test for acute myocardial infarction and hence be a useful diagnostic aid in the coronary care unit. The initial clinical studies of Tc-pyrophosphate myocardial imaging concluded that this method had a high degree of diagnostic specificity and sensitivity for acute myocardial infarction (Fink/Bennett et al., 1974; Parkey et al., 1974; Willerson et al., 1975a). Willerson et al. (1975a), in the largest clinical series so far reported, studied 202 patients admitted to the CCU and observed that 96 of 101 patients who had proven acute myocardial infarction had positive scintigrams. In contrast, only 9 of 101 patients who failed to show evidence of acute infarction had positive scans.

More recently, there have been reports of positive scans being obtained in patients with unstable angina pectoris (Abdulla et al., 1976; Donsky et al., 1976), ventricular aneurysms (Ahmad et al., 1976), cardiomyopathy (Perez et al., 1976), and even as an incidental finding in those having bone scans performed (Soin et al., 1975). These findings prompted us to examine the diagnostic specificity and sensitivity of this scintigraphic method in a group of patients admitted to the CCU with a diagnosis of possible acute myocardial infarction. This clinical category was selected because it frequently presents a diagnostic problem in the CCU and might be an area in which Tc-pyrophosphate myocardial imaging might be of great diagnostic value within the first few days in hospital.

The findings in the present study indicate that both the diagnostic sensitivity and specificity of Tc-pyrophosphate myocardial imaging for acute myocardial infarct are lower than have been reported previously (Willerson et al., 1975a, b). The detection rate in the 22 patients with proven acute myocardial infarct was only 55 per cent. The reason for the apparent discrepancy between this and other series is probably related to the method of patient selection. Our study, by focusing on patients admitted as ‘rule out myocardial infarct’ effectively excluded those patients who had typical electrocardiographic changes of acute transmural myocardial infarction on admission, thereby selecting a higher proportion of patients with the more subtle diagnostic features observed in nontransmural myocardial infarction. Since nontransmural infarcts are usually smaller in size than transmural infarcts they tend to contain lesser amounts of tracer activity which may be insufficient to be detected externally by the scintillation camera (Botvinick et al., 1975).

The diffuse, moderate uptake pattern of Tc-pyrophosphate has been proposed as a specific diagnostic feature of acute nontransmural myocardial infarct (Poliner et al., 1976). Though this pattern was seen in some of our patients with myocardial infarction it did not, however, prove to be specific for nontransmural myocardial infarct, since it also occurred in patients without evidence of myocardial infarction. These limitations of Tc-pyrophosphate myocardial imaging in the detection of acute nontransmural myocardial infarction need to be recognised, particularly since recent studies have shown that the mortality rate for patients with nontransmural myocardial infarction may be similar to that for transmural myocardial infarction (Madas et al., 1974; Rigo et al., 1975).

Of great interest was the demonstration that a significant number of patients with unstable angina pectoris had positive scans. Most of our patients in this group had grade II positive scans, suggesting that it might not be possible to distinguish scintigraphically between patients with acute myocardial infarction, especially if nontransmural, and those with unstable angina pectoris. This distinction has great clinical and therapeutic importance, since the management of these two groups of patients may differ. Many centres now believe that patients who have unstable angina pectoris should have early coronary angiography followed by myocardial revascularisation surgery, provided the coronary anatomy is suitable (Miller et al., 1973; Bonte et al., 1974; Bonchek et al., 1974). This therapeutic course would be contraindicated in patients with proven acute myocardial infarction.

The explanation for the occurrence of positive scintigrams in some patients with unstable angina pectoris is unclear. Two possibilities exist. First, reversibly injured myocardial cells may be capable of taking up pyrophosphate in significant amounts. This hypothesis is difficult to test in the experimental animal, since no satisfactory animal model of unstable angina pectoris exists. Experimental myocardial uptake and distribution studies of Tc-pyrophosphate have, by necessity, been performed only in acute myocardial infarction. The absence of the usual electrocardiographic or enzymatic markers of recent infarction, together with the known severity of the myocardial ischaemia in unstable angina pectoris, might tend to favour this first explanation. A second possible explanation is that Tc-pyrophosphate myocardial imaging is more sensi-
tive than the currently available methods for the diagnosis of acute myocardial infarction and is, therefore, capable of detecting an infarct missed by the usual diagnostic methods. Recent necropsy studies of unstable angina pectoris lend some support to this hypothesis. Guthrie and co-workers (1975) reported pathological studies on patients with clinical unstable angina pectoris who died after coronary arterial surgery. In 6 cases, recent myocardial infarction, histologically antedating the time of surgery, was shown. In addition, acute myocardial infarction may not be detected in the presence of left bundle-branch block or previous transmural myocardial infarction if the patient is seen a few days after the main symptomatic event when the serum CK and LDH enzymes have returned to normal levels. Thus, the pathogenesis of positive Tc-pyrophosphate scans in patients with clinically unstable angina pectoris must remain uncertain at the present time.

Since this study focused on determining the diagnostic specificity and sensitivity of Tc-pyrophosphate myocardial imaging when used within the first few days of being admitted to hospital, serial scans were not usually obtained. In the small number of patients with unstable angina pectoris who had more than one scan performed, the changes seen were variable. The scan findings tended to be stable during the first week, but became less intense in uptake during the second week, as has been previously noted in patients with acute myocardial infarction (Willerson et al., 1975a).

Positive scans occurring in patients with either mitral valve prolapse or recurrent ventricular arrhythmias have not been previously reported. It could be suggested that the metabolic or haemodynamic abnormalities, which have been shown to occur in these syndromes, result in myocardial cell injury (Samet, 1973; Natarajan et al., 1975). These damaged cells may then be capable of taking up pyrophosphate. Direct current shock has been shown in animals to result in positive technetium pyrophosphate scans, and this may have been a factor in the one patient with ventricular arrhythmias treated by electroversion (DiCola et al., 1976; Pugh et al., 1976). In the animal experiments reported, one to four DC shocks of 320 joules each produced a significant uptake of pyrophosphate in the absence of any demonstrable change in regional blood flow (DiCola et al., 1976).

The diffuse grade I scan was a nonspecific finding in this series being observed in patients with and without cardiac disease. The diffuse grade II scan was, on the other hand, seen only in patients with acute cardiac disease, most commonly nontransmural infarction or unstable angina pectoris. The nonspecific nature of the diffuse scan pattern has recently been confirmed by Prasquier et al. (1976). They noted this appearance in 3 patients with acute nonnonsural myocardial infarction, in 7 of 17 (41%) patients with unstable angina pectoris, and in 2 of 39 (5%) patients with stable angina pectoris. The diffuse pattern was also seen in 11 per cent of 484 patients who had routine bone scans; however, 79 per cent of this group had had prior left mastectomy. Whether this diffuse pattern represents true myocardial uptake or a cardiac blood pool image is still uncertain. The lack of correlation between blood pool activity of 99mTc and the scan uptake in our study suggests that myocardial uptake of 99mTc is responsible for the diffuse pattern. These measurements were made at least 2 to 4 hours after injecting Tc-pyrophosphate intravenously in order to minimise the possibility of blood pool interference. Blood clearance studies of Tc-pyrophosphate show a biexponential pattern of clearance from the blood. The first exponent has a relatively rapid clearance half-time of 13-6 minutes, and the second exponent a slower half-time of 380 minutes. It is believed that the rapid first exponent represents decreasing radioactivity caused by bone uptake, while the second exponent mainly reflects renal excretion of the agent (Krishnamurthy et al., 1975). Hence, blood pool images are more likely to be obtained in patients with impaired renal function or those imaged within approximately the first hour after injection. In addition, since the degree of tissue attenuation will vary from patient to patient, those with thin chest walls are more likely to have blood pool Tc-pyrophosphate images.

From the analysis of the scans of 80 patients admitted to the CCU with possible myocardial infarction, we have shown that Tc-pyrophosphate myocardial scintigraphy: (1) may give positive scans in patients with unstable angina pectoris and other acute cardiac syndromes, and (2) may fail to detect acute myocardial infarction especially if nontransmural. Our results, therefore, suggest caution in the diagnostic application of Tc-pyrophosphate myocardial scintigraphic findings in patients admitted to hospital with 'rule out myocardial infarction'.

References


Tc-99m-pyrophosphate myocardial scintigraphy


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