Emission computed tomography with technetium-99m pyrophosphate for delineating location and size of acute myocardial infarction in man

SHUNICHI TAMAKI,* KAZUNORI KADOTA,* HIROFUMI KAMBARA,*
YUKISONO SUZUKI,* RYUJI NOHARA,* TOMOYUKI MURAKAMI,* CHUICHI KAWAI,*
NAGARA TAMAKI,† KANJI TORIZUKA†

*From the *Third Division, Department of Internal Medicine, and the †Department of Nuclear Medicine, Faculty of Medicine, Kyoto University, Kyoto, Japan*

SUMMARY Emission computed tomography with technetium-99m pyrophosphate was used to delineate the location and estimate the size of myocardial infarcts in 20 patients with documented acute myocardial infarction. Tomography was performed after planar imaging within 2-5 days after the onset of infarction. A series of transaxial, frontal, and sagittal tomograms were reconstructed from 32 views imaged from the left side of the patient's chest with a rotating gammacamera. Infarct volume was measured from the tomographic images by computerised planimetry and was compared with the cumulative release of creatine kinase MB isoenzyme. The planar images showed discrete myocardial uptake in 13 of the 20 patients and diffuse uptake throughout the cardiac region in the remaining seven. In contrast, the tomographic images clearly delineated discrete myocardial uptake by avoiding confusion of myocardial activity with that of surrounding structures, particularly bones, in all patients. For the 10 patients whose infarct size was assessed by analysis of the creatine kinase MB curve there was a close correlation between infarct volume estimated by tomography and by cumulative creatine kinase MB release. Thus emission computed tomography can provide a three dimensional map of technetium-99m pyrophosphate distribution within the heart and is thus able accurately to localise and estimate the size of myocardial infarcts in man.

Since its introduction into clinical medicine in 1974^{1,2} myocardial scintigraphy with technetium-99m pyrophosphate has been widely used for detecting, localising, and estimating the size of acute myocardial infarcts. Standard planar imaging has, however, some limitations that restrict its clinical application because of the geometric constraints of a two dimensional display. The recent introduction of emission computed tomography provides a complete three dimensional image of the distribution of the tracer.³⁻⁵ This technique has already been applied to thallium-201 myocardial imaging, and some interesting clinical results have been reported.⁶⁻⁸ Furthermore, accurate sizing of acute myocardial infarcts has been carried

out with this technique and technetium-99m pyrophosphate in animal models.^{9,10} Nevertheless, there have been few attempts to apply this technique to technetium-99m pyrophosphate imaging in man.¹¹ We therefore report our experience of using emission computed tomography for technetium-99m pyrophosphate myocardial imaging to delineate the location and size of acute myocardial infarcts in man.

Patients and methods

We studied 20 patients (17 men, three women; mean age 60 (range 31-77) years) admitted to our coronary care unit with acute myocardial infarction between January 1982 and February 1983. Acute myocardial infarction was diagnosed if the following three criteria were met: (a) a history of typical chest pain lasting one hour or more; (b) the presence of a characteristic pattern of increase in the serum creatine kinase MB activ-

Requests for reprints to Dr Chuichi Kawai, The Third Division, Department of Internal Medicine, Kyoto University Hospital, 54 Kawaracho Shogoin, Sakyo-ku, Kyoto, 606 Japan.

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ity above normal values; and (c) the appearance of Q waves or evolution of ST-T changes characteristic of infarction in the electrocardiogram. The electrocardiographic localisation of the infarct was determined according to the criteria of the American Heart Association.¹²

Myocardial scintigraphy with technetium-99m pyrophosphate was performed 2–5 days (mean 3.2 days) after the onset of symptoms of myocardial infarction. Images were obtained approximately three hours after an intravenous injection of 15–20 mCi (540–720 MBq) of technetium-99m pyrophosphate using a large field of view gammacamera (Hitachi: Gamma View) equipped with a low energy high resolution parallel hole collimator. Planar views included the anterior, 45° left anterior oblique, and left lateral projections, collecting 600 000 counts for each image. Scintigrams were interpreted by two observers who were unaware of the clinical diagnosis. Radioactivity in the cardiac region was graded on a scale of 0 to 4+ according to the classification described by Parkey *et al.*² Scintigrams graded 2+ or higher were considered to be positive. In addition, radionuclide uptake was classified as either discrete—if it was localised to one or more myocardial regions not including the left ventricular cavity—or diffuse—if it was present throughout the region of the heart including the left ventricle.¹³

After planar imaging, tomography was performed using a rotating gammacamera with a high resolution parallel hole collimator supported by a gantry (General Electric: Maxi-400 T) interfaced to a digital computer (DEC: PDP 11/60). The camera rotated from a 45° left posterior oblique to a 45° right anterior oblique position of the patient so that data from only the anterior half of the heart were collected. A total of 32 discrete view images—that is, one image every 5.8°—were acquired over 180°. Each image was acquired for 20 s for a total acquisition time of 11 minutes. Contiguous transaxial tomograms were reconstructed into 12 mm thick multiple slices by a filtered back projection method using a convolution algorithm^{5,7} without attenuation correction. Each transaxial tomogram was rotated perpendicular to the long axis of the left ventricle. Thereafter, frontal and sagittal tomograms were reorganised from the set of transaxial tomograms so that the frontal and sagittal tomograms nearly corresponded to the short axis and long axis sections of the heart respectively.^{5,7} The reconstructed images were displayed in a 64 × 64 matrix (Fig. 1).

To estimate infarct volume, we analysed the tomogram in the most appropriate section that showed the uptake transversely, selecting transaxial tomograms in anterior infarcts and frontal tomograms in inferior infarcts. To define the boundary, the mean count

Fig. 1 Emission computed tomograms with technetium-99m pyrophosphate in a patient with acute anterior myocardial infarction: (a) transaxial sections (viewed from below with anterior surface up) imaged from the cranial (left) to the caudal region (right); (b) frontal sections (viewed from left anterior oblique projection) from the apical (left) to the basal region (right); and (c) sagittal sections (viewed from right anterior oblique projection) from the septal (left) to the lateral region (right). Discrete uptake in the anterior myocardial wall is shown by arrows. In the schematic drawings the solid areas represent the damaged regions. r, ribs; s, sternum; v, vertebrae.

Fig. 2 Emission computed tomograms with technetium-99m pyrophosphate showing size of infarct. Profile of counts along horizontal markers (between two lines 5 to 10 pixels) through the infarct was plotted (a) and the mean count at the points of the steepest change across the edges calculated to give background threshold, which was subtracted from the entire image (b). The area of the infarct was outlined with a light pen and measured by computerised planimetry (c).

density was plotted along 5 to 10 horizontal profiles selected as passing through the infarct edge in each tomogram (Fig. 2a). The mean count at the points of the steepest change in counts across the edges was calculated and subtracted from each image (Fig. 2b). In the resulting image the area of increased tracer uptake was outlined with a light pen and measured by computerised planimetry (Fig. 2c). The total number of pixels in all slices showing increased tracer uptake were added together and multiplied by a size factor (0.432 ml per one pixel) to determine infarct volume. Infarct volume thus obtained was expressed in millilitres. The tomographic images were interpreted independently by two observers without knowledge of the patient's clinical and laboratory findings. The site of the image abnormality was the same in all cases. The interobserver variation in measuring infarct volume was within 7% and the intraobserver variation within 5%.

A biochemical estimate of the extent of myocardial tissue damage was obtained in 10 patients who were admitted within six hours after the onset of infarction. Serum samples were collected for creatine kinase MB analysis at four hour intervals for 48 hours from the time of admission and every 12 hours for the following 48 hours. Creatine kinase MB isoenzyme activity was separated from sera by diethylaminoethyl-Sephadex column chromatography using minicolumns.¹⁴ Enzyme activity of the column eluate was determined according to Rosalki.¹⁵ A computer was used to generate each serum creatine kinase MB time-activity curve to fit an exponential to the downslope of the curve by the least squares method and to derive an individual disappearance constant of creatine kinase

MB from serum for each patient. The cumulative release of creatine kinase MB was calculated using a modification¹⁶ of the original formula of Shell *et al.*,¹⁷ Sobel *et al.*,¹⁸ and Roberts *et al.*¹⁹ and represents the total amount of creatine kinase MB that would appear in the serum in the absence of enzyme disappearance. Enzyme curves were analysed only in patients whose creatine kinase MB concentrations at the onset of the serum sampling period were within normal limits.

Infarct volume estimated by tomography with technetium-99m pyrophosphate in each patient was compared with the cumulative release of creatine kinase MB by linear regression, and a correlation coefficient was obtained.

Results

The results are summarised in the Table. Of the 20 patients studied, the electrocardiographic site of transmural infarction was anteroseptal in seven, anterolateral in three, anteroseptal with lateral wall involvement in two, and inferior in seven. In the seven patients with an inferior infarct, electrocardiography indicated additional transmural lateral wall involvement in one and posterior wall involvement in two. One patient had a subendocardial infarct. Two had a documented previous myocardial infarct.

The planar images showed uptake of technetium-99m pyrophosphate graded 2+ or higher in the cardiac region in all patients. Thirteen patients had discrete myocardial uptake localised to regions which corresponded anatomically with the electrocardiographic localisation of the infarct on their planar images. The remaining seven patients (five with

Table Scintigraphic and enzymatic data

Case No	Age (sex)	ECG location of MI	Planar uptake pattern	Emission computed tomography		Cumulative CKMB release (IU/l)
				Location of infarct	Infarct volume (ml)	
1	54 (M)	Anterolateral	Discrete	Ant, Lat	58	—
2	48 (M)	Inferior	Discrete	Inf	18	52
3	60 (M)	Anteroseptal, antero-lateral	Discrete	Ant, Sep, Lat	108	677
4	73 (M)	Inferior	Discrete	Inf	38	—
5	58 (M)	Anteroseptal	Discrete	Ant, Sep	54	—
6	54 (M)	Anteroseptal	Diffuse	Ant, Sep	15	62
7	75 (F)	Anteroseptal	Discrete	Ant, Sep	40	—
8	75 (M)	Inferior	Discrete	Inf	18	—
9	73 (M)	Inferoposterior	Discrete	Inf, Post	67	408
10	48 (M)	Anteroseptal	Discrete	Ant, Sep	10	108
11	62 (M)	Anteroseptal	Diffuse	Ant, Sep	46	405
12	59 (M)	Inferoposterior	Diffuse	Inf, Post	30	—
13	60 (M)	Anteroseptal, antero-lateral	Diffuse	Ant, Sep, Lat	81	—
14	56 (M)	Anterolateral	Discrete	Ant, Lat	10	51
15	53 (M)	Anteroseptal	Diffuse	Ant, Sep	65	—
16	77 (F)	Inferior, anteroseptal	Discrete	Inf	26	170
17	70 (M)	Anterolateral	Discrete	Ant, Lat	72	235
18	67 (F)	Subendocardial	Diffuse	Ant, Lat	17	—
19	59 (M)	Inferolateral	Discrete	Inf, Lat	35	250
20	31 (M)	Anteroseptal	Diffuse	Ant, Sep	48	—

Ant, anterior wall; Sep, septum; Lat, lateral wall; Inf, inferior wall; Post, posterior wall; CKMB, creatine kinase MB isoenzyme.

anterior, one with inferior, and one with subendocardial myocardial infarction), however, had diffuse uptake throughout the cardiac region and the site of the infarct could not be localised accurately with the planar images. In contrast, the tomographic images improved visualisation of the infarct by suppressing overlying activity and increasing contrast between the infarct and the background. The uptake in the myocardium was clearly separated from that in the bones (Fig. 1). In all cases, including seven patients with diffuse uptake by the planar images, the tomographic images showed discrete radionuclide uptake in the infarcted wall. Thirteen patients had anterior wall uptake by tomography with involvement of the septum in nine and involvement of the lateral wall in six. Seven patients had an inferior infarct: all had uptake involving the inferior wall with extension to the posterior or posterolateral wall in three. Fig. 3 shows planar and tomographic images in a patient with anteroseptal myocardial infarct. Whereas the planar images showed diffuse patterns of uptake throughout the cardiac region including the left ventricular cavity, the tomographic images clearly showed discrete myocardial uptake localised to the anterior wall and the septum. Fig. 4 shows a set of frontal tomograms and planar images in a patient with inferior infarct. The distribution of radionuclide uptake on the inferior wall could be seen only on the edge in three planar views. The tomographic images provided more detailed information on the anatomical distribution of radionuclide uptake.

Infarct volume measured from tomographic images ranged from 10 ml to 108 ml (Table). For the 10 patients in whom enzymatic infarct size was obtained by integration of the completed creatine kinase MB curve there was a close correlation between infarct volume measured by tomography and by the cumulative release of creatine kinase MB ($r=0.91$, $p<0.001$, Fig. 5). Five of these 10 patients had inferior infarct and the remaining five had anterior infarct.

Discussion

Because technetium-99m pyrophosphate myocardial scintigraphy directly visualises the acutely infarcted myocardium it has been used to aid in the detection and localisation of acute myocardial infarcts.^{1 2 20} This technique is of particular value when other clinical and laboratory evidence is inconclusive.^{21 22} In addition to its diagnostic potential, scintigraphy provides prognostic information as well.^{23 24} Many previous studies using conventional two dimensional imaging have shown that well localised radionuclide images of cardiac activity have been consistently correlated with documented regions of acute myocardial infarction.^{20 25} Because of diffuse uptake throughout the left ventricular region the clinical application of this technique is, however, limited when two dimensional imaging is used.^{13 26 27} Initially, the diffuse pattern of radionuclide uptake was identified in patients with subendocardial myocardial infarction.²⁸ But this pattern was also noted in significant proportions of

Fig. 3 (a) Planar images and (b) transaxial, frontal, and sagittal tomograms with their schematic drawings in a patient with acute anterior myocardial infarction. The planar images showed diffuse uptake throughout the cardiac region without evidence of the left ventricular cavity, whereas the tomograms clearly showed discrete myocardial uptake localised to the anterior wall with involvement of the septum. In the schematic drawings the solid areas represent the infarcts. r, ribs; v, vertebrae; R, right side; L, left side; LAO, left anterior oblique.

patients with unstable angina,^{29,30} myocarditis,³¹ cardiomyopathy,^{29,32} and even in some patients without apparent heart disease.^{13,33} In some cases this diffuse pattern may be due to persistent blood pool activity,^{13,33} which may be mistaken for a positive image with planar imaging. Furthermore, the planar images cannot localise the site of the infarct when they show diffuse uptake.

In the present study tomography improved visualisation of the infarct by clearly separating myocardial activity from that of overlying or underlying struc-

tures, particularly bones, and by increasing contrast between infarct and background (Figs. 1, 3, and 4). The tomographic images showed discrete myocardial uptake corresponding to the electrocardiographic site of the infarct in all patients with acute myocardial infarction, including seven with diffuse uptake on the planar images (Fig. 3). Our equipment can reorganise not only transaxial tomograms but also frontal and sagittal tomograms, which greatly assisted the accurate assessment of radionuclide distribution. Thus, emission computed tomography can provide more

Fig. 4 (a) Planar images and (b) frontal tomograms in a patient with acute inferior myocardial infarction. In the schematic drawing the solid area represents the infarct. The tomograms provided more detailed information on the anatomical extension of the infarct (arrows). r, ribs; s, sternum.

Fig. 5 Correlation between infarct volume estimated by emission computed tomography with technetium-99m pyrophosphate and the cumulative release of creatine kinase MB isoenzyme in 10 patients with acute anterior (●) and inferior (○) myocardial infarction.

detailed three dimensional information on the anatomical location of infarcts. It may also improve the specificity of the diffuse pattern of uptake, although this subject requires further study. Technetium-99m pyrophosphate myocardial imaging has also been valuable in estimating infarct size. Pre-

vious studies in animals have shown excellent correlations between scintigraphic estimates of infarct size and histological infarct weight.³⁴⁻³⁶ Several problems are, however, encountered in estimating infarct size with planar myocardial imaging in man. Probably the most fundamental problem results from the two dimensional representation of a three dimensional structure.³⁷ Nevertheless, good correlations have been reported between the area of radionuclide uptake and peak creatine kinase activity,^{20,38} cumulative creatine kinase release,³⁹ and precordial electrocardiographic mapping measurement⁴⁰ in patients with anterior infarcts. On the other hand, a weaker correlation has been found in patients with inferior infarcts because the entire area of the inferior infarct cannot be viewed from in front in the standard planar projections.³⁹ These limitations can be overcome with tomographic imaging techniques. Initial animal studies using a rotating gammacamera system reported an excellent result in all locations of experimental infarcts.^{9,10} Lewis *et al* used rotating slanthole tomography for three dimensional sizing of experimental infarcts and obtained satisfactory results.⁴¹ Recently, Holman *et al* have applied emission computed tomography with a multiple scanning detector system to radionuclide imaging in man and reported a

significant relation between infarct size estimated by this tomographic technique and the patient's prognosis.¹¹

In the present study we used emission computed tomography with a rotating gammacamera to measure infarct volume in patients with acute myocardial infarction and obtained a close correlation between infarct volume measured from tomographic images and cumulative creatine kinase MB release (Fig. 5). Since the images are effectively three dimensional inferior infarcts could be equally accurately sized by this technique. Thus emission computed tomography can extend the infarct sizing capability of radionuclide imaging to include inferior infarcts as well as anterior infarcts in man.

With single photon emission computed tomography, another problem is the inability to correct fully for attenuation, which may produce image distortion. It has been pointed out, however, that correction for attenuation is much less of a problem when the volume occupied by the radioactivity rather than the absolute amount of activity present in that volume is measured.^{4,11} In addition, the extent of infarction is more strongly related to the distribution of technetium-99m pyrophosphate than to the concentration of the tracer because its concentration in necrotic myocardium is dependent on flow.^{25,42,43} This fact may be an advantage in emission computed tomography in sizing infarcts. We, therefore, analysed the distribution of radionuclide uptake to measure the extent of infarction. We believe that emission computed tomography can provide geometrically reliable three dimensional sections of radionuclide uptake distribution.

In summary, this preliminary clinical study of patients with acute myocardial infarction indicated the feasibility of emission computed tomography for assessing technetium-99m pyrophosphate myocardial uptake in man. The multiplanar tomograms were of good quality and were acquired quickly enough for clinical purposes. This technique can lead to accurate quantification as well as improved localisation of acute myocardial infarction. Since it uses commercially available tracers it appears to be promising for widespread clinical application.

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References

- 1 Bonte FJ, Parkey RW, Graham KD, Moore J, Stokely EM. A new method for radionuclide imaging of myocardial infarcts. *Radiology* 1974; 110: 473-4.
- 2 Parkey RW, Bonte FJ, Meyer SL, et al. A new method for radionuclide imaging of acute myocardial infarction in humans. *Circulation* 1974; 50: 540-6.
- 3 Holman BL, Hill TC, Wynne J, Lovett RD, Zimmerman RE, Smith EM. Single-photon transaxial emission computed tomography of the heart in normal subjects and in patients with infarction. *J Nucl Med* 1979; 20: 736-40.
- 4 Burdine JA, Murphy PH, DePuey EG. Radionuclide computed tomography of the body using routine radiopharmaceuticals. II. Clinical applications. *J Nucl Med* 1979; 20: 108-14.
- 5 Tamaki N, Mukai T, Ishii Y, et al. Comparative study of thallium emission myocardial tomography with 180° and 360° data collection. *J Nucl Med* 1982; 23: 661-6.
- 6 Maublant J, Cassagnes J, Le Jeune JJ, et al. A comparison between conventional scintigraphy and emission tomography with thallium-201 in the detection of myocardial infarction: concise communication. *J Nucl Med* 1982; 23: 204-8.
- 7 Tamaki S, Nakajima H, Murakami T, et al. Estimation of infarct size by myocardial emission computed tomography with thallium-201 and its relation to creatine kinase-MB release after myocardial infarction in man. *Circulation* 1982; 66: 994-1001.
- 8 Ritchie JL, Williams DL, Harp G, Stratton JL, Caldwell JH. Transaxial tomography with thallium-201 for detecting remote myocardial infarction. Comparison with planar imaging. *Am J Cardiol* 1982; 50: 1236-41.
- 9 Keyes JW Jr, Leonard PF, Brody SL, Svetkoff DJ, Rogers WL, Lucchesi BR. Myocardial infarct quantification in the dog by single photon emission computed tomography. *Circulation* 1978; 58: 227-32.
- 10 Singh M, Berggren MJ, Gustafson DE, Dewanjee MK, Bahn RC, Ritman EL. Emission-computed tomography and its application to imaging of acute myocardial infarction in intact dogs using Tc-99m pyrophosphate. *J Nucl Med* 1979; 20: 50-6.
- 11 Holman BL, Goldhaber SZ, Kirsch CM, et al. Measurement of infarct size using single photon emission computed tomography and technetium-99m pyrophosphate: a description of the method and comparison with patient prognosis. *Am J Cardiol* 1982; 50: 503-11.
- 12 Austen WG, Edwards JE, Frye RL, et al. A reporting system on patients evaluated for coronary artery disease. Report of the Ad Hoc Committee for grading of coronary artery disease, Council on Cardiovascular Surgery, American Heart Association. *Circulation* 1975; 51 (suppl): 5-40.
- 13 Prasquier R, Taradash MR, Botvinick EH, Shames DM, Parmley WW. The specificity of the diffuse pattern of cardiac uptake in myocardial infarction imaging with technetium-99m stannous pyrophosphate. *Circulation* 1977; 55: 61-6.
- 14 Mercer DW. Separation of tissue and serum creatine kinase isoenzymes by ion-exchange column chromatography. *Clin Chem* 1974; 20: 36-40.
- 15 Rosalki SB. An improved procedure for serum creatine phosphokinase determination. *J Lab Clin Med* 1967; 69: 696-705.
- 16 Norris RM, Whitlock RML, Barratt-Boyes C, Small CW. Clinical measurement of myocardial infarct size. Modification of a method for the estimation of total creatine phosphokinase release after myocardial infarction. *Circulation* 1975; 51: 614-20.

- 17 Shell WE, Kjekshus JK, Sobel BE. Quantitative assessment of the extent of myocardial infarction in the conscious dog by means of analysis of serial changes in serum creatine phosphokinase activity. *J Clin Invest* 1971; 50: 2614-25.
- 18 Sobel BE, Bresnahan GF, Shell WE, Yoder RD. Estimation of infarct size in man and its relation to prognosis. *Circulation* 1972; 46: 640-8.
- 19 Roberts R, Henry PD, Sobel BE. An improved basis for enzymatic estimation of infarct size. *Circulation* 1975; 52: 743-54.
- 20 Willerson JT, Parkey RW, Bonte FJ, Meyer SL, Atkins JM, Stokely EM. Technetium stannous pyrophosphate myocardial scintigrams in patients with chest pain of varying etiology. *Circulation* 1975; 51: 1046-52.
- 21 Sharpe DN, Botvinick EH, Shames DM, et al. The noninvasive diagnosis of right ventricular infarction. *Circulation* 1978; 57: 483-90.
- 22 Righetti A, O'Rourke RA, Schelbert H, et al. Usefulness of preoperative and postoperative Tc-99m(Sn)-pyrophosphate scans in patients with ischemic and valvular heart disease. *Am J Cardiol* 1977; 39: 43-9.
- 23 Holman BL, Chisholm RJ, Braunwald E. The prognostic implications of acute myocardial infarct scintigraphy with ^{99m}Tc-pyrophosphate. *Circulation* 1978; 57: 320-6.
- 24 Ahmad M, Logan KW, Martin RH. Doughnut pattern of technetium-99m pyrophosphate myocardial uptake in patients with acute myocardial infarction: a sign of poor long-term prognosis. *Am J Cardiol* 1979; 44: 13-7.
- 25 Bruno FP, Cobb FR, Rivas F, Goodrich JK. Evaluation of ^{99m}Technetium stannous pyrophosphate as an imaging agent in acute myocardial infarction. *Circulation* 1976; 54: 71-8.
- 26 Berman DS, Amsterdam EA, Hines HH, et al. New approach to interpretation of technetium-99m pyrophosphate scintigraphy in detection of acute myocardial infarction. Clinical assessment of diagnostic accuracy. *Am J Cardiol* 1977; 39: 341-6.
- 27 Massie BM, Botvinick EH, Werner JA, Chatterjee K, Parmley WW. Myocardial scintigraphy with technetium-99m stannous pyrophosphate: an insensitive test for nontransmural myocardial infarction. *Am J Cardiol* 1979; 43: 186-92.
- 28 Willerson JT, Parkey RW, Bonte FJ, Meyer SL, Stokely EM. Acute subendocardial myocardial infarction in patients. Its detection by technetium-99m stannous pyrophosphate myocardial scintigrams. *Circulation* 1975; 51: 436-41.
- 29 Ahmad M, Dubiel JP, Logan KW, Verdon TA, Martin RH. Limited clinical diagnostic specificity of technetium-99m stannous pyrophosphate myocardial imaging in acute myocardial infarction. *Am J Cardiol* 1977; 39: 50-4.
- 30 Donsky MS, Curry GC, Parkey RW, et al. Unstable angina pectoris: clinical, angiographic, and myocardial scintigraphic observations. *Br Heart J* 1976; 38: 257-63.
- 31 Kadota K, Matsumori A, Kambara H, Kawai C. Myocardial uptake of technetium-99m stannous pyrophosphate in experimental viral myopericarditis. *J Nucl Med* 1979; 20: 1047-50.
- 32 Perez LA, Hayt DB, Freeman LM. Localization of myocardial disorders other than infarction with 99m Tc-labeled phosphate agents. *J Nucl Med* 1976; 17: 241-6.
- 33 Cowley MJ, Mantle JA, Rogers WJ, Russell RO Jr, Rackley CE, Logic JR. Technetium-99m stannous pyrophosphate myocardial scintigraphy. Reliability and limitations in assessment of acute myocardial infarction. *Circulation* 1977; 56: 192-8.
- 34 Botvinick EH, Shames D, Lappin H, Tyberg JV, Townsend R, Parmley WW. Noninvasive quantitation of myocardial infarction with technetium 99m pyrophosphate. *Circulation* 1975; 52: 909-15.
- 35 Stokely EM, Buja LM, Lewis SE, et al. Measurement of acute myocardial infarcts in dogs with ^{99m}Tc-stannous pyrophosphate scintigrams. *J Nucl Med* 1976; 17: 1-5.
- 36 Poliner LR, Buja LM, Parkey RW, et al. Comparison of different noninvasive methods of infarct sizing during experimental myocardial infarction. *J Nucl Med* 1977; 18: 517-23.
- 37 Marcus ML, Kerber RE, Ehrhardt J, Abboud FM. Three dimensional geometry of acutely ischemic myocardium. *Circulation* 1975; 52: 254-63.
- 38 Davies GJ, Fakhrai B, Morgan A, Muir JR. Estimation of myocardial infarct size in man using 99m Tc polyphosphate. *Br Heart J* 1979; 41: 668-75.
- 39 Henning H, Schelbert HR, Righetti A, Ashburn WL, O'Rourke RA. Dual myocardial imaging with technetium-99m pyrophosphate and thallium-201 for detecting, localizing and sizing acute myocardial infarction. *Am J Cardiol* 1977; 40: 147-55.
- 40 Willerson JT, Parkey RW, Stokely EM, et al. Infarct sizing with technetium-99m stannous pyrophosphate scintigraphy in dogs and man; relationship between scintigraphic and precordial mapping estimates of infarct size in patients. *Cardiovasc Res* 1977; 11: 291-8.
- 41 Lewis SE, Stokely EM, Devous MD, et al. Quantitation of experimental canine infarct size with multipinhole and rotating-slanthole tomography. *J Nucl Med* 1981; 22: 1000-5.
- 42 Marcus ML, Tomanek RJ, Ehrhardt JC, Kerber RE, Brown DD, Abboud FM. Relationships between myocardial perfusion, myocardial necrosis, and technetium-99m pyrophosphate uptake in dogs subjected to sudden coronary occlusion. *Circulation* 1976; 54: 647-53.
- 43 Buja LM, Parkey RW, Stokely EM, Bonte FJ, Willerson JT. Pathophysiology of technetium-99m stannous pyrophosphate and thallium-201 scintigraphy of acute anterior myocardial infarcts in dogs. *J Clin Invest* 1976; 57: 1508-22.