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Quantitative analysis of acute myocardial infarction using single photon emission computed tomography using technetium-99m pyrophosphate

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Summary

The usefulness of single photon emission computed tomography (SPECT) using technetium-99m pyrophosphate (^{99m}Tc-PPi) was evaluated in 15 patients with acute myocardial infarction. SPECT was performed with a rotating gamma camera after conventional planar images were made.

Infarct size was measured from transaxial images of myocardial pyrophosphate uptakes. In each slice, the boundary was defined by subtracting 70 percent of the maximal counts and the number of voxels automatically counted. This subtraction rate was determined by phantom study and by compraing SPECT using ^{99m}Tc-PPi with thallium-201-gated myocardial scintigraphy (^{201}Tl gated SPECT).

The planar images showed diffuse uptakes in two of the 15 patients, and in these cases it was difficult to detect the infarct site. In contrast, SPECT images clearly imaged the infarct site consistent with the electrocardiographic findings, and they were definitely separated from the uptakes in the bones in all cases. Infarct size, ranging from 3.4 m*l* to 78.3 m*l*, correlated well with cumulative creatine kinase release ($r=0.84$, $p<0.01$, $y=772x+13900$). Correlation of infarct size with peak serum creatine kinase level was also significant ($r=0.66$, $p<0.01$, $y=10.6x+693$).

In conclusion, SPECT with ^{99m}Tc-PPi is a useful means of investigating the spatial distribution of pyrophosphate uptake and of evaluating the size of myocardial infarction.

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Introduction

^{99m}Tc-PPi myocardial scintigraphy, reported by Bonte et al.[1], has been utilized for the detection and localization of myocardial necrosis[2~5]. However, the conventional planar image has some limitations. The diffuse distribution or low uptake of ^{99m}Tc-PPi in the myocardium, and the uptake of bones overlapping the myocardium, sometimes preclude the diagnosis of myocardial infarction[6~8].

Single photon emission computed tomography (SPECT) can provide three-dimensional information about 99m Tc-PPi uptake and can distinguish myocardial uptake from that in bones.

In this study, the method of SPECT using ^{99m}Tc-PPi, and its usefulness in diagnosing acute myocardial infarction, were investigated.

Material and methods

Fifteen patients consisting of 12 men and three women with acute myocardial infarction were admitted to Kenritsu Imabari Hospital between September 1983 and June 1985, and they were the materials of this study. Myocardial infarction was diagnosed by a history of typical chest pain, electrocardiographic changes and patterns of serum creatine kinase elevation. The mean age of patients was 65.9±9.4 (mean ±SD) (**Table 1**).

^{99m}Tc-PPi myocardial scintigraphy was performed two to six days after the onset of myocardial infarction. Conventional planar images, anterior, 30 to 60 degrees left anterior oblique and left lateral projections, were made two to three hours after the injection of 20 mCi 99m Tc-PPi. Images were obtained at preset

Table 1. Electrocardiographic, planar and SPECT uptake findings of 15 patients with acute myocardial infarction

No.		Age	Sex	ECG	Plannar uptake		SPECT uptake	
				Location	Degree	Pattern	Pattern	Location
1.	Y.H.	54	M	I, L	III	focal	focal	I, L
2.	M.H.	49	M	A, S	II	focal	focal	A
3.	K.M.	76	F	A, L	III	diffuse	focal	A, L (S, I)
4.	T.S.	52	M	I	I	focal	focal	I
5.	M.H.	71	M	A, S, L	IV	doughnut	focal	A, S, L
6.	M.Y.	72	M	A, S, L	IV	diffuse	focal	A, S, L
7.	K.Y.	70	M	A, S	III	focal	focal	A (S, I)
8.	S.A.	75	M	I	II	focal	focal	I
9.	I.O.	62	M	P	II	focal	focal	P (A)
10.	S.F.	77	F	I, L	III	focal	focal	I, L
11.	S.T.	63	M	I	III	focal	focal	I
12.	C.A.	61	M	I	III	focal	focal	I
13.	M.S.	73	F	I	IV	focal	focal	I
14.	S.K.	59	M	(L)	III	focal	focal	L
15.	K.H.	55	M	A, S	III	focal	focal	A, S

A=anterior wall; I=inferior; L=lateral; S=septal; P=posterior.

Fig. 1. Measurement of infarct size.
Color-coded tomogram of technetium-99m (left) and the automatically-detected boundary using 70% subtraction of the maximal counts (right).

times of 1 to 1.5 minutes, with a low energy, high resolution, and parallel-hole collimator.

After obtaining the planar images, SPECT was performed using a rotating gamma camera (Gamma View-F Hitachi), rotating from 45 degrees right anterior oblique to 135 degrees left anterior oblique. A total of 32 projections were obtained 15 seconds in each projection. These data were stored as 64×64 matrixes using

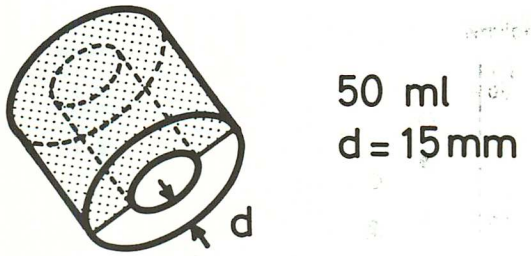

Fig. 2. Cylindrical phantom.

a nuclear medicine computer system (HARP system).

From two to four weeks after the onset of myocardial infarction, ^{201}Tl gated SPECT was performed using the same method as for ^{99m}Tc-PPi scintigraphy. Gated images were collected during about 100 beats in each projection 20 minutes after the injection of three to five mCi thallium-201 chloride.

Transaxial tomograms were reconstructed for both ^{99m}Tc-PPi and ^{201}Tl scintigraphy. Coronal and sagittal tomograms were reconstructed in a similar fashion. Sagittal long axial, coronal long axial and short axial tomograms in the cardiac axis were reconstructed with 201-Tl gated SPECT. In the same cardiac axis as

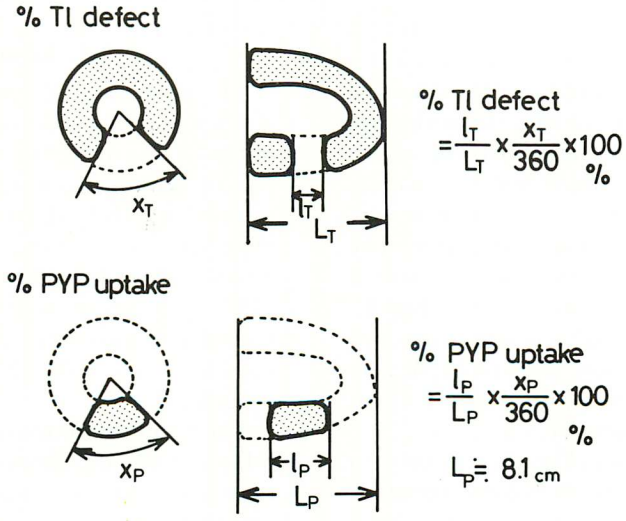

Fig. 3. %Tl defect and %PYP uptake.

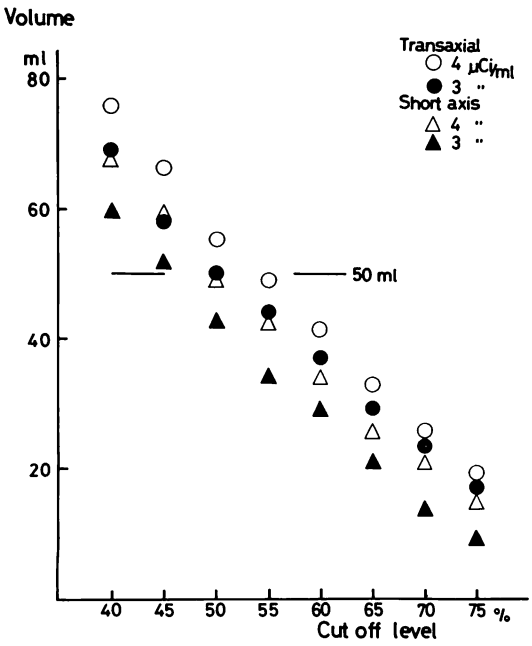

Fig. 4. Phantom volumes measured by SPECT and (70%) subtraction rate of the maximal counts.

Open circles: transaxial images, 4 μCi/m*l* Tc O_4^-
Closed circles: transaxial images, 3 μCi/m*l* Tc O_4^-
Open triangles: short-axial images, 4 μCi/m*l* Tc O_4^-
Closed triangles: short-axial images, 3 μCi/m*l* Tc O_4^-

201-Tl gated SPECT, three 99m Tc-PPi cardiac axial tomograms were reconstructed.

Infarct size was estimated with transaxial tomograms using 99m Tc-PPi. In each slice where myocardial uptake was seen, the region of interest around the infarct was set, and the boundary was obtained by a subtraction rate (70% cut off level) of the maximal counts. The voxels of the myocardial areas were measured automatically by a computer system (**Fig. 1**). The total numbers of voxels of myocardial uptake summed from all slices were multiplied by 0.227 m*l*/voxel (one voxel with a side 0.61 cm long) to determine infarct size.

A cylindrical phantom (**Fig. 2**) was used to determine the sensitivity of volume measurement. The upper half of this cylinder, volume of which was 50 m*l*, was filled with a uniform aqueous solution containing 3 μCi/m*l* and 4 μCi/m*l* of $^{99m}TcO_4^-$. This phantom was then placed in the same axis as the cardiac long axis. Phantom volume was measured with both transaxial and cardiac short axial tomograms in various subtraction rates from 40 to 75% of maximal counts.

%Tl defect, the index of the infarcted myocardium compared with the entire myocardium of the left ventricle, was calculated as follows:

$$\%\text{Tl defect} = \frac{l_t}{L_t} \times \frac{x_t}{360} \times 100 \quad (\%)$$

Where L_t was the length of the sagittal long axis of 201-Tl gated SPECT without background subtraction, l_t was the length of the defect due to infarct, and x_t was the defect angle on short axial tomograms (**Fig. 3**).

%PYP uptake was calculated in a similar fashion. L_p was the approximate value, 8.1 cm, as detected by the mean length of L_t in 201-Tl gated SPECT.

Serum creatine kinase was measured at three hour intervals for 24 hours after the time of admission, then six hour intervals for 48 hours, then 12 hour intervals for 48 hours, and finally, 24 hour intervals until the enzyme level became normalized. The cumulative release of creatine kinase was calculated using a method modified after the original formula of Shell et al[9].

Results

The electrocardiographic location of infarct, and findings of planar and tomographic images of the 15 patients are shown in **Table 1**. Twelve patients with planar images had focal uptake in accord with their electrocardiographic finding. However, two patients had diffuse uptake, which made it difficult to detect the infarct site. SPECT images showed focal uptake consistent with electrocardiographic finding in all patients, including two with diffuse uptake by planar imaging.

The results of measurements using a cylindrical phantom are shown in **Fig. 4**. A 50% subtraction rate was found to be adequate for measuring phantom volume. However, the volume was affected by the concentration of

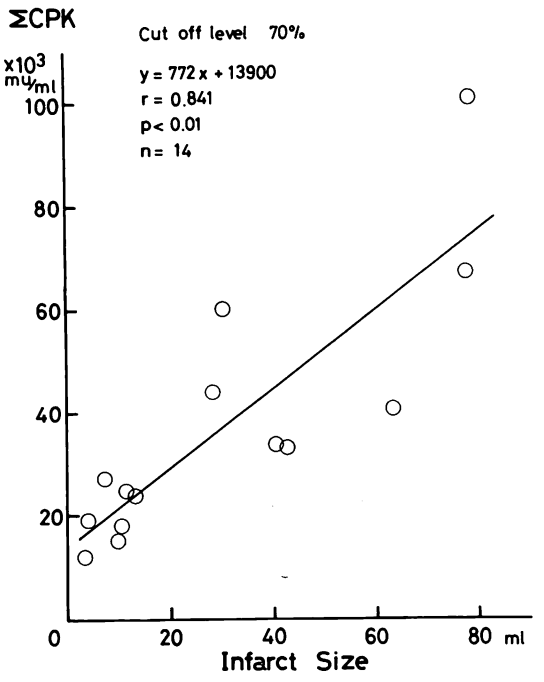

Fig. 5. Correlation between cumulative creatine kinase release and infarct size.

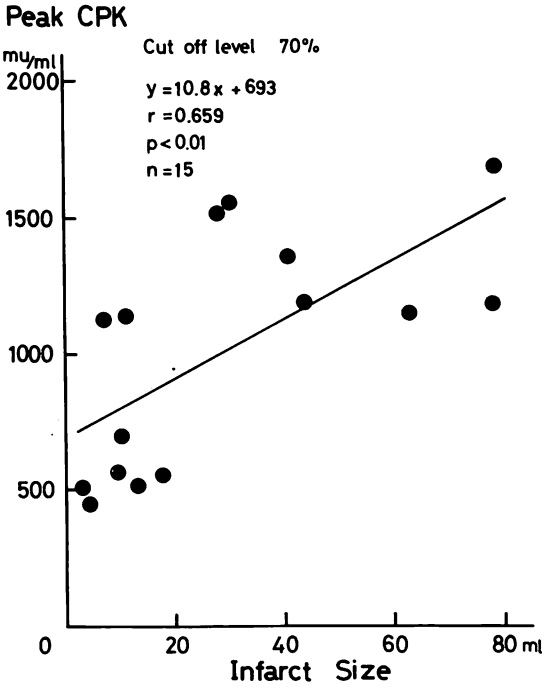

Fig. 6. Correlation between peak creatine kinase level and infarct size.

$^{99m}TcO_4^-$ and the method of reconstructing transaxial or cardiac short axial images.

The mean value of %Tl defect and %PYP uptake of 15 patients were approximately 20% of the left ventricular myocardium. Then, the mean volume of infarcted mass was expected to range from 20 to 30 m*l*. Because the weight of the entire left ventricular mass ranged from 100 to 150 g, the mean value of %Tl uptake and %PYP uptake were approximately 20% and the specific weight of myocardial tissue was 1.05 g/m*l*.

The mean infarct size of 15 patients was 107.8±108.5 m*l* (mean±SD) with 50% subtraction of the maximal counts, 60.8±53.8 m*l* with 60% subtraction, 30.1±26.8 m*l* with 70% subtraction and 11.8±8.5 m*l* with 80% subtraction. Therefore, the infarct size of the 15 patients was measured by 70% subtraction of the maximal counts. Infarct size ranged from 3.4 to 78.3 m*l*.

There was a good correlation between cumulative creatine kinase release and infarct size as shown in **Fig. 5** ($r=0.84$, $p<0.01$, $y=772x+13900$). The peak serum creatine kinase also correlated well with infarct size ($r=0.66$, $p<0.01$, $y=10.6x+693$) (**Fig. 6**).

Representative SPECT images of a patient (No. 5) with anteroseptal and lateral infarction are shown in **Fig. 7**. His electrocardiographic pattern consisted of ST elevation and abnormal Q waves in chest leads V_1 to V_4. There was echocardiographic asynergy in the anteroseptal wall. SPECT images clearly showed his myocardial necrosis in the anteroseptal and lateral walls.

Discussion

^{99m}Tc-PPi myocardial scintigraphy has been used to accurately diagnose myocardial infarction in the early stage and to localize the site and determine its extent[2~5]. However, because of some limitations due to diffuse up-

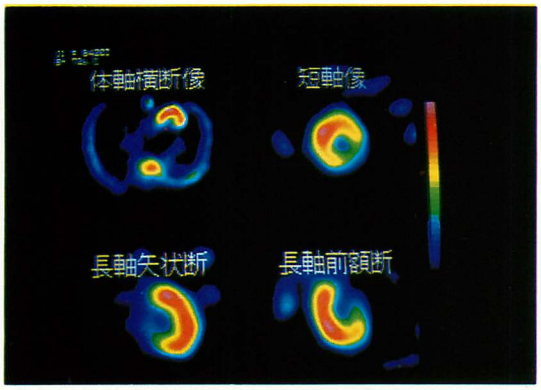

Fig. 7. Tomographic images in a patient (No. 5).
Transaxial tomogram (left upper panel), short-axial (right upper panel), sagittal long-axial (left lower panel) and coronal long-axial (right lower panel) views show anteroseptal and lateral uptake of technetium-99m pyrophosphate.

take of ^{99m}Tc-PPi, it is sometimes difficult to determine the localization[6~8]. Diffuse uptake is also seen in patients with other heart diseases[6,7,10], and even in those without heart disease[11,12]. Furthermore, localization of myocardial uptake is obscured in some cases because of uptake of 99m Tc-PPi in bones.

In contrast, SPECT with 99m Tc-PPi can provide arbitrary tomographic images. It is anticipated that SPECT can evaluate three-dimensional information and can discriminate uptake in the myocardium from that in bones. Several studies of the utility of SPECT have been reported[13,14].

In the present study, two patients (No. 3, No. 5) exhibited diffuse uptake in planar images and one patient (No. 4) showed a doughnut pattern. All patients' SPECT images showed focal uptake and localization of their uptake nearly consistent with their electrocardiographic findings. In one patient (No. 3), the electrocardiographic findings and SPECT were not consistent. The former suggested lateral transmural and anterior nontransmural infarction; the latter, anterior, lateral, and even septal and inferior wall lesions. Echocardiography, however, showed extensive motion abnormalities from the anterior to inferior walls, so that the findings of SPECT more accurately reflected myocardial necrosis.

In previous studies, infarct size has been estimated using 99m Tc-PPi myocardial scintigraphy. Several animal studies of planar images have shown a good correlation between histologically-determined infarct weights and scintigraphically-imaged infarct areas[15~17]. In humans, serum peak creatine kinase levels and scintigraphically-imaged infarct areas have correlated well[18]. Analysis of serum creatine kinase curves has been used as an index of infarct size[9]. Recently, SPECT has been used to estimate infarct size both in animals[19~21] and humans[22~24].

Tauxe et al.[25] showed that a threshold of 45 to 46% of maximal activity predicted most closely the true volumes of cylindrical phantoms without background preparation. In our study, 50% subtraction of the maximal counts was the most adequate subtraction rate for the measurement of a 50 m*l* cylindrical phantom. However, infarct size of 15 patients which was estimated in this way was overestimated.

Holman et al.[22] and Corvett et al.[24] defined the boundary as 65% subtraction of the maximal counts by a phantom study with background preparation.

In our study, %Tl defect and %PYP uptake were investigated to determine the best subtraction rate of the maximal counts, and 70% subtraction was the most accurate for measuring infarct sizes.

In conclusion, SPECT with ^{99m}Tc-PPi is a useful means of evaluating the spatial distribution of pyrophosphate uptake and for estimating the sizes of myocardial infarction.

^{99m}Tc ピロリン酸 SPECT を用いた急性心筋梗塞の定量的評価

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急性心筋梗塞に single photon emission com-

puted tomography (SPECT) を用いた ^{99m}Tc ピロリン酸スキャンを行い，従来の planar image と比較検討した．また SPECT 像より心筋梗塞量 (infarct size) を求め，心筋梗塞の定量的評価を試みた．

急性心筋梗塞 15 例に通常の planar image を行い，ついで回転型ガンマカメラにて，180°，24 方向より SPECT 像を得た．心筋梗塞量は，体軸断層像で，phantom study および心電図同期 ^{201}Tl 心筋 SPECT 像の検討より求めた 70% cut off level で辺縁を描出し，voxel 数を加算する事により求めた．

Planar image との比較では，planar 像上 diffuse pattern で梗塞の局在が不明な例でも，SPECT 像では局在が明瞭であり，心電図所見とよく一致していた．

SPECT 像より求めた梗塞量は，CPK 流出量 (ΣCPK) との間に $r=0.841$ ($p<0.01$)，$y=772x+1.39\times10^4$ の良好な相関があり，また CPK 最高値 (peak CPK) との間には $r=0.659$ ($p<0.01$)，$y=10.8x+693$ の良い相関があった．

SPECT 像を用いた ^{99m}Tc ピロリン酸心筋スキャンは，急性心筋梗塞の定量的評価に有用であると考えられた．

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