Characterization of Nontransmural Myocardial Infarction by Positron-emission Tomography

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SUMMARY The present study was performed to determine whether positron emission tomography (PET) performed after i.v. 11C-palmitate permits detection and characterization of nontransmural myocardial infarction. PET was performed after the i.v. injection of 11C-palmitate in 10 normal subjects, 24 patients with initial nontransmural myocardial infarction (defined electrocardiographically), and 22 patients with transmural infarction. Depressed accumulation of 11C-palmitate was detected with sagittal, coronal and transverse reconstructions, and quantified based on 14 contiguous transaxial reconstructions. Defects with homogeneously intense depression of accumulation of tracer were detected in all 22 patients with transmural infarction (100%). Abnormalities of the distribution of 11C-palmitate in the myocardium were detected in 23 patients with nontransmural infarction (96%). Thallium scintigrams were abnormal in only 11 of 18 patients with nontransmural infarction (61%). Tomographically estimated infarct size was greater among patients with transmural infarction (50.4 ± 7.8 PET-6Eq/m² [± SEM]) compared with those with nontransmural infarction (19 ± 4 PET-6Eq, p < 0.01). Residual accumulation of 11C-palmitate within regions of infarction was more intensely depressed among patients with transmural compared to nontransmural infarction (33 ± 1 vs 39 ± 1% maximal myocardial radioactivity, p < 0.01). Thus, PET and metabolic imaging with 11C-palmitate is a sensitive means of detecting, quantifying and characterizing nontransmural and transmural myocardial infarction.

POSITIVE-EMISSION TOMOGRAPHY (PET) after i.v. carbon-11 (11C) palmitate facilitates quantitative assessment of regional myocardial metabolism noninvasively in vivo. Its accuracy and value in localizing and estimating the magnitude of transmural infarction have been documented.1-4 However, the sensitivity of this technique and the feasibility of using it to distinguish between transmural and nontransmural myocardial infarction have not been elucidated.

Myocardial infarction is generally diagnosed by historical, electrocardiographic and enzymatic criteria.5 However, diagnosis may be difficult when patients present late after suspected infarction or with relatively nonspecific electrocardiographic manifestations accompanying nontransmural myocardial infarction.5-8 Other noninvasive techniques, including technetium-99m (99mTc) pyrophosphate infarct imaging and thallium-201 (201Tl) scintigraphy have been used under these conditions.9-11 However, patients with nontransmural infarction exhibit inconsistent patterns of 99mTc accumulation, ranging from poorly defined, diffuse accumulation to intense local uptake indistinguishable from that of typical myocardial infarction.12,13 The sensitivity of 201Tl scintigraphy for nontransmural infarction is also limited.14,15

This study was performed to assess the sensitivity of PET compared with that of 201Tl scintigraphy and to characterize its value for delineating the extent, nature and anatomic distribution of injury with nontransmural compared with transmural myocardial infarction.

Materials and Methods

Patients

All 56 subjects gave informed written consent. The group included 10 normal subjects (six males and four females, average age 39 years, range 23-68 years) and 46 patients who had survived acute myocardial infarction for at least 72 hours. Control subjects were seven normal volunteers without a history of chest pain or myocardial infarction and with normal physical examinations and three patients admitted to the coronary care unit for the evaluation of atypical chest pain in whom myocardial infarction was excluded based on serial electrocardiographic and enzymatic criteria. None of the controls had experienced previous myocardial infarction or exhibited Q waves on the ECG.

The 46 patients (31 male, 15 female, mean age 57 years, range of 29-84 years) experienced myocardial infarction documented by a history of precordial chest pain of at least 20 minutes duration and serial elevations of total and MB plasma CK. Demographic data are summarized in table 1.

Patients with myocardial infarction preceding the index episode were excluded. Transmural myocardial infarction was considered to be present if Q waves of 30 msec duration were seen in recordings from at least two concordant leads. In the absence of these criteria, nontransmural myocardial infarction was considered to be present. Infarction was transmural in 22 and nontransmural in 24 patients.

Radiochemicals and Tomographic Procedures

The 11C-palmitate was prepared with a synthesis developed at Washington University that involves the addition of 11CO2 produced in the medical center cyclotron to a Grignard reagent (1-MgBr-pentade-
cane). Blood pool tomographic imaging was performed with red blood cells labeled in vivo with $^{14}$CO administered by inhalation.

The total body radiation absorbed from combined myocardial and blood pool tomography using 20 mCi of $^{11}$C-palmitate and 30 mCi of $^{11}$C-carbon monoxide was $\leq 450$ mrem, with a maximum of 2600 mrem delivered to the liver and 1740 mrem delivered to the blood.

Tomography was performed with a positron-emission transaxial tomograph (PETT-IV), which provides for the simultaneous acquisition of data needed to reconstruct seven parallel transaxial cross sections (slices) of the heart. Midpoints of the sections are separated by approximately 1 cm. After moving the patient 1 cm and repeating the tomographic imaging procedure, 14 interleaving transaxial slices can be reconstructed, spanning a height of 12.35 cm. Initially, a ring containing a positron-emitting radioisotope, gallium-68 ($^{68}$Ga), was placed around the patient to provide data for measuring attenuation coefficients. Subsequently, patients were studied after i.v. injection of 15–20 mCi of $^{11}$C-palmitate. After a delay of approximately 2 hours to permit decay of the $^{11}$C-palmitate (half-life of 20.4 minutes), patients were restudied after inhaling 20–30 mCi of $^{14}$CO to delineate the approximate endocardial borders in each transaxial slice by comparing the $^{14}$CO reconstruction superimposed on the $^{11}$C-palmitate reconstruction. All studies were performed without gating of the cardiac cycle, because the limitations of the spatial averaging used were not considered critical to the primary purpose of detecting and localizing subendocardial injury. The resolution of the tomographic system was 13.5 mm (full-width, half maximum) in the plane of the section with a section thickness of 16 mm.

To assess the potential dependence of the sensitivity of PET on the time after onset of myocardial infarction, we performed studies at selected intervals after the apparent onset of infarction. Patients with nontransmural infarction were studied an average of 31 days (range 3–46 days) after its onset, when hemodynamics were stable and the patients were not experiencing chest pain. Patients with transmural infarction were studied an average of 42 days after onset (range 2–175 days). During all tomographic studies, patients were attended by a physician. The ECG and vital signs were monitored continuously. No complications of the procedure were encountered.

**Assessment of the Extent of Myocardial Injury**

Tomographic reconstructions of the distribution of $^{11}$C-palmitate accumulation in normal subjects generally exhibited homogeneous accumulation of tracer throughout a horseshoe-shaped region with a nearly constant ventricular wall thickness. The most posterior aspect of the ventricle generally exhibited a discontinuity of $^{11}$C-palmitate accumulation in the region of the mitral valve apparatus, because the apparatus and atrial myocardium are so thin and metabolically inactive. However, among patients with infarction, regions of depressed accumulation of palmitate appeared as either abnormal discontinuities of accumulation of palmitate or as apparent variation of the thickness of the horseshoe-shaped region of ventricular uptake and inhomogeneity in the magnitude of accumulation of palmitate within this region (figs. 1–3). Data from each transaxial, sagittal, and coronal section were displayed on an oscilloscope in a 100 × 100 element grid with a 256-level gray scale. A printout was generated with a Versatec printer/plotter of the region encompassing the heart in which a numerical value from 0–255 was assigned to each pixel, indicating the relative radioactivity detected within each corresponding region of tissue. The contour of the ventricle was constructed and the region of infarction defined as a zone within the contour that contained less than 50% of the maximal myocardial radioactivity as previously described (fig. 2). The extent of the infarction was calculated by the formula

$$\text{Infarct size} = \sum_{i=1}^{n} V_i \frac{[100 - a_i]}{100} \times 10^{-\frac{g}{cm^2}}$$

where $n$ is the number of transverse reconstructions with a defect, $V$ is the volume of the infarction in a reconstruction (calculated from the thickness of the section and multiplied by the total area of the defect), and $a$ is the average radioactivity within the region of the defect in the slice. This calculation reflects both the distribution and the integrated magnitude of the depression of accumulation of $^{11}$C-palmitate. The calculated volume of the lesion is converted to gram-equivalents (g-Eq), based on the assumption that the specific density of myocardium is approximately 1 g/cm$^3$.

Both maximal radioactivity within normal myocardium and mean activity within regions of infarction were corrected for background radioactivity by measuring mean radioactivity within a background region within the atrial blood pool. Background was not based on the ventricular blood pool because cardiac motion may artifactually increase apparent activity in the ventricular blood pool region due to partial volume effects. A separate background value was obtained for each tomographic reconstruction. In the caudal sections that contained no atrial blood pool re-
Figur 1. Color superimpositions of images obtained after i.v. \textsuperscript{11}C-palmitate (green) and subsequent inhalation of \textsuperscript{13}C-carbon monoxide (red) from a normal subject and from patients with anterior nontransmural and anterior transmural myocardial infarction.

region, background was determined from the descending aortic blood pool region.

Among patients with inferior and inferoapical myocardial infarction (either transmural or nontransmural), sagittal and coronal reconstructions were required to estimate the extent of myocardial injury reflected by diminished accumulation of \textsuperscript{11}C-palmitate because reductions of uptake were often confined to the one or two most caudal transaxial sections in which the delineation of the endocardial borders is difficult. However, inferoapical and inferoposterior regions of injury were easily visualized in coronal and sagittal reconstructions. These reconstructions were performed after mathematical stacking of interdigitated transaxial reconstructions from initial and repeat data collections. Since sagittal and coronal reconstructions contained data that were collected in a nonsimultaneous fashion, with data collection intervals of different durations (in order to ensure adequate counting statistics), data from either the first or second set of transverse tomographic reconstructions were corrected with a scaling factor to normalize the count density in the alternating sections. In normal subjects, the accumulation of isotope was homogeneous, reflecting a relatively uniform apparent myocardial wall thickness in sagittal and coronal reconstructions with variations of only two to four pixels (fig. 2).

Sagittal and coronal reconstructions were displayed oscilloscopically and the data within the region encompassing the heart were plotted with a 16-level gray scale. Regions with less than 40\% of the maximal myocardial radioactivity were white. A 40\% threshold (as opposed to a 50\% threshold used for transaxial sections) was used to minimize a banding effect related to the time-dependent acquisition of differing counts in alternating transaxial sections. Myocardial outlines were constructed (assuming a uniform wall thickness for the normal ventricle), and regions within the outline containing less than 40\% of maximal myocardial radioactivity were designated as zones of infarction (fig. 2). Data from the sagittal and coronal reconstructions were used only to delineate the approximate coordinates of the region of infarction rather than for calculations. The information defining boundaries obtained from sagittal and coronal reconstructions was transposed to the transverse reconstruction as shown in figure 2B, and both normal and abnormal regions were outlined. Infarct size was than calculated with the same algorithm used for direct analysis of transaxial data.

Thallium Imaging

Myocardial imaging was performed with \textsuperscript{201}TI to compare its sensitivity to that of PET. Imaging was performed with the patient at rest, 10-15 minutes after administration of 1-1.5 mCi of \textsuperscript{201}TiCl\textsubscript{5} intravenously. Data were collected with a standard-field (25.4-cm-diameter, 0.64-cm-thick NaI crystal) scintillation camera (Searle LEM) fitted with a low-energy, medium-resolution, parallel-hole collimator interfaced to a dedicated minicomputer (Technicare VIP 450). Images were obtained in the anterior, 35\° and 65\° left anterior oblique and left lateral projec-
Thallium imaging was performed within a mean of 2 ± 3 (SD) days of the corresponding PET study. Studies were interpreted from both analog images obtained at the time of data collection displayed on transparency film and from digital data displayed on the minicomputer after selected levels of background subtraction and contrast enhancement. We previously reported a close agreement between independent observers using this technique. Thallium and PET studies were interpreted independently by separate observers without knowledge of the results of the other procedure or the clinical diagnosis.

FIGURE 2. (A) Representative midventricular transverse reconstruction from a normal subject obtained with positron-emission transaxial tomography (PET IV) after $^{14}$C-palmitate is displayed (center) along with sagittal (top) and coronal (right) reconstructions. The planes of sagittal and coronal reconstructions are indicated by the solid lines. The white area to the left of the coronal reconstruction represents the liver, which has been partially blocked out for photographic purposes. $S$ = superior; $I$ = inferior; $A$ = anterior; $P$ = posterior; $L$ = left; $R$ = right. (B) Schematic representations of transverse (center), sagittal (top) and coronal (right) reconstructions from a patient with an infero-posterior infarction. The horizontal bars on the sagittal and coronal views indicate the plane of the transverse reconstruction. The solid lines connecting the sagittal, coronal and transverse views indicate the planes of section. The discontinuities indicated by the interrupted chamber outlines indicate regions of infarction.

Statistical Methods

Results are expressed as mean ± SD or SEM, as indicated. Mean data were compared using the t test for unpaired samples, and proportions were compared by chi-square analysis or McNemar's test, where appropriate.

Results

Tomography in Control Subjects

The normal left ventricular contour delineated by PET at the midventricular level conformed to a horse-shoe-shaped region with a uniform apparent wall thickness averaging 7.0 ± 0.3 (SEM) pixels in the septum, 8.0 ± 0.3 in the anterior wall and 7.9 ± 0.2 in the lateral wall (fig. 1). The regions corresponding to the mitral valve and atria did not accumulate enough radiopharmaceutical to be visualized due to the thinness of these structures and their relatively low metabolic rate. The right ventricle was visualized as a thin crescent, anterior and to the right of the left ventricle. The extent of accumulation of palmitate in the right ventricle was less than that in the left ventricle (often only 20–40% of maximal myocardial palmitate activity). This relatively slight accumulation reflects the low metabolic demands and the thin structure of the right ventricle. When $^{14}$C-carboxyhemoglobin blood pool and $^{14}$C-palmitate reconstructions obtained in normal patients were superimposed, the blood pool completely filled the horseshoe-shaped ventricular region of palmitate accumulation and extended posteriorly, representing atrial blood pools as well. The borders of the region of $^{14}$C-carbon monoxide activity and $^{14}$C-palmitate accumulation were in close approximation (fig. 1).

Serial sagittal and coronal reconstructions in normal subjects demonstrated comparable apparent thickness of the regions of palmitate accumulation in the anterior, anteroapical and inferior walls with homogeneous accumulation of palmitate (fig. 2A). In posterior coronal reconstructions, a zone of absent accumulation was generally observed in the superior portion of the septal region due to the thin, membranous portion of the ventricular septum. In sagittal
reconstructions, a discontinuity was visualized in the superoposterior aspect of the cardiac outline due to the mitral valve apparatus and atria (fig. 2A). PET images demonstrated this homogeneous accumulation in all three planes in eight of the 10 control subjects. In one clinically normal, 27-year-old male medical center employee, a small discontinuity (considered to be a false-positive result) was noted in two transverse reconstructions. In one other control subject, a 51-year-old female who had been admitted to the coronary care unit for chest pain and new ST-T abnormalities in whom infarction was excluded by enzymatic criteria, a larger defect was observed in transaxial reconstructions performed after i.v. $^{11}$C-palmitate, and images obtained after injection of $^{201}$TI showed corresponding abnormalities. Thus, although this patient may be considered to represent a false-positive result, antecedent infarction may have caused the abnormalities.

Transmural Myocardial Infarction

Transmural myocardial infarction appeared as a confluent region of homogeneously diminished accumulation of palmitate (fig. 1). A large area with diminished activity is evident in the anterior and anterolateral regions of the left ventricle, with apparent bulging of the ventricular blood pool due to an anteroapical left ventricular dyskinetic area. With transmural infarction, regions involved consistently demonstrated homogeneously decreased accumulation of tracer, and normal zones demonstrated homogeneous uptake throughout.

A close concordance was observed between electrocardiographic and the tomographic loci of infarction. Thus, infarction associated with Q waves in V$_1$–V$_6$ was associated with depression of accumulation of palmitate in regions corresponding to the septum and midanterior wall. Infarction associated with Q waves in leads V$_1$–V$_6$ was associated with depressed accumulation of palmitate in regions corresponding to anterolateral regions of the ventricle. Electrocardiographically typical apical or inferior infarctions were usually associated with no tomographic defect in the midventricular transverse reconstructions. However, defects were evident consistently in sagittal and coronal reconstructions and were localized to the apical and inferior walls. Decreased accumulation of palmitate was detected in all 11 patients with transmural infarction, with the estimated mass of infarction averaging $50.4 \pm 7.8$ (SEM) (table 2).

Nontransmural Infarction

Nontransmural myocardial infarction was evident as a region of diminished myocardial accumulation of palmitate. However, the regions of depressed accumulation of isotope were often not transmural. Frequently, they were manifest by apparent thinning of the zone of accumulation of palmitate (fig. 1). In the reconstruction shown, the septum and posterior wall exhibited normal accumulation of palmitate. The

![PET IV $^{11}$C-Palmitate](image)

**Figure 3.** Positron-emission transaxial tomographic (PET IV) images of the myocardium from a normal subject and from patients with nontransmural and transmural myocardial infarction after i.v. $^{11}$C-palmitate. In each row all pixels with radioactivity below the threshold shown in the left column (expressed as a percentage of maximal myocardial radioactivity) are displayed in black. The white area to the left of the heart seen in both patients with infarction represents the liver, which has been partially blocked out for photographic purposes.

<table>
<thead>
<tr>
<th>Table 2. Tomographic Characteristics of Infarcts</th>
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<tbody>
<tr>
<td>Infarct size (PET-g-Eq)</td>
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<td></td>
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<tr>
<td>Residual radioactivity in zone of infarction (% max. myocardial radioactivity)</td>
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<tr>
<td>Proportion of patients with abnormal PET images</td>
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</table>

Values are mean $\pm$ SEM.
Abbreviation: PET = positron-emission tomography.
anterior and anterolateral regions of the left ventricle exhibited shell-like regions of depressed palmitate accumulation on both endocardial and epicardial aspects of a region of more intense accumulation. The tomographically thinner anterior region of the ventricle exhibits heterogeneous accumulation of palmitate in marked contrast to the homogeneous depression typical in regions of transmural infarction. Because of the heterogeneity, the myocardial (palmitate) image fails to abut the cardiac blood pool image. Separation between the "thinned" section of the anterior and anterolateral region of accumulation of palmitate and the cardiac blood pool may represent a region of sub-endocardial infarction that does not accumulate palmitate. Alternatively, it may reflect a more uniform apparent depression of palmitate accumulation attributable to partial volume effects and regionally depressed wall motion. Reconstructions are performed without gating, and thus include spatial averages blurred by cardiac motion. If a region of myocardium accumulates palmitate normally, but does not move, the radioactivity in that region would be high, but apparently distributed throughout a thinner zone on the image than a similarly radioactive region that was moving during the imaging interval.

A zone with apparent depression of accumulation of palmitate and a thin configuration could result from a mixture of normal and abnormal tissue blurred by motion or from a severely depressed regional accumulation of isotope within a zone of myocardium with no motion.

Heterogeneous accumulation of palmitate within zones of relatively "normal" myocardium near the region of the infarction was striking in addition to the marked heterogeneity noted within the region of the apparent infarction itself. When transverse reconstructions were displayed after background subtraction (fig. 3), the heterogeneity of the depression of the accumulation of palmitate became particularly evident. The images shown in figure 3 were obtained by displaying midventricular transaxial reconstructions with selected levels of background subtraction. Regions in the reconstructions that exhibited levels of accumulation of isotope below the threshold listed in the left column of the figure are displayed in black, and regions of accumulation of isotope above the threshold are displayed on a gray scale in proportion to the intensity of the accumulation of isotope. Regions with activity in the displays shown in the top row of the figure but not in displays shown in the middle row contained only 30-40% of maximal radioactivity within the myocardium. Those with activity in the displays in the middle row but not in those in the bottom row of the figure contained 40-50% of maximal radioactivity within the myocardium. Substantially more regions with radioactivity in the 30-50% range of maximum were evident in hearts with nontransmural infarction compared to those with transmural infarction.

In addition, myocardial accumulation of palmitate was severely and homogeneously depressed in regions of transmural infarction, but only heterogeneously and less severely depressed in regions of nontransmural infarction (fig. 3). Residual radioactivity within the region of infarction (expressed as a percentage of the maximal myocardial radioactivity) averaged 33 ± 1% (SEM) among patients with transmural infarction in contrast to 39 ± 1% among patients with nontransmural infarction (p < 0.01) (table 2).

Nontransmural infarction in tomographic reconstructions was characterized by apparent thinning of the region of accumulation of palmitate within left ventricular myocardium and by heterogeneity of depression of accumulation as well. Figure 4 shows transverse PET reconstructions from a normal subject and from subjects with nontransmural myocardial infarction. Only one of the 24 patients with nontransmural myocardial infarction exhibited normal and homogeneous patterns of accumulation of 11C-palmitate in transverse, sagittal and coronal reconstructions. The remaining 23 (96%) had striking abnormalities; examples are shown in figure 4. Patients 109 and 94 had regions of accumulation of palmitate, with only shell-like intramural regions of apparently normal accumulation of palmitate remaining within the regions of apparent infarction. Palmitate accumulation is heterogeneous within the

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**Figure 4.** Positron-emission transaxial tomographic (PETT IV) images obtained after i.v. 11C-palmitate at approximately the midventricular level in a normal subject and from patients with nontransmural myocardial infarction at the loci indicated.
Thallium Imaging

Thallium-201 imaging was performed in 18 of the 24 patients with nontransmural infarction; the six others were reluctant to undergo a second radionuclide procedure. There were no obvious or statistically significant differences in gender, age, infarct location or estimated infarct size among patients who were compared to those who were not studied with $^{201}$Tl. Among the 18 patients studied with thallium, 11 (61%) had abnormal $^{201}$Tl images. The location of the abnormalities in the $^{201}$Tl images corresponded to the location of the discontinuities of the accumulation of palmitate in PET reconstructions in these patients. In contrast, PET reconstructions exhibited regions of depressed regional palmitate accumulation in 17 of the 18 patients (94%). Overall, abnormalities were detected in 23 of 24 patients with nontransmural infarction studied with PET, compared to 11 of 18 patients studied with $^{201}$Tl ($p < 0.05$) (table 4).

No significant differences in mean estimated infarct size distinguished patients with normal compared to those with abnormal thallium images. Among the patients with normal $^{201}$Tl images, one exhibited a large region of diminished accumulation of palmitate (patient 104, fig. 4). Another exhibited relatively small, nontransmural diminutions of accumulation of palmitate (patient 94, fig. 4). Several exhibited primarily apical diminution of accumulation of $^{11}$C-palmitate, evident only in sagittal and coronal reconstructions. In general, among patients who exhibited an abnormality on the $^{201}$Tl scan, the locus corresponded to regions of

<table>
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<th>Pt</th>
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<th>PET location</th>
<th>Thallium location</th>
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diminished accumulation of $^{11}$C-palmitate seen with PET (table 3).

**Discussion**

Results of this study indicate that PET is a sensitive and specific technique for detecting nontransmural and transmural myocardial infarction. Abnormalities were detected by PET in all 22 patients with transmural infarction and 23 of 24 patients with nontransmural infarction. In contrast to the apparent sensitivity of PET for nontransmural infarction of 96%, only 61% of patients with nontransmural infarction had abnormal $^{201}$TI scintigrams. Small regions of depressed accumulations of palmitate were noted in septal regions of two of 10 control subjects. However, one of these subjects may have had antecedent intramural infarction.

Substantial differences distinguished the tomographic appearance of transmural from nontransmural infarction. Transmural infarction (defined electrocardiographically) exhibited homogeneous depression of accumulation of $^{11}$C-palmitate extending from the endocardial to the epicardial surface. In contrast, PET reconstructions from patients with nontransmural infarction exhibited marked spatial heterogeneity of myocardial accumulation of palmitate. In some patients, only marked heterogeneity was observed; in others, regions of heterogeneous accumulation of isotope were interspersed with regions of apparent thinning of the palmitate uptake zone. In a few patients, homogeneous depression was seen similar to that more typical of transmural infarction. The extent of the regions with depressed accumulation of tracer appeared to be more modest and more heterogeneous than that of the regions typical of transmural infarction. Overall, the extent of myocardial infarction, assessed by PET, was less among patients with nontransmural compared to those with transmural infarction. In addition, the distribution of palmitate was more heterogeneous in grossly normal zones.

Previous studies have shown substantial variability in the sensitivity of thallium imaging for detecting myocardial infarction, depending on the time of the imaging after infarction, the location, intramural extent, and the size of the infarct. A sensitivity of almost 100% has been achieved among patients with transmural infarction imaged within the first 6-12 hours after onset of infarction. However, when imaging is delayed by 24 hours, sensitivity is dramatically decreased. Unfortunately, the high early sensitivity may reflect scintigraphic changes due to ischemia rather than infarction per se. In the present study, $^{201}$TI imaging was performed late. However, tomographic studies and $^{201}$TI scintigraphy were performed at approximately the same interval after infarction. Three of the seven patients with normal $^{201}$TI scintigrams were imaged before a PET study that was positive. The greatest decrease in sensitivity of $^{201}$TI scintigraphy occurs within the first 24-36 hours after infarction. Further delays do not appear to change sensitivity markedly. Thus, only slight differences in sensitivity would be expected among patients studied by $^{201}$TI scintigraphy on the fifth compared to the tenth day after infarction.

Autopsy data indicate a wide spectrum of anatomic abnormalities in hearts of patients who die with nontransmural infarction, ranging from relatively small scars that are limited to the inner one-third or one-half of the myocardium to large circumferential zones of necrosis involving 50-70% of the inner layer of the left ventricle. Some subjects who exhibit only ST-T abnormalities on the ECG exhibit typical transmural lesions at autopsy. It is not surprising that the spectrum of abnormalities detectable by PET in patients with electrocardiographically identified nontransmural infarction is wide.

Heterogeneous accumulation of palmitate in patients with nontransmural infarction reflects interspersed regions of normal and abnormal accumulation. In addition, the almost continuous variation of activity even within small zones may well reflect closely admixed normal and abnormal cells. The gross, spatial heterogeneity is probably a reflection of the consequences of the multivessel coronary artery disease so common among patients with nontransmural infarction.

Tomographic reconstructions are affected by cardiac motion during data collection. Wall motion tends to blur borders between metabolically normal and abnormal regions. Movement within the plane of section and movement in and out of the plane of the section influences results. The consequent blurring results in spatial averaging, and tends to "smooth" the data, making it appear more homogeneous. The consistently high accumulation of palmitate in normal regions and relatively uniform depression of accumulation of palmitate within abnormal regions of transmural infarcts are consistent with completed, homogeneous infarction adjacent to myocardium remaining viable with normal metabolism when the patient is at rest. Patients with nontransmural infarction often have a clinically stuttering syndrome, with small extensions of infarction after the initial insult. Thus, in hearts of patients with nontransmural infarction, zones of completed infarction may be interspersed with regions of evolving or very recent infarction and with regions remaining at high risk for subsequent infarction. This heterogeneous distribution appears to be reflected by corresponding heterogeneity in tomographic images.

Our data indicate significant differences in the appearance of PET reconstructions from patients with

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**Table 4. Relative Sensitivity of Positron-emission Tomography and Thallium-201 Imaging**

<table>
<thead>
<tr>
<th>PET</th>
<th>Thallium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>96%</td>
</tr>
<tr>
<td>(abnormal/total)</td>
<td>(23/24)</td>
</tr>
<tr>
<td>Specificity</td>
<td>80%</td>
</tr>
<tr>
<td>(abnormal/total)</td>
<td>(2/10)</td>
</tr>
</tbody>
</table>

*Previously published from this institution.19

Abbreviation: PET = positron-emission tomography.
transmural compared with nontransmural myocardial infarction, but they do not permit an assessment of the value of PET for separating patients with unstable angina from those with nontransmural infarction. A recent study performed at our institution indicates that the initial accumulation of palmitate is comparable for regions of canine myocardium supplied by normal and partially obstructed coronary arteries. The region supplied by the partially obstructed coronary artery cannot be distinguished from normally perfused myocardium with the first transaxial tomographic reconstruction. However, when time-activity curves are constructed for normally perfused and underperfused regions, clearance of palmitate is depressed in ischemic but still viable regions supplied by partially occluded coronary arteries. Thus, ischemic, infarcted and normal myocardium are distinguished by dynamic tomographic studies that should be applicable to patients as rapid scanning instrumentation becomes available.

Our findings indicate that PET, performed after the i.v. injection of $^{11}$C-palmitate, is a sensitive and specific means of detecting and characterizing nontransmural and transmural myocardial infarction. Transmural and nontransmural myocardial infarctions are distinctly different. Transmural infarction exhibits homogeneous, intense depression of the accumulation of palmitate. Nontransmural infarction exhibits marked heterogeneity in the accumulation of palmitate. The spectrum of tomographic manifestations of nontransmural infarction reflects the spectrum of morphologic abnormalities. The present findings suggest that PET with $^{11}$C-palmitate will be useful not only in detecting nontransmural infarction and its definitive diagnosis, but also in characterizing its natural history and response to interventions designed to salvage jeopardized regions within the overall zone at risk.

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Characterization of nontransmural myocardial infarction by positron-emission tomography.
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