Single-Photon Transaxial Emission Computed Tomography of the Heart in Normal Subjects and in Patients with Infarction

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Resting computerized transaxial tomography was performed after the i.v. injection of thallium-201 in six normal subjects and in five patients who had had myocardial infarctions 3 mo to 4 yr before scintigraphy. Decreased myocardial activity corresponded to the site of previous infarction in all cases and was clearly separated from adjacent myocardium with normal activity. With tomography, the left ventricle was clearly separated from surrounding structures such as the left-ventricular cavity, the lungs, and the liver. This study demonstrates the feasibility for the assessment of myocardial perfusion using single-photon transaxial emission computed tomography.

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Myocardial scintigraphy with thallium-201 has become a routine procedure for assessing regional myocardial perfusion, particularly in patients with suspected coronary artery disease. Because of the geometric constraints of two-dimensional imaging (*1*), the procedure has limitations with regard to its sensitivity and its ability to estimate the extent of regional ischemia.

Single-photon transaxial emission computed tomography (ECT) has been applied clinically in the central nervous system (*2,3*) resulting in an increase in sensitivity and specificity when compared with conventional radionuclide imaging (*2*). Recently, a single-photon transaxial ECT unit for imaging the thorax and abdomen has become available commercially. We have evaluated myocardial perfusion using this unit and Tl-201 in normal subjects and patients with previous myocardial infarction.

METHODS

We have studied six male subjects without clinical evidence of coronary artery disease, and five patients who had sustained acute myocardial infarction within the prior 3 mo to 4 yr. Documentation of acute myocardial infarction at the time of the initial episode included the following criteria: a) precordial chest pain lasting 1 hr or more, b) typical serial changes in plasma creatine kinase (CK) activity, and c) standard ECG changes indicative of acute infarction, including evolution of Q waves. Patients with documented infarction were chosen randomly for inclusion in the study without consideration for the location of the infarct. The five patients reported in this preliminary note, however, all sustained anterior or anteroseptal infarcts. All studies were obtained in the resting state, 15–30

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min after the injection of 1.5 mCi of Tl-201.

The CLEON 711 Radionuclide Body Function Imager* was used to perform the ECT study. The detection system consists of a ring-shaped gantry assembly in which are mounted ten scanning detectors at 36-degree intervals around the opening of 61 cm. Each detector consists of a focused collimator, an 8- × 5- × 1-in. NAI(Tl) crystal, light pipe, 3.5-in. diameter PMT, preamplifier, amplifier, and pulse-height analyzer. The effective field of view is limited to the central 50.8 cm. The focal length of the collimator is 43 cm. The manufacturer's specifications for Tc-99m resolution along the 52-cm scan direction of the detector is 19 mm (FWHM). The FWHM for Tc-99m along the direction of pallet (patient) travel is 20.3 cm. Our independently determined measurement of resolution in the plane of the detectors was 17 mm FWHM using as the source an extended capillary tube loaded with Tc-99m. The sensitivity for Tc-99m is 8500 cps/μCi-ml, measured with a cylindrical phantom 20 cm in diameter. These values may differ on current systems due to upgrading in software and hardware.

The detectors move in pairs, such that when one pair of detectors is scanning tangentially and incremented towards the opening (patient), the adjacent pairs are scanning tangentially and incremented away from the opening. The focal point of each detector scans half the field of view. Each of the six opposing detector pairs performs a rectilinear scan on the plane of the slice over the body from a different angle. After a scan pattern is completed, the entire detector assembly is rotated 18° and the scan process repeated. Thus, in effect, the body is viewed by 20 detectors spaced at 18-degree intervals.

The detectors perform 12 tangential line scans spaced at 2.4-cm intervals, each line being 52 cm long and divided into 128 resolution elements. The spacing between slices can be selected in multiples of ⅛-in. and is automatically controlled by the movement of the patient's couch. The gantry can be tilted through an angle of ±15° to the vertical, allowing image sections at various angles.

The computer cabinet contains a dual floppy-diskette drive for data storage, a computer with 48K of memory, and a disk drive unit for a single-platter hard disk. The computer can interrogate the operator's console, where all display and scanning parameters are selected. The console is used to control the entire process of scanning, data acquisition, reconstruction, and display. Hard-copy output is available on x-ray and/or Polaroid film.

Image reconstruction commences after the data for the first slice have been acquired. An analytical reconstruction method is used for image formation. Each opposed pair of detectors acquires a projection of the final image. The following mathematical operations are performed on each of the acquired ten equiangularly spaced projections: collimator correction, smoothing, filtering, and empirical attenuation correction, and the projections are rotated and interpolated. Finally the ten projections are normalized and combined into a single image.

The ECT study was performed using a slice interval of 0.5 in. beginning at the base of the heart and progressing towards the apex. These slice intervals were contiguous and thus represent serial transaxial slices through the heart. Data acquisition was not gated to the electrocardiogram. Four or five sections were obtained during the study on each patient. Each section required 5 min for data collection and 2 min for data processing. A complete 4-section study would take 22 min, since reconstruction begins as soon as the data for that section have been acquired. Each transaxial section contained between 200,000 and 350,000 counts. The study was displayed on a video monitor with a 16-level grey scale using a 240 × 256 image matrix. All images were initially interpreted without contrast enhancement or background subtraction. The images were then displayed with a background subtraction of 20–40%. This percentage was chosen on the basis of subjective clinical preference for image interpretation, and more importantly to remove a certain noise level inherent in the image due to residual background of reconstruction artifacts from the filtering process. There was no difference in the number of normal and abnormal images obtained with and without background subtraction.

RESULTS

ECT images obtained in the six normal subjects had a characteristic appearance (Fig. 1). At the base of the heart, the left ventricle appeared horseshoe-shaped, with the long axis of the horseshoe oriented between 35° and 45° toward the left anterior oblique. The distribution throughout the septum and the anterior and lateral walls was homogeneous. The open end of the horseshoe corresponded anatomically to the mitral and aortic valves. Sections obtained in the midventricular plane demonstrated a doughnut-shaped appearance, with uniform uptake throughout the doughnut except for some thinning and decreased activity along the posterior wall near the base of the heart. This latter region corresponded to the open end of the horseshoe seen on slices at the base of the heart. The absent activity at the center of the doughnut corresponded anatomically to the left-ventricular cavity. Slices obtained at the apex showed a round or ovoid region of activity with a minimal or absent

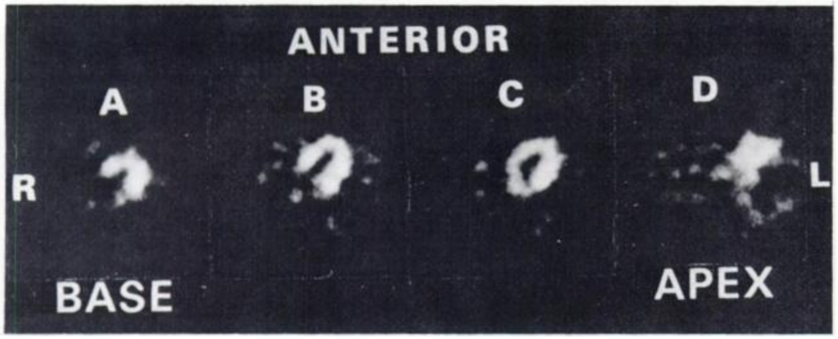

FIG. 1. Normal transaxial tomography of the heart. Slices are oriented as though viewer is looking from below, with anterior surface up. See text for description. A, B = base of left ventricle; C = midventricle; D = apex.

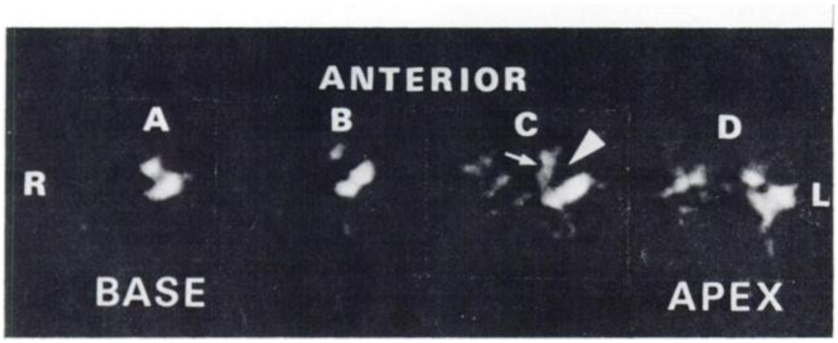

FIG. 2. Transaxial perfusion tomography in patient with anteroseptal infarct. Note reduced activity in region of intraventricular septum (arrow) and markedly reduced activity in region of anterior wall of left ventricle (arrowhead). A, B = base of left ventricle; C = midventricle; D = apex.

central defect; this appearance is consistent with a transverse slice through the apical wall distal to the cardiac chamber. Right-ventricular and atrial activity could not be detected.

In all five patients with previous myocardial infarction, regions of markedly reduced Tl-201 uptake were noted in areas corresponding to the location of the infarct (Figs. 2 and 3). The borders between the normal myocardial activity and the reduced activity were abrupt and clearly defined on tomography. In all five cases the regions of reduced myocardial activity were clearly separated from the left-ventricular cavity, lungs, and liver.

DISCUSSION

Radionuclide techniques that assess regional myocardial perfusion provide information useful for the detection and evaluation of coronary artery disease and in the assessment of therapies aimed at limiting the degree of ischemia and the extent of tissue necrosis. Myocardial perfusion scintigraphy with Tl-201, performed after exercise, is more sensitive than the stress electrocardiogram in detecting the presence of coronary artery disease (*4–6*). Nevertheless, the technique has limitations as a screening test for coronary artery disease and as a technique to determine the extent of tissue injury. It is not sufficiently sensitive to justify omitting coronary angiography in patients with chest pain but with normal scintigrams and exercise electrocardiograms. For example, in one series of patients without previous myocardial infarction but with hemodynamically significant coronary artery disease, only 77% had abnormal thallium myocardial scintigraphy with exercise (*4*). In another series almost one quarter of patients with coronary disease had no defects found on either the rest or the exercise Tl-201 image (*6*).

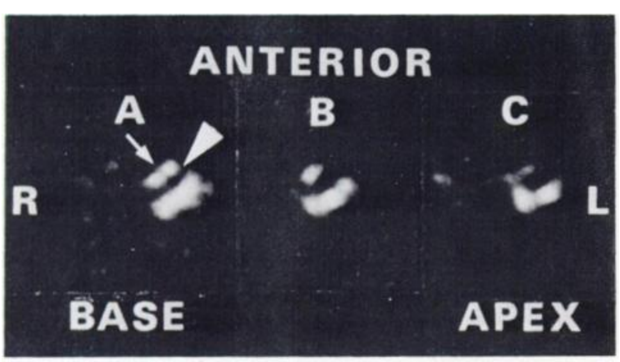

FIG. 3. Transaxial tomography in patient with decreased perfusion to septum (arrow) and markedly reduced perfusion to anterior wall of left ventricle (arrowhead). A = base of left ventricle; B = midventricle; C = apex.

A further limitation of conventional scintigraphy is that determination of the extent of the damaged myocardium cannot be made accurately. Decreased activity due to the left-ventricular cavity must be differentiated from decreased myocardial uptake. Perfusion defects along the inferior border of the myocardium may be masked by overlapping liver, particularly at rest. Superimposition of normally perfused myocardium over regions of altered perfusion may cause a low estimate in the extent and degree of perfusion deficits (*1*). Thus, the correlation between estimates of infarct size, determined at postmortem examination and from two-dimensional scintigraphy, has been only fair when the extent of infarction was determined manually (r = 0.69) and when it was determined with computer assistance (r = 0.72). There was good correlation only when the infarcts were grouped according to their location (*7*).

Tomographic imaging techniques overcome the geometric limitations of the standard two-dimensional scintigraphic methods. Three-dimensional image reconstruction using positron-emitting radiotracers (PCT) has been applied to the myocardium, and with this technique, myocardial perfusion has been estimated (*8,9*) and acute infarction detected (*10*). PCT has the additional advantage over conventional thallium perfusion scintigraphy that physiologic substrates such as C-11 palmitic acid can be applied to the assessment of myocardial metabolism. The uptake of this tracer is greatly reduced under conditions in which hypoxia accompanies normal perfusion. The clinical application of PCT is limited, however. It requires either an on-site cyclotron with radiopharmaceutical expertise for the synthesis of the radiotracers, or close access to regional suppliers of short-lived tracers such as F-18, Rb-81, and Fe-52. Of the positron emitters for assessing myocardial perfusion, only Rb-82 has the potential for widespread clinical availability. It may be limited by its 75-sec physical half-life.

Emission tomography using gamma-emitting radionuclides has been described using a single-crystal camera (*11,12*), but the imaging time and reconstruction time were too long for routine clinical application. Recently, accurate sizing of acute infarction has been reported with Tc-99 pyrophosphate (*13*), and with less satisfactory detection of altered perfusion using Tl-201 and the same single-crystal device (*14*).

Another approach to the quantitation of regional myocardial perfusion has been performed after obtaining longitudinal tomography with technetium-99m microspheres and the Fresnel zone plate camera (*15*). The size of the reduced myocardial activity accurately estimated the extent of myocardial damage in a canine model of infarction. Although this technique used a commercially available radiotracer and an inexpensive camera, it required the intracoronary injection of the radiotracer.

More recently, longitudinal tomograms of the heart have been obtained with Tl-201 and a seven-pinhole collimator (*16*). With this approach, the sensitivity for detecting hemodynamic coronary artery lesions is reported as 95% (*17*). The collimator can be used with commercially available large-field-of-view gamma cameras. The pinhole collimator results in image distortion, however, which may affect estimates of infarct size.

In this report, we have demonstrated the feasibility of myocardial scintigraphy with Tl-201 using a whole-body ECT scanner. Transaxial tomograms, depicting the three-dimensional distribution of Tl-201, were of diagnostic quality and were acquired quickly enough to be clinically practical for the determination of infarct size (ECT ar rest) and for the detection and assessment of coronary artery disease (ECT after exercise). Perfusion defects found in patients with prior infarction were clearly separated from other anatomic structures such as the lung, liver, cardiac chamber, and normally perfused myocardium. Single-photon ECT of the heart using Tl-201 yields high-contrast images that permit prompt and easy identification of myocardial infarcts. Since this technique uses commercially available tracers, it has potential for widespread application in clinical nuclear medicine, limited only by the cost of the imaging device. Because imaging is rapid (5 min per image) due to the high efficiency of the multiple-detector array, tomography can be completed within 20–30 min. Therefore, this technique is suitable for assessing myocardial perfusion during exercise. The ECT imaging device is not portable, however, and imaging of acute infarction is limited to patients who can be transported to the nuclear medicine clinical unit.

FOOTNOTE

* Union Carbide Imaging Systems, Norwood, MA.

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