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COMPARISON OF POSITRON TOMOGRAPHY AND SCINTIGRAPHY WITH ^{201}Tl FOR DELINEATION OF THE MYOCARDIUM

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Introduction

Recent advances in nuclear medicine instrumentation have led to the development of improved positron-imaging systems which exceed in performance the earlier systems which were limited mainly by low count rate capability. This has led to renewed interest in positron imaging in general, primarily because such devices offer better resolution and higher sensitivity than conventional, mechanically collimated gamma cameras, as well as tomographic capability which may provide additional and more accurate information for the clinician. Furthermore, the unique capabilities of positrons for use in reconstructive imaging are beginning to be exploited. In the present report, results are presented from a preliminary study in which longitudinal tomographic myocardial images, produced with ^{81}Rb as the positron-emitting label using the double camera coincidence system described by Muehllehner (7) are compared with conventional myocardial images obtained with ^{201}Tl and a Searle Pho-Gamma HP camera.

Methods

The positron imaging device used represents a refinement of the concept first proposed by H. O. Anger (1) and originally incorporated into research prototypes by a number of individuals. Unlike the single-detector, mechanically collimated gamma camera, this system localizes a positron-emitting radioisotope distribution by electronic coincidence collimation of the 511 keV annihilation pairs. It has high sensitivity ($\sim$ 200 c/s/μCi), good resolution at all depths (better than 10 mm FWHM), and a significantly improved count rate capability (up to 8,000 counts/second under favorable clinical conditions). In addition, since the image is formed by viewing the source from many angles, the technique is inherently tomographic and allows imaging of planes of interest at different depths through an object. Lastly, since both 511 keV γ rays of a coincident pair travel the same total distance through an object regardless of the depth of the original annihilation, correction for the overall attenuation and nonuniform detector sensitivity may be carried out by normalization to a transmission image. The most substantial modifications compared with the original system were the use of graded absorbers to reduce scattered radiation from the patient. Also, the standard 1/2 inch-thick scintillation crystals were replaced by 1 inch-thick crystals to increase the probability that both annihilation quanta are detected in coincidence. In addition, pulse-shortening filters and D.C.-coupled,

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low-dead-time electronics were added to the cameras to allow higher rates of data acquisition (8).

For the thallium images, a Searle Pho-Gamma HP camera was used with a 20% window centered on the mercury x-rays. The high-resolution collimator (No. 821741) used gave spatial resolution comparable to that of the positron system. As radiopharmaceuticals, ^{201}Tl obtained commercially and ^{81}Rb produced locally (4) free of ^{82}Rb, were injected intravenously in three normal healthy individuals, eleven patients with well-documented myocardial infarcts, and two patients with non-ischemic heart disease with normal coronary angiograms. In 7 of the subjects, it was possible to carry out complete studies with both methods within a period of less than 48 hours. The presence of ^{201}Tl did not interfere significantly with a subsequent ^{81}Rb scan, since the graded absorbers used to reduce source scatter effectively prevented the low-energy ^{201}Tl radiation from entering the crystal. Thallium studies were always done first. Images in four equally spaced planes of focus, spaced 3 cm apart, were produced simultaneously in the ^{81}Rb study, while four projections in the anterior-posterior (AP), 30° left anterior oblique (LAO), 60° LAO, and 30° right anterior oblique (RAO) were taken with ^{201}Tl. All pictures contained 300,000 counts and were recorded in conventional analogue form on Polaroid film and in digital form in the 120x128 matrix of an Ohio Nuclear 150 Data System. The positron images were corrected for the marked radial variation of sensitivity and variation of attenuation by normalization to the corresponding tomographic transmission images made with a ^{68}Ge-^{68}Ga sheet source using the uniformity correction function of the data system.

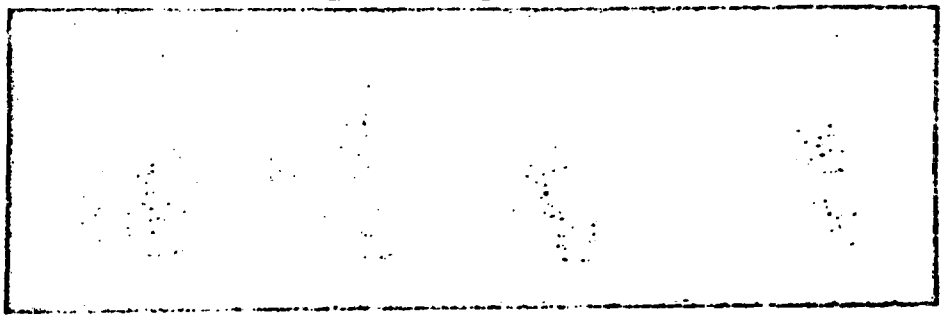
Results

Using comparable doses of isotope in both examinations (0.9-1.2 mCi of ^{201}Tl and 0.8-1.6 mCi of ^{81}Rb), pictures containing the same number of counts (300,000) were produced in about 7.5 min with the positron camera and in about 12.5 min in the thallium studies, leading to a total imaging time of 20 min for ^{81}Rb, including the transmission image, and about 60 min for the four views made with ^{201}Tl.

It appeared feasible to define perfusion defects in the anterior, lateral, apical, inferior, septal, and posterior regions of the heart. Six of the seven patients had well-defined clinical myocardial infarcts, whereas the symptoms in one patient proved to be unrelated to cardiac pathology. A typical example of a comparison of the two studies is shown in Fig. 1. In both examinations, the results matched quite well, and were in agreement with the clinical findings in six cases (5 infarcts, 1 non-infarct patient). In one case, neither method demonstrated any uptake defect. In this patient infarction was diagnosed only by a moderate rise in enzymes, but not in the EKG; therefore this infarct must be regarded clinically as being very small. The clinical results are summarized in Table 1.

The group of subjects in whom incomplete studies were carried out provided necessary data for evaluation of the various optional imaging modes. To obtain maximum image resolution and contrast, only photopeak coincidences were used. Isotope doses were limited by the ratio of random coincidence counts to true coincidence counts, and pictures taken at single event rates of 400,000 counts/sec leading to photopeak coincidence rates of 700 counts/sec seemed to be optimal in terms of the appearance of the image and the imaging time. Although the positron system is capable of high coincidence count rates in the absence of much

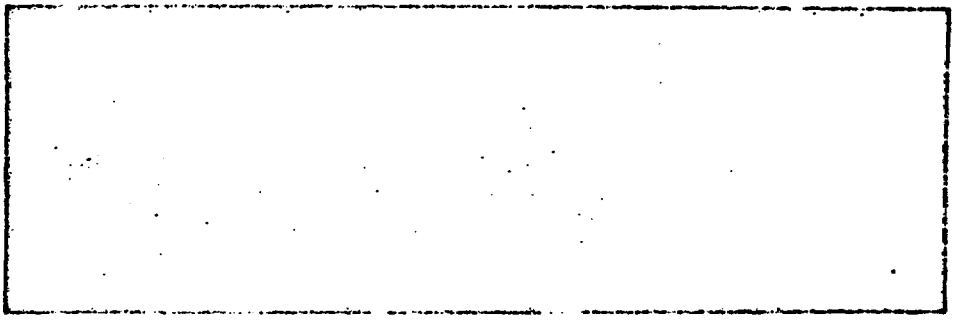
Scintigraphic Images with ^{201}Tl



30° RAO Anterior 30° LAO 60° LAO

30° RAO: Septal and inferior defect is seen clearly.
Anterior: Defect in septal and inferior regions again demonstrated.
30° LAO: Apical and inferior defect is visible.
60° LAO: No obvious defect is seen.

A-P Longitudinal Tomographic Images with ^{81}Rb
(plane separation 3 cm)



1 2 3 4

1: Superficial plane through anterior part of ventricular cavity shows inferior and septal defect.
2,3: Two central planes show septal and inferior uptake defects in left ventricular wall.
4: Deepest plane demonstrates no defect.

FIG. 1 (case 5, Table 1)

TABLE 1

Correlation of Location of Infarcts by EKG with Location of Uptake Defects Visualized with ^{201}Tl Scintigraphy and ^{81}Rb Positron Tomography

Infarct Location by EKG	Location of Uptake Defect: Anterior	Lateral	Apical	Inferior	Septal	Posterior		Remarks
1) Anterior Septal			XX	X			^{201}Tl	Acute
		X	XX				^{81}Rb	
2) Inferior				XX	X	X	^{201}Tl	Old
					X		^{81}Rb	
3) Inferior			X	XX	XX	X	^{201}Tl	Acute
				X	XX	X	^{81}Rb	
4) Antero Septal	XX	X	X		X		^{201}Tl	Old Antero Septal
Antero Lateral	XX	X	X		X		^{81}Rb	Acute Antero Lateral
5) Inferior			X	XX	X		^{201}Tl	Acute (Illustrated in Fig. 1)
				X	XX		^{81}Rb	
6) Normal EKG							^{201}Tl	Acute. Moderate Enzyme Increase Only
							^{81}Rb	
7) No Cardiac Lesion							^{201}Tl	Normal Angiogram
							^{81}Rb	

X denotes partial involvement of region.
XX denotes extensive involvement of region.
All patients with acute infarcts were studied 2-3 weeks after onset of symptoms.

extraneous radioactivity, in the case of heart images the presence of substantial activity in the liver and other nearby tissues limited the usable true coincidence rates as indicated above. The random coincidence rates under the circumstances of the present study were approximately 30% of the total rate. The spatial distribution of random events in the images can be evaluated by adjustment of the coincidence time windows to be out of phase by means of electronic delay lines. This procedure resulted in an image formed only by the random coincidence events. The spatial count distribution in this image was very similar to the response to a sheet source, except when the actual source was extremely asymmetrical. The images presented in this study have not been corrected for random events.

Measurements of system resolution by use of a ^{68}Ge-^{68}Ga line source surrounded by 20 cm of scattering material revealed depth-independent values of less than 10 mm FWHM for the positron camera, while the FWHM measured with a ^{201}Tl line source varied from 9.8 mm at the collimator face to 14.0 mm at 10 cm from the collimator face in scattering material. This difference between the measured resolutions in the two systems was not demonstrable in the clinical images. The ratio of count densities between the left lateral wall of the heart and the adjacent left lung in the anterior projection were determined in all studies by use of a small area of interest (36 picture elements containing 1000 to 5000 counts) positioned over each region. The resulting values, 2.29±0.35 (10 images) for ^{201}Tl and 2.49±0.55 (55 images) for ^{81}Rb, were nearly the same, a surprising result considering that tomographic images have inherently low contrast. Other factors contributing to possible differences in image contrast in the two systems are source scatter which is present with the thallium images and largely eliminated in the positron system, random coincidences which of course, do not affect the scintigraphic system and possible differences in the radionuclide uptake ratios. The measured width of the count density profile of the left cardiac border from the highest count level down to the level of the left lung was the same for the thallium images and for the two central planes in the tomographic images. Assuming that a sharp edge separates the left lateral cardiac wall from the left lung, the width of this edge in the image is a direct measurement of the spatial resolution. The highest and lowest planes appeared to have somewhat broader edges. This is consistent with the actual situation, since the highest and lowest planes show mainly the anterior and posterior walls of the heart and since these structures do not present such sharp edges against the background activity. Both methods appear to show the same anatomical details of the heart, although in different ways, and no new structures could be identified.

The somewhat smaller field of view of the positron camera and its increased sensitivity at the center of the field of view results in substantially greater count density (60%) in the central region of the image as compared to the thallium images containing the same total number of counts. This improves the quality of the myocardial images substantially when the heart is properly centered.

Discussion

Thallium-201 was chosen as a basis for comparison because this recently available agent appears to give the best myocardial images at the present time (2,5,9,11,12,13). Rubidium-81 was selected as the positron source because of its good myocardial localization and its 4.7 h half-life, which makes it potentially available to users without

production facilities. Both agents act as potassium analogues and should, in consequence, be taken up by the myocardial cells in proportion to the local perfusion. Recent animal studies in mice (12) reveal a somewhat higher specific concentration of ^{201}Tl in the myocardium compared with ^{81}Rb.

Rubidium-81 is not a pure positron emitter; it has strong peaks at 446 keV (0.23 per disintegration) and at 190 keV (0.64 per disintegration from the daughter product, ^{81m}Kr) as well as the annihilation radiation at 511 keV (0.61 photons per disintegration). In addition, gamma rays between 244 keV and 1.178 MeV are emitted (total 0.35 per disintegration (6)). Fortunately, only 7% of the 446 keV radiation is in coincidence with the annihilation radiation, of which a significant fraction is eliminated by the energy windows. The non-coincident 190 keV peak is attenuated to a large degree by the graded absorbers. These extraneous gamma photons contribute to both the single event and random coincidence rates.

The whole body absorbed dose is approximately 200 m rad/mCi (10) for ^{201}Tl and 100 m rad/mCi for ^{81}Rb (4).

In general, it appears in the present study that the images obtained with the positron camera system are comparable to those obtained the conventional system with ^{201}Tl, as judged subjectively (Fig. 1). The principal difference is the time required to carry out the entire imaging procedure. The fact that all tomographic planes are obtained simultaneously with the positron system is the principal factor in this difference, since the various views with ^{201}Tl must be obtained sequentially. There are additional potential gains in the use of the positron system in that the digital collection of the data in the list mode permits complete flexibility in selection of the location of the planes of focus, since they can be reconstructed by simple computer techniques instead of analogue methods. In fact, the low contrast inherent in the tomographic image presentation, combined with the radial variation in sensitivity, makes unprocessed analogue images almost unusable. Further, it appears possible, with the digital technique, to alter the inclination of the planes to the axis of the system if this is desirable.

An additional and much more exciting capability which appears possible is the application of the reconstruction method of Chang, McDonald, and Perez-Mendez (3) which, in essence, removes the out-of-focus data from the tomographic planes of interest. This should result in images with much higher contrast and lead to full realization of the intrinsically superior resolution of the positron imaging mode.

From the present comparative study, it can be concluded that the digital tomographic images obtained with this positron coincidence imaging device in a clinical situation are equivalent to pictures taken with conventional scintigraphic methods, but require a shorter imaging time. The information derived appears comparable in quality and content. From the point of technical performance, even at this early stage the new system appears potentially superior to conventional nuclear imaging techniques, and it appears easily adaptable to flexible digital manipulations, including quantitative reconstruction.

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ABSTRACT

In a preliminary study, the delineation of myocardial infarctions using thallium-201 with a conventional gamma camera has been compared with the results obtained with a tomographic positron camera using rubidium-81. Six patients with documented myocardial infarcts were studied with both methods, collecting 300,000 counts per image. The four projections obtained sequentially with thallium required about 60 minutes. Four tomographic planes recorded simultaneously with the positron system required about 20 minutes imaging time. The image quality was approximately the same for both systems, which demonstrated the lesions well. The positron system thus appears to be superior in performance and in connection with digital methods is capable of flexible extension to any number of simultaneous planes of focus and to reconstructive imaging.

ABSTRAKT

Im Rahmen einer ersten Untersuchung wurden konventionelle ^{201}Tl Myocardscintigramme mit Tomoscintigrammen verglichen, welche mit einem neuentwickelten Positronkamerasystem aufgenommen wurden. Sechs Patienten mit nachgewiesenem Herzinfarkt wurden mit beiden Methoden untersucht. Vier aufeinanderfolgende Bilder von je 300 000 counts benötigten mit ^{201}Tl ungefähr eine Stunde Aufnahmezeit, während die simultane Aufzeichnung von vier tomographischen Schichten ungefähr 20 Minuten dauerte. Die Bildqualität bei beiden Verfahre erwies sich als etwa gleichwertig und beide Techniken zeigten vorhandene Herzmuskellaesionen sehr gut. Die Positronkamera weist demzufolge eine hervorragende technische Leistungsfähigkeit auf und bietet in Verbindung mit digitaler Datenverarbeitung die Möglichkeit zur Bildrekonstruktion und der Bestimmung von flexiblen tomographischen Ebenen in beliebiger Anzahl durch das Objekt.

ABREGE

Lors d'une étude préliminaire sur la délinéation de l'infarctus du myocarde, on a comparé les résultats obtenus par l'emploi du Thallium 201 et d'une gamma caméra conventionnelle avec ceux obtenus par le Rubidium 81 et une positron caméra tomographique. On a étudié par les deux méthodes, 6 patients souffrant d'infarctus du myocarde caracterisés. En prenant 300 000 points par images avec le Thallium les 4 projections obtenues en séquence ont pris environ 60 min. Les 4 plans tomographiques enregistrés simultanément avec le système du positron demandent environ 20 min pour la prise d'image. La qualité de l'image est très comparable pour les deux systèmes, qui dans les deux cas font bien apparaître les lésions. Cependent le système du positron semble avoir des performances supérieures et, couplé avec des méthodes digitales, est capable d'extensions flexibles à n'importe quel nombre de plans focaux simultanés et à la reconstruction d'images.