Determination of Radionuclide Concentrations with Positron CT Scanning (PETT): Concise Communication

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A series of experiments was undertaken to evaluate the response of a positron emission transverse tomograph (PETT) to measured radionuclide concentrations similar to those encountered in human studies. The correlation between the response of the imaging system (mean PETT number/min), and the concentration of the radioactivity producing the output data, was linear with a computed sensitivity of 2720 PETT number/min, per μCi/ml, per picture element, for a radionuclide (100% β^+) contained in either of two phantoms and imaged with a resolution of 1.5 cm. It was concluded that the output data are essentially independent of the imaged object's physical dimensions for the range of 18–28-cm diam and faithfully reflect the regional radioactivity concentration within the object, provided valid attenuation correction is achieved and the sampled area is not compromised by the imaging system's limitations of spatial resolution.

J Nucl Med 18: 845–847, 1977

The capability of positron emission transverse tomographic (PETT) reconstruction to visualize structures not ordinarily observed with conventional nuclear medicine imaging devices has been shown (*1–3*). The result, achieved by the high contrast and uniform resolution inherent in annihilation coincidence detection—and by the elimination of the superposition of structures through the use of the mathematical reconstruction—provides a significant advance in nuclear medicine structural imaging. Another important attribute of positron computerized tomography (CT), however, provides the impetus for exploration of new areas in nuclear medicine. This attribute is the ability of positron CT scanning to yield accurately the regional in vivo concentrations of a radionuclide within an organ. This capability, unique to reconstructive techniques, permits positron CT scanning to be employed in a variety of applications, such as (A) the quantitative uptake of radionuclides in regions of interest; (B) the accurate determination, for dosimetry purposes, of the time course of a radiopharmaceutical through specific organs; and most important, (C) the regional determination of a wide array of physiologic and anatomic quantities, i.e., parametric imaging, in which the display represents the distribution of the computed quantity. The purpose of this communication is to show experimental results demonstrating the ability of positron CT scanning to predict faithfully the in vivo concentrations of radioactivity.

METHODS

Since the principles of operation of positron CT scanning have been extensively described elsewhere (*1,4,5*) this subject will not be discussed here.

Several experiments were undertaken to evaluate the response of the positron emission transverse tomograph (PETT) to measured radionuclide concentrations similar to those encountered in human studies. Two cylindrical plexiglass phantoms each constructed of five compartments were used, the larger having a diameter of 28 cm and the smaller

Received Dec. 3, 1976; revision accepted March 2, 1977.

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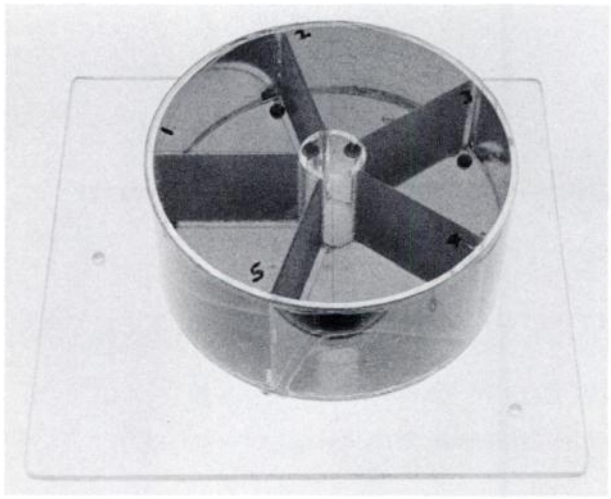

FIG. 1. Cylindrical plexiglass phantom (18-cm diam) showing the five compartments.

(Fig. 1) 18 cm. In a typical experiment each phantom was filled with radioactivity (20.3-min C-11) and sequentially scanned. For example, three scans, spaced at 20-min intervals, of a phantom having compartmental concentration ratios of 1:2:3:7:10 yielded 15 data points covering a concentration range of approximately 40:1. The relative concentrations in the various chambers were assessed by counting weighed aliquots (0.5 ml) with a 3-in. × 3-in. NaI(*Tl*) well detector. Conversion to approximate absolute values was done with a calibrated well ionization chamber.

Removable lead irises are employed in the PETT to define the inherent spatial resolution of the system. These experiments were performed with irises that provided a spatial resolution of approximately 1.5 cm in terms of FWHM of LSFs.

The data collected by the PETT were computer corrected for physical decay of the radionuclide occurring during the scan and, by either of two techniques, for attenuation. The attenuation was measured with the aid of a transmission scan and was also computed from known values of the attenuation coefficient and the object's physical dimensions (*1*). The results obtained by the two methods were in excellent agreement.

RESULTS

A representative reconstructed image of one of the test phantoms obtained with good sampling statistics is shown in Fig. 2.

Figure 3 shows the correlation between the response of the imaging system (mean PETT number/min) and the concentration of the radioactivity (arbitrary cps/ml) producing the output data for a typical experiment. The relationship is adequately represented (correlation coefficient, r = 0.998) by a linear regression line of

$$\text{mean PETT number/min} = 4.21 + 0.127\ (\text{cps/ml}).$$

Calibration of the detection system employed in counting the compartment aliquots permits computation of the PETT sensitivity. For a resolution of 1.5 cm this sensitivity was calculated to be 2720 PETT number/min, per μCi/ml, per picture element, for a radionuclide (100% β^+) contained in either phantom.

Table 1 lists the individual results obtained for a series of experiments involving the phantoms.

DISCUSSION

From the data shown in Fig. 3 it is observed that, for a wide range of concentrations, the output of the imaging system is linear with the concentration of radioactivity contained in the region of interest. In

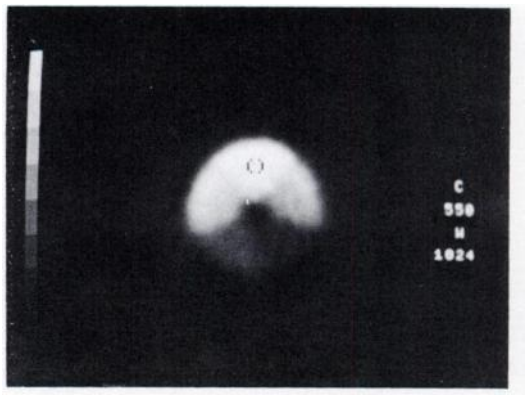

FIG. 2. Reconstructed image of test phantom showing cursor used for assessing mean data density of a particular area.

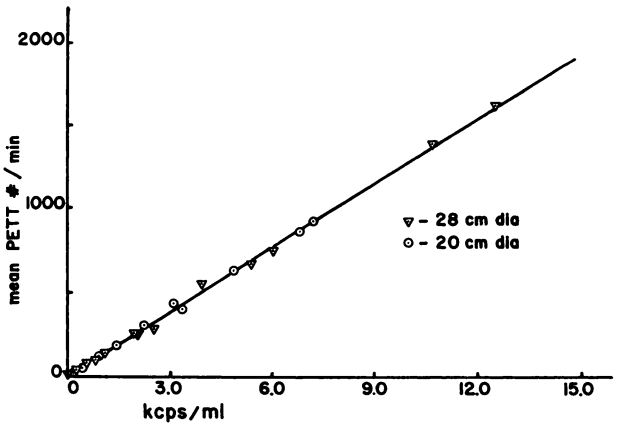

FIG. 3. Relationship between response of positron CT scanner (reconstructed mean PETT number/min) and regional radionuclide concentration (cps/ml) of imaged object.

TABLE 1. COMPILATION OF CALCULATED PARAMETERS FOR EIGHT EXPERIMENTS

Date of experiment	Phantom diameter (cm)	Linear regression parameters*		
		a_0	a_1	r
6/23/76	28	2.0	0.134	0.988
8/26/76†	18	10.8	0.126	0.998
8/26/76†	28	0.2	0.127	0.999
9/9/76	18	5.2	0.130	0.993
10/7/76	18	12.1	0.131	0.993
10/7/76	28	8.3	0.134	0.990
10/11/76	18	−3.2	0.122	0.997
10/22/76	18	−14.4	0.126	0.996

* PETT number/min = $a_0 + a_1$ (cps/ml).
† These experiments comprise the composite data of Fig. 3.

addition, the system response vanishes as the concentration approaches zero for this range of object concentrations. This behavior was consistent for system counting rates less than about 150,000 coincidence counts per minute. At appreciably higher concentrations, however, the effect of random coincident events was to reduce the slope of the regression line and yield a positive intercept, i.e., generate output data corresponding to regions containing no radioactivity. Thus it is prudent to conduct quantitative studies in the concentration range that permit adequate sampling statistics and acceptable collection times without introducing the perturbing effects of random events. This constraint is somewhat academic, however, since output counting rates in excess of 150,000 coincidence counts per minute are not generally attained in human studies.

It is also observed from Fig. 3 that the system response is essentially identical for the two phantoms employed, which correspond approximately to the object sizes encountered in head and torso studies. Thus the output data are independent of the imaged objects' physical dimensions for this range and faithfully reflect the regional radioactivity concentration within the object. In addition, it was observed that the system response is independent of the radioactivity gradients within the test object. These two observations strongly suggest that the PETT system can accurately measure the radionuclide concentration within structures of this size range provided valid attenuation correction is achieved and the sampled area is not compromised by the system's limited spatial resolution.

The small variation in the slopes of the regression lines (a_1) for the experiments listed in Table 1 indicates an excellent stability of sensitivity of the PETT system for substantial periods of time (a_1 = mean PETT number/min, per μCi/ml). This observation is reinforced by the fact that a_1 also reflects any change in sensitivity of the well scintillation detector used for determining the radioactivity concentrations. The wide range of values for the parameter a_0 results primarily from the random fluctuation of the small computed value of the y intercept. The minimal influence of a_0 in the computation of $y(y = a_0 + a_1x)$ is evident from an examination of the ratio a_0/y. This ratio is less than 0.05 for the majority of the data generated by these experiments.

It is concluded that positron CT scanning with the PETT provides a means of determining regional radioactivity concentration in vivo. This capability should stimulate the development of new and innovative techniques for nuclear medicine imaging.

ACKNOWLEDGMENTS

We wish to thank L. Troutt and W. Margenau for preparing the cyclotron-produced radionuclides employed in this study. This work was supported by USPHS Grant 5 P01 HL13851.

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