Determination of Organ Volume by Single-Photon Emission Tomography

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A method for estimation of organ volume is proposed, based on analysis of individual slices obtained from SPET images. In a phantom simulating clinical circumstances, the data show that the level a threshold at 46% of the maximum activity predicts most closely the true volume over a wide range above one liter. The level at 45% predicted better volumes of less than one liter. For phantoms of 839 ml or less, the error was 6.3 ml (one standard error of estimation). This level seems to be independent of the plane or position of the phantom and also independent of the amount of scattering material around it. Nonradioactive voids ("holes") within a phantom may be included or excluded at will when their edges are not tangent to the edge of the phantom. In such cases, their edges are not distinguishable from the edge of the phantom and their volumes are excluded. Knowledge of organ volumes has both diagnostic and therapeutic importance and could lead to a more precisely quantitated total of the radioactivity contained in an organ or space.

J Nucl Med 23: 984–987, 1982

Three-dimensional information, such as organ volume, has long been sought from two-dimensional nuclear medical images. Understandably, errors have often been high. Since single-photon emission tomography (SPET) provides the third dimension, it offers hope for more accurate quantification of organ volume. The purpose of this paper is to present the results of preliminary experience in the development of a linked series of computer programs, or macrofunction, utilizing SPET for the prediction of the volumes of various phantoms and organs.

MATERIALS AND METHODS

Phantom preparation. Seven cylindrical Lucite phantoms of varying volumes (53 to 5047 ml) were filled with a uniform aqueous solution containing 1 μCi/ml of $Na^{99m}TcO_4$. The cylindrical phantoms were first imaged individually and then one inside another in various combinations of two or three (Fig. 2), using unlabeled water to provide nonradioactive voids or "holes." In other instances, radioactive phantoms were placed inside larger vessels containing up to five liters of nonradioactive water to provide scattering material. Fourteen rubber ellipsoidal phantoms (balloons) containing 91 to 3261 ml of aqueous pertechnetate were also studied. Volumes were carefully determined by weight and by direct measurement.

Determination of pixel size. A pipette (~1 mm i.d.) was wrapped at 2-cm intervals with 5-mm lead bands 1 mm thick, then was filled with pertechnetate evenly dispersed in water for imaging and computer processing. Counts were printed out, pixel by pixel, by the computer. These were plotted on graph paper. Peak-to-peak and valley-to-valley distances (in pixels) were compared with analogous distances measured from the phantom for determination of the pixel length. A voxel was defined as a cubic pixel. A single emission tomographic system was used to provide all images in either two-dimensional or tomographic mode (*1,2*).

Imaging of phantoms involved the recording of 64 images at even angular intervals by a camera rotating around the object. Cylindrical phantoms were imaged with the flat end surfaces parallel to the transverse, sagittal, and frontal planes of the imaging device.

All tomographic images were reconstructed by computer according to the algorithm of Soussaline et al. (*1,2*). Field uniformity was analyzed carefully and corrected by the method of Todd-Pokropek et al. (*3*).

Received Feb. 4, 1982; revision accepted July 27, 1982.

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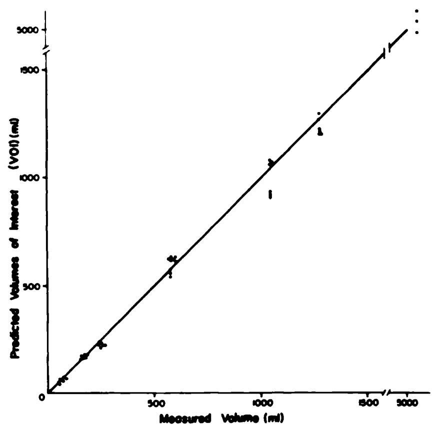

FIG. 1. Correlation of volumes of plastic cylinders containing $^{99m}TcO_4^-$ in water, determined by computer program (macrofunction) using single-photon emission scintigraphic data compared with measured volume. At each volume, three points on ordinate are shown, representing three planes studied.

Data processing. After reconstruction, each image was sliced at pixel intervals along the transverse, sagittal, and longitudinal planes oriented along the long axis of the imaging bed, and displayed as if seen from the feet of the subject. The voxel containing the maximum activity within a volume of interest (VOI) of the phantom or organ was sought. The data were then analyzed to determine the threshold that yielded the best correlation between calculated and measured volumes.

VOIs were grossly delineated in each projection at first by outlining the image with a cursor. This was performed on composite or individual slices.

The volume-estimation program was written so that, for each slice of the VOI, the computer added up the number of voxels containing activity that exceeded a threshold representing a given percentage of the maximum for the VOI. For each percentile between 35 and 55% of the maximum activity, voxel counts from all slices in a given projection were summed, converted into milliliters, and printed out. The program, called TVOL, was designed to measure only those volumes that contained radioactivity and not voids or "holes" in the VOI.

An alternative program, FVOL, was designed to estimate total volume, including any holes contained within a VOI, by thresholding only at the outer two edges of the lines from a slice and counting all voxels contained between the threshold points of these two ends, regardless of the counting rate. In both TVOL and FVOL, volumes were calculated at each percentage threshold level and compared with measured volumes.

RESULTS

The pixel length was found to be 0.64 cm when imaged in horizontal positions with respect to the detector and 0.64 cm in vertical positions. The mean pixel length of 0.64 gives a voxel volume of 0.26 ml.

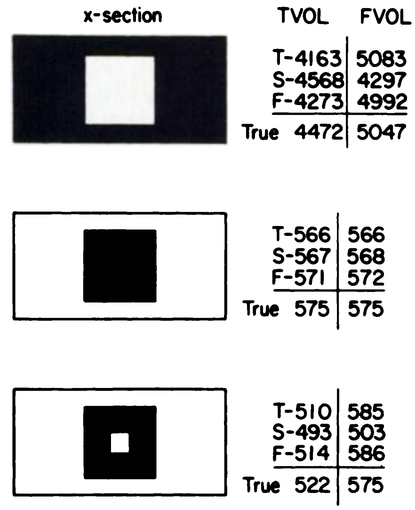

FIG. 2. Configuration of Lucite cylinder phantoms containing water (white) and $^{99m}TcO_4^-$ dispersed in water (black). Two computer programs (macrofunctions), TVOL and FVOL, were used to estimate volumes. TVOL estimated radioactive component only, excluding "holes"; FVOL included holes as well.

For the cylinders, the threshold level yielding a calculated volume closest to the determined volume occurred at 50.06% ± 3.12 (n = 43). Fifty percent was used as a threshold for subsequent calculations (Fig. 1). The regression equations and errors incurred at various volume ranges are presented in Table 1. The error over the whole range studied was approximately three times that observed when the upper limits of the range was lowered to 625 ml.

When the phantoms were rearranged so that they contained "holes" (Fig. 2), and were imaged in scattering material, it was found that both TVOL and FVOL predicted expected volumes (with or without "holes") with a high degree of correlation: coefficients for TVOL, FVOL, and measured volumes were 0.998, 0.995, and 0.996, respectively. FVOL permitted the estimation of global phantom volume including the hole, provided that the hole did not touch an outer edge of the phantom in any given projection. In the latter event, the program did not distinguish the edge of the hole from the edge of the phantom. In these experiments, nonradioactive scattering material had no effect on the accuracy of the

TABLE 1. CYLINDRICAL PHANTOM VOLUME PREDICTION (ml)

Range ml	Equation	$S_{y \cdot x}$*	r
53–5047	0.979x + 1.96	30.41	0.9977
53–625	1.014x − 5.24	8.65	0.9992
53–232	0.965x + 1.74	9.46	0.9935

* Standard error of the estimate.

TABLE 2. VOLUME PREDICTION:ELLIPSOIDS

Measured Volume (ml)	n	Calculated volume at %	$S_{y \cdot x}$* (ml)
3216	42	45.8	3.4
1571	36	45.6	3.5
1057	33	45.2	3.4
830	31	44.8	3.3
608	27	44.4	3.2
438	24	43.7	2.7

* Standard error of the estimate.

TABLE 3. ELLIPSOIDAL PHANTOM VOLUME PREDICTION

Range ml	Equation	$S_{y \cdot x}$*	r
91–3216	1.035x − 3.13	29.53	0.9995
91–1571	1.072x − 17.93	9.79	0.9998
91–1057	1.075x − 18.77	8.06	0.9997
91–608	1.090x − 23.30	6.48	0.9989

* Standard error of the estimate.

volume estimations. There were no significant differences among volumes estimated from transverse, sagittal, or frontal planes: the five-liter phantom yielded volumes of 5083, 5100, and 4963 ml when oriented along different axes with respect to the imaging table of the camera.

Ellipsoidal phantoms were then analyzed and it was found that FVOL predicted volumes at threshold levels that were proportionate to the size of the volumes (see Table 2). The overall best threshold for volumes of 91 to 3216 ml was found at 45.8% of maximum. For volumes greater than or equal to 1057 ml, where most clinical situations lie, 45.2% appeared to offer better predictions. Accordingly, for most clinical studies, 45% was used as the level to estimate organ volume (Fig. 3). Over the entire range, the error was 29.5 ml, but this dropped significantly when only the lower volumes of 1571 ml or less (Table 3) were considered.

DISCUSSION

The extremely close agreement between experimentally derived and measured phantom volumes in a variety of lifelike situations support the validity of our approach to organ-volume quantification. If accuracy is confirmed further, this noninvasive method may allow a better estimate of thyroid or other organ weight for the calculation of radiation dose, and a better estimate of cardiac chamber volumes for determinations of ejection fraction, stroke volume, and cardiac output. Precise kidney volumes may lead to earlier and more reliable diagnosis of various pathways of transplant rejection (*4*), various nephrological diseases, and may serve as a basis for therapy. Brain volumes calculated from positive SPET imaging, as suggested by Winchell (*5*) and Kuhl (*6*), could provide significant diagnostic information. Precise lung, liver, and spleen volumes could constitute important diagnostic parameters. Many of these studies are currently under evaluation. Knowledge of the volume of an organ constitutes an important first step in the quantification of radioactivity within an organ.

Although we did not test volumes less than 53 ml, the correlations might be expected to be less at lower volumes, owing to the relatively large size of the indivisible volume unit—one voxel = 0.26 ml. Using ellipsoidal phantoms, the error was approximately 3 ml over a wide range. If it remains at this level at volumes on the order of 30 ml, the percentage error would rise to ~10%.

Our data suggest that the optimum threshold for ellipsoidal phantoms varies slightly (1%) as a function of phantom size. It is possible that thresholds other than 45% and 46% of maximum might be better under other clinical circumstances. These will need to be verified as the availability of clinical data permits. It is not expected that the data gathered from cylindrical phantoms will prove to be of clinical value, since there are no cylindrical human organs. Data are presented to demonstrate the effects of variations in geometry should they be desired for quality-control phantoms.

We did not observe any effects of the presence of scattering material up to five liters on the accuracy of volume estimations. To minimize error, it may be useful to choose regression equations and thresholds appropriate to the size of the organ to be studied.

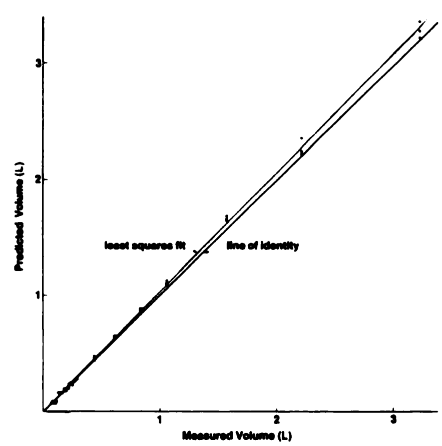

FIG. 3. Correlation of volumes of ellipsoidal phantoms (balloons) containing $^{99m}TcO_4^-$ dispersed in water, by macrofunction using single-photon emission scintigraphic data compared with measured volume. At each volume, three points are shown, representing data from each of three tomographic planes analyzed—transverse, sagittal, and frontal.

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