DIAGNOSTIC NUCLEAR MEDICINE

Comparison of 180° and 360° Data Collection in Thallium-201 Imaging Using Single-Photon Emission Computerized Tomography (SPECT): Concise Communication

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Thallium-201 imaging using SPECT is being done with 180° (RAO to LPO) data collection in some centers with single-gamma camera systems. Using our SPECT system with two gamma cameras, we have compared the effects of 180° data collection without attenuation correction against 360° collection with attenuation correction, using phantoms and patients. With a heart phantom in a chest phantom, Tl-201 activities simulating "normal myocardium," "ischemia," "infarction," and "background" were placed in object contrast ratios (with respect to background) of 5.0, 2.0, and −1.0, respectively. The 180° data gave image contrast ratios of 1.6, 0.2, and −0.8, and the 360° data gave ratios of 1.5, 0.8, and −0.3, respectively. Uniform activity throughout the heart gave similar image contrast with both data-collection methods, but there was more variability with the 180° collection than with 360° collection. Since attenuation correction is available with the 360° collection, the effects of attenuation are seen only on the 180° collection images. In eight patients the image contrasts from the 180° and 360° collections are similar. For our two-camera SPECT system, the 360° collection permits attenuation correction, has less variability in counting statistics, and gives contrast ratios like those of 180° collection.

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The myocardial distribution of thallium-201 corresponds to blood flow over a wide range of blood flow in animals killed 5 min after the administration of the thallium-201 during exercise (*1*). Several studies have shown the ability of serial thallium-201 imaging to detect coronary artery disease (*2–4*). Single-photon emission computerized tomography (SPECT) offers an advantage over routine gamma-camera and seven-pinhole imaging since it suppresses activity in front of and behind the region of interest (*5,6*). Recently Keyes et al. (*7*) have demonstrated that SPECT imaging of thallium-201 in excised canine hearts is accurate in measuring myocardial mass and acute myocardial injury. In patient studies using single-camera SPECT systems, thallium-201 imaging is being performed only from 180° sweeps (right anterior oblique to left posterior oblique) since the heart is located anteriorly in the left chest (*8,9*). The signal from the opposite 180° is markedly attenuated and could degrade the image. The purpose of this study is to compare the effects of 180° data collection without attenuation correction and 360° data collection with attenuation correction on image contrast and noise using our two-camera SPECT system. We have utilized phantom and patient studies in the evaluation.

MATERIALS AND METHODS

The SPECT system consists of two LFOV scintillation cameras mounted in opposition on a rotatable gantry and interfaced to a minicomputer with 256 kbyte of memory. The cameras are fitted with low-energy all-purpose collimators. They move continuously through 360° during collection of data. Data are framed in 2-deg angular intervals and reconstructed in a 128 × 128 format. Data for computing a body contour (required by our attenuation compensation algorithm) are acquired si-

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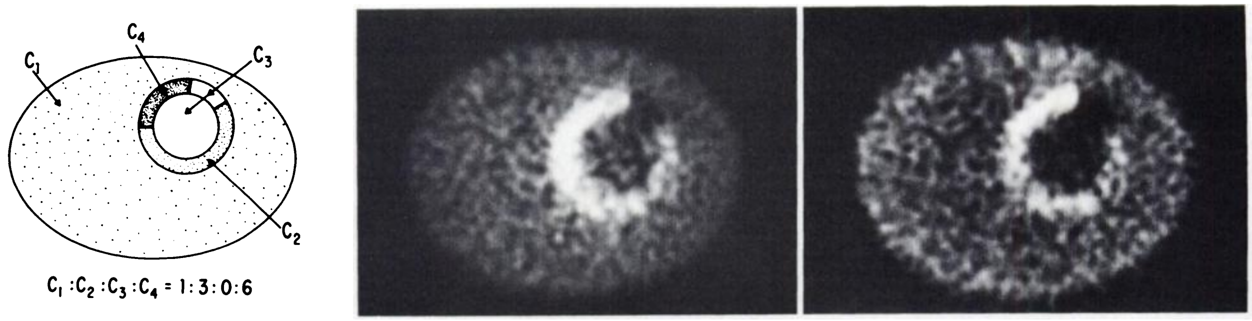

FIG. 1. (Left): Drawing of chest phantom with simulated heart containing various Tl-201 concentrations. (Center): Image from attenuation-corrected 360° collection. (Right): Image from 180° collection. Note decreased density in central area.

multaneously with the primary photopeak projection data using photons that have undergone Compton scattering within the phantom or patient (*10*).

Thirty-two contiguous transverse slices are obtained and can be reorganized into 16 coronal and 16 sagittal images. We have not incorporated the algorithm for performing oblique-angle tomography (*11*).

The phantom studies use a chest phantom with an elliptical cross section (30 × 22 cm) containing a simulated heart (10-cm-diameter cylinder with a 1-cm thickness). There are three compartments in the wall (1-cm ring) of the simulated heart. The length of the chest phantom is 22 cm, and that of the simulated heart 12 cm. The axes of the chest and heart phantoms are placed parallel to the axis of camera revolution. The axis of the heart phantom is offset 4.7 cm from that of the chest phantom, in a direction that moves the heart toward the position of a LAO detector (Fig. 1, left). To evaluate image contrast and noise, thallium-201 is placed in the three compartments and background (Fig. 1), in concentration ratios of 1:3:0:6, representing background (C_1), "ischemic myocardium" (C_2), "infarcted myocardium" (C_3), and "normal myocardium" (C_4). To evaluate the effect of attenuation on image contrast and noise, Tl-201 is given uniform concentrations in "normal myocardium" and background in a ratio of 10:1 (Fig. 2). The phantoms are scanned for 22 min through the full 360°. The data are then processed for the summed 360° scans of both cameras and for the summed scans of both cameras from only the RAO to LPO (180°) projections. Approximately 200,000 counts per slice are obtained with the 360° collection and approximately 100,000 counts per slice with the 180° collection.

The same back-projection algorithm (*5*) and spatial-frequency filter (*6*) were used to reconstruct both sets of projection data. The first-order attenuation compensation algorithm of Chang (*12*) is used for the attenuation correction of the 360° data collection, with $\mu = 0.14$/cm. The attenuation-correction program requires data from 360° and currently cannot be used with 180° data collection.

During data acquisition, each pair of photon-event coordinates is digitized to seven bits of accuracy and stored in buffer memory with identifying information for detector head and energy channel (photopeak and Compton-scattered windows). List-mode to multislice projection-mode conversion and angular framing are performed in real time. The resulting projections are stored on a 67-Mbyte disc and subsequently are transferred to magnetic tape for image reconstruction at a later time. Projections are stored in arrays of 128 elements. The 40-cm field of the LFOV scintillation cameras and seven-bit sampling result in a linear sampling interval of 3.2 mm when using parallel beam collimation. The maximum sampling or Nyquist frequency is 1.6 cycles/cm. Thus, no resolution is lost because of sampling.

A generalized filtered and weighted backprojection algorithm (*10*) is used to reconstruct transverse sectional images. The filter function consists of a ramp filter

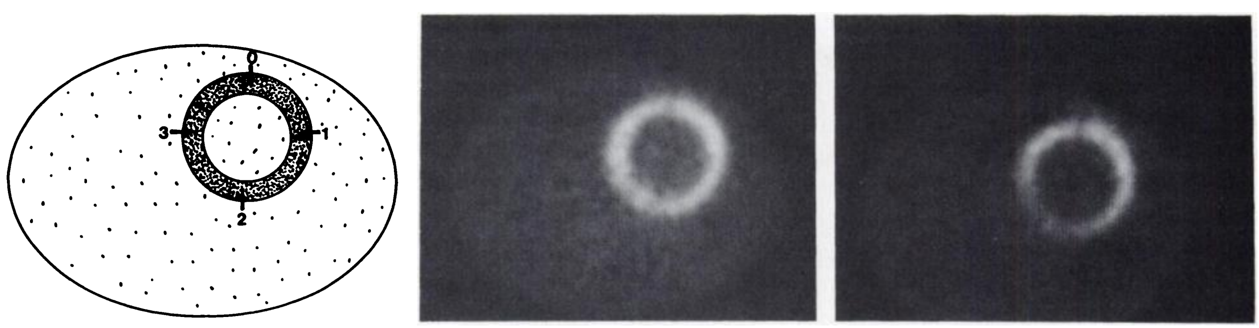

FIG. 2. (Left): Drawing of chest phantom with simulated heart containing uniform activity. "Myocardium": background = 10:1. Location of myocardial ROIs are noted (see Table 2). (Center): Image from attenuation-corrected 360° collection. (Right): Image from 180° collection. "Myocardium" in B appears uniform whereas there is decreased density centrally in C.

TABLE 1. DATA FROM SPECT THALLIUM-201 PHANTOM STUDY

Background:"Ischemic myocardium":"Infarcted myocardium":"Normal myocardium" = 1:3:0:6

	360° Collection				180° Collection		
	C_{OBJECT}	Heart	Background	C_{IMAGE}	Heart	Background	C_{IMAGE}
Normal myocardium	5.0	4.3 ± 0.3*	1.7 ± 0.2	1.5	0.29 ± 0.03	0.11 ± 0.02	1.6
Ischemic myocardium	2.0	3.1 ± 0.3	1.7 ± 0.2	0.8	0.21 ± 0.04	0.18 ± 0.02	0.2
Infarcted myocardium	−1.0	1.0 ± 0.2	1.4 ± 0.2	−0.3	0.04 ± 0.03	0.20 ± 0.03	−0.8
Background	0	1.7 ± 0.2	1.7 ± 0.2	0	0.11 ± 0.02	0.11 ± 0.02	0

* Mean counts/pixel ± standard deviation.

modified by amplitude adjustments to the low frequencies multiplied by the following apodization function W(f):

$$W(f) = 0.5\left(1 + \cos\frac{\pi|f|}{fc}\right), \quad |f| \leq fc$$

or

$$= 0, \quad |f| > fc \text{ or } |f| > fn,$$

where fc is the cutoff frequency and fn is the Nyquist or highest sampling frequency (equal to 1.6 cycles/cm). During image reconstruction the parameter fc may be selected to have values of 4fn, 2fn, fn, or fn/2, which correspond to frequency filters numbered 0,1,2, or 3, respectively (*6*). The images presented here have been processed using spatial-frequency filter No. 2, which corresponds to a cutoff value equal to the Nyquist frequency or 1.6 cycles/cm.

Data analysis consists of determining regions of interest (ROIs) obtained over areas of the heart and background. In the first phantom study, small rectangular ROIs including 16 pixels are used for determining counts in the four areas of different radionuclide concentration. Each pixel represents a 3.2 × 3.2 × 6.4 mm (~0.065 cm^3) voxel; thus, each ROI represents 1.0 cm^3. In the second phantom study, four rectangular ROIs are placed at approximately 0°, 90°, 180°, and 270° (denoted as positions 0,1,2,3) around the ring and four rectangular background ROIs are obtained in regions near the myocardial ROI (see Fig. 2). In Tables 1 and 2, the standard deviations represent the values within each 16-pixel ROI. Furthermore, continuous circumferential ROIs were placed in the "myocardium," with 1 cm outside of the "myocardium" representing background. The counts/pixel around the circumference of the "myocardial" and background ROIs were plotted from the lowest value to the highest (Fig. 3).

Object contrast (C_{OBJECT}) is defined as the actual radionuclide concentration in the region of "heart" phantom minus background concentration in "body" phantom, divided by background concentration in "body" phantom. Image contrast (C_{IMAGE}) is defined as "myocardial" counts/pixel − bkg counts/pixel, divided by bkg counts/pixel.

TABLE 2. DATA FROM SPECT THALLIUM-201 PHANTOM STUDY HEART:BACKGROUND = 10:1

Angular position*	Heart	Background	C_{IMAGE}
	360° Collection with attenuation correction		
0	80 ± 6.1†	25 ± 3.0	2.1
1	88 ± 11	24 ± 1.5	2.7
2	71 ± 5.9	24 ± 2.5	1.9
3	84 ± 7.5	21 ± 1.9	3.0
	81 ± 7.5‡	23.5 ± 1.7	2.4 ± 0.5
	180° Collection		
0	16 ± 1.5	4.7 ± 0.6	2.4
1	16 ± 2.1	3.4 ± 0.3	3.8
2	10 ± 1.1	3.5 ± 0.3	1.8
3	12 ± 1.6	2.7 ± 0.3	3.6
	14 ± 3.0	3.6 ± 0.8	2.9 ± 1.0

† Mean counts/pixel ± standard deviation.
‡ Mean counts/pixel ± standard deviation of mean values.
* See Fig. 2A for location of these ROIs.

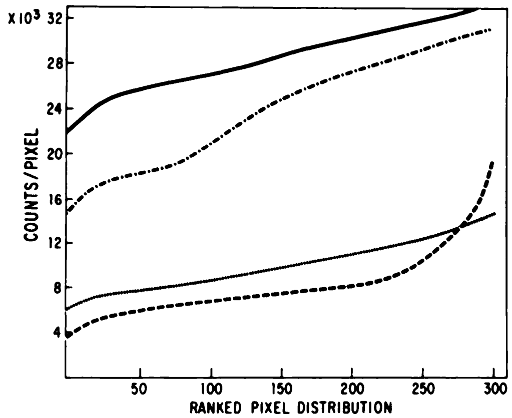

FIG. 3. Graph of normalized counts per pixel from phantom of Fig. 2A. Upper two curves represent "myocardium" from attenuation-corrected 360° (——) and uncorrected 180° (- · · · · ·) collections. Lower two curves represent background from attenuation-corrected 360° (. . . . . .) and uncorrected 180° (- - - - -) collections. Wider range of counts in myocardium and background for 180° collection is apparent. Accurate representation of object counts would be a straight horizontal line.

Eight patient studies are evaluated. These studies are obtained approximately 1 hr after the intravenous administration of 2.0 mCi of thallium-201 at peak bicycle exercise. The data are collected and processed as in the phantom studies.

RESULTS

The image contrast is similar for the different concentration ratios of thallium-201 using the 180° and the 360° data (Table 1, Figs. 1B, and 1C). Although there are minor differences in the images, the regions with the different concentrations in the phantom can be readily discerned in each image.

In the 360° data the mean count per pixel in the uniformly "normal myocardium" is more than five times that in the 180° data. The increase in counts is due to the additional 180° data collection and the attenuation-correction program (Table 1,2). The random variation is greater for the 180° than the 360° collection. There is less uniformity of counts around the "normal myocardium" for the 180° collection compared with the 360° collection (CV = 21.4% compared to 9.3%) (Figs. 2 and 3; Table 2). The image contrast ratios are similar for the 180° and 360° data. Although the counts per pixel and the image contrast at Position 2 (Fig. 2A) are lowest for the 360° collection, the slight differences are not apparent in the image (Fig. 2B). The low value in Position 2 suggests that the average attenuation coefficient should be slightly higher in this phantom study. This low value at Position 2 for the 360° collection differs much less from the value at Position 0 than do the corresponding values for the 180° collection. Thus the artifactual effects of attenuation are greater for the images from the 180° collection than in those from 360° collection (Fig. 2).

The results of two representative patient studies are included in Table 3. These patients had normal coronary artery angiograms. A greater number of counts in the heart and background from the 360° collection are again noted. The variability of the counts in the heart and background is greater for the 180° than for 360° collection. The image contrast is similar for the two methods in our patient studies. With the 360° collection, accurate definition of activity within the surrounding structures and posterior myocardium can be obtained (Fig. 4).

DISCUSSION

Although thallium-201 imaging with the gamma camera is an accepted technique in the evaluation of patients with suspected coronary artery disease, there are several attempts to improve thallium-201 image interpretation by various techniques. (*2,3,13–17*). For thallium-201 imaging to be highly objective, there is need for a method to quantitate reliably the distribution of Tl-201 in the myocardium (*3*). SPECT can accurately

TABLE 3. DATA FROM SPECT THALLIUM-201 PATIENT STUDIES

		360° Collection			180° Collection		
	Angle	Heart	Background	C_{IMAGE}	Heart	Background	C_{IMAGE}
Patient A	0	2.8 ± 0.4*	0.6 ± 0.2	3.6	0.60 ± 0.09	0.13 ± 0.03	3.6
	90	4.3 ± 0.6	0.9 ± 0.2	3.8	0.94 ± 0.16	0.24 ± 0.07	2.9
	180	4.6 ± 0.4	1.2 ± 0.5	2.8	0.72 ± 0.10	0.17 ± 0.03	3.2
	270	2.9 ± 0.2	1.3 ± 0.3	1.2	0.39 ± 0.06	0.16 ± 0.05	1.4
Patient B	0	2.3 ± 0.2	0.6 ± 0.2	2.8	0.22 ± 0.02	0.09 ± 0.02	1.4
	90	2.7 ± 0.1	0.5 ± 0.1	4.4	0.28 ± 0.02	0.05 ± 0.02	4.6
	180	2.6 ± 0.2	0.8 ± 0.2	2.3	0.15 ± 0.01	0.05 ± 0.02	2.0
	270	2.0 ± 0.3	0.9 ± 0.2	1.2	0.13 ± 0.02	0.05 ± 0.02	1.6

* Mean counts/pixel ± standard deviation.

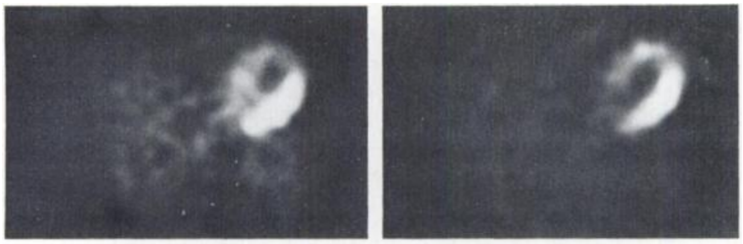

FIG. 4. Images from a patient study. Attenuation-corrected 360° collection (left) and uncorrected 180° collection (right). Increased activity posteriorly in 360° image can be appreciated.

quantitate volumes of spheres from 4 ml to 110 ml placed in a 22-cm cylinder (*6*). The determination of accurate radionuclide concentration by SPECT is more difficult and requires information related to the amount of scattered radiation in the object and a correction factor for contrast loss due to the system's spatial resolution (*6*). There have been no reports of phantom or patient studies using SPECT to determine the concentration ratios of thallium-201 between the myocardium and surrounding tissues.

Keyes et al. (*7*) used transaxial emission computerized tomography to evaluate viable and infarcted myocardium in canine hearts excised after administration of Tl-201. By using a model in which attenuating tissue surrounding the heart was removed, they found the technique to be accurate in determining both perfused and infarcted myocardial mass. Other studies have demonstrated that good images can be obtained in patients following administration of approximately 2 mCi of Tl-201 (*8,9,18–20*).

Some investigators (*7,8*) with SPECT systems having a single gamma camera use 180° (RAO to LPO) data collection. Since the heart is located anteriorly in the left chest, more signal is obtained in this 180° collection than in the opposite 180° (LPO to RAO). Standard gamma-camera images from these LPO to RAO angles have less information since the detector is farther from the heart and thus the signal is more attenuated (*9,21*). Furthermore, the reconstructed SPECT images of Tl-201 from this 180° collection are also of poor quality.

Even though there may be no obvious information in the 180° data that are farther from the heart, we felt it important to evaluate the difference between 180° and 360° data collection. Frequently there is information in projection data even though the contrast may not be great enough to visualize a lesion. For example, projection images of a liver phantom do not reveal deep lesions that can be detected by SPECT (*22*). Another reason for evaluating 180° against 360° data collection is that our system has an attenuation correction program that requires projection data obtained with 360° collection. Since we have two camera heads, half of our data collection would have to be discarded if 180° data are better than 360° data.

Our results indicate that, in the phantoms we evaluated, similar image contrast is obtained using 180° data collection without attenuation correction and 360° collection with attenuation correction. The percent standard deviations of the counts over the "heart" and background are higher for the 180° collection, and there is more variability in areas of uniform activity. There is no appreciable difference in image quality except that the effect of attenuation is readily noted on the 180° collection and it could not be attenuation-corrected using our present algorithms. In our patients with normal coronary arteries, image contrast is similar with the two techniques but there is greater variability in the 180° data. The myocardial images with thallium-201 show no large differences related to the method of data collection in the eight patients studied. However, the artifacts resulting from inadequate attenuation compensation and geometric collimator response are made evident by the inaccurate representation of activity in the posterior myocardium and behind the heart with the 180° collection.

We conclude that the 360° accumulation is appropriate for Tl-201 studies with our two-camera SPECT system. With the 360° collection, we can do attenuation correction that cannot be done currently with 180° collection. Furthermore, there is less variability from poor counting statistics, and the image contrast in patients is similar to that with the 180° collection. The 180° collection does not offer us any time advantage since our two-camera system would have to go through a 360° revolution to have both cameras use the appropriate 180°. The 180° collection may be advantageous to single-camera SPECT systems, but techniques for attenuation correction will need to be implemented.

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