Changes in Quantitative SPECT Thallium-201 Results Associated with the Use of Energy-Weighted Acquisition

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The effect of utilizing energy-weighted acquisition on quantitative analysis of SPECT thallium-201 images was evaluated by simultaneously acquiring energy-weighted and windowed projection images in ten patients. The paired image sets were processed identically and evaluated by probability analysis of defect magnitude as indicated by a commercially available software analysis package. It was predicted that defect magnitude would increase as a result of improved image contrast. This was confirmed experimentally. One should be cautious in relying on strict quantitative criteria in cardiac studies with thallium-201, especially when major changes in the imaging system or technique are introduced.

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In our practice, approximately 1,400 stress and redistribution thallium-201 studies were carried out in 1989 on four imaging systems provided by one vendor (two 7500 ZLC, and two 3700 ZLC Gamma cameras, each utilizing a Microdelta computer; Siemens Medical Systems Inc., Des Plaines, IL). These studies are evaluated primarily by visual inspection of the planar and tomographic images, but the tomographic data are also subjected to quantitative analysis using a commercial program (Cedars-Sinai).

Beginning in March 1989, these systems underwent a modification by the vendor in which an energy-weighted acquisition (EWA) module was interfaced directly to the detector head. This module is used as a real-time spatial filtering signal processor wherein each detected photon is assigned a weighted value which is utilized in construction of the final image. This is a departure from the usual method where discreet energy windows (DEW) are utilized in an all-or-none manner to accept or reject a detected photon in construction of the image. The ultimate result is an increase in image contrast, both in planar and in tomographic images (*1–5*).

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Since any alteration of the imaging system that would substantially change image contrast, or any other major component of the final image, would have the potential to alter the results of a subsequent quantitative analysis of that image, we felt it necessary to test for such an effect prior to using or releasing quantitative data acquired with EWA.

The EWA module allows the simultaneous acquisition of standard DEW acquired images as well as EWA images. By processing both of these data sets in identical fashion, a direct comparison of image quality and of quantitative information could be achieved, utilizing each patient as his own control.

MATERIALS AND METHODS

Ten consecutive patients (six males, four females) were each injected with 3.0-3.2 mCi thallium-201 at the point of peak treadmill stress. They continued to exercise for one minute following tracer injection. They were subsequently placed on a SPECT imaging table where 300,000-count planar images were obtained in the anterior and 45° LAO projection utilizing a large field of view camera equipped with an all-purpose parallel-hole collimator. Subsequently, single-photon emission computed tomographic (SPECT) imaging was carried out utilizing a 180° imaging arc (45° RAO to 45° LPO) and 32 acquisitions of 40 sec each. Using a 64 × 64, 16-bit (word) matrix, pixel size was adjusted so that the actual slice thickness was 6 mm/pixel. The radius of rotation varied from 26 cm to 30 cm depending on patient size.

Simultaneous storage of EWA data utilized a preset filter for thallium imaging with an all-purpose collimator and DEW imaging utilized a 20% energy window centered on the 80-keV x-ray peak and a 10% window centered on the 167-keV gamma-ray peak.

Since tomographic projection images were acquired for a preset time, variability in cardiac uptake, body structure, and other variables resulted in considerable variation in the total number of acquired counts. In general, there were fewer total counts in the EWA data than in the DEW data (752 ± 91K/EWA versus 1,122 ± 173K/DEW).

Image reconstruction and quantitative analysis on both data sets for each patient were carried out by a single, experienced individual (R.B.M.). Filtered backprojection reconstruction utilized a fifth-order Butterworth Filter with a 0.5 Nyquist cutoff frequency. Each of the projections had been corrected for nonuniformity with a flood source containing 30,000,000 counts. The mechanical center of rotation was also determined in order to align the projection data with respect to the reconstruction matrix.

Each data set (EWA and DEW) was subjected to quantitative analysis utilizing the Cedars-Sinai software protocol. With this program, three-dimensional SPECT data are presented as a two-dimensional, color-coded polar coordinate ("bull's-eye") map. Two types of polar maps are generated. The first represents the distribution of counts contained in the left ventricle. These data are a plot of the actual normalized profiles which were extracted from the short- and long-axis tomograms for both the stress and delayed studies.

The second type of polar map represents the results from comparing the patient's tomographic profiles to the normal limits supplied with the program. This map displays the predicted extent of disease, if present, in three different levels of severity. The normal region is represented with the highest level of the color scale, and the abnormal regions are separated into equivocal, abnormal, and severely abnormal. The last two categories are those in which the patient's profile fell below the lower limit of normal. By interpreting the levels of severity, an indication of the degree of abnormality or disease can be derived. Below the stress polar map, the coronary arteries are listed along with an indication of what percentage of the points in that territory were abnormal.

In order for a diagnosis of coronary disease to be made, the following minimum abnormality in each territory must be present: left anterior descending >12%, left circumflex >12%, and right coronary artery >9%. Reversibility is not evaluated by the program, but it is assessed by visually interpreting the stress and delayed tomograms.

RESULTS

The percent defect observed in each coronary artery territory, for each patient, utilizing EWA and DEW acquisition is summarized in Table 1. In the left anterior descending territory, the EWA acquisition yielded a substantially larger defect in every case compared to the DEW data. In the right coronary distribution, the EWA defect was larger in seven cases, identical in two cases, and smaller in one case. In the left circumflex distribution, there was a slightly greater defect observed with the DEW data. The total average defect was substantially larger with the EWA data sets. Statistical analysis using a paired t-test indicated a high level of statistical significance.

Utilizing the strict numerical criteria given above, there was an abnormal defect in ten coronary regions by DEW and in fourteen coronary regions by EWA. Eight of ten patients were abnormal in one or more territories using DEW data sets, and nine of ten patients were abnormal in one or more territories with the EWA data set. The change was most notable in the right coronary territory, where three patients changed from normal to abnormal with the EWA data.

This study was not designed to evaluate the accuracy of the Cedars-Sinai program. However, limited clinical data was available on the ten patients studied. Nine patients ultimately underwent coronary angiography within a 6-mo period preceding or following the stress thallium exam. (The patient who did not undergo coronary angiography, underwent the examination as part of a work-related exam, had no clinical history suggesting coronary disease, had no abnormal electrocardiographic changes during treadmill exercises, had a normal interpretation of his exercise and redistribution thallium images, and has had no clinical evidence of coronary disease during a 1-yr follow-up since the original exam.) Angiographic demonstration of 70% or greater luminal narrowing in the right, left anterior descending, or circumflex coronary distributions were considered to be positive for disease.

Table 2 correlates the presence or absence of disease by coronary angiography (or by normal historical data in one patient) with the presence or absence of a "defect" exceeding the normal threshold limits for that coronary distribution in the quantitative polar plot utilizing first the windowed acquisition data and subsequently the EWA data. Considering three regions in each of the ten patients,

TABLE 1
Percent Defect Observed in Each Coronary Artery Territory

Patient no.	%Defect LAD X	LAD Y	RCA X	RCA Y	LCX X	LCX Y	Total X	Total Y
1	12	8	7	1	0	6	8	6
2	26	20	12	6	1	1	15	12
3	25	15	0	0	1	2	12	8
4	43	20	26	2	0	1	29	13
5	27	19	53	2	1	0	27	10
6	22	11	31	1	4	7	22	10
7	28	21	4	7	3	4	19	17
8	37	19	59	43	1	3	33	21
9	22	16	15	15	0	0	16	12
10	29	24	10	0	7	9	21	16
Average defect	26.9	17.3	21.7	7.7	1.8	3.3	20.2	12.4
	$p < 0.0005$		$p < 0.02$		$p = 0.05$		$p < 0.005$	

X = %defect with weighted-acquisition data set.
Y = %defect with windowed data set.

TABLE 2
Presence of Coronary Disease Versus Quantitative Thallium-201 Analysis
(Coronary Disease by Angiography*)

			LAD +	LAD −	RCA +	RCA −	LCX +	LCX −
^{201}Tl quantitative analysis	DEW	+	6	2	1	1	0	0
		−	1	1	3	5	2	8
	EWA	+	6	3	4	1	0	0
		−	0	1	1	4	2	8

* One patient was considered to have non-diseased coronary arteries based on clinical information (see text).

there were a total of thirty regions for correlation. DEW, correctly categorized 21 of 30 regions and 7 of 10 patients, while EWA correctly diagnosed 23 of 30 segments and 8 of 10 patients. Two patients, who were normal by angiography, were categorized as abnormal with the analysis of both data sets. An additional abnormal patient was categorized as normal by analysis of the DEW data. The correlation of the quantitative analysis and clinical data is provided in Table 2.

DISCUSSION

In this study, we evaluated the effect on quantitative thallium-201 SPECT of a new method of scatter rejection using EWA. Unlike the all-or-none approach of the usual discrete energy window acquisition, EWA determines, on a statistical basis, the source of each event from either photopeak or scatter process. This scatter-probability data is obtained through an analysis of the energy and position distributions unique to the radionuclide and collimator combinations used. The results of this analysis are used to build the final image which is, statistically, free from the side effects of the scatter process.

Two operator-selected weighting functions enable simultaneous acquisition of independent data sets for direct comparison of one weighted image with another, or of a weighted image with the image provided through a standard analyzer-window process (as was the case for this investigation). The radionuclide-collimator energy-weighting functions are derived by optimizing point-source images in model patient geometrics. Theoretically, experimentally, and clinically, it has been shown to improve contrast in thallium-201 images without causing artifacts (*1–5*). The data confirm our prediction that use of EWA would alter the results of quantitative evaluation of stress thallium-201 cardiac exams using the Cedars-Sinai program.

The defects were usually larger using EWA, and the magnitude of the change reached a high level of statistical significance. Utilizing the recommended strict numerical criteria for diagnosis, eight patients were positive for disease utilizing DEW data and one additional patient became positive utilizing EWA data.

When evaluated in light of the clinical data that was available on these patients, it is unclear if the effects on quantitative analysis are adverse or beneficial. There was indeed a highly statistically significant difference in the magnitude of the perfusion defect between DEW and EWA data, but the difference in clinical diagnosis of regional or global disease was not nearly so great. The slight advantage suggested for the EWA data are not statistically significant in this very small patient population.

In our institution, EWA yields an image that is subjectively of higher quality in comparison to discrete energy window images and is preferred by physicians for visual interpretation of both planar and tomographic image sets. The "defect magnitude" maps are used quite cautiously, however, until further studies have been performed. We feel it will be necessary to develop a completely new data bank of gender-matched controls with EWA acquisition. At this time, our quantitative thallium-201 analysis program does not allow creation of a new data bank. On-site development of institution-specific data banks, if made available, would allow:

1. Compensation for changes or differences in imaging system configuration or technique that are different from those existing at the site where the data base was originally assembled.
2. Compensation for any differences in the basic constitution in patient populations existing between the clinical site and the institution where the data base was originally obtained.

EWA yields thallium-201 images that have greater contrast than discrete energy windowing and are often more visually pleasing. Further study with a more expanded patient data base may improve quantitative analysis and optimize clinical utility of exercise thallium-201 studies.

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