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Evaluation of left ventricular ejection fraction from radial long-axis tomography: A new reconstruction algorithm for ECG-gated technetium-99m sestamibi SPECT

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Radial long-axis tomography can provide views similar to contrast left ventriculography (LVG) including the basal and apical areas of the left ventricle, not possible in routine short-axis tomography. We applied this method to ECG-gated Tc-99m Sestamibi (MIBI) myocardial SPECT images to estimate the left ventricular ejection fraction (LVEF).

Methods: ECG-gated Tc-99m MIBI SPECT was performed with a temporal resolution of 10 frames per R-R interval. LVEF was calculated on the basis of left ventricular volume estimates at end diastole (ED) and end systole (ES) with using an ellipsoid body model. To validate this method, LVEF's derived from ECG-gated Tc-99m MIBI SPECT were compared with those from LVG in 11 patients with coronary artery disease.

Results: There was a close linear correlation between LVEF values calculated from Tc-99m MIBI SPECT and those from LVG ($r = 0.89$, $p < 0.001$), although the gated SPECT underestimated LVEF compared to LVG. The technique showed excellent reproducibility (intra-observer variability, $r = 0.96$, $p < 0.001$; inter-observer variability, $r = 0.71$, $p < 0.005$).

Conclusion: The radial long-axis tomography technique gives a good estimate of LVEF, in agreement with estimates based on LVG. ECG-gated Tc-99m MIBI SPECT can, therefore, be applicable to assess myocardial perfusion and ventricular function at the same time.

Key words: left ventricular ejection fraction, ECG-gated Tc-99m MIBI SPECT, radial long-axis tomography

INTRODUCTION

LEFT VENTRICULAR EJECTION FRACTION (LVEF) has been traditionally measured by echocardiography, contrast ventriculography, or radionuclide ventriculography. For the evaluation of cardiac function in patients with coronary artery disease, examination of both myocardial perfusion and LVEF are necessary, but it usually requires two separate studies.

The myocardial perfusion imaging agent Tc-99m Sestamibi (Tc-99m MIBI) has the advantage of high photon energy leading to less scatter, less tissue attenuation and sufficiently high counting statistics to make ECG-gated SPECT clinically possible but, the estimation of LVEF based on short axis tomography is known to be inaccurate. We previously developed a new method named radial long-axis tomography, which gives views similar to left ventriculography (LVG). We applied this technique to ECG-gated Tc-99m MIBI images and estimated LVEF. The LVEF obtained by ECG-gated Tc-99m MIBI SPECT was validated by comparison with those obtained by contrast LVG.

MATERIALS AND METHODS

ECG-gated Tc-99m MIBI SPECT was performed in eleven patients with clinically stable coronary artery disease (10

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men and 1 woman), aged from 42 to 75 years (mean ± S.D. 52.1 ± 10.5 years). Six patients had myocardial infarction (antero-septal, 4 cases; inferior, 1 case; and apical, 1 case) and 5 patients had angina pectoris. The diagnosis of myocardial infarction was confirmed by the combination of typical chest pain of at least 30 minutes duration, diagnostic serial ECG changes consisting of new pathologic Q wave or ST and T wave changes, and a typical increase in serum myocardial enzymes including MB-CK. ECG gated Tc-99m MIBI SPECT and LVG were performed within 4 weeks (21.3 ± 6.2 days). No changes in symptoms or ECG were observed during the period between these two examinations. All patients were in sinus rhythm.

Imaging protocol

All patients underwent imaging in the fasting state, and a 740 MBq of Tc-99m MIBI (Cardiolite, Daiichi Radioisotope Laboratory, Tokyo, Japan) was injected intravenously. One hour after the administration, ECG-gated SPECT images were acquired with a three-headed rotating gamma camera (GCA 9300A/HG, Toshiba Medical Co., Tokyo, Japan) equipped with a low-energy general-purpose collimator. Sixty projection images were acquired for 90 seconds each at 6° increments over 120°, and stored in a 64 × 64 matrix. At each projection, a total of 10 individual ECG-gated frames per cardiac cycle were acquired. The acquired data was processed in an on-line computer (HARP 2, Hitachi Medical Co., Tokyo, Japan) to generate the radial long-axis tomograms.

Data processing

The method for reconstructing the radial long-axis tomograms has been described previously.[1–3] After determining the orientation of the long axis of the left ventricle and reconstructing the short-axis tomograms by standard techniques, the thirty long-axis tomographic slices oriented at 6° angle intervals were reconstructed. In each slice, a maximum count profile curve of Tc-99m MIBI was obtained. For the basal 2/3 regions, the profile curve consisted of pixels with maximum counts on the upper and lower myocardial portions of the lines vertical to the long-axis (Fig. 1). For the remaining apical 1/3 regions, the semi-circumferential maximum-count profile curve from 30 radii spaced at 6° intervals was computed.

Calculation of left ventricular ejection fraction from ECG-gated radial long-axis tomography

Two slices of radial long-axis tomograms which correspond to the left anterior oblique (LAO) 60° and right anterior oblique (RAO) 30° images in LVG were selected to calculate LVEF (Fig. 2). End-diastole (ED) was identified as the beginning of the R-wave (the first frame), and end-systole (ES) was defined as the third frame which usually contained the maximum count among the 10 images during the cardiac cycle. Three bars were then added to ED and ES long-axis SPECT images manually (Fig. 2, bar I, II, III). The A, B, and C values (Fig. 2) were automatically calculated by using the maximum count profile curve. The A and B values were the distances between two points showing maximum count on the bar I in LAO and RAO views, respectively. The C value was the length on bar III between bar II and the maximum count profile curve. LVEF was calculated from the ED and ES images on the basis of the ellipsoid model (Fig. 3). The LV volume was calculated as:

$$\text{LV volume} = \text{ABC}\pi/6.$$

From the calculated LV volume at ED (EDV) and ES (ESV), LVEF was calculated as:

$$\text{LVEF} = (\text{EDV} - \text{ESV})/\text{EDV}.$$

Contrast left ventriculography

All patients underwent cardiac catheterization according to the standard Seldinger technique. Left ventriculography was performed in the RAO 30° projection. A Vanguard motion analyzer (Vanguard Instrument Corporation, Melville, New York, USA) was used to draw the outline of the LV during ES and ED. LV volumes and LVEF were obtained from single-plane cine angiography by means of the area length formula,[4] and corrected for magnification factors.

Statistical analysis

Data are expressed as the mean ± S.D. Comparisons between two groups were performed with the paired t-test. Probability values less than 0.05 were considered as significant.

RESULTS

First we checked the inter-observer and intra-observer reliability. LVEF obtained by ECG-gated Tc-99m MIBI SPECT showed a significant agreement between two independent observers ($r = 0.71$, $p < 0.005$, Fig. 4). The reproducibility for the observer was also good ($r = 0.96$, $p < 0.001$, Fig. 5). These results indicated excellent reliability of the estimation LVEF obtained with the current technique.

Figure 6 shows the correlation between LVEF obtained by the ECG-gated Tc-99m MIBI radial long-axis tomography and that obtained from LVG. There was a significant correlation between these two estimates ($r = 0.89$, $p < 0.001$). Nevertheless, the slope of the regression line ((SPECT EF) = 0.67* (LVG EF) − 0.40) was less than 1, suggesting that SPECT EF underestimates by 30% compared to LVG EF, but accurate LVEF could be estimated by ECG-gated Tc-99m MIBI SPECT with the regression line.

DISCUSSION

We applied radial long-axis tomography to ECG-gated Tc-99m MIBI myocardial SPECT images to estimate

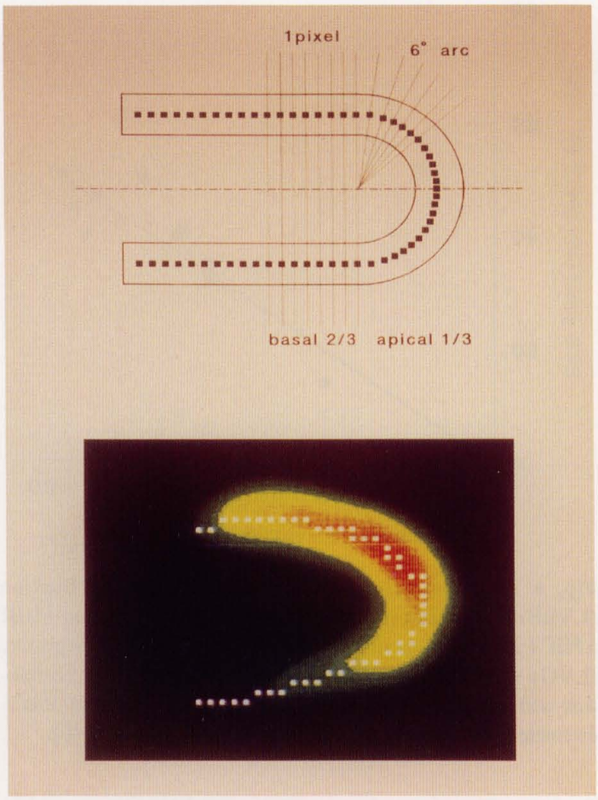

Fig. 1 Schematic representation of maximum point profile curve of Tc-99m MIBI myocardial distribution in radial long-axis tomograms. The upper panel shows the method to obtain the maximum point profile curve. For the basal 2/3 regions, profile curve is consisted with the pixels showing the maximum count on the upper or lower myocardial portion of the line (spaced at 1 pixel) vertical to the long-axis. For the remaining apical 1/3 regions, the semi-circumferential profile curve is consisted with the pixels showing the maximum count on each radius spaced at 6° intervals. These three curves were then combined. The lower panel showed one example.

LVEF. The current method can produce views similar to LVG including the basal and apical areas of the left ventricle. To validate the current method, LVEF derived from ECG-gated Tc-99m MIBI SPECT was compared with that from LVG. The LVEF estimated from ECG-gated Tc-99m MIBI SPECT images was well correlated,

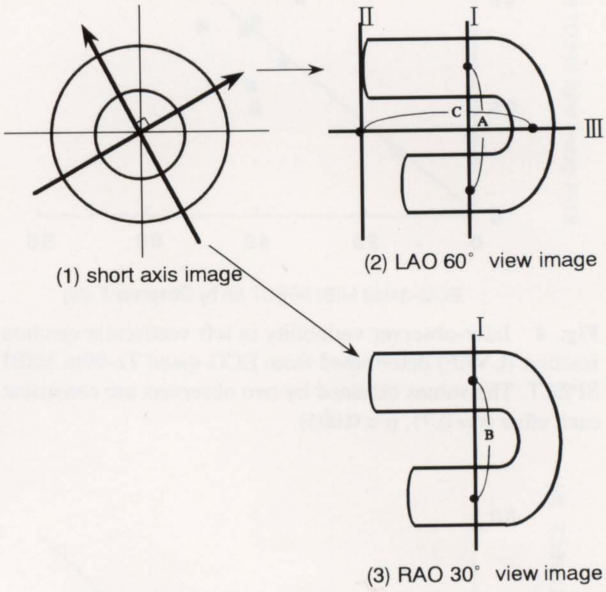

Fig. 2 Scheme to estimate left ventricle (LV) volume. Bars I, II, and III represent the center line between apical and basal left ventricle, the outline of basal left ventricle, and the center line between top and bottom left ventricle, respectively. The values of A and B are the distances between two points showing maximum count on the bar I in LAO and RAO views, respectively. The value of C is the length on bar III between the bar II and maximum count profile curve. (1) Short axial image. (2) LAO 60° view long axial image. (3) RAO 30° view long axial image.

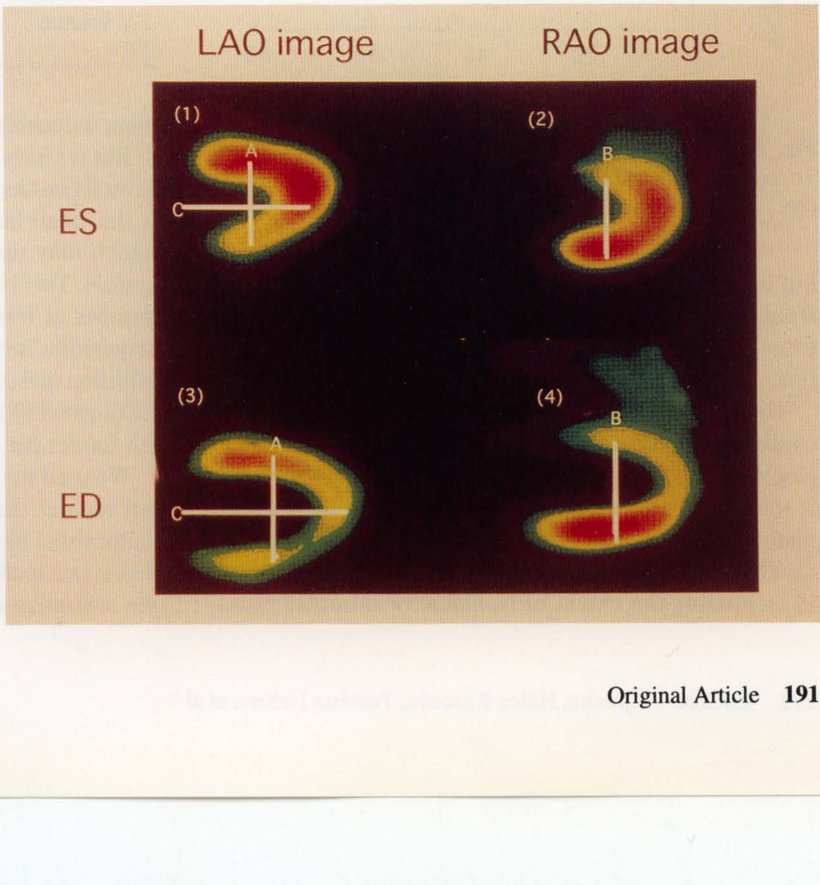

Fig. 3 Example of the measurement of parameters for LV volume. (1) LAO 60° view of the long axial image at end-systole (ES). (2) RAO 30° view of the long axial image at end-systole. (3) LAO 60° view of the long axial image at end-diastole (ED). (4) RAO 30° view of the long axial image at end-diastole.

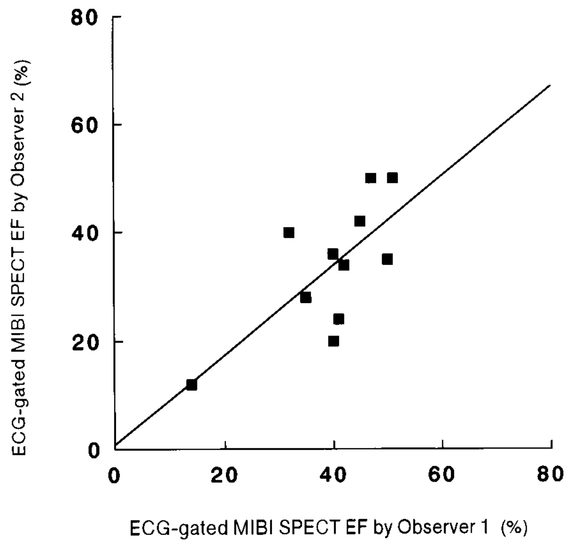

Fig. 4 Inter-observer variability in left ventricular ejection fraction (LVEF) determined from ECG-gated Tc-99m MIBI SPECT. The values obtained by two observers are consistent each other ($r = 0.71$, $p < 0.005$).

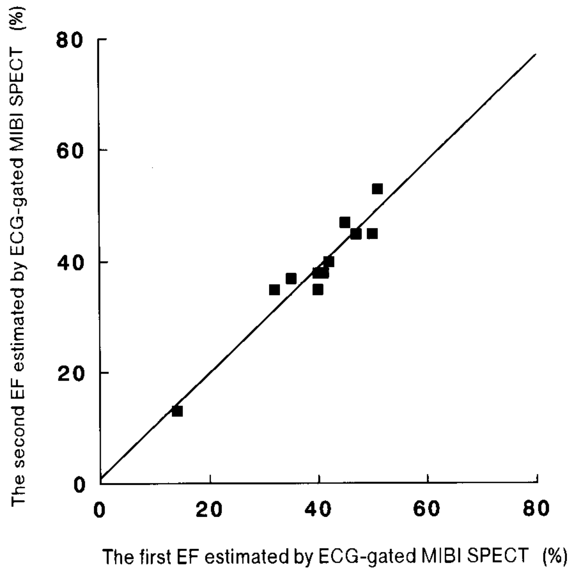

Fig. 5 Intra-observer variability determined from ECG-gated Tc-99m MIBI SPECT. The first and the second estimates are consistent each other ($r = 0.96$, $p < 0.001$).

but underestimated by 30% compared to that obtained from LVG, but LVEF obtained by LVG was estimated from ECG-gated Tc-99m MIBI SPECT by the regression line.

The current technique has the unique advantage of evaluating myocardial perfusion and LV function in a single study. This method had good reproducibility, and it took about ten minutes to calculate LVEF by this method. Further, thirty radial long axial tomograms can also be generated by this method, which would be useful in estimating the extent of ischemic or infarcted areas

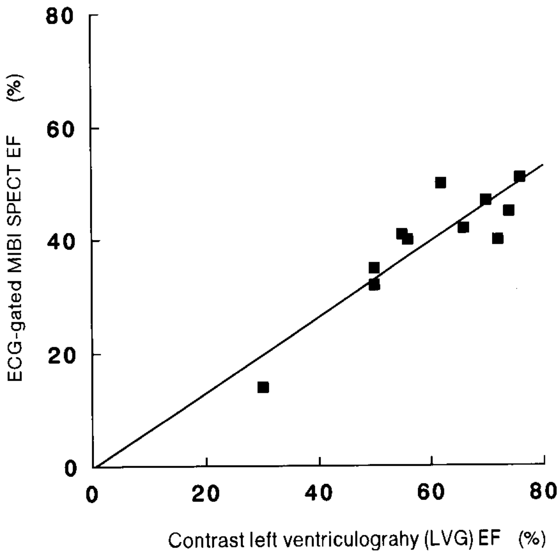

Fig. 6 Relation between left ventricular ejection fraction (LVEF) values determined from ECG-gated Tc-99m MIBI SPECT and those obtained from contrast left ventriculography (LVG). LVEF estimated by SPECT shows significant correlation with EF obtained by LVG ($r = 0.89$, $p < 0.001$), but underestimates ((EF by SPECT) = 0.67* (EF by LVG) − 0.40).

Table 1 The relation between the actual LV volume and LV volume estimated by maximum counts method. The left ventricle is modeled as a spheroid with 40 mm in diameter as a short axis and 70 mm in diameter as a long axis at end-diastole. Ejection fraction is considered as 60%, and the LV profile curve obtained by maximum counts method is considered to pass the middle point between endocardium and epicardium

	actual value		estimated value		
	ES	ED	ES	ED	
short axis	29.5	40.0	41.5	50.0	mm
long axis	44.2	60.0	56.2	70.0	mm
wall thickness	12.0	10.0	—	—	mm
LV volume	20.1	50.2	50.7	91.6	m*l*
EF	0.60		0.45		

more accurately than by the conventional SPECT method.

But we have to consider several limitations. There are several reasons for the underestimation of LVEF. The first is the small number of frames during a cardiac cycle, which may make it difficult to identity the true end-systole. This problem could be solved by increasing the number of frames per cycle, but it would prolong the acquisition time and the computing time. Prolonged acquisition makes patients uncomfortable. In many clinical ECG-gated SPECT studies,[5–14] the acquisition of eight or ten frames per cardiac cycle has been used, as we did.

We used the maximum counts method to delineate the left ventricle cavity because it is not easy to determine the endocardial border. The second reason for underestimation is due to this method. The LV profile curve based on the maximum counts method overestimates the LV volume especially in the ES phase. To illustrate the relation between the LV volume estimated by our method and the actual volume, let us consider the example shown in Table 1. Table 1 summarizes the actual and estimated LV volume at end-systole and end-diastole in the example. As shown in Table 1 and our results, ECG-gated Tc-99m MIBI SPECT EF assessed by our method was underestimated about 30% in comparison with LVG EF.

Another limitation may exist in the application of this technique to patients with myocardial infarction. Drawing of the LV profile curve in patients showing signs of extensive, severe perfusion defects may be difficult, but in this study no subject showed the myocardium so poorly defined, particularly when using the black and white image display, that the observer was unable to estimate the maximum counts curve of an infarcted region in the left ventricle. It would be desirable to develop software which provides automated or semi-automated endocardial edge detection and valve plane determination, and could consequently increase precision.[15] To date the results of automatic endocardial edge-finding algorithms applied to ECG-gated Tc-99m MIBI tomograms in CAD patients for measurement of LVEF ($r = 0.72$)[16,17] are not much better than that we have observed with our manual method, but the automatic quantification method of LVEF developed by Germano et al.[18] is rapid and closely agrees with conventional radionuclide measurements of LVEF.

In conclusion, ECG-gated Tc-99m MIBI radial long-axis tomography can give views similar to LVG, including basal and apical areas of the left ventricle, which are not possible in short-axis tomography. This new reconstruction method is useful for the accurate estimation of ventricular function in addition to myocardial perfusion.

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