

## Measurement of LVEF using ECG-Gated SPECT and Angiography: a Correlation Study

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### Abstract

**Introduction-** Left ventricular ejection fraction (LVEF) is an important clinical index in diagnosis and treatment of myocardial diseases. There are three major methods for measurement of LVEF: echocardiography, angiography and ECG-gated SPECT. The first method is economical, safe and rapid. The second one is more accurate, however invasive and the third one lies somewhere in between. Multi-gated SPECT usually suffers from low reproducibility compared to other methods. This is due to variation in processing factors, mainly reconstruction methods and filtration. Up to now, there is no standard method of processing of cardiac SPECT.

**Methods-** In this study, we attempted to find the optimum processing protocol in which the results are consistent with the angiographic results. Forty patients (referred to our department for myocardial perfusion SPECT) who had angiography within 2 weeks of the test were included in the study. All the patients had a positive history of myocardial infarction. All imaging performed with a single head GE gamma camera SPECT system model DSX using  $^{99m}\text{Tc}$ -MIBI. Two commonly used reconstruction methods i.e., filtered back projection and ordered subset expectation maximization with different parameters were used and the results compared with that of echocardiography and angiography.

**Results-** In filtered back projection technique, maximum correlation between ECG-Gated SPECT and angiography ( $r = 0.775$ ) was observed when using Metz filter with psf FWHM=5 and order=5. In OSEM reconstruction technique, the maximum correlation ( $r = 0.706$ ) between ECG-Gated SPECT and angiography was found using iteration of 2 and subset of 12.

**Discussion-** Angiography is usually assumed the standard method for calculation of LVEF. However, techniques such as ECG-gated SPECT can be equally accurate if the method of processing is selected optimally. We optimized the method of processing in our department in correlation with the results of angiography (*Iranian Heart Journal 2007; 8 (3): 6-15*).

**Key words:** ECG-gated SPECT ■ LVEF ■ LV volumes ■ image reconstruction ■ filtration

Left ventricular ejection fraction (LVEF), end-diastolic and end-systolic volumes are important clinical indexes in diagnosis and treatment of patients with chronic coronary disease.<sup>1</sup>

There are several methods for measurement of these indices, including echocardiography, angiography, MRI and ECG-gated SPECT.<sup>2-7</sup> Echocardiography is the most economic, safe and rapid.<sup>5</sup> Angiography is the most accurate,

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however it is invasive.<sup>6</sup>

Myocardial perfusion single photon emission computed tomography (SPECT) has been used as a reliable diagnostic and prognostic means of assessment of heart disease since 1999.<sup>4,7</sup> Gated myocardial perfusion SPECT is widely used for qualitative and quantitative analysis of left ventricular function.<sup>8</sup> The test allows determination of myocardial perfusion and function in a single study.<sup>9</sup> The left ventricular function is calculated subtracting the end systolic volume from the end diastolic volume using endocardial contours.<sup>10,11</sup> Gated perfusion SPECT makes it possible to calculate several other clinically important parameters such as absolute heart volume, myocardial mass and temporal evolution of wall thickening.<sup>12,13</sup>

Several algorithms have been described for calculation of LVEF from gated myocardial perfusion SPECT,<sup>14</sup> the most widely accepted being known as the Cedars Sinai QGS algorithm.<sup>15</sup> The LVEF values obtained using this algorithm have been compared to those from first-pass radionuclide ventriculography,<sup>16,17</sup> equilibrium radionuclide ventriculography<sup>18,19</sup> and MRI.<sup>20,21</sup> However the correlation coefficients reported were variant, ranging from 0.51 to 0.94.<sup>22</sup>

Many factors are responsible for this wide range, including the reconstruction and filtering conditions. The calculation of LVEF relies upon the detection of the endocardial surface.<sup>1</sup> The filtering condition may have significant effect on the accuracy of the edge detection algorithms.

It has been previously demonstrated that the reconstruction filter affects the correlation of LVEFs from GSPECT with those from RNVG.<sup>3,23</sup> However, the algorithm used to calculate LVEFs from GSPECT was not the QGS algorithm that is the most widely used algorithm.

The aim of this study was to quantify the effect of reconstruction conditions on calculation of LVEF and ventricular volumes using QGS algorithm. The gold standard was

assumed to be the values derived from angiographic study performed within 2 weeks of GSPECT studies. Up to now, there is no standard method of processing for cardiac SPECT.

## Methods

**Patient study:** Totally 52 patients' data were processed in this study. The patients (referred to our department for myocardial perfusion SPECT) who had angiography within 2 weeks of the test were included in the study. All the patients had a positive history of myocardial infarction. They were 48 males and 4 females, aged 48 to 70 years (mean 55.3 years).

**Gated SPECT imaging:** A single head SMV gamma camera SPECT system model DSX, equipped with low energy high-resolution parallel hole collimator was used. Energy window was set at  $\pm 10\%$  of photo peak. A total of 32 projection images in  $64 \times 64$  matrix size and 8 frames per cardiac cycle were acquired. Imaging was performed over 180 degrees from  $-45^\circ$  (left posterior oblique) to  $135^\circ$  (right anterior oblique). Circular orbit, radius of rotation between 25 to 30 cm (depending on the patient's size), step-and-shoot mode, and zoom factor of 1.33 were used. The time per view was 30 sec/view for the rest imaging. Imaging was performed 45-60 min after injection of 750-950 MBq Tc99m-sestamibi at rest condition.

**Reconstruction and filtration:** Two reconstruction methods, the filtered back projection (FBP) and the ordered subset expectation maximization (OSEM) were used to construct tomographic slice images of the heart. In the FBP technique, five reconstruction filters, Metz (psf FWHM = 3.5, 4, 4.5, 5, 5.5, and 6, order = 3, 6 and 9), Butterworth (cutoff = 0.2, 0.25, 0.3, 0.35, and 0.4, order = 2, 4, and 6), Hanning (cutoff = 0.3, 0.35, 0.4, 0.45 and 0.5), Wiener (psf FWHM = 4, 4.5, 5, 5.5 and 6) and Gaussian (Alfa = 2, 2.5, 3, 3.5 and 4) were examined. For OSEM

combination of three iterations (2, 4, 6) and four subsets (4, 8, 12, and 16) were examined.

**Statistical analysis:** Continuous variables for LVEDV, LVESV and LVEF are quoted as mean  $\pm$  standard deviations (SD). Regression analysis was used to assess the relationship between ejection fractions calculated using gated SPECT with those calculated using angiographic data. Pearson's  $r$  was also calculated to quantify the correlation. In addition, the standard error of the estimate (SEE) was calculated.

Bland-Altman analysis was used to assess agreement between the ejection fractions and volumes calculated with each reconstruction filter. The Wilcoxon signed rank test was used to test for statistically significant differences between values calculated using each filter, and for differences between the widths of the 95% prediction intervals.

### Results

Correlation coefficients between LVEF values calculated using different filter and angiographic data are presented in Table I.

**Table .I. Pearson correlation of ejection fraction using ECG-Gated SPECT and angiography**

Reconstruction	Pearson correlation
FBP Metz(psf FWHM=5 and order=3)	0.776
FBP Butterworth (cutoff=0.2 and order=4)	0.763
FBP Weiner(psf FWHM= 6)	0.759
FBP Gaussian(alpha =2.5)	0.752
FBP Hanning (cutoff=0.35)	0.720
FBP ramp filter	0.654
OSEM (iteration=2 and subset=12)	0.706
OSEM (iteration=4 and subset=4)	0.585

Correlation is significant at the 0.01 level (2-tailed).

When using FBP, the maximum correlation between ECG-Gated SPECT and angiography ( $r = 0.775$ ) was found for Metz filter (FWHM=5 and order=5). In the case of OSEM reconstruction the maximum correlation ( $r = 0.706$ ) was found with iteration=2, subset=12. The minimum correlation was found with OSEM reconstruction with iteration = 4, subset=4.

The maximum correlation with Butterworth filter (cutoff=0.2 and order=4) was 0.763 and with Weiner filter (FWHM= 6) it was 0.759. With Gaussian filter (alpha =2.5) maximum correlation was 0.752 and with Hanning filter (cutoff = 0.35) it was 0.720. The correlation with ramp filter was 0.654.

The mean  $\pm$  standard deviation and the absolute values for LVEF from ECG-gated SPECT with 95% width are shown in Table II. The mean LVEF with FBP Metz (psf FWHM = 5 and order = 3) was  $59.62 \pm 13.72$  but the mean LVEF with OSEM (iteration=2 and subset=12) was  $46.69 \pm 10.95$ , that is the nearest value to the mean of the angiographic data ( $48.09 \pm 8.93$ ).

Surprisingly, the mean value for the ramp filter was very much closer to the mean value for angiographic data than any other values calculated. However, the correlation of angiographic values and the values obtained using the ramp filter was poor. The mean  $\pm$  standard deviation for LVSV, LVEDV and LVESV from ECG-gated SPECT are shown in Table II.

Table II. Mean and standard deviation of LVEF, LVSV, LVEDV and LVESV

Reconstruction methods and filter	LVEF		LVSV		LVEDV		LVESV	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
FBP Ramp filter	48.44	10.77	58.37	16.95	99.10	64.72	64.95	38.59
FBP Gaussain (alpha =2.5)	56.71	12.29	62.25	18.06	92.77	54.94	58.88	33.48
FBP Hanning (cutoff=0.35)	57.29	12.38	62.20	16.65	91.80	52.48	58.24	31.76
FBP Weiner (psf FWHM= 6)	57.00	14.69	58.42	17.87	87.45	47.51	57.23	31.72
FBP Butterworth (cutoff=0.2 and order=4)	57.60	13.25	58.88	16.03	85.62	48.34	55.53	31.79
FBP Metz(psf FWHM=5 and order=3)	59.62	13.72	61.50	17.33	87.84	48.84	56.14	32.95
OSEM (iteration=2 and subset=12 Ramp filter)	46.69	10.95	59.09	18.79	105.42	74.02	69.68	46.38
OSEM (iteration=4 and subset=4 Ramp filter)	49.98	9.83	60.87	22.00	103.10	67.89	66.00	37.32
Angiography	48.09	8.93	-	-	-	-	-	-

Comparison of reconstructed images using different filters by two different methods, FBP and OSEM, suggests that FBP reconstruction method with Metz (psf FWHM

= 5, order = 3) creates more consistent results (quantitatively and qualitatively) for evaluation of LVEF volumes (Fig. 1) and others (Figs. 2-A, 2-B, 2-C).

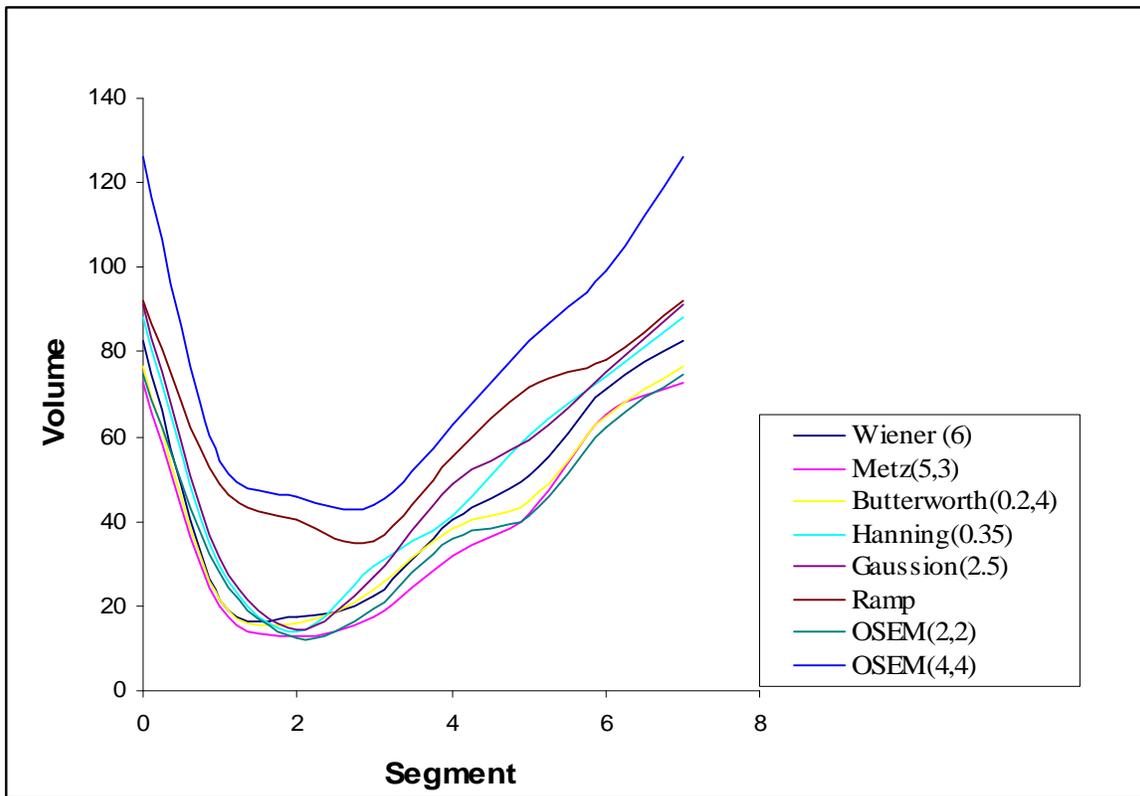
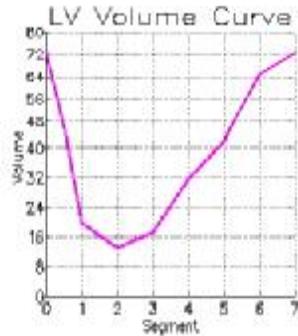
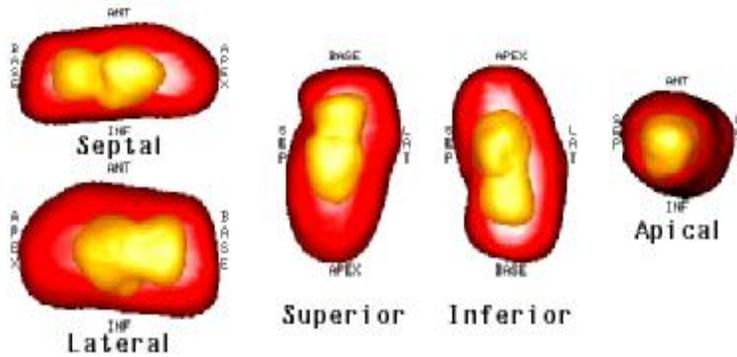


Fig. 1. LVEF calculated with different filters

Metz filter (5,3)



PATIENT STATISTICS

HT cm:	***
WT kg:	***
BSA m <sup>2</sup> :	***
HR bpm:	65

FUNCTIONAL VALUES

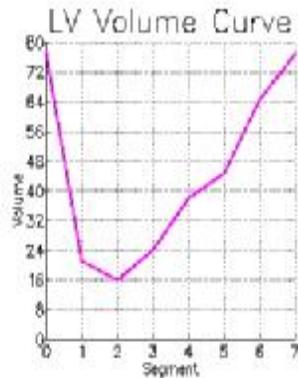
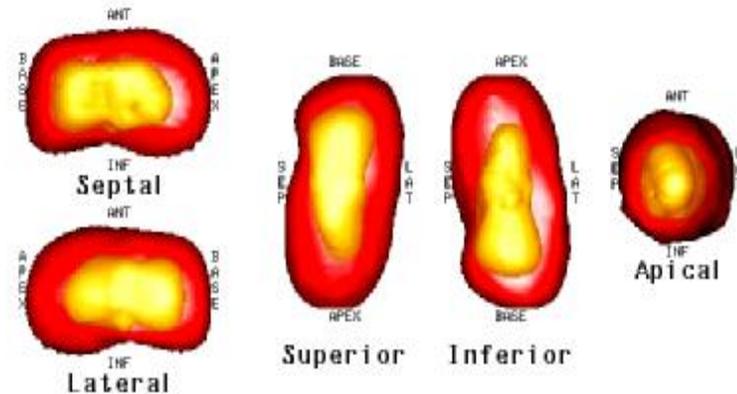
LVEF %:	82
EDV ml:	73
ESV ml:	13
SV ml:	59
CO l/min:	3.8

BSA ADJUSTED INDICES

EDV ml/m <sup>2</sup> :	***
ESV ml/m <sup>2</sup> :	***
SV ml/m <sup>2</sup> :	***

Butterworth filter(0.2,4)

Wall Motion Report



PATIENT STATISTICS

HT cm:	***
WT kg:	***
BSA m <sup>2</sup> :	***
HR bpm:	65

FUNCTIONAL VALUES

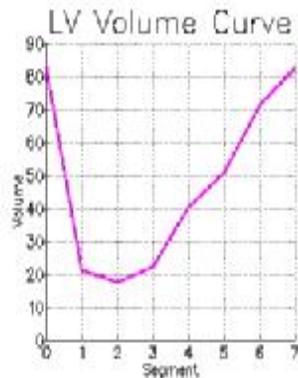
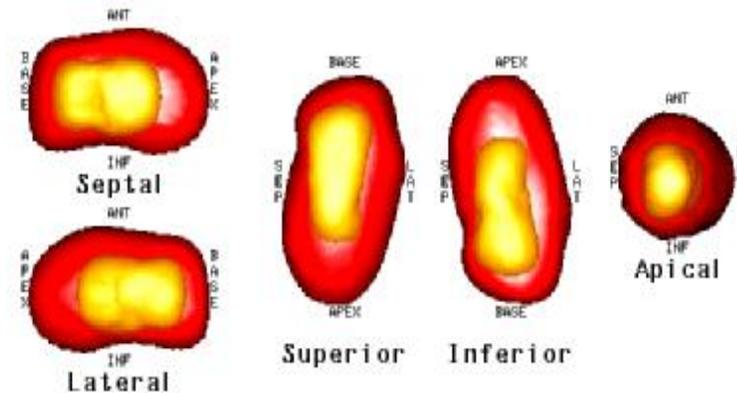
LVEF %:	79
EDV ml:	77
ESV ml:	16
SV ml:	61
CO l/min:	3.9

BSA ADJUSTED INDICES

EDV ml/m <sup>2</sup> :	***
ESV ml/m <sup>2</sup> :	***
SV ml/m <sup>2</sup> :	***

Wiener filter (6)

Wall Motion Report



PATIENT STATISTICS

HT cm:	***
WT kg:	***
BSA m <sup>2</sup> :	***
HR bpm:	65

FUNCTIONAL VALUES

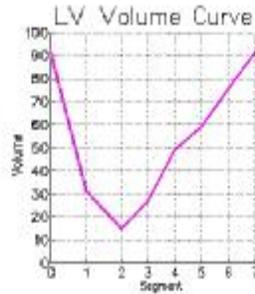
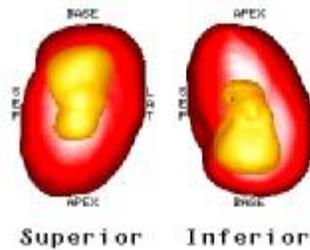
LVEF %:	79
EDV ml:	83
ESV ml:	18
SV ml:	65
CO l/min:	4.2

BSA ADJUSTED INDICES

EDV ml/m <sup>2</sup> :	***
ESV ml/m <sup>2</sup> :	***
SV ml/m <sup>2</sup> :	***

Fig. 2-A. Comparison of images reconstructed by FBP method using Metz , Butterworth and Wiener filters.

**Gaussian(2.5)**



PATIENT STATISTICS

HT cm: \*\*\*  
 WT kg: \*\*\*  
 BSA m<sup>2</sup>: \*\*\*  
 HR bpm: 65

FUNCTIONAL VALUES

LVEF %: 84  
 EDV ml: 91  
 ESV ml: 15  
 SV ml: 77  
 CO l/min: 4.9

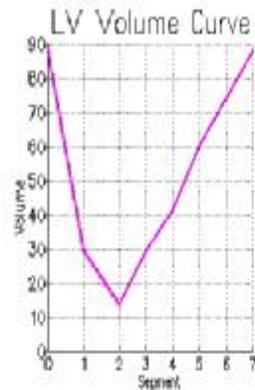
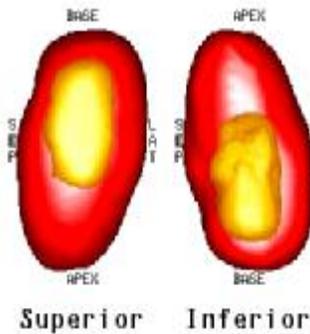
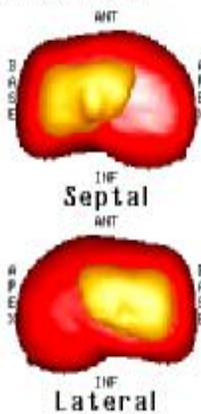
BSA ADJUSTED INDICES

EDV ml/m<sup>2</sup>: \*\*\*  
 ESV ml/m<sup>2</sup>: \*\*\*  
 SV ml/m<sup>2</sup>: \*\*\*

TID

vs. Study 2: 1.034  
 vs. Study 3: 0.991

**Hanning(0.35)**



PATIENT STATISTICS

HT cm: \*\*\*  
 WT kg: \*\*\*  
 BSA m<sup>2</sup>: \*\*\*  
 HR bpm: 65

FUNCTIONAL VALUES

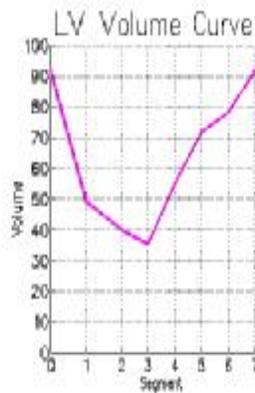
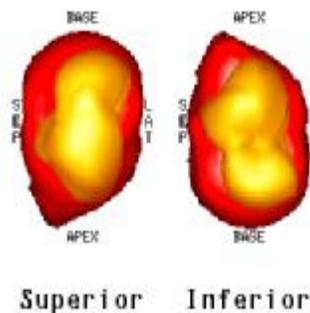
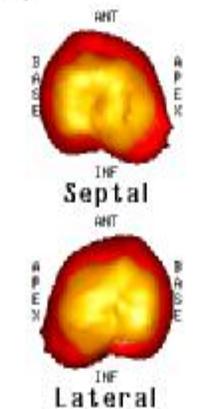
LVEF %: 84  
 EDV ml: 88  
 ESV ml: 14  
 SV ml: 74  
 CO l/min: 4.8

BSA ADJUSTED INDICES

EDV ml/m<sup>2</sup>: \*\*\*  
 ESV ml/m<sup>2</sup>: \*\*\*  
 SV ml/m<sup>2</sup>: \*\*\*

**Wall Motion Report**

**Ramp**



PATIENT STATISTICS

HT cm: \*\*\*  
 WT kg: \*\*\*  
 BSA m<sup>2</sup>: \*\*\*  
 HR bpm: 65

FUNCTIONAL VALUES

LVEF %: 62  
 EDV ml: 92  
 ESV ml: 35  
 SV ml: 57  
 CO l/min: 3.7

BSA ADJUSTED INDICES

EDV ml/m<sup>2</sup>: \*\*\*  
 ESV ml/m<sup>2</sup>: \*\*\*  
 SV ml/m<sup>2</sup>: \*\*\*

**Fig. 2-B.** Comparison of images reconstructed by FBP using Gaussian, Hanning and Ramp filters.

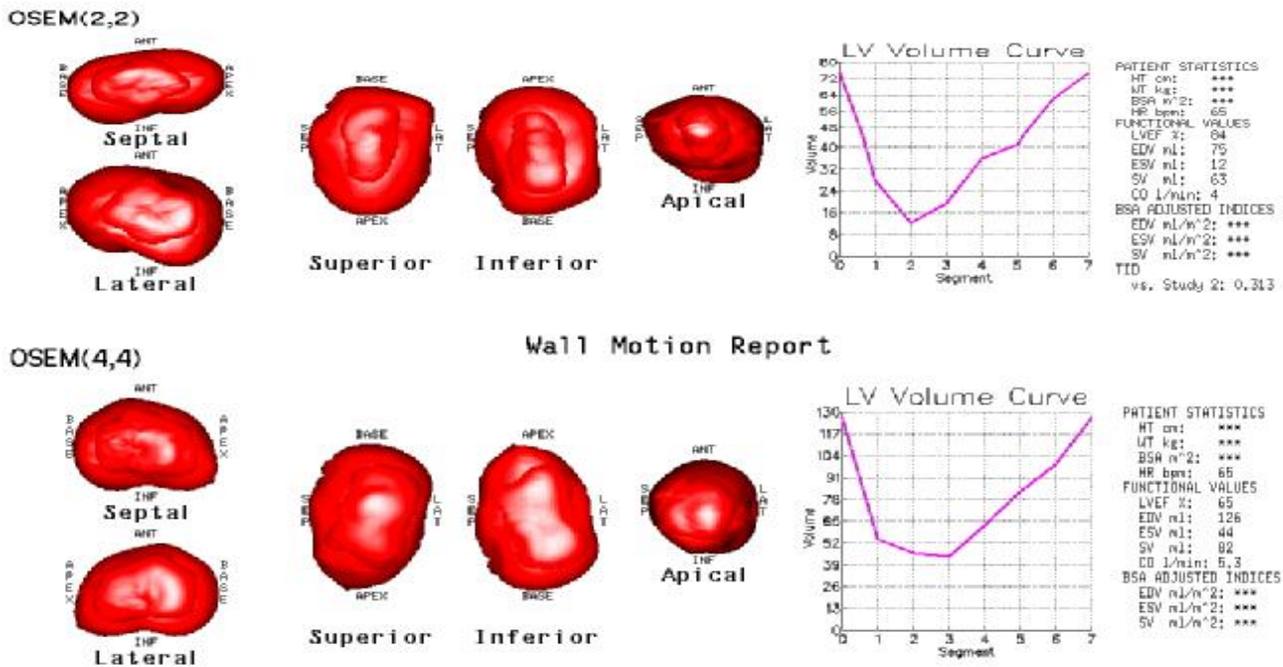


Fig. 2-C. Comparison of images reconstructed by OSEM method using iteration (2,4) and subset (2,4).

### Discussion

This study investigated the effect of the reconstruction and filtration on left ventricular ejection fraction and volumes calculated from gated myocardial perfusion tomography using QGS algorithm. Angiography is usually assumed as the most reliable method for calculation of LVEF. However, such techniques as ECG-gated SPECT can be equally accurate if the method of processing is selected optimally.

ECG-gated SPECT is a technique in which myocardial perfusion could be evaluated in addition to quantitative and qualitative assessment of LV function. However, low reproducibility is the main disadvantage of

the technique. Therefore, variations in reconstruction methods and filtration are the main concerns. As a result, high accuracy is achievable if the selection of reconstruction method and filtration is optimum. Since the technique is non-invasive and extremely useful in patients with poor-window echo, in particular the definition of the optimal reconstruction method is of value. In our study the best results, i.e., the nearest results to angiography, were found using FBP with Metz filter (FWHM=5 and order=3).

The calculated LVEF was shown to increase with resolution recovery filters, although the magnitude of the change was small. Metz and

Wiener are two typical resolution recovery filters. Both filters divide the frequency components of the data by MTF of the system. MTF is the normalized Fourier transform of system spread function. This action compensates the blurring effect introduced by MTF.

It should not be overlooked that different manufacturers may define filters in slightly different ways. Moreover, the definition of the cut-off frequency differs between filter types. Therefore, it may be difficult to compare the results of filtering when data are processed in different systems.

Besides the filtering condition, other factors like patient selection, administered activity, collimator may also have adverse effects on the calculation of LVEF and cardiac volumes.

### References

1. Go V, Bhatt MR, Hendel RC. The Diagnostic and Prognostic Value of ECG-Gated SPECT Myocardial Perfusion Imaging. *J Nucl Med* May 2004; 45 (5): 912-921.
2. Itti E, Rosso J, Damien P, Auffret M, Thirion JP, Meignan M. Assessment of ejection fraction with Tl-201 gated SPECT in myocardial infarction: precision in a rest-redistribution study and accuracy versus planar angiography. *J Nucl Cardiol* 2001; 8: 31-39.
3. Manrique A, Faraggi M, Vera P, Vilain D, Lebtahi R, Cribier A, Le Guludec D. 201Tl and 99mTc-MIBI gated SPECT in patients with large perfusion defects and left ventricular dysfunction: comparison with equilibrium radionuclide angiography. *J Nucl Med* 1999; 40(5):805-809.
4. Bavelaar-Croon CD, Atsma DE, van der Wall EE et al. The additive value of gated SPET myocardial perfusion imaging in patients with known and suspected coronary artery disease. *Nucl Med Commun* 2001; 22: 45-55.
5. Omar W, Abdel-Ghany M, Reda A. Comparison between gated SPECT and echocardiography in evaluation of left ventricular ejection fraction. *J Egyptain Nat Cancer Inst* 2000; 12(4): 301-306.
6. Yoon SN, Lee DS, Chung JK, Lee MC. Comparative study of single-injection, single-acquisition 99mTc-MIBI gated SPET and stress-rest perfusion SPET for the evaluation of myocardial viability after bypass surgery in coronary artery disease. *Eur J Nucl Med* 2000; 27(12):1747-1753.
7. Gonzalez JM, Castell-Conesa J, Candell-Riera J, Rosselló-Urgell J. Relevance of 99mTc-MIBI rest uptake, ejection fraction and location of contractile abnormality in predicting myocardial recovery after revascularization. *Nucl Med Commun* 2001; 22(7): 795-805.
8. Visser JJ, Sokole EB, Verberne HJ, Habraken JB, van de Stadt HJ, Jaspers JE, Shehata M, Heeman PM, van Eck-Smit BL. A realistic 3-D gated cardiac phantom for quality control of gated myocardial perfusion SPET: the Amsterdam gated (AGATE) cardiac phantom. *Eur J Nucl Med Mol Imaging* 2004; 31:222-228.
9. Hashimoto J, Suzuki T, Nakahara T, Kosuda S, Kubo A. Preoperative risk stratification using stress myocardial perfusion scintigraphy with electrocardiography gating. *J Nucl Med* 2003; 44 (3): 385-390.
10. Bestetti A, Di Leo C, Alessi A, Triulzi A, Tagliabue L, Tarolo GL. Post-stress end-systolic left

- ventricular dilation: a marker of endocardial post-ischemic stunning. *Nucl Med Commun* 2001;22: 685-693.
11. Itti E, Levy M, Pouillart F, Perez T, Bellorini M, Rosso J, Meignan M. Thallium gated SPECT: relation between immediate post-stress evolution of ejection fraction and severity of perfusion pattern. *Nucl Med Commun* 2001; 22: 57-64.
  12. Higuchi T, Taki J, Nakajima K, Kinuya S, Ikeda M, Namura M, Tonami N. Left ventricular ejection and filling rate measurement based on the automatic edge detection method of ECG-gated blood pool single-photon emission tomography. *Annals Nucl Med* 2004; 18(6): 507-511.
  13. Deou D, Vilain D, Colin P, Lebtahi R, Fourme T, Coaguila C, Benada A, Idy-Peretti I, Slama M and Le Guludec D, Comparative value of ECG-gated blood pool SPET and ECG-gated myocardial perfusion SPET in the assessment of global systolic left ventricular function. *Eur J Nucl Med Mol Imaging* 2003; 30: 859-867.
  14. Everaert H, Bossuyt A and Franken P R. Left ventricular ejection fraction and volumes from gated single photon emission tomographic myocardial perfusion images: comparison between two algorithms working in three-dimensional space. *J Nucl Cardiol* 1997; 4: 472-476
  15. Germano G, Kiat H, Kavanagh PB, Moriel M, Mazzanti M, Su HT, Van Train KF, Berman DS. Automatic quantification of ejection fraction from gated myocardial perfusion SPECT. *J Nucl Med* 1995;36: 2138-2147.
  16. He ZX, Cwajg E, Preslar JS, Mahmarian JJ, Verani MS. Accuracy of left ventricular ejection fraction determined by gated myocardial perfusion SPECT with Tl-201 and Tc-99m sestamibi: comparison with firstpass radionuclide angiography. *J Nucl Cardiol* 1999; 6: 412-417.
  17. Vallejo E, Dione DP, Sinusas AJ, Wackers FJ. Assessment of left ventricular ejection fraction with quantitative gated SPECT: accuracy and correlation with first-pass radionuclide angiography. *J Nucl Cardiol* 2000; 7: 461-70.
  18. Véra P, Manrique A, Pontvianne V, Hitzel A, Koning R, Cribier A. Thallium-gated SPECT in patients with major myocardial infarction: effect of filtering and zooming in comparison with equilibrium radionuclide imaging and left ventriculography. *J Nucl Med* 1999; 40: 513-521.
  19. Williams K A, Taillon L A. Left ventricular function in patients with coronary artery disease assessed by gated tomographic myocardial perfusion images: comparison with assessment by contrast ventriculography and first-pass radionuclide angiography. *J Am Coll Cardiol* 1996; 27: 173-181.
  20. Vaduganathan P, He ZX, Vick GW 3rd, Mahmarian JJ, Verani MS. Evaluation of left ventricular wall motion, volumes, and ejection fraction by gated myocardial tomography with technetium 99m-labeled tetrofosmin: a comparison with cine magnetic resonance imaging. *J Nucl Cardiol* 1999; 6: 3-10.
  21. Vallejo E, Dione DP, Bruni WL, Constable RT, Borek PP, Soares JP, Carr JG, Condos SG, Wackers FJ, Sinusas AJ. Reproducibility and accuracy of

gated SPECT for determination of left ventricular volumes and ejection fraction: experimental validation using MRI. *J Nucl Med* 2000;41: 874–882.

22. Wright GA, McDade M, Martin W, Hutton I. Quantitative gated SPECT: the effect of reconstruction filter on calculated left ventricular ejection fraction and volumes. *Phys Med Biol* 2002; 47: 99-105.

23. Wright G A, McDade M, Keeble. Are ejection fractions from gated SPECT perfusion studies clinically useful? A comparison with radionuclide ventriculography. *Physiol Meas* 2001; 22: 413–422.