Comparison of two software in gated myocardial perfusion single photon emission tomography, for the measurement of left ventricular volumes and ejection fraction, in patients with and without perfusion defects

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Abstract

Emory cardiac toolbox (ECTb) and quantitative gated single photon emission tomography – SPET (QGS) software are the two most often used techniques for automatic calculation of left ventricular volumes (LVV) and ejection fraction (LVEF). Few studies have shown that these software are not interchangeable, however the effect of perfusion defects on performance of these software has not been widely studied. The aim of this study was to compare the performance of QGS and ECTb for the calculation of LVEF, end-systolic volume (ESV) and end-diastolic volume (EDV) in patients with normal and abnormal myocardial perfusion. One hundred and forty-four consecutive patients with suspected coronary artery disease underwent a two-day protocol with dipyridamole stress/rest gated technetium-99m-methoxy isobutyl isonitrile (^{99m}Tc-sestamibi) myocardial perfusion SPET (GSPET) (8 gates/cardiac cycles). Rest GSPET scintiscan findings were analyzed using QGS and ECTb. Correlation between the results of QGS and ECTb was greater than 90%. In patients with no perfusion defects, EDV and LVEF using ECTb, were significantly higher than using QGS ($P<0.001$), whereas no significant difference was noticed in ESV ($P=0.741$). In patients with perfusion defects, also ECTb yielded significantly higher values for EDV, ESV and LVEF than QGS ($P<0.001$). In tomograms of patients with perfusion defects, mean differences of EDV and ESV between the two software, were significantly higher than in tomograms of patients without defects ($P<0.001$), while for LVEF this difference was not significant ($P=0.093$). Patients were classified into three subgroups based on the summed rest score (SRS); G1: patients with SRS≤3 (n=109), G2: patients with 4≤SRS≤8 (n=13) and G3: patients with SRS≥9 (n=22). One-way ANOVA showed that the mean differences of EDV and ESV values between ECTb and QGS between the subgroups were significant ($P<0.001$ for both parameters), while no significant difference was noticed between the subgroups, as for the mean difference of LVEF, calculated by the two software ($P=0.07$). By increasing SRS, the EDV and ESV values were overestimated to a higher level by the ECTb as compared to the QGS software. Linear regression analysis showed that the difference in LVV values, between the two software increased, when SRS also increased ($P<0.001$). *In conclusion*, correlation between QGS and ECTb, software was very good both in patients with and without perfusion defects. In patients with perfusion defects, calculated LVEF, ESV and EDV values are higher using ECTb compared to the QGS software. However, the more extensive the perfusion defect was, the greater the difference of LVV between these two software. For the follow up of patients, we suggest the use of a single software either QGS or ECTb, for serial measurements of LV function.

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Introduction

In coronary artery disease (CAD), data acquisition from gated single-photon emission tomography (GSPET) allows myocardial perfusion imaging with subsequent analysis of regional wall motion and calculation of global myocardial function by referring especially to left ventricular (LV) end-diastolic, end-systolic volumes (EDV, ESV) and ejection fraction (LVEF) [1, 2]. This integrated approach with simultaneous evaluation of myocardial perfusion and function, is clinically useful for the diagnosis, prognosis and follow-up of CAD [3, 4].

Available software algorithms are: Quantitative Gated SPET (QGS, Cedars-Sinai Medical Center, Los Angeles, California, USA), Emory Cardiac Toolbox (ECTb, Emory University,

Atlanta, Georgia, USA), 4D-MSPET (University of Michigan, Medical Center), layer of maximum counts (LMC), MultiDim (Sopha, Medical Vision International, Buc, France) and left ventricular global thickening fraction (LVGTF) [1, 5-7]. Previous studies have compared these methods against cardiac magnetic resonance imaging (cMRI) [2, 8-12], echocardiography [13, 14], gated blood pool SPET [5, 7, 15, 16], contrast ventriculography [15, 17, 18], and simulated images [19]. Each of the above methods has its own advantages and drawbacks in estimating the left ventricular volumes (LVV) and LVEF [20]. Several studies have demonstrated that both methods, QGS and ECTb, are significantly correlated with each other and with 'gold standard' techniques in estimating myocardial functional parameters [5, 6, 12, 14, 16, 20-22]. Nevertheless, the effect of perfusion defects on calculation of the above functional parameters, has not been widely studied.

The purpose of this study is to further elucidate the behavior of QGS and ECTb software packages, calculating the same data of LV functional parameters in a considerable number of patients, with or without perfusion defects.

Patients and methods

Study population

We have studied 144 patients (74 men and 70 women), ranging in age between 27 and 86 years (mean age: 56.72±11.3 years) with known or suspected CAD, referred to us for myocardial perfusion GSPET. Twenty-five (17.4%) of the patients had a coronary artery bypass graft, and 5 (3.5%) had undergone percutaneous transluminal coronary angioplasty. Patients with arrhythmia, atrial fibrillation, severe motion artifacts and patients with high extra-cardiac activity were excluded from the study. According to the rest –GSPET findings and also according to the summed rest score (SRS),patients were divided into those having or not perfusion defects. From the 144 patients studied, 109 patients (75.7%) had no perfusion defects and 35 patients (24.3%) had one or more perfusion defect in the rest myocardial perfusion SPET.

Study protocol

All patients underwent stress/rest GSPET test using a 2-day protocol, started with the stress GSPET test. On the first day 740-925 MBq technetium-99m-sestamibi (^{99m}Tc-sestamibi) was injected intravenously (iv), after the infusion of 0.568 mg of dipyridamole. GSPET was performed 90 min after the radiotracer injection. The next day, rest GSPET was performed 90 min after the iv injection of the same as above dose activity of ^{99m}Tc-sestamibi. GSPET was performed in the supine position by the use of a dual-head gamma-camera (E.CAM; Siemens, Germany), equipped with high-resolution, low-energy collimators. Thirty two views over a 180° orbit were obtained from RAO 45° to LPO 45° with a zoom factor 1.45, at 25 sec per view and 8 frames per cardiac cycle. Images were stored in a 64×64 matrix in the computer and reconstructed by filtered back projection, using a Butterworth filter (cut-off value was 0.35 cycle/cm for gated data and 0.55 cycle/cm for ungated data, order =5). The transverse images were reoriented into the three orthogonal slices i.e. short, horizontal and vertical long axis, for display and interpretation. No attenuation or scatter correction was applied. Myocardial perfusion was assessed visually and semi-quantitatively. The 17-segment five point scoring system was used for semi-quantitative assessment of myocardial perfusion [23]. The SSS and SRS were calculated.

Gated data analysis

Rest GSPET images were analyzed for the same functional variables with two different quantification software packages, QGS and ECTb on a Siemens e.soft workstation. Automatic processing was used for both algorithms with manual reprocessing, used only if the myocardial borders were not detected adequately. LVV including EDV and ESV as well as LVEF, were calculated by both algorithms.

Patients were classified into two groups based on the presence (n=35, 24.3%) or absence of perfusion defects (n = 109, 75.7%) in the rest myocardial perfusion SPET images. In order to study if perfusion defects affect the above calculations of LVV and LVEF, we have calculated the mean difference of these indices between the two software ($\Delta EDV = EDV_{ECTb} - EDV_{QGS}$, $\Delta ESV = ESV_{ECTb} - ESV_{QGS}$ and $\Delta EF = EF_{ECTb} - EF_{QGS}$) in patients with and without perfusion defects. In order to study the effect of the size of the perfusion defects, patients were also classified into three subgroups based on SRS; Group1 (G1): patients with SRS≤3 (n=109), Group 2 (G2): patients with 4≤SRS≤8 (n=13) and Group 3(G3): patients with SRS≥9 (n=22). The mean difference of left ventricular function indices between these two software ($\Delta EDV = EDV_{ECTb} - EDV_{QGS}$, $\Delta ESV = ESV_{ECTb} - ESV_{QGS}$ and $\Delta EF = EF_{ECTb} - EF_{QGS}$) in different patients subgroups, were calculated.

Statistical analysis

Statistical analysis was performed using SPSS software (version 10.1). EDV, ESV and LVEF were expressed as mean values ± standard deviation (SD). Paired t-test was used for comparison of the mean values between the two software algorithms in all groups. One-way ANOVA was used for comparison of the mean EDV, ESV and LVEF values between the subgroups. Also Tukey's honestly significant difference test (Tukey HSD) was used for comparison between groups in post Hoc analysis. Comparison between two independent groups was done using independent samples *t* test. Pearson correlation was calculated for group comparison. Also linear regression analysis was done. A P value of less than 0.05 was considered statistically significant.

Results

Good correlation was noticed between calculated rest EDV, ESV and LVEF by ECTb and QGS. All Pearson correlation coefficients were above 0.90 (P<0.001). In all patients, the mean EDV and LVEF, from the rest phase images, when calculated by ECTb were: 106.9±50.8 ml and 75.6%±17.7%

respectively, and significantly higher than when calculated that by QGS (70.0±34.8 ml, and 64.3%±17.5% respectively, P<0.001). Also, mean ESV values were significantly higher when those calculated by ECTb than by QGS (34.0±44.1 ml, and 29.6±30.9 ml respectively, P=0.002).

In patients with no perfusion defects (n=109, 75.7%), calculations of EDV were also higher by ECTb than by QGS (91.7±32.1ml and 59.7±21.6ml respectively, P<0.001), and also calculations of LVEF: (82.6%±10.5% and 70.7%±12.9% respectively, P<0.001). No significant difference as for the above calculations was noticed for ESV (ECTb: 19.1±21.0 and QGS: 19.4±16 ml, respectively P= 0.741) (Fig. 1). In patients with perfusion defects (n=35, 24.3%), calculated EDV, ESV and LVEF by using QGS were: 101.9±47.2 ml, 61.3±42.8 ml and 44.3%±14.7% respectively significantly less than those when calculated by ECTb (154.2 ±67.3 ml, 80.4±62.1 ml and 53.8%±18.3% respectively, P<0.001) (Fig.1).

In the tomograms of patients with perfusion defects, mean ΔEDV and ΔESV were significantly higher than those in the tomograms of patients without defects. For LVEF this difference was not statistically significant (P= 0.093), (Table 1).

Mean SRS was 3.72±6.8 (range: 0-41). One-way ANOVA showed that the mean ΔEDV and ΔESV were significantly different between subgroups G1, G2 and G3 (For both parameters: P<0.001). No significant difference was noticed between the subgroups for the ΔEF (P=0.07). Table 2 summarizes these results.

Linear regression analysis for the relationship between SRS and the difference in functional indices between the two software, showed that the difference in volume indices ΔEDV and ΔESV between the two software was increasing following the increase in SRS. ΔEF was weakly and negatively correlated with SRS (Fig. 2).

Discussion

For the computation of LVV and LVEF, the commercially available automated QGS software has most frequently been validated using the currently established gold standard of cMRI. cMRI does not rely on geometric assumptions of the left ventricular shape [12]. Other analytical programs have also been sporadically compared with cMRI [2, 8-12, 22, 24]. Both QGS and ECTb software are fully automated, work in 3-D space and use the short-axis data set. The QGS method, in case it fails to adequately delineate myocardial borders, offers the chance to reselect manual processing. The ECTb method offers the possibility to change the short-axis radius and centre [5]. ECTb is able to analyze data only if acquired and gated by using 8 frames/cardiac cycle [25]. If data are acquired with 16 frames/cardiac cycle, it is necessary to truncate the images to 8 frames/cardiac cycle prior to analysis with ECTb [6].

Table 1. *Differences between left ventricular end-diastolic volume, end-systolic volume and ejection fraction at rest GSPET, calculated by ECTb and QGS, in patients with and without perfusion defects: $\Delta EDV = EDV_{ECTb} - EDV_{QGS}$, $\Delta ESV = ESV_{ECTb} - ESV_{QGS}$ and $\Delta EF = LVEF_{ECTb} - LVEF_{QGS}$*

Measured quantity	No perfusion defects	With perfusion defects	P value
ΔEDV (ml)	31.9±14.9	52.3±26.7	<0.001
ΔESV (ml)	–0.32±10.1	19.1±23.5	<0.001
ΔEF (%)	11.8±7.2	9.5±6.6	0.093

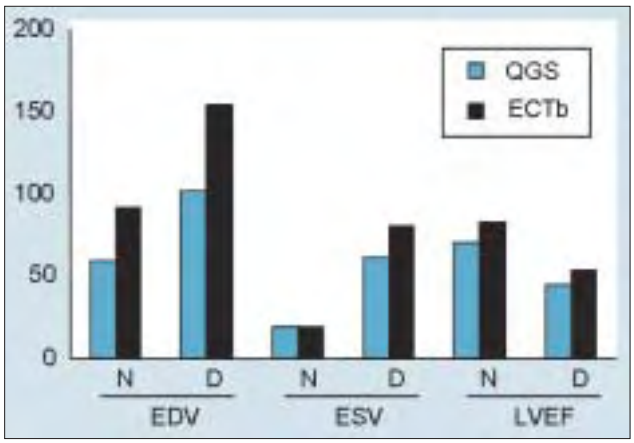

Figure 1. Calculation of end-diastolic volume (EDV), end-systolic volume (ESV) and left ventricular ejection fraction (LVEF%) by QGS and ECTb software on rest GSPECT for patients without perfusion defects (N) and with perfusion defects (D)

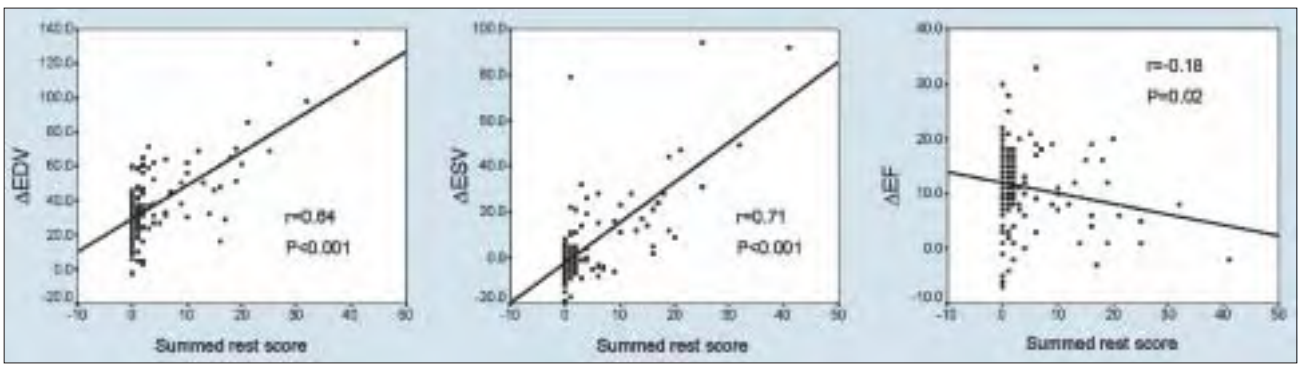

Figure 2. Linear regression between summed rest score and differences of calculated end-diastolic volume (EDV), end-systolic volume (ESV) and left ventricular ejection fraction (LVEF) by ECTb and QGS: $\Delta EDV = EDV_{ECTb} - EDV_{QGS}$, $\Delta ESV = ESV_{ECTb} - ESV_{QGS}$ and $\Delta EF = LVEF_{ECTb} - LVEF_{QGS}$

Table 2. *Differences of ΔEDV, ΔESV and ΔEF between three subgroups; G1: patients with SRS≤3, G2: patients with 4≤SRS≤8 and G3: patients with SRS≥9. (ΔEDV = EDV_{ECTb}–EDV_{QGS} , ΔESV=ESV_{ECTb}–ESV_{QGS} and ΔEF=$LVEF_{ECTb}$–$LVEF_{QGS}$)*

Measured quantity	Subgroups	Mean difference between two subgroups	P value
ΔEDV	G2 vs. G1	7.9	0.27
	G3 vs. G2	20.4	0.004
	G3 vs. G1	28.4	<0.001
ΔESV	G2 vs. G1	4.8	0.45
	G3 vs. G2	21.7	<0.001
	G3 vs. G1	26.6	<0.001
ΔEF	G2 vs. G1	2.2	0.53
	G3 vs. G2	–5.3	0.08
	G3 vs. G1	–3.1	0.14

Previous studies have shown good correlation, of EDV, ESV and LVEF values calculated by either QGS or ECTb, with cMRI [2, 8-12, 22, 24]. Consistent to our findings, good correlation between the above values, calculated by QGS and ECTb have also been reported [5, 6, 12, 20]. This was to be expected, because QGS and ECTb methods were based on the same ^{99m}Tc-sestamibi GSPET data set. These software may not be used interchangeably because their actual results differ. In the present study, some characteristic systematic differences were observed in the measurements between the two software.

In agreement with our data referring to the total number of our patients, others have also found that EDV and LVEF are significantly higher when estimated by ECTb than by QGS [6, 16]. These authors failed to present data for ESV. Many other studies included a mixture of patients with normal and abnormal myocardial perfusion findings and thus the effect of perfusion defects on the estimation of LVV was not studied [2, 5, 12]. Others have also reported significantly higher calculated EDV and LVEF by ECTb than by QGS software, but ESV yielded significantly lower values by ECTb than by QGS [12]. This study was conducted on a mixture of 70 patients using a MultiSPET 3 triple-head γ-camera (Gammasonics, Siemens Inc., Germany) with a zoom factor 1.23 and did not show results based on perfusion defect patterns [12].

In a study of 20 patients with small hearts (EDV <85 ml, as assessed by gated blood pool imaging) studied with ^{99m}Tc-tetrofosmin GSPET, the EDV and LVEF values determined by ECTb were also significantly higher than by OGS (P<0.0001). The mean ESV by ECTb and QGS was not statistically different [5]. In another study using also ^{99m}Tc-tetrofosmin GSPET stress test, conducted on 74 patients with abnormal myocardial perfusion, LVEF was also significantly higher by ECTb than by the QGS software [20]. No significant difference in mean EDV, was noticed between the two software [20]. As for ESV, this study, in contrast to ours and to previous results of the same authors [5], reported that the mean ESV calculated by ECTb, was significantly lower than when calculated by the QGS. Different techniques may have different results due to selection criteria of their patients' groups, imaging methods or to different acquisition and processing protocols [26-31]. Others have shown that measurements of LVEF performed by QGS when done by using 8 instead of 16 frames per cardiac cycle, resulted in a constant and predictable 4% points decrease [21]. Thus, the interchangeability of these two software GSPET methods is of limited clinical value [14, 16, 20, 26].

Other studies have also shown that LVEF calculated by ECTb, provided higher values in comparison with QGS with a mean value of about 8%-8.4% points [20, 22, 32]. In our study, this difference in patients with and without perfusion defects was 9.5% and 11.8% points respectively. In patients with perfusion defects, the edge detection-based techniques may not be reliable due to inaccuracy in outlining the hypoperfused myocardial segments [20]. The dependence of QGS on count profiles might explain the sensitivity of this method in cases with myocardial perfusion defects. In the ECTb software, the algorithm forces the hypoperfused segment to show a smooth connection to the adjacent non-infarcted portions of the myocardial wall and also since the hypoperfused segment is not thickening, its end diastolic positions are considered in both the end-diastole and end-systole frames [20, 25]. Further studies are needed to elucidate the controversial findings mentioned above on the LVV and LVEF. Anyhow, all studies mentioned above as well as ours, have shown that calculated LVEF is higher by ECTb than by QGS software.

In our study, a systematic increase in the ΔEDV and ΔESV was noticed in patients with perfusion defects as compared to those patients with no perfusion defects. In other words, perfusion defects result in more increased ventricular volumes by ECTb as compared to QGS (Table1). Increased volumes of EDV and ESV by ECTb were even higher when the SRS was also increased (Table 2, Fig. 2). Although ANOVA analysis showed no significant difference in ΔEF between the subgroups, Figure 2 shows that by increasing SRS there is a mild tendency to decrease the ΔEF.

Based on the significant difference we have found between the two software in the calculation of LVV and LVEF, we routinely use at present, the QGS software for the calculations of LVEF and LVV. However if our patients had been previously studied by ECTb, we use that same software for their follow up study.

In conclusion, in GSPET tomograms of patients with perfusion defects, calculated LVEF, ESV and EDV values are higher using ECTb compared to the QGS software. This difference was more pronounced for LVV, when there was an increase in the extent and severity of myocardial perfusion defects. Considering the significant differences between these two software, we suggest that the same software package should be used for the same patient throughout all his GSPET studies.

Bibliography

1. Smanio PE, Watson DD, Segalla DL, et al. Value of gating of technetium-99m sestamibi single-photon emission computer tomographic imaging. *J Am Coll Cardiol* 1997; 30: 1687-1692.
2. Lipke CSA, Kühl HP, Nowak B, et al. Validation of 4D-MSPECT and QGS for quantification of left ventricular volumes and ejection fraction from gated ^{99m}Tc-MIBI SPET: comparison with cardiac magnetic resonance imaging. *Eur J Nucl Med Mol Imaging* 2004; 31: 482-490.
3. DePuey EG, Rozanski A. Using gated technetium-99m-sestamibi SPECT to characterize fixed myocardial defects as infarct or artifact. *J Nucl Med* 1995; 36: 952-955.
4. Sharir T, Germano G, Kavanagh PB, et al. Incremental prognostic value of post-stress left ventricular ejection fraction and volume by gated myocardial perfusion single photon emission computed tomography. *Circulation* 1999; 100: 1035-1042.
5. Khalil MM, Elgazzar A, Khalil W, et al. Assessment of left ventricular ejection fraction by four different methods using ^{99m}Tc tetrofosmin gated SPECT in patients with small hearts: correlation with gated blood pool. *Nucl Med Commun* 2005; 26: 885-893.
6. Lum DP, Coel MN. Comparison of automatic quantification software for the measurement of ventricular volume and ejection fraction in gated myocardial perfusion SPECT. *Nucl Med Commun* 2003; 24: 259-266.
7. Vera P, Koning R, Cribier R, Manrique A. Comparison of two three-dimensional gated SPECT methods with thallium in patients with large myocardial infarction. *J Nucl Cardiol* 2000; 7: 312-319.
8. Bavelaar-Croon CD, Kayser HW, van der Wall EE, et al. Left ventricular function: correlation of quantitative gated SPECT and MR imaging over a wide range of values. *Radiology* 2000; 217: 572-575.
9. Bax JJ, Lamb H, Dibbets P, et al. Comparison of gated single-photon emission computed tomography with magnetic resonance imaging for evaluation of left ventricular function in ischemic cardiomyopathy. *Am J Cardiol* 2000; 86: 1299-1305.
10. Vaduganathan P, He ZX, Vick GW, et al. 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.
11. Tadamura E, Kudoh T, Motooka M, et al. Assessment of regional and global left ventricular function by reinjection ^{201}Tl and rest ^{99m}Tc- sestamibi ECG-gated SPECT: comparison with three-dimensional magnetic resonance imaging. *J Am Coll Cardiol* 1999; 33: 991-997.
12. Schaefer WM, Lipke CSA, Standke D, et al. Quantification of left ventricular volumes and ejection fraction from gated ^{99m}Tc-MIBI SPECT: MRI validation and comparison of the Emory Cardiac Tool Box with QGS and 4D-MSPECT. *J Nucl Med* 2005; 46: 1256-1263.
13. Chua T, Kiat H, Germano G, et al. Gated technetium-99m sestamibi for simultaneous assessment of stress myocardial perfusion, postexercise regional ventricular function and myocardial viability: correlation with echocardiography and rest thallium-201 scintigraphy. *J Am Coll Cardiol* 1994; 23: 1107-1114.
14. Nichols K, Lefkowitz D, Faber T, et al. Echocardiographic validation of gated SPECT ventricular function measurements. *J Nucl Med* 2000; 41: 1308-1314.
15. Paul A, Hasegawa S, Yoshioka J, et al. Left ventricular volume and ejection fraction from quantitative gated SPECT: comparison with gated pool SPECT and contrast ventriculography. *J Nucl Med* 1999; 40(P): 178.
16. Nakajima K, Higuchi T, Taki J, et al. Accuracy of ventricular volume and ejection fraction measured by gated myocardial SPECT: comparison of 4 software programs. *J Nucl Med 2001*; 42: 1571-1578.
17. Atsma DE, Bavelaar-Croon CD, Germano G, et al. Good correlation between gated single photon emission computed myocardial tomography and contrast ventriculography in the assessment of global and regional left ventricular function. *Int J Card Imaging* 2000; 16: 447-453.
18. Yoshioka J, Hasegawa S, Yamaguchi H, et al. Left ventricular volume and ejection fraction calculated from quantitative electrographic gated 99m technetium tetrofosmin myocardial SPECT. *J Nucl Med* 1999; 40: 1693-1698.
19. Achtert AD, King MA, Dahlberg ST, et al. An investigation of the estimation of ejection fractions and cardiac volumes by a quantitative gated SPECT software package in simulated gated SPECT images. *J Nucl Cardiol* 1998; 5: 144-152.
20. Khalil MM, Elgazzar A, Khalil W. Evaluation of left ventricular ejection fraction by the quantitative algorithms QGS, ECTb, LMC and LVGTF using gated myocardial perfusion SPECT: investigation of relative accuracy. *Nucl Med Commun* 2006; 27: 321-332.
21. Germano G, Kiat H, Kavanagh PB, et al. Automatic quantification of ejection fraction from gated myocardial perfusion SPECT. *J Nucl Med* 1995; 36: 2138-2147.
22. Faber TL, Vansant JP, Pettigrew RI, et al. Evaluation of left ventricular endocardial volumes and ejection fractions computed from gated perfusion SPECT with magnetic resonance imaging: comparison of two methods. *J Nucl Cardiol* 2001; 8:645-651.
23. Kakhki VD, Zakavi SR. Prediction of the left ventricular ejection fraction using cavity-to-myocardium count ratio and perfusion scores in myocardial perfusion SPECT. *Hell J Nucl Med* 2004; 7: 127-130.
24. Thorley PJ, Plein S, Bloomer TN, et al. Comparison of ^{99m}Tc- tetrofosmin gated SPECT measurements of left ventricular volumes and ejection fraction with MRI over a wide range of values. *Nucl Med Commun* 2003; 24: 763-769.
25. Faber TL, Cooke CD, Folks RD, et al. Left ventricular function and perfusion from gated perfusion images: an integrated method. *J Nucl Med* 1999; 40: 650-659.
26. Feng B, Sitek A, Gullberg GT. Calculation of the left ventricular ejection fraction without edge detection: application to small hearts. *J Nucl Med* 2002; 43: 786-794.
27. Schaefer WM, Lipke CSA, Kühl HP, et al. Prone versus supine patient positioning during gated ^{99m}Tc-sestamibi SPECT: effect on left ventricular volumes, ejection fraction, and heart rate. *J Nucl Med* 2004; 45: 2016-2020.
28. Kakhki VD, Zakavi SR, Bakhtiari H. Effect of patient positioning on left ventricular volumes and function during gated ^{99m}Tc sestamibi myocardial perfusion SPECT: comparison between the results obtained in prone and supine positions. *World J Nucl Med* 2006; 5: 9-12.
29. Iakovou I, Psarouli E, Boundas D, et al. Ordered-subset-expectation-maximization reconstruction algorithm: the effect of different cut-off frequencies on the measurement of left ventricular functional parameters from gated SPECT studies. Comparison with equilibrium radionuclide angiography. *Hell J Nucl Med* 2003; 6: 160-165.
30. Gayed I, Cid E, Boccalandero F, et al. Factors affecting left ventricular ejection fraction using automated quantitative gated SPECT. *Clin Nucl Med* 2003; 28: 290-295.
31. Véra P, Manrique A, Pontvianne V, et al. 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.
32. Nichols K, Santana CA, Folks R, et al. Comparison between ECTb and QGS for assessment of left ventricular function from gated myocardial perfusion SPECT. *J Nucl Cardiol* 2002; 9: 285-293.