Left Ventricular Volumes and Ejection Fraction Calculated from Quantitative Electrocardiographic-Gated ^{99m}Tc-Tetrofosmin Myocardial SPECT

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We compared the left ventricular (LV) end-diastolic volume (EDV), end-systolic volume (ESV) and ejection fraction (LVEF) as calculated by Cedars automated quantitative gated SPECT (QGS) to those determined by first-pass radionuclide angiography (FPRNA) and contrast left ventriculography (LVG) in a group of 21 patients (mean age 61.4 ± 9.2 y). **Methods:** A total of 740 MBq ^{99m}Tc-tetrofosmin was administered rapidly into the right cubital vein at rest, and FPRNA was performed using a multicrystal gamma camera. One hour after injection, QGS was performed with a temporal resolution of 10 frames per R-R interval. LVG was performed within 2 wk. **Results:** The EDV, ESV and LVEF calculated by QGS were highly reproducible (intraobserver, r = 0.99, r = 0.99 and r = 0.99, respectively; interobserver, r = 0.99, r = 0.99 and r = 0.99, respectively; $P < 0.01$) and were more consistent than those determined by FPRNA (intraobserver, r = 0.97, r = 0.95 and r = 0.93, respectively; interobserver, r = 0.86, r = 0.96 and r = 0.91, respectively; $P < 0.01$). There was a good correlation between EDV, ESV and LVEF by FPRNA and those by LVG (r = 0.61, r = 0.72 and r = 0.91, respectively; $P < 0.01$), and there was an excellent correlation between QGS and LVG (r = 0.73, r = 0.83 and r = 0.87, respectively; $P < 0.01$). The mean EDV by QGS (100 ± 11.3 mL) was significantly lower than by FPRNA (132 ± 16.8 mL) or LVG (130 ± 8.1 mL), and the mean ESV by QGS (53.8 ± 9.3 mL) was lower than by FPRNA (73.0 ± 13.3 mL). Ejection fraction values were highest by LVG (57.1% ± 3.2%), then QGS (51.8% ± 3.0%) and FPRNA (48.9% ± 2.4%). **Conclusion:** QGS gave more reproducible results than FPRNA. LV volumes and LVEF calculated by QGS correlated well to those by LVG.

Key Words: ^{99m}Tc-tetrofosmin; gated SPECT; first-pass radionuclide angiography; contrast left ventriculography; automatic ejection fraction quantitation

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Automatic quantification from electrocardiographic (ECG)-gated myocardial SPECT with ^{99m}Tc-labeled radiopharmaceuticals was developed at the Cedars Sinai Medical Center (Los Angeles, CA) by Germano et al. (*1*) and is widely used for simultaneous assessment of myocardial perfusion and left ventricular (LV) function. ECG-gated myocardial SPECT imaging allows automated computer calculation of LV volumes and LV ejection fraction (LVEF). Clinically, it is important to validate the agreement between the methods used to measure LV volumes and LVEF because traditionally they have been measured by contrast left ventriculography (LVG), ECG or radionuclide ventriculography. Although several recent studies (*2–5*) have shown that LV volumes and LVEF can be assessed with precision from ECG-gated SPECT images, most previous reports either were subjective or used a partially automatic technique. Therefore, we compared the LV volumes and the LVEF as calculated by Cedars automated quantitative gated SPECT (QGS) perfusion imaging at rest to those determined by both first-pass radionuclide angiography (FPRNA) at rest and LVG in a group of 21 patients who underwent each study within 2 wk.

MATERIALS AND METHODS

A total of 21 patients (5 women, 16 men; age range 21–78 y; mean age 61.4 ± 9.2 y) were simultaneously evaluated with FPRNA and ECG-gated ^{99m}Tc-tetrofosmin SPECT. All patients showed normal sinus rhythm without bundle branch block. LVEF and LV volumes were determined at rest by each method in all patients. Sixteen patients had coronary heart disease with evidence of perfusion abnormalities on ^{99m}Tc-tetrofosmin SPECT and with ≥50% stenosis on coronary angiography. Five patients had undergone previous percutaneous transluminal catheter angioplasty, and 4 had previous coronary artery bypass graft surgery. Three patients had documented idiopathic dilatated cardiomyopathy, and 1 had cardiac amyloidosis on histological examinations. One patient had chest pain with normal coronary angiograms and

normal perfusion images on ^{99m}Tc-tetrofosmin SPECT. The LVG studies were performed within 2 wk in all patients. No major clinical events were observed, and ECG showed no significant changes in any patients between these examinations.

First-Pass Radionuclide Angiography

All patients underwent FPRNA in the fasting state. A total of 740 MBq ^{99m}Tc-tetrofosmin (Myoview; Nihon Medi-Physics Co., Tokyo, Japan) in a volume of less than 1 mL was administered rapidly into the right cubital vein and was flushed with 20 mL normal saline solution through a 20-gauge indwelling catheter. The FPRNA studies were performed during the injections of ^{99m}Tc-tetrofosmin using a multicrystal, high-counting-rate gamma camera (SIM-400; Picker International Inc., Cleveland, OH) and a high-sensitivity collimator. Anterior projection images were obtained in the upright position at rest. Data were acquired at 25 ms per frame for 1000 frames and were processed by previously described standard methods (*6,7*). A representative LV volume was generated by summing frames of 8–15 cardiac cycles.

Electrocardiographic-Gated ^{99m}Tc-Tetrofosmin SPECT

One hour after the administration of ^{99m}Tc-tetrofosmin, ECG-gated SPECT rest images were obtained with a three-head rotating gamma camera (GCA 9300A/HG; Toshiba Medical Co., Tokyo, Japan) equipped with a low-energy general-purpose collimator. Twenty projection images were acquired for 90 s each at 6° increments over 120° and were stored in a 64 × 64 matrix. At each projection angle, a total of 10 individual ECG-gated frames per R-R interval were acquired. The acquired data were processed on a dedicated computer system (GMS-5500; Toshiba Medical Co., Tokyo, Japan). The projection datasets were prefiltered with a two-dimensional Butterworth filter (order = 8 and critical frequency = 0.28 cycles/pixel), reconstructed with filtered backprojection (Shepp and Logan filter) and no attenuation correction. The resulting transaxial image sets were reoriented with respect to short-axis sets. The LV short-axis slices were then used in the automatic algorithm developed at Cedars-Sinai (*1*) to calculate LV end-diastolic volume (EDV), end-systolic volume (ESV) and LVEF.

For analysis of myocardial perfusion defects, the frames of raw tomographic data were summed and ungated tomograms were reconstructed.

Contrast Left Ventriculography

All patients underwent LVG at rest in concert with coronary angiography. Contrast ventriculographic images were acquired at 30 frames/s in the right anterior oblique 30° projection during noniodinated contrast agent (Iopamiron; Schering Co., Berlin, Germany) injection through a 5F or 6F pigtail catheter. The outlines of endocardial walls were drawn carefully with manual manipulation at end-diastole and end-systole using a Vanguard motion analyzer (Vanguard Instrument Co., Melville, NY). LV volumes and LVEF were calculated from single-plane cineangiograms by means of the area length formula (*8*).

Statistical Analysis

Linear regression analysis, determination of the SEE and Bland-Altman analysis (*9,10*) were used to compare the data. Paired Student t test was used to determine significant difference, defined as $P < 0.05$. Data are presented as mean value ± 1 SD.

RESULTS

Myocardial Perfusion Images

On the basis of visual scintigraphic analysis from the nongated SPECT images, 7 (33%) patients were found to have severe myocardial perfusion defects, 1 (5%) had moderate defects, 12 (57%) had mild perfusion abnormalities and 1 (5%) exhibited normal perfusion. In 7 patients with nearly absent segmental perfusion, automatic determination of the endocardial and epicardial surface was successful, although 1 patient had documented dyskinetic wall motion abnormalities and 2 patients had documented akinetic wall motion abnormalities on LVG. Segmentation and contouring of the left ventricle was successful in 21 of 21 (100%) of the studies, despite widely varying perfusion patterns.

Reproducibility of Calculated Data

We checked the intraobserver and interobserver reproducibility of the data from FPRNA and QGS in all patients (Table 1). EDV, ESV and LVEF obtained with FPRNA showed a good correlation between the first and second analyses by the same observer ($r = 0.97$, $r = 0.95$ and $r = 0.93$, respectively; $P < 0.01$) or between two independent observers ($r = 0.86$, $r = 0.96$ and $r = 0.91$, respectively; $P < 0.01$). The Bland-Altman plot demonstrated a significant positive correlation between mean values and differences in EDV and ESV on interobserver analysis and in ESV on intraobserver analysis obtained with FPRNA. However, there was no apparent trend across the complete range of LVEF from FPRNA. EDV, ESV and LVEF obtained with QGS showed an even stronger correlation between first and second analyses by the same observer ($r = 0.99$, $r = 0.99$ and $r = 0.99$, respectively; $P < 0.01$) or between two independent observers ($r = 0.99$, $r = 0.99$ and $r = 0.99$, respectively; $P < 0.01$). The Bland-Altman plot demonstrated no significant bias or correlation between mean values and differences for each dataset obtained with QGS.

Comparison of Data from Electrocardiographic-Gated SPECT, First-Pass Radionuclide Angiography and Contrast Left Ventriculography

Results of FPRNA and LVG correlated well in all patients, with coefficients of $r = 0.61$ for EDV, 0.72 for ESV and 0.91 for LVEF ($P < 0.01$). The Bland-Altman trend graph for EDV demonstrated a positive regression slope of 0.85 and a negative intercept at −110 mL ($r = 0.71$, $P < 0.01$). The graph for ESV was similar, with a positive regression slope of 0.68 and a negative intercept at −29 ($r = 0.68$, $P < 0.01$). Consequently, the LVEF graph had a negative Bland-Altman slope of −0.30 and an intercept at 7.7 ($r = 0.59$, $P < 0.01$). This suggested that the first-pass technique of the LVEF gave a progressively increasing underestimation at the higher range of values, with a mean underestimation of 8.2% ± 6.5% (Fig. 1).

There was an excellent linear correlation between QGS with LVG for all patients, with coefficients of $r = 0.73$ for EDV, 0.83 for ESV and 0.87 for LVEF ($P < 0.01$). The

TABLE 1
Reproducibility of Data Calculated from First-Pass Radionuclide Angiography (FPRNA) and Quantitative Electrocardiographic-Gated SPECT (QGS)

	Scatter plots				Bland-Altman plots			
	r	Regression equation	SEE	*P*	Mean difference	*r*	Regression equation	*P*
FPRNA EDV								
Intraobserver	0.97	y = 0.88x + 14.7	16	$P < 0.01$	1.6 ± 19	0.42	y = 0.11x − 12.4	$P = 0.06$
Interobserver	0.86	y = 0.86x + 54.1	18	$P < 0.01$	20 ± 47	0.86	y = 0.72x − 66.9	$P < 0.01$
FPRNA ESV								
Intraobserver	0.95	y = 0.73x + 17.1	14	$P < 0.01$	3.0 ± 22	0.68	y = 0.28x − 17.0	$P < 0.01$
Interobserver	0.96	y = 0.54x + 20.2	9.4	$P < 0.01$	14 ± 30	0.92	y = 0.58x − 24.7	$P < 0.01$
FPRNA LVEF								
Intraobserver	0.93	y = 0.89x + 4.84	4.2	$P < 0.01$	0.5 ± 4.3	0.10	y = 0.04x − 1.38	$P = 0.62$
Interobserver	0.91	y = 1.01x + 0.55	5.1	$P < 0.01$	−0.9 ± 5.0	−0.23	y = −0.10x + 4.14	$P = 0.32$
QGS EDV								
Intraobserver	0.99	y = 0.97x + 3.21	3.2	$P < 0.01$	−0.3 ± 3.5	0.40	y = 0.03x − 3.07	$P = 0.07$
Interobserver	0.99	y = 0.97x + 0.99	3.3	$P < 0.01$	1.8 ± 3.5	0.37	y = 0.03x − 0.80	$P = 0.10$
QGS ESV								
Intraobserver	0.99	y = 0.96x + 2.48	3.2	$P < 0.01$	−0.6 ± 3.5	0.40	y = 0.03x − 2.37	$P = 0.07$
Interobserver	0.99	y = 0.98x + 0.62	2.7	$P < 0.01$	0.7 ± 2.8	0.33	y = 0.02x − 0.52	$P = 0.14$
QGS LVEF								
Intraobserver	0.99	y = 0.96x + 1.03	2.4	$P < 0.01$	0.8 ± 2.4	0.12	y = 0.02x − 0.26	$P = 0.62$
Interobserver	0.99	y = 0.96x + 1.40	2.2	$P < 0.01$	0.5 ± 2.2	0.14	y = −0.02x − 0.74	$P = 0.55$

EDV = end-diastolic volume; ESV = end-systolic volume; LVEF = left ventricular ejection fraction.

Bland-Altman trend graph for EDV differences versus EDV means demonstrated that the positive regression slope of 0.38 and the negative intercept at −74 mL were largely due to QGS EDVs being lower than LVG values. There was an underestimation of the contrast EDV by QGS with a mean difference of 30 ± 35 mL ($r = 0.45$, $P = 0.04$). The Bland-Altman graphs for ESV and for LVEF demonstrated no apparent trend (Fig. 2).

Table 2 summarizes the mean values of EDV, ESV and LVEF calculated from QGS, FPRNA and LVG. By paired *t* test, mean EDV obtained with QGS was significantly lower than both FPRNA and LVG results ($P < 0.01$), and mean ESV obtained with QGS was also significantly lower than first-pass value ($P < 0.05$). The highest ejection fraction (EF) values were seen by LVG, then QGS and FPRNA.

DISCUSSION

LV function and perfusion can be assessed simultaneously, either by following the first pass of ^{99m}Tc-labeled agents through the heart or by ECG-gated acquisition of myocardial images. However, as the planar technique, FPRNA has limitations that include manual region of interest (ROI) drawing and uncertainty regarding the valve plane location. Hence, in this study, the reproducibility of the first-pass method was not as good as with gated SPECT. LVEF calculated by gated SPECT was first described by DePuey et al. (*11*). They found a good relation ($r = 0.88$) with LVEF measured by equilibrium radionuclide ventriculography, but the intra- and interobserver correlation was not as good ($r = 0.75$, $r = 0.75$), because it was done by manual drawing of endocardial borders. Williams and Taillon (*5*) showed that the results of semiautomated LVEF obtained from poststress gated SPECT ^{99m}Tc-sestamibi perfusion images are reproducible (intraobserver $r = 0.99$, interobserver $r = 0.93$) and correlate well with the results of FPRNA ($r = 0.83$) but are closer in value to those obtained with LVG ($r = 0.93$). They proposed a modification based on an inversion of the display of the gated tomograms. The inversion-derived EFs were slightly lower (2.7 units) and first-pass EFs were much lower (8.0 units) than those obtained with LVG. A disadvantage of these aforementioned methods of measuring LVEF is that they use only two images of the full three-dimensional tomographic dataset, and this leads to underrepresentation of dysfunctional segments located outside the midventricular slices (*12*). Germano et al. (*1*) developed a completely automatic algorithm to quantitatively measure LVEF using gated short-axis image volumes in three dimensions, which identifies the midmyocardial surface and determines the endocardium and epicardium from asymmetric Gaussian fit of count profiles across this surface without operator interaction. The algorithm was validated in 65 patients undergoing gated ^{99m}Tc-methoxyisobutyl isonitrile SPECT by comparison with FPRNA by Germano et al. The correlation between the two methods for LVEF was excellent ($r = 0.91$), with the QGS-derived LVEF being approximately 10% higher than the first-pass LVEF.

In this study, LVEF calculated from QGS was approximately 3% higher than first-pass LVEF. EDV and ESV obtained with QGS were lower than those of first-pass

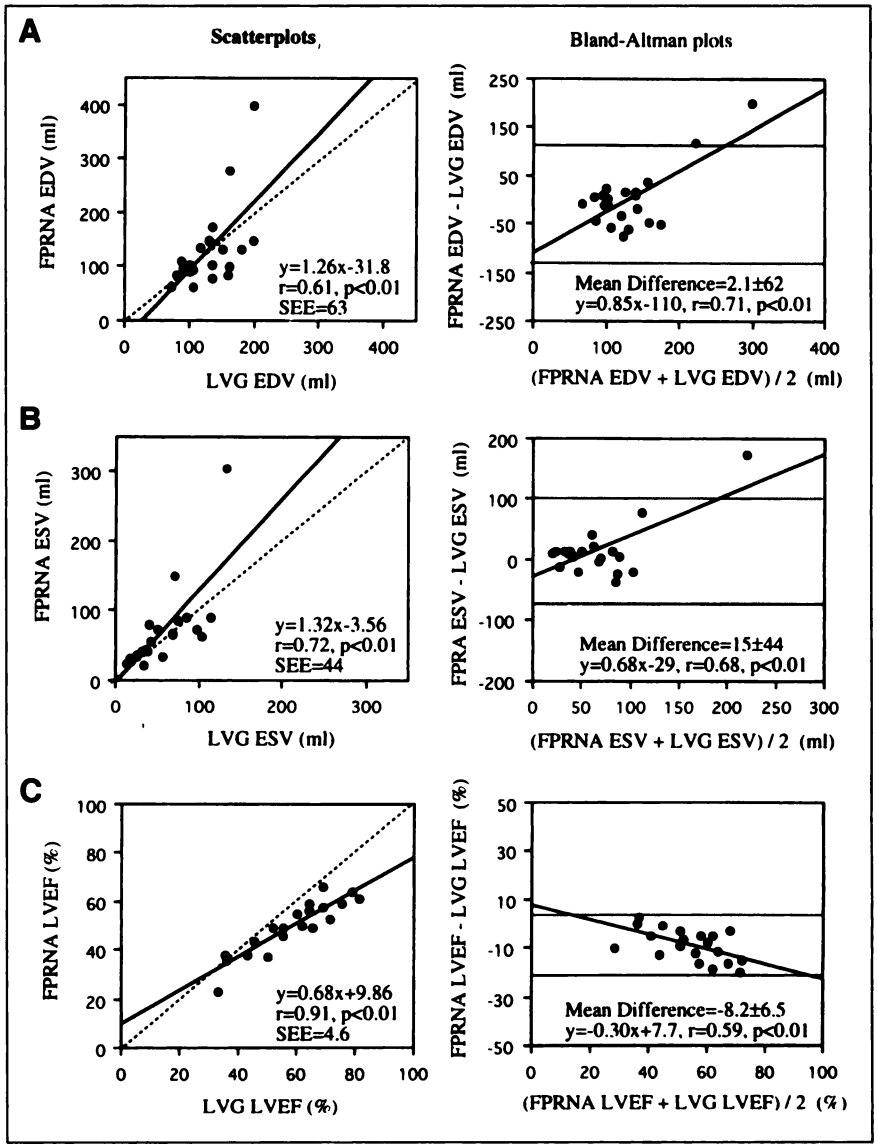

FIGURE 1. Comparison of left ventricular end-diastolic volume (EDV) (A), end-systolic volume (ESV) (B) and ejection fraction (LVEF) (C) between first-pass radionuclide angiography (FPRNA) and contrast left ventriculography (LVG). Left panels show plots and linear regression analysis; right panels show Bland-Altman plots.

methods. A possible explanation for the difference in LV volumes between QGS and first-pass methods could be that in gated SPECT images spillover of radioactivity emitted from myocardium was into the blood pool, but in first-pass radionuclide images spillover passed from the blood pool to myocardium. In previous studies, FPRNA has underestimated the LVEF obtained with LVG by 12%–25% (*13, 14*). Williams and Taillon (*5*) speculated that this underestimation may be ascribed to the physiologic decline in LV preload on assumption of the upright position for first-pass studies resulting in lower EF by the Frank-Starling mechanism and that this underestimation may also be ascribed to the use of the currently standard fixed ROI drawn at end-diastole, which in practice frequently includes counts superior to the valve plane during end-systole as a result of motion of the cardiac base toward the apex. In our observations, the LV cavity was filled frequently with inadequate contrast medium at end-systole. Therefore, endocardial contours tend to be drawn smaller than the actual endocardial borders. This may also account for contrast ventriculographic ESV being lower and LVEF being higher than with the first-pass method.

On the other hand, we compared QGS values with LVG values. Leo et al. (*15*) compared the LVEF and the LV volumes as calculated by an automatic Cedars quantitative gated method to those determined by LVG in 12 patients. They found a good correlation ($r = 0.85$, $P < 0.05$) between LVEF and no significant difference between LVEF (gated SPECT, 48% ± 13%, versus ventriculography, 46% ± 3%; P was not significant) and LV volumes. In our cases, however, EDV obtained with QGS was significantly lower than with LVG. In addition, Bland-Altman analysis suggested that the lower the mean value of EDV, the higher the volume difference between QGS and LVG. The most likely reason for this trend is that angiographic endocardial drawings sometimes include more outflow tract than is routinely visible on gated tomograms. ESV obtained with QGS was as low as with LVG. Consequently, gated SPECT LVEF was

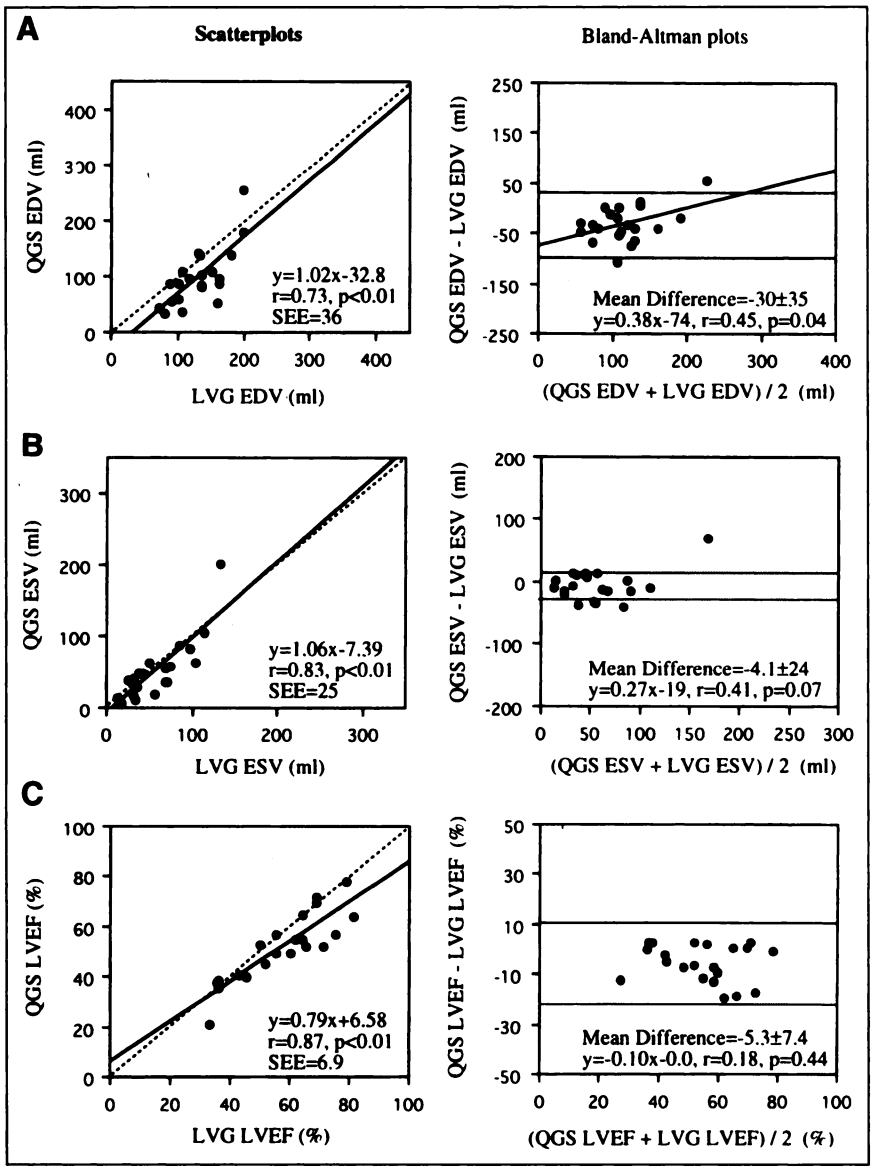

FIGURE 2. Comparison of left ventricular end-diastolic volume (EDV) (A), end-systolic volume (ESV) (B) and ejection fraction (LVEF) (C) between quantitative ECG-gated SPECT (QGS) and contrast left ventriculography (LVG). Left panels show scatter plots and linear regression analysis; right panels show Bland-Altman plots.

lower than LVG. Nichols et al. (*16*) demonstrated that gated SPECT EDV and LVEF were significantly lower than contrast angiographic measurements and suggested that additional angiographic volume, contributed by inclusion of a greater portion of the outflow tract, would give rise to a large percent volume difference between the two methods in the lower volume range but not for larger volumes. Case et al. (*17*) reported overestimation of LVEF by gated SPECT in patients with small hearts. They pointed out that the effect of noise filtering on edge-detection algorithms reduces ESV measurement (greater curvature) in relation to EDV (less curvature), leading to higher LVEF values for small ESV. Thus, an overestimation of LVEF by QGS could be compatible in a small ventricle even though EDV by QGS is underestimated in the case of low EDV.

Although we used LVG as a reference method to compare each method in this study, as previously observed (*18*), LV volumes calculated from the single-plane cineangiograms by means of the area length method overestimate true volumes determined by the postmortem LV cast. In contrast, LV volumes determined by the QGS software package were generally underestimated compared with true volumes determined by the three-dimensional dynamic mathematic cardiac torso phantom and ranged from 68% to 101% for 360° and from 75% to 93% for 180° reconstruction (*19*). Therefore, it seems reasonable to suppose that LV volumes obtained with QGS could be underestimated compared with LVG.

This study was performed in a small group and included only a few patients with akinetic or dyskinetic wall motion abnormalities. Although it was reported that QGS is capable of automatic edge contouring (*1*), even in the apparent absence of perfusion, by using smoothness, the isocontours of the coordinate system and the geometry of the defect boundaries as constraints, the possibility remains that QGS regards dyskinetic wall motion as akinesis. Limitations of

TABLE 2
Comparison of Left Ventricular End-Diastolic Volume (EDV), End-Systolic Volume (ESV) and Ejection Fraction (LVEF) Calculated from Quantitative Electrocardiographic-Gated SPECT (QGS), First-Pass Radionuclide Angiography (FPRNA) and Contrast Left Ventriculography (LVG)

	QGS	FPRNA	LVG
EDV (mL)	100 ± 11.3*	132 ± 16.8	130 ± 8.1
ESV (mL)	53.8 ± 9.3†	73.0 ± 13.3	57.9 ± 7.2
LVEF (%)	51.8 ± 3.0‡	48.9 ± 2.4§	57.1 ± 3.2

*$P < 0.01$ versus two other methods.
†$P < 0.05$ versus FPRNA.
‡$P < 0.01$ versus LVG and $P < 0.05$ versus FPRNA.
§$P < 0.01$ versus LVG.

this study include comparison of the LV values in these cases. The use of low framing rates during acquisition (10 frames) may also account for the slight underestimation of LVEF by QGS.

Conclusion

We compared the LV values calculated by QGS with those calculated by FPRNA and LVG. The results of QGS were more reproducible than FPRNA estimates. LV volumes by QGS were lower and LVEF was higher than the values calculated by FPRNA. LV volumes and LVEF that were calculated by QGS correlated well with those values calculated by LVG, but EDV and LVEF calculated by QGS were slightly lower than values calculated by LVG. These considerations might be clinically important in the practical use of Cedars automated gated SPECT.

REFERENCES

1. 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.
2. Everaert H, Franken PR, Flamen P, Goris ML, Momen A, Bossuyt A. Left ventricular ejection fraction from gated SPECT myocardial perfusion studies: a method based on the radial distribution of count rate density across the myocardial wall. *Eur J Nucl Med.* 1996;23:1628–1633.
3. Goris ML, Thompson C, Malone L, Franken PR. Modeling the integration of myocardial regional perfusion and function. *Nucl Med Commun.* 1994;15:9–20.
4. Kim SM, Zhang JJ, Intenzo CM. Accuracy of left ventricular ejection fraction measurement from gated ^{99m}Tc-sestamibi myocardial SPECT: validation with first pass radionuclide angiography [abstract]. *J Nucl Cardiol.* 1997;4:S78.
5. Williams KA, Taillon MS. 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 method radionuclide angiography. *J Am Coll Cardiol.* 1996;27:173–181.
6. Gal R, Grenier RP, Carpenter J, Schmidt DH, Port SC. High count rate first-pass radionuclide angiography using a digital gamma camera. *J Nucl Med.* 1986;27:198–206.
7. Gal R, Grenie RP, Schmidt DH, Port SC. Background correction in first-pass radionuclide angiography: comparison of several approaches. *J Nucl Med.* 1986;27:1480–1486.
8. Rackley CE, Hood WP, Grossman W. Measurement of ventricular volume, mass and ejection fraction. In: Grossman W, ed. *Cardiac Catheterization and Angiography.* Philadelphia, PA: Lea & Febiger; 1980:232.
9. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet.* 1986;i:307–310.
10. Bland JM, Altman DG. Comparing methods of measurement: why plotting difference against standard method is misleading. *Lancet.* 1995;346:1085–1087.
11. DePuey EG, Nichols K, Dobrinsky C. Left ventricular ejection fraction assessed from gated technetium-99m-sestamibi SPECT. *J Nucl Med.* 1993;34:1871–1876.
12. Anagnostopoulos C, Underwood SR. Simultaneous assessment of myocardial perfusion and function: how and when? *Eur J Nucl Med.* 1998;25:555–558.
13. Nusynowitz ML, Benedetto AR, Walsh RA, Starling MR. First-pass anger camera radiocardiography: biventricular ejection fraction, flow, and volume measurements. *J Nucl Med.* 1987;28:950–959.
14. Folland ED, Hamilton GW, Larson SM, Kennedy JW, Williams DL, Richie JL. The radionuclide ejection fraction: a comparison of three radionuclide techniques with contrast angiography. *J Nucl Med.* 1977;18:1159–1166.
15. Leo CD, Bestetti A, Tagliabue L, et al. ^{99m}Tc-tetrofosmin gated-SPECT LVEF: correlation with echocardiography and contrastographic ventriculography [abstract]. *J Nucl Cardiol.* 1997;4:S56.
16. Nichols K, Tamis J, Depuey EG, Mieres J, Malhotra S, Rozanski A. Relationship of gated SPECT ventricular function parameters to angiographic measurements. *J Nucl Cardiol.* 1998;5:295–303.
17. Case JA, Cullom SJ, Bateman TM, Barnhart C, Saunders MJ. Overestimation of LVEF by gated MIBI myocardial perfusion SPECT in patients with small hearts [abstract]. *J Am Coll Cardiol.* 1998;31(suppl):43A.
18. Wynne J, Green LH, Mann T, Levin D, Grossman W. Estimation of left ventricular volumes in man from biplane cineangiograms filmed in oblique projections. *Am J Cardiol.* 1978;41:726–732.
19. Achtert AD, King MA, Dahlberg ST, Pretorius PH, LaCroix KJ, Tsui BMW. 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.* 1997;5:144–152.