Journal of the American College of Cardiology
© 2002 by the American College of Cardiology Foundation
Published by Elsevier Science Inc.

Vol. 39, No. 12, 2002
ISSN 0735-1097/02/$22.00
PII S0735-1097(02)01882-X

Electrocardiogram-Gated Single-Photon Emission Computed Tomography Versus Cardiac Magnetic Resonance Imaging for the Assessment of Left Ventricular Volumes and Ejection Fraction

A Meta-Analysis

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OBJECTIVES The purpose of this study was to evaluate the accuracy of electrocardiogram (ECG)-gated single-photon emission computed tomography (SPECT) for assessment of left ventricular (LV) end-diastolic volume (EDV), end-systolic volume (ESV) and ejection fraction (EF) compared with the gold standard of cardiac magnetic resonance imaging (MRI).

BACKGROUND Several comparisons of ECG-gated SPECT with cardiac MRI have been performed for evaluation of LV volumes and EF, but each has considered few subjects, thus leaving uncertainty about the frequency of discrepancies between the two methods.

METHODS We performed a meta-analysis of data on 164 subjects from nine studies comparing ECG-gated SPECT versus cardiac MRI. Data were pooled in correlation and regression analyses relating ECG-gated SPECT and cardiac MRI measurements. The frequency of discrepancies of at least 30 ml in EDV, 20 ml in ESV and 5% or 10% in EF and concordance for EF ≤40% versus >40% were determined.

RESULTS There was an overall excellent correlation between ECG-gated SPECT and cardiac MRI for EDV (r = 0.89), ESV (r = 0.92) and EF (r = 0.87). However, rates of discrepancies for individual subjects were considerable (37% [95% confidence interval {CI}, 26% to 50%] for at least 30 ml in EDV; 35% [95% CI, 23% to 49%] for at least 20 ml in ESV; 52% [95% CI, 37% to 63%] for at least 5% in EF; and 23% [95% CI, 11% to 42%] for at least 10% in EF). The misclassification rate for the 40% EF cutoff was 11%.

CONCLUSIONS Electrocardiogram-gated SPECT measurements of EDV, ESV and EF show high correlation with cardiac MRI measurements, but substantial errors may occur in individual patients. Electrocardiogram-gated SPECT offers useful functional information, but cardiac MRI should be used when accurate measurement is required. (J Am Coll Cardiol 2002;39: 2059–68) © 2002 by the American College of Cardiology Foundation

Electrocardiogram (ECG)-gated single-photon emission computed tomography (SPECT), primarily using technetium-99m, is advocated as an imaging technique that can offer valuable information in the assessment of both myocardial perfusion and ventricular function. While the value of ECG-gated SPECT in assessing myocardial perfusion is undisputed (1,2), there are fewer data on the accuracy of ECG-gated SPECT for estimating left ventricular (LV) volumes and ejection fraction (EF). Cardiac magnetic resonance imaging (MRI) is currently considered the gold standard for these evaluations (3,4). Although studies evaluating the performance of ECG-gated SPECT versus cardiac MRI have suggested a good concordance of the two methods (5–14), each study has included few patients. Generalizations and broader inferences are difficult from isolated investigations. It is also difficult to assess from isolated studies whether the comparative accuracy of ECG-gated SPECT differs in various patient subgroups. To address these issues, we performed a meta-analysis of all available data comparing ECG-gated SPECT versus cardiac MRI. A patient-level meta-analysis approach enhanced the power of detecting differences between the two methods and maximized accuracy in estimating their magnitude.

METHODS

Eligibility criteria and search strategy. We considered studies evaluating LV volumes (end-systolic volume [ESV] and end-diastolic volume [EDV]) and EF by ECG-gated SPECT (using technetium-99m-labeled sestamibi or tetrofosmin or thallium-201) as well as by cardiac MRI in the same subjects. Data were eligible regardless of whether they referred to healthy subjects or patients with suspected or proven disease, and regardless of whether ECG-gated SPECT images were acquired at rest or after stress. Data

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Manuscript received September 18, 2001; revised manuscript received February 25, 2002, accepted March 14, 2002.

JACC Vol. 39, No. 12, 2002
June 19, 2002:2059–68

Abbreviations and Acronyms

CAD = coronary artery disease
CI = confidence interval
ECG = electrocardiogram
EDV = end-diastolic volume
EF = ejection fraction
ESV = end-systolic volume
LV = left ventricle/ventricular
MRI = magnetic resonance imaging
SEE = standard error of estimate
SPECT = single-photon emission computed tomography

were also eligible regardless of the technical parameters used for either test and regardless of the algorithm used for LV volumes and EF calculations. Phantom-only and animal studies were excluded.

We identified eligible studies by searching MEDLINE and EMBASE (last search updated December 2001). The search combined the terms "gated," "SPECT," "technetium" or "Tc-99m," "tetrofosmin," "sestamibi," "thallium" or "Tl-201" and "magnetic resonance imaging," "MRI" and "ejection fraction." In addition, we perused bibliographies of retrieved articles and reviews and communicated with experts in the field. Meeting abstracts were excluded because they would not provide individual patient data and their results might not be final.

The retrieved studies were carefully examined to exclude duplication or overlap of subjects. Duplicate/overlapping data were counted only once in the meta-analysis.

Data extraction. The following information was extracted from each pertinent study: first author, year of publication and journal; study population characteristics including gender, mean age (and standard deviation), clinical setting, selection of subjects (consecutive vs. other), study design (prospective vs. retrospective or unspecified), inclusion and exclusion criteria; relative timing of the two imaging procedures; technical characteristics of the ECG-gated SPECT and the cardiac MRI; blinding of evaluators of one test to the results of the other and to the clinical condition of the tested subject; total number of subjects in the study; number of subjects evaluated with either test and reasons for nonevaluations; quantitative or qualitative assessment of regional thickening; and percentage of subjects with history of myocardial infarction and median EF by cardiac MRI. The two latter parameters were used to characterize the clinical background and average severity of LV dysfunction in the studied population. For each subject, we recorded the EDV, ESV and EF with each imaging modality. Whenever numerical data were not given directly, we extracted the relevant data using scanned computerized images of the pertinent scatter plots and by communication with the study investigators. When ECG-gated SPECT measurements had been corrected by a phantom-study correction factor,

Table 1. Characteristics of Included Studies

Study	Number of Subjects				Study Population	Men (%)	Age (Mean)	Prior MI (%)	Timing (Range)*	Blinding		EF (Median)
	All	SPECT	MRI	Both						Clinical	Test	
Mochizuki et al. (6)	43	43	18	18	Mixed (SPECT referrals)	74	62	42	1–118	ND	MRI	53
Vaduganathan et al. (7)	25	25	25	25	Post-AMI (within 5 days)	72	64	100	< 2	MRI	Both	65
Stolfuss et al. (8)	21	21	21	21	EF < 40% or severe WMA	95	60	81	< 1	ND	ND	31
	5	5	5	5	Normal EF	ND	48	0	< 1	ND	ND	64
Faber et al. (9)	89	89	7	7	Known/suspected CAD	ND	59	100	< 2	MRI	MRI	53
Tadamura et al. (10)	ND	ND	20	20	CAD by angiography	75	65	65	< 7	SPECT	Both	52
Tadamura et al. (11)	16	16	16	16	Post-CABG	81	66	88	< 1	SPECT	Both	
Bax et al. (12)	29	22	22	22	Chronic CAD	86	67	95	2–27	ND	Both	27
Bavelaar-Croon et al. (13)	21	21	21	21	Known/suspected CAD	67	58	62	< 42	ND	ND	44
Faber et al. (14)	35	30	35	30	Known CAD	83	62	49	< 2	ND	Both	58

Mochizuki et al. (6) data on gender, age and prior MI are based on 31 patients who had electrocardiogram-gated SPECT as well as either left ventriculography or cardiac MRI (no data are given separately for the 18 patients who had MRI). Vaduganathan et al. (7) assessed wall motion in all 25 subjects of their study, but volumes and EF were estimated in only 17 of the 25 subjects. *Range of time (in days) intervening between MRI and SPECT.

AMI = acute myocardial infarction; CABG = coronary artery bypass grafting; CAD = coronary artery disease; EF = ejection fraction; MI = myocardial infarction; MRI = magnetic resonance imaging; ND = no data; SPECT = single-photon emission computed tomography; WMAs = wall motion abnormalities.

Table 2. Technical Characteristics of Imaging

	ECG-Gated SPECT					Cardiac MRI	
Study	**Radioisotope**	**Dose (MBq)**	**Acquisition**	**Frames/RR**	**Volume Calculation**	**Sequence**	**Volume Calculation**
Mochizuki et al. (6)	Tc-99m (sestamibi or tetrofosmin)	740–1,110	N/A	8	Long axis	GRE	Long axis
Vaduganathan et al. (7)	Tc-99m tetrofosmin	925–1,110	Rest	8	QGS*	GRE	Simpson's rule
Stolfuss et al. (8)	Tc-99m tetrofosmin	280–370	Rest	12	Long axis†	GRE	Simpson's rule
Faber et al. (9)	Tc-99m sestamibi	814	Rest	8	Truncated ellipsoid	GRE	Simpson's rule
Tadamura et al. (10)	Tc-99m sestamibi	600	Rest	8	QGS*	GRE	Simpson's rule
	Tl-201	148					
Tadamura et al. (11)	Tc-99m sestamibi	600	Rest	8	QGS*	GRE	Simpson's rule
Bax et al. (12)	Tc-99m tetrofosmin	250	Rest	16	QGS*	GRE	Simpson's rule
Balevaar-Croon et al. (13)	Tc-99m tetrofosmin	250	Rest	16	Simpson's rule	GRE	Simpson's rule
	Tc-99m tetrofosmin	750	Stress				
Faber et al. (14)	Tc-99m tetrofosmin	814	Stress	8	QGS* Truncated ellipsoid	GRE	Simpson's rule

*Germano et al. (22); †DePuey et al. (23).
ECG = electrocardiogram; GRE = gradient echo; MRI = magnetic resonance imaging; N/A = not available; QGS = quantitative gated SPECT; SPECT = single-photon emission computed tomography.

analysis was performed both with uncorrected and corrected values.

Data extraction was performed in duplicate by two independent investigators. Discrepancies were solved by consensus and by using a third investigator as arbitrator. We verified that regression analyses from the data of each study replicated the regression coefficients provided in the respective published report, typically within 1%.

Data synthesis. CORRELATION AND REGRESSION ANALYSES. Each identified study had evaluated relatively few subjects. Therefore, the main analysis involved pooling of individual subject data across studies. Scatter plots were generated with ECG-gated SPECT measurements on the *y* axis and cardiac MRI measurements on the *x* axis. Pearson correlation coefficients (r) were estimated, and a linear regression was fit to each set of the ECG-gated SPECT versus cardiac MRI data with unweighted least squares estimation for intercept and slope coefficients and 95% confidence intervals (CI). Coefficients of determination (R^2) and standard errors of the estimate (SEE) were calculated for each regression. We also estimated correlation coefficients and regression slopes for individual studies and examined whether the regression slopes are significantly heterogeneous. Bland-Altman plots and regressions examined whether the difference in the two measurements varied at different levels of EDV, ESV or EF (15).

FREQUENCY OF DISCREPANCIES AND SUBGROUP ANALYSES. We evaluated the proportion of cases and 95% CI for differences of ≥30 ml in the EDV, ≥20 ml in the ESV and ≥5% or ≥10% in the EF between the two methods. The cutoffs were defined a priori and reflect discrepancies that are likely to be meaningful in situations where substantial accuracy is needed for ventricular volumes and EF. We used both simple pooling and weighted random effects modeling to estimate the overall proportions and 95% CI of differences exceeding the specified cutoffs (16). Between-study heterogeneity was assessed using exact inference for n*2 tables, where n is the number of studies. In the presence of significant heterogeneity, the random effects estimates provide wider CI than simple pooling because they incorporate an estimate of the between-study variance in the calculations. Thus, random effects are preferable when significant heterogeneity is present.

Separate analyses were performed for subgroups defined on the basis of low EF (≤40% by ECG-gated SPECT) versus normal/intermediate EF, normal versus low ESV (70 ml cutoff by ECG-gated SPECT) and blinding parameters. The cutoff EF of 40% is often used clinically to differentiate between mild and significant systolic dysfunction. Selection for the ESV cutoff was based on prognostic data for coronary artery disease (CAD) reported by Sharir et al. (17). We did not use an EDV cutoff, as adjustments for body surface area would be important, but such data were not available. Subgroups were compared to evaluate whether they differed in the concordance of the two methods as

JACC Vol. 39, No. 12, 2002
June 19, 2002:2059–68

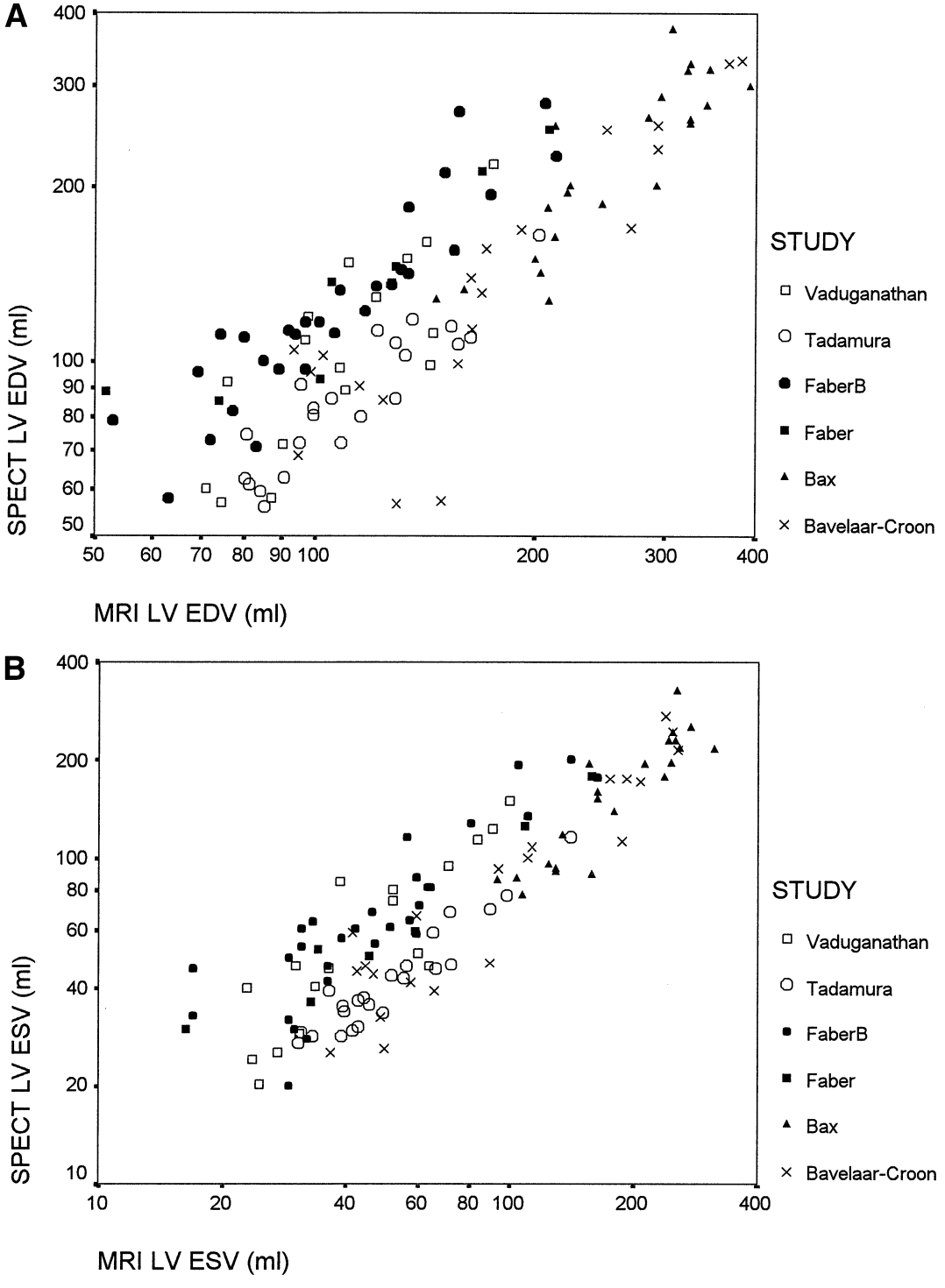

Figure 1. Scatter plots of cardiac magnetic resonance imaging (MRI) and electrocardiogram (ECG)-gated single-photon emission computed tomography (SPECT) measurements in subjects who underwent imaging with both modalities. **(A)** Left ventricular (LV) end-diastolic volume (EDV) in ml; **(B)** LV end-systolic volume (ESV) in ml; **(C)** LV ejection fraction (EF). Patients in the two publications by Tadamura et al. (10,11) are shown as belonging to the same study. End-diastolic volume and ESV data were not provided for individual subjects in Stolfuss et al. (8) and could only be discerned for subjects with substantial discrepancies between cardiac MRI and ECG-gated SPECT in Mochizuki et al. (6) (not shown here, but included in the calculations of the proportion with discrepancies). Faber pertains to reference 9, while FaberB pertains to reference 14.

expressed by the metrics previously described. In the presented analyses, subgroup estimates are obtained with pooling of the pertinent subjects across the eligible studies, but random effects yielded similar estimates (not shown).

EXTENT OF MISCLASSIFICATION. Finally, we evaluated the sensitivity and specificity and overall misclassification rate of ECG-gated SPECT measurements in terms of classifying subjects as having EF >40% versus ≤40%. Sensitivity and

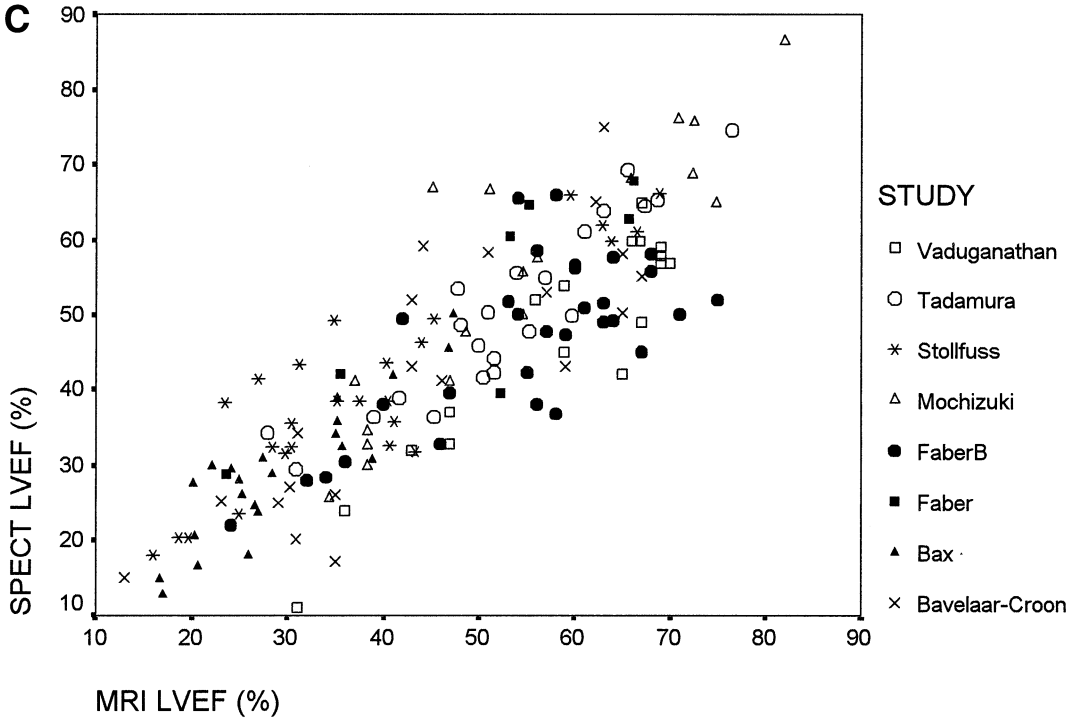

Figure 1. Continued.

specificity values were estimated separately for each study and synthesized by simple pooling and by random effects across studies. Random effects independent synthesis of sensitivity and specificity may tend to underestimate both parameters (18), but a formal summary operating characteristic curve approach (18) was not particularly helpful for these data because the studies tended to operate in the same area of the curve.

SOFTWARE. Analyses were performed in Advanced SPSS 10.0 (SPSS, Inc., Chicago, Illinois), Meta-Analyst (Joseph Lau, Boston, Massachusetts), Meta-Test (Joseph Lau) and StatXact3 (Cytel, Inc., Boston, Massachusetts). All p values are two-tailed.

RESULTS

Eligibility of studies and extraction of individual patient data. Thirteen potentially eligible reports were considered (5–14,19–21). Of those, three were excluded because in two studies there was no assessment of volumes (19,20), and one study was performed on experimental animals (21). Two of the remaining publications (5,8) pertained to the same study, and all subjects in one publication were included in the larger dataset of the earlier report; only the earlier report was considered. Another team (10,11) had also published two reports, and 13 of the 16 subjects in one report were included among the 20 subjects of the other report; in the meta-analysis, we considered the 20 subjects of the latter report and the three additional nonoverlapping subjects from the smaller study. In all, information on 164 subjects who had both ECG-gated SPECT and cardiac MRI was analyzed (Table 1).

Characteristics of subjects and of studies. In most studies, all patients who underwent cardiac MRI also had ECG-gated SPECT and vice versa. However, there were some exceptions (6,9,14). The study population was defined with different criteria across studies, but usually patients had a clinical indication for ECG-gated SPECT, typically related to CAD. Stolfluss et al. (8) also included five healthy subjects. Men accounted for 67% to 95% of each study's population, and the mean age was characteristic of CAD patients. The proportion of subjects with prior myocardial infarction varied from 42% to 100%, and median EF (by cardiac MRI) ranged between 27% and 65% across studies. Information on the number of segments with absent counts that could not be assessed and on the number of severe defects (photon counts $<70\%$ of maximal, absent counts or qualitatively characterized as severe defects) were provided only in two studies (8,11). The time interval between ECG-gated SPECT and cardiac MRI was consistently <1 week in six studies. Three studies (6,12,13) allowed also larger time windows but assured that patients were clinically stable in the interim. Blinded interpretation was not consistently used in all studies (Table 1).

All studies had used Tc-99m sestamibi or tetrofosmin. One study (10) also performed imaging with Tl-201 (in the same study population as for Tc-99m imaging). Concordance of ECG-gated SPECT with cardiac MRI was fairly similar in the Tc-99m and Tl-201 evaluations. All the reported calculations in the meta-analysis use only the

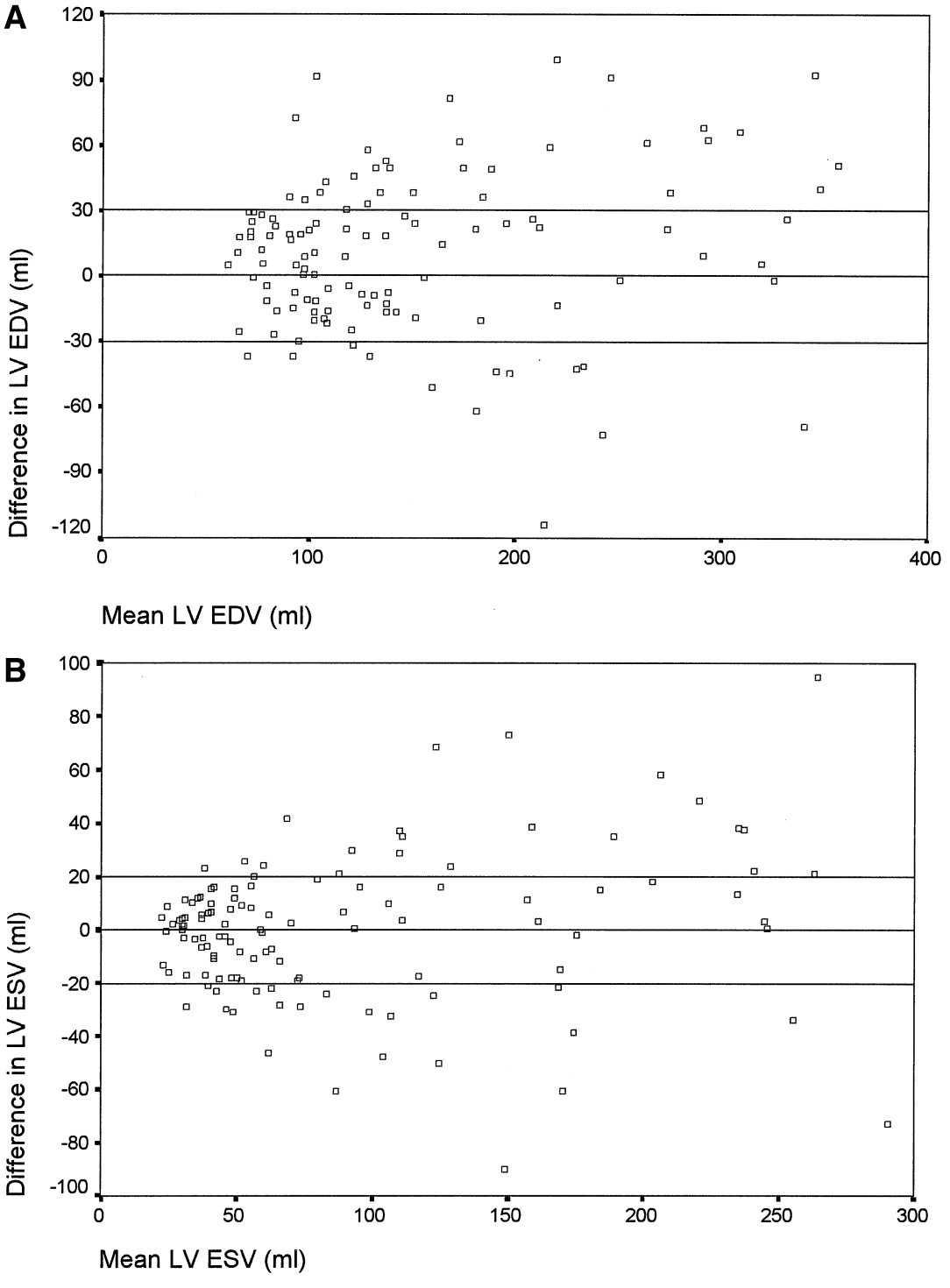

Figure 2. Bland-Altman plots of the data presented in Figure 1. **(A)** Left ventricular (LV) end-diastolic volume (EDV) in ml; **(B)** LV end-systolic volume (ESV) in ml; **(C)** LV ejection fraction (EF).

Tc-99m data. All studies used rest acquisitions, except for one investigation with 30 patients (14) and 6 of the 21 patients in another study (13). For volumetric MRI measurements, all but one (6) study used the disk-area method (Simpson's rule). For ECG-gated SPECT measurements, the majority of the studies used an automated quantitative software package (22). Geometrical modeling of the LV based on a single (23) or multiple ventricular dimensions was also used. One study used two different automatic methods of computation of the LV parameters (14), quan-

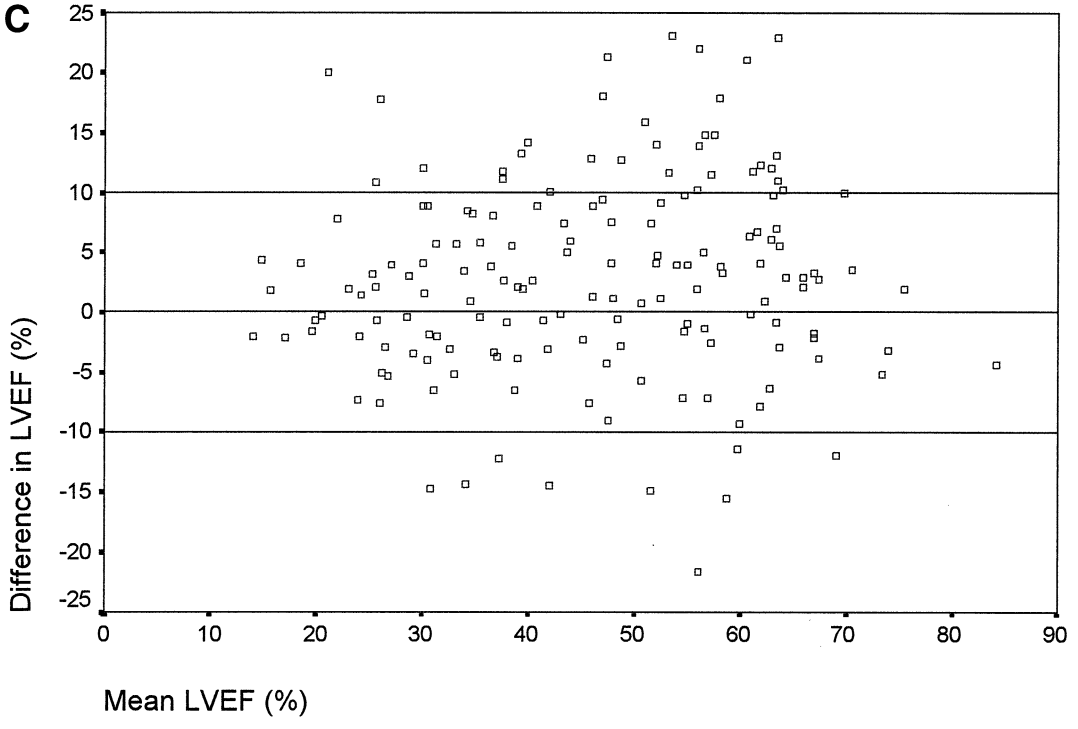

Figure 2. Continued.

titative gated SPECT and Emory cardiac toolbox. The first one is used in the main data synthesis because it is more commonly used. Sensitivity analyses using the data obtained with the other method yielded largely similar results (not shown). Other technical characteristics are shown in Table 2.

Pooled analyses. Overall, there was very good correlation between the ECG-gated SPECT and cardiac MRI measurements (correlation coefficients, 0.89 for EDV, 0.92 for ESV, 0.87 for EF; $p < 0.001$ for all) (Fig. 1). The correlation was also excellent when limited to studies with all measurements obtained at rest (correlation coefficients, 0.92 for EDV, 0.94 for ESV, 0.90 for EF; $p < 0.001$). The best-fit regression lines in the pooled analyses for predicting the ECG-gated SPECT values as a function of the cardiac MRI values were as follows: $y = 0.84x + 14$ for EDV (SEE = 34); $y = 0.87x + 12$ for ESV (SEE = 26) and $y = 0.83x + 5.2\%$ for the EF (SEE = 7.8). The R^2 values were 0.80, 0.85 and 0.75, respectively. The regressions suggest that ECG-gated SPECT tends to overestimate EDV and ESV compared with cardiac MRI for values <89 ml, while it tends to overestimate EDV and ESV at higher volumes. The expected ESV difference is 1 ml at ESV = 100 ml. The expected EDV difference is 18 ml at EDV = 200 ml. On average, ECG-gated SPECT tends to overestimate EF when EF is very low (<31%), while it tends to underestimate EF when ventricular function is preserved. The expected difference is 5% at EF = 60%. Results were similar when phantom-study corrections were used for one study (10,11).

Correlation coefficients were consistently high in all included studies (range: 0.81 to 0.97 for EDV; 0.87 to 0.99 for ESV; 0.72 to 0.93 for EF). However, there was variability in the regression slopes (range: 0.76 to 1.28 for EDV; 0.79 to 1.29 for ESV; 0.65 to 1.10 for EF). Variability in EDV and ESV was largely accounted by the low slopes obtained for the Tadamura et al. (10,11) data (it was substantially reduced when volumes in this study were corrected with a phantom-correction). Variability in EF was largely accounted by the low slope in Faber et al. (14), regardless of the automatic method used for SPECT volume calculation.

The difference between the ECG-gated SPECT and cardiac MRI measurements did not vary substantially at different levels of LV EDV or EF (Fig. 2A and 2C). However, there was a suggestion that for ESV the average difference between the ECG-gated SPECT and cardiac MRI measurements was greater at larger ESV values ($p = 0.070$) (Fig. 2B).

Discrepancies between ECG-gated SPECT and cardiac MRI. Despite an overall excellent correlation, considerable discrepancies between the ECG-gated SPECT and cardiac MRI measurements were common for individual subjects (Table 3). There was substantial heterogeneity in the rates of large discrepancies between the included studies, in particular for EF; therefore, weighted random effects calculations are more appropriate than pooling. By random effects, the percentage of large discrepancies was 37% (95% CI, 26% to 50%) for ≥30 ml in EDV, 35% (95% CI, 23% to 49%) for ≥20 ml in ESV, 52% (95% CI, 37% to 63%) for ≥5% in EF and 23% (95% CI, 11% to 42%) for ≥10% in EF.

JACC Vol. 39, No. 12, 2002
June 19, 2002:2059–68

Table 3. Proportion of Differences Between ECG-Gated SPECT and Cardiac MRI Measurements

Study	Subjects With Difference (%)			
	≥30 ml in EDV	≥20 ml in ESV	≥5% in EF	≥10% in EF
Mochizuki et al. (6)	5/18 (28)	4/18 (22)	8/18 (44)	0/18 (0)
Vaduganathan et al. (7)	4/17 (24)	7/17 (41)	14/17 (82)	11/17 (65)
Stolfuss et al. (8)	ND	ND	10/26 (38)	5/26 (19)
Faber et al. (9)	4/7 (57)	1/7 (14)	5/7 (72)	1/7 (14)
Tadamura et al. (10,11)	28/23 (35)	4/23 (17)	9/23 (39)	2/23 (9)
Bax et al. (12)	12/22 (55)	14/22 (64)	5/22 (23)	0/22 (0)
Bavelaar-Croon et al. (13)	11/21 (52)	7/21 (33)	11/21 (52)	7/21 (33)
Faber et al. (14)	6/29 (21)	12/29 (41)	22/30 (73)	14/30 (47)
Total, sum	50/137 (36)	49/137 (36)	84/164 (51)	40/164 (24)
Heterogeneity p value	0.07	0.03	0.0006	< 0.0001

Faber et al. (14) estimates are based on the QGS (Quantitative Gated SPECT) program data; the respective rates for Emory Cardiac Toolbox data are 15/29, 9/29, 17/30 and 8/30, respectively. End-systolic volume and EDV data for MRI are missing in one patient from Faber et al. (14).

ECG = electrocardiogram; EDV = end-diastolic volume; EF = ejection fraction; ESV = end-systolic volume; MRI = magnetic resonance imaging; ND = no data; SPECT = single-photon emission computed tomography.

Subgroup analyses. The frequency of large discrepancies was slightly less common in subjects where the ECG-gated SPECT EF was ≤40% than in those with larger ECG-gated SPECT EF estimates, but the difference was not formally significant. The cardiac MRI EF differed by at least 10% in 12/67 and 28/97 subjects in the two subgroups, respectively ($p = 0.10$). For differences of ≥5%, the respective proportions were 31/67 versus 53/97 ($p = 0.29$).

Large discrepancies in the ESV estimates were significantly more common in subjects with SPECT-estimated ESV of <70 ml than those with SPECT-estimated ESV of >70 ml. The rates of discrepancies of ≥20 ml were 12/73 (16%) versus 37/64 (58%) in the two subgroups respectively ($p < 0.001$). When the cutoff of 70 ml was based on the cardiac MRI measurements, the results were similar (discrepancy rates 15/78 [19%] vs. 34/59 [58%], respectively, $p < 0.001$).

Finally, the results of four studies where each test had been interpreted blinded to the results of the other did not differ from the results of studies where this was not assured. Similarly, blinding to clinical data did not affect the frequency of discrepancies (not shown).

Misclassification. The ability of ECG-gated SPECT in identifying subjects with an EF of ≤40% using the MRI as the gold standard was very good across studies. Sensitivity ranged between 50% and 100% across studies; specificity estimates ranged between 75% and 100%. By simple pooling, SPECT correctly diagnosed EF ≤40% in 53 of 58 subjects (sensitivity 91% [95% CI, 80% to 97%]) and correctly found EF >40% in 93 of 106 subjects (specificity 88% [95% CI, 80% to 93%]). Thus, 18 of 164 subjects were misclassified (11%). Random effects calculations estimated a sensitivity of 83% (95% CI, 69% to 92%) and specificity of 84% (95% CI, 75% to 90%), respectively.

DISCUSSION

Electrocardiogram-gated SPECT is the most commonly employed technique for simultaneous assessment of LV perfusion and function. Compared with nongated SPECT acquisitions, ECG-gated approaches are better for defining perfusion defects and assessing regional wall motion. They may have particular utility for evaluation of women (24), differentiation of etiology of cardiomyopathy (25) and overall assessment of viability (5,26,27). The measurement of LV EF and volumes with ECG-gated SPECT can be obtained at no additional exposure to radiation, cost or patient discomfort. Information regarding EF and volumes has important prognostic implications in patients with known or suspected CAD (17,28). Automated, reproducible algorithms for LV EF and volume data remove subjectivity from these measurements.

Electrocardiogram-gated SPECT has been tested in several small studies with phantom experiments, animal studies and patient series. However, small series may suffer from large statistical uncertainty and may apply only to specific, selected patient populations. In this meta-analysis we have tried to evaluate on a broader scale the clinical utility of ECG-gated SPECT for measurement of LV EF and volumes. We found a very high correlation between ECG-gated SPECT and cardiac MRI measurements. On average, the two imaging modalities show very good concordance. However, we also found that for measurements on individual subjects, the likelihood of substantial error is considerable.

Per our estimates, half of the ECG-gated SPECT EF determinations may deviate by at least 5% from the cardiac MRI-obtained values, and one of four may deviate by 10% or more. Substantial errors in EDV and ESV calculations are common, and for ESV the average deviation between the two imaging modalities tended to increase with larger

LV ESV values. One in nine subjects would be judged by ECG-gated SPECT to be in the wrong category of LV function, when EF must be categorized as being ≤40% or >40%. Thus, ECG-gated SPECT may not be reliable for determination of LV volumes and EF when large accuracy is required, such as in patients with cardiomyopathies, those receiving cardiotoxic chemotherapy and those considered for transplantation and in the evaluation of volumes for clinical research studies.

Measurement error may be even larger in everyday clinical practice. Images in the considered studies were almost exclusively acquired at rest, while ECG-gated SPECT acquisitions are typically performed after stress. In patients with severe CAD, subendocardial perfusion may be decreased, accounting for apparent LV cavity dilation (29,30). For these patients, calculations of LV EF and volumes may be inaccurate, yet these are the patients in whom it would be most important to have accurate assessments. Nevertheless, the one study that used exclusively post-stress images (14) did not show different results from the others. However, there were few patients with low EF in that study, and more evidence should be accumulated in this setting.

The meta-analysis suggests some areas where additional research regarding the accuracy of ECG-gated SPECT for assessment of LV volumes and EF would be warranted. First, in patients with severe perfusion defects: in these patients, severe reduction of photon counts in a myocardial region (or absence of photon counts) may lead to underestimation of regional wall motion, due to inadequate visualization (31). More data are needed on whether newer approaches may overcome this limitation (32). Second, in women: in all studies together, fewer than 30 women were included. A smaller LV cavity in women may cause errors related to partial volume averaging (33). Finally, more experience is needed for Tl-201 imaging. One study suggested good concordance between Tc-99m and Tl-201 imaging (10), but Tl-201 has been reported to have higher variability than Tc-99m in studies that did not use cardiac MRI for comparison (34,35).

In conclusion, ECG-gated SPECT correlates well with cardiac MRI for measurement of LV volumes and EF. However, on an individual patient level, significant errors may occur and, thus, when accurate measurement is required, cardiac MRI is recommended.

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