Multimodality imaging of coronary artery bypass grafts
Salm, L.P.

Chapter 8

Global and regional left ventricular function assessment with 16-detector row CT: comparison with echocardiography and cardiovascular magnetic resonance

Liesbeth P. Salm
Joanne D. Schuijf
Albert de Roos
Hildo J. Lamb
Hubert W. Vliegen
J. Wouter Jukema
Raoul Joemai
Ernst E. van der Wall
Jeroen J. Bax

Eur J Echocardiogr 2006; 7, 4, 308-314

ABSTRACT

Aims: To compare multidetector row computed tomography (MDCT) global and regional left ventricular (LV) function assessment with echocardiography and cardiovascular magnetic resonance (CMR).

Methods and Results: In 25 patients, who were referred for noninvasive angiography with 16-detector row CT, LV function assessment was also performed. A subsequent echocardiogram was performed, and in a subgroup of patients, CMR examination was completed to evaluate LV function. For global function assessment, the LV ejection fraction (LVEF) was calculated. Regional LV function was scored using a 17-segment model and a 4–point scoring system.

MDCT agreed well with echocardiography for the assessment of LVEF ($r = 0.96$; bias 0.54%; $p<0.0001$), and regional LV function ($\kappa = 0.78$). Eight patients had no contra-indications and gave informed consent for CMR examination. A fair correlation between MDCT and CMR was demonstrated in the assessment of LVEF ($r = 0.86$; bias –1.5%; $p<0.01$). Regional LV function agreement between MDCT and CMR was good ($\kappa = 0.86$).

Conclusion: MDCT agreed well with both echocardiography and CMR in the assessment of global and regional LV function. Global and regional LV function may accurately be evaluated by 16-detector row CT, and can be added to a routine CT image analysis protocol without need for additional contrast or imaging time.

Introduction

Global and regional left ventricular (LV) function are well-known indicators of cardiac disease. For patients with heart failure LV function assessment is often used to identify systolic and diastolic LV dysfunction, and to monitor the progression of the disease (1). Moreover, after myocardial infarction, left ventricular ejection fraction (LVEF) is an important prognostic marker (2-4).

Noninvasive modalities to measure global and regional LV function include echocardiography, cardiovascular magnetic resonance (CMR), and single photon emission computed tomography (SPECT). These techniques have been shown to agree well with invasively acquired LV function assessment by angiography (5-7). Multidetector row computed tomography (MDCT) is a relatively new technique used for noninvasive angiography, but does also allow evaluation of LV function. Several studies showed that 4-detector row CT allowed accurate assessment of global and regional LV function (8-10). The first study using the next-generation 16-detector row CT has shown to evaluate LV function with similar accuracy (11). However, no validation of global and regional LV function assessment with 16-detector row CT has yet been conducted. Accordingly, the purpose of the present study is to compare global and regional LV function assessment by 16-detector row CT with echocardiography and CMR.

Methods

Patients

In patients who were referred for noninvasive coronary angiography by MDCT for evaluation of coronary artery disease, LV function assessment was also performed. A subsequent echocardiogram was scheduled. If no contra-indications for CMR existed, patients were also asked for a CMR examination to assess LV function. Contra-indications for CMR were metal implants, irregular heart rhythm, and claustrophobia. The examinations were performed within three months after the first examination. No cardiac events occurred between examinations. All patients gave informed consent and the study was approved by the institutional ethical committee.

MDCT

MDCT examination was performed using a 16-detector row CT scanner (Aquilion 16, Toshiba, Japan). Patients did not receive additional β-blockers to reduce heart rate. A localizer scan was obtained to establish the scanning range. The sure-start feature was used to determine the arrival of contrast agent in the ascending aorta. Data acquisition was initiated after the contrast agent (jobitridol, Guerbet, Aulnay sur Bois, France) appeared in the ascending aorta, and the patient was instructed to hold his breath. Additional scan parameters were: 16 x 0.5 mm detector collimation, 0.4-0.5 s rotation time, 3.2-4.0 pitch and 97-200 ms temporal resolution dependent on patient's heart rate, 0.4 mm^3 pixel size, 120 kV at 320 mA tube voltage, 150-200 mm scanning range, administration of intravenous contrast agent at 4 ml/s to a total of 160 ml, and 25-30 s breathhold duration. An electrocardiogram (ECG) was simultaneously recorded, and data were retrospectively reconstructed using a multisegmental reconstruction algorithm, obviating the use of additional β-blockers to lower heart rate. Axial images were reconstructed at intervals of 5% throughout the cardiac cycle with 0.4 mm increment. A short axis view of the left ventricle was reconstructed by multiplanar reformat (10) by an experienced observer. Endocardial contours were manually traced using cardiac analysis software (CT MASS, Medis, Leiden, the Netherlands), and LVEF was calculated. An independent, second observer additionally performed manual tracing of endocardial contours, blinded to the results of the first observer, in order to establish interobserver agreement. For assessment of regional LV function, a 17-segment model was used (12). Each segment was assigned a wall motion score (WMS), with 1) normal wall motion; 2) hypokinesia; 3) akinesia; and 4) dyskinesia. Short axis views at 0% to 95% were presented in cine on a Linux workstation and regional LV function was evaluated by an experienced cardiologist.

Echocardiography

Patients were imaged in the left lateral decubitus position using a commercially available system (Vingmed system Seven, General Electric-Vingmed, Milwaukee, Wisconsin, USA). Images were obtained using a 3.5-MHz transducer, at a depth of 16 cm in the parasternal and apical views (standard parasternal long- and short-axis, apical 2- and 4-chamber images). The images were saved in cine loop format (triggered to the ECG). The LVEF was calculated from the conventional apical 2- and 4-chamber images, using the biplane Simpson's technique and commercially available software (Echopac 6.1, General Electric - Vingmed) (13;14). For the evaluation of regional LV function, the same 17-segment model was used as with MDCT, with a similar scoring system (scores 1 to 4, from normokinesia to dyskinesia). The echocardiography LV function assessment was performed by an experienced cardiologist, who was blinded to the results of MDCT.

CMR

For CMR imaging a 1.5 T Gyroscan ACS-NT MR scanner (Philips Medical Systems, Best, the Netherlands), equipped with Powertrak 6000 gradients, a cardiac research software patch, and 5-element cardiac synergy coil was used. Gross cardiac anatomy was visualized by means of a scout scan. A SENSE reference scan was performed in order to use this application in the subsequent scans. A 2-chamber view was planned on the transversal scout and scanned by means of a breathhold, ECG-triggered, balanced fast field echo sequence. A 4-chamber view was then scanned using the 2-chamber view for planning. The short-axis view was scanned in 3 breathholds using the 2-chamber and 4-chamber views in end-systole and end-diastole for reference. MR parameters for the 2-chamber, 4-chamber, and short axis views were: TR/TE 3.6/1.8 ms, flip angle of 50°, temporal resolution of 32 ms, field of view of 400 x 400 mm, data acquisition matrix of 256 x 256 mm, section thickness of 10 mm, scan duration of 26 heart beats. At short axis, 12 slices were acquired at 10 mm slice thickness. Image data were transferred to a personal computer and viewed using MASS Suite 6.0.6 (Medis, Leiden, the Netherlands). For global LV function analysis endocardial contours were manually traced, and LVEF was calculated by an experienced observer, who was blinded to the results of MDCT and echocardiography. For regional LV function analysis short axis views in cine were evaluated by an experienced cardiologist, who was blinded to the results of MDCT and echocardiography, using the 17-segment model identically as for the MDCT images.

Statistical Analysis

Data is presented as mean ± standard deviation. Agreement between the imaging methods and observers was calculated as Pearson correlation and by means of Bland-Altman analysis (15). The 95% limits of agreement were defined as the range of values ± 2 SD from the mean difference. Agreement between methods on regional function was expressed as percentage and κ-value, in which κ-values <0.4, between 0.4 and 0.75, and >0.75 represented modest, fair to good, and excellent agreement, respectively. A p-value <0.05 was considered significant.

Results

MDCT

A total of 25 patients were enrolled in the study. Patient characteristics are summarized in Table 8.1. Heart rate at MDCT scanning varied from 53 to 85 beats per minute (mean 64 ± 9 bpm). For all patients global and regional function could be assessed by MDCT. Mean LVEF was 48.9 ± 15.2% (range 15.4 to 73.5%). Interobserver agreement was excellent with a correlation coefficient (r) of 0.96, p<0.0001. At Bland-Altman analysis, the bias was 1.8%, and 95% limits of agreement ranged between -6.7 and 10.3%. For regional function assessment, 425 segments were analyzed. A normal WMS was assigned to 325 segments, 58 segments were hypokinetic, 30 segments akinetic, and 12 dyskinetic.

Echocardiography

All patients underwent 2-dimensional echocardiography. At echocardiography, the mean LVEF was 48.3 ± 15.1% (range 19 to 75%). All 425 segments could be analyzed; 325 segments had normal wall motion, 50 were hypokinetic, 42 akinetic and 8 dyskinetic.

CMR

Eight of 25 patients gave informed consent for the CMR examination. Contra-indications for CMR existed for 9 patients, 8 patients refused to give informed consent. Mean LVEF derived from MR images was 56.7 ± 16.7% (range 28.4 to 77.6%). A total of 136 segments were analyzed for regional LV function assessment. Normal WMS was allocated to 104 segments, 25 segments were hypokinetic, and 7 akinetic; none were dyskinetic.

Number of patients	25
Gender (M/F)	24/1
Age (years)	66.7 ± 9.4
Diabetes mellitus	8 (32%)
Currently smoking	3 (12%)
Hypertension	13 (52%)
Hypercholesterolemia	16 (64%)
Prior myocardial infarction	14 (56%)
Pacemaker or ICD	2 (8%)

Table 8.1
Patient Characteristics
ICD = intracardiac defibrillator

MDCT versus Echocardiography

For global LV function evaluation, the LVEF correlated well for MDCT and echocardiography. The trendline equalled y = 0.97x + 1.83, r = 0.96, p<0.0001 (Figure 8.1). At Bland-Altman analysis a bias of 0.54% was demonstrated, and 95% limits of agreement ranged from -7.7% to 8.8%. All data points stayed within 2 SD of the mean difference. For regional LV function assessment, MDCT agreed well with echocardiography in 91% of segments (κ = 0.78; Table 8.2).

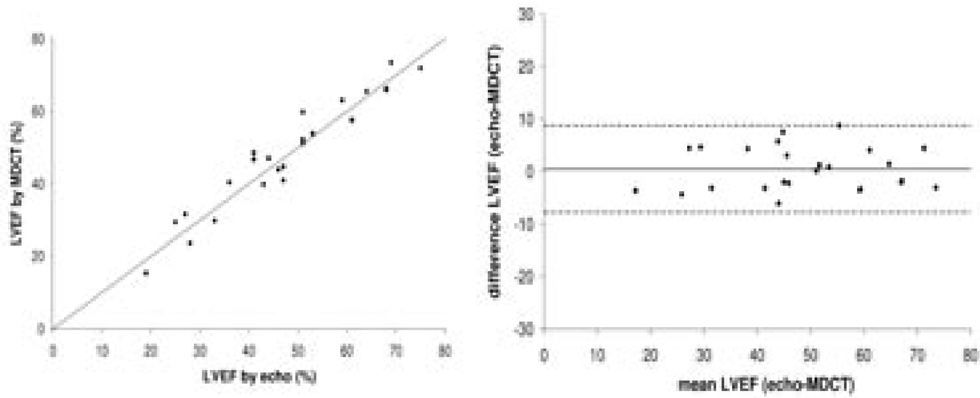

Figure 8.1

Correlation and Bland-Altman plot of LVEF by echocardiography and MDCT. Identity line (y = x) is shown in the correlation plot in gray.

	Echocardiography					
	WMS	1	2	3	4	Total
MDCT	1	314	9	2	0	325
	2	10	39	9	0	58
	3	1	2	27	0	30
	4	0	0	4	8	12
	Total	325	50	42	8	425

Table 8.2

Agreement between MDCT and Echocardiography in Wall Motion Score

Wall motion scores of 1 to 4 were assigned to the different segments: 1 = normal wall motion; 2 = hypokinesia; 3 = akinesia; 4 = dyskinesia. WMS = wall motion score; MDCT = multidetector row computed tomography

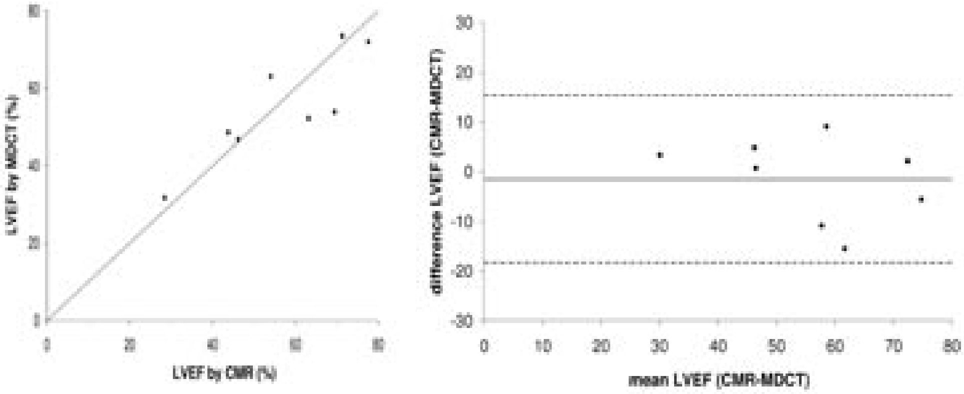

Figure 8.2
Correlation and Bland-Altman plot of LVEF by CMR and MDCT. Identity line (y = x) is shown in the correlation plot in gray.

	CMR					
	WMS	1	2	3	4	Total
	1	102	4	0	0	106
	2	2	21	1	0	24
MDCT	3	0	0	6	0	6
	4	0	0	0	0	0
	Total	104	25	7	0	136

Table 8.3
Agreement between MDCT and CMR in Wall Motion Score
Wall motion scores of 1 to 4 were assigned to the different segments: 1 = normal wall motion; 2 = hypokinesia; 3 = akinesia; 4 = dyskinesia. CMR = cardiovascular magnetic resonance; WMS = wall motion score; MDCT = multidetector row computed tomography

MDCT versus CMR
A fair correlation of MDCT and CMR on LVEF calculation was shown, $y = 0.72x + 14.3$, $r = 0.86$, $p<0.01$. At Bland-Altman analysis, the bias for MDCT was -1.5%, with 95% limits of agreement ranging from -18.3% to 15.3% (Figure 8.2). At regional LV function assessment, MDCT agreed well with CMR in 95% of segments ($\kappa = 0.86$; Table 8.3).

Discussion
In the present study, LV function measurements by 16-detector row CT were compared with echocardiography and CMR. The results demonstrate a good agreement between MDCT and echocardiography/CMR for the evaluation of LVEF and regional wall motion abnormalities. Moreover, interobserver agreement for LVEF assessment by MDCT was excellent.

LV Ejection Fraction with MDCT

Four-detector row CT has been shown to assess LVEF accurately. A comparison with echocardiography was performed in patients with unstable angina pectoris, demonstrating a good correlation (r = 0.93) and agreement (bias 1.3%) with MDCT for assessment of LVEF (10). Also, in comparison with cineventriculography, MDCT showed a fair correlation (r = 0.8) in the measurement of LVEF (8). In addition, Juergens et al. reported LVEF derived by MDCT to correlate and agree well (r = 0.89; bias 0.25%) with LVEF derived by CMR in patients with known or suspected coronary artery disease (9). In another direct comparison with CMR however, a significant underestimation in LVEF by MDCT (bias -8.5%) was shown (16). This underestimation may be related to the use of a standard image reconstruction algorithm, resulting in limited temporal resolution of MDCT (125-250 ms, heart rate dependent). Superior resolution can be obtained using multisegmental resolution (temporal resolution 75-130 ms), resulting in a better agreement between CMR and MDCT for assessment of LVEF (17).

In the present study, LVEF assessment by 16-detector row CT agreed well with both LVEF assessment by echocardiography (r = 0.96; bias 0.54%), and by CMR (r = 0.86; bias –1.5%). Moreover, for LVEF assessment by MDCT, the interobserver agreement was excellent (r = 0.96; bias 1.8%).

LV Wall Motion Analysis with MDCT

An early study compared single-detector row, ECG-gated CT with echocardiography and left ventriculography for assessment of regional wall motion (18). A good correlation with both echocardiography (86%), and left ventriculography (82%) was shown. Similarly, wall motion assessment by 4-detector row CT has been demonstrated to agree well with echocardiography (88%; κ = 0.84) (10). Also, good agreement between CMR and 4-detector row CT for assessment of wall motion was shown (agreement 84% [κ = 0.56] when standard image reconstruction was used, and 93% [κ = 0.82] when multisegmental reconstruction was used) (17). The results of the current study show that 16-detector row MDCT agreed well with both echocardiography (91%; κ = 0.78) and CMR (95%; κ = 0.86) for assessment of regional wall motion.

Why Another Modality for Assessment of LV Function?

Currently, several noninvasive imaging techniques are available for the assessment of LV function. The most frequently used technique in daily routine is 2D echocardiography, which is fast, easily accessible, and contains no radiation exposure (5;19). For patients with obesity, chronic obstructive pulmonary disease (COPD), or prior cardiothoracic surgery, echocardiography may be less optimal, due to poor acoustic windows (20). The current gold standard to evaluate LV function noninvasively is CMR (6;21). This technique is fast, and without radiation exposure. However, CMR is often not readily available, and comprises certain contra-indications, such as metal implants, irregular heart rhythm, and claustrophobia. SPECT imaging, traditionally used for assessment of perfusion, is yet another technique that (with the introduction of ECG gating) allows accurate assessment of global and regional LV function, but it exposes patients to radiation (7;22).

Similar to SPECT imaging, MDCT also requires exposure to radiation (7-8 mSv per cardiac study), but allows examination of patients with a pacemaker or other metal implants, obesity, COPD, or prior cardiac surgery. With the growing interest in noninvasive angiography by MDCT (in particular with the 16-detector and higher detector row technology) (23;24), evaluation of function by MDCT is of value, since it can be obtained in the same session for noninvasive angiography, without the need for additional contrast or prolonged data acquisition.

Limitations

A limited number of patients underwent CMR imaging, due to contra-indications or refusal of informed consent. Therefore, a larger direct comparison of 16-detector row CT and CMR in the evaluation of LV function is required to confirm the current findings.

Conclusion

MDCT agreed well with both echocardiography and CMR in the assessment of global and regional LV function. Global and regional LV function may accurately be evaluated by 16-detector row CT (in the same session, without need for additional contrast), and can be added when noninvasive angiography with MDCT is performed.

References

1. Hunt SA, Baker DW, Chin MH et al. ACC/AHA guidelines for the evaluation and management of chronic heart failure in the adult: executive summary. J Heart Lung Transplant 2002;21:189-203.
2. Schwammenthal E, Adler Y, Amichai K et al. Prognostic value of global myocardial performance indices in acute myocardial infarction: comparison to measures of systolic and diastolic left ventricular function. Chest 2003;124:1645-51.
3. Braunwald E, Antman EM, Beasley JW et al. ACC/AHA 2002 guideline update for the management of patients with unstable angina and non-ST-segment elevation myocardial infarction--summary article: a report of the American College of Cardiology/American Heart Association task force on practice guidelines (Committee on the Management of Patients With Unstable Angina). J Am Coll Cardiol 2002;40:1366-74.
4. Ryan TJ, Antman EM, Brooks NH et al. 1999 update: ACC/AHA guidelines for the management of patients with acute myocardial infarction. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Management of Acute Myocardial Infarction). J Am Coll Cardiol 1999;34:890-911.
5. Folland ED, Parisi AF, Moynihan PF, Jones DR, Feldman CL, Tow DE. Assessment of left ventricular ejection fraction and volumes by real-time, two-dimensional echocardiography. A comparison of cineangiographic and radionuclide techniques. Circulation 1979;60:760-6.
6. Ichikawa Y, Sakuma H, Kitagawa K et al. Evaluation of left ventricular volumes and ejection fraction using fast steady-state cine MR imaging: comparison with left ventricular angiography. J Cardiovasc Magn Reson 2003;5:333-42.
7. Iskandrian AE, Germano G, Vandecker W et al. Validation of left ventricular volume measurements by gated SPECT 99mTc-labeled sestamibi imaging. J Nucl Cardiol 1998;5:574-8.
8. Juergens KU, Grude M, Fallenberg EM et al. Using ECG-gated multidetector CT to evaluate global left ventricular myocardial function in patients with coronary artery disease. AJR Am J Roentgenol 2002;179:1545-50.
9. Juergens KU, Grude M, Maintz D et al. Multi-detector row CT of left ventricular function with dedicated analysis software versus MR imaging: initial experience. Radiology 2004;230:403-10.
10. Dirksen MS, Bax JJ, de Roos A et al. Usefulness of dynamic multislice computed tomography of left ventricular function in unstable angina pectoris and comparison with echocardiography. Am J Cardiol 2002;90:1157-60.
11. Schuijf JD, Bax JJ, Salm LP et al. Assessment of left ventricular function using 16-slice computed tomography. Am J Cardiol 2005;95:571-4.
12. Cerqueira MD, Weissman NJ, Dilsizian V et al. Standardized myocardial segmentation and nomenclature for tomographic imaging of the heart: a statement for healthcare professionals from the Cardiac Imaging Committee of the Council on Clinical Cardiology of the American Heart Association. Circulation 2002;105:539-42.
13. Schiller NB, Acquatella H, Ports TA et al. Left ventricular volume from paired biplane two-dimensional echocardiography. Circulation 1979;60:547-55.
14. Otterstad JE, Froeland G, St John SM, Holme I. Accuracy and reproducibility of biplane two-dimensional echocardiographic measurements of left ventricular dimensions and function. Eur Heart J 1997;18:507-13.
15. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1:307-10.
16. Grude M, Juergens KU, Wichter T et al. Evaluation of global left ventricular myocardial function with electrocardiogram-gated multidetector computed tomography: comparison with magnetic resonance imaging. Invest Radiol 2003;38:653-61.
17. Mahnken AH, Spuentrup E, Niethammer M et al. Quantitative and qualitative assessment of left ventricular volume with ECG-gated multislice spiral CT: value of different image reconstruction algorithms in comparison to MRI. Acta Radiol 2003;44:604-11.
18. Bouchard A, Lipton MJ, Farmer DW et al. Evaluation of regional ventricular wall motion by ECG-gated CT. J Comput Assist Tomogr 1987;11:969-74.
19. Parisi AF, Moynihan PF, Folland ED, Feldman CL. Quantitative detection of regional left ventricular contraction abnormalities by two-dimensional echocardiography. II. Accuracy in coronary artery disease. Circulation 1981;63:761-7.
20. Geleijnse ML, Fioretti PM, Roelandt JR. Methodology, feasibility, safety and diagnostic accuracy of dobutamine stress echocardiography. J Am Coll Cardiol 1997;30:595-606.
21. Pattynama PM, Lamb HJ, van der Velde EA, van der Wall EE, de Roos A. Left ventricular measurements with cine and spin-echo MR imaging: a study of reproducibility with variance component analysis. Radiology 1993;187:261-8.

22. Vaduganathan P, He ZX, Vick GW, III, 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.
23. Nieman K, Cademartiri F, Lemos PA, Raaijmakers R, Pattynama PM, de Feyter PJ. Reliable noninvasive coronary angiography with fast submillimeter multislice spiral computed tomography. Circulation 2002;106:2051-4.
24. Schlosser T, Konorza T, Hunold P, Kuhl H, Schmermund A, Barkhausen J. Noninvasive visualization of coronary artery bypass grafts using 16-detector row computed tomography. J Am Coll Cardiol 2004;44:1224-9.