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Assessment of left ventricular ejection fraction and regional wall motion with 64-slice multidetector CT: a comparison with two-dimensional transthoracic echocardiography

S-M KO, MD, Y-J KIM, MD, J-H PARK, MD and N-M CHOI, MD

Department of Radiology, Konkuk University Hospital, Konkuk University School of Medicine, Seoul, Korea

ABSTRACT. The aim of this study was to compare the measurement of left ventricular ejection fraction (LVEF) and regional wall motion using 64-slice multidetector CT (MDCT) with that using two-dimensional transthoracic echocardiography (2D-TTE) in a heterogeneous patient population. In 126 patients with angina pectoris, acute myocardial infarction, chronic myocardial infarction, atypical chest pain without coronary artery disease or valvular heart disease, 64-slice MDCT was performed using retrospective electrocardiography gating without dose modulation. 20 phases of the cardiac cycle were analysed to identify the end-diastolic and end-systolic phases and to assess regional LV wall motion. For these measurements, 2D-TTE served as the reference standard. MDCT and 2D-TTE were performed within 10 days of each other. An excellent correlation between MDCT and 2D-TTE was shown for the evaluation of LVEF ($59.2\pm11\%$ *vs* $57.9\pm10\%$, respectively; $r=0.87$). LVEF was slightly overestimated by MDCT, when compared with 2D-TTE, by an average of $1.4\pm5.6\%$. Good agreement was obtained between the use of the two techniques, with 94% of the segments scored identically on both modalities ($\kappa=0.70$). MDCT had a sensitivity of 97% and a specificity of 82% when compared with 2D-TTE as the reference standard. In conclusion, the use of 64-slice MDCT can provide comparable results to those using 2D-TTE for LVEF and regional wall motion assessment in a heterogeneous population.

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Accurate and reproducible determination of left ventricular (LV) function is essential for the diagnosis, disease stratification, therapeutic guidance, follow-up and estimation of prognosis for the majority of cardiac diseases [1–3]. Two-dimensional transthoracic echocardiography (2D-TTE) is the most widely used method for LV function assessment, but the modality is operator dependent and can be impaired by a poor acoustic window [4]. Cardiac MRI has been considered the clinical ''gold standard'' for LV function assessment, but it is expensive, of limited availability and cannot be performed in patients with implanted pacemakers or defibrillators [5–8]. Multidetector CT (MDCT) of the heart is used largely to evaluate the coronary arteries [9–11]. Currently, MDCT is increasingly being considered as a potential tool for the combined assessment of the coronary anatomy and LV function [12–14]. Retrospective electrocardiography (ECG)-gated MDCT allows for image reconstruction in any phase of the cardiac cycle. Thus, LV end-diastolic (ED) and end-systolic (ES) volumes can be assessed. In addition, ventricular wall motion can be assessed visually by the use of cine loop displays of multiple cardiac phases. According to recent reports [15–32], measurements for various LV functional parameters with MDCT were correlated and agreed with measurements obtained with MRI, 2D-TTE and ECG-gated single photon emission CT (SPECT). However, the experience with 64-slice MDCT for cardiac function assessment remains limited by small patient numbers and the inclusion of homogeneous patient populations [24–32].

The purpose of this study was to assess LV ejection fraction (LVEF) and regional wall motion using 64-slice MDCT and to compare this with 2D-TTE in a heterogeneous patient population.

Methods and materials

Patient population

Between October 2006 and May 2007, 187 patients who underwent 64-slice MDCT coronary angiography without ECG-dependent dose modulation to evaluate known or suspected coronary artery disease, to evaluate a myocardial enhancement pattern or to assess the patency of a coronary stent were identified retrospectively. Among the 187 patients, 61 patients were excluded from the study. 48 patients did not undergo echocardiography, 4 had poor acoustic window at echocardiography, 7 had arrhythmia and 2 had respiratory motion artefact. Of the remaining 126 patients, 45 patients had angina pectoris, 32 had acute myocardial infarction, 24 had chronic myocardial infarction, 17 had atypical chest pain and 8 had aortic valvular disease. The study population consisted of 96 men and 30 women, aged 39–81 years

Address correspondence to: Sung-Min Ko, Department of Radiology, Konkuk University Hospital, Konkuk University School of Medicine, 4-12 Hwayang-dong, Gwangjin-gu, Seoul, 143-729, Korea. E-mail: ksm9723@yahoo.co.kr

(mean age, 61±10 years). From the same data set used for the evaluation of the coronary arteries, regional LV function and LVEF were assessed and compared with the use of 2D-TTE. MDCT and 2D-TTE were performed within 10 days of each other. Our institutional review board approved this retrospective study and informed consent was not required.

MDCT scanning protocol, reconstruction and analysis

Before the examination, the heart rate (HR) of each patient was measured. Patients with a pre-scan HR ⩾65 beats per minute (bpm) were administered 25–50 mg of atenolol orally 1 h before the scan to reduce the chances of motion artefact. All patients received 0.6 mg of nitroglycerin sublingually 1 min before the examination to dilate the coronary arteries.

MDCT coronary angiography was performed using a 64-slice MDCT-scanner (Sensation 64; Siemens Medical Solutions, Forchheim, Germany). Scan parameters were as follows: slice collimation 32×0.6 mm, rotation time 0.33 ms, tube voltage 100–120 kV (depending on age and weight/length), effective tube current–time product 630 mAs and pitch 0.2 (3.84 mm table feed per tube rotation). The scan time was approximately 10 s in a single breath-hold. No ECG-dependent dose modulation technique was applied. CT angiography was triggered automatically by the arrival of a main contrast bolus (automatic bolus tracking). A pre-scan image was taken at the level of the aortic root and a region of interest was identified on the ascending aorta. As soon as the signal density level in the ascending aorta reached a pre-defined threshold of 130 Hounsfield units (HU), the scan was started. 70–80 ml of non-ionic contrast media (Iomeron 400, iomeprol, 400 mg ml^{-1}; Bracco, Milan, Italy) was injected at a flow rate of 5.0 ml s^{-1}. This injection was followed by 50 ml of saline–contrast media mixture at a flow rate of 5 ml s^{-1} in order to produce sufficient enhancement for assessment of the right ventricle. During the scan, an ECG was recorded simultaneously. For image reconstruction, a bi-segmental algorithm with a temporal resolution ranging from 83 ms to 165 ms, depending on the patient's heart rate, was used. From the raw data, 20 axial image series were reconstructed every 5% (0–95%) of the RR interval with an effective slice thickness of 2.0 mm and a reconstruction increment of 2.0 mm.

MDCT data sets were evaluated by two experienced radiologists, who were blinded to any clinical information and the results of the 2D-TTE. LV functional analysis was performed on an offline workstation (Leonardo; Siemens Medical Solutions) using commercially available software (Circulation; Siemens Medical Solutions) (Figure 1). LVEF was measured and calculated by using a threshold-based technique. The appropriate reconstruction window for the ED and ES phases were visually identified as the images showing the minimum ventricular diameter (typically found at 25–30% of the RR interval) and the maximum ventricular diameter (typically found at 95–0% of the RR interval) on the basis of axial images reconstructed at the mid ventricular level. LV endocardial and epicardial contours were drawn semi-automatically on serial short-axis slices of both ED and ES images. Manual adjustments were made whenever needed. LVEF was calculated directly by the software. LV ED and ES volumes were calculated using Simpson's method by summing the endocardial area of all LV ED and ES short-axis slices multiplied by the slice thickness. The papillary muscles and trabeculae were regarded as being part of the left ventricular cavity. Multiplanar reformatted images were reconstructed in planes corresponding to the planes used in TTE for regional wall motion assessment. Segmental LV wall motion analysis was performed on horizontal and vertical long-axis views and short-axis cine loops. The short-axis view was evaluated at the basal, mid-ventricular and apical positions along the long axis. Using the 17-segmental American Heart Association (AHA) model [33], each segment was scored as: 1= normal, 2= hypokinetic and 3= akinetic or dyskinetic.

Intra- and interobserver reliability of CT measurements

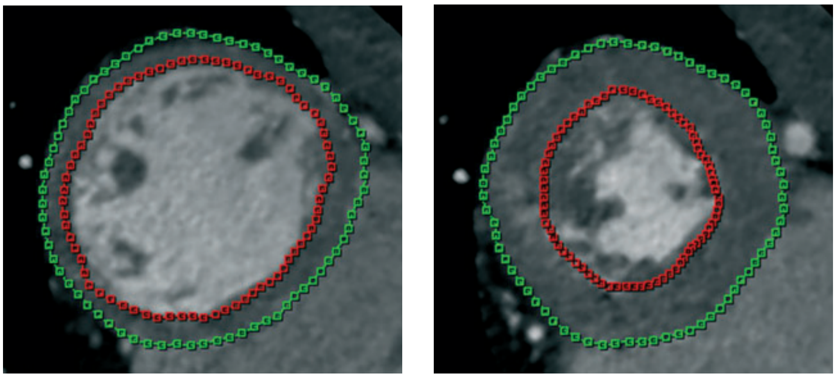
For assessment of intraobserver reliability, a second reading was performed on all CT data after a two month interlude. Interobserver reliability was analysed by comparing CT measurements of two radiologists (S.M.K. and Y.J.K.) with six years' and two years' experience in cardiac imaging, respectively.

Two-dimensional echocardiography

All patients underwent 2D-TTE using a standard protocol. Echocardiographic examinations were performed on one of two machines — an Acuson Sequoia (Siemens Medical Systems USA, Mountain View, CA) or a GE Vivid 3 (GE Healthcare, Milwaukee, WI) — and were recorded on S-VHS videotape. Images were obtained using a 3.5 MHz transducer, and images were acquired in standard apical and parasternal two- and four-chamber views. Two readers measured the chamber and wall dimensions using standard recommendations for chamber quantification in consensus [34]. LVEF was calculated using the modified Simpson's method [35, 36]. Regional wall motion was assessed using the same protocol as used for MDCT.

Data and statistical analysis

Continuous variables are presented as the mean ± standard deviation. Agreement for LVEF was determined by the use of Pearson's correlation coefficient (r) and Bland–Altman analysis. The Pearson correlation coefficient was valued as follows: poor =0; slight =0.01–0.20; fair =0.21–0.40; moderate =0.41–0.60, good =0.61–0.80; and excellent =0.81–1.00. Bland–Altman analysis was used to compare the LVEF measured with MDCT and that with 2D-TTE. The Pearson correlation coefficient was used to determine intra- or interobserver agreement in LVEF obtained by the two MDCT readers. Regional wall motion scores were expressed in a cross table. The cross table was repeated using binary values (normal and abnormal). Agreement between MDCT and 2D-TTE with regard to LV regional wall motion scores was calculated



(a) (b)

Figure 1. A 63-year-old woman with atypical chest pain. Example of 64-slice MDCT short-axis reconstructions in (a) end-diastole and (b) end-systole to assess global left ventricular (LV) function. LV endocardial and epicardial contours drawn on reformatted short-axis views show that papillary muscles and trabeculae are included in the ventricular volume. The example is provided of a patient with a normal LV ejection fraction of 62%.

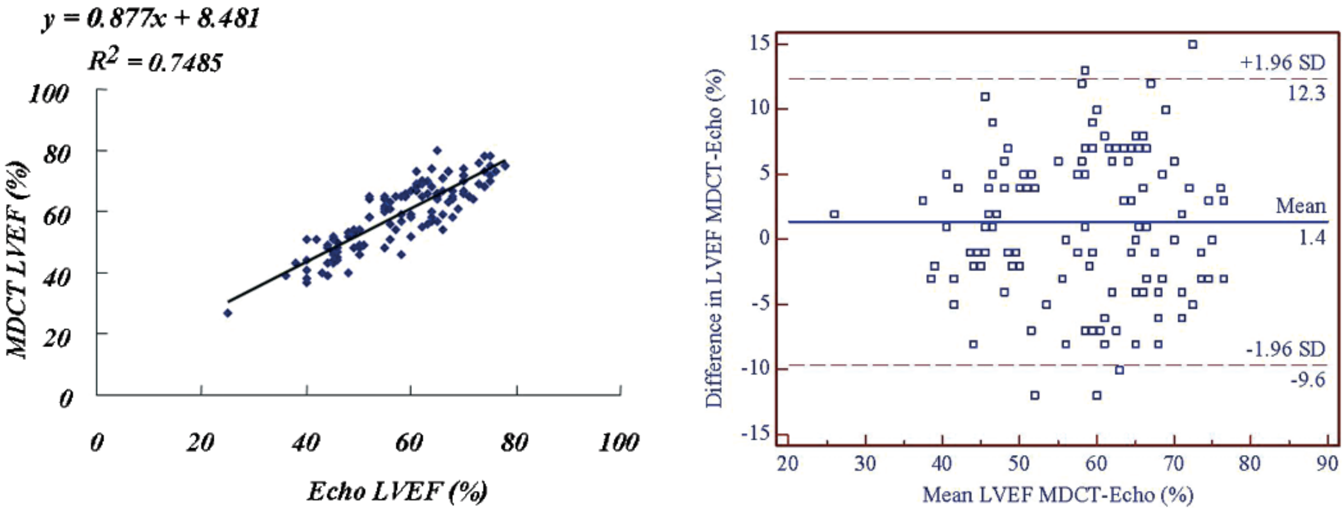
and κ values were determined (<0.4=poor agreement; 0.4–0.75=fair to good agreement; >0.75=excellent agreement). The kappa analysis was used for intra- or interobserver agreement in regional wall motion scores obtained by the two MDCT readers. Assuming 2D-TTE to be the ''reference standard'', the sensitivity and specificity of MDCT to diagnose an abnormal segment were calculated for all segments. The statistical significance of the mean difference between the different modalities was tested by use of the Student's t-test for paired samples. A p-value <0.05 was considered to be statistically significant. For statistical analysis, commercially available Windows-based software was used (SPSS 12.0.1, 2003; SPSS, Chicago, IL).

Results

MDCT was performed without complications in each of the 126 patients. Oral atenolol was administered in 80% (101/126) of the patients. The average HR during MDCT was 66±11 bpm. All MDCT examinations were suitable for analysis. The calculated effective radiation dose for each patient was 14±3.5 mSv.

There was high intraobserver agreement for LVEF obtained by MDCT (r=0.98 and r=0.97). In addition, interobserver agreement for assessment of LVEF with MDCT proved high (r=0.97). The mean LVEF was 59.2±11% measured on MDCT, compared with 57.9±10.7% when measured on 2D-TTE. Pearson's regression analysis showed an excellent correlation, with a correlation coefficient of 0.87 (p<0.001). Bland–Altman analysis showed a trend towards MDCT resulting in slightly higher values for LVEF when compared with TTE (1.4±5.6%) (Figure 2).

For regional wall motion assessment using MDCT, the mean κ statistics of intraobserver agreement were 0.83 (range, 0.62–0.96) for Observer 1 and 0.80 (range, 0.65–0.91) for Observer 2. In addition, the mean κ statistics of interobserver agreement for regional wall assessment with MDCT was 0.68 (range, 0.45–0.92). On 2D-TTE, regional wall motion abnormalities were detected in 247 (12%) of 2142 segments, with 176 segments showing hypokinesia and 71 segments showing akinesia or dyskinesia. In 270 (13%) of 2142 segments, abnormal wall motion was noted on the MDCT images (Table 1). Good agreement was shown between the two techniques, with 94% (2004 of 2142 segments) of the segments



(a) (b)

Figure 2. (a) Linear regression plot shows the correlation between left ventricular ejection fraction (LVEF) measured by 64-slice multidetector CT (MDCT) and two-dimensional echocardiography (echo). (b) Bland–Altman plot of LVEF shows the difference between each pair plotted against the average value of the same pair and the mean value of differences ±2 standard deviations (SDs).

Table 1. Contingency table showing the relative agreement between 64-slice MDCT and two-dimensional echocardiography for scores 1 to 3

All segments	MDCT score			
	1	2	3	Total
Echocardiograph score				
1	1828	65	2	1895
2	39	131	6	176
3	5	21	45	71
Total	1872	217	53	2142

MDCT, multidetector CT.
Wall motion scores of 1 to 3 were assigned to the different segments: 1 = normal wall motion; 2 = hypokinesia; 3 = akinesia or dyskinesia.

Table 2. Contingency table showing the relative agreement between 64-slice MDCT and two-dimensional echocardiography for binary scores

All segments	MDCT score		
	Normal	Abnormal	Total
Echocardiograph score			
Normal	1828	44	1872
Abnormal	67	203	270
Total	1895	247	2142

MDCT, multidetector CT.

scored identically with use of both modalities (κ=0.70). An example of wall motion assessment by MDCT is shown in Figure 3. The results of evaluation using a binary approach are listed in Table 2. Using this approach, agreement slightly increased to 95% (2031 of 2142 segments). Regarding 2D-TTE as the ''reference standard'', MDCT had a sensitivity of 97%, a specificity of 82% and an accuracy of 95% when compared with 2D-TTE, using the 17-segment approach.

Discussion

In the present study, measurements of LV function made with the use of 64-slice MDCT were compared with those using 2D-TTE. The results demonstrated good agreement between MDCT and 2D-TTE for the evaluation of LVEF and regional wall motion abnormalities.

LVEF with MDCT

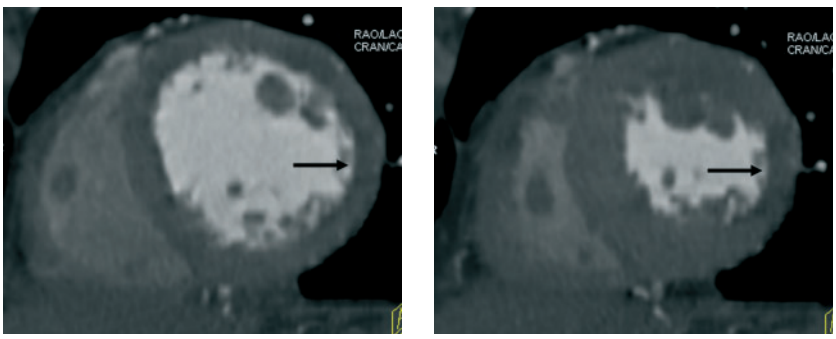
The accurate determination of LVEF is an important clinical aspect in the care of patients with various cardiac conditions to provide prognostic values and guide management. Multiple studies have been published regarding the assessment of LVEF using 4-, 8-, 16- and 64-slice and dual-source MDCT [15–32, 37–41]. LVEF as determined by the use of MDCT showed good or excellent agreement with the respective measurements from cineventriculography, 2D-echocardiography, MRI and SPECT (Table 3). In our study, assessment of LVEF using 64-slice MDCT showed excellent intra- and interobserver agreement and excellent correlation with 2D-TTE. LVEF was slightly overestimated with MDCT by an average of $1.4 \pm 5.6\%$.

A temporal resolution of 30–50 ms per image is necessary for the exact measurement of LVEF, especially in patients with higher HRs. The temporal resolution of MDCT is still inferior to that of echocardiography. Generally, end-systole is always overestimated owing to the limited temporal resolution of MDCT and, subsequently, LVEF is then underestimated. The temporal resolution of MDCT is associated with gantry rotation time, the use of an image reconstruction algorithm and HR. We used a 64-slice MDCT scanner with a 330 ms rotation time and bi-segmental image reconstruction. Thus, the temporal resolution provided was between 83 ms and 165 ms. Furthermore, we used 20 cardiac phases (0–95%) sampled during each cardiac cycle in order to detect the ES and ED period.

Automatic endocardial contour detection with manual adjustment of the LV cavity in MDCT using analysis software showed high reproducibility and excellent correlation with echocardiography, even though papillary muscle and trabeculae were included in the LV cavity. Measurement of LVEF using cardiac MRI was significantly different according to the alternative inclusion of papillary muscles and trabeculae in either cavity or myocardial volumes [42]. Precise endocardial contour delineation with the inclusion of papillary muscle and trabeculae in the myocardial volume is potentially a new ''gold standard'' in volume assessment [43].

LV wall motion analysis with MDCT

Abnormalities of regional LV wall motion are important markers of myocardial ischaemia and are assessed visually on cine loops from echocardiography, cineven-



(a) (b)

Figure 3. A 73-year-old man with a history of lateral myocardial infarction with a heart rate of 70 beats per minute. The multidetector CT short-axis images at (a) end-diastole and (b) end-systole disclose akinesia in the lateral region (arrows). The example is provided of a patient with a normal left ventricular ejection fraction of 61%.

Table 3. Determination of left ventricular ejection fraction from 4-, 16- and 64-slice and dual-source MDCT of the heart in comparison with competitive imaging modalities

Author(s)	Scanner type	Gantry rotation (ms)	Number of phases of recon used	Modality compared with MDCT	Correlation coefficient	Difference (%)
Juergens et al [37]	4-slice	500	20	CGV	0.80	−11.5±5.7
Dirksen et al [38]	4-slice	500	20	2D-echo	0.93	−1.3±4.5
Dirksen et al [39]	4-slice	500	20	2D-echo	0.95	0.7±3.9
Mahnken et al [15]	16-slice	420	20	MRI	0.99	−0.07±2.0
Dewey et al [16]	16-slice	400	10	MRI	0.91	−2.1±10.2
Salm et al [17]	16-slice	400–500	20	2D-echo	0.96	0.54
				MRI	0.86	−1.5%
Belge et al [18]	16-slice	420	8	MRI	0.95	Under
Heuschmid et al [19]	16-slice	420	20	MRI	0.88	−1.8±4.7
Schuijf et al [21]	16-slice	400–500	20	2D-echo	0.91	1.7±4.9
Bansal et al [22]	16-slice	Not described	8	2D-echo	0.59	2.18±11.3
Mahnken et al [23]	16-slice	420	20	MRI	0.99	0.3
				SPECT	0.99	0.6
Fischbach et al [20]	16-slice	420	20	MRI	0.83	−2.5±4.2
Abbara et al [28]	16-slice	420	10	2D-echo	0.26	4.6
				SPECT	0.76	−2.3
	64-slice	330	10	2D-echo	0.89	1.5
				SPECT	0.90	0
Henneman et al [25]	64-slice	400–450	20	2D-echo	0.91	2.5
Butler et al [26]	64-slice	330	10	2D-echo	0.67	2±6
Wu et al [29]	64-slice	400–500	20	MRI	0.97	−0.22±4.18
				2D-echo	0.87	Under
Wu et al [30]	64-slice	400–500	20	CGV		Under
				MRI	0.95	−0.06±6.04
Ferencik et al [27]	64-slice	330	10	2D-echo	0.49–0.54	−2±9
Schepis et al [24]	64-slice	350	10	SPECT	0.825	1.1±1.7
Palazzuoli et al [32]	64-slice	375	20	2D-echo	0.84	−0.8±6.5
Cury et al [31]	64-slice	330	16	2D-echo	0.68	−2±12
Brodoefel et al [40]	Dual-source	330	20	MRI	0.95	−0.7
Busch et al [41]	Dual-source	330	20	MRI	0.64	3.8±9.4

CGV, cineventriculography; 2D-echo, two-dimensional echocardiography; SPECT, single photon emission CT; MDCT, multi-detector CT; recon, reconstruction; Under, underestimation.

triculography or cardiac MRI. As image reconstruction is possible in virtually any phase of the cardiac cycle by retrospective ECG gating, MDCT has been used for regional wall motion assessment with promising results when compared with echocardiography and cardiac MRI [15–18, 20, 23–26, 29–31, 39, 40]. A study by Fischbach et al [20] in patients with a variety of cardiac diseases and a large range of LV volumes when compared with cardiac MRI reported an overall agreement in wall motion scores of 86.7% (κ=0.81). Similarly, wall motion assessment by 64-slice MDCT has been demonstrated to agree well with 2D-TTE (75%; κ=0.61) in patients with heart failure [26]. In addition, excellent agreement between the use of cardiac MRI and 64-slice MDCT for assessment of wall motion was shown (90%; κ=0.78) in patients with clinical acute myocardial infarction [31]. In our study, agreement between the use of 64-slice MDCT and 2D-TTE was 94% (κ=0.70), which is similar to results in a study by Henneman et al [25], who reported an agreement in 96% of the ventricular segments. However, MDCT scored a greater number of abnormal segments than 2D-TTE. Using echocardiography as the ''reference standard'', the sensitivity was very high (97%) but specificity was somewhat reduced (82%) for the detection of regional dysfunction. These results can be explained by relatively high interobserver variability (κ=0.68) owing to impaired temporal resolution of MDCT compared with echocardiography. Even though interpretation thresholds for rating regional LV wall motion as abnormal are subjective, the limited temporal resolution of MDCT remains the primary cause of limitation in the evaluation of regional wall motion abnormality. With dual-source MDCT in comparison with MRI, a 96.7% agreement (κ=0.88) in regional wall motion has been reported [40]. Further advances in the temporal resolution of dual-source MDCT would be helpful to match results from competitive imaging modalities.

Limitations

There are several limitations to the present study. Functional parameters were compared with 2D-TTE instead of the current ''gold standard'' for volumetric measurement, *i.e* MRI. When compared with cardiac MRI, it is likely that the assessment of LVEF and regional wall motion of MDCT would vary. MDCT and 2D-TTE were performed within 10 days of each other. Pre-medication with β-blockers was used for MDCT but not for 2D-TTE. The delay time between CT and echocardiography and pre-medication with β-blockers could have changed myocardial contraction and LV volumes as measured with the two methods. Finally, the radiation exposure of the applied protocol is still considerable.

ECG-dependent tube current modulation is currently the most effective tool for dose reduction and may reduce patient dose by up to 50% according to the individual ECG [44]. It is important to note that two points of the cardiac cycle (end-systole and end-diastole) with modulation of tube current were not used in our study because ECG-gated dose modulation was only applicable to 50–90% of the RR interval on ECG. If the aim is to evaluate coronary arteries only, it is recommended to use an ECG-dependent dose modulation technique.

Conclusions

The present study suggests that assessment of LVEF and regional wall motion is feasible with the use of 64-slice MDCT and may be regarded as a useful clinical index that is reflective of 2D-TTE.

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