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CARDIOVASCULAR IMAGING

ORIGINAL ARTICLE

Assessment of global left ventricular systolic function with multidetector CT and 2D echocardiography: a comparison between reconstructions of 1-mm and 2-mm slice thickness at multidetector CT

Murat Vural, Özgül Uçar, Nadir Alper Selvi, Lale Paşaoğlu, Müge Onbaşıoğlu Gürbüz, Hülya Çiçekçioğlu, Sinan Aydoğdu, Suha Koparal

PURPOSE
To compare multidetector computed tomography (MDCT) and two-dimensional transthoracic echocardiography (2DE) for left ventricular ejection fraction (EF); and to make comparison between reconstructions of 1-mm and 2-mm slice thickness at MDCT in left ventricular analysis by using a semi-automated segmentation algorithm.

MATERIALS AND METHODS
In 43 patients global left ventricular systolic function was assessed by using both MDCT and 2DE. Functional MDCT data sets were reconstructed in 20 cardiac phases (0–95%) with both 1-mm and 2-mm slice thickness.With semi-automatic left ventricle segmentation, end-diastolic volume (EDV), end-systolic volume (ESV) and EF were calculated seperately for both 1-mm and 2-mm reconstructions.

RESULTS
On MDCT with 1-mm slice thickness, mean EF was 66.8 ± 5.6 %, mean EDV was 133.7 ± 38.9 mL, and mean ESV was 45.1 ± 17.9 mL, these values for 2-mm slice thickness were 66.2 ± 5.6 %, 133.5 ± 39.6 mL, and 45.9 ± 18.3 mL, respectively. On 2DE, mean EF was 66.7 ± 5.7 %, mean EDV was 98.7 ± 42.1 mL, and mean ESV was 33.6 ± 18.7 mL. There was no difference between EF values calculated with 1-mm and 2-mm reconstructions and 2DE ($P = 0.83$ and $P = 0.3705$, respectively). However, EDV and ESV values calculated by MDCT were significantly higher than those obtained by 2DE ($P < 0.0001$).

CONCLUSION
There was a good correlation between MDCT and 2DE in the evaluation of left ventricular EF. At MDCT left ventricular ESV was statistically smaller, EF was statistically greater by using 1-mm rather than 2-mm slice thickness. However, these differences are not clinically relevant.

Key words: • tomography, x-ray computed • echocardiography • ventricular ejection fraction

From the Departments of Radiology (M.V. ✉ *mvural99@hotmail.com*, N.A.S., L.P., M.O.G., S.K.), and Cardiology (Ö.U., H.Ç., S.A.), Ankara Numune Education and Research Hospital, Ankara, Turkey.

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Multidetector computed tomography (MDCT) is a good, noninvasive alternative for the diagnosis and follow-up of coronary artery disease. It is also a highly reliable technique for detecting coronary artery anomalies and evaluating bypass graft patency (1–4). Left ventricular end-diastolic volume (EDV) and end-systolic volume (ESV) can also be calculated because the continuous acquisition of CT in spiral mode during ECG gating generates a data set that contains all information about the phases of the cardiac cycle.

Accurate determination of left ventricular ejection fraction (EF) is important for clinical diagnosis, risk stratification and prognosis estimation in many patients with cardiac disease. Currently, magnetic resonance imaging (MRI) is the gold standard technique for assessing left ventricular volumes and EF. However, MRI is a costly, time-consuming examination and is not widely available for this purpose. By comparison, 2D echocardiography (2DE) is more readily available for assessing left ventricular systolic function due to its lower cost.

The primary purpose of this study was to compare 16-slice MDCT and 2DE in terms of displaying left ventricular systolic function. As a secondary target, reconstructions based on 1-mm- and 2-mm-thick slices were compared for their ability to analyze left ventricular systolic function.

Materials and methods

Patients

Patients who were referred to the radiology department to be evaluated for coronary artery disease by MDCT were recruited. Exclusion criteria were renal insufficiency (plasma creatinine >2 mg/dL), allergy to iodinated contrast media and atrial fibrillation. A subsequent echocardiogram was performed on the same day as MDCT.

The study was approved by the ethics committee of our institution, and all patients gave informed consent for participation in the study.-

Multidetector CT

MDCT was performed using a 16-detector Toshiba Aquilion system (Toshiba Medical Systems, Otawara, Japan). The imaging and reconstruction parameters were as follows: detector collimation, 16 mm x 0.75 mm; voltage, 120 kV; effective tube current, 350 mA or 400 mA (depending on the patient size) and gantry rotation time, 420–500 ms. All CT scans were obtained in the craniocaudal direction. Image acquisition was performed during an inspiratory breath-hold. If not contraindicated, patients who had a prescan heart rate exceeding 70 beats per minute were given a single oral dose of 100 mg metoprolol 1 hour before the examination.

A 100-ml bolus of a non-ionic contrast agent (Iomeprol, Iomeron 350 mgI/mL, Bracco, Italy) was injected in the antebrachial vein with a flow

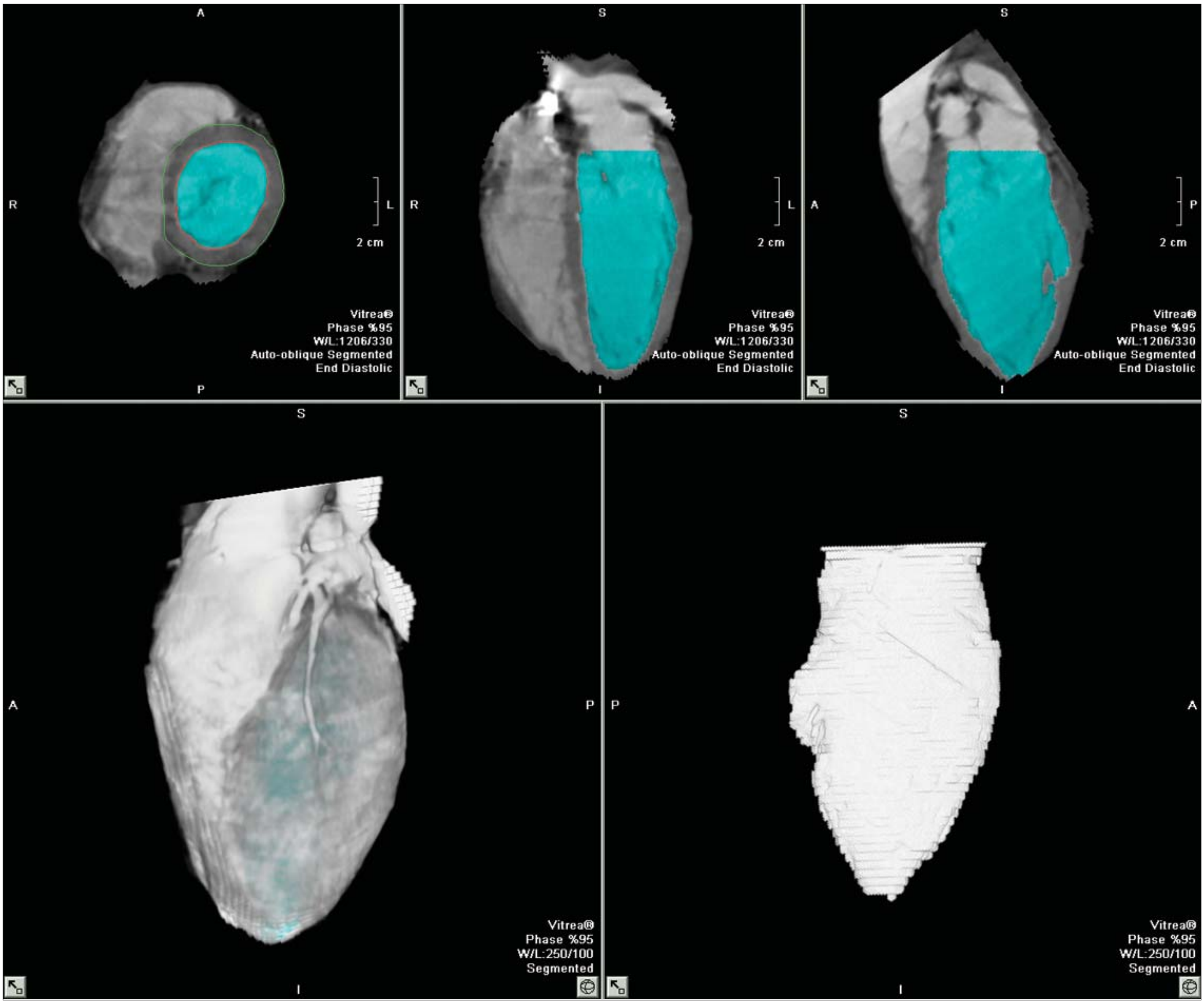

Figure 1. Short axis, horizontal long axis and vertical long axis multiplanar reformat views *(along the top row),* and 3D shaded heart view and tinted left ventricle view *(along the top row)* are obtained by MDCT.

rate of 4.5 mL/s. Data acquisition was initiated with a bolus-tracking technique with a threshold value of 120 HU and a delay time of six seconds after the contrast agent arrived in the ascending aorta. Overlapping transaxial images were reconstructed with an image matrix of 512 x 512 pixels with an ECG gated half-scan algorithm. Twenty axial images were reconstructed separately to obtain a slice thickness of either 1 mm (reconstruction increment of 0.5 mm) or 2 mm (reconstruction increment of 2 mm).

Image reconstruction was performed in 5% steps throughout the entire R–R interval, and 0–95% cine images were evaluated in the transverse, sagittal and coronal planes of the heart for both 1-mm and 2-mm reconstructions. Multiplanar reformats were reconstructed on a Vitrea® post-processing workstation (Vital Images, Plymouth, Minnesota, USA). Endocardial contours were semi-automatically traced using cardiac functional analysis software (VPMC-7707B, Vital Images), and the EF was calculated based on the volume of the contrast agent between the mitral valve and endocardial contours of the left ventricle throughout the entire cardiac cycle (Fig. 1). Endocardial contours could be manually corrected so that only pixels with a certain minimum HU density were recognized as part of the blood pool. The papillary muscles were considered part of the left ventricular cavity.

Transthoracic echocardiography

An experienced cardiologist blinded to the results of the cardiac MDCT acquired apical views of the left ventricle using harmonic imaging with a commercially available echocardiography machine (Vivid 7, GE-Vingmed Ultrasound AS, Horten, Norway) equipped with a 2.5-MHz phased array transducer. Left ventricular opacification was not used. EDV measurements were made at the time of mitral valve closure, and ESV measurements were made on the image with the smallest left ventricular cavity. Volumes were obtained from apical four- and two-chamber views using the biplane Simpson method, and three sets of measurements were averaged for each view. Papillary muscles and left ventricular trabeculations were included in the LV cavity. The ejection fraction was calculated as follows:

$$\frac{\text{LVEDV} - \text{LVESV}}{\text{LVEDV}}$$

Statistical analysis

SPSS software package version 11.0 (SPSS Inc., Chicago, USA) was used for statistical evaluations. Values for EDV, ESV and EF are presented as the mean ± SD. Pearson's correlation coefficient was calculated to determine whether there was a correlation either between the EDV, ESV and EF values calculated by MDCT and 2DE or between the two different slice thickness methods of MDCT. A paired *t*-test was used to evaluate the statistical significance of the differences in LV volumes and functional data as determined using MDCT and 2DE and between two different slice thickness methods of cardiac MDCT. Inter-technique agreement was evaluated using Bland-Altman analysis. A *P* value of less than 0.05 was considered significant.

Results

A total of 43 patients (23 males, 20 females) with an average age of 46.9 ± 13.9 years (range, 18–74 years) were enrolled in the study. During MDCT scanning, the average heart rate was 61.8 ± 7.1 beats/min and varied from 47 to 75 beats/min. For all patients, global left ventricular systolic function could be assessed by MDCT. On MDCT with 1-mm reconstructions, the mean EF was 66.8% ± 5.6%, the mean EDV was 133.7 ± 38.9 mL and the mean ESV was 45.1 ± 17.9 mL. The values for 2-mm reconstructions were 66.2% ± 5.6%, 133.5 ± 39.6 mL and 45.9 ± 18.3 mL, respectively. From 2DE imaging, the mean EF was 66.7% ± 5.7%, the mean EDV was 98.7 ± 42.1 mL and the mean ESV was 33.6 ± 18.7 mL.

The EDV and ESV values calculated with MDCT by both 1-mm and 2-mm reconstructions were significantly higher than those values obtained by 2DE ($P < 0.0001$ for both). There was no difference between LVEF values calculated by these two slice thicknesses and 2DE ($P = 0.83$ and 0.3705, respectively) (Table).

The EDV values calculated by 1-mm and 2-mm reconstructions were similar (133.7 ± 38.9 mL vs. 133.5 ± 39.6 mL, $P = 0.5761$). However, the ESV and EF values differed statistically between these two different slice thickness (45.1 ± 17.9 mL vs. 45.9 ± 18.3 mL, $P = 0.022$; 66.8% ± 5.6% vs. 66.2% ± 5.6%, $P = 0.0016$, respectively).

The EF values measured by the two different slice thicknesses of MDCT showed an excellent correlation (r = 0.9772; $P < 0.0001$) (Fig. 2).

Bland-Altman analysis showed good inter-technique agreement between both the 1-mm and 2-mm reconstructions generated from MDCT and 2DE images for left ventricular EF (Figs. 3 and 4).

Discussion

In this study, we found a good correlation between left ventricular volumes and EFs measured by 16-slice MDCT and 2DE. Accurate detection of left ventricular volumes and EF is fundamental for the diagnosis, prognosis and follow-up of many different forms of cardiovascular disease. Due to its particular advantages, echocardiography is the most widely used imaging technique for this purpose. It is an easily available bedside method that is also cheap, fast and noninvasive. Echocardiography enables cardiac anatomy and systolic and diastolic left ventricular functions to be evaluated without exposing the patient to radiation. There is no need for patient preparation, and it can be repeated at any time. Echocardiography has a high temporal resolution; therefore, measurements are not affected by cardiac arrhythmias. Despite these advantages, echocardiography has some handicaps such as a poor acoustic window and operator dependency. The image quality can be unfavorably affected in obese patients and patients with chronic obstructive lung disease, and quality echocardiographic views cannot be obtained in up to 10% of the patients (5, 6). Although sonographic contrast agents can be administrated to obtain better image quality, they are not widely used.

The standard technique for determining global and regional left ventricular systolic functions is cine magnetic resonance imaging (CMR). This technique does not require a contrast agent, involves no radiation and offers high temporal and spatial resolution; however, it is not widely accessible, is contraindicated in patients with metallic implants or pacemakers and is time consuming. It is also susceptible to motion artifacts. Recently developed sequences have improved temporal resolution, so CMR can be used in arrhythmic patients without ECG-triggering during one breath-hold (7, 8).

As a new method in functional cardiac imaging, MDCT seems to offer some solutions for the difficulties faced in echocardiography and CMR. First, MDCT does not necessitate a good acoustic window and is not operator dependent. Additionally, it can be safely performed in patients with metallic implants, such as pacemak-

Table. Comparison of 1-mm and 2-mm slice thickness of MDCT and 2DE for left ventricular EDV, ESV and EF

	MDCT 1-mm	MDCT 2-mm	2DE	MDCT 1-mm vs. 2DE	MDCT 2-mm vs. 2DE	MDCT 1-mm vs. 2-mm
EDV (mL)	133.7 ± 38.9	133.5 ± 39.6	98.7 ± 42.1	r = 0.9404 *P* < 0.0001	r = 0.9408 *P* < 0.0001	r = 0.9982 *P* = 0.5761
ESV (mL)	45.1 ± 17.9	45.9 ± 18.3	33.6 ± 18.7	r = 0.9033 *P* < 0.0001	r = 0.9108 *P* < 0.0001	r = 0.9938 *P* = 0.022
EF (%)	66.8 ± 5.6	66.2 ± 5.6	66.7 ± 5.7	r = 0.8049 *P* = 0.83	r = 0.7958 *P* = 0.3705	r = 0.9772 *P* = 0.0016

MDCT, multidetector computed tomography; 2DE, two-dimensional transthoracic echocardiography; EDV, end-diastolic volume; ESV, end-systolic volume; EF, ejection fraction.

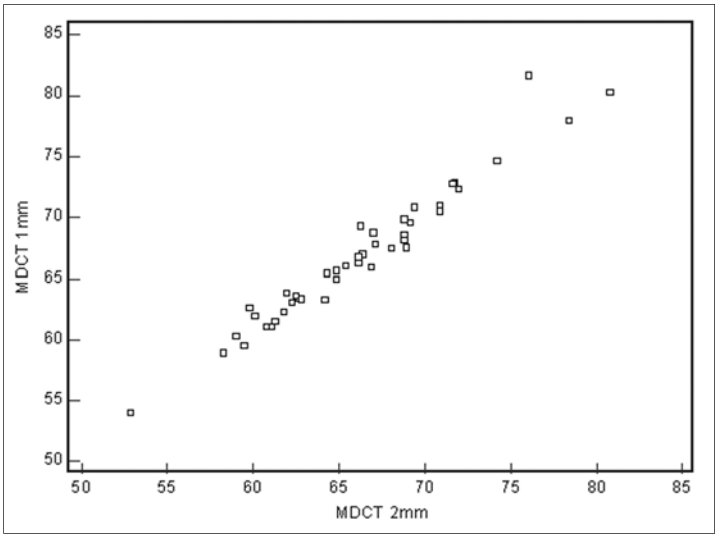

Figure 2. Correlation between left ventricular EF measured by 1-mm and 2-mm slice thickness MDCT (r = 0.9772; *P* < 0.0001; 95% confidence interval for r = 0.9580 to 0.9877).

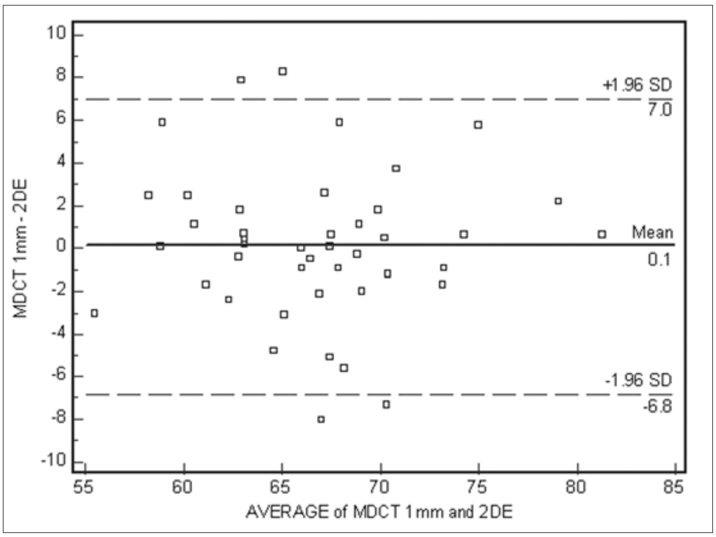

Figure 3. Bland-Altman plot for left ventricular EF measured by 1-mm slice thickness MDCT and by 2DE. The graph shows good inter-technique agreement.

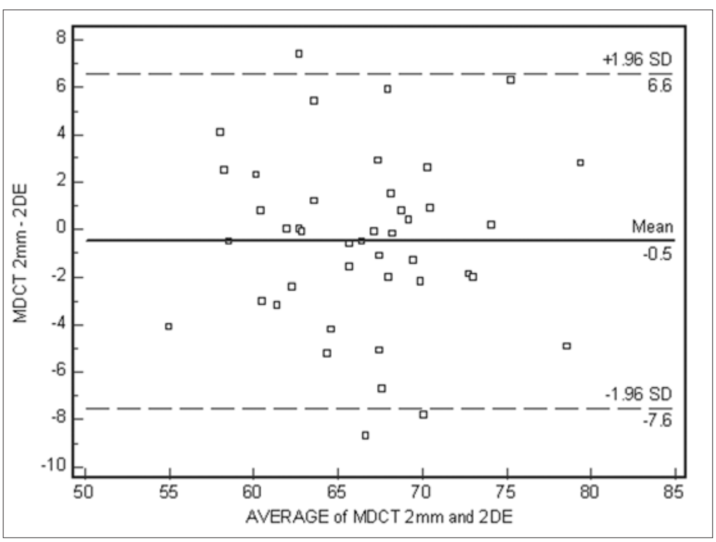

Figure 4. Bland-Altman plot for left ventricular EF measured by 2-mm slice thickness MDCT and by 2DE. The graph shows good inter-technique agreement.

ers, defibrillators and prostheses, who are inappropriate candidates for CMR. Recent studies showed good agreement between the values obtained by MDCT and the gold standard CMR. However, MDCT slightly overestimates left ventricular ESV values and underestimates left ventricular EF values compared to CMR, and these changes may be caused by the limited temporal resolution of MDCT (9–11). To capture the end-systolic phase, a temporal resolution of 20–50 ms is needed. Recent MDCT scanners have reached a temporal resolution of 82 ms (12). Future improvements in the temporal resolution of new MDCT scanners may lead to more accurate calculations of left ventricular volumes and EFs. Two- and three-dimensional echocardiography has a temporal resolution of 15–60 ms, which is enough to capture the cardiac phases (13). However, 2D-echocardiographic devices use 2D calculation methods to obtain volume values, which can underestimate the actual values. Another possible cause of inadequate measurements with echocardiography can be weak visualization of the endocardial borders, especially in patients with poor acoustic windows.

After a standard MDCT coronary angiography, functional assessments can be performed without any additional contrast material or radiation exposure via some post-processing calculation steps that can be made by semi-automatic software. Left ventricular analysis via semi-automatic software reduces the post-processing time for volumetric data for all 20 reconstruction phases within the cardiac cycle compared with manual contour drawing. Homogeneous contrast distribution and high contrast between the ventricular cavity and the myocardium are necessary for precise detection of endocardial borders with semi-automatic segmentation software.

Recent studies that compared the left ventricular systolic function values obtained by echocardiography and MDCT have demonstrated good correlations (5, 14, 15). However, left ventricular volume values calculated by MDCT were significantly higher than those obtained by echocardiography. As mentioned above, the left ventricular volume values found by MDCT were also slightly higher than the values calculated by CMR (16, 17). Similar to previous studies, we also found a good correlation between all parameters obtained by MDCT and 2DE. However, left ventricular volume values calculated by MDCT were significantly overestimated, whereas EF values showed no statistical difference. This can be caused by a systematic failure during the calculation of volumes by these two methods. As mentioned previously, echocardiography uses analytical methods based on 2D techniques, whereas MDCT and CMR use 3D calculation methods.

In this study, we also compared MDCT reconstructions based on 1-mm and 2-mm thick slices in terms of accurate depiction of left ventricular EDV, ESV and EF. We found no difference in EDV values. However, left ventricular ESV values measured by MDCT with 1-mm slice thickness were slightly smaller, and EF values measured based on a 1-mm slice thickness were slightly greater than those measured based on a 2-mm slice thickness. The analyzed data sets with 1-mm slice thicknesses had higher spatial resolutions than those with 2-mm slice thickness and may have resulted in a better capture of end-systolic frame and smaller ESV values. Although statistically significant, we do not feel that differences in ESV and EF values calculated by MDCT with 1-mm and 2-mm reconstructions are clinically relevant and worth the longer post-processing duration required by the 1-mm slices. The time required for reconstructing 2-mm slices (approximately 1,000 images) is 11 minutes, transfer of the images to the external workstation takes 4 minutes and segmentation of the endocardial contours of the left ventricle by semi-automatic software requires approximately 10 minutes, which is a total time of 25 minutes. This post-processing time is increased when 1-mm reconstructions are used because approximately 4,000 images are processed.

Our study was done with 20 phase reconstructions for the precise determination of end-systole and end-diastole, and the results of 1-mm and 2-mm reconstructions were compared. In our opinion, the results of previous studies, which were conducted via the manual drawing of endocardial contours with thick slice reconstructions (5 mm or larger) and less than 10 phases, could have been different, especially for ESV, if they had used thinner slices with semi-automatic segmentation of the left ventricle and full phase reconstructions.

Although 2DE is the most frequently applied technique in the clinical setting, the lack of the gold standard CMR measurements is a limitation of our study. Beta blockers, which are applied before the MDCT examination, may alter left ventricular systolic functions. We tried to reduce this potential negative effect on the study results by performing the MDCT and echocardiographic examinations successively on the same day.

One potential disadvantage is that 16-slice MDCT exposes the patient to 6.4 ± 1.9 mSv (18). Additionally, the requirement of the nephrotoxic and allergenic contrast medium is another disadvantage of this method. Because of these disadvantages, MDCT is generally not a first-line examination for calculating only left ventricular volumes and EF.

In conclusion, MDCT can be used to determine left ventricular EF in patients referred for coronary artery analysis. Although the differences in ESV and EF values calculated by MDCT with 1-mm and 2-mm reconstructions are statistically significant, we do not recommend routine reconstructions with 1-mm slice thickness for left ventricular volume and EF analysis because of the long post-processing time.

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