Original Article

Assessment of Regional Left Ventricular Wall Motion Abnormalities and Global Left Ventricular Function Obtained by Dual Source Computed Tomography in Patients with Coronary Artery Disease

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Abstract

Purpose：The aim of this study was to evaluate the accuracy of dual-source computed tomography（DSCT）for assessment of regional left ventricular（LV）wall motion abnormalities and global LV function, using left ventriculography（LVG）as a gold standard.
Methods：Forty-three patients（25 men；mean age, 64.4±16.9 years）with confirmed or suspected coronary artery disease（CAD）underwent cardiac DSCT and invasive LVG；DSCT and LVG were performed within 3 months of one another. In the DSCT cine mode, the regional wall motion of each segment was assigned a score from 1-4（normal=1, reduced=2, akinetic=3, dyskinetic/aneurysmal=4）based on the maximum intensity projection（MIP）in the right anterior and left anterior oblique views using a seven-segment model（cine-MIP）. We also assessed global LV function by DSCT with a semiautomatic, three-dimensional region growing algorithm. LVG was used as a gold standard to evaluate regional wall motion and global LV function. Our institutional review board approved this retrospective study.
Results：DSCT cine-MIP detected regional wall motion abnormalities on a per-patient basis with a sensitivity of 90%（17/19）, specificity of 88%（21/24）and overall agreement rate of 88%（39/43）. There was a good correlation（Cohen's kappa=0.766）between DSCT and LVG. On a per-segment basis, the overall agreement rate was 81%（243/301）. Ejection fraction obtained by DSCT showed a good correlation with that obtained by LVG（r=0.888）.
Conclusion：DSCT can be used to accurately evaluate global LV function as well as regional wall motion abnormalities in CAD patients.
（Key words：Cardiac function, Coronary artery disease, Computed tomography, Left ventricle, Wall motion）

Introduction

The presence of left ventricular（LV）dysfunction has been recognized as an important determinant of subsequent morbidity and mortality in coronary artery diseases（CAD）（1）；therefore, the accurate and reproducible assessment of LV function is essential for the diagnosis and management of CAD. Two-dimensional transthoracic echocardiography is widely used to assess global LV function and regional LV wall motion, but its accuracy is dependent on the acoustic window and examiner, and this method is limited in the assessment of motion of the apex（2, 3）. Single photon emission computed tomography is another good modality to evaluate LV function（4）, but it is expensive. In recent years, magnetic resonance imaging（MRI）, which provides excellent temporal and spatial resolution, has been regarded as the gold standard for cardiac function assessment（5）.

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However, cardiac MRI cannot be used in some cases, such as in patients with an implanted device.

Technical progress has resulted in the development of multidetector row computer tomography (MDCT) for noninvasive coronary angiography. This method has good sensitivity and specificity and has seen widespread use as a modality for the diagnosis of CAD (6-9). Cardiac CT provides other information beyond the status of the coronary arteries, and has been shown to be useful in the assessment of cardiac function (2-5, 10-24). Because of the limited temporal resolution of MDCT, beta-blockade pretreatment is needed to lower and stabilize the heart rate for cardiac imaging (13, 16, 17, 20-21, 23). However, previous studies showed that beta-blockade administration led to a significant reduction of ejection fraction (EF), suggesting that this a limitation of MDCT for physiological assessment of LV function (12, 13). Dual-source computed tomography (DSCT) has a better time resolution of <83 ms, and it can provide better physiological assessment without the need for beta-blockade (10, 11, 14, 19). Therefore, DSCT is an excellent modality to rule out CAD and to obtain information on LV function at the same time, rather than subjecting patients to invasive coronary angiography (CAG) and left ventriculography (LVG). There are some studies that compared MDCT with LVG (18, 20, 21), but only a limited number of functional studies have compared DSCT with LVG (19).

The purpose of our study was to evaluate the reliability of DSCT for assessment of regional LV wall motion abnormalities and global LV function in patients with CAD using LVG as a gold standard.

Methods

Patients

Between September 27th 2007 and June 20th 2009, we retrospectively analyzed data from 43 patients (25 men, 18 women, mean age 64 ± 17 years ; range, 42-78 years) with confirmed or suspected CAD who underwent cardiac DSCT and invasive LVG exams within 3 months. Exclusion criteria were arrhythmia, severe aortic regurgitation with hemodynamic instability, the use of prospective electrocardiogram-gated tube current modulation (ECG modulation), or percutaneous coronary intervention or coronary artery bypass graft surgery between the DSCT and LVG exams. All patients gave informed consent to undergo DSCT and LVG. Our institutional review board approved this retrospective study.

Invasive LVG

LVG was performed following coronary angiography using 30 ml contrast medium by biplane angiography with the right anterior oblique (RAO) 30° and left anterior oblique (LAO) 60°. Images were acquired using a frame rate of 30/s. The acquired data were evaluated using software (Quantcor QCA, Goodman, Nagoya, Japan) by experienced cardiologists who were blinded to the results of DSCT. After manually tracing the endocardial border, end-diastolic volume (EDV), end-systolic volume (ESV), stroke volume (SV) and EF were calculated semiautomatically. Wall motion abnormalities in LVG were analyzed visually and classified using a seven-segment model as defined by the American Heart Association classification system (1=anterobasal, 2=anterolateral, 3=apical, 4=diaphragmatic, 5=posterobasal, 6=septal, and 7=posterolateral). Wall motion in each segment was assigned a score from 1 to 4 (1=normal, 2=reduced, 3=akinetic, 4=dyskinetic/aneurysmal).

DSCT Scanning protocol

All CT examinations were performed on a DSCT system (Somatom Definition, Siemens Medical Solutions, Forchheim, Germany) with 120 kV, 370 mAs for each X-ray tube, 330 ms gantry rotation, 32 × 0.6 mm detector collimation, 64 × 0.6 mm slice acquisition, and a pitch of 0.20-0.44 adapted to the heart rate. The scanning delay was the peak time + 3 seconds, which was determined using the test bolus technique with 10 ml of contrast medium (chosen according to body weight from three variable concentrations : 300, 350, and 370 mg/ml) followed by a 20-ml saline flush. For the cardiac DSCT examination, retrospective ECG gating was used, the injection rate was 3.5-5 ml/s (*0.06-0.08 ml/kg/s*) and the volume of contrast (ml) was determined by multiplying the injection rate by the scan time plus 3 seconds. The contrast injection was followed by a 30-mL saline flush. No beta-blockade was given to any patient prior to the DSCT scan.

The DSCT axial data sets were reconstructed in 20 phases of the cardiac cycle (0-95% in 5% increments) with an effective slice thickness of 1 mm and a reconstruction increment of 1 mm (14).

Regional LV wall motion assessment

Two independent and blinded readers used Syngo Circulation software (Siemens, Forchheim, Germany) to evaluate regional LV wall motion abnormalities in the maximum intensity projection (MIP) of RAO 30° /LAO 60° using standard LVG planes in the cine mode (cine-MIP). We used a seven-segment model and a score of 1 to 4 for assessment of cine-MIP images obtained by LVG (**Figures 1, 2**).

Global LV function assessment

The axial DSCT images of the diastolic and systolic phases were indicated visually by agreement of the two readers and analyzed with a three-dimensional region growing algorithm (Syngo Circulation, Siemens) (3D algorithm), which requires manual definition of the plane of the mitral valve and the anterior interventricular junction, followed by automatic tracing of the LV endocardial and epicardial borders (**Figure 3a, b**). Furthermore, we also assessed global LV function with two-dimensional manual contour

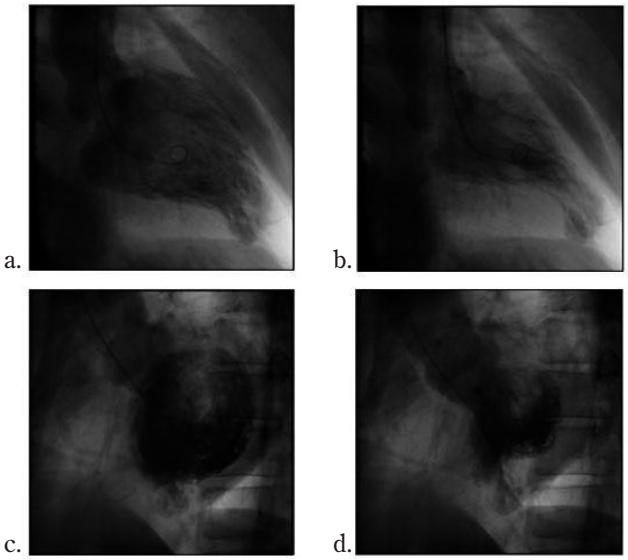

Figure 1

Images of a 64-year-old man with a regional left ventricular wall motion abnormality due to an apical aneurysm. **(a, b)** Left ventriculography images in diastole and systole in the right anterior oblique 30° view and **(c, d)** the left anterior oblique 60° view show the apical aneurysm.

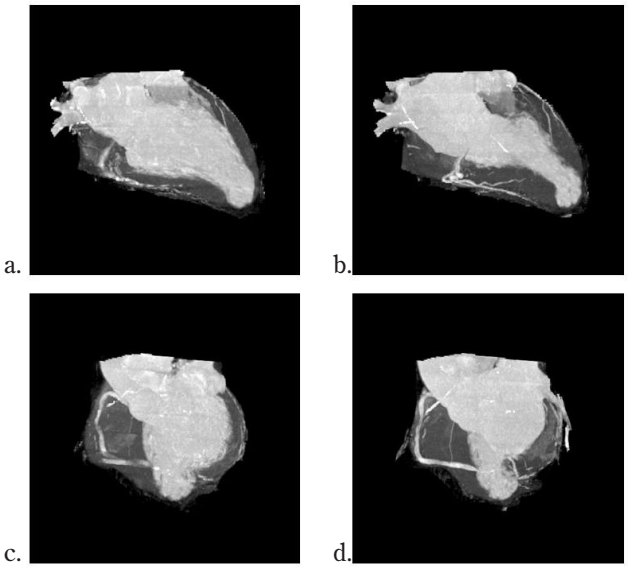

Figure 2

Images of a 64-year-old man with a regional left ventricular wall motion abnormality due to an apical aneurysm (the same case as in Figure 1). Dual-source computed tomography cine-maximum intensity projection images reproduce the apical aneurysm ; **(a, b)** images in diastole and systole in the right anterior oblique 30° view and **(c, d)** the left anterior oblique 60° view.

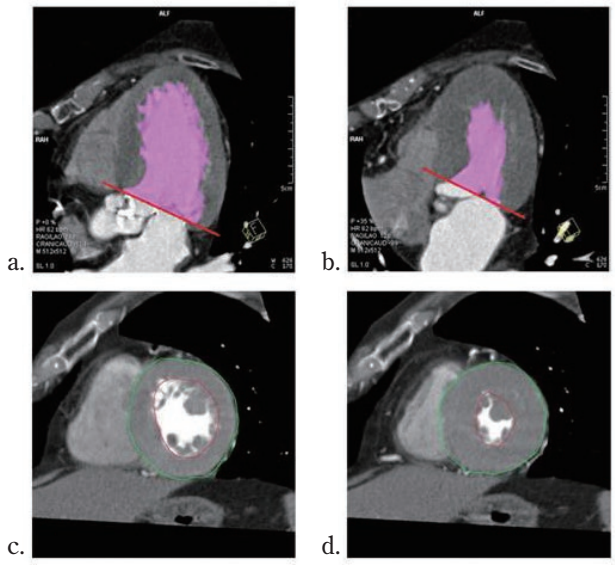

Figure 3

Images of a 74-year-old woman with normal left ventricular (LV) wall function. End-diastolic and end-systolic images obtained by Dual-source computed tomography show the area recognized as the ventricular lumen by both the 3-dimensional (3D) **(a, b)** and 2-dimensional (2D) **(c, d)** algorithms ; the LV endocardial and epicardial borders were traced automatically after definition of the plane of the mitral valve and the anterior interventricular junction in 3D algorithms **(a, b)**, endocardial and epicardial borders were traced manually, and the papillary muscles were included in the ventricular lumen in 2D algorithms **(c, d)**.

detection software (ARGUS, Siemens) (2D algorithm) using the 5-mm slice multiplanar reconstructions (MPRs) of the short axis with Simpson's method (10, 23). With the 2D algorithm, endocardial and epicardial borders were traced manually at each phase, and the papillary muscles were included in the ventricular lumen (10, 23) (**Figure 3c, d**). The parameters for evaluation were EDV, ESV, SV and EF.

Data analysis

To compare with LVG, the DSCT data from the senior reader was used for regional LV wall motion assessment. However, the mean of the DSCT values obtained from both readers were used to assess global LV function. All statistical analyses were performed using software (SPSS version 11.0, SPSS, Chicago, IL, and Excel 2007, Redmond, WA).

For regional LV wall motion abnormalities assessment, the sensitivity, specificity and overall agreement between DSCT and LVG was determined based on the analysis of all seven segments in each patient. A Cohen's kappa analysis was performed to evaluate the intermodality variabilities. In addition, the intermodality agreement rates were also expressed as percentages on a per-patient and per-segment basis.

For global LV function assessment, the correlation between DSCT and LVG was assessed by Pearson's

correlation coefficient. The paired t test was used to detect significant differences between groups for continuous variables.

Result

Patient population

The mean difference between DSCT and invasive LVG exams was 33 ± 47 days (range, 2-87 days). Six patients underwent LVG first but could not undergo CAG ; therefore, these patients had CT coronary angiography with DSCT. The mean heart rate during DSCT and LVG was 71 ± 28 bpm (range, 45-113 bpm) and 69 ± 27 bpm (range, 46-111 bpm), respectively. There was no significant difference in mean heart rate between LVG and DSCT (p=0.312). The mean radiation dose of DSCT examinations derived from the dose-length-product according to previous published calculation protocols was 21 ± 11 mSv.

Regional LV wall motion assessment

By invasive LVG, at least one myocardial segment with abnormal wall motion was found in 19 of 43 patients (44%), and 105 of 301 segments (35 %) were graded as abnormal (82 segments were classified as reduced, 17 as akinetic, and six as dyskinetic/aneurysmal).

To detect the presence of a regional LV wall motion abnormality on a per-patient basis with DSCT cine-MIP (**Table 1**), the sensitivity was 90% (17/19), the specificity was 88% (21/24) and the agreement rate was 88% (38/43). There was good correlation (Cohen's kappa=0.766) when compared with LVG.

To detect the presence of a regional wall motion abnormality on a per-segment basis with DSCT cine-MIP, the sensitivity was 71% (75/105) and the specificity was 92% (180/196). Furthermore, there was a good correlation with LVG (kappa=0.653).

Using a four-point scale on a per-segment basis, a total of 301 segments were compared using DSCT and LVG (**Table 2**) ; 81% (243/301) of the total segments evaluated by DSCT showed agreement with LVG, and there was a substantial correlation (kappa=0.6) between the two methods.

Table 1 shows that a wall motion abnormity in segment 1 (anterobasal) was the most difficult to detect, since the sensitivity to detect an abnormality in this segment with DSCT cine-MIP was only 54% (7/13). Table 2 shows there were seven segmental lesions that showed a difference of 2 points (based on the 4-point scale) compared with LVG ; four normal lesions as akinetic, one reduced lesion as dyskinetic/aneurismal, and two akinetic lesions as normal. Both underestimated lesions were in segment 4, and one overestimated lesion was in segment 5 ; these three lesions were located next to abnormal segments that also had the same incorrect point assignment. The other four overestimated lesions were in segment 3 (three lesions) and segment 5 (one lesion).

Global LV function assessment

The results of volume and global function measurements by LVG and DSCT using the 3D and 2D algorithms are summarized in Tables 3 and 4. The correlation coefficients (r) between LVG and DSCT for EDV, ESV and EF were excellent, but the EF obtained by DSCT was significantly larger than that obtained by LVG (67.6 ± 28.4% vs 63.2 ± 24.8%, P < 0.001). Between the 2D and 3D algorithms, the correlation coefficients were excellent, and there were no significant differences in EF (68.6 ± 32.7 % vs 67.6 ± 28.4 %, P=0.201).

Table 1. DSCT cine-MIP assessment of regional LV wall motion abnormalities when compared with LVG.

	Sensitivity (%)		Specificity (%)		PPV (%)		NPV (%)		Cohen's kappa	Agreement rate (%)	
Per-patient	90	17/19	88	21/24	85	17/20	91	21/23	0.766	88	38/43
On each segment											
1	54	7/13	93	28/30	78	7/9	82	28/34	0.517	81	35/43
2	71	12/17	92	24/26	86	12/14	83	24/29	0.649	84	36/43
3	75	12/16	93	25/27	86	12/14	86	25/29	0.694	86	37/43
4	63	10/16	96	26/27	91	10/11	81	26/32	0.628	84	36/43
5	83	10/12	90	28/31	77	10/13	93	28/30	0.718	88	38/43
6	75	12/16	85	23/27	75	12/16	85	23/27	0.602	81	35/43
7	80	12/15	93	26/28	86	12/14	90	26/29	0.74	88	38/43
All segments	71	75/105	92	180/196	82	75/91	86	180/210	0.653	85	255/301

Cohen's kappa analyses : 0–0.20, low agreement ; 0.21–0.40, moderate agreement ; 0.41–0.60, substantial agreement ; 0.61–0.80, good agreement ; ≥0.81, perfect agreement.

DSCT, Dual-source computed tomography ; MIP, maximum intensity projection ; LV, left ventricular ; LVG, left ventriculography ; PPV, positive predictive value ; NPV, negative predictive value.

Table 2. Agreement between DSCT cine-MIP (by Reader 1) and LVG for evaluation of regional LV wall motion abnormalities.

Dual-Source CT	LVG				
	Normal	Reduced	Akinetic	Dyskinetic/aneurysmal	Total
Normal	180	28	2	0	210
Reduced	12	49	6	0	67
Akinetic	4	4	9	1	18
Dyskinetic/aneurysmal	0	1	0	5	6
Total	196	82	17	6	301

DSCT, Dual-source computed tomography ; MIP, maximum intensity projection ; LV, left ventricular ; LVG, left ventriculography.

Table 3. Global left ventricular function parameters assessed by DSCT and LVG

	3D algorithm	LVG	r	P value
EDV (ml)	130.2±147.7	168.3±160.9	0.819	<0.001
ESV (ml)	49.5±99.4	73.8±122.2	0.907	<0.001
SV (ml)	80.7±64.5	94.5±87.8	0.398	0.041
EF (%)	67.6±28.4	63.2±24.8	0.888	<0.001

Data are expressed as the mean value ± standard deviation (SD).
A p value <0.05 was considered statistically significant.
DSCT, Dual-source computed tomography; LVG, left ventriculography; 3D algorithm, three-dimensional region growing algorithm; EDV, end-diastolic volume; ESV, end-systolic volume; SV, stroke volume; EF, ejection fraction.

Table 4. Global left ventricular function parameters assessed by DSCT using the 2D algorithm compared with LVG and the 3D algorithm.

		Compared to LVG		Compared to 3D algorithm	
	2D algorithm	r	P value	r	P value
EDV (ml)	138.7±157.3	0.822	<0.001	0.99	<0.001
ESV (ml)	53.4±157.3	0.889	<0.001	0.993	0.0022
SV (ml)	85.3±60.3	0.434	0.148	0.945	0.019
EF (%)	68.6±32.7	0.871	<0.001	0.958	0.201

Data are expressed as the mean value ± standard deviation (SD).
A p value <0.05 was considered statistically significant.
DSCT, Dual-source computed tomography; 2D algorithm, two-dimensional manual contour detection software; 3D algorithm, three-dimensional region growing algorithm; LVG, left ventriculography; EDV, end-diastolic volume; ESV, end-systolic volume; SV, stroke volume; EF, ejection fraction.

Discussion

This study showed that the high time resolution of DSCT allows assessment of LV function under usual conditions without beta-blockade. This study included high-risk patients with confirmed or suspected CAD who ultimately required invasive catheterization rather than normal risk individuals. We used cine-MIP, which is a new, easy and accurate method, to evaluate the reliability of DSCT for assessment of regional LV wall motion abnormalities when compared with LVG, which is the current gold standard for assessment of regional LV wall motion abnormalities and global LV function in the clinical setting.

While MDCT is limited by heart rate-related time resolution, DSCT has a higher time resolution of <83 ms regardless of the heart rate. The higher time resolution results from the use of two X-ray tubes, corresponding detectors in a 90° geometry, and high rotation speed of 330 ms. The use of two tubes in combination with half-scan interpolation results in a 83 ms time resolution (330 ms divided by four). DSCT can provide assessment without the need for a beta-blockade that could reduce LV function. There are many studies showing the usefulness of DSCT for the assessment of LV function, but few studies have compared DSCT with LVG (19). LVG is a traditional assessment of LV function following CAG, which is an invasive examination in CAD patients. DSCT is a good modality for the first examination of patients with suspected CAD to detect coronary artery stenosis and to assess LV wall motion abnormality and global LV function at the same time under usual conditions without beta-blockade before invasive catheterization.

Regional LV wall motion assessment

DSCT cine-MIP is similar to LVG in that they both utilize the superimposition of several LV cross-sections. Cine-MIP has not previously been described and is a novel method. The good Cohen's kappa value suggests that DSCT cine-MIP correlates well with LVG. We used 20-phase reconstruction of the cardiac cycle with DSCT, since this was reported to show more accurate wall motion than 10-phase reconstruction (14). Using 20-phase reconstruction, we could observe LV motion in detail, even in the same time resolution defined by scanning protocol, with the use of the same CT machine and heart rate of objects. But there were rough movie images in cine-MIP in the systolic phase because DSCT has smaller time resolution than LVG, which might result in difficulty in the detection of areas with 'reduced' wall motion. Three of five overestimated lesions in cine-MIP when compared with LVG were present in segment 3. This lesion is the apical region, which moves faster than other regions, possibly resulting in lower time resolution.

Compared with our study, previous studies showed better sensitivity, specificity, and intermodality correlation when MDCT or DSCT cine-MPR were compared with LVG using a seven-segment model or 17-segment model obtained from modified LA, short axis and four-chamber views (2, 4, 10, 18, 19, 25). In particular, the sensitivity to detect abnormal wall motion in segment 1 (anterobasal) was low in our study, and we speculate that the enhancement of the left ascending aorta continuing to the LV cavity may have interfered with the evaluation of the anterobasal area by DSCT cine-MIP. When compared with LVG, a dense and uniform contrast effect made the border of the ascending aorta and LV unclear in DSCT cine-MIP because of the larger amount of contrast media injected from the vein.

Three of seven incorrect graded lesions were next to true abnormal segments, which suggests that errors may have been due to abnormal adjacent segments. Because we compared LVG with DSCT, we did not use the 17-segment model based on the American Heart Association/American College of Cardiology recommendations (26). Use of a 17-segment model can improve the detection of mild wall motion abnormalities by DSCT, but a previous study reported that assignment of segments obtained by DSCT in the short axis view to an LVG model was also difficult (19). It is necessary to assess regional LV wall motion abnormality in detail with the short axis or four-chamber views, but immediate evaluation of wall motion abnormalities by cine-MIP would be useful in routine clinical practice to determine the next strategy, including invasive catheterization.

Global LV function assessment

For global LV function assessment, our study showed that DSCT has a good correlation with LVG, as shown in previous studies with 64-slice MDCT (18, 20). However, there were also differences between CT and LVG in the parameters in each study ; the difference in evaluating volumes may be related to calibration of CT machines or software for measurement and/or from the error of tracing the endocardial border mainly in the systolic phase, especially in the apex, which may cause a difference in EF. In previous studies, the authors suggested that insufficient time resolution of MDCT was one reason for the overestimation of LV volumes (21) ; other authors suggested that the difference might come from asynergy of apical wall motion, in which EF was particularly low (20). There were also patients with asynergy of apical wall motion in our study, and difficulty in defining the LV lumen in both the diastolic and systolic phases in these patients might account for the difference in parameters between CT and LVG. There are no other studies that compared EF obtained by DSCT and LVG. We thought that the improved time resolution of DSCT may increase the contrast between LV muscle and lumen when compared with MDCT ; however, this benefit was not sufficient to overcome the obstacle of apical asynergy.

Because manual tracing of the borders of the LV lumen

at each phase is not needed with the 3D algorithm, the 3D algorithm is easier and faster when compared with the traditional 2D algorithm. Tracing borders of LV lumen manually and excluding papillary muscles also takes time. We did not compare the time required for post-processing between the 2D and 3D algorithms, but some studies showed that the 3D algorithm took less time than the conventional 2D manual contour-drawing algorithm (22-24). We believe that the 3D algorithm is useful in clinical practice, because it is available and accurate for the evaluation of LV volumes excluding the papillary muscles.

Limitations

There are several limitations of our study. Our study was a retrospective study with a relatively small sample size. Furthermore, we did not compare DSCT with MRI, which has recently come to be regarded as the gold standard for left ventricular function analysis. In addition, we excluded patients where ECG modulation was used in DSCT, and all patients underwent a classical retrospective ECG-gated scan. This results in a higher radiation dose. In our study, the mean radiation dose of DSCT examinations was 21 ± 11 mSv. A previous study using ECG modulation limited the full tube current in the R-R interval and reduced radiation outside the window, which showed good results for the detection of LV wall motion abnormalities (2, 19). There are also several reports that some new technology, such as a new reconstruction technique and wide-area coverage MDCTs, can reduce the radiation dose and increase image quality (27-30). The use of ECG modulation and further advances in multidetector technology and higher rotation time of DSCT will reduce the radiation dose needed for LV function analysis, even in cine-MIP. At that time, cine-MIP will be a more acceptable method for assessing LV motion.

In conclusion, DSCT can accurately evaluate global LV function and regional wall motion abnormalities with cine-MIP using the same scan as that for CT coronary angiography without the need for reduction of cardiac function via beta-blockade. With further progress in reducing radiation doses and improving time resolution, DSCT will play an important role in the clinical evaluation of LV function.

Declaration of interest

The authors have no conflict of interest to declare.

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２管球 CT による冠動脈疾患患者における左室壁運動異常および定量的左室機能評価

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要　　約

２管球CT（DSCT）での局所壁運動異常と定量的左室機能評価の精度について左室造影と比較し検証した。対象は冠動脈疾患の既知あるいは疑い患者のうち，DSCTと左室造影が３カ月以内に行われた43人（男性25人，平均年齢64.4±16.9歳）。DSCTでの局所壁運動評価は最大値投影法を用い7 segment分類における４段階で行い，定量的左室機能は3Dアルゴリズムで半自動的に計測した。DSCTでの壁運動異常検出は，患者毎の検討では感度90％（17/19），特異度88％（21/24），一致率88％（39/43）で，左室造影の間に良好な相関が得られた（κ=0.766）。segment毎の検討では一致率81％（243/301）であった。左室駆出率はDSCTと左室造影とで良好な相関が得られた（r=0.888）。DSCTは冠動脈疾患患者において，定量的左室機能だけでなく局所的壁運動異常評価にも有用である。
（キーワード：心機能，冠動脈疾患，CT，左室，壁運動）

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