ORIGINAL

Accurate estimation of regional and global cardiac function in old myocardial infarction patients by multidetector-row computed tomography

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Abstract : Recently we can evaluate cardiac function by multidetector-row computed tomography (MDCT) and quantitative gated SPECT(QGS) as well as left ventriculography (LVG). We evaluated regional and global cardiac function using MDCT and QGS, compared to LVG, and also evaluated parameters *of left ventricular (LV) diastolic function using MDCT*. Regional cardiac function was evaluated using shortening fraction(SF). Global cardiac function was evaluated using ejection fraction(EF). The peak filling rate(PFR) and the ratio of time to peak filling rate to RR interval(tPFR/RR) on MDCT were measured as parameters *of LV diastolic function*. The SFs by MDCT and LVG were correlated in almost each segment, but those by QGS and LVG were not correlated in some each segment. The SFs by QGS and LVG were not correlated in the myocardial infarcted segments, but those by QGS and LVG were correlated in the non-infarcted segments. Except for patients who had wall motion abnormalities at the ventricular septum or posterolateral wall, the EFs by MDCT and LVG were correlated, but those by QGS and LVG were not correlated. MDCT was more useful in detecting regional and global cardiac function compared to QGS, and parameters of LV diastolic function could be also measured by MDCT. J. Med. Invest. 54 : 72-82, February, 2007

Keywords : *multidetector-row computed tomography, myocardial infarction, cardiac function*

INTRODUCTION

The clinical application of multidetector-row computed tomography (MDCT) with a multi-row helical CT detector has quickly facilitated high-quality tomographic and three-dimensional scanning. Recent studies have reported its usefulness in the evaluation of coronary stenosis and plaques (1-3). Using the same MDCT data, left ventricular (LV) volumes such as end-diastolic(ED) and end-systolic(ES) volumes and ejection fraction(EF) can potentially be assessed. In addition, a time-volume curve is prepared based on serial changes in the LV volume, and parameters of LV diastolic function can be evaluated in the diastolic phase. In the other hand, left ventriculography (LVG) and quantitative gated SPECT (QGS) has been employed previously as a parameter of LV cardiac function. However, 30-degree right anterior

Received for publication November 24, 2006 ; accepted December 20, 2006.

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oblique (RAO) images from LVG, which are used in clinical practice, may not reflect wall motion abnormalities at the ventricular septum or posterolateral wall, and when the infarcted area with no radionuclide uptake is extensive, cardiac function cannot be accurately measured by QGS.

In the present study, we evaluated regional and global cardiac function using 16-row MDCT and QGS, and compared these procedures with LVG. In addition, we evaluated parameters of LV diastolic function.

PATIENTS AND METHODS

1) Patients

Fifteen consecutive patients with a history of old myocardial infarction (OMI) who had undergone MDCT, LVG, QGS and ultrasound echocardiography (UCG) were included in the study (9 men and 6 women ; mean age : 68.4 ± 8.5years). Patients with cardiac failure who could not remain in the supine position and with atrial fibrillation for whom it was difficult to perform QGS and patients who had frequent extrasystoles were excluded from the study. Written informed consent was obtained from all patients prior to enrollment in the study. The study was performed in accordance with protocols approved by the Committee on Human Rights in Research of the University of Tokushima.

The diagnosis of OMI is typically based on history, electrocardiographic (ECG) findings, UCG findings and cardiac catheterization findings. Infarction had occurred in the anteroseptal wall in 7 patients, the inferior wall in 5 patients, and the posterolateral wall in 3 patients.

2) Left ventriculography (LVG)

LVG was performed with biplane imaging using a 6 french pigtail catheter. Images were obtained in 2 projections, RAO and 60- degree left anterior oblique (LAO). Meglumine diatrizoate (30 to 40 ml) was infused as a contrast at a rate of 12 ml/sec. Images were recorded on 35-mm cine film at 30 frames per second.

LVES and LVED endocardial contours from LVG were traced from normal, non-postpremature sinus beat images. Regional cardiac function was evaluated according to the center line method described by Sheehan, *et al.* (4-6). Briefly, ED and ES contours were traced from the frames of the LVG of RAO and LAO views by visual inspection. A center line was constructed by the computer midway between the ED and ES contours (Fig. 1A). One hundred equidistant chords were drawn perpendicular to the center line, extending from the ED to the ES contour. The length of each cord corresponded to the motion of the corresponding points on the LV contour. To adjust for differences in heart size, the shortening fraction (SF) at each cord was calculated using the following formula.

SF= (chord length/end-diastolic perimeter)×100(%)

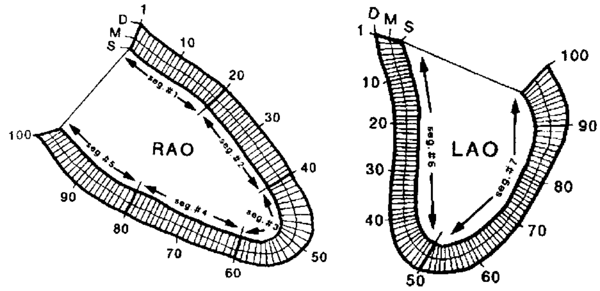

Fig. 1A Center line method of analyzing left ventricular regional cardiac function in RAO and LAO views (Sheehan, *et al.* (4-6))
RAO, 30-degree right anterior oblique ; LAO, 60- degree left anterior oblique.

3) Protocol of MDCT scan

MDCT images were obtained using an Advanced Multidetector-row CT Aquilion (Superheart edition, Toshiba, Tokyo, Japan) containing 16 rows of detectors by the ECG-gated reconstruction method. The ECG-gated unit with 40 rows × 896 detectors was operated by 16-row simultaneous sampling (16 DAS) at an X-ray tube rotation speed of 0.4 seconds/rotation, X-ray tube heat capacity of 7.5 MHU, and a slice thickness of 0.5 mm.

The subjects practiced holding their breath prior to the actual examination. They were trained to hold their breath at an inhaled position for about 30 seconds after breathing oxygen at 3 L/min using a mask and to keep the thorax and diaphragm stationary during this period without straining. During the training, changes in the heart rate during breath holding were observed, and optimal values for the scanning parameters were determined.

The subjects were screened for lesions around the heart and in the coronary artery without the use of a contrast medium, and the scanning area for the study was determined. Cardiac scanning was performed by placing a 20 guage polyethylene tube in the brachial median superficial vein and infusing 100 milliliters of a non-ionic iodine contrast medium

(300 mgI/ml) in 2 steps (step 1, 60 ml at 3.0 ml/sec ; step 2, 30 ml at 1.8 ml/sec simultaneously with 30 ml of physiological saline at 1.8 ml/sec to push the contrast medium from behind) using a 2-syringe automatic contrast medium injector.

Scanning was started by the bolous tracking technique. Using real time observation of the influx of the contrast medium into the ascending aorta, scanning was started manually and advanced from the cephalic to the caudal direction. The scanning area was from the level of the trunk of the pulmonary artery to about 1 cm caudally from the lower margin of the heart. The scanning time was about 30 seconds for all subjects. After scanning, the absence of any abnormality was confirmed in each subject, and the needle was removed.

Using imaging software (Ziosoft M900 QUADRA), ES volumes (ESV), ED volumes (EDV) and LV ejection fraction (LVEF) as systolic functional parameters were calculated and the LV time-volume curves were reconstructed from the first three Fourier harmonics (Fig. 1B), and the value of the peak filling rate (PFR) was determined by computing the first derivative of the filling curve and was expressed in units of ml/sec. The time of occurrence of the PFR was measured as the time from ES on the volume curve to the time of peak filling. Because of the wide variability in heart rate, the RR interval was averaged and the time to PFR (tPFR) was normalized for the cardiac cycle length and was expressed as the percent of the total RR interval (tPFR/RR).

4) Quantitative gated SPECT ; QGS method

A dose of 600 MBq of technetium-99m hexakis-2-methoxy-2-isobutylisonitrile (MIBI) was administered intravenously under a resting condition. Approximately one hour after the tracer injection, ECG-gated SPECT images were acquired. A three-headed rotating gamma camera (e.cam, Toshiba Medical, Tokyo, Japan) equipped with a low-energy, high resolution collimator (system resolution, FWHM : full width at half maximum 7.7mm) and a medical image processor GMS-7700 A/UI (Toshiba Co., Ltd, Tokyo, Japan) were employed for image processing. The gamma camera rotated, collecting 60 projections over 360 degrees.

The projection data were reconstructed into 64 × 64 matrix images using the filter back projection method with a Butterworth filter (order 8, cutoff 0.45 cycles/cm) and a ramp filter. For gating, 16 frames per cardiac cycle with a re-fixed RR interval and a 25% window were used. In the data analysis, the QGS program (Cedars-Sinai Medical Center, Los Angeles, CA), previously described and validated by Germano, *et al.* (7-9), was applied to process short-axis tomograms to determine ESV, EDV and LVEF.

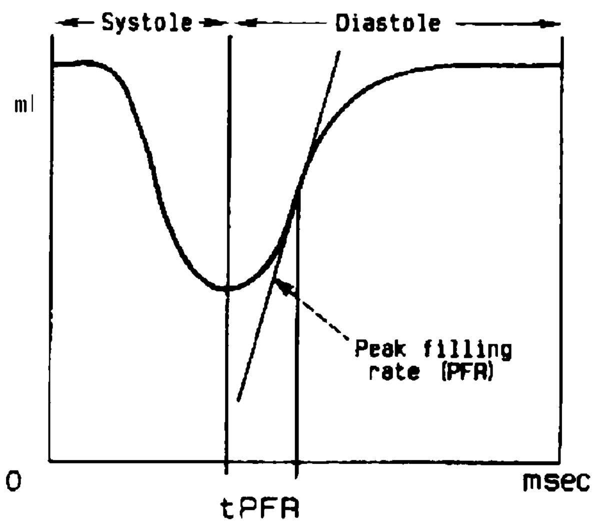

Fig. 1B Left ventricular time-volume curve reconstructed from the first three Fourier harmonics.
PFR, peak filling rate ; tPFR, the time to peak filling rate

5) Regional cardiac function

Mean values for the SFs were obtained from the RAO and LAO views from chord numbers 1 to 20, 21 to 40, 41 to 60, 61 to 80 and 81 to 100, and 1 to 50 and 51 to 100, respectively (fig. 1A). In the present study, each mean SF value was used to evaluate wall motion for segment 1 (anterobasal), segment 2 (anterolateral), segment 3 (apical), segment 4 (diaphragmatic), segment 5 (posterobasal), segment 6 (septal) and segment 7 (posterolateral) defined in the AHA classification system (10).

6) Ultrasound echocardiography (UCG)

UCG was performed on a stripchart recorder at a speed of 50 mm/s with simultaneous electrocardiogram and phonocardiogram tracings for all patients within 2 weeks of the MIBI study. There were no significant clinical events between the test and the MIBI study. A sample volume was set at the mitral valve orifice in the long-axis view of the left ventricle recorded from the cardiac apex, and transmitral flow velocity patterns were recorded using a commercially available Toshiba SSA-770A instrument (Toshiba Corporation, Tokyo, Japan ; 3.75 MHz probe) (Fig. 1C). From the pattern obtained, the peak early diastolic velocity (E) and peak atrial systolic velocity (A), and their ratio (E/A ratio) were determined as parameters of LV diastolic function (Fig. 1C).

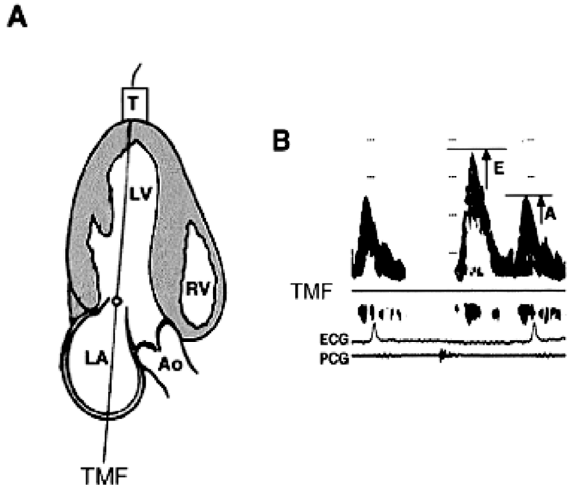

Fig. 1C Pulsed Doppler echocardiographic recording of TMF velocity from the apical long axis view of LV (A). Typical TMF velocity patterns are shown (B).
TMF, transmitral flow ; LV, left ventricle ; LA, left atrium ; Ao, ascending aorta ; RV, right ventricle ; T, transducer ; E, peak early diastolic TMF velocity ; A, peak atrial systolic TMF velocity ; ECG, electrocardiogram ; PCG, phonocardiogram.

7) Statistical analyses

Statistical analyses were performed using Stat View 5.0 (SAS Institute Inc., USA). Data were expressed as the mean ± standard error of the mean (SEM). Correlations between the cardiac parameters by the procedures were examined by simple regression analysis. A value of $p<0.05$ was considered statistically significant.

RESULTS

1) Regional cardiac function determined by LVG and MDCT using SF

The comparison between SFs for each myocardial segment (segment 1-7), determined by LVG and MDCT using a regression analysis, is shown in Fig. 2. There were significant correlations between the two methods except for the segment 1.

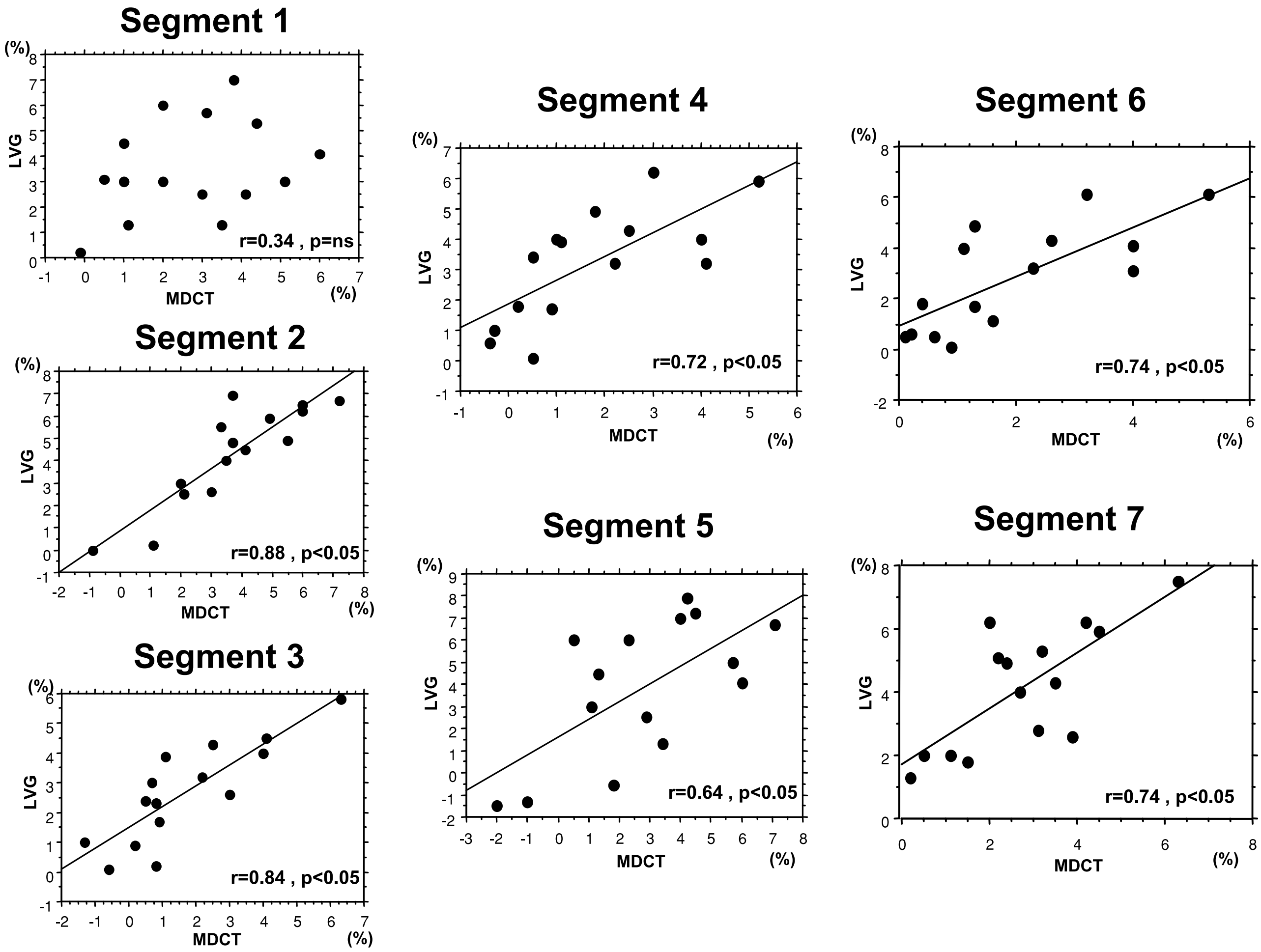

Fig. 2 Comparison of SFs determined by LVG and MDCT using regression analysis.
SF, shortening fraction ; LVG, left ventriculography ; MDCT, multidetector-row computed tomography.

2) Regional cardiac function determined by LVG and QGS using SF

The comparison between SFs for each myocardial segment (segment 1-7), determined by LVG and QGS using a regression analysis, is shown in Fig. 3. There were significant correlations between the two methods except for the segment 2, 3 and 6.

3) Regional cardiac function for infarcted segments and non-infarcted segments determined by LVG and QGS using SF

All segments were divided into myocardial infarcted segments and non-infarcted segments. The SFs calculated by QGS were compared to those by LVG. No significant correlation was found in the infarcted segments in Fig. 4A. In the other hand, a significant correlation was found in the non-infarcted segments in Fig. 4B.

4) Representative anterior OMI case

Fig. 5 shows LVG, MDCT and QGS images for a 65-year-old male with a myocardial infarction involving the anterior wall. Fig. 5A , 5C and 5E show ED images of the left ventricle and Fig. 5B, 5D and 5F show ES images. In this patient, Compared to LVG, the SFs for the infarcted segments 2 and 3 on MDCT were measured as well, but the SFs for the same segments on QGS were not measured accurately.

5) Global cardiac function determined by LVG, MDCT and QGS using LVEF

The LVEFs calculated by MDCT were compared to those calculated by LVG. No significant correlation was found between the two methods in determining LVEF for all patients, but there was a significant correlation except for patients who had wall motion abnormalities of segments 6 or 7 in Fig. 6A. In the other hand, the LVEFs calculated by QGS were

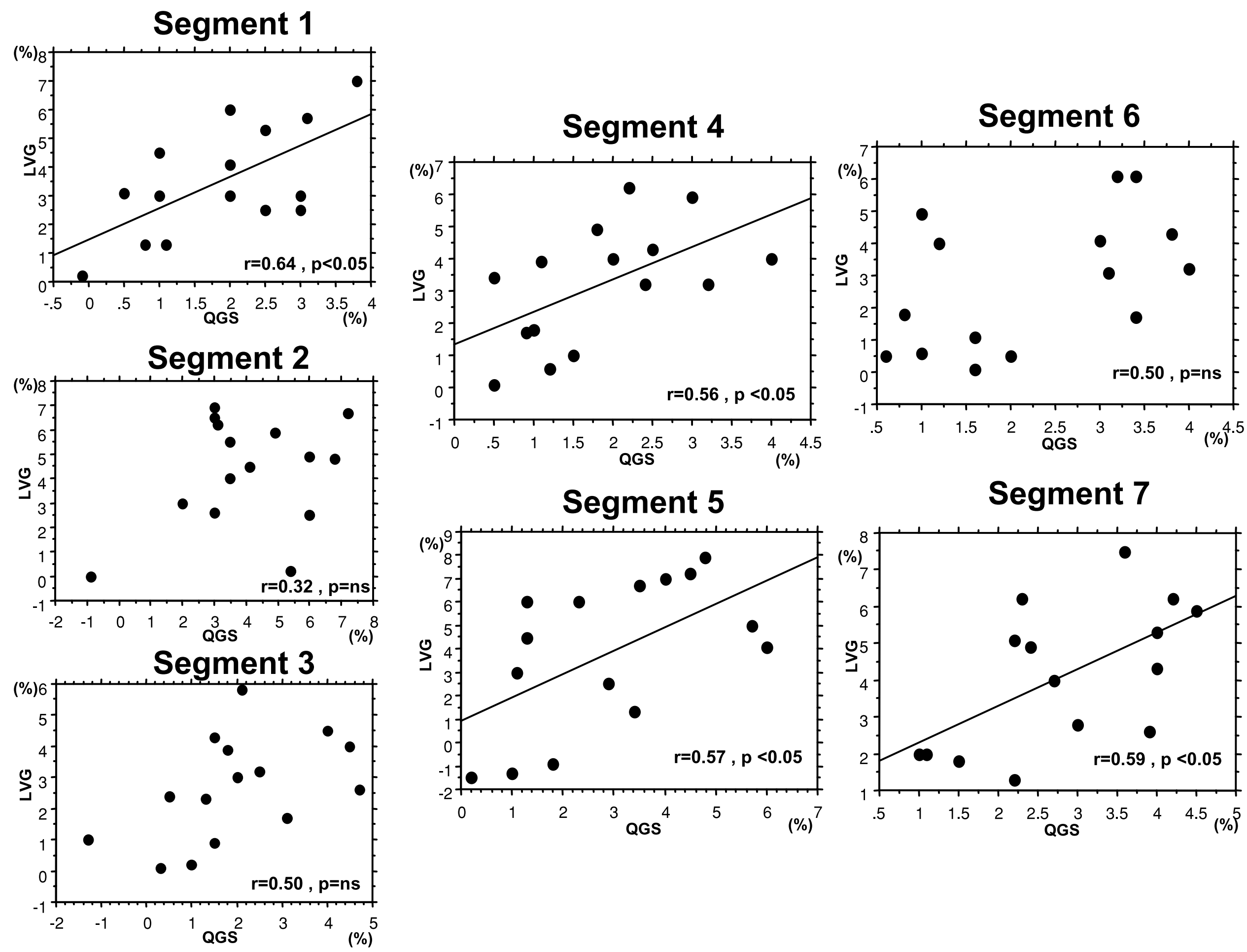

Fig. 3 Comparison of SFs determined by LVG and QGS using regression analysis.
SF, shortening fraction ; LVG, left ventriculography ; QGS, quantitative gated SPECT.

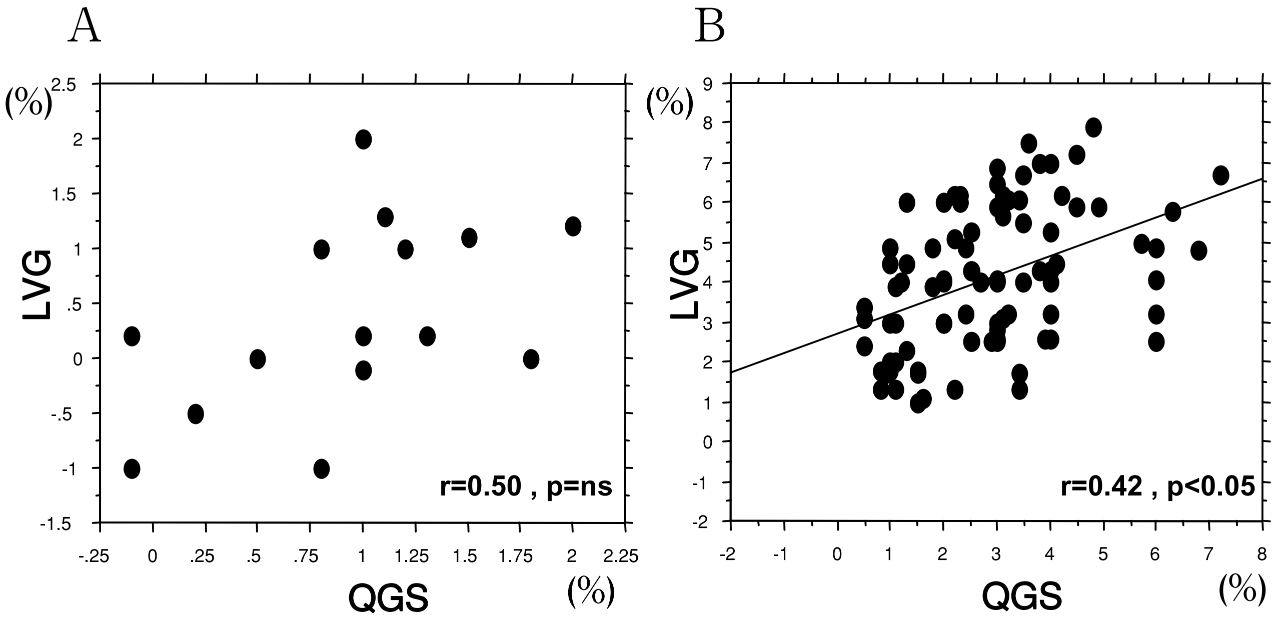

Fig. 4 Comparison between SFs for infarcted segments (A) and non-infarcted segments (B) determined by LVG and QGS using regression analysis.
SF, shortening fraction ; LVG, left ventriculography ; QGS, quantitative gated SPECT.

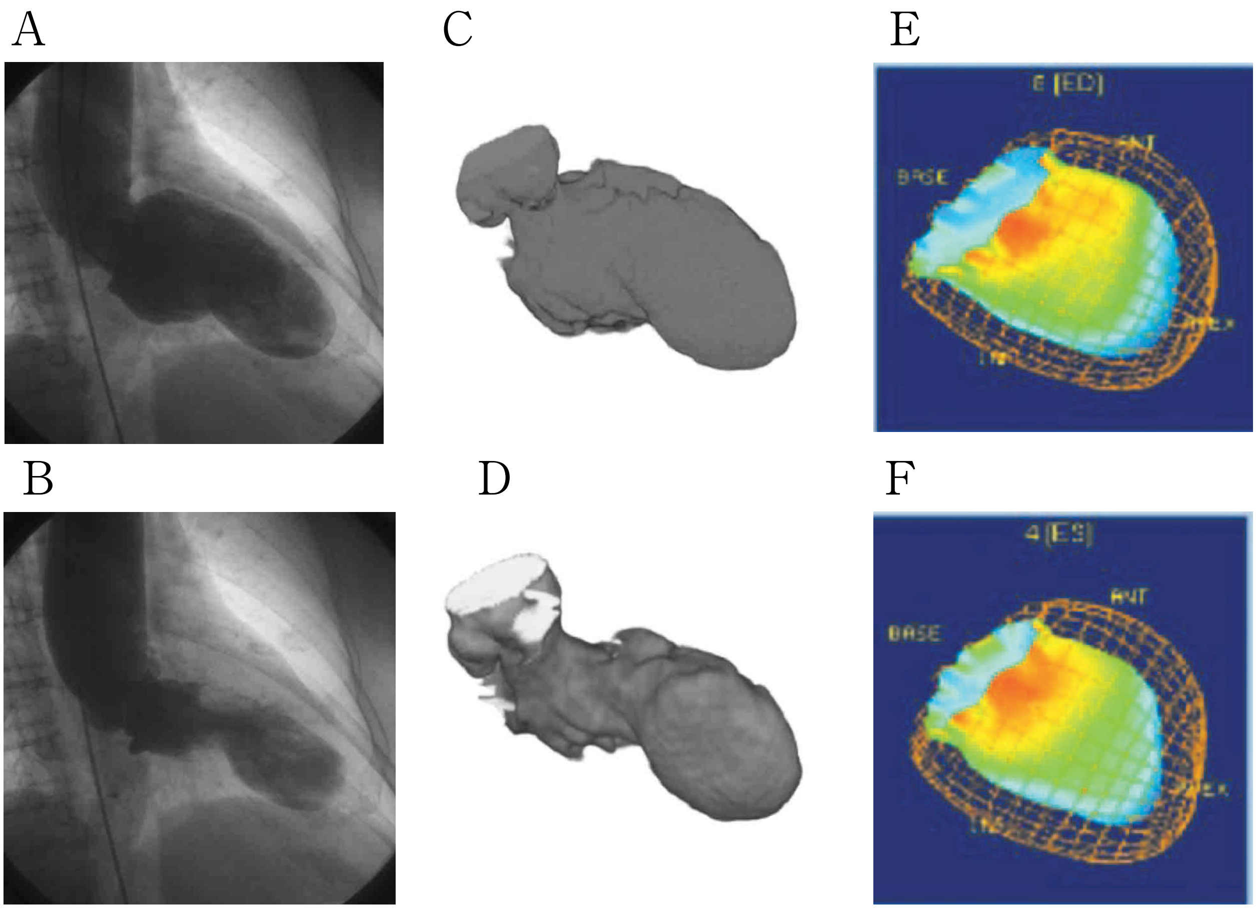

Fig. 5 Left ventricular images in the RAO view, of a 65-year-old patient with a history of anterior myocardial infarction based on LVG (A : end-diastolic, B : end-systolic), MDCT (C : end-diastolic, D : end-systolic) and QGS (E : end-diastolic, F : end-systolic).
RAO, 30-degree right anterior oblique ; LVG, left ventriculography ; MDCT, multidetector-row computed tomography ; QGS, quantitative gated SPECT.

compared to those calculated by LVG, but no significant correlation was found between the two methods regardless of the infarcted segments in Fig. 6B.

6) Representative lateral OMI case

Fig. 7A and 7B show RAO and LAO views on LVG, respectively, for a 60-year-old male with a myocardial infarction involving the lateral wall. In the LAO view, the wall motion at segment 7 was akinesis. However, in the RAO view, there were no wall motion abnormalities, and the LVEF value was 60%, within the normal range.

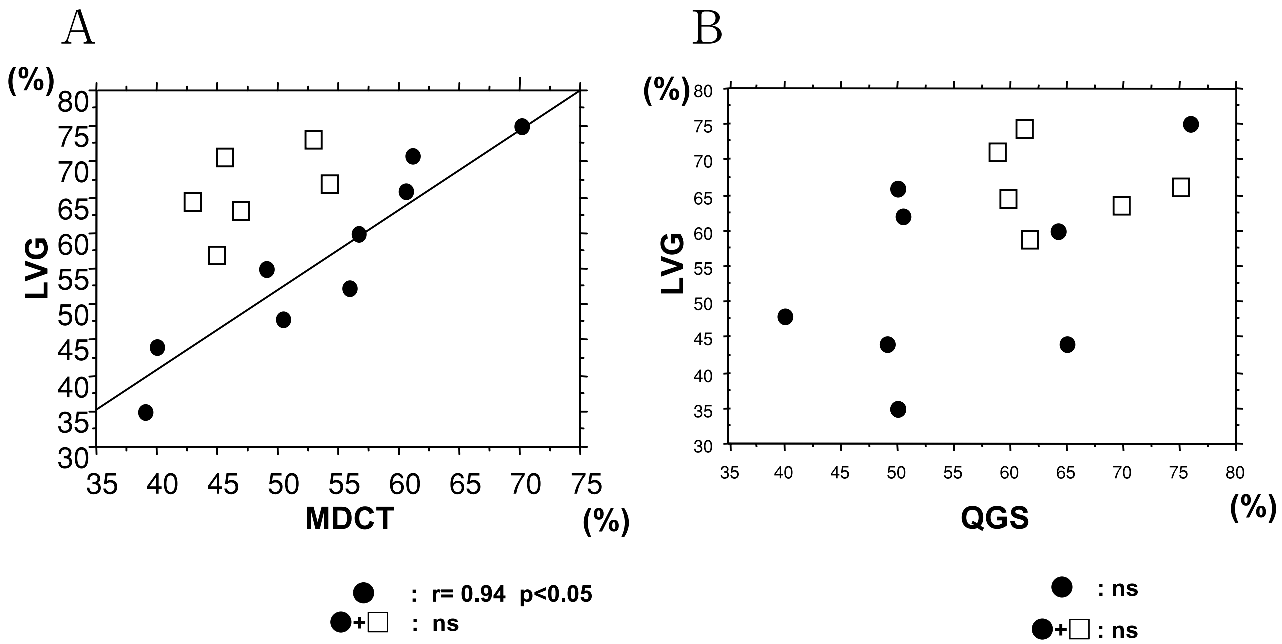

Fig. 6 Comparison between LVEFs determined by LVG and MDCT (A) and by LVG and QGS (B) using regression analysis.
□ : patients who had wall motion abnormalities of segment 6 or 7.
LVEF, left ventricular ejection fraction ; LVG, left ventriculography ; MDCT, multidetector-row computed tomography ; QGS, quantitative gated SPECT.

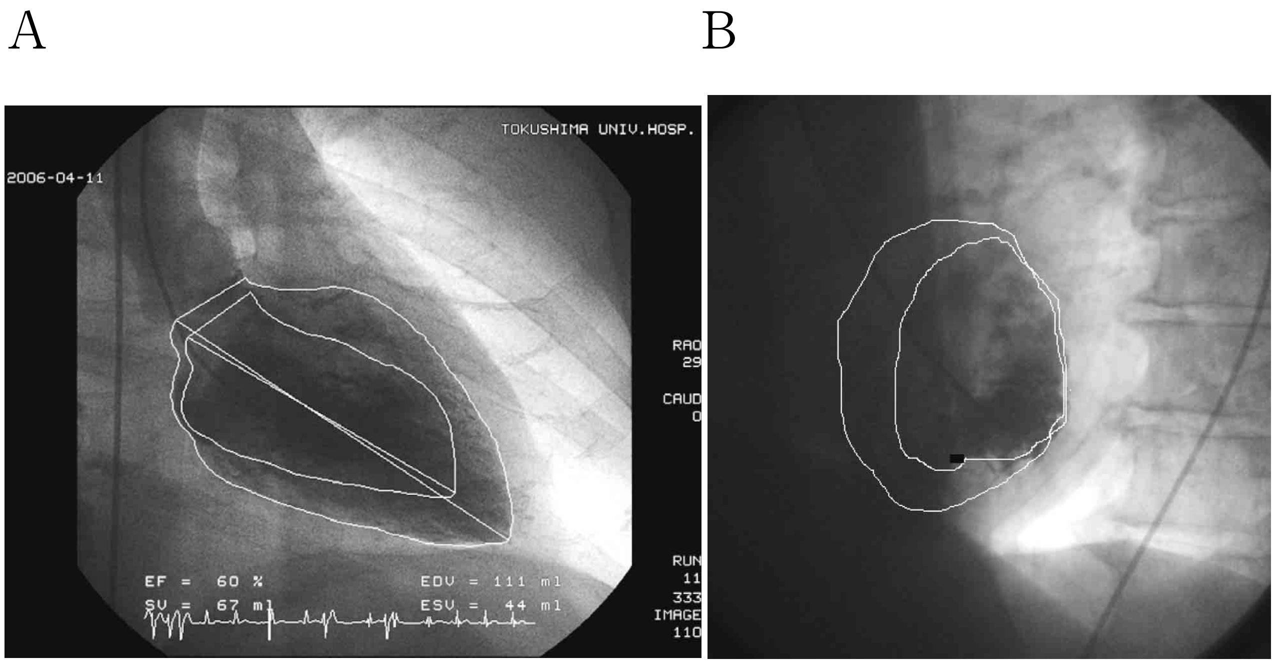

Fig. 7 LVG images of a 60-year-old patient with a history of lateral myocardial infarction in the RAO (A) and LAO (B) view.
LVG, left ventriculography ; RAO, 30-degree right anterior oblique ; LAO, 60- degree left anterior oblique.

7) Parameters of LV diastolic function determined by MDCT and UCG

Fig. 8A and 8B show transmitral flow velocity patterns on UCG and a time-volume curve per heart cycle calculated on MDCT for a 73-year-old male with a myocardial infarction involving the anterior wall, respectively. In this patient, the E wave was 43 cm/sec, the A wave was 71 cm/sec, and the E/A ratio was 0.61. In the time-volume curve calculated on MDCT, the PFR and tPFR/RR values were 169.2 ml/sec and 29.5%, respectively.

Fig. 9 shows the correlation between Doppler E/A ratio on UCG and PFR and tPFR/RR on MDCT. The E/A ratio on UCG was positively correlated with the PFR, and was negatively correlated with the tPFR/RR.

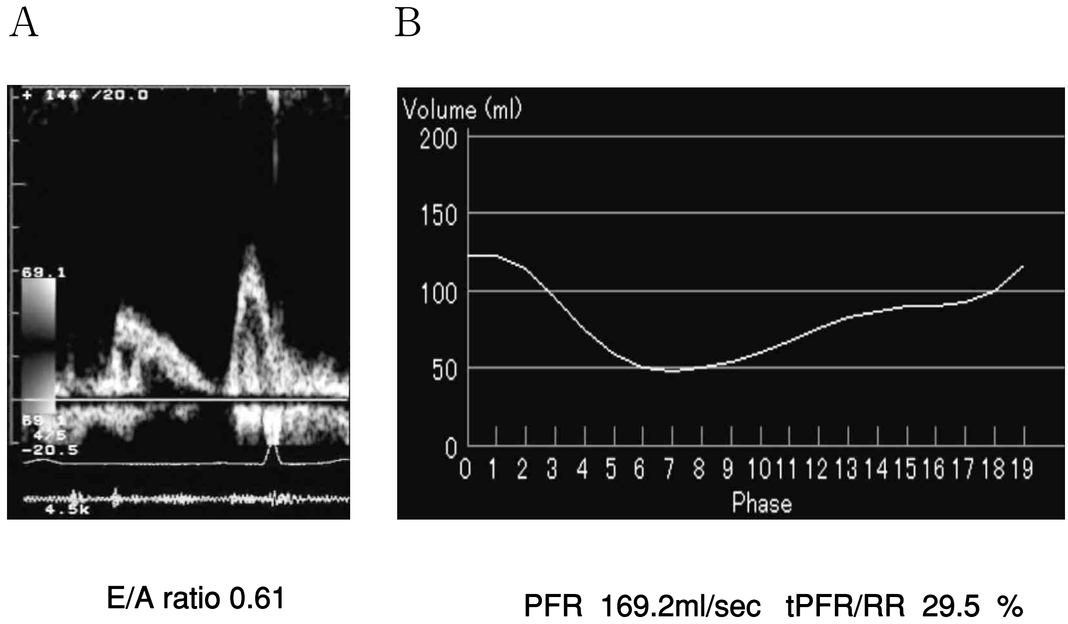

Fig. 8 Doppler E/A ratio determined by UCG (A) and the left ventricular time-volume curve determined by MDCT (B).
E/A ratio, the ratio of the peak E wave (early diastolic inflow wave) velocity to the peak A wave (atrial systolic wave) velocity ; UCG, ultrasound echocardiography ; MDCT, multidetector-row computed tomography.

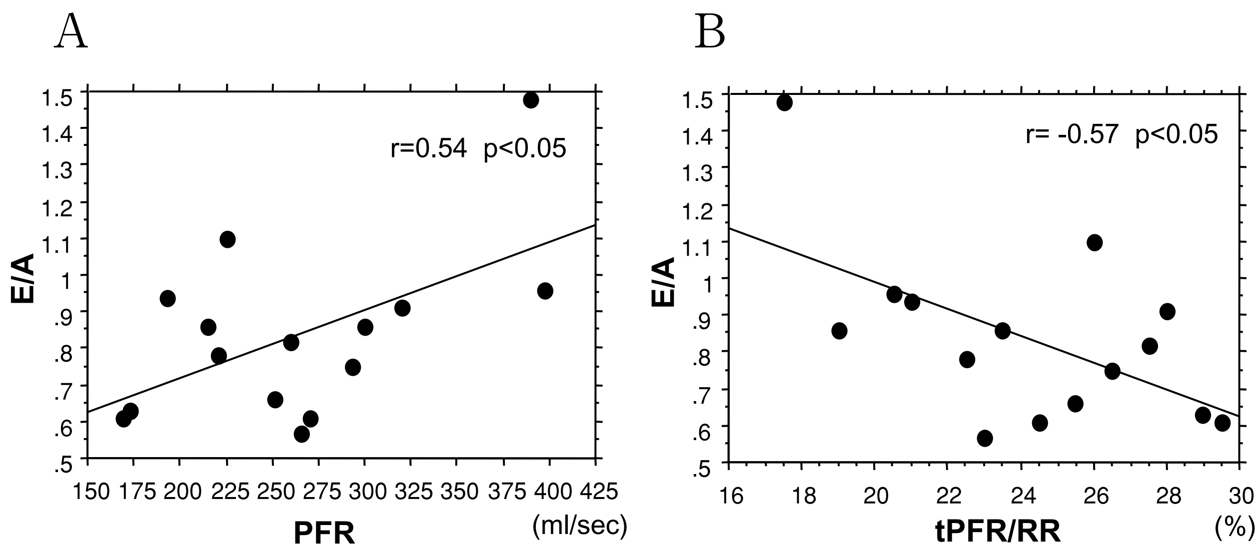

Fig. 9 Comparison of E/A ratio determined by UCG and PFR (A) and tPFR/RR (B) determined by MDCT using regression analysis. E/A, the ratio of the peak E wave (early diastolic inflow wave) velocity to peak A wave (atrial systolic wave) velocity ; UCG, ultrasound echocardiography ; PFR, peak filling rate ; tPFR/RR, ratio of time to peak filling rate to RR interval ; MDCT, multidetector-row computed tomography.

DISCUSSION

The current noninvasive cardiac examinations include UCG, QGS, and MRI, and are routinely employed, considering their characteristics (11-14). LVG and UCG are routinely employed in clinical practice to evaluate LV cardiac function, and recently we can also evaluate cardiac function by MDCT and QGS. In the present study, in OMI patients we evaluated regional and global cardiac function using MDCT and QGS, compared to LVG, and also evaluated parameter *of LV diastolic function using MDCT, compared to UCG.*

1) Assessment of regional cardiac function by MDCT and QGS, compared to LVG

In 2002, a 16-row detector type MDCT was introduced, providing 0.5 mm thick slices and facilitating the accurate evaluation of the coronary artery. In this procedure, ED and ES images can be obtained as three-dimensional volume data in addition to the evaluation of the coronary artery. Therefore, diastolic and systolic ventricular volumes, LVEF, and myocardial volume can be measured. Based on the images obtained, wall motion and contractility can be serially animated (15).

The automatic visualization of the endocardial and epicardial surfaces using QGS method has recently facilitated the evaluation of heart beat-related volume changes (16). However, in patients with a marked decrease in blood flow at the segment of the myocardial infarction in whom there is no radionuclide uptake, indicating a defect, automated edge detection with an asymmetric Gaussian fitting of radial count profiles and midpoint of tracer accumulation in the myocardial tissue and mathematical calculations are employed. However, when the infarction area with complete defect is extensive, cardiac function cannot be accurately measured.

In the present study, there were significant correlations between LVG and MDCT for the almost segments, but there were not significant correlations between LVG and QGS for the segment 2,3 and 6. And between LVG and QGS, no significant correlation was found in the only infarcted segments, but except for the infarcted segments, a significant correlation was found. This is possibly because a decrease in blood flow at the segment of the myocardial infarction made it impossible to evaluate reduced radionuclide uptake and ventricular wall that could not be visualized as a defect, and because regional cardiac function at the infarcted segment was overestimated on QGS.

Assessment of global cardiac function by MDCT and QGS, compared to LVG

LVG has been employed previously as a parameter of LV contractility. However, RAO images, which are used in clinical practice, may not reflect wall motion abnormalities at the ventricular septum or posterolateral wall and LVEF on LVG is overestimated in patients with an infarction involving the ventricular septum or posterolateral wall. In the present study, except for the patient with wall motion abnormalities at the ventricular septum or posterolateral wall, there was a significant correlation between LVG and MDCT, but there was not a significant correlation between LVG and QGS. And for all patients there were not significant correlations. This results suggests that LVEF can not be evaluated accurately for the patient with wall motion abnormalities at the ventricular septum or posterolateral wall, and MDCT is more useful in assessment of global cardiac function than QGS.

2) Assessment of parameter of LV diastolic function by MDCT, compared to UCG

As a parameter of LV diastolic function, the E/A ratio, obtained from LV inflow velocity waveforms on UCG, is commonly used (17-18). Pressure differences between the left atrium and the left ventricle are reduced with deterioration of the LV compliance disorder, decreasing the E wave and E/A ratio. However, when the LVED pressure increases, pseudo-normalization, with an increase in E/A ratio is observed. Unless pulmonary venous blood flow waveforms are investigated, it is sometimes impossible to evaluate the presence or absence of a dilatation disorder. In the present study, we did not examine any heart failure patient with an increase in LVED pressure. However, even in heart failure patients, LV diastolic function may be quantitatively evaluated from a LV time-volume curve.

In the evaluation of diastolic function (19-24), the rate of LV relaxation and the time of occurrence of the PFR are considered to be important and thus PFR and tPFR are used as a conventional standard for diastolic functional parameters. Normalization of the tPFR to the RR interval has been suggested as a means of accounting for variable heart rates in different patient populations (20).

In the present study, as parameters of LV diastolic function, we employed PFR and tPFR/RR, obtained by correcting the interval from the ES phase until PFR was obtained with the RR interval, based on the LV time-volume curve obtained on MDCT and its differential curve. The two parameters were correlated with the E/A ratio, suggesting the utility of MDCT in the assessment of parameters of LV diastolic function.

4) The merits of cardiac diagnosis with MDCT

Cardiac diagnosis with MDCT has the following merits in comparison with LVG, QGS, and UCG : the procedure facilitates the evaluation of the coronary artery, is less invasive, and provides three-dimensional information and high-reproducibility images. In this study, we did not measure the amount of radiation and contrast media and the procedure time, and these parameters should be compared between procedures in the future.

In conclusion, the results of the present study suggest that in OMI patients, MDCT was more useful in detecting regional and global cardiac function compared to QGS, and parameters of LV diastolic function could be measured by MDCT.

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