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Assessment of Myocardial Viability in Reperfused Acute Myocardial Infarction Using 16-Slice Computed Tomography in Comparison to Magnetic Resonance Imaging

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OBJECTIVES The aim of this study was to examine if contrast-enhanced multislice spiral computed tomography (MSCT) is comparable to contrast-enhanced magnetic resonance imaging (MRI) for depiction of acute myocardial infarction (MI).

BACKGROUND Delayed-enhancement MRI of MI is well established, but there are no clinical reports about MSCT for this indication. Early perfusion deficit on MSCT has been reported to correlate with the presence of MI.

METHODS A total of 28 consecutive patients (23 men; 55.9 ± 11.4 years) with reperfused MI underwent contrast-enhanced cardiac 16-slice MSCT. Images were acquired in the arterial phase and the late phase 15 min after administration of 120 ml contrast material. Within 5 days, patients underwent MRI after administration of 0.2 mmol Gd-dimeglumine/kg/bodyweight. All examinations were completed within two weeks after MI. The area of MI was compared between the different imaging techniques using Bland-Altman method and multivariate analysis. Agreement of the contrast enhancement patterns was evaluated with a weighted kappa test.

RESULTS Mean infarct size on MRI was 31.2 ± 22.5% per slice compared with 33.3 ± 23.8% per slice for late-enhancement MSCT and 24.5 ± 18.3% per slice for early-perfusion-deficit MSCT. Bland-Altman data showed a good agreement between late-enhancement MRI and late-enhancement MSCT. Contrast enhancement patterns demonstrated an excellent agreement between late-enhancement MRI and late-enhancement MSCT (kappa = 0.878). The results were worse comparing MRI and early-phase MSCT (kappa = 0.635).

CONCLUSIONS Multislice spiral computed tomography allows for the assessment of acute MI. Late-enhancement MSCT appears to be as reliable as delayed contrast-enhanced MRI in assessing infarct size and myocardial viability in acute MI. (J Am Coll Cardiol 2005;45:2042–7)
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Magnetic resonance imaging (MRI) is well established for the assessment of myocardial viability. Magnetic resonance imaging of delayed myocardial enhancement using extracellular contrast agents shows an excellent correlation with the extent of acute and chronic myocardial infarction (MI), allowing prediction of functional recovery (1–3). Although this technique is widely accepted in clinical routine, contraindications for MRI, as well as its limited availability, have to be considered.

Delayed-enhancement MRI is ascribed to the increased concentration of gadolinium chelates in the infarcted area. This is explained by the exclusion of contrast material from intracellular space of living myocytes with intact sarcomere membranes and the resulting increased extracellular space in infarcted regions (4). Contrast agents used for computed tomography (CT) have similar pharmacokinetics (5). Consequently, we hypothesized that cardiac multislice spiral computed tomography (MSCT) should be capable of depicting MI in a way similar to MRI.

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The potential of late-enhanced CT for visualization of MI was shown as early as 1978, but with single-slice CT scanners this technique was not valued as a clinical tool (6,7). An alternative technique proved early perfusion deficit on CT to be related to the presence of MI (8–10). The aim of our study was to evaluate cardiac MSCT for the assessment of acute MI using early perfusion deficit and myocardial late enhancement in comparison to MRI.

METHODS

Patients. Twenty-eight consecutive patients (23 men) with reperfused acute MI were included in this prospective study (Table 1). Inclusion criteria were acute ST-segment elevation MI, elevated creatine kinase levels, revascularization of the infarct-related coronary arteries, sinus rhythm, normal renal and thyroid function, and no history of MI. For revascularization, stent placement was performed in all patients immediately after admission to the hospital (left anterior descending, n = 12; left circumflex artery, n = 3; right coronary artery, n = 13). After approval from the local ethics committee, informed consent was obtained from all

Abbreviations and Acronyms

CT = computed tomography
ECG = electrocardiogram
HU = Hounsfield unit
MI = myocardial infarction
MRI = magnetic resonance imaging
MSCT = multislice spiral computed tomography

patients. All patients underwent cardiac MSCT and MRI within two weeks after MI (median 5 days [range 1 to 10 days]).

Imaging procedures. All MRI studies were performed on a 1.5-T whole-body MR scanner (Intera, Philips Medical Systems, Best, the Netherlands) using a five-element cardiac synergy coil with the patient placed supine. Images were acquired during endexpiratory breath-hold. Fifteen minutes after intravenous injection of 0.2 mmol/kg body weight Gd-DTPA (Magnevist, Schering, Berlin, Germany), 8-mm short-axis slices were acquired with a prospectively electrocardiogram (ECG)-gated gradient echo sequence with inversion prepulse. Imaging parameters were as follows: repetition time (TR) 2 heartbeats, echo time (TE) 5.0 ms, flip angle 25°, field of view 380 × 380 mm^2, 256 × 256 matrix, in-plane resolution 1.5 mm^2. The inversion time of the pre-pulse varied according to subjective visual judgment from 275 to 300 ms in order to achieve optimal signal suppression of viable myocardium and, consequently, optimal image contrast between infarcted and viable myocardium. For further analysis, images were transferred to a workstation equipped with a dedicated cardiac software package (MassSoftware, Medis, Leiden, the Netherlands).

Retrospective ECG-gated MSCT was performed with patients in supine position using a 16-slice MSCT scanner (Sensation16, Siemens, Forchheim, Germany) during end-inspiratory breath-hold. Standardized examination protocols were used with 16 × 0.75 mm collimation, 3.4-mm table feed per rotation, and a tube rotation time of 420 ms. For visualization of the myocardium during the arterial (early) phase, 120 ml of nonionic contrast material (Ultravist370, Schering) was injected and a tube voltage of 120 kV with 550 effective mAs_{eff} was applied. Start delay was determined using the bolus tracking technique. Fifteen minutes after injection of contrast material a second retrospectively ECG-gated MSCT scan applying a tube voltage of 80 kV and an effective tube current-time product of 500 mAs_{eff} was performed. From both datasets axial images with an effective slice thickness of 1.0 mm and an increment of 0.6 mm were reconstructed at 60% of the RR interval. A field of view of 180 × 180 mm^2 with a 512 × 512 matrix and a medium smooth convolution kernel (B30f) were chosen, resulting in an in-plane resolution of 0.4 × 0.4 mm^2. From axial images, 8-mm short-axis multiplanar reformats were calculated for further analysis. Radiation dose was calculated (WinDose 2.1, Wellhöfer, Schwarzenbruck, Germany).

Table 1. Patient Characteristics

	Mean ± SD
Age (yrs)	55.9 ± 11.4
Weight (kg)	80.6 ± 15.7
Height (cm)	173.5 ± 8.4
Peak CK (U/l)	2,551.7 ± 1,303.6
Heart rate (beats/min)	66.4 ± 10.9
Ejection fraction (%)	48.0 ± 9.5
MSCT to MRI (days)	2.5 ± 2.2

CK = creatine kinase; MRI = magnetic resonance imaging; MSCT = multislice spiral computed tomography.

Magnetic resonance imaging and MSCT data were assessed by separate readers blinded to the results of the other imaging technique. Myocardial segments presenting with delayed contrast enhancement on MRI and MSCT, as well as hypoenhanced areas on early-phase MSCT, were determined using a 16-segment model of the left ventricle (11). Magnetic resonance imaging hyperenhancement was defined as a signal intensity three standard deviations above the mean of remote myocardium (4). For early- and late-phase MSCT, a mean difference of 20 Hounsfield units (HU) (greatest image noise level plus 50% tolerance) between pathologic enhancement and the mean CT value of the remote myocardium was used to differentiate infarcted from normal myocardium. Myocardial infarction was classified as nontransmural or transmural. Size of MI as percentage of left ventricular area per slice (% slice) was calculated for all images from manually drawn regions of interest. Computed tomography values of normal and infarcted myocardium were measured.

Statistical analysis. Values are given as mean ± SD. Agreement of the myocardial enhancement patterns was assessed using a weighted kappa test. The kappa statistics were weighted as follows: 0 to 0.2 low, 0.21 to 0.4 moderate, 0.41 to 0.6 good, 0.61 to 0.8 substantial, and >0.81 perfect agreement. Size of MI was compared with the Bland-Altman method. To find significant differences among the imaging techniques, a multivariate analysis with repeated measures was calculated. In case of significant differences, post-hoc Bonferroni *t* tests were calculated. To compare CT values a paired Student *t* test was used. A significance level of 5% was assumed. Thus, after alpha adjustment a p value <0.025 was considered statistically significant.

RESULTS

A total of 448 myocardial segments were assessed. Comparing delayed enhancement on MRI and MSCT, the extent of MI agreed in 415 segments (92.63%), whereas early-phase MSCT agreed in 375 segments with MRI

Table 2. Evaluation of Cardiac Segments for the Visualization of Acute Myocardial Infarction

	Late-Enhancement MSCT			
MRI	**Normal**	**Nontransmural**	**Transmural**	**Total**
Normal	325	2	1	329
Nontransmural	5	31	2	37
Transmural	1	23	58	82
Total	331	56	61	448
	Early-Perfusion-Deficit MSCT			
MRI	**Normal**	**Nontransmural**	**Transmural**	**Total**
Normal	309	16	13	339
Nontransmural	7	33	16	55
Transmural	12	10	32	54
Total	328	59	61	448
	Early-Perfusion-Deficit MSCT			
Late-enhancement MSCT	**Normal**	**Nontransmural**	**Transmural**	**Total**
Normal	310	12	17	340
Nontransmural	5	18	28	50
Transmural	11	7	40	58
Total	326	37	85	448

Abbreviations as in Table 1.

(83.70%) and in 369 segments with late-enhancement MSCT (82.36%). The corresponding kappa values were kappa = 0.878, kappa = 0.635, and kappa = 0.631, respectively (Table 2).

On MRI as well as on MSCT, 160 slices presented with delayed enhancement, whereas early perfusion deficit was found on 151 MSCT slices. Mean size of MI on MRI was 31.2 ± 22.5% per slice compared with 33.3 ± 23.8% per slice for late-enhancement MSCT and 24.5 ± 18.3% slice for MSCT with early perfusion deficit. On early-phase and late-phase MSCT, CT values of MI were significantly different from normal myocardium ($p < 0.001$). Mean CT value of normal myocardium was 100.8 ± 15.4 HU during early phase and 74.5 ± 11.0 HU on late-phase MSCT. The corresponding CT values of infarcted myocardium were 58.8 ± 17.0 HU and 108.0 ± 15.9 HU (Fig. 1). On MSCT, percent differences of the CT values between hyperenhanced and hypoenhanced versus normal myocardium were 146.0 ± 13.7% and −181.5 ± 47.8%, respectively. Magnetic resonance signal-to-noise ratios in hyperenhanced areas were 718.2 ± 169.9% of remote normal myocardium. The calculated effective radiation dose for arterial-phase MSCT was 8.21 ± 1.71 mSv (10.72 ± 2.33 mSv) for male (female) patients and 2.72 ± 0.42 mSv (3.79 ± 0.55 mSv) for late-phase MSCT.

When comparing late-enhancement MRI and MSCT, a good agreement of the MI size and location was found, with both modalities presenting late enhancement in identical coronary artery territories. Agreement between early-perfusion-deficit MSCT and delayed-contrast-enhanced MRI as well as late-enhancement MSCT was distinctly worse (Fig. 2).This is mirrored by the Bland-Altman data: comparing MRI delayed enhancement versus MSCT late

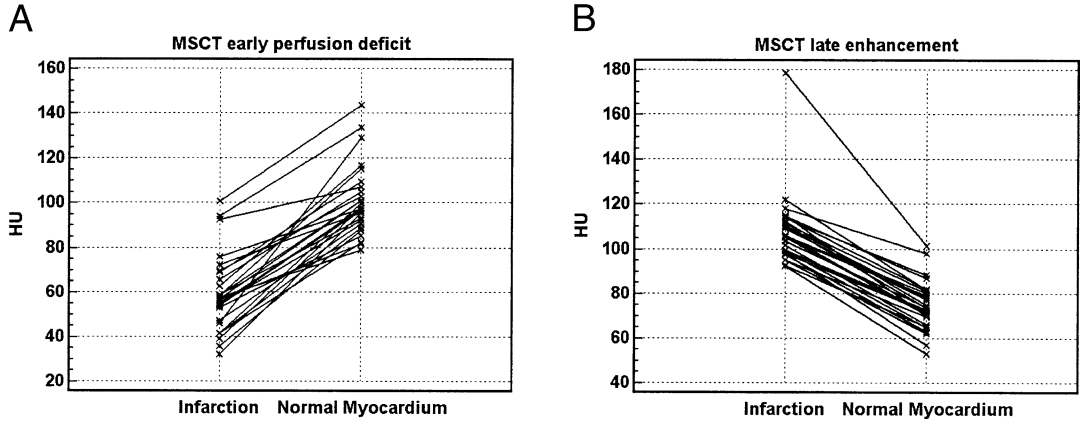

Figure 1. The dot-and-line diagrams for early-phase multislice spiral computed tomography (MSCT) **(A)** and late-enhancement MSCT **(B)** show the differences in the computerized tomography values between infarcted and normal myocardium.

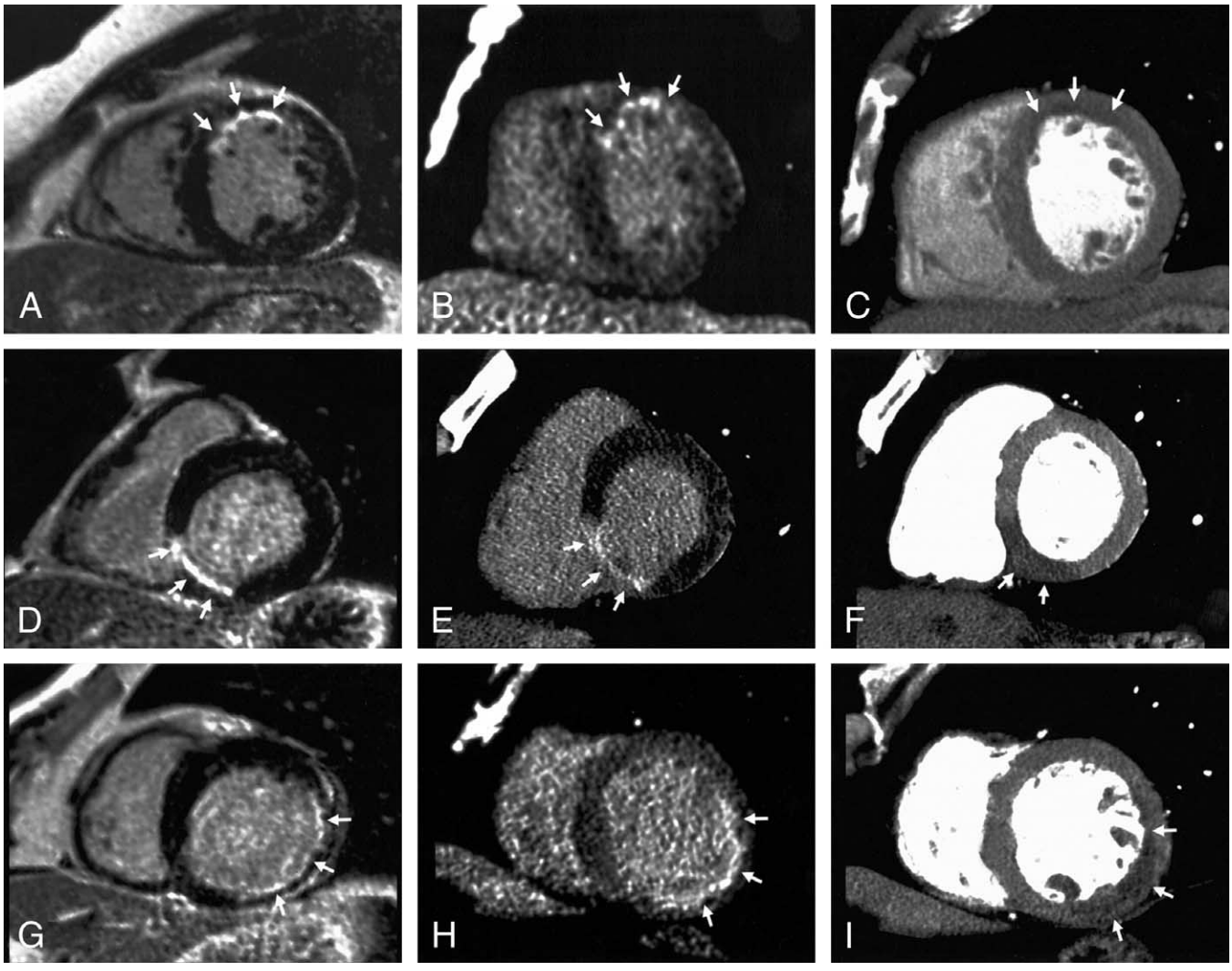

Figure 2. Short-axis view magnetic resonance imaging (MRI) **(A,D,G)** and short-axis multislice spiral computed tomography (MSCT) images **(B,C,E,F,H,I)** in three different patients with acute myocardial infarction (MI) **(arrows)** attributable to left anterior descending **(A to C)**, right coronary artery **(D to F)**, and left circumflex artery **(G to I)** occlusion after successful revascularization. There was an excellent agreement between delayed-enhancement MRI **(A,D,G)** and late-enhancement MSCT **(B,E,H)**. Agreement with arterial-phase MSCT **(C,F,I)** was slightly worse.

enhancement, the mean difference (MEAN) was −2.2% (lower [−LOA] and upper limits [+LOA] of agreement −12.1% and 7.8%). The corresponding MEANs (−/+LOA) for MRI versus MSCT early perfusion deficit were 6.4% (−27.2%/40.0%) and for delayed-enhancement MSCT versus early-perfusion MSCT deficit 8.6% (−26.3%/43.4%) (Fig. 3).

Multivariate analysis revealed significant differences between the various methods ($p = 0.001$). Post-hoc t tests showed significant differences between MI on early-phase MSCT and MRI ($p = 0.002$) as well as late-enhancement MSCT ($p = 0.004$). No significant difference was observed between delayed-contrast enhancement on MRI and late-enhancement MSCT ($p = 0.398$).

DISCUSSION

Myocardial delayed-enhancement MRI is related to irreversibly damaged myocardium (1). The differentiation of infarcted from viable myocardium is important to predict improvement in left ventricular function after coronary artery revascularization (12). So far, only SPECT, stress echocardiography, and MRI have been used clinically for the assessment of viability and risk stratification in the setting of acute MI (7). Introduction of cardiac MSCT for this indication exposes the patient to a relevant amount of radiation and potentially nephrotoxic contrast material. When compared to MRI, these limitations have to be weighted against MSCT's nearly ubiquitous availability, short examination times, and ease of application.

Using a different approach, we ascribed areas of reduced contrast enhancement during the arterial phase to acute MI (8–10). However, the reliability of this technique has not yet been proven. We assumed that because of reduced perfusion, acute MI presents with diminished contrast enhancement at the site of infarction during the

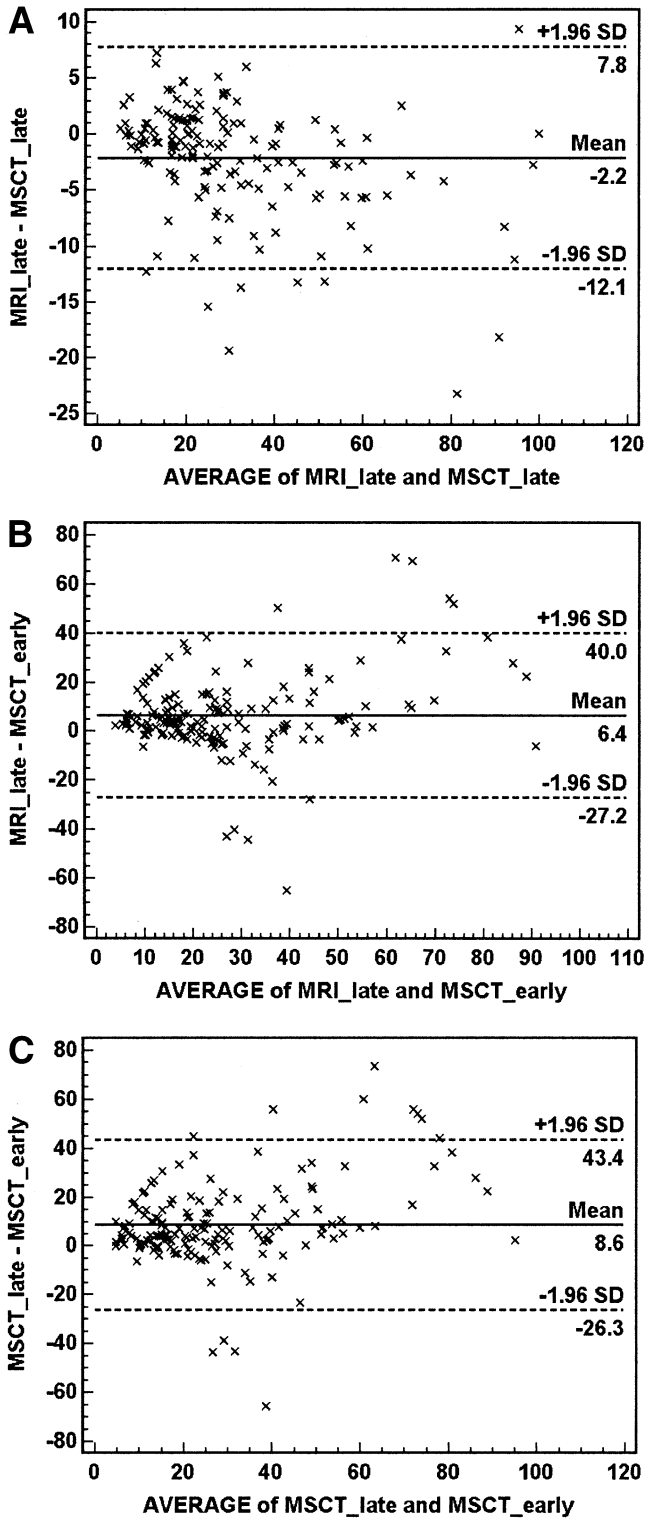

Figure 3. Bland-Altman plots comparing MI size between delayed-enhancement MRI and late-enhancement MSCT **(A)**, MRI and early-phase MSCT **(B)**, and late-enhancement MSCT and early-phase MSCT **(C)**. Abbreviations as in Figures 1 and 2.

early phase. This is likely to represent a lack of blood and contrast material flowing into the infarcted area, probably owing to microvascular damage.

Our study proved an excellent agreement of MI size for late-enhancement MSCT and MRI, whereas the agreement between early-phase MSCT and MRI was worse. Late-enhanced MSCT slightly overestimated the infarction size when compared to MRI, likely because of a distribution of the contrast material in the peri-infarction zone (13). Because of the high spatial resolution of MSCT, even subendocardial infarctions were detectable. As the study population consisted exclusively of patients with reperfused MI, early-phase contrast-enhanced MSCT significantly underestimated the size of MI.

In combination with left ventricular functional analysis (14), late-enhancement MSCT possibly offers an examination strategy comparable to delayed-enhancement and functional MRI. Nevertheless, further research, including experimental studies for optimization of imaging parameters, especially in terms of radiation exposure, is needed before late-enhancement MSCT can be recommended as a clinical tool for the assessment of myocardial viability.

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