Heterogeneous Microinfarcts Caused by Coronary Microemboli: Evaluation with Multidetector CT and MR Imaging in a Swine Model

**Purpose:** To directly compare the sensitivity of 64-section multidetector computed tomography (CT) with that of 1.5-T magnetic resonance (MR) imaging in the depiction and measurement of heterogeneous 7–8-week-old microinfarcts and the quantification of regional left ventricular (LV) function and perfusion in the territory of coronary intervention in a swine model.

**Materials and Methods:** Approval was obtained from the institutional animal committee. An x-ray/MR system was used to catheterize the left anterior descending (LAD) coronary artery with x-ray guidance and to delineate the perfusion territory. The vessel was selectively microembolized in six pigs with small-diameter embolic material (40–120 µm, 250 000 count). At 7–8 weeks after microembolization, multidetector CT and MR imaging were used to assess LV function, first-pass perfusion, and delayed contrast enhancement in remote myocardium and microinfarct scars. Histochemical staining with triphenyltetrazolium chloride (TTC) was used to confirm and quantify heterogeneous microinfarct scars. The two-tailed Wilcoxon signed rank test was used to detect differences between modalities and myocardial regions.

**Results:** The LAD territory was 32.4% ± 3.8 (standard error of the mean) of the LV mass. Multidetector CT and MR imaging have similar sensitivity in the detection of regional and global LV dysfunction and extent of microinfarct. The mean LV end-diastolic volume, end-systolic volume, and ejection fraction were 93 mL ± 8, 46 mL ± 4, and 50% ± 3, respectively, on multidetector CT images and 92 mL ± 8, 48 mL ± 5, and 48% ± 3, respectively, on MR images (P ≥ .05). The extent of heterogeneous microinfarct was not significantly different between multidetector CT (6.3% ± 0.8 of the LV mass), MR imaging (6.6% ± 0.5 of the LV mass), and TTC staining (7.0% ± 0.6 of the LV mass). First-pass multidetector CT and MR imaging demonstrated significant regional differences (P < .05) in time to peak between the heterogeneous microinfarct and remote myocardium (17.0 seconds ± 0.3 and 12.4 seconds ± 0.6, respectively, for multidetector CT and 17.2 seconds ± 0.8 and 12.3 seconds ± 1.0, respectively, for MR imaging).

**Conclusion:** Modern multidetector CT and MR imaging are sensitive modalities with which to depict heterogeneous microinfarcts and determine regional LV dysfunction and decreased perfusion in the territory of intervention.

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Percutaneous coronary intervention is commonly used to treat coronary artery disease. With the aging population in the United States and other countries, the number of these procedures has increased each year. In relatively recent studies, researchers have identified coronary microemboli as a compounding cause of regional myocardial contractile dysfunction and perfusion deficits in these patients (1–5). In fact, coronary microemboli have been documented at autopsy in patients after sudden death (4,6,7).

Noninvasive cardiac imaging is now key in the diagnosis and care of patients who are known to have or are suspected of having coronary artery disease. Myocardial viability imaging is performed with fluorine 18 fluorodeoxyglucose positron emission tomography, single photon emission computed tomography, magnetic resonance (MR) imaging, and—recently—64-section multidetector computed tomography (CT). Unlike imaging of homogeneous large infarcts, however, imaging of heterogeneous microinfarcts is challenging because of the limited spatial resolution and the fact that the microinfarcted area contains a mixture of viable and nonviable myocytes.

Microinfarcts are defined as bright heterogeneous subregions seen on delayed contrast material–enhanced MR images and pale unstained necrotic subregions seen on histochemically stained specimens (8–11). In several studies, researchers found heterogeneous microinfarcts in patients (2,5,12,13) and animals (8–11) on delayed contrast-enhanced MR images. Experimental studies have shown that a heterogeneous microinfarct exceeding 5% of the region of interest could be detected with delayed contrast-enhanced MR imaging 6–8 hours after delivery of microemboli into the left anterior descending (LAD) coronary artery territory (10,11). The differential enhancement of heterogeneous microinfarct is related to the larger distribution volume and relatively slow wash-in and wash-out of extracellular contrast media (14–16). To the best of our knowledge, however, heterogeneous microinfarcts have not been previously studied with modern multidetector CT or a combination of multidetector CT and MR imaging. The aim of this study was to directly compare the sensitivity of 64-section multidetector CT with that of 1.5-T MR imaging in the depiction and measurement of heterogeneous 7–8-week-old microinfarcts and the quantification of regional left ventricular (LV) function and perfusion in the territory of coronary intervention in a swine model.

Materials and Methods

Study Protocol and Microemboli

This study was performed between November 30, 2007, and February 18, 2008, in accordance with the Guide for the Care and Use of Laboratory Animals (17) and with approval from our institutional committee on animal research. Eight adult healthy farm pigs (mean weight, 33 kg ± 1; standard error of the mean) were anesthetized with a mixture of 2%–5% isoflurane and oxygen at a rate of 2–3 L/min, as described previously (8,9). Two animals died within 24 hours after delivery of the embolic materials. Coronary catheterization, intervention, and imaging were performed in a hybrid x-ray/MR suite that comprised an x-ray system (Integris V5000; Philips Medical Systems, Best, the Netherlands) and an MR imager (Achieva I/T, Philips Medical Systems). The LAD coronary artery was catheterized with x-ray fluoroscopy, as described previously (18). The animals were brought to the MR imager after the 3-F infusion catheter (Cook, Chicago, Ill) was placed distal to the first diagonal branch of the LAD. First-pass perfusion MR images were acquired during intraarterial injection of 10 mL of 10% diluted gadoterate meglumine (Dotarem; Guerbet, Paris, France). The method of delineation of the LAD coronary artery territory has been described recently (18). Short-axis sections covering the LV were acquired to define the perfusion territory with a saturation-recovery gradient-echo sequence (repetition time msec/echo time msec, 4.5/2.2; section thickness, 10 mm; field of view, 26 × 26 cm; matrix, 128 × 128; flip angle, 20°; acquisition time, three R-R intervals per dynamic acquisition). Thereafter, coronary microembolization was achieved with slow (60 sec) infusion of 250,000 count of 40–120-µm-diameter embolic material (Embosphere; Biosphere Medical, Rockland, Mass) through the 3-F catheter. To enable us to confirm the presence of regional ischemia, additional first-pass perfusion MR imaging was performed 1 hour after microembolization with the same perfusion sequence.

Implication for Patient Care

Multidetector CT and MR imaging may be used to detect cardiac microinfarcts in patients with a wide range of diseases—such as atherosclerosis, valvular disease, endocarditis, and arrhythmias—as well as after invasive coronary interventions.

Author contributions:

Guarantors of integrity of entire study, M.C., M.S.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; manuscript final version approval, all authors; literature research, M.C., M.S.; experimental studies, M.C., A.J.M., P.C.U., M.S.; statistical analysis, M.C., M.S.; and manuscript editing, all authors

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Experimental studies: 720

in-plane spatial resolution of 0.625 with 5-mm section thickness and approximately the same time during the R-R interval of 60 seconds to obtain images at approximately 15° flip angle; shot interval, two R-R intervals; 3-mm section thickness; no section gap; 26 × 26-cm field of view; 256 × 162 matrix). The inversion time was chosen to null normal myocardium.

**Image Analysis**

Two authors (M.S., M.C.; 21 and 9 years of experience, respectively) performed multidetector CT, MR imaging, and histochemical measurements in consensus at different times and in a random fashion. Multidetector CT and MR LV function, perfusion, and viability images were analyzed using Segment, version 1.7, software (Segment; http://segment.heiberg.se) (31,32). The method of image analysis used for multidetector CT did not differ from that used for MR. Cine images were used to measure the ejection fraction, end-diastolic volume, and end-systolic volume by delineating the endocardium in all short-axis sections at end diastole and end systole. The difference in epicardial and endocardial volumes was multiplied by 1.05 g/mL and used to determine LV mass. Systolic wall thickening was quantified in eight segments in three consecutive short-axis sections, as described previously (33). The mean wall thickening of the microinfarcted segments was calculated and compared with that of the remote segments of the same short-axis section. First-pass perfusion images were used to quantify maximum upslope, peak signal intensity, and time to peak in the LV blood pool, LAD coronary artery territory with microinfarct scar, and remote myocardium (9,25). The total extent of heterogeneous microinfarct scar was measured on delayed contrast-enhanced images by thresholding and selecting subregions with a signal intensity or attenuation three standard deviations above the signal intensity or attenuation of remote myocardium (9). The attenuation (measured in Hounsfield units) and enhancement (measured in arbitrary units [a.u.])

CT scanning was performed with a 64-section multidetector unit (LightSpeed Ultra; GE Healthcare, Princeton, NJ) and with the animals in the supine position during an end-expiratory breath hold. After scout imaging was performed to localize the heart, cine imaging, first-pass perfusion, and delayed contrast-enhanced sequences were performed. Iodinated contrast media (300 mg of iodine per milliliter, Omnipaque; GE Healthcare) followed by a 40-mL saline chaser was administered during perfusion (1 mL per kilogram of body weight) and LV function (2 mL/kg) imaging. The following sequences were performed (21–23):

- First-pass perfusion was performed with a tube voltage of 120 kV; a tube current of 100 mAs; and one full gantry rotation per heart beat, which was calculated by dividing the heart rate by 60 seconds to obtain images at approximately the same time during the R-R interval. Eight sections were acquired with 5-mm section thickness and an in-plane spatial resolution of 0.625 × 0.625 mm. The injection rate of CT contrast media was 5 mL/sec.

- Cine images were acquired to enable us to assess LV function and reconstruct every 5% of the cardiac cycle (tube voltage, 120 kV; tube current, 650 mAs; spatial resolution of reconstructed images, 0.625 × 0.625 × 0.625 mm). Delayed contrast-enhanced multidetector CT images were acquired to assess viability 3–5 minutes after the administration of contrast media for LV function (tube voltage, 120 kV; tube current, 630 mAs; spatial resolution of reconstructed images, 0.625 × 0.625 × 0.625 mm). The rationale for the time delay of 3–5 min between contrast material injection and imaging was based on the results of recent clinical and experimental multidetector CT studies on homogeneous infarcts (24–26). In these clinical and experimental studies, we found that an interval of 3–5 minutes between contrast material injection and multidetector CT scanning yielded the best contrast between homogeneous infarcts, viable myocardium, and LV blood pool. A time delay of 5 minutes has been shown to yield the best differentiation of remote myocardium, infarcts, and LV blood pool in porcine models (27) and has been used previously (23). Multiplanar reformations of the cine and delayed contrast-enhanced images were reconstructed in 5-mm sections in the short-axis view.

**MR Imaging**

The following MR sequences (19,28,29) were used to measure LV function, perfusion, and viability and to compare the data with multidetector CT.

- Cine MR imaging was performed in the short-axis view, encompassing the LV, with a steady-state free precession sequence (3.5/1.75, 20° flip angle, 10-mm section thickness, no section gap, 25 × 25-cm field of view, 160 × 152 matrix, 16 heart phases).

- First-pass perfusion MR images were acquired after administration of 0.1 mmol/kg gadoterate meglumine in four short-axis sections with a saturation-recovery gradient-echo sequence (4.5/2.2, 10-mm section thickness, 26 × 26-cm field of view, 128 × 128 matrix, 20° flip angle, and two R-R intervals per dynamic acquisition). The injection rate of MR contrast media was 3 mL/sec.

- Delayed contrast-enhanced MR images were acquired after injection of another 0.05 mmol/kg of gadoterate meglumine. These images were obtained 5–10 minutes after injection because the wash in and wash out of the contrast media from a heterogeneous microinfarct are faster than the wash in and wash out from a homogeneous infarct (8,9,10,30). We have previously shown that an imaging time of 6 minutes ± 4 after contrast media administration yielded the best contrast between the microinfarct and the remote myocardium (9). Images were acquired in short- and long-axis views encompassing the LV with an inversion-recovery gradient-echo sequence (5/2; 15° flip angle; shot interval, two R-R intervals; 3-mm section thickness; no section gap; 26 × 26-cm field of view; 256 × 162 matrix). The inversion time was chosen to null normal myocardium.
of microinfarcts and remote myocardium obtained on delayed contrast-enhanced multidetector CT and delayed contrast-enhanced MR images were compared.

**Postmortem Analysis**

After completion of the imaging studies, the animals were euthanized with 40 mL of saturated KCl. The hearts were excised rapidly, cut into 10-mm-thick slices, and soaked for 30–45 minutes in 2% triphenyltetrazolium chloride (TTC). Histochemical staining served as the reference standard in the measurement of microinfarcts. Digital images of the TTC-stained slices were converted to black and white images with Adobe Photoshop CS2 software (Adobe; http://www.adobe.com/) and measured with ImageJ, version 1.30, software (National Institutes of Health; http://rsb.info.nih.gov/ij/). For histopathologic analysis, representative tissue samples were taken from the microinfarcted region and remote myocardium (P.C.U., more than 25 years of experience). The samples were dehydrated and embedded in paraffin in accordance with the standard procedure and cut into 5-µm-thick slices; adjacent slices were stained with hematoxylin-eosin and Masson trichrome stains (29). Postmortem analyses were performed without knowledge of the multidetector CT and MR imaging results.

**Table 1**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Cine MR Imaging</th>
<th>Multidetector CT</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ejection fraction (%)</td>
<td>48 ± 3 (38–59)</td>
<td>50 ± 3 (38–56)</td>
<td>.16</td>
</tr>
<tr>
<td>End-diastolic volume (mL)</td>
<td>92 ± 8 (73–128)</td>
<td>93 ± 8 (73–127)</td>
<td>&gt;.99</td>
</tr>
<tr>
<td>End-systolic volume (mL)</td>
<td>48 ± 5 (31–66)</td>
<td>46 ± 4 (36–58)</td>
<td>.69</td>
</tr>
<tr>
<td>Cardiac output (L/min)</td>
<td>3.8 ± 0.3 (2.7–4.7)</td>
<td>3.9 ± 0.4 (2.9–5.8)</td>
<td>.69</td>
</tr>
<tr>
<td>Left ventricular mass (g)</td>
<td>109 ± 5 (91–120)</td>
<td>102 ± 4 (85–114)</td>
<td>.06</td>
</tr>
</tbody>
</table>

Note.—Unless otherwise indicated, data are means ± standard errors of the mean. Data in parentheses are ranges.

**Statistical Analyses**

Continuous variables are presented as means ± standard errors of the mean, unless otherwise stated. All statistical analyses were performed with GraphPad software (GraphPad Prism for Windows, version 5.00; GraphPad Software, San Diego, Calif). The two-tailed Wilcoxon test was used to determine if variables differed between imaging
modalities and between remote and microinfarcted myocardium. The parameters tested for differences between imaging modalities were LV volumes, ejection fraction, LV mass, cardiac output, microinfarcted size, and signal intensity and attenuation of the myocardium. The variables tested to assess differences between remote and microinfarcted myocardium were systolic wall thickening for regional function and maximum upslope, maximum enhancement or attenuation, and time to peak for regional perfusion. Bias for microinfarct size on multidetector CT and MR images was determined with Bland-Altman analysis as the mean difference ± standard deviation of the difference, with TTC staining serving as the reference standard. Bias was also calculated for the global LV function parameters by using the mean results of multidetector CT and MR images as a reference standard. A P value of less than .05 was considered indicative of a significant difference.

Results

X-ray MR Imaging in Defining LAD Coronary Artery Territory
The LAD coronary artery was successfully catheterized with x-ray guidance in all animals. With MR imaging, the LAD coronary artery territory was seen as a hyperenhanced region during an intravenous bolus injection of MR contrast media (18). The extent of LAD coronary artery territory was 32.4% ± 3.8 of the LV mass. Delivery of the embolic materials caused myocardial ischemia, as shown on electrocardiograms by ST-T wave changes. The presence of regional ischemia was confirmed on additional first-pass perfusion MR images as a hypoenhanced region in the LAD coronary artery territory. A transient (approximately 30-minute) decline in mean heart rate (from 92 beats per minute ± 5 to 82 beats per minute ± 2, P < .05) was observed after delivery of the embolic material.

Multidetector CT and MR Imaging in the Assessment of Global and Regional LV Function
A direct (intraindividual) comparison between multidetector CT and MR imaging was performed 7–8 weeks after delivery of the embolic material. Figures 1 and 2 show MR and multidetector CT images acquired from the same animal. Both modalities yielded excellent contrast between the blood pool and the LV wall: The attenuation was 498% ± 50 higher in the blood pool than in the LV wall on multidetector CT images, and the signal intensity was 485% ± 64 higher in the blood pool on MR images. There was no significant difference between the multidetector CT and MR measurements of global LV function (ejection fraction, end-diastolic volume, end-systolic volume, and cardiac output) and LV mass (Table 1). The biases for functional parameters with multidetector CT compared with those with MR imaging were 2.6% ± 3.6 for ejection fraction, 0.8 mL ± 8.5 for end-diastolic volume, 1.9 mL ± 6.5 for end-systolic volume, 0.2 L/min ± 0.6 for cardiac output, and −6.7 g ± 5.6 for LV mass.

Both multidetector CT and MR imaging revealed a decrease in systolic wall thickening in the microinfarcted LAD coronary artery territory compared with that of the remote myocardium (Fig 3).

Multidetector CT and MR Imaging in the Assessment of Regional Perfusion
The LAD coronary artery territory with heterogeneous microinfarcts could not be detected as differential enhancement with either modality at visual analysis. However, quantitative analysis of regions of interest revealed a minor difference in regional perfusion between the LAD coronary artery territory with heterogeneous microinfarcts and remote myocardium on both multidetector CT and MR images (Fig 4). MR estimates of perfusion in the LAD coronary artery territory with heterogeneous microinfarct scar showed a decrease in maximum upslope and time to peak (P = .03 for both) compared

Figure 3
Figure 3: Bar graphs show regional systolic wall thickening in (a) basal (Base), (b) middle (Mid), and (c) apical (Apex) sections on MR and multidetector CT (MDCT) images. Lines extending from the bars indicate standard errors of the mean. Note the impairment in systolic wall thickening in the microinfarcted LAD territory compared with remote myocardium 7–8 weeks after embolization with both methods. * = A significant difference (P < .05) was seen when comparing microinfarcted wall thickening with remote myocardium within each section.
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Covered the LAD coronary artery territory (8–11). The signal intensity of microinfarct scar on delayed contrast-enhanced MR images was 843% ± 90% higher than that of remote myocardium (114 ± 51 vs. 128 ± 15, P = .03). However, the attenuation of microinfarct scars on delayed contrast-enhanced multidetector CT images was only 60% ± 4 higher than that of remote myocardium (172 HU ± 9 vs. 107 HU ± 6, P = .03). Thus, delayed contrast-enhanced MR images had a 15 ± 3-fold higher signal intensity ratio between microinfarct scar and remote myocardium.

Multidetector CT and MR Imaging in the Detection of Heterogeneous Microinfarct Scar

At 7–8 weeks, heterogeneous microinfarct scars were clearly seen as hyperenhanced subregions in the LAD coronary artery territory on delayed contrast-enhanced multidetector CT and delayed contrast-enhanced MR images (Fig 5). Delayed contrast-enhanced multidetector CT and MR images obtained in the long-axis view also showed hyperenhanced stripes of microinfarct extending from the epicardium to the endocardium in the LAD coronary artery territory. Unlike homogeneous (20,34) infarcts caused by occlusion or reperfusion of major coronary arteries, the distribution of microinfarcts caused by microemboli was heterogeneous and covered the LAD coronary artery territory (8–11). The signal intensity of microinfarct scar on delayed contrast-enhanced MR images was 843% ± 90 higher than that of remote myocardium (114 ± 51 vs. 128 ± 15, P = .03). However, the attenuation of microinfarct scars on delayed contrast-enhanced multidetector CT images was only 60% ± 4 higher than that of remote myocardium (172 HU ± 9 vs. 107 HU ± 6, P = .03). Thus, delayed contrast-enhanced MR images had a 15 ± 3-fold higher signal intensity ratio between microinfarct scar and remote myocardium.

Table 2

Regional Assessment of Myocardial Perfusion with First-Pass MR Imaging and Multidetector CT

<table>
<thead>
<tr>
<th>Measurement</th>
<th>MR Imaging</th>
<th>Multidetector CT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LV Blood</td>
<td>Remote Myocardium</td>
</tr>
<tr>
<td>Maximum upslope (sec⁻¹)</td>
<td>1780 ± 242</td>
<td>166 ± 26</td>
</tr>
<tr>
<td>Maximum signal intensity (HU)</td>
<td>5471 ± 605</td>
<td>1627 ± 203</td>
</tr>
<tr>
<td>Time to peak (sec)</td>
<td>7.5 ± 0.7</td>
<td>12.5 ± 1.0</td>
</tr>
</tbody>
</table>

Note.—Mean heart rate was 88 beats per minute ± 5 for MR imaging and 88 beats per minute ± 2 for multidetector CT. Data were obtained in six pigs.

* P < .05 compared with remote myocardium.

Figure 4

Plots show the quantitative analysis of first-pass perfusion on (a) multidetector CT and (b) MR images 7–8 weeks after microembolization. LAD territory with heterogeneous microinfarct scar showed perfusion deficit compared with remote myocardium on both CT and MR images. The results (mean ± standard error of the mean) from the myocardium are shown at a magnified scale for clarity. □ = microinfarct, △ = LV blood pool, ○ = remote myocardium.
myocardium compared with multidetector CT ($P = .03$). The total extent of microinfarct measured with delayed contrast-enhanced multidetector CT, delayed contrast-enhanced MR imaging, and TTC staining with the semiautomatic method was $6.3\% \pm 0.8$, $6.6\% \pm 0.5$, and $7.0\% \pm 0.6$, respectively. The results were not significantly different (multidetector CT vs MR imaging, $P = .84$; delayed contrast-enhanced multidetector CT vs TTC staining, $P = .31$; delayed contrast-enhanced MR imaging vs TTC staining, $P = .69$). Figure 6 shows the agreement between multidetector CT, MR imaging, and TTC staining with the Bland-Altman test. The bias for the extent of microinfarct on delayed contrast-enhanced multidetector CT and MR images was $-0.6 \pm 1.9$ and $-0.4 \pm 1.3$, respectively, as compared with TTC staining. This suggested that both modalities have similar sensitivity in the measurement of heterogeneous microinfarct scars.

**Histopathologic Analysis**

TTC staining revealed a heterogeneous distribution of scarred microinfarcts in the LAD territory (Fig 7). The distribution and sizes of microinfarct varied from slice to slice and from animal to animal. Microscopic examination revealed the heterogeneous transmural distribution of the microinfarct scar 7–8 weeks after microembolization (Fig 7). Hematoxylin-eosin staining revealed the embolic material trapped in the scar tissue. Masson trichrome staining revealed the presence of stripes (tongues of fibrous tissue) extending from the epicardium to the endocardium and indicating the path of occluded blood microvessels.

**Discussion**

The main findings of this study are that (a) modern multidetector CT and MR imaging are sensitive modalities with which to visualize and measure heterogeneous microinfarcts and (b)
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EXPERIMENTAL STUDIES:

Multidetector CT and MR imaging can be used to detect regional perfusion deficits 7–8 weeks after coronary intervention.

We used multidetector CT and MR imaging to assess myocardial viability, perfusion, and LV function in microinfarcts 7–8 weeks after coronary intervention, simulating atheromatous microembolism in patients with coronary artery disease. Our findings suggest that either delayed contrast-enhanced multidetector CT or delayed contrast-enhanced MR imaging can be used in patients to depict microinfarcts after percutaneous coronary intervention.

Myocardial microinfarcts resulting from showers of microemboli shed after coronary intervention are not limited to percutaneous coronary intervention for atherosclerosis but include a wide range of abnormalities, such as valvular disease, prosthetic valve placement, endocarditis, cardiomyopathy with mural thrombus, arrhythmias, and heart-lung bypass (35–41). This disease has also been reported in patients with hypertension, diabetes (3), systemic lupus erythematosus (42), and sickle cell disease; in these patients, abnormally shaped erythrocytes obstructing the capillaries and small arteries may cause microinfarct (43).

The results of previous studies have shown that delayed contrast-enhanced MR imaging is able to depict acute heterogeneous microinfarcts in patients (2,5,12,13) and animals (9–11). Nassenstein and co-workers (10,11) found that a heterogeneous microinfarct exceeding 5% of myocardium per slice at histologic examination could be detected in vivo with delayed contrast-enhanced MR imaging in swine with a sensitivity of 83%. Our results have shown that delayed contrast-enhanced multidetector CT and delayed contrast-enhanced MR imaging can be used to depict and accurately quantify heterogeneous microinfarct scar 7–8 weeks after microembolization. Interestingly, both modalities yielded comparable data regarding the extent of heterogeneous microinfarct scar, and they were not significantly different from TTC staining microinfarct size. These findings are in line with those of clinical studies, in which delayed contrast-enhanced multidetector

Figure 7: (a, b) Histochemical and (c, d) histopathologic staining show the transmural distribution of heterogeneous microinfarct scar. Arrowheads indicate the extent of LAD territory where heterogeneous microinfarct was detected. In c, the embolic material (arrows) is trapped in the core of scar tissue. (Hematoxylin-eosin stain; original magnification, ×100.) In d, we confirmed the presence of stripes that extend from the epicardium to the endocardium, indicating the path of occluded blood vessels. (Masson trichrome stain; original magnification, ×40.) F = tongues of fibrous tissue, V = viable myocardium.
CT and MR imaging yielded comparable sizes of homogeneous infarct (27,44). In a recent study, investigators compared multidetector CT with MR imaging in the definition of the perinfarct zone surrounding homogeneous infarct scars in swine (34). They suggested that delayed contrast-enhanced multidetector CT enables a more detailed assessment of the small perinfarct zone in scarred homogeneous infarcts and is less susceptible to the partial volume averaging effect than is MR imaging.

Study results have shown the potential of first pass multidetector CT (21–23,25) and MR imaging (28,45–47) in the detection of acute and subacute perfusion deficits in homogeneous infarcts. In the current study, we found a minor perfusion deficit in scarred microinfarcts compared with remote myocardium on first-pass multidetector CT and MR images. The differences were pronounced for maximum upslope and time to peak but were not visible on the images. The smaller standard error of the mean for multidetector CT compared with MR imaging seen in Figure 4 is inherent to the difference in the techniques. The signal intensity on MR images was measured in arbitrary units, while the attenuation on CT images was measured in Hounsfield units and was fairly constant between studies. Contrast-enhanced multidetector CT attenuation values are determined by the physical properties of the blood and myocardium (viable and nonviable) that result from direct x-ray attenuation by iodine. On the other hand, contrast-enhanced MR imaging values are based on gadolinium-induced alterations of water relaxivity and thus reflect indirect measurement of the amount and distribution of contrast media in the blood pool and myocardium (viable and nonviable) (34). This is reflected in the smaller increase in attenuation in the myocardium on multidetector CT images compared with the signal intensity increase on MR images after contrast media administration.

Both modalities yielded comparable regional and global data on LV function. MR imaging has emerged as the reference standard with which to evaluate LV function because of its three-dimensional coverage, high spatial resolution, and excellent contrast between the myocardium and blood pool. Retrospectively, electrocardiographically gated multidetector CT has been used to quantify LV volumes, ejection fraction, and contractility (48). Our findings indicate that global LV functional measurements—namely, ejection fraction, end-diastolic volume, end-systolic volume, and cardiac output—quantified on multidetector CT images are comparable with those quantified on the reference standard MR images.

The ejection fraction in healthy swine with matched body weight is between 57.1% ± 4.7 and 58.4% ± 6.1 with MR imaging (49) and echocardiography (50), respectively. The ejection fraction in the animals in the current study was substantially lower (47.5% ± 3.2) than that in our previous study in healthy swine (49). At the regional level, both imaging modalities depicted the decrease in regional wall thickening in the LAD coronary artery territory with microinfarct scars compared with that in remote myocardium.

The advantages of 64-section multidetector CT are the wide availability of CT scanners, their ease of use, and their high spatial resolution. On the other hand, the disadvantages of multidetector CT are the lower differential contrast between microinfarct and viable myocardium compared with MR imaging; the need for repeated injection of iodide-based contrast media, which may affect the use in patients with renal failure; and the relatively high radiation dose to patients. Recent studies, however, have shown that gadolinium-based contrast media may cause nephrogenic systemic fibrosis in patients with a reduced glomerular filtration rate (51). Finally, there is presently a larger body of published evidence on the diagnostic capabilities of MR imaging compared with those of multidetector CT in the measurement of perfusion, function, and viability of homogeneous infarcts (27,44).

This study comprised a small number of animals (a) because our institutional animal care and use committee imposed a restriction on all investigations, forcing them to use the minimum number of animals required to achieve significance, and (b) because of the high cost of imaging, surgery, and up to 8 weeks of animal husbandry. Thus, we did not perform a power calculation; instead, we based the number of animals in our study on the number of animals in previous studies. The number of animals in our study, however, was greater than or similar to the number of animals in relatively recently published reports (52–54). Another limitation was the use of a single injection and the limited range of embolic material (40–120 μm). However, the size range of the embolic materials used represented the common sizes of microemboli retrieved after placing distal protection devices (55). Additional multidetector CT, MR imaging, gross pathologic, and microscopic studies are needed to investigate the morphology, distribution, and pathophysiology of different sizes of microemboli. Future work will be needed to demonstrate the capability of multidetector CT to depict microinfarcts in patients.

Practical applications: This study has shown that multidetector CT and MR imaging are sensitive modalities with which to depict (a) heterogeneous microinfarcted scars resulting from microembolization and (b) the deleterious effect of microembolization on regional LV function and perfusion. These imaging modalities may be useful in depicting microinfarcts in other diseases, such as valvular disease, hypertension, diabetes, systemic lupus erythematosus, and sickle cell disease.

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References


