Characterization of Peri-Infarct Zone Heterogeneity by Contrast-Enhanced Multidetector Computed Tomography A Comparison With Magnetic Resonance Imaging

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Objectives This study examined whether multidetector computed tomography (MDCT) improves the ability to define peri-infarct zone (PIZ) heterogeneity relative to magnetic resonance imaging (MRI).

Background The PIZ as characterized by delayed contrast-enhancement (DE)-MRI identifies patients susceptible to ventricular arrhythmias and predicts outcome after myocardial infarction (MI).

Methods Fifteen mini-pigs underwent coronary artery occlusion followed by reperfusion. Both MDCT and MRI were performed on the same day approximately 6 months after MI induction, followed by animal euthanization and ex vivo MRI (n = 5). Signal density threshold algorithms were applied to MRI and MDCT datasets reconstructed at various slice thicknesses (1 to 8 mm) to define the PIZ and to quantify partial volume effects.

Results The DE-MDCT reconstructed at 8-mm slice thickness showed excellent correlation of infarct size with post-mortem pathology ($r^2 = 0.97; p < 0.0001$) and MRI ($r^2 = 0.92; p < 0.0001$). The DE-MDCT and -MRI were able to detect a PIZ in all animals, which correlates to a mixture of viable and nonviable myocytes at the PIZ by histology. The ex vivo DE-MRI PIZ volume decreased with slice thickness from 0.9 ± 0.2 ml at 8 mm to 0.2 ± 0.1 ml at 1 mm (p = 0.01). The PIZ volume/mass by DE-MDCT increased with decreasing slice thickness because of declining partial volume averaging in the PIZ, but was susceptible to increased image noise.

Conclusions A DE-MDCT provides a more detailed assessment of the PIZ in chronic MI and is less susceptible to partial volume effects than MRI. This increased resolution best reflects the extent of tissue mixture by histopathology and has the potential to further enhance the ability to define the substrate of malignant arrhythmia in ischemic heart disease noninvasively. (J Am Coll Cardiol 2009;53:1699–707) © 2009 by the American College of Cardiology Foundation
Images were obtained after the last in vivo experiment. Pathology at 2-mm slice thickness was immediately after the MDCT scan before MRI data could be acquired. A total of 15 animals were studied. One animal died on the same day.

MDCT and MRI studies were performed in random order. Animals progressed to heart failure (Table 1), and all MDCT and MRI studies were performed in random order on the same day.

Animal model. All animal studies were approved by the Johns Hopkins University Institutional Animal Care and Use Committee and comply with the Guide for the Care and Use of Laboratory Animals (National Institutes of Health Publication no. 80-23, revised 1985). Female Göttingen mini-pigs were purchased from Marshall BioResources (North Rose, New York).

Animals with chronic infarcts were created as previously described in detail. Briefly, MI was induced by engaging the left anterior descending coronary artery (LAD) with an 8-F hockey stick catheter under fluoroscopic guidance. Then, a 0.014-inch angioplasty guidewire was inserted into the LAD and a 2.5 × 12-mm Maverick balloon (Boston Scientific, Natick, Massachusetts) was inflated to 4 atm just distal to the second diagonal branch of the LAD. After 120 min, occlusion of the vessel was terminated by deflating the balloon, and restoration of flow in the LAD was confirmed by angiography.

Animals progressed to heart failure (Table 1), and all MDCT and MRI studies were performed in random order on the same day.

<table>
<thead>
<tr>
<th>Age</th>
<th>Mean</th>
<th>SD</th>
<th>SEM</th>
<th>95% CI of Mean</th>
</tr>
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<tbody>
<tr>
<td>Days</td>
<td>191</td>
<td>4</td>
<td>0.1</td>
<td>187–195</td>
</tr>
<tr>
<td>Months</td>
<td>6.4</td>
<td>0.5</td>
<td>0.1</td>
<td>6.0–6.7</td>
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<tr>
<td>Days</td>
<td>191</td>
<td>5</td>
<td>4</td>
<td>182–200</td>
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Methods

The purpose of this study was 2-fold: 1) to compare DE-MRI and -MDCT assessment of the PIZ in a chronic 6-month occlusion/reperfusion model of healed MI; and 2) to characterize the effect of slice thickness (partial volume averaging) on DE-MDCT and -MRI infarct and PIZ measurements.

The effect of slice thickness and partial volume effects on infarct size and infarct heterogeneity relative to MRI has not been systematically studied for DE-MDCT imaging. Accordingly, MDCT has the potential to greatly decrease partial volume effects and accurately characterize the PIZ. However, the high z-axis spatial resolution of MDCT comes at the expense of higher image noise, which may preclude accurate assessment of the PIZ. The effect of slice thickness and partial volume effects on infarct size and infarct heterogeneity relative to MRI has not been systematically studied for DE-MDCT imaging. Accordingly, the purpose of this study was 2-fold: 1) to compare DE-MRI and -MDCT assessment of the PIZ in a chronic 6-month occlusion/reperfusion model of healed MI; and 2) to characterize the effect of slice thickness (partial volume averaging) on DE-MDCT and -MRI infarct and PIZ measurements.

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The DE images were acquired 15 min after intravenous injection of gadolinium diethylenetriamine penta-acetic acid (0.2 mmol/kg body weight, Magnevist, Berlex, Wayne, New Jersey), using an electrocardiogram-gated, breath-hold, interleaved, inversion recovery, fast gradient repetition echo pulse sequence. The DE-MRI images were acquired using the same slice prescription used for short-axis cine images. Imaging parameters were: echo time/repetition time 3.3/7.3 ms; flip angle 25°; bandwidth 31.2 kHz; field of view 280 mm; 256 × 196 matrix; 1.3 × 1.3 × 8.0 mm³; 8-mm slice thickness/no gap. Inversion recovery time (≈200 ms) was manually adjusted as needed to null the normal myocardium (22).

Ex vivo MRI was conducted in a subset of 5 animals to visualize infarct morphology at submillimeter resolution. After intravenous administration of heparin 5,000 IU and 0.20 mmol/kg gadolinium diethylenetriamine penta-acetic acid, the animals were euthanized and the hearts were removed and filled with vinyl polysiloxane to ensure diastolic arrest. The heart was scanned in a 1.5-T Sonata MR scanner (Siemens Medical Solutions, Erlangen, Germany) with a 3-dimensional gradient echo sequence. The imaging parameters were as follows: echo time/repetition time 4.02/9.7 ms; flip angle 20°; bandwidth ±130 Hz/pixel; field of view 100 mm; image matrix 256 × 256; spatial resolution 0.39 × 0.39 × 0.39 mm³. Images were then averaged to achieve multiple slice thicknesses (1, 2, 4, and 8 mm) for assessment of partial volume effects on the PIZ and infarct core.

**Imaging analysis.** Cine MRI images, DE-MDCT, and DE-MR images were analyzed using a custom research software package (Cine Tool, GE Medical Systems). To evaluate resting LV function, endocardial and epicardial borders of the LV were defined each in the end-diastolic and -systolic frame in contiguous slices and end-diastolic LV volume, end-systolic LV volume, LV stroke volume, and LV ejection fraction were calculated (Table 1). Infarct size in DE-MDCT and -MR images was defined by SDs of the signal intensity to the remote mean (noninfarct) myocardium for the core infarct and 2 SD of the signal intensity from the remote mean to the PIZ as described previously (23).

The SNRs were calculated for MDCT and MRI by dividing the mean signal intensity in the infarct area with the SD of signal intensity outside of the thorax. The SD of the air measurements reflects the degree of image noise. Mean signal intensity and SD were obtained by measuring air/noise outside the body or in the lung field. Image contrast-to-noise ratios (CNR) were calculated by using the following equation: (mean signal intensity of the infarct − mean signal intensity of the remote region)/SD of noise.

**Pathology and histology.** Animals were immediately killed after the imaging study. Hearts were arrested in diastole by slow retrograde infusion of an ice-cold solution of 4 mmol/l potassium chloride (KCl) and 4% paraformaldehyde dissolved in phosphate-buffered saline. The porcine hearts were excised, filled with dental rubber to avoid uneven tissue shrinkage, and post-fixed in 4% paraformaldehyde overnight at 4°C. For post-mortem infarct size assessment, the fixed porcine hearts were sectioned from apex to base at 2-mm slice thickness with a commercial available meat slicer. Myocardial slices were weighed, and the apical and basal aspect of each slice was digitally photographed. The infarct scar and areas of viable myocardium were manually traced using imaging analysis software (Sigma Scan Pro5, Systat Software Inc., San Jose, California). The infarct mass was calculated according to slice weight, and infarct size was expressed as percentage of LV mass excluding the papillary muscle.

Fixed tissue samples from the peri-infarct area were embedded in paraffin, and 5-µm sections were cut and stained with a Masson trichrome protocol. Light microscopy images were obtained on a Zeiss Axioscope microscope (Carl Zeiss NTS GmbH, Oberkochen, Germany).

**Electron microscopy.** Small tissue samples including both chronic infarct scar and viable myocardium were dissected from the porcine hearts after perfusion with ice-cold phosphate-buffered saline solution. For transmission electron microscopy (TEM) and scanning electron microscopy (SEM), the cardiac tissue was fixed in 2% glutaraldehyde in 0.1 M cacodylate pH 7.4 with 3% sucrose and 3 mM CaCl₂ overnight at 4°C. The TEM samples were post-fixed with 1% osmium tetroxide reduced in potassium ferrocyanide for 1 h at 4°C. Tissue was incubated in 0.15% tannic acid for 1 min to enhance the visualization of collagen fibers, and placed in 2% uranyl acetate for 1 h at room temperature.

After fixation, the tissue was stained en bloc with a 2% aqueous solution of uranyl acetate and dehydrated in graded ethanol and embedded. Ultra-thin sections (70 to 90 nm) were cut and stained with uranyl acetate and lead citrate. Samples were viewed and photographed on a Hitachi 7600 TEM (Hitachi High Technologies America, Inc., Gaithersburg, Maryland).

The SEM samples were fixed and dried with liquid CO₂, mounted onto SEM stubs, and sputter coated with 20-nm gold palladium. The SEM images were obtained on a LE01530 field emission SEM (Carl Zeiss NTS GmbH).

**Statistical analysis.** All data are presented as mean ± standard error of the mean unless otherwise stated. For infarct size and infarct volume/mass comparison, Pearson correlation and linear regression analysis were used to compare MDCT versus post-mortem pathology and MRI. Results were confirmed by Bland-Altman analysis and agreement expressed as mean ± SD difference between methods at 95% confidence intervals.

The MDCT and MRI data at 8-mm slice thickness (Table 2) were evaluated with a paired Student t test. These analyses were performed in MedCalc (MedCalc Software, Mariakerke, Belgium).

Because the study involved repeated measurements of individual animals, an a linear mixed model (24) was used for analysis of the data depending on slice thickness. The model
included fixed effects for imaging modality and/or slice thickness, as well as their interaction when both were included in the model, and a random animal effect. Post-hoc comparisons were made among adjusted means using Wald tests. The linear mixed model analyses were performed in SAS (SAS/STAT Software, Cary, North Carolina). In all analyses, values of $p < 0.05$ were considered significant.

Results

**MDCT viability imaging.** First-pass DE-MDCT imaging showed homogenous myocardial enhancement of the remote myocardium and hypodense regions in the LAD territory. Post-infarct MDCT imaging at 5, 10, and 15 min after contrast injection identified collagenous myocardial scar that was characterized by well-delineated hyperdense regions. Density analysis of the LV blood pool, infarct region, and remote myocardium at all time points confirmed that optimal image quality (highest CNR) occurred at 10-min post-contrast, and thus all DE-MDCT images were analyzed at this time point.

**DE-MDCT versus -MRI and pathology.** The morphology and distribution of chronic infarct scar assessed by DE-MDCT correlated well with gross pathology and with ex vivo and in vivo MRI (Fig. 1). Infarct mass was 4.3 $\pm$ 0.6 g evaluated by gross pathology. Total infarct size as percent of LV mass by MDCT at 8 mm correlated well with in vivo MRI ($r^2 = 0.92; p < 0.0001$) and post-mortem pathology ($r^2 = 0.97; p < 0.0001$) with a 8.2% mean underestimation by MDCT versus MRI and a qualitative trend toward overestimation by MDCT versus pathology with mean difference $-8.2\%$. Matching slice thickness of 2 mm for DE-MDCT images and post-mortem pathology, the overestimation of DE-MDCT decreased to a mean difference of $-7.3\%$.

**PIZ imaging.** A PIZ could be measured for both DE-MDCT and -MRI in all animals at all slice thicknesses (Table 2, Fig. 2). We used standard histology TEM and SEM as a reference to investigate the tissue composition of the PIZ and to clarify the imaged substrate. Gross pathology and Masson trichrome staining showed transmural infarct scars with densely packed collagen fibers (Figs. 2C and 2F) in all animals. Infarct scar and viable myocardium were clearly delineated in all chronic MI (Figs. 2G to 2I), and islands of viable myocytes could be detected by Masson trichrome staining at the border zone of the infarcts (Figs. 2C and 2F). All myocardial infarcts showed this intermingling of viable and nonviable tissue at the border zone of the infarct scar.

**Effect of slice thickness on the PIZ.** Slice thickness had a marked effect on the calculated mass of the PIZ for both in vivo and ex vivo DE-MRI experiments (Fig. 3), suggesting a strong partial volume effect. For ex vivo MRI, the PIZ mass decreased from 0.9 $\pm$ 0.2 mg to 0.2 $\pm$ 0.1 mg comparing 8- and 1-mm thickness, respectively ($p = 0.0001$). The DE-MDCT PIZ volume showed a trend toward increasing values with decreasing slice thickness (Fig. 4). Additionally, the relative proportion of the PIZ expressed as a percentage of the total infarct core changed significantly with slice thickness (Table 3, Fig. 5). These results were consistent with increased CNR and decreased SNR in the PIZ with thinner slices by visual and quantitative assessment (Figs. 6B and 6C).

Discussion

To the best of our knowledge, this is the first report of DE-MDCT and -MRI PIZ imaging with post-mortem pathology in dense remodeled scar 6 months’ post-MI. The

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### Table 2

<table>
<thead>
<tr>
<th></th>
<th>MDCT</th>
<th>MRI</th>
<th>$p$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infarct (% of LV mass)</td>
<td>18.5 $\pm$ 1.5</td>
<td>25.0 $\pm$ 1.8</td>
<td>0.01</td>
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<tr>
<td>Total infarct mass (g)</td>
<td>7.6 $\pm$ 0.7</td>
<td>10.4 $\pm$ 0.9</td>
<td>0.02</td>
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<tr>
<td>Core infarct mass (g)</td>
<td>7.0 $\pm$ 0.6</td>
<td>10.1 $\pm$ 0.9</td>
<td>0.01</td>
</tr>
<tr>
<td>Peri-infarct mass (g)</td>
<td>0.6 $\pm$ 0.1</td>
<td>0.3 $\pm$ 0.1</td>
<td>0.01</td>
</tr>
<tr>
<td>LVED mass (g)</td>
<td>39.9 $\pm$ 1.6</td>
<td>41.7 $\pm$ 1.6</td>
<td>0.46</td>
</tr>
</tbody>
</table>

LV = left ventricular; LVED = left ventricular end-diastolic; MDCT = multidetector computed tomography; MRI = magnetic resonance imaging.

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Figure 1

**Comparison of Infarct Morphology by MDCT With Post-Mortem Pathology and MRI**

Example images in short-axis orientation for (A) delayed contrast-enhancement multidetector computed tomography (DE-MDCT) at 2 mm, (B) post-mortem pathology at 2 mm, and (C) ex vivo and (D) in vivo magnetic resonance imaging (MRI) at 4-mm slice thickness show a similar location and distribution pattern of the chronic collagenous scar in the anterior septal left ventricular wall.
major findings of this study are that DE-MDCT is superior to MRI in its ability to detect and quantify the PIZ after contrast delivery in chronic MI. Furthermore, we characterize the influence of partial volume effects on the measurement of the PIZ by imaging methods and provide detailed comparisons against histopathology.

**Scar enhancement by MDCT: comparison with MRI.** Delayed hyperenhancement in chronic collagenous myocardial scar results from an accumulation of contrast media in the interstitial space between collagen fibers, resulting in an increased volume of contrast distribution in the scar tissue compared with that of tightly packed myocytes (7). The accumulation of contrast material in the collagenous scar matrix is a passive process, and the timing between administration of contrast agents and imaging is crucial to differentiate blood pool from scar and the PIZ. The DE-MDCT density values are somewhat unique and determined by the physical properties of individual constituents of the heart including blood and viable and nonviable myocardium that result from direct X-ray attenuation by iodine. Although not a perfect binary system, such imaging is theoretically well suited to characterize infarct heterogeneity.

Because of its high CNR and lack of ionizing radiation, DE-MRI is a highly attractive modality for myocardial viability imaging. This approach is based on gadolinium-induced alterations of water relaxivity and thus represents a

![Image](https://example.com/image.png)
surrogate measure of the amount and distribution of contrast in the extracellular space. Recent studies have shown that DE-MDCT and -MRI infarct size compare well in patients (14,25), despite the lower image quality of DE-MDCT examinations. The lower image quality of DE-MDCT is likely related to technical factors such as temporal resolution as well as differences in the mechanisms of hyperenhancement between DE-MDCT and -MRI (e.g., the lack of iodine–water interactions that modulate signals). The quality of acute DE-MDCT infarct imaging is improved over that of scar imaging because iodine is able to access the intracellular space rather than the limited extra-
cellular space generated by a collagen matrix (15). Other features unique to DE-MRI data acquisition, such as inversion recovery based myocardial nulling, further improve scar visualization over DE-MDCT but may also partly explain the overestimation of infarct size by DE-MRI in our chronic infarcts and in the acute setting (26).

**Partial volume effects and the appearance of the PIZ.** The appearance of the PIZ by DE-MDCT and -MRI can be explained by 2 possible orientations of the normal myocardium with respect to scar: 1) an area of uniformly dense scar adjacent to preserved myocardium with a sharp binary transition; or 2) the intermingling of bundles of fibrotic scar with viable myocytes. Partial volume effects are related to the 3-dimensional spatial resolution of a tomographic image. If a given voxel at the infarct periphery contains both infarct and noninfarct tissue, the 2 different signal intensities will be averaged, and this particular voxel will be represented by an intermediate attenuation value. For standard clinical DE-MRI, voxel volumes are typically $\frac{1}{H11022}13 \, \text{mm}^3 (1.3 \, \text{mm}^3)$ and thus approximately 200,000 cells at the interface between infarcted and viable tissue in the PIZ can occur in a single voxel. To quantify the effect of partial volume averaging for DE-MRI, we acquired high-resolution ex vivo MR images at 0.4-mm slice thickness using a 3-dimensional sequence with an isotropic voxel size $\frac{1}{H11003}0.39 \, \text{mm}^3$, resulting in a pixel volume $\frac{1}{H9262}59 \, \text{mm}^3$, which allowed for reproduction of various slice thicknesses. The measured PIZ decreased 350% when comparing a clinically used slice thickness (8 mm) with 1-mm slices. We also observed a similar decrease in the PIZ when comparing in vivo DE-MRI images. These data suggest a strong partial volume effect that greatly decreases local CNR in the PIZ and support the hypothesis that the PIZ measured by DE-MRI may overestimate the actual PIZ.

In MDCT imaging with 64-detector-row scanners, raw data can be acquired and displayed at a high isotropic resolution with a voxel volume of $43 \, \mu\text{m}^3 (0.35 \times 0.35 \times 0.35 \, \text{mm}^3)$, which is 2 orders of magnitude smaller than that of in vivo MRI. During the MDCT reconstruction process it is possible to reconstruct and analyze multiple slice thicknesses from the original data set, which allows partial

<table>
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<tr>
<th>Table 3</th>
<th>Infarct Parameters at Different Slice Thickness by MDCT (n = 12)</th>
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<tr>
<td>Infarct (% of LV mass)</td>
<td>17.3 ± 1.1</td>
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<tr>
<td>Total volume (g)</td>
<td>7.0 ± 0.6</td>
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<tr>
<td>Core volume</td>
<td>6.4 ± 0.6</td>
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<tr>
<td>%</td>
<td>90.8 ± 1.3</td>
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<tr>
<td>PIZ volume</td>
<td>0.6 ± 0.1</td>
</tr>
<tr>
<td>%</td>
<td>9.2 ± 1.3</td>
</tr>
<tr>
<td>LVED mass (g)</td>
<td>39.2 ± 1.6</td>
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</table>

* $p < 0.001$ compared with 8-mm slice thickness. † $p < 0.05$ compared with 4-mm slice thickness. ‡ $p < 0.01$ compared with 4-mm slice thickness. § $p < 0.01$ compared with 2-mm slice thickness. ¶ $p < 0.05$ compared with 8-mm slice thickness.

PIZ = peri-infarct zone; other abbreviations as in Table 2.
volume effects to be quantified. At thinner slices, partial volume averaging decreases and CNR increases at the expense of decreased SNR. Unlike the DE-MRI derived PIZ, the DE-MDCT PIZ volume increased with increasing slice thickness. This is likely explained by an increase in CNR in the PIZ that allows better differentiation of viable cells and scar because partial volume averaging is greatly decreased. These advantages, however, are partly offset by increased image noise that may limit PIZ assessment.

Overall, the PIZ in these experiments in chronic infarct scars was small. This is partly because of the lack of collateral coronary circulation in swine species that generates well-delineated infarcts with sharp borders. Further, the iodine washout in the chronic porcine model is more rapid compared with our previous experiments in a canine model of acute MI (15). The rich collateral supply in dog hearts facilitates the passive accumulation and distribution of contrast material in the infarct area and delays the clearance of iodine, creating a more intense infarct signal and greater PIZ. However, our PIZ size correlates well with human data reported for patients with small PIZ volumes (10).

Clinical implications. The potential value of imaging the PIZ has been recently reported (9,10). This very pathologically complex region contains a mixture of both viable and nonviable electrically inactive scar that is thought to provide substrate for ventricular tachycardia via macroreentry mechanisms. Thus, accurate characterization and phenotyping of the PIZ may allow selection of optimal candidates for implantable defibrillators and identify targets for ablation therapy during interventional electrophysiology procedures. We are currently using DE-MDCT of the PIZ for this purpose at our institution in a porcine model of ventricular tachycardia.

Standardized low-radiation DE-MDCT protocols are required for ultimate translation of PIZ assessment into the clinical setting. We have recently described a prospectively gated protocol for high-resolution DE-MDCT imaging that lowers radiation dose by an order of magnitude (27). The focus of such protocols is achieving a reasonable balance of SNR and CNR for visual and quantitative infarct measurements while minimizing partial volume effects. Based on the results of these studies, a slice thickness of 1 to 2 mm seems to provide this balance. Further studies are required to determine optimal threshold cutoffs and determine whether the evaluation of the PIZ with DE-MDCT has prognostic value as suggested for MRI (9,10). The ability to image healed MI in heart failure with DE-MDCT and to quantify the PIZ may enhance identification of patients susceptible to life-threatening arrhythmias and sudden cardiac death.

Study limitations. We applied previously published signal density threshold algorithms to define the infarct core and peri-infarct region. However, specific optimal cutoff values for normal, PIZ, and core zones of myocardium are unknown and are likely dependent on study quality. Additionally, because of the passive contrast kinetics of iodinated

### Figure 6

**Effect of Slice Thickness on DE-MDCT Density and SNR and CNR**

- **A** Signal density in Hounsfield units for the LVBP, IN, PIZ, and RE; the LVBP and RE do not show different attenuation values at different slice thickness, whereas IN values (*p < 0.05, 1 mm vs. 4 mm and 2 mm vs. 4 mm; †p = 0.01, 1 mm vs. 8 mm, 2 mm vs. 8 mm) and PIZ values (‡p < 0.01, 1 mm vs. 4 and 8 mm, and 2 mm vs. 8 mm) change with the reconstructed slice thickness parameters (§p = 0.007 and ¶p = 0.002, respectively).
- **B** Mean MDCT SNR (8 mm vs. 2 and 1 mm (†p = 0.01 and ¶p < 0.01, respectively; and 4 mm vs. 1 mm, *p < 0.05; †p = 0.003), and (C) mean MDCT CNR (8 mm vs. 2 and 1 mm, †p < 0.01; **p = 0.008) change with the reconstructed slice thickness, which reflects reduced imaging quality of thinner reconstructed slices.

- **SNR** signal-to-noise ratio; **IN** infarcted myocardium; **LVBP** left ventricular blood pool; **RE** remote myocardium; **SNR** signal-to-noise ratio; other abbreviations as in Figures 1 and 2.
contrast and the limited collateral circulation in pigs, DE-MDCT imaging of collagenous scar in this model requires a relatively large dose of iodine to cause a sufficient change in the volume of distribution in that myocardial bed. In this study we used $1.5 \times$ a human equivalent dose, although successful viability imaging in humans has been reported in several studies with standard contrast volumes used for coronary CT angiography (25). A further limitation of the study is the lack of quantitative histological gold standards to index the degree of heterogeneity of the PIZ.

**Conclusions**

This study found that DE-MDCT provides an accurate measure of the spatial extent of chronic collagenous infarct scars relative to MRI and post-mortem pathology. The improved spatial resolution of DE-MDCT minimizes partial volume averaging and allows for quantification of complex tissue substrates in the PIZ.

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**REFERENCES**


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