Stress and Rest Dynamic Myocardial Perfusion Imaging by Evaluation of Complete Time-Attenuation Curves With Dual-Source CT

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OBJECTIVES This study sought to describe a protocol for myocardial perfusion imaging using dipyridamole stress, with 128-slice dual-source computed tomography (CT), and to assess the ability of CT myocardial perfusion imaging (MPI) to detect abnormal flow reserve and infarction in comparison with nuclear MPI (NMPI).

BACKGROUND CT MPI has not been previously described with the 128-slice dual-source CT scanner, or with the complete evaluation of dynamic time-attenuation curves of the myocardium.

METHODS Thirty-five patients underwent a stress CT MPI protocol. Complete time-attenuation curves of the myocardium were acquired using a novel scan mode, which acquires prospectively electrocardiogram (ECG)-triggered axial images at 2 rapidly alternating positions. Myocardial blood flow (MBF) values of fixed and reversible defects obtained were compared between rest and stress. Findings on CT MPI were correlated to NMPI. Perfusion defects detected on CT were correlated to coronary stenoses detected on CT angiography (CTA) and invasive coronary angiography (ICA).

RESULTS There was a 1.5-fold difference between stress (1.21 ± 0.31 cc/cc/min) and rest (0.82 ± 0.22 cc/cc/min) MBF in normal tissue. In reversible defects, MBF was 0.65 ± 0.21 cc/cc/min and 0.63 ± 0.18 cc/cc/min at stress and rest, respectively. In fixed defects, the MBF was 0.57 ± 0.22 cc/cc/min at stress and 0.54 ± 0.23 cc/cc/min at rest. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of CT MPI for identifying segments with perfusion defects was 0.83, 0.78, 0.79, and 0.82, respectively. ICA results were available for 30 patients. Sensitivity, specificity, PPV, and NPV of CT MPI compared with ICA were 0.95, 0.65, 0.78, and 0.79, respectively. The radiation dose for CT MPI was 9.15 ± 1.32 mSv for the stress scan and 9.09 ± 1.40 mSv for the rest scan.

CONCLUSIONS Vasodilator-stress CT MPI may be feasible in human subjects at a radiation dose similar to NMPI. It identifies areas of abnormal flow reserve and infarction with a high degree of correlation to NMPI as well as to stenoses detected in CTA and ICA. (J Am Coll Cardiol Img 2010;3: 811–20) © 2010 by the American College of Cardiology Foundation

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Computed tomography (CT) allows noninvasive assessment of coronary stenoses with a high negative predictive value (NPV) (1,2). Beyond detection of coronary morphology, an ideal evaluative approach to coronary artery disease (CAD) would also include functional data about ischemia and infarction (3–5). To date, there are few data regarding CT imaging of myocardial perfusion, besides early experiences with electron beam CT (6). Studies conducted in humans were limited to static imaging of contrast distribution at 1 time point. They aimed either at demonstrating myocardial infarction (MI) at rest only (7,8), or compared static images at stress and rest (9,10). Static imaging lacks quantitative perfusion data such as blood flow and blood volume. Initial reports on dynamic CT myocardial perfusion imaging (MPI) that have evaluated flow have been limited to animal studies (11,12).

In light of these observations, we describe our initial experience with imaging of abnormal flow reserve and infarction with dynamic CT MPI, and compare it with nuclear myocardial perfusion imaging (NMPI).

The purpose of this study was 2-fold: 1) to describe a protocol for MPI using dipyridamole stress with a dual-source CT scanner; and 2) to assess the ability of stress CT MPI to detect abnormal flow reserve and infarction in comparison to the reference standard of dipyridamole-stress nuclear perfusion imaging.

**METHODS**

**Patient population.** All procedures were approved by the Domain Specific Review Boards of the National Healthcare Group, Singapore. Study subjects gave informed consent to participate.

Patients were eligible for the study if they had either fixed or reversible defects on a nuclear stress test within 3 months of the recruitment. Patients were screened for contraindications to cardiac CT and vasodilator administration. These were allergy to iodinated contrast, abnormal renal function (serum creatinine >200 μmol/l and not on renal dialysis), inability to follow breath-hold instructions, a history of active asthma or severe obstructive lung disease, second- (Mobitz Type II) or third-degree AV block without a function-ing pacemaker, atrial fibrillation, an acute MI (within 48 h), unstable MI coronary syndrome, and systolic blood pressure <90 mm Hg.

**Patient preparation.** Patients abstained from caffeine for 12 h and from methylxanthine-containing products, oral dipyridamole, theophylline, and beta-blockers for 24 h before stress testing. An 18-gauge venula was inserted into the right antecubital vein for stress agent and contrast administration. For the perfusion scan, patients were instructed to hold their breath for 30 s. They were asked to exhale gently over a few seconds and not abruptly, if unable to maintain the breath hold. All patients were observed for an hour after the study.

**Stress protocol.** Dipyridamole was infused intravenously at a dose of 0.56 mg/kg body weight over 4 min. Once image acquisition was completed, intravenous aminophylline (1.5 mg/kg body weight) was administered over 5 min to reverse the effects of dipyridamole (13).

**CT perfusion imaging.** Dynamic CT perfusion imaging requires the entire myocardium to be imaged repeatedly over time. This was achieved using a novel electrocardiogram (ECG)-triggered dynamic perfusion scan mode, which became available with the most recent dual-source CT scanner (Somatom Definition Flash, Siemens Healthcare, Forchheim, Germany). The technique allows acquisition of complete time-attenuation curves (TAC) of the aorta and left ventricular myocardium (Fig. 1).

**Axial shuttle scan mode.** The scanner rapidly alternates between 2 table positions and acquires prospectively ECG-triggered axial images at these 2 positions. Alternating between 2 table positions using a detector width of 38.4 mm with an overlap of 10% yields a coverage of 73 mm. For heart rates below 63 beats/min, the 2 table positions are imaged in consecutive heart beats. The resulting sampling rate is 1 full scan every 2 heart beats, and 1 scan every 4 heart beats for heart rates exceeding 63 beats/min.

**Scan parameters.** Data acquisition lasted 30 s. Gantry rotation time was 285 ms, slice collimation 128 × 0.6 mm, tube voltage 100 kV for both X-ray tubes, and the total tube current-time product was 300 mAs/rot. Image acquisition was ECG-triggered at end-systole, 200 ms after the R-wave.

**Image acquisition.** Contrast agent (Ultravist 370, Bayer Schering Pharma, Berlin, Germany) was warmed to body temperature in order to decrease viscosity. Patients received a detailed explanation of the imaging procedure and the breath-hold commands.
The dipyridamole infusion was commenced. Three minutes after the infusion, a test bolus scan was acquired at the level of the mid-left ventricle after injection of 18 cc of contrast, followed by 50 cc of saline. Immediately thereafter, stress perfusion images of the myocardium were acquired with injection of 50 cc of contrast, followed by 50 cc of saline. The scan commenced 4 s before arrival of contrast in the left ventricle; timing was based on the TAC from the test bolus scan.

After the stress scan, aminophylline was administered intravenously over 5 min. Fifteen minutes were allowed to elapse for the effects of the dipyridamole to be reversed and for the heart rate to return to the baseline. If the heart rate differed by more than 20% from that during the stress scan, a second test bolus scan was acquired. Next, rest perfusion images were acquired with the same injection protocol as the stress scan. Thereafter, a coronary CT angiography (CTA) dataset of the entire heart and, if present, bypass grafts was acquired after injection of 60 cc of contrast, followed by 60 cc of saline. A prospectively ECG-triggered axial image acquisition mode was used, with 100-kV tube voltage and 370 reference mAs.

The scan was timed to take place during the maximum attenuation seen in the TAC in the aorta during the rest perfusion scan. Flow rate for all contrast and saline injections was 6 cc/s.

**Image reconstruction.** Each stress or rest scan yielded 10 to 15 3-dimensional volume datasets, containing the TACs for each individual voxel of the entire myocardium.

A dedicated reconstruction algorithm for myocardial perfusion (14) automatically generated each CT image from low spatial frequency components from a full rotation reconstruction and high spatial frequency components from a cardiac reconstruction. This approach yielded images with a high temporal resolution, while maintaining CT value stability (15).

Images were reconstructed with a slice thickness of 3 mm, an increment of 2 mm, and a medium smooth kernel (B25).

**Computation of myocardial blood flow.** Myocardial blood flow (MBF) was computed from the TACs contained in the 4-dimensional volume datasets using a prototype version of now commercially available software (syngo VolumePerfusion-CT-Myocardium, Siemens), installed on a commercially available workstation (syngo Multi Modality).
Workplace, Siemens). All other post-processing was done on that same workstation.

The algorithm contains an automated nonrigid registration of all individual data volumes of the perfusion scan to compensate for effects of residual motion.

Blood flow through each voxel of myocardium was computed based on the maximum slope of the TAC of this voxel (14).

This computation yielded a 3-dimensional CT dataset, with the intensity values representing MBF in cubic centimeters of blood per cubic centimeter of tissue per minute instead of Hounsfield units. These quantitative 3-dimensional color maps of MBF can be analyzed visually or quantitatively, and can be overlaid onto the anatomical Hounsfield unit CT dataset.

Data evaluation. Two readers, by consensus, read the single-photon emission computed tomography (SPECT) data according to the 17-segment American College of Cardiology (ACC) model (16), coding the severity of perfusion defects between 0 and 4 (17).

The rest and stress CT MBF datasets were registered by an automatic algorithm to compensate for motion between the 2 separate scans (syngo 3D Fusion, Siemens). From the registered scans, the same standard long- and short-axis reformatations as in NMPI were generated. The CT perfusion data were read similarly according to the 17-segment ACC model. The two readers, by consensus, established which sections of the CT perfusion images were normal and which were abnormal, and recorded MBF values generated by the above algorithm in rest and stress. A defect was defined as decreased blood flow in comparison to surrounding tissue. A defect was deemed to be reversible on CT MPI if its MBF was less than that of normal myocardium in the stress image as well as in the rest image. A fixed defect was one where MBF was less than that of normal myocardium in the stress image, but was similar to MBF in the normal segments in the rest image. A fixed defect was deemed to be reversible on CT MPI if its MBF was less than that of normal myocardium in the stress image as well as in the rest image.

### RESULTS

#### Patient characteristics.

Twenty-one patients with reversible defects and 14 with fixed defects on NMPI were included in this study. The mean age was 56 ± 12 years, 30 (86%) were male, 14 (40%) had previous MI, 20 (57%) had undergone previous revascularization (percutaneous coronary intervention/coronary artery bypass grafting). Eight (23%) had diabetes, 24 (69%) hypertension, 35 (100%) dyslipidemia, and 8 (23%) were smokers. Thirty (86%) patients also had a coronary angiogram within 3 months of CT MPI.

#### Stress perfusion imaging protocol.

All CT MPI was acquired in 35 patients. In the first 3 patients, the CT MPI protocol was not yet optimized, and TACs were incomplete. These studies are excluded from further analysis, and we present the findings in 32 patients with complete TACs (21 patients with reversible and 11 patients with fixed defects as detected in NMPI).

The myocardial perfusion results of 1,088 segments, or 96 vascular territories, were analyzed (17 segments each in 32 patients, rest and stress perfusion for each patient) on the basis of 1) segmental and 2) defect-level evaluation, sensitivity, specificity, positive predictive value (PPV), and NPV for CT MPI in comparison to NMPI were 0.83, 0.78, 0.79, 0.82 (Table 1), and 0.94, 0.65, 0.93, 0.69, respectively. On average, there was a 1.5-fold difference in MBF in normal segments between stress (1.21 ± 0.31 cc/cc/min) and rest (0.82 ± 0.22 cc/cc/min) CT MPI. In reversible defects, MBF was 0.65 ± 0.21 cc/cc/min at stress and 0.63 ± 0.18 cc/cc/min at rest (Fig. 2). In fixed defects, the MBF was 0.57 ± 0.22 cc/cc/min at stress and 0.54 ± 0.23 cc/cc/min at rest (Figs. 3 and 4). CT MPI correctly identified all 89 fixed and all 64 reversible defects. All fixed defects in CT MPI corroborated with a
ICA correlation existed for 9 out of 11 territories where CT MPI and NMPI disagreed. In 7 territories, ICA confirmed NMPI findings.

**DISCUSSION**

**Key findings.** Our key findings were that 1) vasodilator-stress CT MPI is feasible in human subjects and that 2) CTMPI provides perfusion information comparable to dipyridamole nuclear stress imaging, and identifies areas of abnormal flow reserve and infarction with a high degree of correlation to NMPI.

**Approaches to perfusion imaging.** The term “perfusion imaging” is applied to both static and dynamic imaging. Static arterial phase CT imaging acquires contrast distribution during that specific phase and cannot quantitate blood flow. Arterial contrast distribution inhomogeneity. Past clinical CT MPI research has focused on static imaging of the myocardium because technical limitations have prevented rapid repetitive imaging that is required for dynamic perfusion imaging (10,20,21).

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**Table 1. Diagnostic Accuracy of CT MPI With NMPI as the Reference Standard for Identifying Perfusion Defects in the LAD, LCx, and RCA Territories**

<table>
<thead>
<tr>
<th>Territory</th>
<th>Segment</th>
<th>TP</th>
<th>FP</th>
<th>TN</th>
<th>FN</th>
<th>Sn</th>
<th>Sp</th>
<th>PPV</th>
<th>NPV</th>
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<tbody>
<tr>
<td>LAD</td>
<td>A1</td>
<td>14</td>
<td>2</td>
<td>11</td>
<td>5</td>
<td>0.74 (0.64–0.97)</td>
<td>0.85 (0.39–0.94)</td>
<td>0.88 (0.64–0.97)</td>
<td>0.69 (0.39–0.94)</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>13</td>
<td>3</td>
<td>13</td>
<td>3</td>
<td>0.81 (0.67–0.99)</td>
<td>0.81 (0.39–0.91)</td>
<td>0.81 (0.58–0.95)</td>
<td>0.81 (0.48–0.98)</td>
</tr>
<tr>
<td></td>
<td>A17</td>
<td>22</td>
<td>2</td>
<td>6</td>
<td>2</td>
<td>0.92 (0.54–0.96)</td>
<td>0.75 (0.48–0.93)</td>
<td>0.92 (0.50–0.93)</td>
<td>0.75 (0.52–0.96)</td>
</tr>
<tr>
<td></td>
<td>M1</td>
<td>15</td>
<td>2</td>
<td>12</td>
<td>3</td>
<td>0.83 (0.4–0.97)</td>
<td>0.86 (0.66–0.97)</td>
<td>0.88 (0.35–0.93)</td>
<td>0.80 (0.71–0.99)</td>
</tr>
<tr>
<td></td>
<td>M2</td>
<td>12</td>
<td>2</td>
<td>15</td>
<td>3</td>
<td>0.80 (0.5–0.93)</td>
<td>0.88 (0.6–0.98)</td>
<td>0.86 (0.6–0.98)</td>
<td>0.83 (0.5–0.93)</td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>15</td>
<td>6</td>
<td>10</td>
<td>1</td>
<td>0.94 (0.24–0.91)</td>
<td>0.63 (0.68–0.97)</td>
<td>0.71 (0.24–0.91)</td>
<td>0.91 (0.68–0.97)</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>8</td>
<td>8</td>
<td>14</td>
<td>2</td>
<td>0.80 (0.49–0.91)</td>
<td>0.64 (0.55–0.98)</td>
<td>0.50 (0.62–0.98)</td>
<td>0.88 (0.41–0.89)</td>
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<tr>
<td>LCx</td>
<td>A4</td>
<td>17</td>
<td>1</td>
<td>9</td>
<td>5</td>
<td>0.77 (0.54–0.96)</td>
<td>0.90 (0.54–0.96)</td>
<td>0.94 (0.54–0.96)</td>
<td>0.64 (0.54–0.96)</td>
</tr>
<tr>
<td></td>
<td>M5</td>
<td>13</td>
<td>4</td>
<td>12</td>
<td>3</td>
<td>0.81 (0.7–0.99)</td>
<td>0.75 (0.31–0.89)</td>
<td>0.76 (0.61–0.95)</td>
<td>0.80 (0.4–0.97)</td>
</tr>
<tr>
<td></td>
<td>M6</td>
<td>7</td>
<td>3</td>
<td>20</td>
<td>2</td>
<td>0.78 (0.55–0.92)</td>
<td>0.87 (0.55–1.00)</td>
<td>0.70 (0.73–1.00)</td>
<td>0.91 (0.35–0.87)</td>
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<tr>
<td></td>
<td>B5</td>
<td>13</td>
<td>2</td>
<td>13</td>
<td>4</td>
<td>0.76 (0.59–0.96)</td>
<td>0.87 (0.57–0.98)</td>
<td>0.87 (0.64–0.99)</td>
<td>0.76 (0.52–0.96)</td>
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<tr>
<td></td>
<td>B6</td>
<td>5</td>
<td>3</td>
<td>21</td>
<td>3</td>
<td>0.63 (0.52–0.96)</td>
<td>0.88 (0.64–0.99)</td>
<td>0.63 (0.57–0.98)</td>
<td>0.88 (0.59–0.96)</td>
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<tr>
<td>RCA</td>
<td>A3</td>
<td>19</td>
<td>4</td>
<td>7</td>
<td>2</td>
<td>0.90 (0.66–1.00)</td>
<td>0.64 (0.73–1.00)</td>
<td>0.83 (0.66–1.00)</td>
<td>0.78 (0.73–1.00)</td>
</tr>
<tr>
<td></td>
<td>M3</td>
<td>13</td>
<td>1</td>
<td>17</td>
<td>1</td>
<td>0.93 (0.7–1.00)</td>
<td>0.94 (0.35–0.85)</td>
<td>0.93 (0.48–0.89)</td>
<td>0.94 (0.59–1.00)</td>
</tr>
<tr>
<td></td>
<td>M4</td>
<td>18</td>
<td>3</td>
<td>8</td>
<td>3</td>
<td>0.86 (0.44–0.97)</td>
<td>0.73 (0.41–0.83)</td>
<td>0.86 (0.25–0.75)</td>
<td>0.73 (0.62–0.98)</td>
</tr>
<tr>
<td></td>
<td>B3</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>2</td>
<td>0.82 (0.48–0.98)</td>
<td>0.52 (0.3–0.74)</td>
<td>0.47 (0.24–0.71)</td>
<td>0.85 (0.55–0.98)</td>
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<tr>
<td></td>
<td>B4</td>
<td>17</td>
<td>4</td>
<td>9</td>
<td>2</td>
<td>0.89 (0.73–0.99)</td>
<td>0.69 (0.35–0.97)</td>
<td>0.81 (0.73–0.99)</td>
<td>0.82 (0.35–0.97)</td>
</tr>
</tbody>
</table>

Summary: 544 Seg. 230 Seg. 60 Seg. 208 Seg. 46 Seg. 0.83 0.78 0.79 0.82

Perfusion defects were found in 7 segments in the LAD territory, 5 segments in the LCx territory, and 5 segments in the RCA territory. American College of Cardiology/American Heart Association 17 segment model. CT = computed tomography; FN = false negative; FP = false positive; LAD = left anterior descending coronary artery; LCx = left circumflex coronary artery; MPI = myocardial perfusion imaging; NMPI = nuclear myocardial perfusion imaging; NPV = negative predictive value; PPV = positive predictive value; RCA = right coronary artery; Seg. = segments; Sn = sensitivity; Sp = specificity; TN = true negative; TP = true positive.
Dynamic perfusion imaging refers to repeated imaging of the tissue of interest to capture the inflow and washout of contrast agent. Analytical evaluation of the TACs for each voxel of the imaged volume by dedicated algorithms yields blood flow parameters (22,23). Dynamic perfusion imaging requires a high enough temporal resolution to image at stress heart rates and sufficient detector coverage to image the entire myocardium in rapid succession. The combination of these 2 key capabilities became available only recently with the introduction of a large coverage dual-source CT scanner (24).

Clinical feasibility of the CT perfusion protocol. The stress protocol used for CT MPI was modeled after the dipyridamole-stress NMPI protocol (25). The entire CT perfusion imaging protocol could be completed in 40 min. Patients needed to be able to cooperate with breath-hold instructions for up to 30 s, though use of motion-correction software mitigated the effects of breathing on image evaluation.

End systolic triggering was chosen because at the stress heart rates (26), quality of cardiac CT is equal or better (27) at end-systole and the myocardium is thicker, providing a more robust basis for evaluation (9).

Radiation dose. The radiation dose of 9 mSv for each of the rest and stress CT MPI scans is comparable to the mean radiation dose for single-day technetium stress-rest NMPI of 15 mSv (28). Possible means of reducing dose might include a reduction of tube current. It remains to be evaluated how the resulting increase in image noise would impact CT MPI results.

Identification of perfusion defects. On average, MBF in normal segments varied by a factor of 1.5 between stress and rest images. This ratio is termed the myocardial blood flow reserve (MBFR). For both fixed and reversible defects, the MBFR was 1.08 (Figs. 4A and 4B). In fixed defects, the flow was lower than in normal tissue, both at rest and stress (Fig. 3). In reversible defects, at stress, the flow was lower than that in normal tissue, and at rest, flow in defect and normal tissue were of the same magnitude (Fig. 2).

Differentiating fixed from reversible defects. In order to determine whether a perfusion defect that is
detected during stress is reversible or fixed, it is necessary to compare its MBF to the flow in healthy myocardium at rest. If the defect is also present at rest, i.e., its MBF is less than that of normal tissue at rest, it is considered a fixed defect. If the defect resolves at rest, i.e., has the same MBF as normal tissue, it is considered reversible. Due to the large interindividual variation of MBF values in normal myocardium (29), there are no universal norms for MBF at rest. This indicates a need to perform both stress and rest scans in each patient.

Figure 4B illustrates the interindividual variation of MBF we found. An alternative approach to

![Figure 3. Fixed Defect in CT MPI and NMPI and ICA Findings](image)

Demonstration of a fixed defect involving the anterior wall and septum on CT MPI and NMPI and the corresponding occluded proximal left anterior descending artery in the invasive angiography study. The infarcted area shows a severely reduced MBF of similar magnitude in both the rest and stress images (0.54 cc/cc/min and 0.56 cc/cc/min, respectively, displayed in blue). MBF of the lateral wall and inferior wall in the stress and rest images were 1.10 cc/cc/min (red) and 0.80 cc/cc/min (green) respectively. This demonstrates increased myocardial blood flow during stress in myocardium supplied by LCx and RCA, but no increase in myocardium supplied by the LAD.

Abbreviations as in Figures 1 and 2.

![Figure 4. CT MBF](image)

(A) MBF for normal tissue, fixed and reversible defects at rest and stress. (B) MBF for perfusion defects and normal tissue at stress. Median (cross), interquartile range (box), and mean ± 1.96 SD (whiskers). Abbreviations as in Figures 1 and 2.
assessing the defect at rest might be to replace the dynamic rest CT MPI scan with a static first-pass enhancement scan to detect or exclude infarction. This could lower the radiation dose of CT MPI considerably. The feasibility of obtaining data on severity and extent of a perfusion defect that would allow meaningful comparison to flow values at stress needs to be explored in further studies.

**Range of MBF values in literature.** There is a large interindividual range of MBF values in normal myocardium during vasodilator-stress administration (approximately 2.5 cc/cc/min to 5.0 cc/cc/min) (30,31), and between different modalities (positron emission tomography, cardiac magnetic resonance, dynamic SPECT, and CT [32–35]). The 1.5-fold difference in MBF between stress and rest in our study is at the lower end of the range described in the literature (36,37). It has been previously documented that coronary flow reserve (CFR) and stress MBF in angiographically normal regions of patients with CAD are lower than in normal subjects (38,39). Our entire population has documented CAD (either MI or coronary ischemia), and our findings are consistent with this phenomenon. A reason for varying MBF values obtained from different imaging modalities might lie in different uptake kinetics of contrast agents and tracers used (40). Whether normalization of MBF values between CT MPI and other modalities is possible remains the subject of further research.

**Diagnostic utility of CT MPI.** CT MPI findings corroborated well with NMPI findings in the same territories (Figs. 1 and 2). The fairly high sensitivity and specificity values encourage further investigation as to which patients and which clinical scenarios will benefit most from CT MPI. The high NPVs suggest that patients undergoing CT MPI will be unlikely to have abnormalities if coronary flow measurements are within normal range. This is relevant to the clinical scenarios of ruling out abnormal flow reserve (excluding hemodynamically significant CAD).

**Clinical implications.** This study demonstrates that CT vasodilator-stress perfusion imaging is clinically feasible, can be performed at a radiation dose comparable to NMPI, and has good correlation with reversible and fixed defects detected with NMPI. The criteria for inclusion of patients into this study included an abnormal dipyridamole-stress nuclear stress test. All patients were already classified as high risk for cardiac events, and the study allowed a true comparison as to the correlation between CT MPI and NMPI in this group. This is important given the widespread use of NMPI for the evaluation of patients with CAD and the likelihood that many cardiologists will use NMPI results as the reference standard in the evaluation of any new technique for stress imaging. However, it is also clear that many aspects of CT MPI will require further research before the technique will be utilized in clinical routine. These include the reduction of radiation dose, potential improvement of contrast injection protocols, and the development and validation of quantitation techniques for defect size and severity.

**Study limitations.** This is a single-center study, and although the results are encouraging, the protocol and experiences need to be verified in more patients. The study did not use adenosine or regadenoson, which are more widely utilized in North America as vasodilator-stress agents. Both are significantly more expensive than generic dipyridamole. Nuclear literature and guidelines, however, indicate that dipyridamole is equivalent to the other 2 agents in the detection of abnormal flow reserve.

The study did not compare CT MBF values to a reference standard of absolute MBF from positron emission tomography or cardiac magnetic resonance.

Each study required a total fluid volume infusion (contrast and saline) of close to 500 cc within an hour. The safety of infusing this volume must be evaluated carefully in patients with impaired renal function or left ventricular ejection fraction.

**CONCLUSIONS**

Vasodilator-stress CT MPI is feasible in human subjects at a reasonable radiation dose. It provides perfusion information comparable to dipyridamole nuclear stress imaging and identifies areas of abnormal flow reserve and infarction with a high degree of correlation to NMPI. The ability to obtain accurate perfusion information, in addition to morphologic information from CT coronary angiography imaging, has significant implications in the diagnosis and treatment of patients with CAD.

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Key Words: CT vasodilator-stress myocardial perfusion imaging ■ nuclear myocardial perfusion imaging ■ time-attenuation curve ■ dynamic perfusion imaging.