Reliable Noninvasive Coronary Angiography With Fast Submillimeter Multislice Spiral Computed Tomography

Koen Nieman, MD; Filippo Cademartiri, MD; Pedro A. Lemos, MD; Rolf Raaijmakers, RT; Peter M.T. Pattynama, MD, PhD; Pim J. de Feyter, MD, PhD

Background—Multislice spiral computed tomography (MSCT) is a promising technique for noninvasive coronary angiography, although clinical application has remained limited because of frequently incomplete interpretability, caused by motion artifacts and calcifications.

Methods and Results—In 59 patients (53 male, aged 58±12 years) with suspected obstructive coronary artery disease, ECG-gated MSCT angiography was performed with a 16-slice MSCT scanner (0.42-s rotation time, 12×0.75-mm detector collimation). Thirty-four patients were given additional β-blockers (average heart rate: 56±6 min⁻¹). After contrast injection, all data were acquired during an approximately 20-s breath hold. The left main (LM), left anterior descending (LAD), left circumflex (LCX), and right coronary artery (RCA), including ≥2.0-mm side branches, were independently evaluated by two blinded observers and screened for ≥50% stenoses. The consensus reading was compared with quantitative coronary angiography. MSCT was successful in 58 patients. Eighty-six of the 231 evaluated branches were significantly diseased. Without exclusion of branches, the sensitivity, specificity and positive and negative predictive value to identify ≥50% obstructed branches was 95% (82/86), 86% (125/145), 80% (82/102), and 97% (125/129), respectively. The overall accuracy for the LM, LAD, RCA, and LCX was 100%, 91%, 86%, and 81%, respectively. No obstructed LM, LAD, or RCA branches remained undetected. Classification of patients as having no, single, or multivessel disease was accurate in 78% (45/58) of patients and no patients with significant obstructions were incorrectly excluded.

Conclusions—Improvements in MSCT technology, combined with heart rate control, allow reliable noninvasive detection of obstructive coronary artery disease. (Circulation. 2002;106:2051-2054.)

Key Words: imaging ■ coronary disease ■ angiography ■ stenosis

During the past decade, considerable progress has been achieved in the field of noninvasive coronary imaging with MRI, electron beam computed tomography (EBCT), and, most recently, multislice spiral computed tomography (MSCT). With the use of 4-slice MSCT scanners, promising results have been published; however, cardiac motion and calcium deposits in the coronary artery wall rendered a substantial number of scans incompletely interpretable.1-3

Motion artifacts limit proper assessment, particularly at higher heart rates.4 Recently, a new generation of MSCT scanners, equipped with more and thinner detector rows and increased rotation speed, have been introduced. The purpose of the present study is to evaluate the diagnostic accuracy of noninvasive coronary angiography with the latest-generation MSCT scanner, combined with effective heart-rate control.

Study Population
Fifty-nine patients (53 male, aged 58±12 years) who had suspected coronary obstructions and were scheduled for elective conventional angiography participated in the study. Criteria for exclusion included previous bypass graft surgery, irregular heart rate, allergy to iodine contrast media, and renal insufficiency (serum creatinine ≥120 mmol/L). Significant coronary obstructions were absent in 8 patients. Single-vessel disease was found in 20 patients, 2-vessel disease in 25 patients, 3-vessel disease in 4 patients, and 4-vessel disease in 1 patient. Eight patients previously underwent PTCA with stent implantation. The average interval between MSCT and conventional angiography was 21±17 days. Thirty-seven patients (64%) used β-receptor–blocking medication at the time of the examination. The study was approved by the ethics committee of the university medical center, and all participating patients gave informed consent.

Scan Protocol and Image Reconstruction
CT angiography was performed with the use of a 16-slice MSCT scanner with a 0.42-s rotation time (Sensation 16, Siemens). For cardiac protocols, the 12 inner detector rings are applied. Thirty-four...
patients (58%), 22 of whom already used β-blockers, had a prescan heart rate >65 min⁻¹, and were given a single oral dose of 100 mg metoprolol one hour before the examination in the absence of contraindications. A bolus of 120 to 140 mL ioxaglic acid (320 mgI/ml) was intravenously injected (4 to 5 mL/s⁻¹). As soon as the signal density level in the ascending aorta, which was monitored at a 1.25-s interval, reached a predefined threshold of 100 Hounsfield units, the patient was automatically instructed to maintain an inspiratory breath hold (20.5±1.4 s), during which the CT data and ECG trace were acquired. Scan parameters: detector collimation 12 × 0.75 mm, table feed 6.7 mm/s⁻¹, tube voltage 120 kV, 400 or 450 mAs (depending on the patient size), and estimated radiation exposure between 8 and 9 mSv. After this feature became available, prospectively ECG-controlled roentgen tube modulation was applied in patients (n=15) with a reliable ECG trace to decrease the roentgen output during systole and reduce the exposure by half at low heart rates.5

Synchronized to the recorded ECG, axial slices were reconstructed from the acquired MSCT data with the use of an algorithm that uses only the data from a half gantry rotation per slice, resulting in a temporal resolution of ≈210 ms.6 The continuous data acquisition allows slice reconstruction at different time positions within the cardiac cycle. Three image data sets were reconstructed during the mid-to-end diastolic phase, during which coronary artery displacement is relatively small, with reconstruction window positions starting at 350, 400, and 450 ms before the next R wave. If indicated, additional window positions were explored, although 400 and 450 ms generally provided nearly motion-free results.

**MSCT Image Interpretation**

Two blinded reviewers independently evaluated the MSCT scans by assessment of the axial slices and with case-dependent application of postprocessing tools, such as multiplanar reconstruction and thin-slab maximum intensity projection. Vessel wall calcification was classified as either calcium spots (small isolated eccentric lesions) or severe calcification (large high-density lesions, extending along the wall, causing partial volume and beam hardening artifacts). The image interpretability was classified as good, adequate, or poor. The 4 main coronary branches—left main (LM), left anterior descending (LAD), left circumflex (LCX), and right coronary artery (RCA), including side branches with a diameter of ≥2.0 mm—were screened for significant narrowing (≥50% diameter reduction) of the lumen. Cases of disagreement were settled by a joined consensus reading. Because of the known low interpretability of small coronary stents, the in-stent lumen was not included in the analysis.

**X-Ray Coronary Angiography**

Conventional selective coronary angiography was performed with standard techniques and evaluated by a blinded reviewer with the use of quantitative coronary angiography (CAAS, Pie Medical), catheter-derived image calibration, and automated vessel contour detection, to determine the diameter of all coronary branches. The diameter stenosis, as a percentage of the reference diameter, was determined in two orthogonal directions and the average between the two determined the stenosis severity.

**Statistical Analysis**

The diagnostic accuracy of MSCT to detect significant stenoses in ≥2.0-mm-diameter segments was evaluated regarding QCA as the standard of reference. All vessels, regardless of the image quality, were included. If a coronary branch contained more than one lesion, the most severe lesions in the most proximal branch determined the diagnostic accuracy of the assessment. Standard descriptive statistics were calculated for each observer and the precision of the overall parameters was expressed with a 95% confidence interval. Concordance between observers was calculated and expressed by the κ value.

**Results**

The average heart rate was 56±6 min⁻¹ (range 45 to 70 min⁻¹). One scan that was prematurely triggered by contrast medium detection in the superior vena cava was excluded from the study because of insufficient contrast enhancement. In the absence of a ≥2.0-mm RCA in a single patient, 231 vessels were available for evaluation. Calcified lesions were present in 61% of the branches, half of which limited to small calcified nodules (Figure 1). All coronary branches included, the overall sensitivity and specificity to detect significantly
stenosed branches was 95% (82/86) and 86% (125/145) (Figure 2). Of the vessels containing ≥70% stenoses, 97% (62/64) were identified (Table 1).

All undetected stenoses (n=4), 2 of which were moderate (51% and 55%), were located in the LCX and marginal branches. Twenty false-positive assessments involved seven 40% to 49% lesions. Seven misinterpreted vessel segments contained extensive calcification, and 8 contained calcium spots. Concordance between both MSCT observers was reasonably good (κ value 0.69).

Contrast medium was detected within all 11 stents, and patency was confirmed by conventional angiography. One case of in-stent restenosis (85%) in the distal LAD was not recognized by MSCT.

The predictive value of MSCT angiography to detect patients with no, single, or multivessel disease was 100% (7/7), 75% (12/16), and 74% (26/35), respectively (overall predictive value 78% [45/58]). Seven out of 8 patients without significant lesions were correctly identified. No incorrect exclusion of patients with significant lesions occurred.

**Discussion**

Four-slice MSCT scanners showed promising results but were not robust enough to consistently produce reliable coronary imaging because of insufficient spatial and temporal resolution. Generally, 20% to 30% of the proximal and middle coronary segments were noninterpretable because of insufficient image quality. The use of a scanner with thinner slices and faster rotation, combined with β-blocking, improved the image quality and diagnostic accuracy of MSCT to detect significant disease in all ≥2.0-mm coronary segments. Advantages of the shorter scan time are a more comfortable breath hold (approximately 20 s), less venous contrast enhancement, and a lower contrast dose. The well-tolerated examination can be performed within 15 minutes and requires no hospital admission. Currently, MSCT coronary angiography is not reliable in patients with arrhythmias, high heart rates, or severely calcified vessels. Disadvantages are the still considerable radiation dose and frequently re-

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### Table: Diagnostic Accuracy to Detect Significantly Stenosed Coronary Arteries*

<table>
<thead>
<tr>
<th></th>
<th>RCA</th>
<th>LM</th>
<th>LAD</th>
<th>CX</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥50% stenosed branches</td>
<td>86</td>
<td>22</td>
<td>3</td>
<td>37</td>
</tr>
<tr>
<td>Well assessable</td>
<td>160 (69)</td>
<td>32 (56)</td>
<td>52 (90)</td>
<td>38 (66)</td>
</tr>
<tr>
<td>Adequately assessable</td>
<td>54 (23)</td>
<td>18 (32)</td>
<td>5 (9)</td>
<td>15 (26)</td>
</tr>
<tr>
<td>Poorly assessable</td>
<td>17 (7)</td>
<td>7 (12)</td>
<td>1 (2)</td>
<td>5 (9)</td>
</tr>
<tr>
<td>No detectable calcium</td>
<td>89 (39)</td>
<td>23 (40)</td>
<td>29 (50)</td>
<td>9 (16)</td>
</tr>
<tr>
<td>Small calcified nodules</td>
<td>74 (32)</td>
<td>14 (25)</td>
<td>19 (33)</td>
<td>26 (45)</td>
</tr>
<tr>
<td>Marked calcification</td>
<td>68 (29)</td>
<td>20 (35)</td>
<td>10 (17)</td>
<td>23 (40)</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>82/86 (95, 89–98)</td>
<td>22/22 (100)</td>
<td>3/3 (100)</td>
<td>37/37 (100)</td>
</tr>
<tr>
<td>Specificity</td>
<td>125/145 (86, 83–88)</td>
<td>27/35 (77)</td>
<td>55/55 (100)</td>
<td>16/21 (76)</td>
</tr>
<tr>
<td>Negative predictive value</td>
<td>82/102 (80, 75–83)</td>
<td>22/30 (73)</td>
<td>3/3 (100)</td>
<td>37/42 (88)</td>
</tr>
<tr>
<td>Positive predictive value</td>
<td>125/129 (97, 93–99)</td>
<td>27/27 (100)</td>
<td>55/55 (100)</td>
<td>16/16 (100)</td>
</tr>
</tbody>
</table>

Values are n (%), 95% confidence interval.

RCA, LM, LAD, and LCX indicate right, left main, left anterior descending, and left circumflex coronary artery, respectively.

*:50% lumen diameter reduction, in ≥2.0 mm diameter vessels, consensus reading.
quired use of β-blockers, which were well tolerated but require observation and a prolonged stay of the patient.

For alternative noninvasive coronary imaging modalities, such as EBCT and MRI, good diagnostic results were reported. However, assessment was usually limited to proximal and middle main branches, and ≤25% of these branches were excluded because of insufficient image quality. Development of both techniques is ongoing, and although no direct comparisons have been performed, they seem at this moment outperformed by 12-slice MSCT with respect to stenosis detection. MSCT will not soon equal the versatility or quantitative accuracy of catheter-based imaging techniques, but it does allow noninvasive detection and exclusion of coronary obstructions.

In what clinical setting CT coronary angiography is of most value for the early detection of coronary artery disease, or evaluation of chest pain, should be the focus of future studies.

References
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