Diagnosis of Coronary In-Stent Restenosis With Multidetector Row Spiral Computed Tomography

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OBJECTIVES
The purpose of this study was to assess the accuracy of a new generation spiral multidetector computed tomography (MDCT) scanner (Brilliance 40, Philips Medical Systems, Cleveland, Ohio) in the diagnosis of coronary in-stent restenosis (ISR).

BACKGROUND
Noninvasive imaging of ISR would be clinically useful, but artifacts caused by metallic stent struts have limited the role of early generation MDCT scanners.

METHODS
We examined 65 patients (age 63 ± 12 years, 48 [73.8%] men) with 111 implanted coronary stents who were referred for repeat invasive coronary angiography (ICA). Patients underwent 40-slice MDCT one to three days before scheduled ICA, using intravenous contrast enhancement. Images were reconstructed in multiple formats using retrospective electrocardiographic gating. Stents were viewed in their long and short axes and luminal contrast attenuation graded from MDCT grade 1 (minimal restenosis) to 4 (severe restenosis) by consensus of two observers.

RESULTS
In-stent restenosis (≥60% luminal narrowing by quantitative coronary angiography) was found on ICA in 18 (16.2%) of the stented segments and in 16 (24.6%) patients. The MDCT findings correlated with ICA restenosis, with restenosis in only 1 of 59 (1.6%) MDCT grade 1 segments, but in more than three-quarters (12 of 15, 80%) of MDCT grade 4 segments (sensitivity 72.2%, specificity 92.5%, positive predictive value [PPV] 65.0%, negative predictive value [NPV] 94.5% [five stents not assessable by MDCT considered as restenosis]). Using MDCT grades 3 or 4 combined for restenosis, sensitivity of MDCT was 88.9%, specificity 80.6%, PPV 47.1%, and NPV 97.4%.

CONCLUSIONS
In-stent restenosis can be diagnosed with moderate sensitivity using a new generation 40-slice MDCT scanner. The high NPV implies a significant role for MDCT in excluding ISR. (J Am Coll Cardiol 2005;46:1573–9) © 2005 by the American College of Cardiology Foundation

Although noninvasive diagnosis of in-stent restenosis (ISR) would be clinically useful, assessment of coronary ISR by a noninvasive imaging modality has been limited, with most reports related to in vitro studies (1,2), individual case reports (3–5), or to stent patency only (6,7). Rapid progress in noninvasive imaging with multidetector row spiral computed tomographic scanners has resulted in progressively wider application of multidetector computed tomography (MDCT) in the field of coronary artery imaging. However, most studies of MDCT using 16-slice or earlier scanning technology have necessarily excluded coronary segments with implanted stents due to extensive imaging artifacts generated by metallic stent struts, which obscure the stent and arterial lumen (8–17).

This report presents our experience with a new generation 40-slice MDCT scanner (Brilliance 40, Philips Medical Systems, Cleveland, Ohio) in the diagnosis of ISR in an unselected patient cohort referred for repeat invasive coronary angiography (ICA) due to clinical suspicion of ISR and/or recurrent angina pectoris.

METHODS

Patient population. Patients with prior percutaneous coronary intervention and coronary stent implantation referred for repeat ICA underwent MDCT imaging one to three days before ICA. Patients with renal failure or allergy to contrast media were excluded from the study. All other patients with prior stent implantation were eligible for the study. All coronary stents present in native vessels or bypass grafts were included in the study. Stent type and nominal stent parameters were recorded if available (not routinely available for stents implanted at other institutions). Patients were given an oral beta-blocker (metoprolol 50 to 100 mg) 1 h before the scan if their heart rate was higher than 65 beats/min. All patients gave written informed consent to the procedure in accordance with a study protocol approved by the hospital ethics committee (institutional review board).

Scanning procedure. Scanning was performed using the Brilliance 40 MDCT scanner (Philips Medical Systems) during a 10- to 12-s breath-hold with retrospective electro-
The present study was performed at a dedicated workstation (Philips Extended Brilliance Workspace). Reconstructed images were viewed in multiple formats: original axial slices, curved multiplanar reformats along the axis of the vessel of interest, and cross-sectional images perpendicular to the vessel’s center line (Figs. 1 and 2). The degree of ISR was evaluated and cross-sectional images perpendicular to the vessel’s center line were viewed in multiple formats: original axial slices, curved multiplanar reformats along the axis of the vessel of interest, and cross-sections taken perpendicular to the vessel’s center line (above). The proximal portion (upper) of the stent (A) shows lack of contrast enhancement in relation to the distal portion of the stent (B), demonstrating restenosis in the proximal portion of the stent (quantitative coronary angiography 78%, multidetector computed tomography grade 4). The center line is drawn along the long axis of the stent, and cross-sections taken perpendicular to the center line show lack of contrast in the proximal portion of the stent (A, right) and contrast enhancement in the distal portion of the stent (B, left).

Figure 1. Diagnosis of in-stent restenosis. A curved multiplanar reformatted (MPR) two-dimensional image of the long axis of the stent is shown (center). The proximal portion (upper) of the stent (A) shows lack of contrast enhancement in relation to the distal portion of the stent (B), demonstrating restenosis in the proximal portion of the stent (quantitative coronary angiography 78%, multidetector computed tomography grade 4). The center line is drawn along the long axis of the stent, and cross-sections taken perpendicular to the center line show lack of contrast in the proximal portion of the stent (A, right) and contrast enhancement in the distal portion of the stent (B, left).

Figure 2. Two-dimensional reconstruction of three stents in curved multiplanar reformatted (MPR) format in long axis (below) and short axis perpendicular to the center line (above). (A) Stent fully patent, with homogeneous contrast enhancement throughout the long- and short-axis images (quantitative coronary angiography [QCA] 0%, multidetector computed tomography [MDCT] grade 1). (B) Partially restenosed stent showing lack of contrast enhancement in lower left portion of long-axis image and in crescent shaped portion of short-axis image taken from lower part of the stent (QCA 39%, MDCT grade 2). (C) An obstructed stent, showing lack of contrast enhancement throughout long- and short-axis images (QCA 100%, MDCT grade 4).
including the stent and 5 mm proximal or distal to the stent edges. Interobserver agreement for significant in-stent and in-segment restenosis was high (kappa = 0.88 for both). For grading (grades 1 to 4) of luminal narrowing, agreement was less good (kappa = 0.61 and 0.54 for in-stent and in-segment restenosis, respectively). When readings of the two observers differed, a consensus was reached and used in the final analysis.

Five stents (4.5%) in four patients could not be assessed by MDCT due to surrounding calcification in one, motion artifacts in two, excessive radio-opacity of stent in one, and small size (underexpanded stent) in one. Because restenosis could not be excluded by MDCT in these patients, they were considered to have MDCT restenosis for the purpose of the primary analysis. Two separate analyses were performed: one excluding nonassessable stents and a second excluding stents implanted in saphenous vein bypass grafts (SVG).

In addition to the graded visual analysis of restenosis, a densitometric analysis was performed comparing proximal, mid-, and distal regions inside each stent. The mean and standard deviation of attenuation in Hounsfield units was measured in demarcated regions of interest in all patent assessable stents. The normal range for in-stent variation in attenuation was assessed as a percentage, from the difference in attenuation between three measurements of mean attenuation (proximal, mid-, and distal) and the standard deviation of the differences, in stents with no ISR on quantitative coronary angiography (QCA) or MDCT (<50% narrowing). The normal range was defined as the mean difference ± 2 standard deviations of the difference. Stents with variability in in-stent densitometric measurements outside this range were defined as having ISR by densitometric analysis. In-stent attenuation could not be meaningfully compared with attenuation in the native artery due to the variable and unpredictable influence of surrounding stent struts on the attenuation values obtained within the stent.

ICA. Angiograms were examined before contrast injection to identify sites of stent implantation. Measurement of in-stent and in-segment narrowing was made using QCA (Coronary Artery Analysis System, version 3.2, Pie Medical Imaging, Maastricht, the Netherlands) using the angiographic catheter diameter as reference for calibration. Narrowing of ≥60% of the luminal diameter in the worst view in relation to a reference segment was defined as clinically relevant restenosis. Data were also examined using the 50% binary cutoff value to allow comparison with other studies. The operator was blinded to the results of the MDCT scan.

Statistical analysis. Sensitivity, specificity, positive (PPV) and negative predictive values (NPV), and predictive accuracy (PA) were calculated separately for in-segment and in-stent restenosis using QCA measurements from ICA as the gold standard. All stented segments were included in the analysis. Restenosis could not be excluded in stented segments that were not assessable by MDCT, and these were therefore considered to have restenosis for the purpose of the analysis. A patient-based analysis was also performed. A patient was considered to have restenosis by ICA or MDCT if restenosis was present in any stented segment for either modality. Data were also presented as receiver-operator characteristic curves, and the areas under the curves were reported for QCA cutoff values of 50% and 60%. Diagnostic accuracy of MDCT may be greater for total rather than subtotal stent occlusion. A separate analysis was performed after excluding totally occluded stents. Interobserver variation in MDCT reading was examined separately for presence of significant restenosis and for grade of stenosis for both in-stent and in-segment restenosis using the kappa test.

RESULTS

Patient characteristics. Sixty-five patients (age 63.1 ± 11.6 years, 48 [73.8%] men) with 111 stents were examined by MDCT and ICA. Demographic data, stent type, and parameters are given in Tables 1 and 2. Seventeen patients (26.2%) were studied after recent acute myocardial infarction (ST-segment elevation in 4 patients, 6.2%, non–ST-segment elevation in 13 patients, 20%), but in only two patients was this possibly related to restenosis of a stent. Twelve patients (18.5%) had undergone prior coronary artery bypass surgery. Nine stents (8.1%) were in SVGs and the remainder in native coronary arteries. Mean implanted stent diameter was 3.3 ± 0.5 mm.

Angiographic findings. Restenosis ≥60% by QCA was diagnosed by ICA in 18 stents (16.2%) in 16 patients (24.6%). Total occlusion of 10 stents was found on ICA (9.0% of all stents, 55.5% of stents with restenosis [≥60% cutoff on QCA], 37.0% of stents with ≥50% narrowing on QCA). Using a ≥50% QCA cutoff value, restenosis was diagnosed in 27 stents (24.3%) in 23 patients (35.4%).

Comparison between MDCT and invasive angiography. The correlation between MDCT and ICA findings was close (Fig. 3). Apart from one outlier, none of the stented segments defined as MDCT grade 1 had restenosis of ≥60% by ICA, while more than three-quarters (12 of 15, 80%) with MDCT grade 4 had ≥60% ICA restenosis (five stents that were not assessable by MDCT were excluded). The outlier was a 2.5-mm very poorly expanded stent in a...
Strut thickness (n = 110) mated the QCA assessment. An MDCT grading of 4 we predesignated as restenosis on MDCT) often overesti-
3 represented similar QCA findings so that grade 3 (which
intermediate grades of restenosis by ICA. Categories 2 and
very poor stent visualization. Grades 2 and 3 MDCT had
existence was almost missed on ICA and on MDCT with
3. The findings using the 50% QCA cutoff for restenoses
were slightly different and are given in Table 3.

The sensitivity for in-segment restenosis in the left
anterior descending coronary artery using 60% QCA cutoff
was 83.3% (five of six restenosed left anterior descending
coronary artery stents), left circumflex coronary artery 50%
(one of two stents), and in the right coronary artery 100%
(seven of seven stents). Specificity was 79.5%, 78.3%, and
80%; PPV 38.5%, 16.7%, and 58.3%; NPV 96.9%, 94.7%,
and 100%; and PA 80.8%, 76.0%, and 84.3%, respectively.

Subanalyses excluding total occlusions, bypass grafts, or
nonassessable stents. Diagnostic accuracy of MDCT may
be greater for total rather than subtotal stent occlusion.
In order to examine such differences, data analysis was repeated
after excluding totally occluded stents (Table 3). Correla-
tions remained good other than for PPV, which was fairly
low by this analysis. Restenosis of SVGs may be easier to
diagnose, particularly when totally occluded (three stents).
We performed a further analysis excluding SVGs. Using a
50% QCA cutoff value for assessment of in-segment reste-


Table 2. Stent Parameters

<table>
<thead>
<tr>
<th>Stent Parameters</th>
<th>Value</th>
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<tbody>
<tr>
<td>Stents per patient</td>
<td>1.7 ± 1.0</td>
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<tr>
<td>Diameter (nominal), mm (mean ± 1 SD)</td>
<td>3.3 ± 0.5</td>
</tr>
<tr>
<td>Length (nominal)</td>
<td>13.4 ± 4.4</td>
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<tr>
<td>Vessel implanted</td>
<td></td>
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<tr>
<td>LAD (%)</td>
<td>45 (40.5)</td>
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<tr>
<td>LCx</td>
<td>25 (22.5)</td>
</tr>
<tr>
<td>RCA</td>
<td>32 (28.8)</td>
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<tr>
<td>SVBG</td>
<td>9 (8.1)</td>
</tr>
<tr>
<td>Stent material (n = 64)</td>
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</tr>
<tr>
<td>Stainless steel</td>
<td>57 (89.1)</td>
</tr>
<tr>
<td>Cobalt alloy</td>
<td>7 (10.9)</td>
</tr>
<tr>
<td>Strut thickness (n = 63)</td>
<td></td>
</tr>
<tr>
<td>Thin strut (≤100 µm)</td>
<td>23 (36.5)</td>
</tr>
<tr>
<td>Thick strut (&gt;100 µm)</td>
<td>38 (60.3)</td>
</tr>
<tr>
<td>Stent in stent</td>
<td>2 (3.2)</td>
</tr>
</tbody>
</table>

LAD = left anterior descending coronary artery; LCx = left circumflex artery; RCA = right coronary artery; SVBG = saphenous vein bypass graft.

totally occluded distal branch of the circumflex artery whose
existence was almost missed on ICA and on MDCT with
very poor stent visualization. Grades 2 and 3 MDCT had
intermediate grades of restenosis by ICA. Categories 2 and
3 represented similar QCA findings so that grade 3 (which
we predesignated as restenosis on MDCT) often overesti-
mated the QCA assessment. An MDCT grading of 4
identified in-segment restenosis with sensitivity 72.2%, speci-
ficity 92.5%, PPV 65.0%, NPV 94.5%, and PA of 89.0% (five
stents not assessable by MDCT considered as restenosis) and
showed a sharp differentiation from the other QCA values.
For in-stent restenosis specifically, MDCT grade 4 had a higher
sensitivity of 76.5%, specificity 95.7%, PPV 76.5%, NPV
95.7%, and PA 92.8%. Better detection of in-stent (vs. in-
segment) restenosis may be related to beam hardening artifacts
sometimes present immediately adjacent to stent edges leading to
under- or overdiagnosis of defects at these points.

Because grade 4 MDCT restenosis had excellent speci-
ficity but limited sensitivity for diagnosing QCA ISR, and
MDCT grade 3 was pre-defined as significant in-stent
narrowing, further analysis was based on MDCT grades 3
and 4 combined. Using this definition for MDCT restenosis,
in-segment restenosis (QCA ≥60% definition) was
correctly diagnosed by MDCT in 16 of 18 stents (sensitivity
88.9% [95% confidence interval (CI) 74.4 to 100]) with a
specificity of 80.6% (95% CI 72.6 to 88.7), PPV 47.1% (95%
CI 30.3 to 63.8), and NPV 97.4% (95% CI 93.8 to
100). Predictive accuracy was 82.0% (95% CI 74.8 to 89.1)
(Table 3). A poorer specificity but higher sensitivity and
similarly high NPV were found when analysis was restricted
to in-stent (Table 3). A false negative diagnosis for in-
segment restenosis was made in two cases using the ≥60%
QCA cutoff. One stent was considered to have moderate
(grade 2) intimal proliferation on MDCT and to be 65%
narrowed on QCA, and the second was in a poorly
visualized distal segment (the outlier described in the
preceding text). There were seven false negative diagnoses
using the ≥50% QCA cutoff value. Three had ≥56%
narrowing on QCA, and in five moderate intimal prolifera-
ation (grade 2) was noted on MDCT. On a patient-based
analysis (QCA cutoff ≥60%), sensitivity was high (87.5%
[95% CI 71.3 to 100]), but specificity and NPV were lower
than for the stent-based analysis (65.3% [95% CI 52.0 to
78.6] and 94.1% [95% CI 86.2 to 100], respectively) (Table
3). The findings using the 50% QCA cutoff for restenoses
were slightly different and are given in Table 3.

Figure 3. Box and whisker plot (median value and quartiles) of angio-
graphic in-segment coronary stenosis (measured by quantitative coronary
angiography [QCA]) for each of the four grades of multidetector
computed tomography (MDCT) narrowing (definitions in section “Re-
construction and analysis of MDCT scans”). Group 4 MDCT narrowing
identified 80% of patients with ≥60% QCA restenosis, while restenosis
was excluded in all but one outlier with MDCT grade 1 (stents not assessable by
MDCT [n = 5, 4.5%] are not included in the figure).
A further analysis was performed excluding nonassessable segments (assumed restenosed in main analysis). Using a 50% QCA cutoff value for assessment of in-segment restenosis, sensitivity fell by 1.9 percentage points to 74.1%, specificity increased by 3.1 percentage points to 86.4%, PPV increased by 3.3 percentage points to 62.1%, NPV was unchanged (90.9%), and PA increased by 1.9 percentage points to 83.0%. Using a 60% QCA cutoff value, sensitivity fell by 0.7 percentage points to 88.2%, specificity increased by 3.7 percentage points to 84.3%, PPV increased by 4.6 percentage points to 51.7%, NPV was unchanged (97.4%), and PA increased by 2.9 percentage points to 84.9%.

**Densitometric assessment.** Eighty-seven stents were evaluated for ISR using a densitometric method of assessment. The normal range of variation of in-stent attenuation was 0% to 26% Hounsfield units. Ten stents (11.5%) had ISR by this criterion. Using the 60% QCA cutoff value as the gold standard, sensitivity was 54.5%, specificity 94.7%, PPV 60%, NPV 93.5%, and PA 89.7%.

**DISCUSSION**

This study showed for the first time that, in patients with coronary stents referred for repeat angiography, a new generation MDCT scanner could diagnose or exclude angiographic restenosis in the stented segment with a high degree of certainty. On a patient-related basis, MDCT excluded restenosis in two-thirds of patients. For a patient population similar to that of the present study (patient prevalence of QCA restenosis 25%), MDCT might allow a reduction in the need for ICA in over two-thirds of patients. If the decision to perform ICA were to rely solely on MDCT, this would result in only 1 in 10 stents with restenosis being missed (or 13.5% of patients).

| Table 3. Correlation Between MDCT (Grades 3 and 4 Combined) and Angiographic ISR |
|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| **n** | **% (95% CI)** | **n** | **% (95% CI)** |
| Stent-based analysis | | | | | |
| Invasive angiography cut-off | | | | | |
| In-segment restenosis | QCA ≥50% | QCA ≥60% | | | |
| Sensitivity | 20/27 | 74.1 (57.5–90.6) | 16/18 | 88.9 (74.4–100) | | |
| Specificity | 70/84 | 83.3 (75.4–91.3) | 75/93 | 80.6 (72.6–88.7) | | |
| PPV | 20/34 | 58.8 (42.3–75.4) | 16/34 | 47.1 (30.3–63.8) | | |
| NPV | 70/77 | 90.9 (84.5–97.3) | 75/77 | 97.4 (93.8–100) | | |
| PA | 90/111 | 81.1 (73.8–88.4) | 91/111 | 82.0 (74.8–89.1) | | |
| Area under ROC | 0.75 (0.64–0.86)* | 0.72 (0.61–0.84) | | | | |
| In-stent restenosis | | | | | | |
| Sensitivity | 14/22 | 63.6 (43.5–83.7) | 13/17 | 76.5 (56.3–96.6) | | |
| Specificity | 78/89 | 87.6 (80.8–94.5) | 82/94 | 87.2 (80.5–94.0) | | |
| PPV | 14/25 | 56.0 (36.5–75.5) | 13/25 | 52.0 (32.4–71.6) | | |
| NPV | 78/86 | 90.7 (84.6–96.8) | 82/86 | 95.3 (90.9–99.8) | | |
| PA | 92/111 | 82.9 (75.9–89.9) | 95/111 | 85.6 (79.1–92.1) | | |
| Area under ROC | 0.76 (0.64–0.89) | 0.74 (0.61–0.87) | | | | |
| Patient-based analysis | | | | | | |
| In-segment restenosis | | | | | | |
| Sensitivity | 18/23 | 78.3 (61.4–95.1) | 14/16 | 87.5 (71.3–100) | | |
| Specificity | 29/42 | 69.0 (55.1–83.0) | 32/49 | 65.3 (52.0–78.6) | | |
| PPV | 18/31 | 58.1 (40.7–75.4) | 14/31 | 45.2 (27.6–62.7) | | |
| NPV | 29/34 | 85.3 (73.4–97.2) | 32/34 | 94.1 (86.2–100) | | |
| PA | 47/65 | 72.3 (61.4–83.2) | 46/65 | 70.8 (59.7–81.8) | | |
| Area under ROC | 0.76 (0.64–0.89) | 0.74 (0.61–0.87) | | | | |
| In-stent restenosis | | | | | | |
| Sensitivity | 12/19 | 63.2 (41.5–84.8) | 11/15 | 73.3 (51.0–95.7) | | |
| Specificity | 36/46 | 78.3 (66.3–90.2) | 39/50 | 78.0 (66.5–89.5) | | |
| PPV | 12/22 | 54.5 (33.7–75.4) | 11/22 | 50.0 (29.1–70.9) | | |
| NPV | 36/43 | 83.7 (72.7–94.8) | 39/43 | 90.7 (82.0–99.4) | | |
| PA | 48/65 | 73.8 (63.2–84.5) | 50/65 | 76.9 (66.7–87.2) | | |
| Total stent occlusion excluded | | | | | | |
| In-segment restenosis | | | | | | |
| Sensitivity | 11/17 | 64.7 (42.0–87.4) | 7/8 | 87.5 (64.6–100) | | |
| Specificity | 70/84 | 83.3 (75.4–91.3) | 75/93 | 80.6 (72.6–88.7) | | |
| PPV | 11/25 | 44.0 (24.5–63.5) | 7/25 | 28.0 (10.4–45.6) | | |
| NPV | 70/76 | 92.1 (86.0–98.2) | 75/76 | 98.7 (96.1–100) | | |
| PA | 81/101 | 80.2 (72.4–88.0) | 82/101 | 81.2 (73.6–88.8) | | |

*± 95% CI.

CI = confidence interval; ISR = in-stent restenosis; MDCT = multidetector computed tomography; NPV = negative predictive value; PA = predictive accuracy; PPV = positive predictive value; QCA = quantitative coronary angiography; ROC = receiver-operator characteristic curves.
struts. This obscures part of the stent lumen and increases the apparent external diameter of the stent. In addition, measurement of contrast attenuation inside the stent is likely to be affected by partial volume averaging tending to mask lack of contrast in the narrowed lumen of the stented segment. Thinner slice scanning (0.67 mm) allows reduction in image noise, and almost complete isotropic spatial resolution obtainable with the 40-slice scanner allows better resolution in the Z axis than previously available. Together these technological improvements help to mitigate artifacts, although some error may remain in assessment of stents oriented vertically to the X-ray beam (18).

Patient and stent-related factors may also affect MDCT interpretation. As opposed to earlier generation 4- and 16-slice scanners, the greater field coverage with 40-slice MDCT allows shorter scanning times so that a study can be completed in 10 to 12 s, obviating the need for prolonged breath-holding. The shorter scanning time reduces the likelihood of irregular beats and allows motion-free scanning in a larger proportion of patients than previously possible. Regarding stents themselves, stent model and strut material may play a role in defining imaging artifacts, although strut thickness does not appear to be important in this regard (18).

Utility of MDCT as a screening test for ISR. The sensitivity of grade 3 to 4 MDCT narrowing for ISR was 88.9%, but PPV was relatively low (47.1% stent-based, 45.2% patient-based). In the present era of drug-eluting stents, the incidence of restenosis is low and decreasing. If the test were to be used to diagnose or exclude restenosis in a population with a lower prevalence of ISR, the rather low PPV would result in a rather high proportion of false positive diagnoses. However, the very high NPV makes current MDCT a potentially useful screening test for exclusion of ISR, especially when the expected angiographic ISR rate is low.

Total occlusions and bypass grafts. The diagnosis of total occlusion of a stented segment on MDCT is more straightforward than partial obstruction, and totally occluded SVGs in particular are easily recognizable on MDCT. The higher the prevalence of total occlusions in the population examined, the greater the sensitivity and PPV of MDCT is likely to be. Ten stented segments were totally occluded in the present study including three SVGs; MDCT diagnosed eight of these correctly, and one additional segment was not assessable due to heavy calcification. One totally occluded segment was poorly visualized and incorrectly diagnosed. A repeat analysis after exclusion of totally occluded segments showed similar sensitivity, specificity, and NPV, but PPV was low (Table 3).

Alternative densitometric assessment of MDCT. Densitometric analysis of stents was examined as a possible alternative method for assessing in-stent stenosis. It was not possible to directly compare in-stent attenuation with that in the native coronary vessel due to the effect of stent struts on the intraluminal stent measurements, even when the struts were outside the defined region of interest. We therefore measured the variability of attenuation within the stent because ISR often occurs along a limited length of the stent. This assessment suffered from the lack of a previously defined normal range for comparison, and this we determined from our own data. It seems likely that, even within the stent, the influence of the stent struts on the measurement may be variable thereby increasing the variability of the measurement and the range of calculated normal values and decreasing the sensitivity for restenosis. Restenosis occurring in a uniform fashion throughout the stent (diffuse ISR) would not be detected by this method.

Study limitations. We examined a selected cohort of patients referred for repeat invasive angiography after clinical suspicion of ISR. Wider applicability to an asymptomatic stent population may yield different results. Nonetheless, it is precisely in symptomatic patients that MDCT should prove to be invaluable, and indeed may obviate the need for invasive angiography in a significant number by excluding ISR. We used a 60% cutoff value for defining ISR by QCA. A 50% binary cutoff value on QCA for ISR increased specificity but decreased sensitivity. However, although widely reported in many studies, the clinical relevance of a 50% restenosis cutoff value regarding selection of patients for repeat intervention is not clear. Grade 4 MDCT narrowing was highly specific but had limited sensitivity for diagnosing ISR. The diagnosis of ISR correlated less well in the intermediate zones (MDCT 2 and 3). We expect improved correlation in these areas as experience in reading and interpreting MDCT of stented segments improves. As MDCT technology provides better definition of lesions, a more quantitative assessment of stent narrowing might be attempted using caliper-based measurements. It should be noted that the clinical significance of intermediate degrees of ISR often depends on additional angiographic findings.

Clinical implications. This study showed that MDCT imaging of coronary stents with new generation technology was feasible and practical, and the technique provides a valuable addition to our diagnostic capability for diagnosing or excluding ISR when its limitations are appreciated. The high NPV makes MDCT a potentially valuable diagnostic tool in patients with clinical symptoms but low expected angiographic ISR rates.

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