Detection of coronary artery stenoses using multi-detector CT with $16 \times 0.75$ collimation and 375 ms rotation

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Aims Insufficient spatial and temporal resolutions have limited image quality and accuracy of multi-detector CT (MDCT) for coronary artery visualization and detection of stenoses. We assessed the accuracy of a new 16-slice scanner with 370 ms rotation and 0.75 mm collimation for detection of coronary stenoses using an analysis approach based on coronary artery segments.

Methods and results Fifty consecutive patients scheduled for diagnostic coronary angiography in stable clinical condition and sinus rhythm were enrolled. All patients with a heart rate >60 b.p.m. received 100 mg atenolol p.o. and up to four doses of 5 mg metoprolol i.v. before the scan. MDCT was performed using $16 \times 0.75$ mm collimation, 120 kV, and ECG-gated tube current modulation. Ninety millilitres of contrast agent was injected intravenously. MDCT images were visually analysed using the 16-segment coronary artery model of the American Heart Association and compared with invasive, quantitative coronary angiography in a blinded fashion. A significant stenosis was assumed if the diameter reduction was $\geq 50\%$. Mean heart rate was 58 b.p.m. during MDCT. After exclusion of two patients with not fully evaluable data sets, MDCT correctly identified at least one coronary stenosis in all 25 patients with significant coronary lesions in angiography and correctly demonstrated the absence of stenoses in 19/23 patients (sensitivity 100%, specificity 83%). Sensitivity and specificity for all 50 patients were 93 and 83%, respectively. On a per-segment basis, nine coronary segments distal of total occlusions and 128 coronary segments with a reference diameter $<1.5$ mm were excluded from the analysis. Twenty-eight of the included 663 segments (4%) were unevaluable due to calcification or motion artefact. In the remaining 635 segments, 50/53 stenoses were detected by MDCT (sensitivity 94%, specificity 96%, negative predictive value 99%, positive predictive value 69%).

Conclusion Increasing temporal and spatial resolutions of MDCT lead to improved evaluation and diagnostic accuracy for detection of coronary stenoses.

Introduction Multi-detector spiral CT (MDCT) with retrospective ECG gating has been shown to permit visualization of the coronary artery lumen as early as 2000.\textsuperscript{1,2,3} However, initial scanner generations with four detector rows provided neither sufficient imaging speed nor spatial resolution so that motion artefacts or partial volume effects frequently rendered images unevaluable and diagnostic performance was not sufficient for clinical applications.\textsuperscript{4-10} The recent introduction of 16-slice MDCT with 0.5–0.75 mm slice collimation and rotation times of 420–500 ms increased both spatial and temporal resolutions. Consequently, unevaluable studies became less frequent and diagnostic accuracy did increase. In five comparisons between 16-slice MDCT and invasive coronary angiography published so far, the sensitivity for detection of haemodynamically relevant coronary artery stenoses by MDCT ranged from 89 to 95\%, whereas specificities were reported to be between 86 and 98%.\textsuperscript{11-15} In these five studies, up to 16\% of coronary arteries were excluded from analysis due to reduced image quality. It has been shown that the presence of large amounts of coronary calcium severely limits the diagnostic accuracy of MDCT.\textsuperscript{16} Recently, a technically improved 16-slice MDCT system with faster rotation time (375 ms) and a more powerful X-ray tube has been introduced.\textsuperscript{17,18} The results of two studies using this technology differed, with sensitivity for stenosis detection ranging from 82 to 95\%.\textsuperscript{17,18} We thus performed a comparison between MDCT and quantitative coronary angiography (QCA) to re-evaluate its accuracy for stenosis detection on a per...
Methods

Patients

Fifty patients who had been referred for a first invasive diagnostic coronary angiography due to suspected, stable coronary artery disease (CAD) were included. We consecutively enrolled all patients referred to our institution for inpatient angiography between 23 January and 13 April, 2004 who had no exclusion criteria and who agreed to participate in the study. During that time interval, a total of 157 inpatients had been admitted for a first diagnostic coronary angiography to our institution. Exclusion criteria were acute coronary syndromes (chest pain at rest, ECG changes suggestive of acute ischaemia or infarction, or elevated cardiac enzymes), absence of sinus rhythm, renal failure (serum creatinine >1.5 mg/dL), simultaneous evaluation for valvular heart disease, known allergy to contrast agent or contraindications to the administration of iodine, and a possible pregnancy. The mean age of the patients was 62 ± 8 years (range: 42–77 years), 25 were female and 25 were male. The mean heart rate 1 h before the MDCT scan was 72 ± 10 b.p.m. (Table 1). All patients who were approached agreed to participate in the MDCT scan.

Multi-detector spiral CT

One hour prior to the MDCT scan, all 43 patients with a heart rate of ≥60 b.p.m. received a single dose of 100 mg atenolol po and, if the heart rate was >60 b.p.m. at the time of MDCT scanning, up to four doses of 5 mg metoprolol i.v. to lower the heart rate to <60 b.p.m. Lowering of the heart rate served to improve image quality through reduction of motion artefacts and to lower radiation exposure in conjunction with ECG-gated tube current modulation (see subsequently). In addition, all patients received 0.8 mg isosorbid dinitrate s.i. immediately prior to MDCT scanning. MDCT was performed using a Sensation 16 Cardiac CT scanner (Siemens Medical Solutions, Erlangen, Germany). After determination of the contrast agent transit time using bolus injection of 10 mL contrast agent (350 mg iodine/mL) was injected continuously into a peripheral vein at 5 mL/s, followed by 50 mL saline, also at 5 mL/s.

Axial cross-sectional images were reconstructed with 1.0 mm slice thickness, 0.5 mm increment and using a half-scan reconstruction algorithm with a temporal resolution of 185 ms in the centre of the scan field. The initial reconstruction was performed with the reconstruction window starting at 65% of the R-peak to R-peak interval. Additional reconstructions (in 5% increments and decrements) were performed if motion artefacts were present.

All MDCT data were evaluated by a single, experienced observer blinded to all clinical data of the patients. The 16-segment model of the American Heart Association was used to define the coronary segments that formed the basis for evaluation. MDCT data sets were reviewed based on interactive reviewing of the acquired axial images, multiplanar reconstructions, and thin-slab maximum intensity projections (Figures 1 and 2). In the first step, the coronary segments were identified based on side branches. Each segment was then judged to be ‘evaluable’ or ‘unevaluable’ (presence of severe calcification, motion artefact, or vessel calibre too small to assess the presence or absence of stenosis). All evaluable segments were subsequently visually judged concerning the presence or absence of ‘significant stenosis’ (diameter reduction of ≥50%).

Three-dimensional reconstructions (surface-weighted volume rendering technique) were created only to display results, they were not used for analysis.

Quantitative coronary angiography

Invasive coronary angiography was performed 1 day following multislice computed tomography (MSCT) via a transradial or transfemoral approach. Standard projections were obtained after intracoronary injection of 0.2 mg isosorbid dinitrate. Coronary angiograms were evaluated off-line by an independent observer using QCA software (‘QuantCor.QCA’, Pie Medical Imaging) and used as gold standard for stenosis detection. The proximal luminal diameter of all coronary segments was measured. In segments with a reference diameter of <1.5 mm, lesions with a diameter reduction of ≥50% were considered to represent significant stenoses. Segments with a diameter of <1.5 mm were excluded from analysis because they usually do not constitute targets for revascularization.

Table 1 Demographic data and prevalence as well as severity of CAD

<table>
<thead>
<tr>
<th></th>
<th>All patients</th>
<th>Men</th>
<th>Women</th>
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<tbody>
<tr>
<td>n</td>
<td>50</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Age (years)</td>
<td>62 ± 8</td>
<td>61 ± 7</td>
<td>62 ± 9</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>82 ± 16</td>
<td>89 ± 14</td>
<td>77 ± 15</td>
</tr>
<tr>
<td>Heart rate 1 h before MDCT (1 b.p.m.)</td>
<td>72 ± 10</td>
<td>72 ± 11</td>
<td>71 ± 9</td>
</tr>
<tr>
<td>Heart rate during MDCT (1 b.p.m.)</td>
<td>58 ± 6</td>
<td>57 ± 5</td>
<td>59 ± 6</td>
</tr>
<tr>
<td>Pre-test likelihood of CADa</td>
<td>59 ± 8</td>
<td>76 ± 21</td>
<td>42 ± 24</td>
</tr>
<tr>
<td>CAD</td>
<td>27 (54%)</td>
<td>19 (76%)</td>
<td>8 (32%)</td>
</tr>
<tr>
<td>One-vessel disease</td>
<td>13 (26%)</td>
<td>7 (28%)</td>
<td>6 (24%)</td>
</tr>
<tr>
<td>Two-vessel disease</td>
<td>11 (22%)</td>
<td>10 (40%)</td>
<td>1 (4%)</td>
</tr>
<tr>
<td>Three-vessel disease</td>
<td>3 (6%)</td>
<td>2 (8%)</td>
<td>1 (4%)</td>
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</table>

aPre-test likelihood of having at least one coronary artery stenosis based on age, gender, and type of symptoms.19

Statistical analysis

Initial analysis was patient based. Patients were considered ‘evaluable’ if all segments were judged to be evaluable and free of stenoses by MDCT or if at least one stenosis had been detected by MDCT. The sensitivity, specificity, and negative and positive predictive values of MDCT to identify patients with at least one stenosis in any vessel segment that had a reference diameter of at least 1.5 mm was determined for ‘evaluable’ patients and for all patients (classifying patients in whom not all vessel segments were evaluable and no coronary stenoses were detected in the evaluable segments as negative for the presence of stenoses). For per-vessel and per-segment analysis, 128 vessel segments with diameter of <1.5 mm in QCA and nine vessel segments distal to three total coronary occlusions were excluded from the analysis. In the remaining 663 segments, the number of ‘evaluable’ coronary arteries and segments by MDCT was determined and for the evaluable arteries and segments, the sensitivity, specificity, and negative and positive predictive values for detection of stenoses with a diameter reduction >50% was determined. Arteries were only considered evaluable if all segments were judged to be evaluable and free of stenoses by MDCT or if at least one stenosis had been detected by MDCT. In
addition, analysis was repeated with inclusion of the ‘unevaluable’ segments, classifying segments with unevalable image quality as failing to show stenosis in MDCT.

Results

MDCT scanning was performed without complications in all 50 patients (Figures 1–6). The mean heart rate during the MDCT scan was $58 \pm 6$ b.p.m. Thirty-two patients had a heart rate of less than $60$ b.p.m. A total of 59 stenoses exceeding 50% diameter reduction were present in the patient group. Fifty-three of these stenoses were located in the 635 segments judged to be ‘evaluable’ by MDCT (mean diameter reduction in QCA: $67 \pm 8\%$).

Per-patient analysis

Clinically, it seems most important to detect patients with at least one significant coronary stenosis in order to initiate further workup and treatment. On a per-patient basis, the MDCT exam was classified as ‘unevaluable’ in two of 50 cases because not all coronary segments were evaluable in MDCT and no stenosis was demonstrated in the evaluable segments. Both of these patients had significant coronary artery lesions in QCA. All other 25 patients with at least one significant coronary stenosis were correctly identified by MDCT (overall sensitivity: 93%, sensitivity 100% in ‘evaluable’ patients). In 19/23 patients, the absence of coronary artery stenoses was correctly detected by MDCT (specificity: 83%, negative predictive value: 100%, positive predictive value: 86%, Table 2).

If analysis was limited to the 32 patients with a heart rate $<60$ b.p.m., per-patient sensitivity was unchanged but specificity was slightly increased to 88%.

Per-artery analysis

Most earlier studies on detection of coronary artery stenoses by computed tomography were evaluated on a per-artery basis. In our study, 193/200 vessels were judged to be ‘evaluable’ (either at least one stenosis seen in MDCT or all segments $\geq 1.5$ mm diameter evaluable and free of stenosis). Of the seven ‘unevaluable’ arteries, three had a significant

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Figure 1  Axial MDCT images (slice thickness 1.0 mm) acquired after intravenous injection of contrast agent in a patient without coronary artery stenoses. (A) Level of the proximal left coronary artery. A segment of the proximal left anterior descending coronary artery (large arrow) and a cross-section of the proximal left circumflex coronary artery (arrowhead) can be seen. (B) Origin of the right coronary artery (small arrow) from the ascending aorta. Large arrow, left anterior descending coronary artery; arrowhead, left circumflex coronary artery. (C) Level of the mid right coronary artery (small arrow). Large arrow, left anterior descending coronary artery; arrowhead, left circumflex coronary artery. (D) Level of the distal right coronary artery (small arrow).
Figure 2  Same patient as in Figure 1. Curved multiplanar reconstructions show the complete course of the coronary arteries (A–C). Thresholded three-dimensional reconstructions show the contrast-filled lumen of the coronary vessels (D and E). (A) Curved multiplanar reconstruction of the left main (small arrow) and left anterior descending coronary artery (large arrow). (B) Curved multiplanar reconstruction of the left circumflex coronary artery (arrow). (C) Curved multiplanar reconstruction of the right coronary artery (arrow). (D–F) Three-dimensional reconstructions showing the left anterior descending (large arrow), left circumflex (arrowhead), and right coronary artery (small arrow).
Figure 3  Patient with a stenosis of the left anterior descending coronary artery. (A) Five millimetres maximum intensity projection of the proximal left anterior descending coronary artery. A stenosis is visible prior to the origin of a diagonal branch (arrow). (B) Three-dimensional reconstruction (arrow: stenosis of left anterior descending coronary artery). (C) Invasive coronary angiogram in a.p. cranial projection. Stenosis of the left anterior descending coronary artery (arrow; 56% diameter reduction in QCA).

Figure 4  Patient with a stenosis of the right coronary artery. (A) Curved multiplanar reconstruction of the right coronary artery (arrow: stenosis). (B) Three-dimensional reconstruction (arrow: stenosis of the right coronary artery). (C) Invasive coronary angiography in left antero-oblique (LAO) projection confirms a stenosis of the right coronary artery with 78% diameter reduction in QCA (arrow).
lesion in QCA and four did not. Out of the 193 evaluable arteries, 41 had at least one significant stenosis in QCA and 40 of these were correctly detected in MDCT (sensitivity: 98%). Out of 152 arteries, 136 were correctly classified as normal (specificity: 90%). If the seven 'unevaluable' arteries were included and considered as failing to show stenosis in MDCT (three of these seven arteries actually had a significant stenosis in coronary angiography), sensitivity for stenosis detection was 91% (40/44), specificity was 90%, negative predictive value was 97%, and positive predictive value was 71%.

**Per-segment analysis**

Out of the 663 coronary artery segments included in the analysis, 28 (4%) were classified as 'unevaluable' in MDCT (13 due to the presence of severe calcification, 15 due to the presence of motion artefact). In 44 patients, all segments that were included in the analysis were evaluable. In the 635 evaluable segments, 53 stenoses were present in QCA and 50 of these stenoses were detected in MDCT (sensitivity: 94%, see Table 2). Out of 582 segments, 559 were correctly classified as normal (specificity: 96%). The negative and positive predictive values were 99 and 68%, respectively. In six of the 28 unevaluable segments, a significant stenosis was present in invasive coronary angiography. If unevaluable segments had been included in the evaluation and MDCT had been classified as 'negative' (no stenosis detected), the sensitivity and specificity would have been 85 and 95%.

Per-segment analysis was repeated separately for the 25 men and 25 women in the patient group. The prevalence of coronary stenoses in men (40 stenoses in 322 segments, 12%) was significantly higher than in women (13 stenoses in 313 segments, 4%, \(P < 0.001\)). For evaluable segments, sensitivity was 98% (39/40) and specificity was 95% (268/282) in men. In women, sensitivity was 85% (11/13) and specificity was 97% (291/300). The number of false-positive and false-negative findings was not significantly different between the two groups.

**Discussion**

In our study, we found a high sensitivity and specificity as well as a high negative predictive value for the detection of coronary artery stenoses by MDCT in a group of 50 consecutive patients with suspected CAD. After excluding two patients in whom not all coronary segments were evaluable, all patients with at least one significant coronary artery lesion were detected by MDCT. As postulated earlier,\(^{21}\) MDCT thus seems to be a useful tool to rule out haemodynamically significant coronary artery stenoses in patients with suspected CAD. Our study is different from previous studies performed by MDCT. Scanner technology has been improved over the material used in previous studies (with faster tube rotation, resulting in a higher temporal resolution of 188 ms in the centre of the field of view and with a stronger X-ray tube, resulting in less image noise). In addition, the patient group was homogeneous with no inclusion of patients with known CAD and a strict protocol has been used to lower the heart rate in all patients who initially presented with a rate of >60 b.p.m. Thus, a mean heart rate of...
58 b.p.m. was achieved during the scan (without any complications due to the use of beta-blockers). Because of these technical improvements, both the rate of evaluable patients, arteries, and coronary artery segments, as well as the diagnostic accuracy of MDCT were higher than in previous reports. Indeed, we found only 4% of vessel segments to be unevaluable due to calcification or remaining motion artefact, whereas in previous studies performed with MDCT scanners at sub-millimetre collimation, the rate of unevaluable arteries was as high as 16%.14

Limitations

Among the limitations of our study is the fact that MDCT images were evaluated visually and, as opposed to the invasive coronary angiograms, not using quantitative analysis software. So far, however, no such algorithms have been evaluated. Only one observer evaluated all MDCT data sets and interobserver variability was not assessed. Previous studies, however, have shown that interobserver variability is low.13,14 Inaccuracies may have occurred due to the assignment of coronary segments to the MDCT data sets and invasive coronary angiograms, it has so far not been evaluated how accurately coronary artery segments, which are usually identified through side branches, can be assigned in one or the other method. We did not perform a separate analysis of coronary calcification because no non-enhanced scan was performed for reasons of radiation exposure. The sample size was relatively small but similar to previous studies that addressed the same question. However, sample size was not formally calculated and the predictive power of the study has not been assessed. Finally, the prevalence of coronary stenoses was relatively low in our patient group, which may have partly been due to the fact that women, in contrary to the real-world situation, comprised 50% of our patient sample.

Analyses of the diagnostic accuracy of MSCT on a per-artery and per-segment basis may have been confounded due to inpatient correlations: the occurrence of a stenosis in a coronary artery is more likely if another vessel of the same patient also has a haemodynamically significant lesion. Therefore, per-patient analysis is the most reliable analysis because it avoids this form of bias which can otherwise severely confound the analysis of diagnostic accuracy. In addition, the exclusion of small coronary segments (diameter <1.5 mm) may have led to a selection bias and to a possible overestimation of sensitivity because it is likely that stenoses in smaller vessel segments, given the difficulties in evaluating smaller structures, would have been missed by MDCT. However, vessel segments with a diameter of <1.5 mm do not constitute a target of

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<th>Evaluable</th>
<th>Sensitivitya (%)</th>
<th>Specificitya (%)</th>
<th>Negative predictive valuea (%)</th>
<th>Positive predictive valuea (%)</th>
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<tbody>
<tr>
<td>Per-segment analysis</td>
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<td>63.5/53</td>
<td>96</td>
<td>635/582</td>
<td>559/562</td>
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<tr>
<td></td>
<td>96%</td>
<td>50/53</td>
<td>96</td>
<td>(85–98)</td>
<td>559/562</td>
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<td></td>
<td></td>
<td>94%</td>
<td>(94–97%)</td>
<td></td>
<td>559/562</td>
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<tr>
<td></td>
<td>Per-artery analysis</td>
<td>193/200</td>
<td>40/41</td>
<td>136/152</td>
<td>136/137</td>
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<tr>
<td></td>
<td>96%</td>
<td>90%</td>
<td>90%</td>
<td>(87–100%)</td>
<td>136/137</td>
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<tr>
<td></td>
<td></td>
<td>(84–93%)</td>
<td>(96–100%)</td>
<td></td>
<td>40/56</td>
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<tr>
<td></td>
<td>Per-patient analysis</td>
<td>48/50</td>
<td>25/25</td>
<td>19/23</td>
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<tr>
<td></td>
<td>96%</td>
<td>83%</td>
<td>83%</td>
<td>(84–100%)</td>
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<td></td>
<td></td>
<td>(62–92%)</td>
<td>(80–100%)</td>
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<td>25/29</td>
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aNumbers in parentheses give 95% confidence interval. In evaluable segments.
revascularization therapy and are, in the context of coronary interventions for symptomatic CAD, not relevant. Thus, the limitation of our analysis to vessel segments >1.5 mm diameter is clinically justified.

General limitations of MDCT for coronary artery imaging include the fact that not all patients can currently be investigated. Sinus rhythm is a pre-requisite, and heart rates of ≥60 b.p.m. are prone to create artefacts. The application of potentially nephrotoxic contrast agent is necessary and radiation exposure is not negligible.22–24 Finally, severe calcifications can render images unevaluable and coronary stents cannot be visualized with sufficiently good image quality to reliably rule out in-stent restenosis.25 Further improvements in temporal and especially spatial resolution will improve image quality and applicability of MDCT for coronary imaging, albeit at the cost of higher radiation dose.

In general, MDCT as performed in this study permits only visualization of the coronary artery morphology, and not the analysis of myocardial perfusion. Data on myocardial function could be extracted from the same data set,26–28 but only during rest, and additional stress imaging would require another dose of contrast agent and radiation.

Clinical implications

In the selected patient group we included in our study, patients in sinus rhythm with suspected, but not pre-existing CAD, MDCT seems to be able to reliably detect those patients who have at least one coronary stenosity. Presence of stenosis can safely be ruled out if an MDCT scan of diagnostic quality fails to demonstrate coronary artery stenoses. This application of MDCT may potentially have a clinical impact on the management of patients who are symptomatic, but have a low pre-test likelihood of significant CAD. Invasive studies would not be necessary if MDCT demonstrated normal coronary arteries. In this context, MDCT will have to compete with other diagnostic modalities, such as stress magnetic resonance imaging, echocardiography, or nuclear medicine studies. Obviously, potential clinical advantages of MDCT will need to be verified in clinical studies of substantially larger size than our investigation.

References

