Noninvasive Coronary Angiography by 320-Row Computed Tomography With Lower Radiation Exposure and Maintained Diagnostic Accuracy

Comparison of Results With Cardiac Catheterization in a Head-to-Head Pilot Investigation

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Background—Noninvasive coronary angiography with the use of multislice computed tomography (CT) scanners is feasible with high sensitivity and negative predictive value; however, the radiation exposure associated with this technique is rather high. We evaluated coronary angiography using whole-heart 320-row CT, which avoids exposure-intensive overscanning and overranging.

Methods and Results—A total of 30 consecutive patients with suspected coronary artery disease referred for clinically indicated conventional coronary angiography (CCA) were included in this prospective intention-to-diagnose study. CT was performed with the use of up to 320 simultaneous detector rows before same-day CCA, which, together with quantitative analysis, served as the reference standard. The per-patient sensitivity and specificity for CT compared with CCA were 100% (95% confidence interval [CI], 72 to 100) and 94% (95% CI, 73 to 100), respectively. Per-vessel versus per-segment sensitivity and specificity were 89% (95% CI, 62 to 98) and 96% (95% CI, 90 to 99) versus 78% (95% CI, 56 to 91) and 98% (95% CI, 96 to 99), respectively. Interobserver agreement between the 2 readers was significantly better for CCA (97% of 121 coronary arteries) than for CT (90%; \(P=0.04\)). Percent diameter stenosis determined with the use of CT showed good correlation with CCA (\(P<0.001, R=0.81\)) without significant underestimation or overestimation (\(-3.1\pm24.4\%\); \(P=0.08\)). Intraindividual comparison of CT with CCA revealed a significantly smaller effective radiation dose (median, 4.2 versus 8.5 mSv; \(P<0.05\)) and amount of contrast agent required (median, 80 versus 111 mL; \(P<0.001\)) for 320-row CT. The majority of patients (87%) indicated that they would prefer CT over CCA for future diagnostic imaging (\(P<0.001\)).

Conclusions—CT with the use of emerging technology has the potential to significantly reduce the radiation dose and amount of contrast agent required compared with CCA while maintaining high diagnostic accuracy. (Circulation. 2009;120:867-875.)

Key Words: angiography ■ computed tomography ■ coronary disease ■ coronary vessels ■ imaging

Reliably detecting coronary artery disease (CAD) in a noninvasive manner is a pivotal goal of today’s medicine, most importantly because of the increasing prevalence and mortality\(^1\) and the economic impact of CAD.\(^2\) Until relatively recently, conventional coronary angiography (CCA), a modality associated with considerable risk,\(^3\) was the only available approach for establishing a definitive diagnosis of coronary artery stenosis. Noninvasive and less risky tests such as multislice computed tomography (CT) and magnetic resonance imaging are current alternatives for the detection of CAD.\(^4\) At present, multislice CT is demonstrably superior to magnetic resonance coronary angiography in terms of identifying patients with coronary artery stenoses.\(^5,6\) However, the radiation exposure of CT is considered the Achilles’ heel of this technology.

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Despite its diagnostic advantages, the high effective dose\(^5,7-9\) and potential adverse consequences of coronary CT angiography (such as an elevated long-term cancer risk, especially in young females)\(^10\) are a cause for concern and have limited the general applicability of this test. The use of...
320-row CT now makes it possible to cover the whole heart in a single CT snapshot; this approach can reduce the radiation exposure by 4- to 5-fold because it avoids the 400% to 500% overlapping rotations for helical cardiac CT (overscanning) and the extra 2 rotations necessary at the beginning and end of CT scans (overranging) that were previously necessary in most cases. We have therefore conducted a prospective study to analyze the effective dose and diagnostic performance of 320-row CT compared with CCA in patients with suspected CAD.

Methods

Study Design
This diagnostic performance study was planned prospectively as a single-institution assessment of 320-row CT for the detection of coronary artery stenoses with ≥50% diameter obstruction, with quantitative analysis of CCA used as the reference standard. An intention-to-diagnose design was used. All patients, coronary vessels, and segments were included in each analysis, with the use of a 6-cell matrix as described, even if a study or a vessel was not interpretable, to avoid overestimating diagnostic accuracy. All 25 criteria of the Standards for Reporting of Diagnostic Accuracy statement can be found in this report (Figure 1). CT was performed before same-day CCA to avoid partial verification bias and limit the likelihood of interim clinical events. The study protocol was approved by the institutional review board and the responsible federal authority (the German Federal Department for Radiation Protection).

Study Group
The study group consisted of consecutive patients referred to the Charité by outpatient centers and scheduled to undergo CCA for clinically suspected CAD. Patients were eligible for the study if they were at least 40 years of age and had sinus rhythm. The age limit of 40 years was defined in discussion with the Federal Department for Radiation Protection because younger patients have increased susceptibility to ionizing radiation. The exclusion criteria were as follows: prior CCA, unstable presentation, coronary artery bypass graft or stent, pregnancy or breast-feeding, guardianship at the time of the study, and creatinine ≥2.0 mg/dL (equal to ≥176.8 μmol/L). Enrollment took place between March 7, 2008, and October 7, 2008 (excluding holidays and weekends). All patients gave written informed consent.

Coronary Angiography With 320-Row CT

Image Acquisition
Because no contraindications to nitroglycerin were present, each patient received 1.2 mg nitroglycerin sublingually to increase coro-
nary artery diameters and facilitate interpretation.15 Fifteen of the patients were on long-term oral β-blocker medication (50%), and additional oral β-blockade (50 mg atenolol) was given in 4 patients 1 hour before the CT scan. Intravenous β-blockers (mean, 244±127 mg esmolol) were given immediately before the CT scan in 17 patients (56%) with heart rates >65 bpm. This was done in an attempt to achieve a target heart rate ≤65 bpm during scanning because this is the threshold below which there is a sufficiently long rest period of the coronary arteries to allow scanning during a single heartbeat. In patients with heart rates >65 bpm, 2 or 3 heartbeats were used for image acquisition to allow adaptive multisegment reconstruction to be applied for improved temporal resolution. Imaging was performed with a snapshot (no table movement, pitch of 0) whole-heart scan on a 320-row CT (Figure 2) with 0.5-mm detector elements, 350 ms of gantry rotation time, and up to 16 cm of coverage in Z direction (Aquilion ONE, Toshiba Medical Systems, Otawara, Japan) as described.16 The median Z direction scan range covered was 12 cm (range, 12 to 14 cm). Scanner settings of 350 to 450 mA (350 mA for ≤60 kg, 400 mA for 60 to 80 kg, and 450 mA for >80 kg) and 120 kV were used.

Immediately before the contrast agent was injected (80 mL nonionic iohexol, dual-phase injection with saline flush of 40 mL; iobitridol, 350 mg of iodine per milliliter; Xenetix 350, Guerbet, Paris, France), a breathhold trial (“mock examination”) was performed by simulating scanning with a single 5-second breathhold command (“breathe in and hold your breath”) to adjust scanner settings to individual patients as described recently.17 The average breathhold time was 3.6±0.6 seconds (including a 3-second delay before scanning, so that the heart rate can normalize after submaximal inspiration).18 and the median radiation exposure time was 0.6 second. The automatic sure-start option of the CT scanner was used to achieve adequate contrast enhancement in the coronary arteries, initiating CT scanning after a threshold of 180 Hounsfield units in the descending aorta had been reached.

Prospective CT angiography was performed from 70% to 100% of the RR interval in patients with heart rates of ≤65 and >65 bpm, respectively. Dose-length product measurements were displayed after each scan on the scanner’s console. Radiation exposure for whole-heart CT angiography was quantified with a dose-length product conversion factor of 0.017 mSv/mGy/cm, as described.

**Image Analysis**

A simultaneous ECG was used to assign the source images to reconstruction intervals within the cardiac cycle by applying either half-scan (in patients with heart rates ≤65 bpm) or adaptive multisegment (in patients with heart rates >65 bpm)20 image reconstruction with up to 3 segments (ie, heartbeats). One, 2, and 3 heartbeats were used for acquisition in 21, 8, and 1 patients, respectively. This approach resulted in an average image reconstruction interval of 159±31 ms per heartbeat at an average heart rate of 59.9 bpm (range, 40 to 71) and made it possible to choose the phase with the least motion of the respective coronary artery for assessment. An axial field of view of 18 cm with an imaging matrix of 512×512 pixels generated a pixel size of 0.35×0.35 mm (~10 line pairs per centimeter). Data were reconstructed with 0.25-mm slice increments, providing up to 640 axial slices with 0.5-mm thickness.

**Conventional Coronary Angiography**

Selective CCA was performed by the transfemoral Judkins approach with the use of standard techniques after right and left intracoronary administration of 100 to 150 mg isosorbide dinitrate. Radiation exposure for CCA was estimated on the basis of dose-area product measurements24 excluding the radiation necessary for interventions in all patients.

Quantitative analysis of the CCA (Axiom Artis BC, Siemens, Erlangen, Germany) was performed and interpreted independently by another 2 readers who were unaware of the CT result. At least 2 orthogonal projections were evaluated; the measurement of percent diameter stenosis was performed in the projection showing the highest degree of narrowing.

**Percent Diameter Stenosis and Segment Adjudication**

We compared percent diameter stenoses determined by CT and CCA as described above using linear regression analysis (to determine correlation coefficients)25 and Bland-Altman analysis (to determine limits of agreement).26 We also compared interobserver variability of CT and CCA for determining percent diameter stenosis using images from both tests analyzed by a second independent reader (separate second reader for each test). Thus, altogether 4 readers were involved in the reading and interpretation process. To ensure correct intermodality evaluation of coronary segments between CT and CCA, an adjudication of all coronary lesions was performed by a fifth independent reader as described recently.

**Patients’ Perception**

We assessed patients’ acceptance of the 2 tests using an established questionnaire including unmarked horizontal (100-mm-long) visual analog scales as measures of subjective pain levels as well as overall satisfaction (on a 5-point Likert scale) as described recently.

**Statistical Analysis**

Because the 320-row CT scanner used was a prototype machine, this study was a feasibility trial that was designed to generate hypotheses for future studies. Thus, the sample size was not defined on the basis of a power analysis. The χ² test, Student paired t test, and Wilcoxon signed rank test were used as appropriate for categorical and continuous variables. A paired t test was used to test for significant underestimation or overestimation of percent diameter stenosis by CT in comparison to CCA, and a paired F test was used to compare the limits of agreement in the interobserver analysis of stenosis quantification by CT and CCA. All data are reported as means±SD (normally distributed data), medians (data not normally distributed), or proportions with 95% confidence intervals (CIs). For unclustered data (per-patient analysis), CIs for single proportions and differences of proportions were obtained with the scoring method described elsewhere.28,30 For the per-vessel and per-segment analysis, we corrected the variance inflation due to clustering using a generalized linear mixed model (binomial error and logit link). This model is
able to account for within-subject correlation.\textsuperscript{31} The model was used for per-vessel and per-segment analysis to account for clustering of arteries and segments within each patient with the use of random effects for patients and vessel. Model selection was based on the likelihood ratio test. A sole random effect for patients was sufficient for these data. The parameters and corresponding 95% CIs were back transformed to the scale of proportions.

Statistical analyses were conducted with the use of SPSS version 12.0 (SPSS Inc, Chicago, Ill), SAS version 9.2 (SAS Institute Inc, Cary, NC), and StatXact version 6.0 (Cytel Software Corporation, Cambridge, Mass). A procedure of the SAS program (GLIMMIX) was used to fit the generalized linear mixed model (binomial error and logit link). CIs for clustered data were calculated with the use of our own program written in R.\textsuperscript{32}

### Results

During the study period, 44 patients were eligible for inclusion. Of these, 4 declined to participate, and 4 had to be excluded because of time constraints before scheduled coronary angiography. Because of maintenance of the CT scanner, 6 patients, who fulfilled all inclusion criteria, could not undergo CT before their scheduled CCA and therefore could not be included in the study. Thus, 30 patients successfully completed the study. Patient characteristics are given in Table 1.\textsuperscript{33,34} No adverse events occurred after either test. Because of insufficient contrast agent inflow into the side branches of the left anterior descending coronary artery (2 segments) at CCA, 1 patient had to be excluded from the per-patient CT-CCA comparison. No segments were uninterpretable in CT, and no coronary artery anomalies were seen by both tests; in all, 14 segments (in 14 patients) were not present, as defined by CCA. Two patients had an intermediate branch. Thus, a total of 121 coronary arteries (left main, left anterior descending, left circumflex, right coronary artery, and intermediate branch) and 466 coronary segments were analyzed. Of the analyzable patients, 38% (11/29) had clinically significant CAD as identified by CCA, 30% (9/30) were aged >65 years, and 63% (19/30) had a body mass index of ≥25. The median interval between the beginning of CT and same-day CCA was 3 hours 21 minutes (mean, 3 hours 42 minutes; range, 35 minutes to 8 hours 55 minutes). Intravascular comparison of CT with catheterization revealed that a significantly smaller effective radiation dose (median, 4.2 versus 8.5 mSv; \(P<0.05\); Figure 3) and contrast agent amount (median, 80 versus 111 mL; \(P<0.001\)) were required for 320-row CT angiography. In the 21 patients with a heart rate of ≤65 bpm, median radiation exposure of coronary CT angiography was 3.9 mSv, which was significantly less than that in the patients with higher heart rates (median, 12.3 mSv; \(P<0.001\)).

Figure 4 shows representative coronary stenoses that were detected by CT and CCA. Table 2 provides direct comparisons of CT with CCA with regard to the analysis of patients, coronary arteries, and coronary segments. Calcified plaques were present in 6 of the 7 false-positive and all 6 false-negative coronary artery segments in CT. Table 3 summarizes the diagnostic performance of CT per coronary segment, per artery, and per patient.

In the per-patient analysis, the sensitivity and specificity of multislice CT were 100% and 94%, respectively (Table 3). In the per-vessel analysis, the sensitivity and specificity of multislice CT were 89% and 96%, respectively. The negative predictive values on the per-segment, per-vessel, and per-patient levels were 99%, 98%, and 100%, respectively.

Agreement between the 2 readers was achieved for 109 of the 121 coronary arteries for CT (90%) and 117 of the 121 coronary arteries for CCA (97%, \(P=0.04\)). Cohen’s \(k\) in the per-vessel analysis was 0.63 (95% CI, 0.53 to 0.72) for CT and 0.87 (95% CI, 0.73 to 0.99) for CCA. Cohen’s \(k\) in the per-patient analysis was 0.72 (95% CI, 0.62 to 0.81) for CT and 0.78 (95% CI, 0.69 to 0.85) for CCA.

Table 1. Patient Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Age, y</th>
<th>Male sex, n (%)</th>
<th>Hyperlipidemia, n (%)</th>
<th>Arterial hypertension, n (%)</th>
<th>Diabetes mellitus, n (%)</th>
<th>Clinical presentation, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>61±10</td>
<td>21 (70)</td>
<td>18 (60)</td>
<td>27 (90)</td>
<td>5 (17)</td>
<td>82 (27)</td>
</tr>
<tr>
<td>Typical angina</td>
<td>8 (27)</td>
<td>9 (30)</td>
<td>3 (10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atypical angina</td>
<td>2 (7)</td>
<td>7 (23)</td>
<td>4 (13)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonspecific chest pain</td>
<td>25.6±4.7</td>
<td>2 (10)</td>
<td>10 (33)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No chest pain*</td>
<td>26.2±4.7</td>
<td>26.2±4.7</td>
<td>26.2±4.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prior myocardial infarction, n (%)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST-T wave changes, n (%)</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body mass index†</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current cigarette smoking, n (%)</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest probability, %§</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agatston coronary artery calcium score</td>
<td>384±742</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values are mean±SD unless indicated otherwise.

*Seven of these 10 patients had positive ischemia tests (exercise ECG or stress echocardiography), and the other 3 patients had dyspnea (New York Heart Association class III); all 10 patients had multiple cardiac risk factors but no anginal symptoms.

†Calculated as the weight in kilograms divided by the square of the height in meters.

§Based on assessment of all 17 coronary segments (regardless of the size of reference vessel diameters).

One patient could not be assessed because of too little contrast agent in the side branches of the left anterior descending coronary artery.

Agreement between the 2 readers was achieved for 109 of the 121 coronary arteries for CT (90%) and 117 of the 121 coronary arteries for CCA (97%, \(P=0.04\)). Cohen’s \(k\) in the per-vessel analysis was 0.63 (95% CI, 0.53 to 0.72) for CT and 0.87 (95% CI, 0.73 to 0.99) for CCA. Cohen’s \(k\) in the per-patient analysis was 0.72 (95% CI, 0.62 to 0.81) for CT and 0.78 (95% CI, 0.69 to 0.85) for CCA.

Percent diameter stenosis determined with the use of CT showed good correlation with quantitative analysis of CCA (\(P<0.001\), \(R=0.81\); Figure 5A) without significant underestimation or overestimation (\(-3.1\%, \ P=0.08\) and limits of agreement of \(±24.4\%\) (Figure 5B). In the interobserver analysis, the limits of agreement of CT (\(±28.0\%\)) and CCA (\(±23.5\%\)) were not significantly different (\(P=0.2\); Figure 5C and 5D).
Nine of the 30 patients (30%) indicated no pain during any procedure, and all other patients (70%) reported the most pain during CCA (Figure 6). Most patients (26/30, 87%) said they would prefer multislice CT over CCA for future diagnostic imaging of the coronary arteries ($P < 0.001$), whereas 2 patients preferred CCA, and 2 other patients did not have a preference. Twenty-eight (93%) and 30 (100%) of the patients indicated that they would be willing to undergo CCA and CT, respectively, again in the future. Overall satisfaction of the patients was significantly higher for CT ($1.5 \pm 0.6$) than for CCA ($1.7 \pm 0.6$; $P < 0.05$).

**Discussion**

Our head-to-head comparison shows that whole-heart coronary 320-row CT angiography significantly reduces the effective radiation dose compared with CCA. With a median dose of $4 \pm 1$ mSv, 320-row CT angiography also relevantly reduces radiation exposure compared with coronary CT with the use of conventional helical acquisition approaches (median, 15.4 mSv). Because of the increased scattered radiation, one might expect a reduction in diagnostic performance with 320-row CT. However, our study also indicates that there is no relevant difference between the diagnostic accuracy of coronary 320-row CT angiography and that reported in coronary CT angiography meta-analyses and multicenter studies with the use of 64-row CT.

Prevalence of disease influences the negative and positive predictive values of diagnostic tests. To apply diagnostic tests most appropriately, pretest likelihoods can be used to estimate the prevalence (based on patients’ characteristics and clinical presentation) before choosing and conducting a test. The most obvious indication for coronary CT angiography is to exclude CAD in patients with a low to intermediate pretest likelihood of disease (eg, patients with inconclusive findings in previous stress tests and those presenting with atypical angina). Patients with a higher pretest likelihood of CAD (>70%; eg, with typical angina, risk factors, and a positive stress test) should not undergo coronary CT angiography as

![Figure 3. Comparison of radiation exposure for CT and CCA.](image)

On the left side, the group values show the significantly lower effective radiation dose for 320-row CT in comparison to CCA as box plots. The effective dose of coronary CT was less than half that of CCA (median, 4.2 versus 8.5 mSv; $P < 0.05$). On the right side, the intraindividual values are plotted, with white dots for CT and black dots for CCA. Radiation exposure for whole-heart CT was quantified with a dose-length product conversion factor of $0.017 \text{mSv/cm} \times \text{Gy}$ as described. Radiation exposure for CCA was estimated on the basis of dose-area product measurements, with a conversion factor of $0.22 \text{mSv/cm} \times \text{Gy}$ as described elsewhere, excluding the radiation necessary for interventions in all patients. The single outlier in the CT group represents a patient with an extrasystole, which increased the radiation exposure time to 2.5 seconds.

![Figure 4. Stenoses in the right coronary artery in a 59-year-old woman.](image)

A shows 3 significant stenoses (arrowheads) on a curved maximum intensity projection (“CATH view”) obtained by CT, and B shows the stenoses on the conventional angiogram.

**Table 2. Direct Comparison of Test Results at the Per-Patient, Per-Vessel, and Per-Segment Levels**

<table>
<thead>
<tr>
<th></th>
<th>320-Row CT</th>
<th>CCA†</th>
<th>Likelihood Ratios (95% CI)‡</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Per-patient level</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td>11</td>
<td>1</td>
<td>12.1 (2.6–56.6)</td>
</tr>
<tr>
<td>Negative</td>
<td>0</td>
<td>17</td>
<td>0.05 (0.003–0.68)</td>
</tr>
<tr>
<td>Not interpretable§</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td><strong>Per-vessel level</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td>17</td>
<td>4</td>
<td>22.8 (8.6–60.4)</td>
</tr>
<tr>
<td>Negative</td>
<td>2</td>
<td>98</td>
<td>0.11 (0.03–0.41)</td>
</tr>
<tr>
<td>Not interpretable*§</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td>102</td>
<td></td>
</tr>
<tr>
<td><strong>Per-segment level</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td>21</td>
<td>7</td>
<td>48.8 (22.8–104.5)</td>
</tr>
<tr>
<td>Negative</td>
<td>6</td>
<td>432</td>
<td>0.23 (0.11–0.46)</td>
</tr>
<tr>
<td>Not interpretable*§</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td>439</td>
<td></td>
</tr>
</tbody>
</table>

*Vessels and segments deemed noninterpretable would have been considered nondiagnostic for statistical analysis. However, none of these could not be adequately interpreted by CT because of poor image quality. A 16-segment coronary model was used for analysis.†One patient (1 vessel, 2 segments) could not be assessed by CCA (not interpretable) because of too little contrast agent in the side branches of the left anterior descending coronary artery. This patient was excluded from the per-patient CT-CCA comparison, but the remaining vessels and segments of this patient were included in the respective analyses.‡Likelihood ratios are reported with 95% CIs for unclustered data (patient level) and clustered data (segment and vessel level) as described.§Patients whose results were not interpretable would have been considered nondiagnostic for statistical analysis.
the first-line modality because more patients in this subgroup will require subsequent CCA and because the negative predictive value of CT is reduced (making a negative CT result less reliable). On the other hand, the positive predictive value is rather low in patients with a very low pretest likelihood of CAD (≤20%; eg, with nonanginal chest pain and a negative stress test), and the CT findings would lead to many unnecessary conventional coronary angiographies. In our study, pretest likelihood was 46% and prevalence was 38%, making the results valid for patients with intermediate probability of disease, who might benefit most from coronary CT angiography. The reduction in radiation dose achieved with 320-row CT is attributable to the fact that it does not require overscanning

<table>
<thead>
<tr>
<th></th>
<th>Per-Segment Level†</th>
<th>Per-Vessel Level</th>
<th>Per-Patient Level‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>21/27 (78 [56–91])</td>
<td>17/19 (89 [62–98])</td>
<td>11/11 (100 [72–100])</td>
</tr>
<tr>
<td>Specificity</td>
<td>432/439 (98 [96–99])</td>
<td>98/102 (96 [90–99])</td>
<td>17/18 (94 [73–100])</td>
</tr>
<tr>
<td>Negative predictive value</td>
<td>432/438 (99 [97–99])</td>
<td>98/100 (98 [92–100])</td>
<td>17/17 (100 [80–100])</td>
</tr>
<tr>
<td>Positive predictive value</td>
<td>21/28 (75 [54–89])</td>
<td>17/21 (81 [56–93])</td>
<td>11/12 (92 [61–100])</td>
</tr>
</tbody>
</table>

Values are n/total n (% [95% CI]).
*95% CIs were estimated as described for unclustered data (patient level)²⁹,³⁰ and clustered data (segment and vessel level).³¹ Results are provided for detection of ≥50% diameter stenoses.
†Using all coronary artery segments that were present and interpretable on CCA (independent of the vessel diameters).
‡One patient could not be assessed because of too little contrast agent in the side branches of the left anterior descending artery on CCA. This patient was excluded from the per-patient CT-CCA comparison, but the remaining vessels and segments of this patient were included in the per-segment and per-vessel analyses.

Figure 5. Percent diameter stenosis quantification with the use of 320-row CT and CCA. All coronary artery segments with at least 20% diameter reduction on quantitative coronary angiography (QCA) were included in this comparison. Thus, data points are for lesions on the segment level. Quantification of CT images was done orthogonal to the vessel (cross-sectional images) as described.²³ A shows linear regression analysis with correlation coefficients for the comparison of CT and CCA. The 95% CIs for all data in the plot are displayed as dashed lines, and the solid line is the linear regression line. The linear mixed model (with patients indicating a cluster) did not provide a better fit (Likelihood Ratio Statistic = 1.38, 1 df) than the linear regression analysis. B shows the Bland-Altman agreement analysis comparing CT and CCA. For agreement, the mean of the 2 methods compared is plotted against the difference of the 2, and the solid line is the mean of the differences, whereas the dashed lines mark the limits of agreement (95% CI = ±1.96 SD). There was no significant underestimation or overestimation by CT (−3.1%; P = 0.08), and the limits of agreement were ±24.4% versus QCA. C and D show the interobserver comparison of CT (C) and CCA (D) with no significant differences (P = 0.2) in the size of the limits of agreement between the 2 comparisons.
and overranging; the effective dose can be reduced by a factor of \(\approx 4\) to 4. This reduction is important for the general application of coronary CT angiography because a dose of 9 to 29 mSv\(^{10}\) (as used in older scanners) considerably increases the long-term cancer risk.\(^{10,40}\) Thus far, no study directly comparing coronary CT with CCA has found a lower dose for CT. Coles et al\(^{4}\) have reported significantly higher doses for CT in a study of 91 patients (14.7\(\pm\)2.2 versus 5.6\(\pm\)3.6 mSv), whereas Dewey et al\(^{5}\) found no significant differences between CT and CCA (12.3\(\pm\)1.4 versus 11.4\(\pm\)4.8 mSv) in 73 patients. Whole-heart CT was recently reported to result in an average radiation dose of 8.3\(\pm\)3.4 mSv\(^{41}\) in a study including 40 consecutive patients with a clinical indication for coronary CT angiography. However, we are unaware of any previous direct comparisons with CCA; our intraindividual comparison now shows that noninvasive coronary angiography with the use of recent CT technology can achieve a significant and relevant dose reduction compared with the reference standard CCA. Radiation exposure reduction was greatest in patients with heart rates \(\leq 65\) bpm, whereas the effective dose was significantly higher in those with higher heart rates because of the necessity of acquiring data over multiple cardiac cycles to increase temporal resolution, highlighting the importance of \(\beta\)-blockade. Given the ongoing concerns about contrast-induced nephropathy, it is also important to note that in our study, coronary CT angiography required significantly less contrast agent than did cardiac catheterization.

The present pilot study included only 30 patients at a single center. Further larger, ideally multicenter, studies are needed to confirm the value of 320-row CT and analyze its role in evaluating patients with suspected CAD. Ionizing radiation is a drawback of this noninvasive test\(^{42}\) and limits its application for serial measurements (eg, during stress and at rest) and follow-up examinations (eg, for coronary plaque volumetric assessment). In addition, patients who undergo noninvasive CT and are found to have a clinically significant stenosis require subsequent CCA with additional radiation exposure, highlighting the importance of properly selecting patients with low to intermediate likelihood of disease for CT, as detailed above.\(^{43,44}\)

Both coronary vessels and segments are clustered within patients, and we statistically adjusted for this using a generalized linear mixed model. CT and CCA are both subjective tests, with considerable variation seen between different readers; interestingly, in our interobserver analysis for detection of stenoses (to our knowledge, the first comparison of the 2 tests in this regard), we identified a significantly better performance of CCA on the per-vessel level. Our analysis of quantification of coronary artery stenosis, however, shows for the first time similar accuracy of CT and CCA in terms of interobserver variability. In addition, there was no significant underestimation or overestimation of percent diameter stenosis with coronary CT angiography, and the limits of agreement in comparison to CCA were comparable to previous reports in which 16- and 64-row technology was used.\(^{23,45–49}\)

The expenditure on coronary diagnostic tests is substantial,\(^{50}\) and every effort should be made to decrease its economic burden on society. Whether 320-row CT can further optimize cost-effectiveness compared with previous CT approaches\(^{51}\) is an important question. Moreover, a diagnostic test is only justified if it can provide incremental information that will change practice so as to favorably affect clinical outcome.\(^{52}\) Coronary CT angiography still must be analyzed in this context. Our analysis of patients’ perceptions shows that coronary CT angiography is preferred to CCA in terms of subjective pain as well as overall satisfaction.

**Conclusions**

In conclusion, the results of this pilot study suggest that whole-heart 320-row CT angiography has the potential to significantly reduce the required radiation dose compared with CCA while preserving high diagnostic accuracy.

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References


**CLINICAL PERSPECTIVE**

Our head-to-head comparison of whole-heart 320-row computed tomography (CT) and conventional coronary angiography has important clinical implications because it shows that 320-row coronary CT angiography has high diagnostic accuracy for detection of coronary artery stenoses, whereas radiation exposure (determined as “effective dose in mSv”) is significantly lower (4.2 versus 8.5 mSv) than that of conventional coronary angiography. Because noninvasive coronary CT angiography would be best applied as a rule-out test to all persons with low to intermediate pretest likelihood of coronary artery disease to avoid unnecessary conventional coronary angiography and thereby reduce complications and risks, it is of tremendous importance to reduce the previously high burden of ionizing radiation of coronary CT angiography. Using whole-heart data prospectively acquired with 320-row CT greatly reduces exposure because it avoids radiation-intensive overscanning and overranging. Moreover, it also increases image quality and results in good diagnostic performance because data are typically acquired in a fraction of a second (0.45 to 0.6 second) during a single heartbeat (if heart rate is <65 bpm). Thus, the entire 3-dimensional data set is temporally uniform and not constructed from multiple consecutive heartbeats as with scanners not covering the entire heart in a snapshot (because of fewer detector rows), thereby reducing heart rate– and breathing-related motion artifacts. Finally, this whole-heart approach has the long-term clinical potential to develop 4-dimensional acquisition strategies for additional analysis of myocardial perfusion with the use of 320-row CT. Such an approach might enable comprehensive evaluation of a range of patients with known or suspected coronary artery disease.
Noninvasive Coronary Angiography by 320-Row Computed Tomography With Lower Radiation Exposure and Maintained Diagnostic Accuracy: Comparison of Results With Cardiac Catheterization in a Head-to-Head Pilot Investigation
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