Influence of Heart Rate on the Diagnostic Accuracy of Dual-Source Computed Tomography Coronary Angiography

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Objectives
We evaluated the influence of heart rate on image quality and diagnostic accuracy of dual-source computed tomography (DSCT) coronary angiography.

Background
Multidetector computed tomography (MDCT) coronary angiography has demonstrated an inverse relationship between heart rate and image quality. Dual-source CT provides a higher temporal resolution.

Methods
One hundred patients were studied by DSCT (DEFINITION, Siemens Medical Solutions, Forchheim, Germany). A contrast-enhanced volume dataset was acquired (two tubes, 120 kV, 400 mAs/rot, collimation 64 × 0.6 mm). Datasets were evaluated concerning the presence of significant coronary stenoses and validated against invasive coronary angiography.

Results
In 44 patients with a heart rate ≥65 beats/min, 566 of 616 coronary segments were evaluable (92%), whereas in 56 patients with a heart rate <65 beats/min, 777 of 778 coronary segments were evaluable (100%, p < 0.001). On a per-patient basis, 93% of patients (≥65 beats/min) and 100% of patients (<65 beats/min) were considered evaluable. By classifying unevaluable segments as positive for stenosis, per-patient sensitivity was 95% (19 of 20) for heart rates ≥65 beats/min and 100% (22 of 22) for heart rates <65 beats/min. Specificity was 87% (21 of 24) versus 76% (26 of 34), and overall diagnostic accuracy was 91% (40 of 44) versus 86% (48 of 56). None of these differences were statistically significant. Similarly, no difference in diagnostic accuracy was found in per-vessel and -segment analyses.

Conclusions
In 100 patients studied without beta-blocker pre-medication, DSCT demonstrated slightly lower per-segment evaluability for high heart rates but no decrease in diagnostic accuracy for the detection of coronary artery stenoses. (J Am Coll Cardiol 2007;50:2393–8) © 2007 by the American College of Cardiology Foundation

Several previous studies using 16- and 64-slice multidetector computed tomography (MDCT) have demonstrated an inverse relationship between heart rate and image quality concerning coronary artery visualization and detection of stenoses (1–4). Therefore, most authors recommend lowering the patient’s heart rate to <65 beats/min to achieve stable image quality (5–10). With that approach, sensitivities ranging from 85% to 99% and specificities between 93% and 98% for the detection of coronary artery stenoses have been reported (7,10). The requirement to premedicate patients with beta-blocker drugs to achieve a sufficiently low heart rate has been considered a major limitation concerning the clinical use of MDCT coronary angiography.

Dual-source computed tomography (DSCT) uses 2 X-ray tubes and detectors to achieve an improved temporal resolution of 83 ms (11). Initial studies demonstrated high image quality of DSCT for coronary visualization without beta-blocker pre-medication (12–14). To assess the influence of heart rate on diagnostic accuracy of DSCT coronary angiography, we compared DSCT without beta-blocker pre-medication with invasive coronary angiography.

Methods

Study population. One hundred consecutive patients referred for a first diagnostic coronary angiogram because of suspected coronary artery disease were included (Table 1). Patients with impaired renal function (creatinine >1.5 mg/dl), in non-sinus rhythm, with previously known coronary disease, with implanted coronary stents or previous
bypass surgery, with acute coronary syndromes, or in unstable hemodynamic situation were not included.

Thirty-four patients were taking chronic beta-blocker medication, which was not discontinued for DSCT. The mean time interval between DSCT and invasive angiography was 1.4 days (0 to 11 days). No patient was included in another scientific study or in any other analysis of DSCT coronary angiography. All patients gave informed consent. The study was approved by the institutional review board.

Scan protocol. All patients received 0.8 mg glycerol trinitrate sublingually directly before the scan. Dual-scan CT (DEFINITION, Siemens Medical Solutions, Forchheim, Germany) was performed in supine position and deep inspiration with 330-ms gantry rotation time. X-ray data were simultaneously acquired in 2 × 64 slices with 0.6 mm collimation. Tube voltage was 120 kV, and tube current was 400 mAs/tube, with electrocardiogram (ECG)–gated tube current modulation to lower the tube current by 80% outside a window from 30% to 70% of the R-to-R interval (11). Depending on heart rate, pitch was set between 0.2 and 0.43 (11,12). Contrast agent (Omnipaque 350, Schering AG, Berlin, Germany) was injected intravenously at a flow rate of 5 ml/s. The duration of injection was the same as that of image acquisition. However, no less than 60 ml of contrast agent were injected. Contrast injection was followed by a saline flush of 50 ml (5 ml/s). Nonenhanced imaging was not routinely performed before contrast-enhanced CT angiography, and no patient was excluded for high calcium scores.

Data reconstruction and interpretation. With an ECG-gated half-scan reconstruction algorithm, transaxial images were reconstructed with a temporal resolution of 83 ms, slice thickness of 0.75 mm, and increment of 0.4 mm. Data were initially reconstructed with the data window starting at 75% of the R-peak to R-peak interval. If motion artifacts were present, additional reconstructions were performed in 5% decrements and increments.

One observer, blinded to all clinical and angiographic data of the patients, analyzed DSCT datasets with interactive display of the transaxial slices, multiplanar reconstruction, and 5-mm maximum-intensity projections (Fig. 1). Initially, DSCT datasets were analyzed on a per-segment basis, with a modified version of the American Heart Association reporting system (15). Each coronary segment was initially classified as “evaluable” or “not evaluable.” “Evaluable” segments were further classified as to the presence or absence of a diameter reduction exceeding 50% with visual estimation. A separate observer analyzed the patient’s invasive coronary angiograms with semi-automated quantitative coronary angiography software (QuantCor.QCA, Pie Medical Imaging, Maastricht, the Netherlands).

Statistical analysis. The DSCT and invasive coronary angiography were compared on a per-segment, -vessel, and -patient basis to determine sensitivity and specificity as well as positive and negative predictive value for the detection of stenoses of at least 50% diameter reduction. Coronary segments with a reference diameter <1.5 mm and coronary artery segments distal to a total occlusion were excluded from the analysis for lack of clinical relevance. Per-segment and -artery analysis were initially performed for segments and vessels classified as “evaluable” only. In a second step, analysis was repeated with all segments that were classified “unevaluable” in DSCT, being rated as having a stenosis. Evaluability and diagnostic accuracy were analyzed in all patients as well as separately in patients with high (≥65 beats/min) and low (<65 beats/min) heart rates. Fisher exact test was used to test for statistical significance between the 2 groups. To compare clinical parameters in the 2 groups, chi-square test was used for categorical and t test for continuous variables. A p value < 0.05 was assumed to indicate statistical significance. Heart rates are reported as mean ± SD.

Results

Invasive coronary angiography. Invasive coronary angiography revealed 80 significant stenoses in 41 patients (single}

<table>
<thead>
<tr>
<th>Table 1 Demographic Data</th>
<th>All Patients</th>
<th>Heart Rate ≥65 beats/min</th>
<th>Heart Rate &lt;65 beats/min</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>100</td>
<td>44</td>
<td>56</td>
<td>NS*</td>
</tr>
<tr>
<td>Female</td>
<td>37</td>
<td>15</td>
<td>22</td>
<td>NS*</td>
</tr>
<tr>
<td>Male</td>
<td>63</td>
<td>29</td>
<td>34</td>
<td>NS*</td>
</tr>
<tr>
<td>Age, mean (yrs)</td>
<td>61</td>
<td>60</td>
<td>62</td>
<td>NS†</td>
</tr>
<tr>
<td>BMI, mean (kg/m²)</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>NS†</td>
</tr>
<tr>
<td>Heart rate, mean (beats/min)</td>
<td>64</td>
<td>76</td>
<td>55</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>Scan range, mean (mm)</td>
<td>124</td>
<td>123</td>
<td>125</td>
<td>NS†</td>
</tr>
<tr>
<td>Scan time, mean (s)</td>
<td>10</td>
<td>9</td>
<td>11</td>
<td>NS†</td>
</tr>
</tbody>
</table>

*Chi-square test; † t test.
BMI = body mass index.
vessel disease: 23 patients; 2-vessel disease: 11 patients; and triple-vessel disease: 7 patients).

**DSCT coronary angiography.** Mean heart rate during CT imaging was 64 ± 13 beats/min (range 37 to 100 beats/min). Fifty-six patients had a heart rate <65 beats/min (mean 55 ± 6 beats/min), whereas 44 patients had a heart rate ≥65 beats/min (mean 76 ± 9 beats/min) (Table 1). The mean effective radiation dose was 15.3 ±

![Figure 1](image)

**Table 2**  
*Per-Segment Analysis of DSCT for the Detection of Coronary Stenoses*

<table>
<thead>
<tr>
<th></th>
<th>All Patients</th>
<th>Heart Rate &gt;65 beats/min</th>
<th>Heart Rate &lt;65 beats/min</th>
<th>p Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Evaluable</strong></td>
<td>96% (1,343/1,394)</td>
<td>92% (566/616)</td>
<td>100% (777/778)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>In evaluable segments</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity</td>
<td>72/80 (90%; 82%–95%)</td>
<td>37/41 (90%; 78%–96%)</td>
<td>35/39 (90%; 76%–96%)</td>
<td>NS</td>
</tr>
<tr>
<td>Specificity</td>
<td>1.244/1.263 (98%; 83%–99%)</td>
<td>523/525 (100%; 99%–100%)</td>
<td>721/738 (98%; 96%–99%)</td>
<td>0.004</td>
</tr>
<tr>
<td>NPV</td>
<td>1.244/1.252 (99%; 99%–100%)</td>
<td>523/527 (99%; 98%–100%)</td>
<td>721/725 (99%; 99-100%)</td>
<td>NS</td>
</tr>
<tr>
<td>PPV</td>
<td>72/91 (79%; 70%–86%)</td>
<td>37/39 (95%; 83%–99%)</td>
<td>35/52 (67%; 54%–79%)</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Overall†</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity</td>
<td>97/105 (92%; 86%–96%)</td>
<td>62/66 (94%; 85%–98%)</td>
<td>35/39 (90%; 76%–96%)</td>
<td>NS</td>
</tr>
<tr>
<td>Specificity</td>
<td>1.244/1.289 (97%; 95%–97%)</td>
<td>523/550 (95%; 93%–97%)</td>
<td>721/739 (98%; 96%–99%)</td>
<td>0.007</td>
</tr>
<tr>
<td>NPV</td>
<td>1.244/1.252 (99%; 99%–100%)</td>
<td>523/527 (99%; 98%–100%)</td>
<td>721/725 (99%; 99%–100%)</td>
<td>NS</td>
</tr>
<tr>
<td>PPV</td>
<td>97/142 (68%; 60%–75%)</td>
<td>62/89 (70%; 60%–78%)</td>
<td>35/53 (66%; 53%–77%)</td>
<td>NS</td>
</tr>
<tr>
<td>Accuracy</td>
<td>1.343/1.394 (96%; 95%–97%)</td>
<td>595/616 (97%; 95%–98%)</td>
<td>756/778 (97%; 96%–98%)</td>
<td>NS</td>
</tr>
</tbody>
</table>

Ranges indicate 95% confidence intervals. *Fisher exact test. †Overall accuracy was calculated by classifying all unevaluable segments as positive.  
DSCT = dual-source computed tomography; NPV = negative predictive value; PPV = positive predictive value.
3.7 mSv for patients with a heart rate <65 beats/min and 15.9 ± 3.11 mSv for patients with a heart rate ≥65 beats/min.

**Per-segment analysis.** In 100 patients, 1,394 coronary segments were available for analysis. 126 segments were anatomically absent, 63 segments had a reference diameter <1.5 mm in invasive angiography, and 17 were located distal to a coronary artery occlusion. In DSCT, 1,343 of 1,394 segments were classified as “evaluable” (96%). Sensitivity for the detection of significant stenoses in evaluable segments was 90% (72 of 80) with a specificity of 98% (1,244 of 1,263) (Fig. 2). The negative and positive predictive values were 99% (1,244 of 1,252) and 79% (72 of 91) (Table 2). Reasons for the classification of segments as “unevaluable” were severe calcifications in 17 and motion artifacts in 34 cases. In 25 unevaluable segments, a stenosis was present in invasive angiography. Classifying unevaluable segments as positive yielded an overall sensitivity of 92% with a specificity of 97%.

In patients with a heart rate <65 beats/min, 777 of 778 segments were evaluable in DSCT (99.9%). Sensitivity and specificity for stenosis detection in evaluable vessels was 90% (35 of 39) and 98% (721 of 738), respectively. In patients with a heart rate ≥65 beats/min, 566 of 616 segments were evaluable (92%, p < 0.001 as compared with patients with a heart rate <65 beats/min). Sensitivity and specificity were 90% (37 of 41) and 99.6% (523 of 525), respectively. Overall accuracy, including unevaluable vessels, was 97% in both groups (Table 2).

**Per-artery analysis.** Of 400 coronary arteries, 390 were evaluable (97%). Sensitivity for the detection of coronary arteries with at least 1 stenosis was 90% (55 of 61) with a specificity of 95% (313 of 329). The negative and positive predictive values were 98% (313 of 319) and 77% (55 of 71), respectively. Classifying unevaluable arteries as stenotic yielded an overall sensitivity of 91% and specificity of 94%.

In patients with a heart rate ≥65 beats/min, 167 of 176 vessels were evaluable (95%). Sensitivity was 93% (26 of 28), and specificity was 98% (136 of 139). In patients with a heart rate <65 beats/min, only 1 vessel was not evaluable (223 of 224). In these patients, sensitivity and specificity for evaluable vessels were 88% (29 of 33) and 93% (177 of 190), respectively. By classifying all unevaluable vessels as positive, overall accuracy was 96% versus 92% (p = NS) (Table 3).

**Per-patient analysis.** Of 100 patients, 97 were classified as evaluable (either all arteries evaluable and free of stenosis or detection of a stenosis in at least 1 coronary artery by DSCT). For the detection of patients with a least 1 significant stenosis, sensitivity was 98% (39 of 40) with a specificity of 84% (47 of 57). The negative and positive predictive values were 98% (47 of 48) and 80% (39 of 49), respectively (Table 4).

All 56 patients with a heart rate <65 beats/min were completely evaluable. All 22 patients with at least 1 stenosis were correctly detected by DSCT. Sensitivity and specificity were 100% and 76% (26 of 34), respectively. Of 44 patients with a heart rate ≥65 beats/min, 41 were evaluable (93%). Sensitivity was 94% (17 of 18), and specificity was 91% (21

![Figure 2 DSCT Coronary Angiography in a 78-Year-Old Male Patient With a Heart Rate of 75 Beats/Min](image-url)

A significant stenosis (arrows) in the proximal part of the left anterior descending coronary artery. (A) Curved multiplanar reconstruction; (B) 3-dimensional reconstruction; (C) invasive coronary angiography. Abbreviation as in Figure 1.
No significant differences were found between patients with low and high heart rates. By classifying all unevaluable patients as positive, analysis of all 100 patients yielded an overall sensitivity of 98% (41 of 42) with a specificity of 81% (47 of 58).

Discussion

To analyze the diagnostic accuracy of DSCT in a patient cohort without specific medication to lower the heart rate, we performed DSCT before invasive coronary angiography in 100 patients with suspected coronary artery disease. With 96% of all coronary segments with a diameter of more than 1.5 mm classified as evaluable, our results indicate that DSCT preserves high diagnostic accuracy in patients with high heart rates. On a per-patient, -vessel, and -segment basis, the accuracy in our study compares favorably with the results of published studies that used 64-slice CT (10), even though the value of comparisons with historical controls is greatly limited. The high diagnostic accuracy of DSCT in patients with high heart rates has clinical relevance. Some patients have contraindications to the use of beta-blocker drugs, and administration of beta-blocker drugs to patients scheduled for CT coronary angiography might be logistically difficult. All the same, our study has several limitations. The patient group was relatively small and consisted of a well-defined patient population referred for their first diagnostic angiogram with suspected stable coronary artery disease. The prevalence of stenoses (40% on a per-patient basis) and especially of multivessel disease was low. In fact, the prevalence of disease influenced the calculations of diagnostic accuracies when nonevaluable segments were classified as “positive.” Therefore, results can not immediately be transferred to other clinical settings, such as patients with known coronary artery disease and a higher prevalence of stenoses. Because patients in nonsinus rhythm were not included, our study did not allow the assessment of the accuracy of DSCT angiography for patients in atrial fibrillation or the evaluation of the efficacy of tube current modulation in that population.

All the same, our data provide further support to previous reports that image quality and diagnostic accuracy of DSCT for the detection of coronary artery stenoses is high in...
patients with a heart rate above the commonly suggested threshold of 65 beats/min (12–14). Most likely, this is secondary to improved temporal resolution of DSCT as compared with previous generations of MDCT. Further studies will have to establish the clinical role for DSCT coronary angiography in various clinical scenarios.

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REFERENCES