Diagnostic Accuracy of Multidetector Computed Tomography Coronary Angiography in Patients With Angiographically Proven Coronary Artery Disease

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OBJECTIVES
The aim of the present study was to evaluate the diagnostic accuracy in detecting high-grade coronary stenoses in patients with known coronary artery disease (CAD) using multidetector computed tomography (MDCT).

BACKGROUND
The MDCT systems with electrocardiographic (ECG)-gating permit visualization of the coronary arteries. However, severe calcifications and higher heart rates are known to degrade image quality and limit correct diagnosis.

METHODS
Sixty-six patients with proven CAD as assessed by conventional coronary angiography (CCA) were studied by MDCT (mean time 24 months postangiography). Total calcium score and all coronary arteries, including distal segments and side branches, were assessed with respect to evaluability, presence of high-grade coronary artery stenoses (>70%), and correct diagnosis. Results were compared to CCA.

RESULTS
A total of 105 lesions were detected by CCA. The MDCT correctly detected 39 lesions (sensitivity 37%, specificity 99%). The correct clinical diagnosis could be obtained in 24 patients (36%). Artifacts due to elevated heart rates or severe coronary artery calcification were the main cause of degraded image quality inhibiting correct diagnosis. In 21/66 patients (32%) all four major coronary vessel segments could be visualized. A threshold for maximum heart rate and a maximum calcification level were established (65 beats/min and an Agatston Score Equivalent of 335, respectively). A second analysis was made using these thresholds. Of all patients studied, 10/11 (91%) were correctly diagnosed when adhering to these thresholds.

CONCLUSIONS
When using MDCT as a noninvasive diagnostic modality to assess advanced CAD, it appears to be mandatory to preselect patients in order to achieve reliable results. (J Am Coll Cardiol 2004;43:831–9) © 2004 by the American College of Cardiology Foundation

The current gold standard to assess coronary artery disease is invasive conventional coronary angiography (CCA). In Germany alone, the total number of CCA cases rose by 45% from 409,000 in 1995 to more than 594,000 annual procedures in the year 2000. Although coronary angiography has become a safe procedure with only a small risk associated, the inconvenience for the patient and the economic burden have both fueled the quest to find an alternative, noninvasive method to visualize and assess coronary arteries.

Since 1999, mechanical multidetector computed tomography (MDCT) systems with simultaneous acquisition of four slices and half-second scanner rotation have become available. Multi-row acquisition with these scanners allows for considerably improved visualization of the coronary arteries (1–5). Initial experiences have shown that coronary lesions can be detected with good sensitivity and specificity (6–12). Also, initial results suggest that even preclinical atheroma and noncalcified plaque tissue can be identified (13–16).

However, several factors are known to impair image quality and image interpretation. The two factors mostly held responsible are severe calcifications and higher heart rates (7,11,15). Patients with advanced coronary artery disease (CAD) frequently have a higher extent of coronary calcium as compared to patients in whom MDCT may be used as a first-line test. This makes MDCT imaging of the coronary arteries in patients with more advanced stages of CAD more difficult. Unfortunately, only limited data are available on patients with advanced CAD. Therefore, it is necessary to evaluate specifically the potential of MDCT in this patient population as earlier studies concentrated either on patients with no previously known CAD or included a
large share of patients without any coronary stenoses present (11,17).

Thus, the purpose of this study was to investigate the conditions under which visualization of coronary arteries using MDCT yields correct results in a collective of patients with proven CAD and planned repeated selective coronary angiography due to recurrent symptoms.

**MATERIALS AND METHODS**

A total of 66 consecutive patients with known CAD referred to our institution for invasive coronary angiography due to a suspected progress of their disease were included in this prospective study. All patients had undergone invasive coronary angiography with or without consecutive percutaneous transluminal coronary angioplasty (PTCA) in the past. Inclusion criteria were symptomatic patients in sinus rhythm with at least one stenosis of minimally 50% diameter stenosis as assessed by selective angiography. Exclusion criteria were contraindications to the administration of iodated contrast agent, atrial fibrillation, prior stent implantation, or prior coronary artery bypass graft (CABG) surgery. The mean elapsed time since last coronary angiography was 24 months (range 1 to 142 months). Patient characteristics are summarized in Table 1. All patients provided written informed consent and were continuously recruited. The local ethics committee approved the study protocol.

**Multidetector computed tomography.** According to previously published protocols used in our institution, MDCT data were acquired using a multidetector computed tomography (CT) scanner (Volume Zoom, Siemens Medical Systems, Forchheim, Germany). First, a native retrospectively electrocardiographic (ECG)-gated scan without contrast media was performed to determine the total calcium burden of the coronary tree (4 × 2.5 mm collimation, table feed 1.5 mm/rotation, effective tube current 133 mAs at 120 kV, effective slice with 3.0 mm, reconstruction increment 1.5 mm). To determine the circulation time for the contrast-enhanced scan, 20 ml of contrast media (20 ml at 4 ml/s, 400 mg iodine/ml, Imeron 400, Byk Gulden, Konstanz, Germany) and a chaser bolus of 20 ml saline were administered in an antecubital vein. The correct scanning delay was established by measuring CT attenuation values in the ascending aorta, using the first slice with a good visible contrast as circulation time. By using a dual-head power injector (Medtron, Saarbrücken, Germany) a total 150 ml intravenous contrast agent plus a 20-ml chaser bolus was injected (50 ml at 4.0 ml/s, then 100 ml at 2.5 ml/s).

To avoid contrast media-related influx artifacts in the superior vena cava, CT imaging started at the diaphragm caudally of all cardiac structures and stopped at the aortic root cranial to the coronary ostia. A contrast-enhanced retrospectively ECG-gated scan (4 × 1.0 mm collimation, table feed 1.5 mm/rotation, effective tube current 400 mAs at 120 kV) was acquired. Average scan length was 36.4 ± 5.8 s. No beta-blocker was administered to modulate heart rate.

To reconstruct the images, the standard built-in retrospectively ECG-dependent reconstruction algorithm was used for both the native and the contrast-enhanced scan. The start of the reconstruction window was set at 60% for all native images and was variable for the contrast-enhanced series (40%, 50%, 60%, 70%). Effective slice thickness was 1.25 mm; the reconstruction increment was 0.8 mm. For further evaluation, the individual coronary artery segment with the fewest artifacts was chosen.

The calcium score was determined on an offline workstation (3D-Virtuoso, Siemens) based on a scoring system previously published protocols used in our institution, MDCT (18). In this work we refer to the Agatston score as assessed by MDCT as Agatston Score Equivalent (19,20).

On the basis of original axial slices, three-dimensional volume-rendering images as well as 1.25- to 4-mm thin-slicing maximum-intensity projections, two experienced readers determined evaluability of each epicardial coronary segment according to a modified American College of Cardiology/American Heart Association (ACC/AHA) classification in a joint reading (21) (Fig. 1). In a direct comparison with the conventional angiogram, side branches were used to identify each segment (10). In the evaluable
segments, the presence of severe coronary lesions was determined based on a visual estimation (lesion >70%). Results were documented separately for all coronary segments, and the results for each patient were then compared with the findings of the CCA as assessed by quantitative coronary angiography (QCA). The MDCT diagnosis was considered to be correct if correspondence with the angiographical results regarding lesion detection/exclusion was obtained.

**Quantitative coronary angiography.** In all patients, coronary angiograms were obtained using 5F catheters the day following the MDCT examination. The angiograms were evaluated by quantitative coronary analysis with automated vessel contour detection with the possibility of manual correction if necessary. The catheter was used for calibration (Quantitative Coronary Analysis, Philips Medical Systems, Eindhoven, Netherlands). Lesions with a diameter stenosis >70% were considered to be severe lesions.

**Data analysis.** Because the primary goal of this study was to establish determinants of correct diagnosis, all MDCT scans were analyzed with respect to evaluability on a segmental basis described above. In addition to sensitivity, specificity, positive and negative predictive value of detection of severe lesions (>70%), the correctness of final diagnosis was also evaluated.

To further analyze factors leading to correct or incorrect diagnosis using MDCT, all patients were subdivided into two groups (correct MDCT diagnosis vs. incorrect MDCT diagnosis). Analysis was made, whether there were clinically relevant differences in respect to calcifications, heart rate, severity of the underlying CAD, and body mass index (BMI), of all factors suspected to be major determinants of image quality and/or evaluability.

As a last step in the data evaluation process, a threshold for each of the above-mentioned criteria was established retrospectively to provide clinically useful patient selection criteria so as to avoid nondiagnostic examinations.

**Statistics.** Patient data were documented by the Department of Diagnostic Radiology, Tuebingen, and transferred to the Institute for Medical Information Processing, which conducted the statistical analyses. This investigation was planned as a pilot study to compare the distribution of clinically relevant variables in the two groups (correct MDCT diagnosis vs. incorrect MDCT diagnosis). For continuous variables that were not normally distributed (p < 0.1 [Shapiro-Wilks test]), the testing for differences was done using the nonparametric Wilcoxon test. For normally distributed variables, the Student t test was employed. Categorical data were compared using the Fisher exact test (Table 2) or the Pearson chi-square test (also see Results). The distributions of continuous variables were presented with their mean and SD. Categorical data were presented with absolute frequencies and percentages. Re-

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Figure 1. Coronary segments after a modified ACC/AHA classification. For the right coronary artery as well as the left anterior descending artery, the nomenclature remained unchanged. In the circumflex branch, the proximal segment was segment 11, the distal posterolateral branches was segment 12, and the first marginal branch was segment 13.

Table 2. Differences Between Diagnostic Patients and Nondiagnostic Patients

<table>
<thead>
<tr>
<th></th>
<th>Diagnostic (n = 24)</th>
<th>Nondiagnostic (n = 42)</th>
<th>p Value</th>
<th>Test Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium score*</td>
<td>101 (0–2506)</td>
<td>504 (0–2792)</td>
<td>0.001</td>
<td>Wilcoxon</td>
</tr>
<tr>
<td>Heart rate (beats/min)*</td>
<td>61.7 (46–90)</td>
<td>68.2 (48.9–102)</td>
<td>0.031</td>
<td>Wilcoxon</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>58.9 ± 8.5</td>
<td>61.3 ± 8.8</td>
<td>0.282</td>
<td>t test</td>
</tr>
<tr>
<td>Time since last angiogram (months)</td>
<td>12.5 (1–142)</td>
<td>30 (2–132) (n = 41)</td>
<td>0.414</td>
<td>Wilcoxon</td>
</tr>
<tr>
<td>Gender</td>
<td>17 male, 7 female</td>
<td>10 male, 22 female</td>
<td></td>
<td>Fisher exact test</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>27.0 ± 3.2 (n = 23)</td>
<td>27.5 ± 4.2 (n = 38)</td>
<td>0.629</td>
<td>t test</td>
</tr>
<tr>
<td>Number of diseased vessels</td>
<td>11 one-, 10 two-, 3 three-vessel</td>
<td>15 one-, 19 two-, 8 three-vessel</td>
<td>0.370</td>
<td>Wilcoxon</td>
</tr>
</tbody>
</table>

*Calcium score and heart rate are relevantly different. BMI = body mass index.
The MDCT was performed without complications in all patients. Of 858 coronary artery segments scanned, 487 were judged to be evaluable (57%); 137 segments were not evaluable owing to severe calcifications (16%) and 234 because of a lack of image quality such as coronary motion, vessel size, breathing artifacts, or technical scan insufficiencies such as scan abortion, misplaced scan range, poorly executed contrast media timing, or ECG misregistrations (27%). In these segments, artifacts caused by coronary motion were significantly different only for the left main coronary artery versus right coronary artery (LM vs. RCA, \( p < 0.002 \); LM vs. left circumflex branch [LCx] \( p < 0.001 \); LM vs. left anterior descending [LAD] \( p < 0.0002 \)). Only 2/66 (3%) LM segments had degraded image quality. For all other segments the percentage of degraded image quality was not significantly different (RCA vs. RCx \( p = 0.6540 \); RCA vs. LAD \( p = 0.7965 \); RCx vs. LAD \( p = 0.4786 \)). Seventy-seven of 264 (29%) segments of the RCA were affected by motion artifacts, 92/330 (28%) of the LAD, and 63/198 (32%) of the RCx.

### RESULTS

#### Evaluability

The results of the statistical tests are presented with two-tailed \( p \) values (adjusted for multiple comparisons when applicable); \( p \) values \( \leq 0.05 \) were considered to be relevant. Computations were performed using SAS-PC for Windows (Version 8.0, SAS Institute, Cary, North Carolina).

<table>
<thead>
<tr>
<th></th>
<th>All Segments</th>
<th>Proximal Segments</th>
<th>All Evaluable Segments</th>
<th>Prox. Evaluable Segments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segments</td>
<td>858</td>
<td>462</td>
<td>487</td>
<td>317</td>
</tr>
<tr>
<td>Lesions by CCA</td>
<td>105</td>
<td>60</td>
<td>59</td>
<td>31</td>
</tr>
<tr>
<td>Lesions by MDCT</td>
<td>47</td>
<td>25</td>
<td>47</td>
<td>25</td>
</tr>
<tr>
<td>False positive</td>
<td>8</td>
<td>4</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>0.37</td>
<td>0.35</td>
<td>0.66</td>
<td>0.68</td>
</tr>
<tr>
<td>Specificity</td>
<td>0.99</td>
<td>0.99</td>
<td>0.98</td>
<td>0.99</td>
</tr>
<tr>
<td>Positive predictive</td>
<td>0.83</td>
<td>0.84</td>
<td>0.83</td>
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<tr>
<td>value</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative predictive</td>
<td>0.92</td>
<td>0.91</td>
<td>0.95</td>
<td>0.97</td>
</tr>
<tr>
<td>value</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

CCA = conventional coronary angiography; MDCT = multidetector computed tomography.

#### Table 3. Severe Lesion Detection

![Figure 2](image-url)

(a) A 59-year-old patient with known single-vessel disease and prior right coronary artery-percutaneous transluminal coronary angioplasty. The entire coronary tree is well visualized in this volume-rendering image. (b) Same image with different window thresholds shows severe calcifications (Agatston score 970) impeded correct diagnosis. (c) Enlargement of (b) shows severe calcium deposits in the left main, left circumflex, and left anterior descending arteries.
Taking only the proximal segments into account (segments 1, 2, 5, 6, 7, 9, and 11), 317 of 472 were judged to be evaluable (69%). Of these, 107 were not evaluable owing to severe calcifications (23%) and 48 to a lack of image quality such as coronary motion, vessel size, breathing artifacts, or scan insufficiencies (10%). In 21/66 patients (32%), all four coronary vessels could be visualized.

**Lesion detection.** To provide comparability of our data with other studies using different evaluation schemes, several evaluation schemes to assess sensitivity, specificity, and both positive and negative predictive values of severe lesion detection were applied in this study. We analyzed all coronary segments, only proximal coronary segments, only evaluable coronary segments, or proximal evaluable coronary segments. The results are shown in Table 3.

**Missed lesions.** Of the 66 not-correctly-assessed lesions, 46 were not detected owing to insufficient image quality or severe calcifications (70%), with calcifications accounting for 28/46 (61%) of these. Thirteen lesions were underestimated, and 7 lesions were missed despite sufficient image quality. Analyzing these data for each vessel, calcifications accounted for 17/22 (77%) in the LAD, 6/18 (33%) in the LCx, and 5/13 (38%) in the RCA of the nondetected lesions.

For proximal vessel segments, calcification inhibited lesion detection in 14/18 (77%) cases in the LAD, in 3/6 (50%) cases in the LCx, and in 4/9 (44%) cases in the RCA (Fig. 2).

**Assessment of correct diagnosis using MDCT.** When analyzing the present data with respect to correct diagnosis per patient, 24 patients were correctly diagnosed (36%) using MDCT. In 42 patients, no correct diagnosis could be obtained. These two groups (correct vs. incorrect diagnosis) were to be statistically analyzed for differences in calcium score, heart rate, distribution of number of diseased vessels, time since last angiography, BMI, age, and gender (Table 2).

Looking at the body-mass indices, time elapsed since last angiography, age, gender, and number of diseased vessels, no relevant differences were found. However, calcium score and heart rate revealed relevant differences (Table 2).

**Threshold determination.** To evaluate a threshold to identify those patients suitable for MDCT, we used the
amount of coronary calcium and heart rate as the two major
determinants as threshold parameters and retrospectively
calculated those combined thresholds that would yield the
largest fraction of patients correctly diagnosed.

Using a calcium score of 335 (Agatston Score Equivalent
as threshold), 32/66 patients (48%) were assumed to be
suited for MDCT. However, in only 18 patients out of that
subpopulation was a correct diagnosis made (56%).

Using a heart rate of 65 beats/min as threshold, 28/66
patients (42%) were assumed to be suited for MDCT. Also
in this group, only 13 of these 28 patients was a correct
clinical diagnosis made (46%) (Fig. 3).

Combining both thresholds mentioned above, a total of
12/65 patients fulfilled these criteria (18%). One of these
patients was excluded from evaluation because a technical
failure (scan abortion) resulted in a nondiagnostic exam. In
that group 10/11 patients (91%) were correctly diagnosed.

DISCUSSION

The most important findings of the present study are that
patients with already proven CAD can benefit from an
MDCT exam of the coronary arteries, if the patients are
selected carefully.

Lesion detection. The overall ability of coronary segment
visualization as well as lesion detection could be performed
with comparable accuracy according to recent studies pub-
lished by Achenbach and Giesler (6,22). Our study yields a
sensitivity of 68%, a specificity of 99%, a positive predictive
value of 84%, and a negative predictive value of 97% for all
patients when looking at proximal evaluable segments (seg-
ments 1,2,5,6,7,9,11). However, in our study the correct
diagnosis, which is the relevant information in clinical
practice, revealed that this would be obtained in only 36% of
all patients. The major reason for this surprising result is the
poor diagnostic visualization of relevant coronary segments
in the presence of severe calcifications and motion artifacts
caused by higher heart rates. Looking at the LAD artery,
which is considered least affected by motion artifacts (10),
70% of the missed lesions are caused by calcifications. In
vessel segments, where image quality is more often affected
by motion artifacts such as left circumflex (LCx) and RCA
(10), calcifications still account for more than 50% of the
missed lesions in proximal vessel segments.

Heart rate. Our group could recently demonstrate that
heart rate has a major impact on image quality (23). Our
findings demonstrate a highly significant inverse rela-
tionship between heart rate and segmental visibility. We have
come to the conclusion that vessel visibility is best for heart
rates ≤65 beats/min. These data are supported by results
published by Giesler, Becker, and others (6,7,13,23,24).
The reason for this heart rate limitation can be explained by
the temporal resolution of the CT image acquisition and
reconstruction system. With a gantry rotation of 500 ms,
the system provides a temporal resolution of 250 ms when
using a single-phase (single heart beat) algorithm to recon-
struct an image. For higher heart rates (>65 beats/min) a
bi-phasic reconstruction algorithm uses two heart beats to
reconstruct an image, achieving a temporal resolution of up
to 125 ms (25). This improved temporal resolution, how-
ever, does not necessarily always translate into better image
quality as two absolutely equal heart cycles are necessary to
generate a motion-free image, a condition that is not always
found during scanning. Our data support the concept that a
single-sector reconstruction algorithm provides better diag-
nostic image quality, given a heart rate where the temporal
resolution of the CT scanner is sufficient to obtain one
image per heart cycle. To overcome this limitation, two
basic strategies are possible. Either the gantry rotation speed
is increased mechanically to improve the system’s immanent
temporal resolution of the CT-scanner or negative chron-
objective substances such as beta-blockers are to be used to
decrease the heart rate to the desired level.
Lesion detection in presence of calcifications. The second major cause for nondiagnostic images of the coronary arteries is severe calcifications. Early reports describe the effect, namely that significant calcifications impair the diagnostic image quality because the lumen compromise cannot sufficiently be visualized (6,8,11). Our data demonstrate that assessment of lumen compromise in the presence of severe calcifications yields unsatisfactory results (Fig. 4). The current spatial resolution of 9-line pairs/cm in xy-direction and 6-line pairs in z-direction, which corresponds to a voxel size of 0.6 × 0.6 × 1.0 mm (compared to 50 line pairs in conventional coronary angiography [7]), provides assessment of structures >0.9 to 1 mm (26). Thus, in visualization of free lumen in coronaries with a diameter of, for example, 2 mm, a lumen loss of 50% diameter stenosis would be at the edge of spatial resolution. In addition to that, common artifacts of CT, such as the “blooming artifact” caused by beam hardening effects of hyperdense structures such as vessel wall calcium as well as partial volume effects, compromise even more the evaluability of a particular diseased vessel segment. To overcome this limitation, one strategy would be a desirable thinner collimation to achieve true isometric submillimeter voxel size.

Other factors known to decrease image quality, such as elevated BMI causing a poor signal-to-noise ratio are true for general CT scanning and are not specific limiting factors in cardiac scanning.

In the case that the total calcium burden exceeds our proposed threshold of 335 (Agatston Score Equivalent), a contrast-enhanced visualization of the coronaries should not be performed and the patient should be referred to CCA if the clinical situation requires such action.

Study limitations. Our study permitted identification of only two factors influencing diagnostic image quality in retrospectively gated, contrast-enhanced cardiac CT, this was because our collective of 66 patients in a single-center setting is a small group to assess every influencing factor with satisfying statistical power. Also, our method to estab-
lish thresholds for certain factors by retrospective computation might lead to an investigative bias. However, our strategy in using the correct diagnosis per patient as most important criteria seems to be an adequate way to assess the clinical benefit of MDCT in the chosen collective. Furthermore, the investigated patient group had a high prevalence of different stages of calcifications (mean Ca score 563 ± 665, median 340, range 0 to 2,792) and an adequate number of coronary lesions as well as a wide range of heart rates to investigate the two main parameters influencing image quality. To demonstrate the effect of higher heart rates on image quality, no beta-blocker was administered deliberately.

As measurement for the total calcium burden, the Agatston Score Equivalent for MDCT might not be the most precise score available. Other scoring methods such as the volume score for EBCT reported by Callister et al. (27) as well as the total calcium burden in mg hydroxyapatite as reported by Becker et al. (28) for MDCT might be more precise and provide better reproducibility and comparability. However, the Agatston Score for EBCT as well as the Agatston Score Equivalent for MDCT is a widespread scoring method with general acceptability, and our principal conclusions appear not to be affected.

A general limitation for all scoring methods is the fact that the overall calcium burden poorly reflects the distribution of calcifications within the coronary tree. A single large calcified plaque in a proximal vessel segment may be more deleterious for image interpretation than multiple small speckles widely distributed. Further studies are warranted to determine the evaluability of MDCT examinations in respect to distribution patterns and plaque morphology.

Even with the limitations cited, this study already provides a good estimation for patients with known CAD with high prevalence of noncalcified plaques using helical CT with retrospective ECG gating. AJR Am. J. Roentgenol. 2000;175:764–71.


