Combining dual-source computed tomography coronary angiography and calcium scoring: added value for the assessment of coronary artery disease

Leschka, S; Scheffel, H; Desbiolles, L; Plass, A; Gaemperli, O; Stolzmann, P; Genoni, M; Luescher, T; Marineck, B; Kaufmann, P; Alkadhi, H

Leschka, S; Scheffel, H; Desbiolles, L; Plass, A; Gaemperli, O; Stolzmann, P; Genoni, M; Luescher, T; Marineck, B; Kaufmann, P; Alkadhi, H (2008). Combining dual-source computed tomography coronary angiography and calcium scoring: added value for the assessment of coronary artery disease. Heart, 94(9):1154-1161.

Postprint available at:
http://www.zora.uzh.ch

Posted at the Zurich Open Repository and Archive, University of Zurich.
http://www.zora.uzh.ch

Originally published at:
Heart 2008, 94(9):1154-1161.
Combining dual-source computed tomography coronary angiography and calcium scoring: added value for the assessment of coronary artery disease

Abstract

OBJECTIVE: To prospectively investigate the diagnostic accuracy of dual-source 64-slice computed tomography coronary angiography (CTCA), calcium scoring (CS) and both methods combined for assessing significant coronary artery stenoses relative to conventional coronary angiography (CCA). DESIGN, SETTING AND PATIENTS: Prospective, single-centre study conducted in a referral centre enrolling 74 consecutive patients (24 women; mean age 62 (SD 12) years) from August-October 2006. All study participants underwent CS, CTCA and CCA. Diagnostic accuracy was calculated for CS, CTCA and both methods combined relative to CCA. Not-evaluative segments at computed tomography were considered false positive. RESULTS: CCA identified 139 stenoses in 36 patients. Average heart rate during CTCA was 68 (13) bpm (range 35-102 bpm), and 2% of segments (21/1001) in 11% of patients (8/74) were not evaluative. Considering these as false positives, per-patient sensitivity and specificity was 98% and 87%. When using CS cut-off values of 0 to exclude and >or=400 to predict stenosis, sensitivity and specificity of CS was 100% and 70%, respectively. Combining CS and CTCA in all patients correctly reclassified five patients, while six were falsely classified as stenotic, all of them correctly classified with CTCA alone. Using CS only in patients with not-evaluative segments correctly reclassified five patients while avoiding misclassifications (sensitivity 98%, specificity 100%). CONCLUSION: Dual-source CTCA allows the diagnosis of significant stenoses with a high diagnostic accuracy. Selectively combining CS with CTCA in patients with not-evaluative coronary segments improves specificity from 87% to 100% without decreasing the high sensitivity of 98%.
Combining dual-source computed tomography coronary angiography and calcium scoring: added value for the assessment of coronary artery disease

S Leschka,¹ H Scheffel,¹ L Desbiolles,¹ A Plass,² O Gaemperli,³ P Stolzmann,¹ M Genoni,² T Luescher,³ B Marincek,¹ P Kaufmann,³,⁴ H Alkadhi¹

ABSTRACT

Objective: To prospectively investigate the diagnostic accuracy of dual-source 64-slice computed tomography coronary angiography (CTCA), calcium scoring (CS) and both methods combined for assessing significant coronary artery stenoses relative to conventional coronary angiography (CCA).

Design, setting and patients: Prospective, single-centre study conducted in a referral centre enrolling 74 consecutive patients (24 women; mean age 62 (SD 12) years) from August-October 2006. All study participants underwent CS, CTCA and CCA. Diagnostic accuracy was calculated for CS, CTCA and both methods combined relative to CCA. Not-evaluative segments at computed tomography were considered false positive.

Results: CCA identified 139 stenoses in 36 patients. Average heart rate during CTCA was 68 (13) bpm (range 35–102 bpm), and 2% of segments (21/1001) in 11% of patients (8/74) were not evaluable. Considering these as false positives, per-patient sensitivity and specificity was 98% and 87%. When using CS cut-off values of 0 to exclude and ≥400 to predict stenosis, sensitivity and specificity of CS was 100% and 70%, respectively.

Combining CS and CTCA in all patients correctly reclassified five patients, while six were falsely classified as stenotic, all of them correctly classified with CTCA alone. Using CS only in patients with not-evaluative segments correctly reclassified five patients while avoiding misclassifications (sensitivity 98%, specificity 100%).

Conclusion: Dual-source CTCA allows the diagnosis of significant stenoses with a high diagnostic accuracy. Selectively combining CS with CTCA in patients with not-evaluative coronary segments improves specificity from 87% to 100% without decreasing the high sensitivity of 98%.

The advent of 64-slice computed tomography (CT) scanner systems has rendered non-invasive CT coronary angiography (CTCA) a reliable tool for evaluating coronary arteries. Several studies have proved a high diagnostic accuracy of 64-slice CTCA to detect or rule out coronary artery disease (CAD).¹-⁵ Nevertheless, even with 64-slice CT diagnostic accuracy is affected by severe vessel wall calcifications and motion artefacts. The most recently developed dual-source CT system further improved temporal resolution to 85 ms.⁶ First experience using dual-source CT demonstrated imaging of coronary arteries without motion artefacts even at high heart rates.⁷

Arterial wall calcifications are characteristic for CAD and several studies have reported that calcium scoring (CS) is sensitive but not specific for predicting coronary stenosis at low CS thresholds, while being highly specific but not sensitive at high CS thresholds.⁸⁻⁹ As misclassification of coronary artery stenosis with CTCA is often associated with severe vessel wall calcifications, the combined evaluation of CTCA and CS might add incremental value to improve diagnosis of CAD.

The purpose of this study was to prospectively investigate the diagnostic accuracy of dual-source CTCA, CS and both methods combined for the assessment of coronary artery stenosis as compared to conventional coronary angiography (CCA).

MATERIALS AND METHODS

Study population

We prospectively performed dual-source CT as part of a research protocol in 80 consecutive patients (26 women, 54 men; mean age 61.9 (SD 12.6) years; age range 37–85 years) between August 2006 and October 2006 who were scheduled for CCA because of typical (n = 40) or atypical chest pain (n = 19), pathological exercise test (n = 12) or dyspnoea (n = 9). Patients were eligible if they had stable clinical conditions—that is, if they were in Canadian Cardiac Society class I to III, and in New York Heart Association functional class I to III. Four patients were excluded from CT because of previous allergic reactions to iodinated contrast media (n = 2), and renal insufficiency (creatinine level >120 µmol/l, n = 2). Two patients denied written informed consent. Thus, the final study population comprised 74 patients (24 women, 50 men; mean age 61.5 (12.2) years; age range 37–86 years). No additional β-blockers were administered for heart rate control before CT; 51 patients (41.9%) continued taking their baseline β-receptor blocking medication. Patients with elevated or irregular heart rates were not excluded from this study. All patients underwent CCA within four weeks after CTCA (mean 8 (7) days; range 0–23 days). The study protocol was approved by the local ethics committee and written informed consent was obtained.

Dual-source CT scan and image reconstruction protocol

All CT examinations were performed on a dual-source CT scanner (Somatom Definition, Siemens 1154

¹ Institute of Diagnostic Radiology, Zurich, Switzerland; ² Clinic for Cardiovascular Surgery, Zurich, Switzerland; ³ Cardiovascular Center, University Hospital Zurich, Switzerland; ⁴ Center for Integrative Human Physiology, University of Zurich, Switzerland

Correspondence to:
Dr Hatem Alkadhi, Institute of Diagnostic Radiology, University Hospital Zurich, Rämistrasse 100, 8091 Zurich, Switzerland; hatem.alkadhi@usz.ch

Accepted 16 October 2007
Published Online First
21 November 2007
s narrowing exceeding 50%. For any disagreement presence of haemodynamically significant stenoses defined as dently assessed all coronary artery segments at CTCA for the segment as being diagnostic or as being not evaluative in both First, both readers judged the image quality of each coronary observers unaware of the clinical history and results from CCA.

Table 1 Demographic data in relation to the presence or absence of significant coronary artery stenoses

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Coronary artery stenosis absent</th>
<th>Coronary artery stenosis present</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of patients</td>
<td>74</td>
<td>38</td>
<td>36</td>
<td>–</td>
</tr>
<tr>
<td>Age (years)</td>
<td>61.7 (12.3)</td>
<td>60.6 (14.4)</td>
<td>62.6 (9.5)</td>
<td>0.26</td>
</tr>
<tr>
<td>Male/female</td>
<td>50/24</td>
<td>26/12</td>
<td>24/12</td>
<td>0.99</td>
</tr>
<tr>
<td>Average heart rate (bpm; SD; range)</td>
<td>67.4 (13.3; 47–102)</td>
<td>65.8 (13.3; 35–94)</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Calcium score (SD; range)</td>
<td>720 (968; 0–4387)</td>
<td>219 (432; 0–1790)</td>
<td>1253 (1090; 17–4387)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>0</td>
<td>18.9% (14/74)</td>
<td>36.8% (14/38)</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>1–399</td>
<td>37.8% (28/74)</td>
<td>18.4% (7/38)</td>
<td>58.3% (21/36)</td>
<td>–</td>
</tr>
<tr>
<td>&gt;400</td>
<td>43.2% (32/74)</td>
<td>44.8% (17/38)</td>
<td>41.7% (15/36)</td>
<td>–</td>
</tr>
<tr>
<td>Patients without calcifications*</td>
<td>18.9% (14/74)</td>
<td>36.8% (14/38)</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Patients with calcifications*</td>
<td>81.1% (60/74)</td>
<td>63.2% (24/38)</td>
<td>100% (36/36)</td>
<td>–</td>
</tr>
<tr>
<td>Not-evaluative segments†</td>
<td>2.1% (2/1001)</td>
<td>3.1% (16/515)</td>
<td>1.0% (5/486)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Patients with not-evaluative segments‡</td>
<td>10.8% (8/74)</td>
<td>15.8% (9/38)</td>
<td>5.8% (2/36)</td>
<td>0.26</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>27.2 (4.0)</td>
<td>26.1 (3.5)</td>
<td>28.3 (4.3)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Arterial hypertension</td>
<td>59.5% (44/74)</td>
<td>66.4% (25/38)</td>
<td>51.4% (19/36)</td>
<td>0.34</td>
</tr>
<tr>
<td>Diabetes mellitus type II</td>
<td>25.7% (19/74)</td>
<td>17.7% (7/38)</td>
<td>32.7% (12/36)</td>
<td>0.19</td>
</tr>
<tr>
<td>Smoking</td>
<td>27.0% (20/74)</td>
<td>13.5% (3/38)</td>
<td>42.1% (15/36)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Hyperlipidaemia</td>
<td>23.0% (17/74)</td>
<td>17.7% (7/38)</td>
<td>28.0% (10/36)</td>
<td>0.41</td>
</tr>
</tbody>
</table>

* Determined by calcium scoring; †, determined by dual-source CT coronary angiography; ‡, defined by Canon-enhanced dual-source CT revealed 563 coronary artery calcifications in 359 segments (35.9%). Mean CS of all patients was 720 (968; range 0–4387). In 18.9% of patients (14/74) CS was 0, in 37.8% of patients (28/74) CS was 0–399 (mean 123 (103); range 0–379) and in 43.2% (32/74) CS was >400 (mean 1557 (958); range 418–4387).

Medical Solutions, Forchheim, Germany) using the following scan parameters: detector collimation 2×32×0.6 mm, slice acquisition 2×64×0.6 mm, gantry rotation time 530 ms, pitch 0.2–0.46 adapted to the heart rate, tube potential 120 kV, and tube current time product 80 mAs per rotation for CTCA, respectively. For CTCA, 80 ml of ioxixanol (Visipaque, 320 mg/ml, GE Healthcare, Bucks, UK) at a flow rate of 5 ml/s followed by 30 ml saline solution was injected and controlled by the bolus tracking technique. Electrocardiography (ECG) pulsing for radiation dose reduction was used in all patients as previously recommended.3 Estimated radiation dose using this protocol was 7–9 mSv.11

Non-enhanced CT angiograms were reconstructed at 70% of the R-R interval using 3 mm thick non-overlapping slices (reconstruction kernel B3S) and contrast-enhanced CT angiograms at 70% of the R-R interval (slice thickness 0.75 mm, increment 0.5 mm) using a soft-tissue (B26f) and a sharp convolution kernel (B46). In case of non-diagnostic image quality, additional reconstructions were performed in 5% steps within the full tube current window.

CT data analysis

Calcifications were quantified with dedicated scoring software (Syngo CaScore, Siemens) by one experienced observer using the Agatston method.12

Coronary segments were defined according to the scheme of the AHA.13 CT data analysis was performed by two independent observers unaware of the clinical history and results from CCA. First, both readers judged the image quality of each coronary segment as being diagnostic or as being not evalutive in both CTCA and CS examinations. Second, both observers independently assessed all coronary artery segments at CTCA for the presence of haemodynamically significant stenoses defined as luminal diameter narrowing exceeding 50%. For any disagreement in data analysis, consensus agreement was achieved.

Combining dual-source CT coronary angiography and calcium scoring

We investigated two approaches for combining CTCA and CS. First, we determined whether a low CS could be used to exclude significant coronary artery stenoses falsely suspected by CTCA, and if a high CS could be used to identify stenoses missed by CTCA. The low and high cut-off values for CS were set as 0 and 400, respectively, as previously published.14–17 Thus at combined evaluation, a CS = 0 excluded significant CAD in a patient even if the results from CTCA indicated a significant stenosis. Similarly, a CS ≥400 indicated presence of significant CAD even if no significant coronary artery stenosis was identified on CTCA.

In the second approach, we combined CS thresholds with CTCA results only in those patients in whom not all coronary segments were of diagnostic image quality with CTCA. In the patients with completely evaluitive CTCA results the results from CS were not included.

Conventional coronary angiography

CCA was performed according to standard techniques and multiple views were recorded for further analysis. Two experienced observers, being aware of the patients’ clinical history but blinded to the results from CTCA, independently evaluated all angiograms according to the same AHA scheme13 with regard to significant stenoses, defined as a diameter reduction >50%. For any disagreement in data analysis, consensus agreement was appended. This was necessary in two stenoses (of two patients) that were considered non-significant by one and significant by the other observer. Consensus reading resulted in two significant stenoses.

Statistical analysis

SPSS (version 12.0) and MedCalc software (MedCalc 9.0.2, Mariakerke, Belgium) were used for statistical testing and a p value of <0.05 was considered statistically significant. Kappa statistics were calculated for inter-observer agreements. CCA was considered the standard of reference. Differences regarding demographic data between patients with and without coronary artery stenoses were calculated using the Fisher exact test for categorical variables and the Wilcoxon signed-rank test for quantitative variables, respectively. Statistics for diagnostic accuracy of CTCA were calculated on a segment-based, a vessel-based and on a patient-based analysis, the latter defined

Heart 2008;94:1154–1161. doi:10.1136/hrt.2007.124800
as presence of at least one significant stenosis or absence of any significant stenosis in each patient. Accuracy of CS and the combined approaches with CS and CTCA were calculated on a per-patient basis. Any differences in diagnostic accuracy for both approaches of combining CTCA and CS were tested for significance by using a McNemar test. As previously suggested, all non-evaluative coronary segment by CT were censored as false-positive, because every patient with any non-evaluative segment would undergo CCA in clinical practice. Receiver operating characteristic (ROC) curve for prediction of significant CAD in patients was calculated for CS.

RESULTS

Average heart rate during CT scanning was 67.7 (13.3) bpm (range 35–102 bpm). A total of 1001 segments were evaluated. Diagnostic image quality was found in 97.9% of all segments (980/1001), while image quality of 21 segments (2.1%) was considered non-diagnostic. Non-diagnostic image quality was most often present in distal segments (segment 3, n = 3; segment 8, n = 1; segment 15, n = 1) and side-branches (segment 4, n = 4; segment 10, n = 8; segment 12, n = 2; segment 14, n = 3; segment 15, n = 2), while only two more proximal segments were considered not evaluable (segment 2, n = 2). Inter-observer agreement for image quality rating was high for both CTCA (kappa = 0.88) and CS (kappa = 1.00).

Prevalence of coronary artery stenosis and calcifications

Patient characteristics are summarised in table 1. Twenty-one patients (28.4%) had known CAD (that is, coronary artery stenosis with luminal narrowing more than 50% identified by previous CCA studies). CCA identified 139 coronary artery stenoses with a luminal diameter narrowing of more than 50% in 36 patients (48.6%). Single-vessel disease was present in 10.8% (8/74) and multivessel disease in 37.8% (28/74). Significant coronary artery stenosis was absent in 51.4% of patients (38/74). All segments with non-evaluative image quality at CTCA were free of significant coronary artery stenosis as identified by CCA.

Significant angiographic coronary artery stenoses were present in 32.0% (115/359) of segments carrying calcifications, while 68.0% of segments with calcifications (244/359) did not show significant stenosis on CCA. Non-calcified plaques were responsible for 24 of the 139 significant coronary artery stenoses (17.3%) in 12 patients (16.2%; mean CS 325 (591); range 130–2045). The mean CS in patients with significant CAD was 1253 (1090; range 87–4387) compared with 215 (432; range 0–897) in patients with no CAD (p<0.001).

There were no statistically significant differences regarding patient age (p = 0.26), gender (p = 0.99) and average heart rate (p = 0.16) in patients with and without coronary artery stenosis as defined by CCA. The rate of not-evaluative segments was significantly lower (5/486; 1.0%) in patients with coronary artery stenosis than in patients without stenosis (16/515; 3.1%; p<0.05). The rate of smokers was significantly higher in patients with stenosis than in patients without (p<0.01), while there was no significant difference in other cardiovascular risk factors between both groups (table 1).

Diagnostic accuracy of CS

Sensitivity and specificity of CS in defining significant stenosis depended on the CS threshold. Using CS to identify significant
The diagnostic accuracy of dual-source CTCA was comparable among the individual coronary arteries (table 3).

Broken lines represent 95% confidence limits. Marked are the CS cut-off points of ≥1 (sensitivity, 100%; specificity, 36.8%), ≥50 (sensitivity, 91.7%; specificity, 52.6%), and ≥400 (sensitivity, 72.2%; specificity, 86.8%). Also marked are the optimal trade-off between high sensitivity (75.0%) and high specificity (87%) that resulted in a sensitivity similar to that of CTCA (94.4%). Although discrimination between diseased and non-diseased patients was possible using CS (area under curve 0.889), no conclusive single cut-off point for discrimination on the basis of CS values was found.

Diagnostic accuracy of dual-source CTCA

The kappa value for coronary artery stenosis detection with CT was 0.84 indicating a high inter-observer agreement. CTCA correctly recognised 132 of the 139 significant stenoses detected with CCA (96.4%) (fig 3). In 15 segments lesions were incorrectly graded as stenotic on CTCA. Including all 21 not-evaluative segments into analysis and considering them as false-positives, the overall sensitivity of CT coronary angiography on a segment-based analysis was 95.0%, the positive predictive value was 72.2%, and the negative predictive value was 99.2% (table 2).
would have been performed in clinical practice and these patients were considered as false-positives in the per-patient analysis (fig 4). In one patient without CAD, CTCA suspected significant stenosis (2.6%; 1/38). On a patient-based analysis, overall sensitivity of CT coronary angiography was 97.2%, the specificity was 86.8%, the positive predictive value was 87.5%, and the negative predictive value was 97.1% (fig 2; table 2).

**Diagnostic accuracy of combined dual-source CTCA and CS**

When combining a CS threshold of 0 to exclude significant CAD with the results from CTCA, the combined approach correctly reclassified the one patient falsely rated as stenosed with CTCA. In addition, all four patients with not-evaluative segments and no stenosis present at CCA had a CS of 0 and were correctly reclassified as having no significant CAD. Including a CS threshold ≥400 into CTCA analysis and considering this threshold to identify significant CAD, no correct reclassification of missed stenoses of CTCA alone was achieved as the patient with false-negative stenosis had a CS between 0 and 400. On the other hand, six patients with a CS ≥400 had no angiographic stenoses, all of them correctly classified with CTCA. Thus combining both CS cut-off points with the results of CTCA did not significantly alter diagnostic accuracy relative to that of CTCA alone (table 2).

By primarily using the CTCA results and only applying the CS thresholds to the patients with not completely evaluative segments, four patients had a CS of 0 and an unnecessary CCA would have been avoided. The differences in diagnostic accuracy between CTCA alone and the combined approach of CTCA and CS in patients with not completely evaluative segments did not reach the level of significance (p = 0.06; table 2).

**Discussion**

CTCA for routine clinical use needs to provide a reliable visualisation of the complete coronary tree in every patient. However, temporal resolution of 64-slice CT scanners has been reported to be insufficient for artefact-free visualisation of the coronary arteries in patients with higher and variable heart rates. Thus, heart rate control by negative chronotropic medication was considered necessary before 64-slice CT."

Introduction of dual-source CT technology has further improved temporal resolution to 83 ms independent of the patients’ heart rate. Preliminary results of dual-source CTCA in 50 patients without heart-rate control reported a high diagnostic accuracy for the diagnosis of CAD with a sensitivity of 96% and a specificity of 98%, while excluding only 1.4% not-evaluative segments. This is in line with our study demonstrating a sensitivity of 95% and specificity of 96% on a per-segment analysis. This diagnostic performance of dual-source CT appears to be comparable to some previous 64-slice CTCA studies; however, dual-source CT provides this accuracy in patients undergoing scanning without forgoing heart rate control. Dual-source CT additionally decreases the rate of not-evaluative coronary segments (2.1%) compared to previous 64-slice CTCA studies reporting not-evaluative segments up to 12%. In contrast to Scheffel and co-workers, we did not exclude not-evaluative segments from analysis but considered them false-positive, resulting in a considerably lower specificity of 79%.

Coronary calcium is a reliable indicator of coronary atherosclerosis and reflects the total plaque burden. In general, higher CS more likely predicts significant CAD than low CS, and a CS ≥400 in asymptomatic patients indicates a high likelihood of significant coronary stenosis. The drawback of CS is that the extent and site of calcified deposits often does not correspond with the site of stenosis. Rumberger and colleagues suggested that a positive CS scan should be used to predict associated atherosclerosis somewhere within the coronary artery tree, but that the presence of calcification may be less useful in predicting luminal narrowing at a specific site. On the other hand, a negative CS scan does not prove the absence of coronary plaques because non-calcified plaques are not sampled by the CS method. In our study sensitivity of CS ranged from 75–100% and specificity from 0–87%, depending on the CS threshold, which is in line with previous studies.

Combining CS and CTCA to improve the diagnostic accuracy of either method has been previously performed in two four-slice CT studies, which found an increase in sensitivity from 72% to 83% and 93% to 100%, respectively, without a loss of specificity by using the combined test relative to CTCA alone. In contrast to these studies, we found the approach to exclude significant CAD in all patients with CS = 0 and to indicate significant CAD in all patients with CS ≥400 to be less useful. Although this approach resulted in a correct reclassification of one patient falsely rated as having significant CAD, six patients were falsely classified as having significant CAD because of CS ≥400, while CTCA correctly identified these patients as having no significant CAD. Discrepancies between our results and previous studies might be explained by the weaker diagnostic accuracy of four-slice CTCA, where the possible benefit of correct reclassification did not outweigh falsely predicted stenoses in patients with a higher CS. As CTCA evaluation often is difficult in severely calcified vessels, in the few patients from our study with extensive calcium load (CS ≥2480) significant stenosis might have been predicted by CS alone.

We found it most helpful to supplement CS in CTCA examinations with not-evaluative coronary segments.

**Table 3**

<table>
<thead>
<tr>
<th>TP</th>
<th>TN</th>
<th>FP*</th>
<th>FN</th>
<th>Sensitivity (95% CI)</th>
<th>Specificity (95% CI)</th>
<th>PPV (95% CI)</th>
<th>NPV (95% CI)</th>
<th>LR− (95% CI)</th>
<th>LR+ (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCA 21</td>
<td>47</td>
<td>2 (2)</td>
<td>0</td>
<td>100% (83.9% to 100%)</td>
<td>98.5% (91.7% to 100%)</td>
<td>90.0% (55.5% to 99.8%)</td>
<td>100% (94.4% to 100%)</td>
<td>12.8 (5.0% to 32.7%)</td>
<td>—</td>
</tr>
<tr>
<td>LM 9</td>
<td>64</td>
<td>1</td>
<td>0</td>
<td>100% (66.7% to 100%)</td>
<td>87.8% (77.0% to 95.7%)</td>
<td>77.8% (57.7% to 91.4%)</td>
<td>100% (92.5% to 100%)</td>
<td>65.0</td>
<td>—</td>
</tr>
<tr>
<td>LAD 30</td>
<td>38</td>
<td>1 (2)</td>
<td>2</td>
<td>93.8% (79.2% to 99.2%)</td>
<td>90.5% (77.4% to 97.3%)</td>
<td>88.2% (72.6% to 96.7%)</td>
<td>95.0% (83.1% to 99.4%)</td>
<td>12.8</td>
<td>14.8</td>
</tr>
<tr>
<td>LCX 26</td>
<td>43</td>
<td>1 (3)</td>
<td>0</td>
<td>100% (86.8% to 100%)</td>
<td>89.6% (77.3% to 96.5%)</td>
<td>83.9%</td>
<td>100% (86.3% to 94.6%)</td>
<td>11.8</td>
<td>—</td>
</tr>
</tbody>
</table>

*Numbers in parenthesis correspond to patients with not completely evaluative coronary artery segments being sanctioned as false-positive. The sum of false positives misclassified in evaluative coronary artery segments and those sanctioned in not-evaluative segments was used for calculation of diagnostic accuracy.

CI, confidence interval; FP, false-positive; FN, false-negative; LAD, left anterior descending artery; LCX, left circumflex artery; LM, left main artery; LR−, likelihood ratio of positive test; LR+, likelihood ratio of negative test; NPV, negative predictive value; PPV, positive predictive value; RCA, right coronary artery; TP, true-positive; TN, true-negative.
Combining a CS = 0 to exclude significant CAD in these patients would have avoided unnecessary CCA in four patients without significant coronary stenosis. In contrast, a CS > 400 did not aid in diagnosis as all patients with false-positive classifications at CTCA had a CS between 0 and 400. In general, high CS often corresponds to more than one significant stenosis in the coronary artery tree. Thus, in patients with not completely evalutative CTCA examinations showing significant stenosis in segments that were amenable to evaluation, subsequent CCA must be considered necessary anyway, and hence the presence of not-evaluative segments would not influence the decision of performing CCA or not. One may argue that a CS = 0 excludes significant coronary artery stenosis and thus might not be accompanied by a subsequent CTCA analysis. However, some previous studies have shown that up to 5% of patients with a negative CS had significant stenoses because of non-calcified plaques. In our study population significant non-calcified plaques were only found in patients also having coronary artery calcifications.

We acknowledge the following study limitations. First, we studied a relatively small number of study patients all of whom were preselected for CCA resulting in an increased probability for CAD. Diagnostic accuracy parameters of CTCA might have been lower in a patient population with a lower prevalence of CALS.

**Figure 3** Computed tomography coronary angiography (CTCA) and coronary angiography (CCA) in a 58-year-old man with atypical chest pain. CTCA curved reformations of the left anterior descending (LAD; A) and the right coronary artery (RCA; B) depict the vessels without atherosclerotic plaques. Volume-rendered image (C) shows a right dominant supply with the posterior descending artery arising from the distal RCA (arrow). Volume-rendered image (D) accurately visualises the LAD and its side branches. CTCA correctly classified this patient as having no CAD. CCA of the LAD (E) and the RCA (F) confirms smooth vessel contours without stenosis.
disease. Therefore, our study design have resulted in a patient selection bias that potentially leads to an overestimation of the ability of CTCA to detect stenoses. This could limit the transfer of our results to clinical practice. In addition, we have only applied a binary classification scheme for coronary artery stenosis rather than a more detailed grading scheme. Moreover, the severity of coronary stenosis was only estimated visually at CCA while no quantitative analysis was performed. Second, stenoses were semi-quantitatively assessed by visual estimation by both CT and CCA while no quantitative coronary angiography was performed. This method of evaluation may have been influenced by subjectivity bias. Third, thresholds of CS for excluding or predicting significant CAD were defined using the Agatston score. Recently, volume and mass quantification have been shown to yield more reproducible results than the Agatston method.27 However, reliable cut-off points for these newer CS methods are not yet defined.

CONCLUSION  
Dual-source CTCA is feasible in a patient population undergoing scanning without heart-rate control and allows the identification and exclusion of significant CAD with a high diagnostic accuracy. A low number of not-evaluative CTCA segments still occurs and would lead to potentially unnecessary CCA examinations in clinical practice. Combining a negative CS with dual-source CTCA in patients with not completely evalutive CTCA examinations improves the diagnostic performance of CTCA alone, can exclude significant CAD with a high diagnostic accuracy and might avoid unnecessary CCA examination in these patients.

Funding: Supported by the National Center for Competence in Research, Computer Aided and Image Guided Medical Interventions of the Swiss National Science Foundation.

Competing interests: None.

REFERENCES


Access the latest content chosen by our Editors

BMJ Journals editors select an article from each issue to be made free online immediately on publication. Other material is free after 12 months to non-subscribers. Access the Editor’s Choice from the home page—or expand your horizons and see what the other BMJ Journals editors have chosen by following the links on any BMJ Journal home page.