

# Significant Coronary Artery Stenosis: Comparison on Per-Patient and Per-Vessel or Per-Segment Basis at 64-Section CT Angiography<sup>1</sup>

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## Purpose:

To prospectively evaluate the accuracy of 64-section computed tomographic (CT) coronary angiography for assessing significant stenosis on a global and segmental level, by using conventional coronary artery angiography as the reference standard.

## Materials and Methods:

This study was HIPAA compliant and had local institutional review board approval. Patients gave informed consent. Patients suspected of having coronary artery disease (CAD) underwent both conventional coronary catheter angiography and contrast material-enhanced retrospectively electrocardiographically gated 64-section multi-detector row CT of the coronary arteries. Two experienced observers analyzed all CT scans for signs of CAD (stenosis of 0%,  $\leq 49\%$ , 50%–69%, 70%–99%, or 100%). Diagnostic accuracy of CT coronary angiography compared with that of conventional angiography was determined on a per-segment, per-vessel, and per-patient basis. No patients, vessels, or segments were excluded from analysis. Spearman correlation, cross tables, and a  $\chi^2$  test were used for statistical analysis.

## Results:

On a per-segment basis, 92.4% (762 of 825) of all segments could be clearly evaluated. In 7.6% of segments, image quality was compromised either by misregistration (16%), motion artifacts (30%), or small vessel size (54%). Correlation coefficients for detection and grading of stenosis were  $r = 0.65$  on a per-segment,  $r = 0.83$  on a per-vessel, and  $r = 0.88$  on a per-patient basis. Stenoses of 50% or greater were detected with accuracy, sensitivity, and specificity, respectively, of 96.1% (793 of 825), 82% (50 of 61), and 97.1% (743 of 765) on a per-segment basis, 90.9% (150 of 165), 89% (32 of 36), and 91.5% (118 of 129) on a per-vessel basis, and 89% (49 of 55), 100% (19 of 19), and 83% (30 of 36) on a per-patient basis.

## Conclusion:

On a per-patient basis, 64-section multi-detector row CT coronary angiography enables the diagnosis of significant ( $\geq 50\%$ ) stenosis in CAD with an accuracy of 89%. On a per-segment and per-vessel basis, diagnostic accuracy is still impaired, primarily by limited spatial resolution.

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A noninvasive method for triaging patients suspected of having coronary artery disease (CAD) is highly desirable to differentiate patients with from those without significant ( $\geq 50\%$ ) stenosis (1). Currently, contrast material-enhanced multi-detector row computed tomographic (CT) angiography appears to provide the most promising combination of temporal and spatial resolution to achieve this goal. Previously published results of series with four- to 16-section CT indicate that the sensitivity of noninvasive CT angiography for the detection of significant ( $>50\%$ ) coronary artery stenosis within proximal vessels ranges between 80% and 90% (2–4). In most investigations, however, fairly high accuracy could only be obtained by excluding patients or segments in whom or in which insufficient spatial and temporal resolution with residual motion artifacts prevented accurate CT assessment (5–8). Because such a strategy is not viable in actual clinical practice, coronary CT angiography for suspected CAD to date has largely resided in the research realm, without widespread clinical application.

With the advent of 64-section multi-detector row CT technology (9), both temporal and spatial resolution of noninvasive coronary CT angiography have further improved to a point where the threshold to actual clinical application may have been crossed (10,11). Thus, the aim of this study was to prospectively evaluate the accuracy of 64-section CT coronary angiography for assessing significant stenosis on a global

and segmental level, by using conventional coronary artery angiography as the reference standard.

## Materials and Methods

### Sources of Support

This study was supported by research grants provided by Siemens Medical Solutions (Malvern, Pa), Bracco Diagnostics (Princeton, NJ), and Medrad (Pittsburgh, Pa). The authors, who are not employees of a company providing support, had control of the data and information submitted for publication.

### Patients

The human research committee of Medical University of South Carolina approved this study, which was compliant with the Health Insurance Portability and Accountability Act. All participating patients gave written informed consent. Between October 2004 and July 2005, all patients scheduled to undergo conventional catheter coronary angiography because of symptomatic but atypical chest pain were approached for participation and recruited into the study if permission of the treating physician and informed patient consent (after explanation of radiation risks) could be obtained and if the following inclusion criteria were met: Low pretest (ie, pre-CT examination) likelihood of CAD (12) but, at the same time, symptomatic chest pain. Low pretest likelihood of CAD was described by a combination of atypical clinical presentation, non-pathologic (stress) electrocardiographic (ECG) findings (ie, normal electrocardiogram with negative T-wave), inconclusive risk factor profiles (ie, hypertension, diabetes mellitus, nicotine abuse, presence of familial coronary atherosclerosis, hypercholesterolemia), and negative troponin-T enzyme levels. Exclusion criteria were as follows: (a) unstable symptoms, vital signs, or ECG findings; (b) previous bypass surgery or coronary artery stent placement; (c) creatinine level of more than 2.0 mg/dL (176.8  $\mu\text{mol/L}$ ); (d) potential pregnancy; and (e) known allergy to iodinated contrast material. Unstable symptoms describes

a situation of unexpected chest pain usually occurring while at rest and with a discomfort that is either more severe and prolonged than that caused by typical angina or that represents the first time a person has had angina.

Unlike in previous investigations, in our study, irregular heart rate, obesity, and marked coronary calcifications were not considered exclusion criteria. Patients with contraindications to the use of  $\beta$ -blocking medication (eg, chronic obstructive pulmonary disease, asthma, sensitivity to  $\beta$ -agonists, second- or third-degree heart block, hypotension [ $<100$  mm Hg systolic blood pressure]) were eligible for participation in the study, but no  $\beta$ -blockers were used in such individuals.

### Image Acquisition

CT scanning was performed with a 64-section multi-detector row CT scanner (Somatom Sensation 64 Cardiac; Siemens, Forchheim, Germany) by using retrospective ECG gating. Contrast-enhanced coronary CT angiography was performed in each patient by using the following parameters:  $64 \times 0.6$ -mm collimation, z-flying focal spot technique, 0.33-second rotation time, pitch of 0.2, 120-kV tube voltage, and 900-mAs tube current. Patients with average heart

## Advances in Knowledge

- Sixty-four-section CT coronary angiography provides a sensitivity and a negative predictive value of 100% each to rule out significant stenosis in patients suspected of having coronary artery disease.
- On a per-segment and a per-vessel basis, sensitivity and overall diagnostic accuracy of 64-section CT coronary angiography were still impaired, most likely because of limited spatial resolution.

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### Abbreviations:

CAD = coronary artery disease  
ECG = electrocardiography  
LCA = left coronary artery  
LCX = left circumflex  
NPV = negative predictive value  
PPV = positive predictive value  
RCA = right coronary artery

### Author contributions:

Guarantors of integrity of entire study, C.H., P.L.Z., C.D.N., U.J.S.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; manuscript final version approval, all authors; literature research, C.H., G.S., U.J.S.; clinical studies, C.H., J.R.D., C.D.N., G.S., T.J.V., U.J.S.; statistical analysis, C.H., S.A.N.; and manuscript editing, C.H., P.L.Z., C.D.N., S.A.N., G.S., T.J.V., P.C., U.J.S.

See Materials and Methods for pertinent disclosures.

rates greater than 65 beats per minute and no contraindications to the use of  $\beta$ -blockers received up to three intravenous injections of 5 mg (up to 15 mg total) of metoprolol tartrate (Lopressor; Novartis, East Hanover, NJ) immediately prior to the examination.

Scanning was begun regardless of the eventual heart rate achieved after metoprolol injection. In the absence of contraindications (hypotension, current use of nitrate medications, migraine sensitive to nitrates) patients were given a 0.4-mg nitroglycerin tablet (NitroQuick; Ethex, St Louis, Mo) sublingually 2 minutes before scanning. Scans were acquired in a craniocaudal direction with simultaneous recording of the patient's ECG signal to enable retrospective registration of image reconstruction to the desired cardiac phase. The scan range extended from the level of the carina to just below the diaphragm. Delay time was determined by injection of a 20-mL test bolus at 5 mL/sec, followed by 50 mL of saline, with a dual-syringe injector (Stellant D; Medrad). The peak time of test bolus enhancement was used as the delay time.

Actual contrast enhancement was achieved with 50–75 mL of a nonionic contrast medium (Iopamidol, Isovue [370 milligrams of iodine per milliliter]; Bracco) infused through an 18-gauge intravenous antecubital catheter at 5 mL/sec, followed by a 50-mL saline chaser bolus. The contrast agent volume was individually computed according to the following formula:  $V = ST \cdot 5$ , where  $V$  is volume in milliliters and  $ST$  is scan time in seconds. Image reconstruction was performed by using single-segment reconstruction and retrospective ECG gating (13–16). Reconstruction intervals relative to the R-R interval (percentage R-R interval) with the least cardiac motion were determined on the basis of a preview series consisting of 20 images reconstructed at 20 different R-R interval positions in 5% increments (0%–95% of R-R interval) at the same  $z$ -position at the midlevel of the heart. Image reconstruction parameters comprised an individually adapted field of view encompassing the heart, a matrix size of  $512 \times 512$  pixels, a medium soft-

tissue convolution kernel (B25f), and a section thickness of 0.75 mm with an increment of 0.3 mm.

### Image Analysis

Image evaluation was performed on a three-dimension viewing-enabled workstation (Leonardo; Siemens) with a standardized window level of 100 HU and window width of 700 HU. Images for each patient were analyzed in consensus by two cardiovascular radiologists (C.H., U.J.S.), both with 6 years of experience reading coronary multi-detector row CT images. Readers were blinded to the patient's clinical data. They were asked to rate vessel visualization and to identify and grade stenosis in each patient. For rating of vessel visualization, the authors had to decide if vessel segments were visible and if evaluation was compromised by misregistration, motion artifacts, or small vessel size (ie, vessel diameters  $< 1.5$  mm).

Transverse sections, multiplanar reformations, and thin-slab maximum intensity projections (5 mm) were used for image display. In addition, lesion severity of CT-depicted stenosis was assessed with the aid of dedicated cardiac CT visualization software (Circulation; Siemens) that extracts the course of the coronary arteries from the contrast-enhanced data set and automatically displays the vessel as a curved multiplanar reformation along the centerline of the vessel. With this tool, the degree of stenosis is evaluated by applying a semiautomated distance measuring tool to the automatically generated curved multiplanar reformations. In case of discrepancies between both observers, measurements were repeated and the results were analyzed in consensus. The extent of CAD was classified as follows: (a) no signs of atherosclerosis, (b) atherosclerosis with stenosis of 49% or less, (c) 50%–69% stenosis, (d) 70%–99% stenosis, and (e) total occlusion.

### Coronary Angiography—Reference Standard

All CT findings were compared with corresponding coronary angiograms, which were performed by using the conventional Judkin technique (17). At least four

views of the left and two views of the right coronary artery (RCA) were analyzed in consensus by three cardiologists (C.D.N., P.L.Z., J.R.D.), with 5, 7, and 12 years of experience, respectively. For the interpretation of coronary angiograms, they had no knowledge of the CT results. Quantitative assessment of stenosis severity on angiograms was performed with a stenosis grading tool with automated distance and scale calibration (Axiom-Artis VA21C; Siemens) and with the same criteria as those used for the CT scans.

### Statistical Analysis

All analyses and graphs were performed with statistical software (Sigma Stat, version 3.0, and Sigma Plot, version 8.0; SPSS, Chicago, Ill). Categorical variables were presented as percentages, and continuous variables were presented as means and ranges.

We calculated the accuracy, sensitivity, specificity, negative predictive value (NPV), and positive predictive value (PPV) to determine the usefulness of 64-section coronary CT angiography for assessing stenosis.

Using conventional coronary artery angiography as the reference standard, sample size was estimated on the basis of a two-tailed significance level with  $P < .05$ . A power analysis was performed by using a one-sample proportion model. The null hypothesized proportion ( $H_0$ ) was  $P_1 = P_2$  or that 64-section CT coronary angiography was equal to conventional coronary artery angiography in assessing stenosis with the same sensitivity and specificity; the alternative proportion ( $H_A$ ) was  $P_1 \neq P_2$  or that 64-section CT coronary angiography was not equal to conventional coronary artery angiography in assessing stenosis. For this study, results of 64-section CT coronary angiography in depicting stenoses were compared with results of conventional coronary artery angiography, the standard of reference. Sensitivity and specificity were calculated on a per-patient, per-vessel, and per-segment basis. The sample size of 55 patients, 165 vessels, and 825 segments, calculated against a constant of 0.99, was determined to have a power

level of 9% to detect a difference of 1% in sensitivity and a power level of 99% to detect a difference of 17% in specificity on a per-patient basis. On a per-vessel basis, a power level of 99% was needed to detect a difference of 11% in sensitivity and a difference of 9% in specificity, and on a per-segment basis, a power level of 99% was required to detect a difference of 18% in sensitivity and a difference of 2% in specificity.

A *P* value of .05 or less was considered to indicate a statistically significant difference for all statistical tests. Using conventional coronary artery angiography as the reference standard, we determined the proportional number of coronary segments visible in multi-detector row CT data sets.

The degree of correlation of multi-detector row CT angiography and invasive coronary angiography in grading coronary atherosclerosis was investigated with the Spearman correlation. The symmetry of the data distribution and any under- or overestimation at multi-detector row CT angiography were computed by using the Bowker test (18).

Diagnostic accuracy of coronary CT angiography in the identification of ste-

noses of 50% or 70% or greater was assessed on a per-segment (1–15,17), per-vessel (RCA, left coronary artery [LCA], and left circumflex [LCX] artery), and per-patient basis by using cross tables. Segments or vessels that were not visualized on CT scans were regarded as free of pathologic findings and thus false-negative if stenoses were present on coronary angiograms.

Any differences between major coronary arteries (RCA, LCA, and LCX) regarding diagnostic accuracy were tested for significance by using a  $\chi^2$  test for comparison of cross tables.

## Results

### Patients

Of the 151 patients who underwent conventional angiography between October 2004 and July 2005 for evaluation of symptomatic but atypical chest pain, 42 were excluded for the following reasons: one because of unstable clinical condition; seven because of a history of contrast material allergy; eight because of a creatinine level of more than 2.0 mg/dL (176.8  $\mu$ mol/L); and 26 because of a history of either percutaneous trans-

luminal coronary angioplasty ( $n = 2$ ) or aortocoronary bypass grafting ( $n = 24$ ). Fourteen patients were not included because of patient refusal, 18 because of referring physician refusal, and 22 because of scheduling issues (Fig 1).

The final group consisted of 55 patients (29 men and 26 women). The mean age of the patients was 67 years (range, 49–73 years). The average heart rate was 64 beats per minute (range, 46–87 beats per minute) at the time of scan acquisition, with an average scan time of 15.3 seconds (range, 13.2–17.8 seconds). In all patients, 64-section multi-detector row CT and conventional coronary catheter angiography were both performed within 24 hours. The average creatinine level of the patients was 0.9 mg/dL (79.6  $\mu$ mol/L) (range, 0.6–1.3 mg/dL [53.0–114.9  $\mu$ mol/L]) (Fig 1).

### Evaluation of CT Data Sets

Globally, all CT coronary angiographic studies (55 of 55) were considered of diagnostic quality and thus assessable. Eight hundred twenty-five coronary artery segments were visible on conventional angiograms, of which 762 (92.4%) were visualized at CT coronary angiography (Table 1). In the remaining 7.6% ( $n = 63$ ) of segments, evaluation was compromised by misregistration (10 segments [16%]), motion artifacts (19 segments [30%]), or small vessel size (34 segments [54%])—that is, vessel diameters less than 1.5 mm.

### Diagnostic Accuracy of CT Coronary Angiography

Correlation between CT coronary angiography and catheter angiography for grading of coronary artery stenosis was good ( $r = 0.65$ ,  $P < .01$ ) on a per-segment basis and was very good on a per-vessel basis ( $r = 0.83$ ,  $P < .01$ ) and per-patient basis ( $r = 0.88$ ,  $P < .01$ ) (Fig 2). At CT, 56.0% (195 of 348) of all stenoses were incorrectly graded, with significantly ( $P < .001$ ) more stenoses being underestimated (135 [38.8%]) than overestimated (60 [17.2%]).

A total of 348 stenotic segments were identified on coronary angiograms. In 61 segments, the degree of stenosis

Figure 1

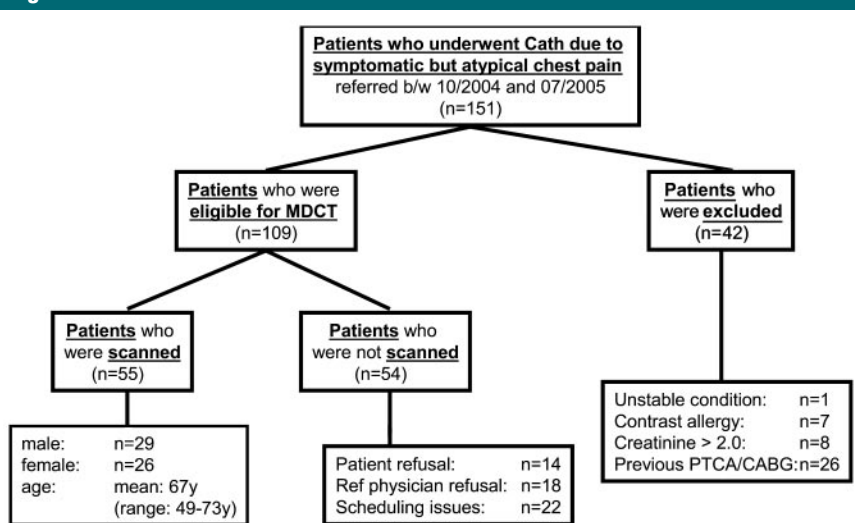


Figure 1: Flowchart shows total number of patients who underwent coronary angiography (Cath) because of symptomatic but atypical chest pain and suspected CAD, as well as number of patients who also underwent multi-detector row CT coronary angiography (MDCT). *b/w* = Between, *CABG* = coronary artery bypass graft, *PTCA* = percutaneous transluminal coronary angioplasty, *ref* = referring.

**Table 1**

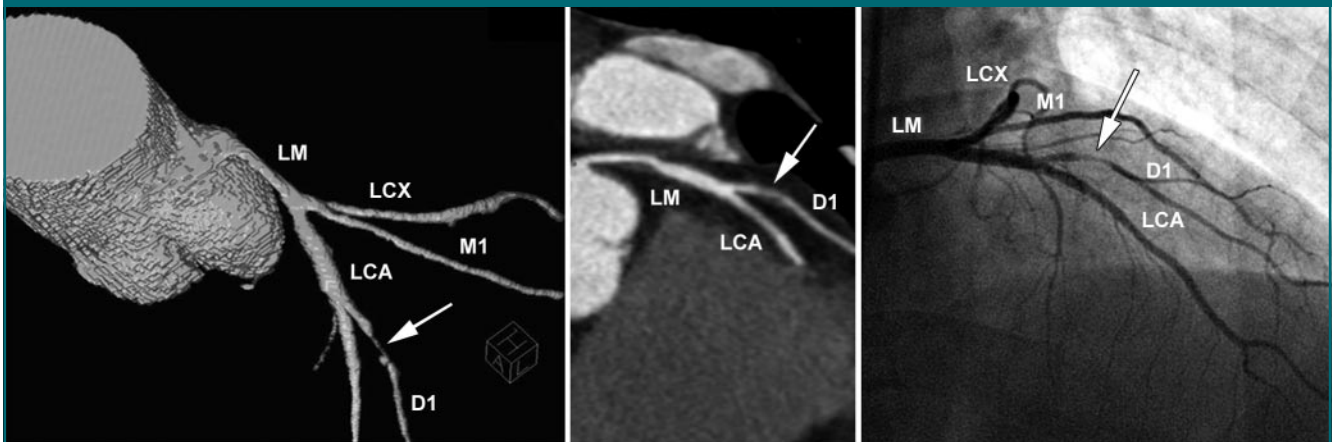
**Number of Visualized Coronary Segments and Segmental Distribution of Stenoses at Conventional and CT Coronary Angiography**

Coronary Artery and Segment	No. of Visible Segments		No. of Stenoses*					No. of Stenoses ≥ 50%		No. of Stenoses ≥ 70%	
	Conventional Angiography	CT Angiography†	0%	0%–49%	50%–69%	70%–99%	100%	Conventional Angiography	CT Angiography†	Conventional Angiography	CT Angiography†
<b>RCA</b>											
1	55	55 (100)	22	27	4	1	1	6	4 (67)	2	1 (50)
2	55	55 (100)	28	23	2	1	1	4	4 (100)	2	2 (100)
3	55	54 (98)	32	21	0	1	1	2	2 (100)	2	1 (50)
4	55	53 (96)	42	12	1	0	0	1	1 (100)	0	0 (0)
<b>LCA</b>											
5	55	55 (100)	37	16	1	1	0	2	2 (100)	1	0 (0)
6	55	55 (100)	21	28	0	6	0	6	6 (100)	6	6 (100)
7	55	55 (100)	25	24	3	3	0	6	6 (100)	3	2 (67)
8	55	54 (98)	32	22	0	1	0	1	1 (100)	1	1 (100)
9	55	53 (96)	28	15	3	8	1	12	12 (100)	9	7 (78)
10	55	47 (86)	34	21	0	0	0	0	0 (0)	0	0 (0)
<b>LCX</b>											
11	55	55 (100)	32	20	2	1	0	3	2 (67)	1	1 (100)
12	55	49 (89)	34	15	3	2	1	6	6 (100)	3	1 (33)
13	55	45 (82)	34	17	3	1	0	4	2 (50)	1	1 (100)
14	55	32 (58)	37	13	2	2	1	5	0 (0)	3	0 (0)
15	55	45 (82)	39	13	2	1	0	3	2 (67)	1	1 (100)
<b>Total</b>											
1–15	825	762 (92.4)	477	287	26	29	6	61	50 (82)	35	24 (69)

\* As visualized at coronary angiography.

† Data in parentheses are percentages.

**Figure 2**



**Figure 2:** Right anterior oblique view of LCA, left main artery (LM), and LCX artery. Volume-rendered display (left) and curved multiplanar reformation (middle) of retrospectively ECG-gated 64-section multi-detector row CT coronary angiography data and conventional catheter coronary angiogram (right) similarly show stenosis of the proximal first diagonal branch (D1) (arrow). CT images correctly revealed a noncalcified 60% stenosis. M1 = ramus intermedius.

was 50% or greater; in 35 of these 61 segments, it was 70% or greater (Table 1). At CT coronary angiography, segments with stenosis of 50% or greater were identified with 82% (50 of 61) sen-

sitivity and 97.1% (743 of 765) specificity (Table 2). Segments with stenosis of 70% or greater ( $n = 35$ ) were identified with 69% (24 of 35) sensitivity and 97.6% (782 of 791) specificity (Table 2).

Nine stenoses of 50% or greater were missed: Two were in segments that were blurred by moderate motion artifacts at heart rates greater than 80 beats per minute, while seven were lo-

cated in small vessels (<1.5 mm) and thus could not be adequately visualized. Six of these stenoses were in fact 70% or greater: the two that were missed

because of motion artifacts and four of those missed because of small vessel size. Two stenoses of 50% or greater were seen but were underestimated.

Five stenoses of 70% or greater were visualized but were miscategorized as 50% or greater only. Twenty-two stenoses of 50% or greater and nine stenoses of 70% or greater were overestimated. In 87% (27 of 31) of cases, this was due to heavy calcification in the area of stenosis (Fig 3).

Thirty-six vessels with stenosis of 50% or greater and 21 vessels with stenosis of 70% or greater were visible on conventional angiograms (Table 1). At CT coronary angiography, vessels with stenosis of 50% or greater were identified with 89% (32 of 36) sensitivity and 91.5% (118 of 129) specificity (Table 2). Vessels with stenosis of 70% or greater were identified with 81% (17 of 21) sensitivity and 96.5% (139 of 144) specificity (Table 2, Fig 4). Discrete differences in sensitivity and specificity were observed for the RCA, LCA, and LCX artery; however, a level of significance was reached for neither stenoses of 50% or greater ( $P = .87$  [sensitivity],  $P = .75$  [specificity]) nor stenoses of 70% or greater ( $P = .78$  [sensitivity],  $P = .97$  [specificity]) (Table 3).

On coronary angiograms, 14 patients had no signs of CAD, 22 had stenosis of 0%–49%, six had stenosis of 50%–69%, nine had stenosis of 70%–

**Table 2**

**Diagnostic Accuracy of 64-Section Coronary CT Angiography in Grading Stenoses 50% or 70% or Greater on Per-Segment, Per-Vessel, and Per-Patient Basis**

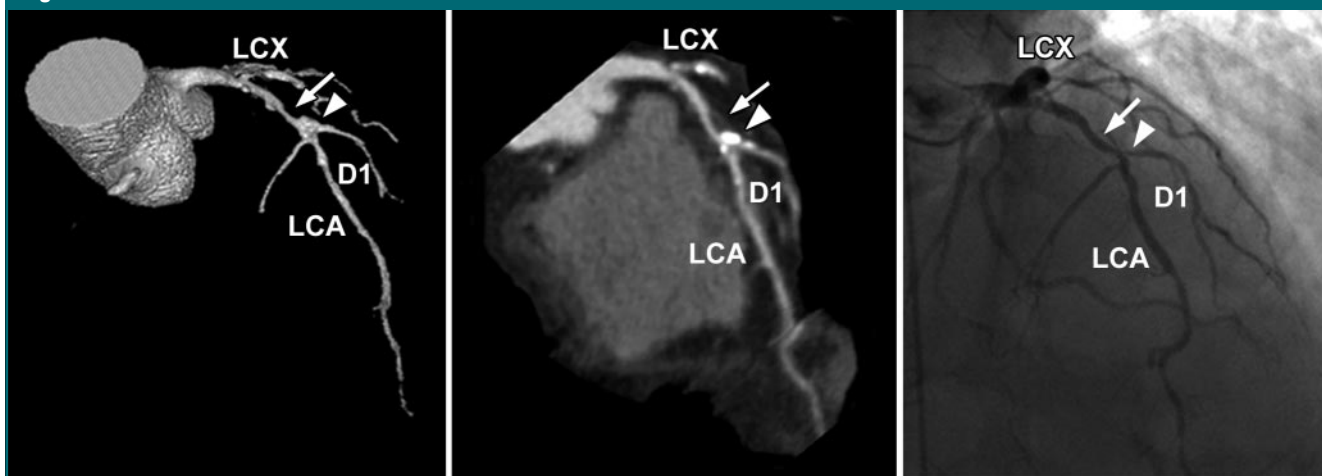
Analysis and Parameter	≥50% Stenosis	≥70% Stenosis
<b>Per segment*</b>		
Accuracy	96.1 (793/825) [94.4, 97.2]	97.7 (806/825) [96.2, 98.5]
Sensitivity	81.9 (50/61) [70.0, 90.6]	68.6 (24/35) [50.7, 83.1]
Specificity	97.1 (743/765) [95.6, 98.1]	97.6 (782/791) [94.8, 98.4]
PPV	69.4 (50/72) [57.4, 79.7]	72.7 (24/33) [54.4, 86.7]
NPV	98.5 (743/754) [97.4, 99.2]	98.6 (782/793) [97.5, 99.3]
<b>Per vessel†</b>		
Accuracy	90.9 (150/165) [85.4, 94.8]	94.6 (156/165) [89.9, 97.4]
Sensitivity	88.8 (32/36) [73.9, 96.8]	80.9 (17/21) [58.0, 94.5]
Specificity	91.5 (118/129) [85.2, 95.6]	96.5 (139/144) [92.0, 98.8]
PPV	74.4 (32/43) [58.8, 86.4]	77.2 (17/22) [54.6, 92.1]
NPV	96.7 (118/122) [91.8, 99.1]	97.2 (139/143) [92.9, 99.2]
<b>Per patient (n = 55)</b>		
Accuracy	89.1 (49/55) [77.7, 95.8]	94.6 (52/55) [84.8, 98.8]
Sensitivity	100 (19/19) [85.4, 100]	100 (13/13) [79.4, 100]
Specificity	83.3 (30/36) [67.1, 93.6]	92.9 (39/42) [80.5, 98.5]
PPV	76.0 (19/25) [54.8, 90.6]	81.2 (13/16) [54.3, 95.9]
NPV	100 (30/30) [90.5, 100]	100 (39/39) [92.6, 100]

Note.—Data are percentages, with raw data in parentheses and 95% confidence intervals in brackets.

\* For segments 1–15.

† For the RCA, LCA, and LCX artery.

**Figure 3**



**Figure 3:** Right anterior oblique view of LCA and LCX artery. Volume-rendered display (left) and curved multiplanar reformation (middle) of retrospectively ECG-gated 64-section multi-detector row CT coronary angiography data and conventional catheter coronary angiogram (right) similarly show a 50% stenosis in distal part of segment 6 (arrow). However, on CT images, the 60% stenosis (arrowhead) at the origin of the first diagonal branch (D1) was overestimated as a 75% stenosis owing to marked calcification in this area.

Figure 4



**Figure 4:** Left anterior oblique view of RCA, LCA, LCX artery, and first diagonal branch (*D1*). Volume-rendered display (left) and curved multiplanar reformation (middle) of retrospectively ECG-gated 64-section multi-detector row CT coronary angiography data and conventional catheter coronary angiogram (right) similarly show a 70% stenosis in the proximal RCA (arrows). Compared with CT, coronary angiography fails to show the calcifications in this area.

99%, and four had total vascular occlusion. Of the 19 patients with stenosis of 50% or greater, seven had one-vessel disease and six each had two- and three-vessel disease. At CT coronary angiography, patients with stenosis of 50% or greater were identified with 100% (19 of 19) sensitivity and 83% (30 of 36) specificity. Accuracy was 89% (49 of 55), NPV was 100% (30 of 30), and PPV was 76% (19 of 25) (Table 2). Patients with stenoses of 70% or greater were identified with 100% (13 of 13) sensitivity and 93% (39 of 42) specificity. Accuracy was 95% (52 of 55), NPV was 100% (13 of 13), and PPV was 81% (13 of 16) (Table 2, Fig 4).

**Discussion**

The results of this study indicate that 64-section CT coronary angiography is able to help exclude the presence of significant coronary artery stenosis in a patient with atypical chest pain. However, overall diagnostic accuracy, especially on a per-segment and per-vessel basis, remains limited because some stenoses are still either underdiagnosed or overestimated. Depending on how the data are analyzed (per segment, per vessel, or per patient), sensitivity for

**Table 3**

**Diagnostic Accuracy of 64-Section Coronary CT Angiography in Grading Stenoses 50% or Greater in RCA, LCA, and LCX Artery**

Vessel and Parameter	≥50% Stenosis	≥70% Stenosis
<b>RCA</b>		
Accuracy	94.5 (53/55) [84.8, 98.8]	92.7 (51/55) [79.7, 96.9]
Sensitivity	90.9 (10/11) [58.7, 99.7]	71.4 (5/7) [29.0, 96.3]
Specificity	95.4 (42/44) [84.5, 99.4]	95.8 (46/48) [85.7, 99.4]
PPV	83.3 (11/13) [51.5, 97.9]	71.4 (5/7) [29.0, 96.3]
NPV	97.6 (42/43) [87.7, 99.9]	95.8 (46/48) [85.7, 99.4]
<b>LCA</b>		
Accuracy	90.9 (50/55) [80.0, 96.98]	96.3 (53/55) [87.4, 99.5]
Sensitivity	90.0 (9/10) [55.5, 99.7]	87.5 (7/8) [47.3, 99.6]
Specificity	91.1 (41/45) [78.7, 97.5]	97.8 (46/47) [88.7, 99.9]
PPV	69.2 (9/13) [38.5, 90.9]	87.5 (7/8) [47.3, 99.6]
NPV	97.6 (41/42) [87.4, 99.9]	97.8 (46/47) [88.7, 99.9]
<b>LCX</b>		
Accuracy	89.0 (49/55) [77.7, 95.8]	94.5 (52/55) [84.8, 98.8]
Sensitivity	86.6 (13/15) [59.5, 98.3]	83.3 (5/6) [35.8, 99.5]
Specificity	90.0 (36/40) [76.3, 97.2]	95.9 (47/49) [86.0, 99.5]
PPV	76.4 (13/17) [50.1, 93.1]	71.4 (5/7) [29.0, 96.3]
NPV	94.7 (36/38) [82.2, 99.3]	97.9 (47/48) [88.9, 99.9]

Note.—Data are percentages, with raw data in parentheses and 95% confidence intervals in brackets.

the detection of stenoses of 50% or greater ranges between 82% and 100%. These findings are somewhat improved, albeit still in the same range, compared with those observed for 16-section CT

coronary angiography (2,5,7), which showed a sensitivity between 73% (on a per-segment basis) and 94% (on a per-patient basis).

However, in contrast to previous

studies (4,19), in our investigation, no segment or vessel was excluded because of impaired image quality, so our experiences may be more relevant for actual clinical use. In addition, quantitative coronary analysis of conventional angiograms was used in our study as a more accurate and objective reference standard compared with subjective visual assessment. Quantitative coronary analysis was performed only in two of the previous studies investigating 16-section CT coronary angiography (4,5).

In our patient cohort, 92.2% of coronary artery segments were assessable, compared with a maximum of 86% assessable segments in similar studies of 16-section CT (5,19,20). Robustness of use thus seems to have markedly improved with further technical development. Sixty-four-section CT, in comparison to 16-section CT, provides an increased number of sections per gantry half-rotation (ie, 64 vs 16) and a faster gantry rotation speed (330 vs 375 msec per rotation), which translate into shorter scan times and superior temporal resolution (ie, 165 vs 188 msec) (9). Marked impairment of diagnostic quality by cardiac motion, misregistration, or breathing artifacts, as described in previous reports (2,4,5,7,8,19,21) were substantially less frequently observed in our investigation. Small vessel size was the main reason for poor visualization of coronary segments in our study, so diagnostic accuracy for detailed assessment appears mainly limited by spatial rather than by temporal resolution. The fact that there were no significant differences in accuracy between the RCA, LCA, and LCX artery territories also seems to support this notion.

Despite substantial improvement in spatial resolution (ie,  $0.4 \times 0.4 \times 0.3$  vs  $0.4 \times 0.4 \times 0.75$  mm), 64-section CT thus still appears somewhat limited for accurate assessment of the entire coronary artery tree, including small peripheral segments. The clinical importance of the latter, however, may be debatable. Leschka et al (10) made similar observations for 64-section CT coronary angiography. However, in their study, the most common cause of impaired image quality was heavily calci-

fied vessel walls (10). In our study, marked calcifications did not necessarily compromise image quality but were reasons for overestimation of moderate stenosis, so specificity was subsequently decreased. Unlike Leschka et al (10), who used qualitative measures, we used quantitative coronary angiography as the reference standard and analyzed all vessels, including those smaller than 1.5 mm. Despite these differences in study design, diagnostic accuracy (94.5% vs 94.1%) is comparable for both studies.

Overall, diagnostic accuracy successively increased, with increasing sensitivity and decreasing specificity, respectively, when the data were analyzed on a per-patient, per-vessel, and per-segment basis. This corresponds well to the results obtained in previous studies performed either with 64-section (11) or 16-section CT scanners (5,20). As our study results show, in some instances, with 64-section CT there are still significant stenoses diagnosed that do not have an angiographic correlate—that is, there is still a certain number of false-positive findings. In addition, specificity and PPV increase to reasonable values when critical stenoses ( $\geq 70\%$ ) are considered. From a clinical standpoint, diagnosis of stenosis of 50% or greater per se without considering the actual patient's symptoms appears to be of limited value (17). Commonly, stenoses of less than 50% are revascularized only in the presence of clinical symptoms, whereas stenoses of more than 70% are ordinarily treated even in the absence of symptoms.

A limitation of our study was that all patients were referred for conventional angiography. Thus, there was a high incidence of true disease (34%), which tends to increase sensitivity. Despite the high disease prevalence, the total amount of significant or critical stenoses was low, and some specific segments (eg, 4, 9, 15) harbored only a small number of stenoses. Patient selection bias thus limits the direct transfer of these results into clinical practice in populations not undergoing catheterization. Although power analysis revealed that the amount of patients was sufficient to provide 91% power to detect

predictive variable differences, confirmation in a greater number of subjects—preferably in a multicenter setting—appears desirable. Finally, per-patient and per-segment analyses based on the  $\chi^2$  method, as used in this study, must be regarded as an approximation because of data clustering. The more appropriate method would have been to use a generalized estimating equation approach. However, because of inadequate sample size, a  $\chi^2$  approach was applied.

In conclusion, 64-section CT coronary angiography provides sufficiently high sensitivity and NPV to rule out significant stenosis in patients suspected of having CAD. On a per-segment basis and a per-vessel basis, diagnostic accuracy is still impaired by limited sensitivity, most likely because of insufficient spatial resolution.

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