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EXPEDITED REVIEWS

Quantification of Obstructive and Nonobstructive Coronary Lesions by 64-Slice Computed Tomography

A Comparative Study With Quantitative Coronary Angiography and Intravascular Ultrasound

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OBJECTIVES The aim of the present study was to determine the diagnostic accuracy of 64-slice computed tomography (CT) to identify and quantify atherosclerotic coronary lesions in comparison with catheter-based angiography and intravascular ultrasound (IVUS).

BACKGROUND Currently, the ability of multislice CT to quantify the degree of coronary artery stenosis and dimensions of coronary plaques has not been evaluated.

METHODS We included 59 patients scheduled for coronary angiography due to stable angina pectoris. A contrast-enhanced 64-slice CT (Senation 64, Siemens Medical Solutions, Forchheim, Germany) was performed before the invasive angiogram. In a subset of 18 patients, IVUS of 32 vessels was part of the catheterization procedure.

RESULTS In 55 of 59 patients, 64-slice CT enabled the visualization of the entire coronary tree with diagnostic image quality (American Heart Association 15-segment model). The overall correlation between the degree of stenosis detected by quantitative coronary angiography compared with 64-slice CT was $r = 0.54$. Sensitivity for the detection of stenosis <50%, stenosis >50%, and stenosis >75% was 79%, 73%, and 80%, respectively, and specificity was 97%. In comparison with IVUS, 46 of 55 (84%) lesions were identified correctly. The mean plaque areas and the percentage of vessel obstruction measured by IVUS and 64-slice CT were 8.1 mm^2 versus 7.3 mm^2 ($p < 0.03$, $r = 0.73$) and 50.4% versus 41.1% ($p < 0.001$, $r = 0.61$), respectively.

CONCLUSIONS Contrast-enhanced 64-slice CT is a clinically robust modality that allows the identification of proximal coronary lesions with excellent accuracy. Measurements of plaque and lumen areas derived by CT correlated well with IVUS. A major limitation is the insufficient ability of CT to exactly quantify the degree of stenosis. (J Am Coll Cardiol 2005;46:147–54) © 2005 by the American College of Cardiology Foundation

A noninvasive method that would allow the evaluation of coronary stenoses with a comparable accuracy to catheter-based angiography would have enormous clinical value. The recent development of 16-slice computed tomography (CT) already constitutes an important step forward in noninvasive

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angiography and, although remarkable results to identify high-grade coronary stenoses were reported from several groups, it is evident that this technology is still affected by numerous limitations (1–5). Because of spatial resolution, the reliable identification of coronary lesions is restricted to major coronary branches with a diameter of at least 2 mm. Partial volume effects caused by coronary calcifications frequently count for false-positive and false-negative results. Furthermore, it is consistently reported that because of the limited temporal resolution, motion artifacts can only be avoided in patients with heart rates of <65 beats/min (3–7). Those limitations probably contributed to the fact that all existing studies focused on the detection of high-grade stenosis only and, until now, no attempt was directed toward a CT-derived stenosis quantification. For clinical purposes, however, it also is necessary to accurately determine the severity of a lesion because the therapeutic consequence of a 50% or a 90% stenosis may be completely different. The recent introduction of a new scanner generation with improved spatial and temporal resolution generating 64 slices per rotation and covering the entire volume of the heart in 8 to 9 s promises a significant improvement of image quality that may allow a more precise evaluation of coronary stenosis. Thus, the aim of the present study was to determine the diagnostic accuracy of a 64-slice CT that offers an isotropic voxel resolution of $0.4 \times 0.4 \times 0.4$ mm to identify and quantify atherosclerotic coronary lesions in comparison with catheter-based angiography and intravascular ultrasound (IVUS).

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Abbreviations and Acronyms

CSA	= cross-sectional area
CT	= computed tomography
EEM	= external elastic membrane
IVUS	= intravascular ultrasound
LAD	= left anterior descending artery
LCX	= left circumflex artery
MSCT	= multislice computed tomography
QCA	= quantitative coronary angiography
RCA	= right coronary artery

METHODS

Patients. From July to November 2004, we studied 59 consecutive patients (no previously known coronary artery disease [n = 49], patients with previous angioplasty [n = 10]) scheduled for conventional coronary angiography because of stable angina pectoris who were suitable for a 64-slice CT scan at least one day before the catheterization procedure. Patients with atrial fibrillation, previous bypass surgery, previous stenting of >1 vessel, an unstable clinical condition, or a contraindication to the administration of contrast agent were excluded. The 64-slice CT scan was performed within two days before coronary angiography in all patients. The study protocol included the oral administration of 50 mg of metoprolol 60 min before the scheduled CT scan in patients with heart rates >70 beats/min. However, in the presence of contraindications for a beta-blocker or an unsatisfactory lowering of the heart rate, the scan was performed even at higher heart rates. The study protocol was approved by the institutional ethics committee of the Grosshadern Hospital of the University of Munich, and all patients gave informed consent to participate in the study.

The 64-slice CT scanning technique. Computed tomographic angiography was performed using a 64-slice CT scanner (Sensation 64, Siemens Medical Solutions, Forchheim, Germany). A bolus of 80 ml of contrast agent (Solutrast 300, 300 mgI/ml^{-1}, Altana, Konstanz, Germany) was injected intravenously (5 ml/s^{-}). As soon as the signal in the ascending aorta reached a predefined threshold of 100 HU, the scan started automatically and the entire volume of the heart was acquired during one breathhold in 8 to 9 s with simultaneous recording of the electrocardiographic trace. The detector collimation was 0.6 mm, gantry rotation speed was 330 ms per rotation, tube voltage was 120 kV at a current of 550 to 750 mAs (depending on patient size) during 55% of the cardiac cycle (diastole), and a reduction of the current by 80% was performed during the remaining time of the R-R interval, leading to an estimated mean effective radiation dose of approximately 10 to 14 mSv. By applying a half scan algorithm (only data from a 180° gantry rotation is used for image reconstruction) in patients with heart rates <65 beats/min, acquisition time was reduced to 165 ms (gantry rotation time/2 = 330 ms/2). For heart rates >65 beats/min, the adaptive cardio volume mode was activated, which automatically switches from a one-segment to a two-segment scan (two segments from consecutive heart cycles that together provide data of a 180° rotation are used for slice reconstruction). Depending on the patient's heart rate, a maximum temporal resolution of 83 ms can be achieved (8,9). Using retrospective electrocardiographic gating, we performed routinely reconstructions at 500, 600, and 700 ms before the R-wave (10). Because of motion artifacts at these reconstructions, additional reconstructions at 300, 400, and 550 ms were performed in six patients.

Image analysis of 64-slice CT. The CT data set was analyzed by two independent experienced readers using the INSIGHT (Neoimagery Co., City of Industry, California) and the Leonardo (Siemens, Forchheim, Germany) software packages. In a first step, image quality was determined by the investigators on the basis of the presence of motion artifacts and on the basis of the contrast-to-noise ratio, as described in previous studies (11).

The grading criteria for image quality were as follows: A high-quality image was defined as no motion artifacts and a contrast-to-noise ratio of >8; a moderate-quality image was defined as motion artifacts present but the vessel still evaluable or a contrast-to-noise ratio between 4 and 8; and a poor-quality image was defined as motion artifacts present that made vessel delineation impossible or a contrast-to-noise ratio <4. Only patients who had high- and moderate-quality images of all coronary segments were considered for further analysis.

Any discernible structure that could be assigned to the coronary artery wall, that had a CT density less than the contrast-enhanced coronary lumen but greater than the surrounding connective tissue, and that could be identified in at least two independent planes was defined as a noncalcified coronary atherosclerotic plaque. Any structure with a density of 130 HU or more that could be visualized separately from the contrast-enhanced coronary lumen (either because it was "embedded" within noncalcified plaque or because its density was above the contrast-enhanced lumen), that could be assigned to the coronary artery wall, and that could be identified in at least two independent planes was defined as a calcified atherosclerotic plaque (12).

The display setting used for lumen and plaque quantification was determined empirically in a subset of six patients (recruited from the cohort of patients in whom IVUS was performed). In each patient, four different coronary sites that were easy to identify because of their location next to landmarks were selected. The image display setting at each site was then manipulated so that the multislice computed tomographic (MSCT) image equaled the IVUS image in size and pattern and allowed exact separation between vessel, surrounding tissue, plaque, and lumen. The values for window width and window level of the respective section were recorded and were set in relation to the mean intensity within the lumen at the corresponding site. The results of this analysis revealed that the optimal setting to detect plaque and outer vessel boundaries is obtained on average at a width representing 155% (range, 395

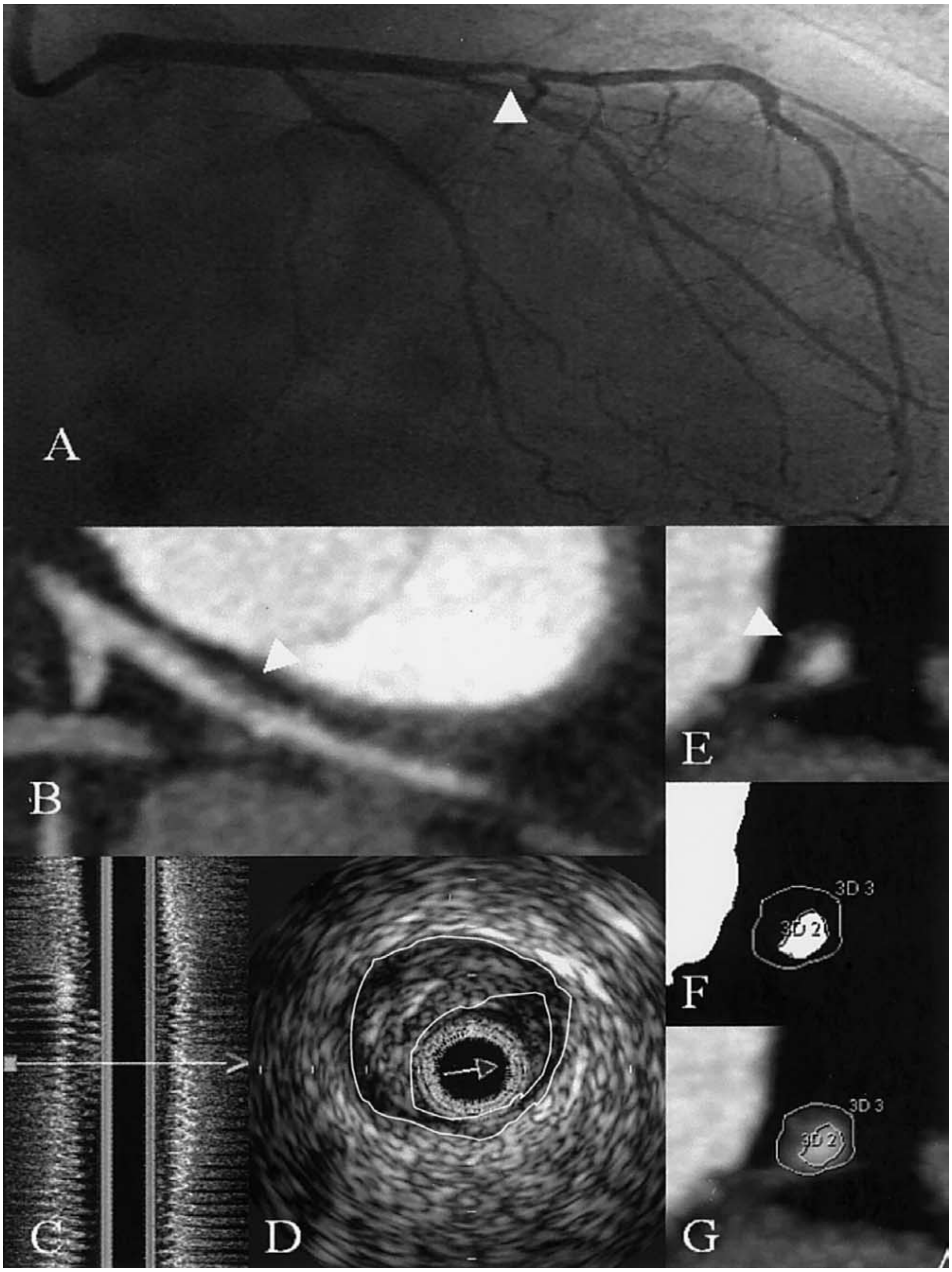

Figure 1. Angiographically nonobstructive lesion of the left anterior descending artery. **(A)** Invasive angiogram: **arrow** indicates a nonobstructive smooth lesion. **(B)** 64-slice computed tomography: **arrowheads** indicate a noncalcified plaque in the left anterior descending artery. **(C)** Intravascular ultrasound: longitudinal reconstruction. **(D)** Intravascular ultrasound cross section: lumen area 4 mm^2, plaque area 11 mm^2. **(E)** Cross-sectional view of the coronary vessel. **(F)** Window setting for lumen measurements: width is reduced to 1 HU, window level is set to 65% (210 HU in this case) of the mean intensity measured in the lumen. **(G)** Window level to determine outer vessel boundaries (width at 155% of mean value within the lumen, level at 65% of mean value). Lumen area is 4 mm^2, plaque area is 1 mm^2.

to 809 HU) of the mean intensity within the lumen and at a level representing 65% of the mean intensity (range, 165 to 339 HU). Keeping the window level (65% of mean intensity within the corresponding lumen) and reducing the width to a HU value of one, measurements provided optimal matching with IVUS (Fig. 1). Those initial measurements were performed by an independent investigator who was not involved in the later comparative analysis.

For comparison with quantitative coronary angiography (QCA), the grade of diameter stenosis (maximum diameter reduction) was determined in longitudinal curved multiplanar reformatted reconstructions by dividing the minimal diameter in the diseased segment through the diameter in the adjacent proximal disease-free section in the same two projections that were used for QCA. For comparison with IVUS, the percent area stenosis as well as plaque and vessel areas were determined in the cross sections of the coronaries using thin maximum intensity projections (Fig. 2).

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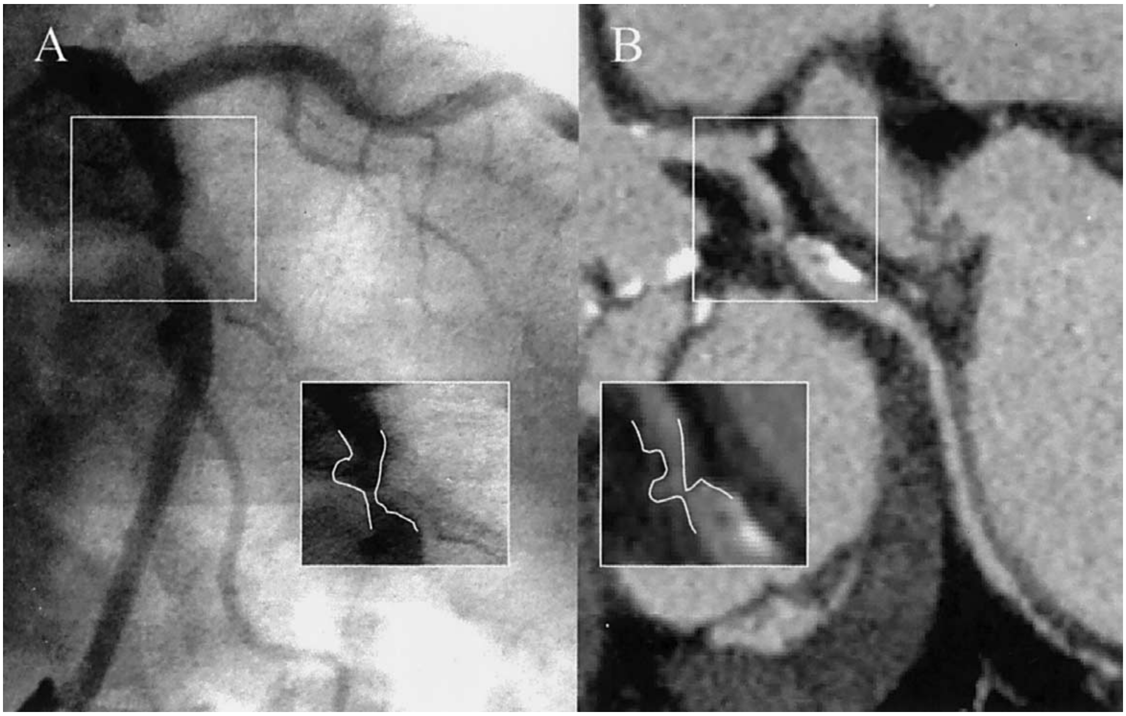

Figure 2. Correlation of quantitative coronary angiography (QCA) and 64-slice computed tomography (CT) angiography: Visualization and quantification of a high-grade stenosis in the left circumflex artery. (Diameter in the reference section 3.1 mm on QCA, 3.0 mm on 64-slice CT; minimal diameter within the stenotic section 0.6 mm on QCA, 0.5 mm on 64-slice CT). **(A)** Invasive coronary angiogram of the left coronary artery (right anterior oblique projection). **(B)** Multiplanar reformatted projection of the left circumflex artery by 64-slice CT.

Catheter-based coronary angiography and IVUS. Invasive coronary angiograms were evaluated by QCA (QuantCor QCA, Siemens Medical Systems, Forchheim, Germany) by an independent, blinded investigator. For coronary artery lesions, the mean diameter reduction was determined in two projections. In 18 patients, the IVUS of 32 coronary arteries was performed as part of the invasive diagnostic procedure (motorized pullback at 0.5 mm/s, electronic 20-MHz eagle view transducer, Volcano Therapeutics, Rancho Cordova, California). For each detectable lesion, the external elastic membrane cross-sectional area (EEM CSA) and the plaque area, defined as lumen CSA subtracted from EEM CSA, was defined by another independent investigator. Those measurements were performed in accordance to the IVUS interpretation guidelines of the American College of Cardiology and the American Heart Association (13).

Comparison of QCA with MSCT. The determination of the diagnostic accuracy of 64-slice CT was performed for lesions with various degrees of luminal narrowing. We calculated sensitivity and specificity for lesions causing stenoses >75%, for stenoses >50%, and for stenoses <50%. Calculations for sensitivity and specificity were conducted on a segmental basis according to the American Heart Association's segment model (15 segments) (1). Furthermore, we correlated measurements for stenosis severity obtained by 64-slice CT to QCA using the Spearman rank correlation.

Comparison of IVUS versus MSCT. We performed IVUS in 32 coronary arteries without significant coronary stenoses of >50% on conventional angiography. The comparison with IVUS was based on a site-by-site basis if single plaques could easily be distinguished as the result of a disease-free section of at least 10 mm between them. In the case that a single plaque involved the entire segment or even more segments, the comparison was performed on a segmental basis. Sections without evidence of atherosclerosis were divided into 10-mm intervals. The site and the longitudinal extent of coronary plaques were determined on the basis of their distance to the ostium and on the basis of fiduciary points like side branches or severe calcifications. For each plaque, the maximum EEM CSA, the maximum plaque area, as well as the maximum percent luminal obstruction were determined.

Statistics. The diagnostic accuracy of 64-slice CT to detect coronary lesions with various degrees of luminal obstruction was evaluated regarding QCA as the standard of reference. Sensitivity and specificity were calculated for stenosis >75%, for stenosis >50%, and for lesions <50% diameter reduction. Furthermore, we separately determined the accuracy for extensively calcified lesions (calcium area >50% of vessel area), for noncalcified or moderately calcified lesions (calcium area <50% of vessel area), and for lesions that were later targeted for a revascularization procedure (e.g., angioplasty or bypass surgery).

The capability of 64-slice CT to detect and quantify

Table 1. Accuracy of 64-Slice CT to Detect Coronary Stenosis in Comparison to QCA

Segments	Sensitivity			Specificity
	<50% Stenosis	>50% Stenosis	>75% Stenosis	
Mid and proximal segments	(37/46) 80%	(21/28) 75%	(22/25) 88%	(318/328) 97%
Distal segments	(15/20) 76%	(8/12) 67%	(6/10) 60%	(320/329) 97%
All segments	(52/66) 79%	(29/40)7 3%	(28/35) 80%	(638/657) 97%
Lesions requiring revascularization	—	(5/6) 83%	(19/21) 91%	—
Severely calcified segments	(16/21) 76%	(6/8) 75%	(8/12) 73%	(87/97) 89%
Non- and moderately calcified segments	(36/45) 67%	(23/32) 72%	(20/23) 87%	(551/560) 98%

American Heart Association 15-segment model: mid and proximal segments: segments 1, 2, 5, 6, 7, 9, 11, 12; distal segments: 3, 4, 8, 10, 13, 14, 15.
CT = computed tomography; QCA = quantitative coronary angiography.

coronary plaques was further compared with IVUS. Sensitivity and specificity were calculated on a plaque-per-plaque basis and were given for different coronary vessels. Sections without atherosclerosis were divided in 10-mm sections and were the basis for specificity calculations. Correlations of EEM CSA, lumen CSA, and plaque CSA, as well as percent vessel obstruction (comparison with IVUS) and diameter stenosis (comparison with QCA) were determined by calculating the Spearman rank correlation coefficient. Mean values were compared using the double-tailed *t* test. A p value <0.05 was considered to be statistically significant. All calculations were performed using the NCSS 2000 software package (NCSS, Kaysville, Utah).

RESULTS

According to the inclusion criteria, contrast-enhanced 64-slice CT was performed successfully without any complications in 59 patients (age, 64 ± 10 years) that were scheduled for conventional invasive coronary angiography. Beta-blockers were administered in 21 patients to reduce their heart rate. The mean heart rate during the scan was 62 ± 13 beats/min.

Four of 59 patients had CT angiograms that were severely affected by motion artifacts (n = 2) or poor contrast-to-noise ratio (n = 2), making an evaluation of all coronary segments impossible. The heart rates of these four patients were 63, 72, 82, and 89 beats/min. In the remaining 55 patients, all coronary segments were graded to provide good or intermediate image quality that was sufficient for evaluation. Nine patients had heart rates >70 beats/min during the investigation, and diagnostic image quality was obtained in six of them.

A comparison between 64-slice CT and QCA was theoretically available in 825 segments from 55 patients. Because of an occlusion of 4 vessels (right coronary artery [RCA], n = 2; left anterior descending artery [LAD], n = 2), 14 distally located segments were not available for comparison. Furthermore, we performed a separate analysis for 13 segments containing a stent. The values for diagnostic accuracy of 64-slice CT to detect coronary stenosis with increasing degrees of luminal narrowing thus were based on 798 comparable segments and are given in Table 1.

Table 2. Consensus Table of Stenosis Severity Determined by 64-Slice CT Versus QCA

QCA	64-Slice CT			
	No Stenosis	<50%	51% to 75%	>75%
No stenosis	638	8	9	2
<50%	14	40	10	2
51% to 75%	4	7	22	7
>75%	2	3	2	28

Abbreviations as in Table 1.

Table 2 compares the classification of lesions derived from 64-slice CT and QCA (798 segments). Consensus in classifying the degree of coronary stenosis with both methods was achieved in 90 of 141 angiographically stenotic segments and in 638 of 657 disease-free segments. Overall, 20 lesions could not be visualized and 12 lesions were underestimated by 64-slice CT, 19 segments were incorrectly graded stenotic, and in 19 segments a present lesion was overestimated. Of seven stenoses >75% that were missed, five were detected but underestimated and two could not be visualized as a result of their location in a side branch (Table 2). Nineteen segments without evidence of atherosclerosis on QCA were graded stenotic on 64-slice CT. A comparison with IVUS was able to be performed in five of these segments, which confirmed the presence of atherosclerotic plaque in all five segments. All segments that were incorrectly classified as >75% stenotic (n = 11) were either distal segments (n = 5) or revealed extensive calcifications (n = 6; IVUS comparison available in one segment confirming calcified plaque).

On a patient basis (patients without a stent, n = 45) 22 of 25 (sensitivity 88%) patients with at least one stenosis >50% on QCA were correctly identified, and in 17 of 20 patients, a stenosis >75% (85%) was correctly ruled out. If considering only patients with stenosis that subsequently required either angioplasty or bypass surgery, 17 of 18 patients (sensitivity 94%) were correctly identified by 64-slice CT. Overall correlation between the degree of stenosis detected by QCA compared with 64-slice CT was r = 0.54 using the Spearman rank correlation coefficient (Fig. 3).

We were able to compare 64-slice CT and QCA in 13 segments containing a stent. Two of two stents with an in-stent restenosis >75% were correctly classified by 64-slice CT. Two of two in-stent stenoses <75% were missed and, in four of nine stents without any restenosis, a restenosis >50% was diagnosed by 64-slice CT.

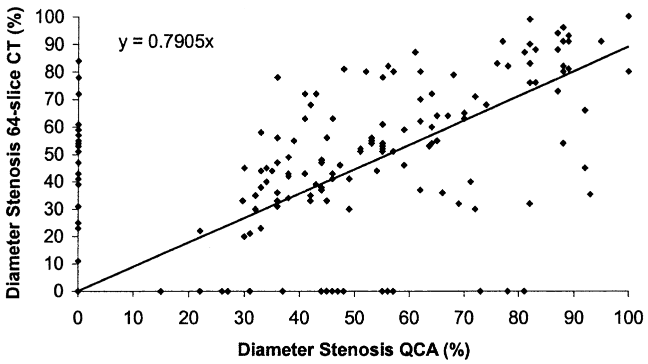

Figure 3. Correlation of quantitative coronary angiography (QCA) and 64-slice computed tomography (CT) measurements of diameter stenosis in diseased coronary segments. Pearson's correlation coefficient r = 0.54.

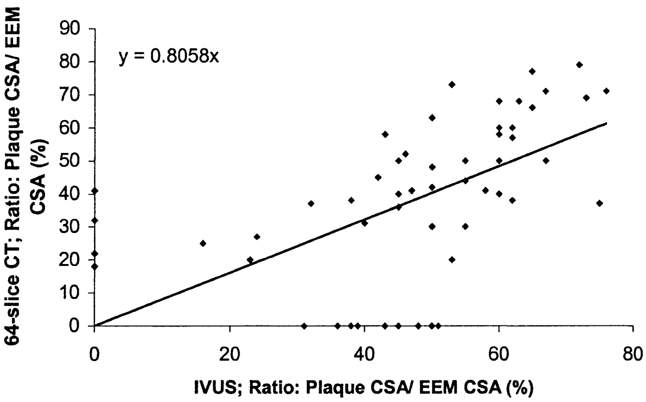

Figure 4. Correlation of the percentage of plaque area contributing to entire vessel area (ratio of plaque area to the external elastic membrane [EEM] cross-sectional area [CSA]) determined by intravascular ultrasound (IVUS) and 64-slice computed tomography (CT). The correlation coefficient between the measurements with both methods is r = 0.61. On average, the percentage of vessel area occupied by plaque is significantly underestimated by 64-slice computed tomography (50.4% vs. 41.1%, $p < 0.001$).

Intravascular ultrasound was part of the invasive catheterization procedure in 18 patients and was performed in 32 coronary vessels (left main and LAD, n = 16; left circumflex artery [LCX], n = 14; RCA, n = 2). No stents were investigated by IVUS. The results for diagnostic accuracy of 64-slice CT to detect coronary plaques in these vessels, based on a site-by-site analysis, are given in Table 3. Overall, 55 coronary plaques were detected on IVUS, and 64-slice CT identified 46 of them (sensitivity 84%); in 39 of 43 disease-free 10-mm sections, the presence of plaque was correctly excluded (specificity 91%; Table 3).

The mean plaque CSA, the mean lumen CSA, the mean EEM CAS, and the percent vessel obstruction (% plaque of EEM CSA) determined by IVUS and 64-slice CT were 8.1 $\pm$ 3.8 mm^2 versus 7.3 $\pm$ 5.1 mm^2 ($p < 0.04$), 8.4 $\pm$ 4.5 mm^2 versus 9.4 $\pm$ 5.1 mm^2 ($p < 0.01$), 16.4 $\pm$ 5.8 mm^2 versus 16.7 $\pm$ 7.1 mm^2 (p = 0.6, NS), and 50.4 $\pm$ 14.0% versus 41.1 $\pm$ 22.7% ($p < 0.001$). The correlation coefficients for these measurements were r = 0.73, r = 0.81, r = 0.88, and r = 0.61, respectively (Fig. 4).

DISCUSSION

In recent publications using 16-slice CT scanners, remarkable results identifying high-grade coronary stenoses were found, although this technology is still affected by several limitations explained by the given spatial and temporal resolution (1,3,7). Those limitations probably contributed to the fact that all existing studies focused on the detection of high-grade stenosis only and, until now, no attempt was directed toward a CT-derived stenosis quantification. In the present study, we used a new generation 64-slice CT with improved spatial and temporal resolution, and we demonstrated that this technology was feasible in identifying obstructive and nonobstructive coronary lesions with high accuracy in major parts of all three coronaries. Furthermore, we found a good correlation to determine plaque areas compared with IVUS. However, the ability to quantify the grade of luminal obstruction is limited.

Table 3. Accuracy of 64-Slice CT to Detect Coronary Lesions in Comparison to IVUS

	Sensitivity	Specificity
RCA	(5/6) 83%	(6/6) 100%
LM	(5/5) 100%	(11/11) 100%
LAD	(26/30) 87%	(13/14) 93%
RCX	(10/14) 71%	(10/13) 77%
Total	(46/55) 84%	(40/44) 91%

CT = computed tomography; IVUS = intravascular ultrasound; LAD = left anterior descending artery; LM = left main artery; RCA = right coronary artery; RCX = right circumflex artery.

Clinical feasibility. Previous MSCT studies revealed that its clinical feasibility mainly is limited by motion artifacts that occurred in patients with heart rates >65 beats/min. Therefore, in most studies CT angiography was performed exclusively in subjects with lower heart rates (1,3). In a recent report, we demonstrated that by administering a beta-blocker, a satisfactory heart rate reduction could only achieved in 80% of patients and that, even in these patients, 10% of CT studies were affected by motion artifacts (7). In the present study, using a scanner with a temporal resolution of 83 to 165 ms, we investigated all patients irrespective of the heart rate (although in 21 of 59 patients a beta-blocker was administered) and we found that complete, assessable CT angiograms were obtained in 55 of 59 patients. When considering only patients with heart rates >70 beats/min, six of nine patients still exhibited diagnostic image quality of all coronary arteries. Compared with 4-slice CT and 16-slice CT investigations, this constitutes a major improvement and is not only explained by improved acquisition time but also by the fact that the entire scan time is significantly shortened to only 8 to 11 s, making this technology more robust against respiratory and motion artifacts of the patient. However, heart rate control by negative chronotropic agents seems still to be reasonable, even with a temporal resolution of 83 to 165 ms.

Diagnostic accuracy of 64-slice CT in detecting angiographically stenotic lesions. In the case of diagnostic image quality, even with 4-slice and 16-slice CT scanners, high sensitivities and specifities were achieved in several independent investigations on various patient populations. However, those studies exclusively aimed to detect high-grade coronary stenosis predominantly in coronary segments with a diameter of at least 2 mm (2–5). The present study was designed to determine the accuracy of 64-slice CT without excluding distal coronary segments and side branches. In the only existing 16-slice CT study that investigated all coronary segments, an overall sensitivity of 63% to detect high-grade stenoses was reported (14) and, thus, our results, demonstrating a sensitivity of 75% (57 of 75 of >50% stenosis), reveal that 64-slice CT may be superior to this technology.

In major segments of the LAD and the RCA, as well as in the proximal part of the LCX, we found an excellent accuracy to detect all degrees of stenosis. Therefore, 24 of 27 (89%) lesions and 94% of patients that later required angioplasty or bypass surgery were identified correctly by 64-slice CT. However, in the distal segments of the LCX (segment 13), the marginal branches (segments 12, 14, and 15) and the LAD (segment 8), sufficient accuracy could not be obtained in most cases, indicating that spatial resolution even with this scanner technology still is not high enough to identify stenosis in peripheral segments. However, distal lesions are rarely a target for an intervention. Similar to 4-slice CT and 16-slice CT, extensive calcifications are a frequent source for missclassifications even with 64 slice CT (Table 1), although the degree of artifacts due to partial volume effects seem to be less severe.

The noninvasive follow-up of coronary stents is a desireable goal, and it is already speculated that 64-slice CT scanners may enable the visualization of in-stent restenosis (15). However, the dense stent material and the resulting artifacts still prevent a correct assessment of the in-stent lumen and, therefore, 6 of 13 stents were missclassified in the present study. Because a comparison only was available in a small number of stents and because we did not use sharper kernel reconstructions that may have improved stent evaluation by 64-slice CT, larger studies are needed to evaluate the true ability of 64-slice CT to assess different types of coronary stents.

Use of 64-slice CT to detect intermediate and nonstenotic coronary lesions (<50% luminal stenosis). Because angiography only allows imaging of the lumen contour of coronary vessels and provides no information concerning the vessel wall, plaque size or compensatory vessel remodelling, IVUS and not angiography is the reference standard for the detection of nonobstructive lesions and for quantitative measurements of lumen size and plaque size.

Furthermore, IVUS also is superior in determining luminal obstruction, especially in the presence of intermediate stenosis (13,16,17). Therefore, we performed a comparison of IVUS and CT in a subset of patients. This comparison revealed the high accuracy of 64-slice CT in identifying coronary lesions in vessels without significant stenosis (>50%) on angiography.

For CT-derived measurements of lumen and plaque, the image display setting may have important influence. Funabashi et al. (18) demonstrated that individually adapted settings that were related to peak attenuation within the vessel lumen are superior to standardized fixed settings (18). Therefore, the measurements in the present study were based on an empirically calculated formula determining the optimal image display settings dependent on the respective lumen attenuation. By using these window settings, a correlation to IVUS was good for lumen and plaque areas but only moderate for percent vessel obstruction because of a significant trend to overestimate lumen areas and underestimate plaque areas. This observation is explained by partial volume effects occurring at the lumen/plaque border either caused by calcium or the dense contrast agent and by the fact that density values of opacified lumen and plaque may overlap in a certain range. In contrast to the latter, partial volume effects will be diminished by scanners with further increased spatial resolution.

Study limitations. The findings of the present study document that 64-slice CT is a clinically suitable and robust noninvasive method to detect and quantify obstructive and nonobstructive coronary disease, although the quantification of luminal obstruction is limited because of technical restrictions. Therefore, this new technique may improve the noninvasive workup of symptomatic and probably even asymptomatic patients in terms of stenosis detection and risk stratification.

The results are influenced by the relatively high prevalence of coronary artery disease in our patient cohort. Thus, sensitivity and specificity values may differ in asymptomatic subjects with a lower prevalence of atherosclerosis. Most patients scheduled for catheterization at our hospital present at the same day of the procedure, leaving no time for a CT scan. Therefore, we investigated only patients that were available for a CT scan at least one day before the invasive angiogram. This fact also explains the low number of consecutive patients recruited during a four-month period.

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