

In-stent area stenosis on 64-slice multi-detector computed tomography coronary angiography: optimal cutoff value for minimum lumen cross-sectional area of coronary stents compared with intravascular ultrasound

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Abstract We aimed to prospectively assess the optimal cutoff value for a minimum lumen cross-sectional area (CSA) on a 64-slice multidetector computed tomography (MDCT) compared with an intravascular ultrasound (IVUS). In 39 patients with 43 stents, the minimum lumen diameter, stent diameter, diameter stenosis, minimum lumen CSA, stent CSA, and area stenosis at the narrowest point were measured independently on 64-slice MDCT and IVUS images. For the assessment of diameter and CSA, 64-slice MDCT showed good correlations with IVUS ($r = 0.82$ for minimum lumen diameter, $r = 0.66$ for stent diameter, $r = 0.79$ for minimum lumen CSA, and $r = 0.75$ for stent CSA, respectively, $P < 0.0001$). For the assessment of diameter and area stenoses, a 64-slice MDCT showed good correlations with IVUS ($r = 0.89$ and 0.91 , respectively, $P < 0.0001$). The overall sensitivity, specificity, positive predictive value, and negative predictive value to detect in-stent area restenosis (≥ 50 % area stenosis) of a 64-slice MDCT were 77, 100, 100, and 91 %, respectively. The cutoff value of a 64-slice MDCT, determined by receiver operator characteristic (ROC) analysis, was 5.0 mm^2 with 76.5 % sensitivity and 92.3 %

specificity for significant in-stent area restenosis; the area under the ROC curve was 0.902 ($P < 0.0001$). A good correlation was found between a 64-slice MDCT and the IVUS, regarding the assessment of diameter and area stenoses of coronary stents in selected patients implanted with stents of more than 3 mm in diameter. Optimal cutoff value for the minimum lumen CSA of coronary stents on the 64-slice MDCT is 5 mm^2 to predict a CSA of 4 mm^2 on IVUS.

Keywords In-stent restenosis · Intravascular ultrasound · Multidetector computed tomography

Introduction

Despite the widespread use of drug-eluting stents (DES) for coronary artery stenosis, in-stent restenosis remains a problem [1]. For the evaluation of in-stent restenosis, intravascular ultrasound (IVUS) is considered an accurate method for visualizing the wall of the coronary artery [2]. The minimum lumen cross-sectional area (CSA) of the coronary artery on IVUS has been found to be a major anatomic predictor of cardiovascular events. Adequate patency of stents, at follow-up, has been defined as a minimum lumen CSA $>4 \text{ mm}^2$ [2, 3].

Multidetector computed tomography (MDCT) angiography is a promising non-invasive method for imaging coronary vessels [4, 5]. Several studies have compared the diagnostic accuracies of MDCT with conventional coronary angiography for the detection of in-stent diameter restenosis [6–8]. For the assessment of in-stent diameter restenosis, MDCT has been shown to have good diagnostic accuracy, compared with conventional angiography, even though a relatively large proportion of stents remain

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uninterpretable [9, 10]. The parameters associated with area, such as minimum lumen CSA and stent CSA on IVUS, are major anatomic predictors of in-stent restenosis [2, 3, 11]. Therefore, a reliable non-invasive diagnostic method for the evaluation of area stenosis of stented coronary arteries would be highly desirable. However, there have been few studies assessing the diagnostic accuracy of a 64-slice MDCT compared with IVUS for the detection of in-stent area restenosis [12, 13].

Despite the widespread use of MDCT to determine in-stent restenosis of coronary stents, the cutoff values of MDCT parameters, at which to predict a CSA of 4 mm² on IVUS, have not been reported. Therefore, the goal of the present study was to investigate the optimal cutoff value of the minimum lumen CSA on the 64-slice MDCT, compared with IVUS.

Materials and methods

The study protocol was approved by the institutional ethics committee. All patients gave written informed consent for participation in this study.

Patients

Between March and November of 2008, we investigated 39 patients [24 men, 15 women; mean age, 62.9 ± 7 years (standard deviation)] with previous coronary stent implantation caused by clinically-suspected recurrent angina. All patients underwent MDCT, follow-up coronary angiography, and IVUS. A 64-slice MDCT was undertaken 708.9 ± 388.7 days after coronary stent implantation. The mean time interval between 64-slice MDCT and follow-up IVUS was 20.7 ± 7.8 days. The exclusion criteria were: overlapping stents, renal insufficiency (serum creatinine ≥2.0 mg/dL), contraindications to beta-blockers (third-degree atrioventricular block, reduced left ventricular function, asthma, or severe chronic obstructive pulmonary disease), previous allergic reactions to contrast media, and atrial fibrillation.

MDCT imaging

A 64-slice MDCT scanner (Brilliance CT: Philips Healthcare Systems, Cleveland, OH, USA) was used prior to conventional angiography. Patients with heart rates >65 beats per minute (bpm) received metoprolol (100 mg orally) 1 h before imaging. A bolus of 80 mL of iopamidol (Pamiray; 370 mg of iodine per 1 mL [mgI/mL]; Dongkuk Pharmaceutical Company Limited, Seoul, Korea) was injected intravenously, at 5 mL/s, followed by a 40 mL saline flush at 4 mL/s. The CT value of the area of interest in

the ascending aorta was monitored from the start of the injection. Imaging was initiated once the CT value of the contrast media in the ascending aorta reached 110 Hounsfield units (HU). The entire volume of the heart was imaged during one breath hold, with simultaneous electrocardiographic recording. The MDCT scanner had the following scan parameters: detector collimation 64 × 0.625 mm, table feed 19 mm/s (0.2 pitch), gantry rotation time 0.42 s, tube voltage 120 kV, and tube current 1000 mAs. Data were reconstructed with a field of view of 220 × 220 mm, image matrix of 512 × 512 pixels, and a sharp kernel (XCD). Cross-sectional images were reconstructed with a section thickness of 1 mm, at 0.5-mm intervals. Image reconstruction was retrospectively gated to the electrocardiogram. The optimal phase of the R–R interval without motion artifact was used for in-stent lumen evaluation with an off-line independent workstation (Extended Brilliance Workspace, Philips Medical Systems, Cleveland, OH, USA).

MDCT data analyses

Two experienced observers, (W.K. and J.C.; experienced in cardiac CT imaging for 7 and 2 years, respectively) who were unaware of the results of the coronary angiography, analyzed the MDCT datasets on the original axial CT images and on the curved multiplanar reconstruction. Disagreements between the two observers were resolved by consensus. To improve stent delineation, images were displayed in zoom mode at the window level of 300 HU, with a window width of 700–1,500 HU. Coronary artery segments containing stents were classified as either assessable or non assessable. Assessable segments were further classified into good or fair. If none of the artifacts were present, and lumens within the stent were clearly visible, the segment belonged to the good, assessable category. In some stents, a minor beam-hardening artifact was seen directly adjacent to the stent struts that did not obscure the vessel lumen. These stents were classified into the fair, assessable category, and the presence of the minor beam-hardening artifact was noted. Stent areas were measured in cross-sectional image planes for comparison with IVUS. At the narrowest point, the minimum lumen diameter, stent diameter, minimum lumen CSA, and stent CSA were measured. Because of the blooming artifacts of the stents, measurement along the inner margin of the stent was regarded as underestimation of CSA, measurement along the outer margin of the stent as overestimation of CSA. Thus, measurement along the middle of the stent was regarded as the stent border. Stent CSA was defined as the area bounded by the stent border [14]. Stenosis diameter was defined as the difference between the stent diameter and the minimum lumen diameter divided by the stent diameter. Area stenosis was defined as the difference between the stent CSA and the minimum

lumen CSA divided by the stent CSA. In-stent diameter restenosis was defined as $\geq 50\%$ diameter stenosis [5]. According to the consensus document on IVUS studies, by the American College of Cardiology, area stenosis in a native coronary artery on IVUS is a lesion that compromises the lumen by $\geq 50\%$ by CSA, compared with a reference segment lumen [14]. However, because we lack a definition of in-stent area restenosis, $\geq 50\%$ area stenosis was taken as the definition of in-stent area restenosis. We also recorded the type and location of the stent. Radiologists and cardiologists discussed the exact stenotic point on MDCT and IVUS.

IVUS imaging

IVUS was performed with a 40-MHz Atlantis SR Pro IVUS catheter (Boston Scientific Natick, MA, USA) or a 20-MHz Eagle Eye catheter (Volcano Corporation, San Diego, CA, USA). After an intracoronary injection of 2 mg of nitrate, an IVUS catheter was positioned at ≥ 1 cm distal to the stent. IVUS images were recorded after initiation of pullback at 0.5 mm/s. Two experienced observers (S.H.L. and S.Y.K.; experienced in IVUS for 7 years and 1 year, respectively) who were unaware of the results of 64-MDCT evaluated the IVUS results. The following IVUS parameters, at the narrowest point, were measured: minimum lumen diameter, stent diameter, minimum lumen CSA, and stent CSA. IVUS analyses were undertaken according to the methods described in the consensus document on IVUS studies by the American College of Cardiology [13]. As for MDCT, in-stent diameter restenosis and in-stent area restenosis were defined as $\geq 50\%$ diameter stenosis and area stenosis.

Statistical analyses

Continuous variables are the mean \pm SD; as mean \pm SD; and categorical variables are as counts and percentages. The value for the detection of in-stent area restenosis by the 64-slice MDCT was determined against that by IVUS as reference standard. Quantitative 64-slice MDCT and IVUS data were correlated by means of Bland–Altman and linear regression analyses and by calculating the intraclass correlation coefficient. Binary data for the presence or absence of in-stent area restenosis were evaluated using the McNemar test. The sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated. The inter-observer reliability for the detection of in-stent area restenosis was determined using the κ -statistic. Receiver operating characteristic (ROC) curves were calculated for minimum lumen CSA on the 64-slice MDCT, using IVUS (minimum lumen CSA < 4 mm² on IVUS was regarded as significant in-stent area

restenosis) as the “gold standard”. Statistical analyses were carried out with SPSS software (version 16.0, SPSS, Chicago, IL, USA), and $P < 0.05$ was considered significant.

Results

We evaluated 43 stents in 39 patients. The baseline clinical characteristics of the study sample are summarized in Table 1. The estimated mean radiation exposure was 16.1 mSv. The mean heart rate during baseline breathing was 57.2 ± 5.8 bpm, decreasing to 56.9 ± 8.2 bpm during MDCT scan acquisition. Heart rate variability was 2.8 ± 2.7 bpm. The number of good, assessable stents was 31, and the number of fair, assessable stents was 12 (1 in proximal RCA, 2 in mid RCA, 1 in proximal LAD, 4 in mid LAD, 1 in distal LCX, 2 in left posterolateral branch, and 1 in ramus intermedius artery). The number of non-assessable stents was 2 (4.4 %) because of motion artifact in mid RCA and blooming artifact in distal LAD, respectively; these were excluded from this study.

The sites of stent implantation were the right coronary artery (RCA) in 11 stents (25.6 %) (5 in proximal RCA, 3 in mid RCA, and 3 in distal RCA), the left anterior descending coronary artery (LAD) in 24 stents (55.8 %) (9 in proximal LAD and 15 in mid LAD), the left circumflex coronary artery (LCX) in 7 stents (16.3 %) (1 in proximal LCX, 2 in distal LCX, and 4 in left posterolateral branch), and the ramus intermedius branch in 1 stent (2.3 %). The mean stent diameter was 3.2 ± 0.5 mm (median, 3 mm; minimum, 2.5 mm; maximum, 4.5 mm). Eight types of stents were evaluated. The four DES used were: Cypher in 18 stents (Cordis, Miami, FL, USA; strut thickness 140 μ m), Taxus Liberte in 9 stents (Boston Scientific, Boston, MA, USA; strut thickness 97 μ m), Endeavor in 5

Table 1 Demographic and angiographic characteristics of patients

Characteristics	N = 39
Age (years)	62.9 \pm 7.3
Male gender	24 (61.5)
BMI (kg/m ²)	25.3 \pm 3.3
Cardiac risk factor	
Hypertension	21 (53.8)
Diabetes mellitus	14 (35.9)
Hypercholesterolemia	9 (23.1)
Current smoking	15 (38.5)
Previous myocardial infarction	18 (46.2)
Single-vessel disease	30 (76.9)
Multi-vessel disease	9 (23.1)

BMI body mass index. Data are number (percentage) of patients or mean value \pm SD

stents (Medtronic, Minneapolis, MN, USA; strut thickness 91 μm), and PicoElite in 6 stents (AMG International GmbH, Raesfeld-Erle, Germany; strut thickness 65 μm). The non-DES used were: Crossflex in 2 stents (Cordis; strut thickness 140 μm), Arthos pico in 1 stent (amg International GmbH; strut thickness 65 μm), Express in 1 stent (Boston Scientific; strut thickness 130 μm), and S7 in 1 stent (Medtronic; strut thickness 102 μm).

The mean diameter stenosis on the 64-slice MDCT and IVUS was 17.4 ± 26.5 and 22.9 ± 24.6 %, respectively. The mean area stenosis on the 64-slice MDCT and IVUS was 25.2 ± 30.7 and 33.5 ± 29.2 %, respectively. Further quantitative details are presented in Table 2. For the assessment of diameter and CSA, 64-slice MDCT showed good correlations with IVUS ($r = 0.82$ for minimum lumen diameter, $r = 0.66$ for stent diameter, $r = 0.79$ for minimum lumen CSA, and $r = 0.75$ for stent CSA, respectively, $P < 0.0001$) (Figs. 1, 2). For the assessment of diameter and area stenoses, the 64-slice MDCT coronary angiography showed good correlation with the IVUS ($r = 0.89$ and 0.91 respectively, $P < 0.0001$) (Fig. 3). For

the assessment of area stenosis for each stent type, the intra-class correlation coefficient was 0.94 for Cypher (Cordis), 0.82 for Taxus Liberte (Boston Scientific), 0.95 for Endeavor (Medtronic), and 0.68 for PicoElite (amg International GmbH) ($P < 0.05$). For the other stent types, the numbers were too small to support a statistical comparison.

The prevalence of in-stent area restenosis was 30.2 % (13 of 43) as determined by IVUS. The overall sensitivity, specificity, PPV, and NPV to detect in-stent area restenosis of the 64-slice MDCT were 77, 100, 100, and 91 %, respectively. The diagnostic accuracy of the 64-slice MDCT, according to stent characteristics, is presented in Table 3. Diagnostic accuracy was higher in ≥ 3 mm-diameter stents compared with that in < 3 mm-diameter stents. Stainless-steel stents showed higher diagnostic accuracy compared with stents made of cobalt chromium. Stents with ≥ 100 - μm strut thickness showed higher diagnostic accuracy than stents with < 100 - μm strut thickness. However, no significant differences were found between open and closed cell designs. For bare-metal stents (BMS), numbers were too small to support a statistical comparison with DES.

The 64-slice MDCT correctly classified 30 patients as having no in-stent area restenosis (Figs. 4, 5). Ten (76.9 %) out of the 13 stents with in-stent area restenosis on the IVUS were correctly identified by the 64-slice MDCT (Fig. 6). Three stents (23.1 %) out of the 13 with in-stent area restenosis on the IVUS showed < 50 % area stenosis on the 64-slice MDCT. An example of a stent underestimated on the 64-slice MDCT is shown in Fig. 7. The parameters for patients with stents underestimated on the 64-slice MDCT are shown in Table 4. The types of stents underestimated on the 64-slice MDCT were Taxus Liberte, Endeavor, and PicoElite. Those stents were located at mid LAD and proximal RCA. Inter-observer agreement for the detection of in-stent diameter stenosis and in-stent area

Table 2 Comparison of quantitative values of 64-slice multidetector computed tomography and intravascular ultrasound

	64-slice MDCT	IVUS	<i>P</i> -value
Minimum lumen diameter, mm	2.5 ± 0.9	2.4 ± 0.8	< 0.0001
Stent diameter, mm	3.0 ± 0.7	3.1 ± 0.7	0.008
Diameter stenosis, %	17.4 ± 26.5	22.9 ± 24.6	< 0.0001
Minimum lumen CSA, mm^2	6.5 ± 3.3	5.1 ± 2.9	0.374
Stent CSA, mm^2	9.0 ± 3.8	7.9 ± 3.3	0.401
Area stenosis, %	25.2 ± 30.7	33.5 ± 29.2	0.004

MDCT multidetector computed tomography, IVUS intravascular ultrasound, CSA cross-sectional area

Fig. 1 Correlation between the 64-slice MDCT and the IVUS for the measurement of **a** minimum lumen and **b** stent diameter. Correlation coefficients for minimum lumen diameter and stent diameter are 0.82 ($P < 0.0001$) and 0.66 ($P < 0.0001$), respectively

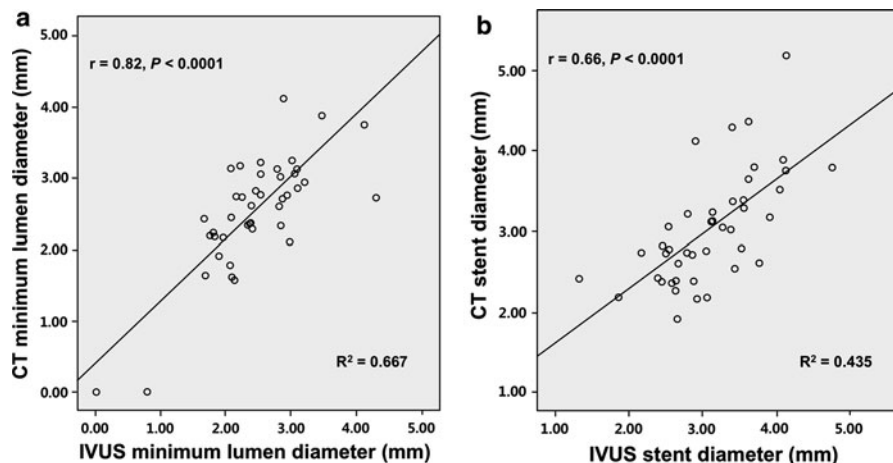


Fig. 2 Correlation between the 64-slice MDCT and the IVUS for the measurement of **a** minimum lumen cross-sectional area (CSA) and **b** stent CSA. Correlation coefficients for minimum lumen CSA and stent CSA are 0.79 ($P < 0.0001$) and 0.75 ($P < 0.0001$), respectively

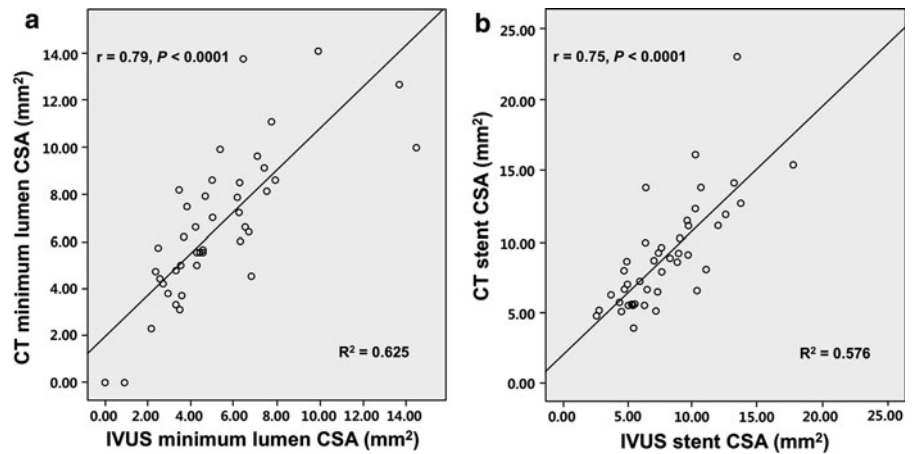


Fig. 3 Correlation between the 64-slice MDCT and the IVUS for the measurement of **a** diameter and **b** area stenosis. Correlation coefficients for diameter stenosis and area stenosis are 0.89 ($P < 0.0001$) and 0.91 ($P < 0.0001$), respectively

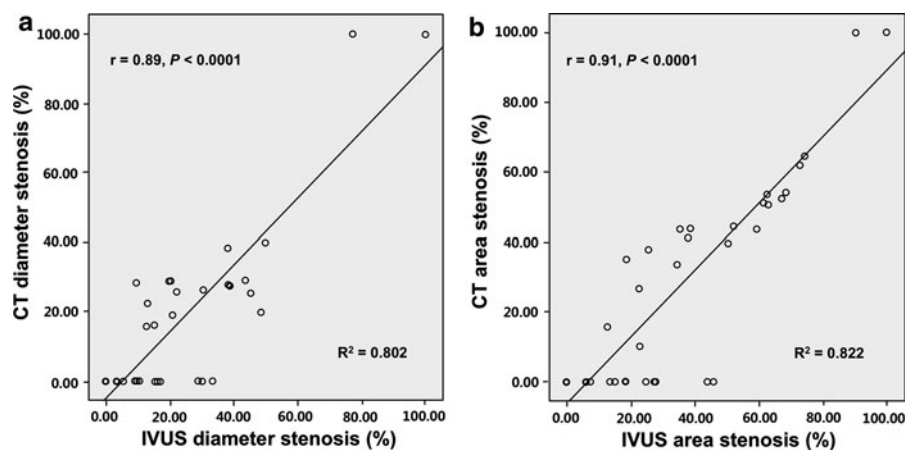


Table 3 Diagnostic accuracy of 64-slice multidetector computed tomography in relation to stent characteristics

	No. of stents	Sensitivity	Specificity	PPV (%)	NPV (%)	Accuracy (%)
Stent diameter (mm)						
<3	14	50 % (15–85)	100 % (72–100)	100	83.3	85.7
≥3	29	88.9 % (57–98)	100 % (84–100)	100	95.2	96.6
Strut thickness (µm)						
<100	21	66.7 % (35–88)	100 % (76–100)	100	80	84.6
≥100	22	100 % (51–100)	100 % (82–100)	100	100	96.7
Stent material						
Stainless steel	31	85.7 % (49–97)	100 % (86–100)	100	96	96.8
Cobalt chromium	12	66.7 % (30–90)	100 % (61–100)	100	75	83.3
Cell shape						
Open	13	80 % (38–96)	100 % (68–100)	100	88.9	92.3
Closed	30	75 % (41–93)	100 % (85–100)	100	91.7	93.3

PPV positive predictive value, NPV negative predictive value. Confidence intervals are given in parenthesis

restenosis was good (κ values of 0.74 and 0.72, respectively).

Upon ROC analyses, the area under the ROC curve was 0.902 ($P < 0.0001$), for per-stent analysis, indicating a high degree of agreement between the 64-slice MDCT

coronary angiography and the IVUS for significant in-stent area restenosis. An optimal cutoff value of 5.0 mm² on the 64-slice MDCT coronary angiography would have yielded a sensitivity of 76.5 % and a specificity of 92.3 % to detect significant in-stent area restenosis (Fig. 8).

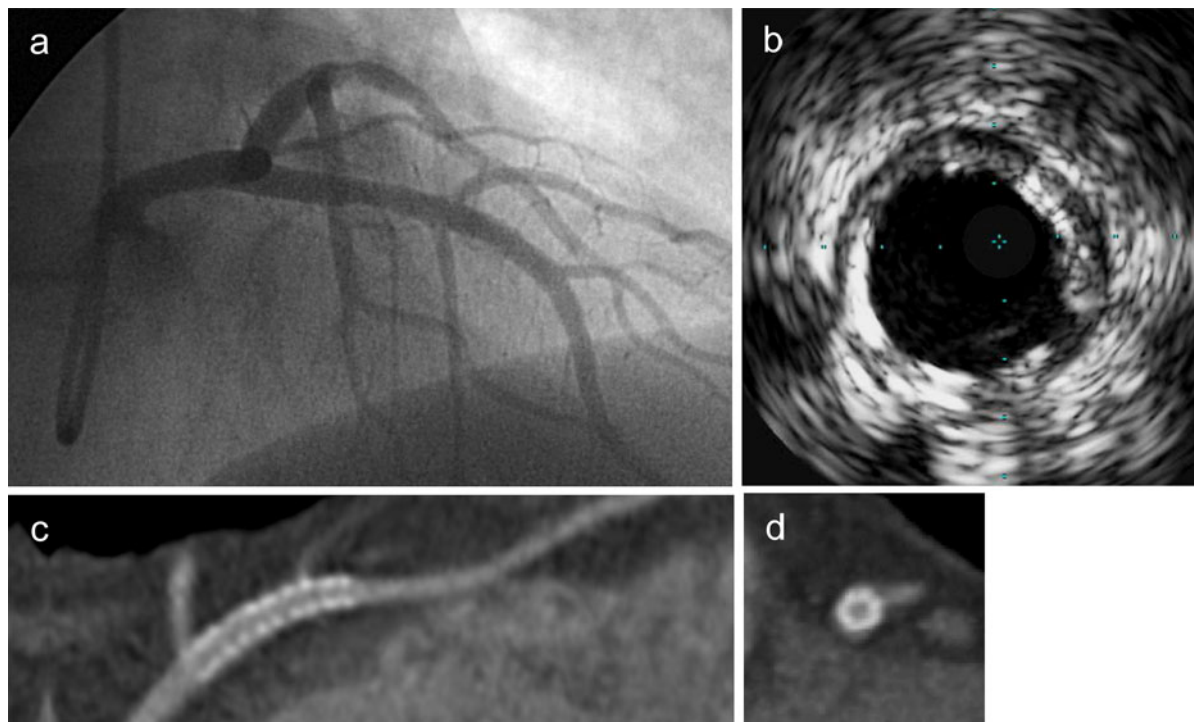


Fig. 4 A 3.5 mm diameter stent placed in the mid left anterior descending artery of a 42-year-old male. **a** conventional coronary angiography and **b** IVUS show no in-stent area restenosis. **c** curved

multiplanar reformation image and **d** cross-sectional image of the 64-slice MDCT coronary angiography also show no in-stent area restenosis

Eleven lesions, among the 13 in-stent area restenoses, were treated by another stent implantation. One patient was treated by balloon angioplasty, using a cutting balloon, and another refused coronary intervention.

Discussion

MDCT may offer a non-invasive approach to evaluating stents as it does for assessing coronary artery stenosis [4]. Although with the previously used 4- and 16-slice MDCT systems, MDCT was of limited value in the assessment and follow-up of patients with coronary stents, due to the frequent occurrence of motion and blooming artifacts [4, 5], with the introduction of the 64-slice MDCT, some of these limitations have been partially overcome due to increased temporal and spatial resolution and enhanced craniocaudal coverage [6–8]. A recent meta-analysis demonstrated that the 64-slice MDCT has good diagnostic accuracy for detection of in-stent diameter restenosis, when compared with conventional coronary angiography (sensitivity, specificity, PPV, and NPV; 86, 93, 70.4, and 97.2 %, respectively) [10]. These observations are not substantially different from those of a meta-analysis that included 16- and 64-slice MDCT systems [9]. In some studies with native coronary arteries, 16- and 64-slice MDCT systems have been shown to have a good correlation with

conventional coronary angiography and IVUS for parameters such as minimum lumen diameter, minimum lumen area, and area stenosis [15, 16]. However, there have been few studies of the 64-slice MDCT compared with IVUS for the evaluation of area stenosis of coronary stents. One study [12] reported a good correlation for the quantitative assessment of stent diameter and stent area ($r = 0.78$ and $r = 0.73$, $P < 0.001$) as well as a moderate correlation for degree of diameter stenosis and area stenosis ($r = 0.65$ and 0.55 , respectively) by MDCT compared with IVUS. The aforementioned study evaluated only two types of stents that were placed at the left main coronary artery, proximal LAD, and proximal LCX. Additionally, they used two MDCT scanners: 16- and 64-slice MDCT. In the present study, RCA, LAD, LCX, and the ramus intermedius branch for seven types of stent were evaluated using only 64-slice MDCT. In another report, 64-slice MDCT showed good correlation with IVUS for percentage stenosis of the diameter and area at the maximum lumen narrowing site of the stent ($r = 0.94$ and $r = 0.90$, $P < 0.0001$) [13]. Those results were not substantially different from those of the present study. Our study showed a moderate sensitivity and an excellent specificity and PPV of MDCT for detection of in-stent area restenosis. We suggest some reasons for the discrepancy between this study and the previous one. Calcium blooming in the region of maximal stenosis leads to a 21 % underestimation of maximum luminal diameter

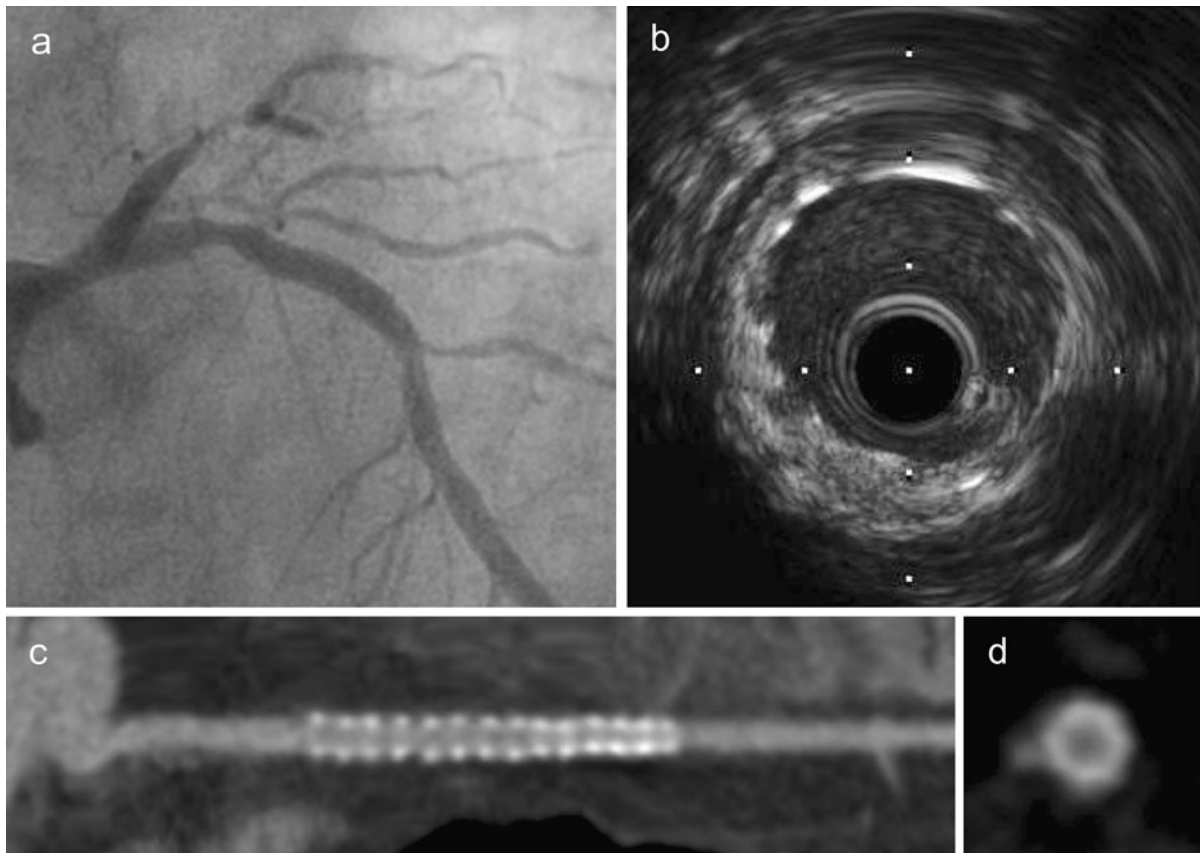


Fig. 5 A 2.75 mm diameter stent placed in the proximal left anterior descending artery of a 69-year-old male. **a** conventional coronary angiography and **b** cross-section view of IVUS show no in-stent area

restenosis. **c** straightened multiplanar reformation image and **d** cross-sectional image of the 64-slice MDCT coronary angiography also show no in-stent restenosis

by MDCT, whereas percent diameter stenosis was overestimated by 39 %, as there is typically less calcium and, therefore, less blooming in the area of the reference segment. The blooming of iodine in the lumen leads to a 27 % overestimation of the maximum luminal area by MDCT but, as this is uniform along the vessel, the percent area stenosis was underestimated by only 5 % [17]. Moderate sensitivity was due to 3 false-negative cases. Among the latter 3 stents one showed a high-density artifact generated by vessel calcification, preventing accurate evaluation of minimum lumen CSA and stent CSA.

As previously reported, stent characteristics—such as material, diameter and strut thickness—may influence the ability of CT to visualize coronary stents [13]. In the particular study [13] mentioned, diagnostic accuracy was higher in stents ≥ 3 mm-diameter than in those < 3 mm-diameter. Our findings were not different from the results of the aforementioned study. No significant differences were found between the aforementioned study and the present one with regard to open and closed cell designs. However, in our study, stainless-steel stents showed higher diagnostic accuracy compared with stents made of cobalt chromium. Stents with ≥ 100 - μm strut thickness showed

higher diagnostic accuracy than those with < 100 - μm strut thickness. These differing results were likely due to the relatively large number of true negative cases of stents with ≥ 100 - μm strut thickness and stainless-steel stents.

The IVUS is an adjunctive diagnostic technique that provides detailed cross-sectional imaging of the coronary arteries [18]. The American College of Cardiology/American Heart Association/Society for Cardiovascular Angiography and Interventions (ACC/AHA/SCAI) 2005 Guideline Update for Percutaneous Coronary Intervention states that IVUS can be used to: (1) assess the adequacy of coronary stent deployment (including the extent of apposition and minimum luminal diameter within the stent), (2) determine the cause of stent restenosis and to guide the selection of appropriate therapy, (3) evaluate coronary obstruction in a patient with suspected flow-limiting stenosis if angiography is difficult because of location, (4) assess a suboptimal angiographic result after percutaneous coronary intervention. In addition, IVUS may be used to assess lesion characteristics and vessel dimensions before percutaneous coronary intervention in order to select an optimal revascularization device (although the efficacy of this application is less well established) [19]. Among

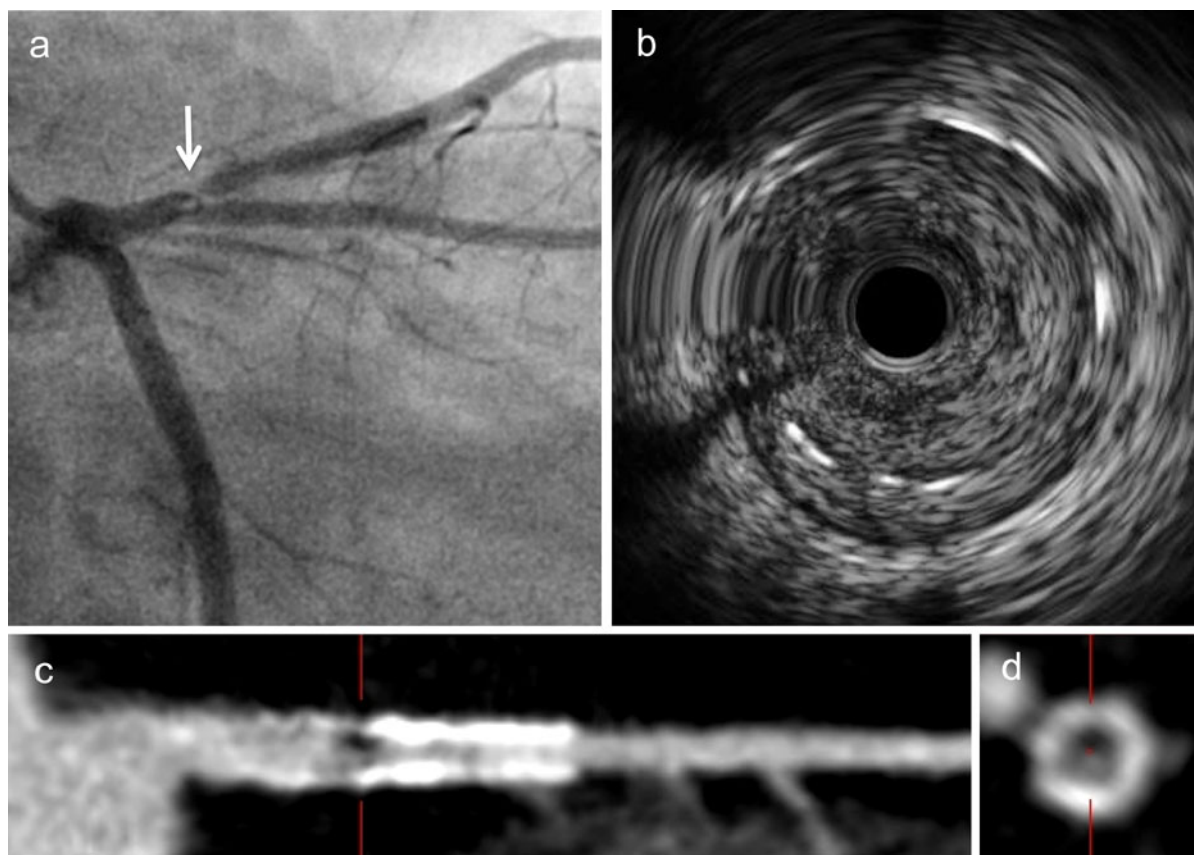


Fig. 6 In-stent area restenosis in a 3.5 mm diameter stent placed in the proximal left anterior descending artery of a 55-year-old male. **a** conventional coronary angiography shows in-stent restenosis (arrow) at the proximal portion of the stent. **b** The IVUS image shows a hyperechoic lesion from 12 o' clock to 9 o' clock, representing in-stent restenosis (area stenosis of 75 %). The minimum

lumen cross-sectional area (CSA) is 2.3 mm². **c** straightened multiplanar reformation image and **d** cross-sectional image of the 64-slice MDCT coronary angiography also show in-stent low density at the proximal portion of the stent (area stenosis of 63 %). The minimum lumen CSA is 2.3 mm²

intracoronary physiologic measurements, a fractional flow reserve (FFR; distal coronary pressure/aortic pressure) cutoff value of 0.75 is a promising parameter for choosing intervention versus medical therapy. IVUS parameters, such as minimum lumen diameter and minimum lumen CSA, have been shown to be significantly correlated with FFR [20].

IVUS parameters can predict restenosis. In the BMS era, a minimum lumen CSA <4 mm² in a major coronary vessel (>3 mm in diameter) has been shown to correlate with ischemia, and a minimum lumen CSA ≥4 mm² is associated with a low prevalence of cardiovascular events with medical therapy [2, 11]. In a sub-study of the Siroli-mus-Eluting Stent in Coronary Lesions (SIRIUS) trial, the investigators defined adequate patency of a stent as an IVUS-determined minimum lumen CSA >4 mm² at follow-up [19]. Therefore, we regarded a minimum lumen CSA <4 mm² on IVUS to represent significant in-stent area restenosis. Hence, ROC curves were calculated for minimum lumen CSA on the 64-slice MDCT, using

significant in-stent area restenosis on the IVUS as the gold standard. Cutoff values of minimum lumen CSA on the 64-slice MDCT compared with IVUS have not been reported. The results of the present study indicate that the 64-slice MDCT may provide a reliable alternative to IVUS as an important non-invasive method for the detection of significant in-stent area restenosis with a cutoff value of 5.0 mm². There was a difference of around 1 mm² of minimum lumen CSA, representing a significant in-stent restenosis between the 64-slice MDCT and the IVUS. The difference was likely due to increased plaque attenuation surrounding the minimum lumen CSA due to intracoronary contrast media on the 64-slice MDCT, or relatively low temporal resolution of the 64-slice MDCT compared with IVUS. Some studies reported that increased contrast media (and thus increased intracoronary attenuation) led to increased plaque attenuation [21, 22].

There were several limitations to the present study. First, we evaluated a relatively small number of patients. Hence, the total number of patients with an in-stent area

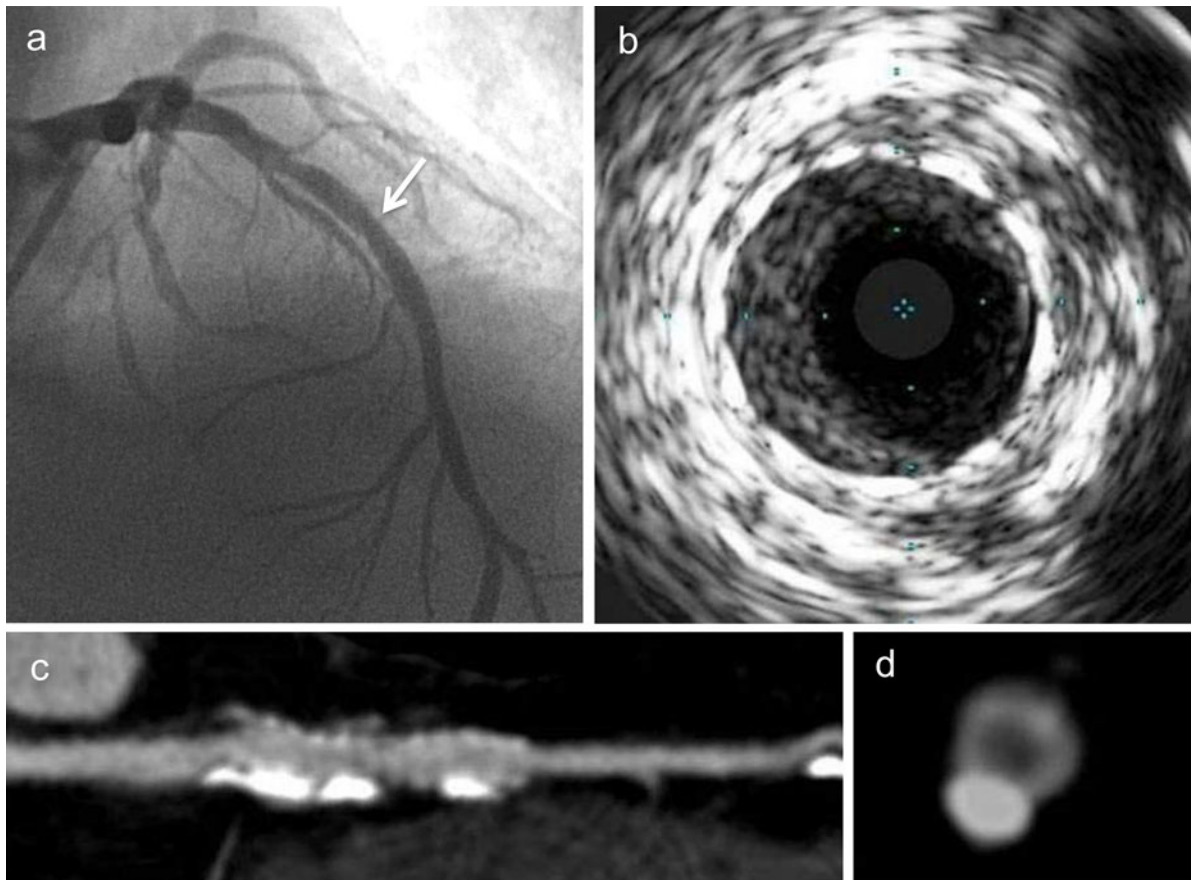


Fig. 7 Underestimated stent with 4 mm diameter on the 64-slice MDCT placed in the mid anterior descending artery of a 60-year-old male. **a** Conventional coronary angiography shows intraluminal narrowing (*arrow*) at the mid portion of the stent. **b** The IVUS image shows a mixed-echoic lesion from 6 o' clock to 12 o' clock, representing intraluminal narrowing (area stenosis of 50.4 %). The

minimum lumen cross-sectional area (CSA) is 6.2 mm². **c** Straightened multiplanar reformation image and **d** cross-sectional image of the 64-slice MDCT coronary angiography show multiple vessel wall calcifications with in-stent small low density (area stenosis of 39.5 %). The minimum lumen CSA is 7.2 mm²

Table 4 Parameters of patients with false-negative 64-slice multidetector computed tomography scans

	64-slice MDCT	IVUS
60 Years/male		
Minimum lumen CSA, mm ²	7.2	6.2
Stent CSA, mm ²	11.9	12.5
Area stenosis, %	39.5	50.4
69 years/Female		
Minimum lumen CSA, mm ²	3.7	3.6
Stent CSA, mm ²	6.5	10.4
Area stenosis, %	43.1	59.4
84 years/Female		
Minimum lumen CSA, mm ²	4.8	3.3
Stent CSA, mm ²	8.6	7.1
Area stenosis, %	44.2	52.2

MDCT multidetector computed tomography, IVUS intravascular ultrasound, CSA cross-sectional area

restenosis was also relatively low. Therefore, our data concerning the sensitivity of the 64-slice MDCT for detecting in-stent area restenosis must be interpreted with caution. Second, only patients with stable and low heart rates were included in the present study, and a high percentage of our sample received β -blockers to further reduce their heart rates.

Conclusion

A good correlation was found between the 64-slice MDCT and the IVUS with regard to the assessment of diameter and area stenosis of coronary stents in selected patients with implanted stents of more than 3 mm in diameter. Optimal cutoff value for the minimum lumen CSA of coronary stents on the 64-slice MDCT is 5 mm² to predict a CSA of 4 mm² on IVUS.

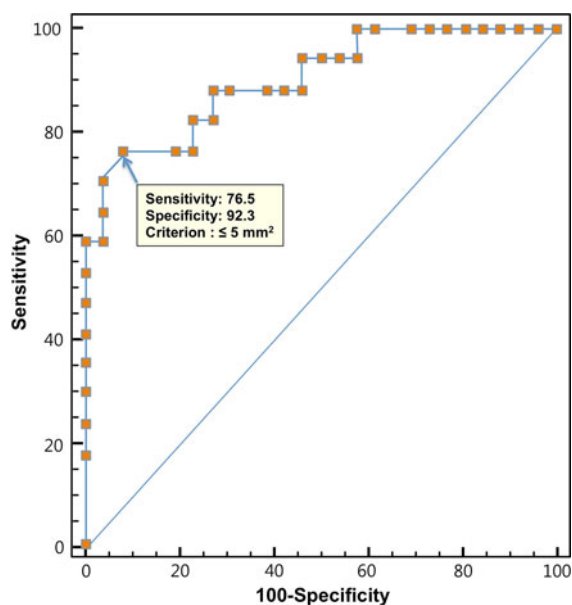


Fig. 8 Receiver operator characteristic (ROC) curve analyses on a per-stent basis comparing the 64-slice MDCT coronary angiography versus the IVUS. The area under the ROC curve was 0.902 ($P < 0.0001$). The cutoff value of 5 mm^2 on the 64-slice MDCT coronary angiography would have yielded a sensitivity of 76.5 % and a specificity of 92.3 % to detect a CSA of 4 mm^2 on IVUS

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Conflict of interest There are no conflicts of interest regarding this manuscript.

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