Imaging of coronary atherosclerosis with multi-slice computed tomography

Pundziūtė, G.

Chapter 5

Evaluation of Patients With Previous Coronary Stent Implantation With 64-Section CT

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Abstract

Aims: To prospectively evaluate the diagnostic accuracy of 64-section computed tomography (CT) for the assessment of in-stent or peri-stent restenosis, with conventional coronary angiography as the reference standard.

Methods: The study was approved by the medical ethics committee, and informed consent was obtained in all 50 enrolled patients (40 men, 10 women; mean age, 60 years±11 [standard deviation]). In addition to conventional coronary angiography with quantitative coronary angiography, 64-section CT was performed. For each stent, assessability was determined and was related to stent characteristics and heart rate by using a χ^2 test. On the interpretable images of stents and peri-stent lumina (5.00 mm proximal and distal to the stent), the presence of significant (≥50%) restenosis was determined. For this analysis, partially overlapping stents were considered to represent a single stent.

Results: Of 76 stents, 65 (86%) were determined to be assessable. Increased heart rate and overlapping positioning were associated with increased uninterpretability of the images of stents ($p<0.05$), whereas location of the stent and thickness of the strut were not. In seven patients, stents were placed in an overlapping manner, resulting in 58 stents available for the evaluation of significant (≥50%) in-stent restenosis. All six significant (≥50%) in-stent restenoses were detected, and the absence of significant (≥50%) restenosis was correctly identified in the 52 remaining stents, resulting in sensitivity and specificity of 100%. Sensitivity and specificity for the detection of significant (≥50%) peri-stent stenosis were 100% and 98%, respectively.

Conclusions: In selected patients with previous stent implantation, 64-section CT can be used to evaluate in-stent restenosis with high accuracy. Accordingly, the technique may be useful for noninvasive exclusion of in-stent or peri-stent restenosis, thereby avoiding invasive imaging in a considerable number of patients.

Introduction

Follow-up imaging in patients who present with recurrent symptoms after previous placement of an intracoronary stent is currently performed with conventional coronary angiography. However, this is an invasive procedure associated with a small but definite risk of serious complications.[1,2] Because a substantial number of procedures are not followed by an intervention, a noninvasive diagnostic procedure that helps evaluate not only native coronary arteries but also coronary stents would therefore be of great benefit. Although promising results have been obtained with multisection computed tomography (CT) for the detection of coronary artery stenoses in native coronary arteries,[3–5] results of evaluation of metallic stents have not been as promising.[6–10] Although image quality and diagnostic accuracy improved substantially with 16-section as compared with four-section CT systems, image quality for relatively large numbers of images of stents has been reported to be inadequate. In particular, images of stents with thicker struts or smaller diameters tended to exhibit degraded image quality.[6,7,9] Recently, 64-section CT systems have become available, and results of studies in which the in vitro assessment of coronary stents was evaluated by using 64-section CT suggest that further improvement in image quality has been achieved.[11,12] However, only limited data with 64-section CT are available in patients thus far, and results have been conflicting. Rixe et al,[13] for example, recently reported that only 58% of images of stents were interpretable.

Thus, the purpose of our study was to prospectively evaluate the diagnostic accuracy of 64-section CT for the assessment of in-stent or peri-stent restenosis, with conventional coronary angiography as the reference standard.

Methods

Patients

The study group consisted of 50 consecutive patients (40 men, 10 women; mean age, 60 years±11 [standard deviation]; range, 41–79 years) who met our criteria and who had previously undergone percutaneous transluminal coronary angioplasty in combination with stent placement. Characteristics of the study population are included in Table 1. Patients were scheduled for diagnostic conventional coronary angiography from June 2005 to May 2006. In addition, multisection CT coronary angiography was performed to allow noninvasive evaluation for the presence of in-stent restenosis or occlusion. Exclusion criteria were the following: (a) atrial fibrillation, (b) renal insufficiency (serum creatinine level >120 mmol/L), (c) known allergy to iodinated contrast media, and (d) pregnancy. All patients were receiving continuous β-adrenergic blocking agent therapy, and no additional β-adrenergic blocking agents were administered prior to multisection CT. On average, multisection CT was performed a mean of 13.4 months±13.3 (range, 1–66 months) after stent implantation.

Conventional coronary angiography in combination with quantitative coronary angiography was performed 14 days±9 (mean±SD) after multisection CT and served as the reference standard. After the study details, including radiation exposure, were explained, all patients gave informed consent for our study that was approved by the ethics committee of the Leiden University Medical Center, Leiden, the Netherlands.

Table 1. Clinical characteristics of 50 patients in the study population

Characteristic	Value
Sex	
Men	40
Women	10
Age (y)*	60±11
Heart rate (beats/min)*	58±10
Single-vessel disease	22 (44)
Multivessel disease	28 (56)
Previous myocardial infarction	46 (92)
Anterior	31 (67)
Inferior	14 (30)
Both	1 (2)
Previous percutaneous transluminal coronary angioplasty	50 (100)
Previous coronary artery bypass graft	0
Stent location	
Left main coronary artery	0
Left anterior descending coronary artery	36 (47)
Left circumflex coronary artery	11 (14)
Right coronary artery	29 (38)

Except where otherwise indicated, data are numbers of patients, and numbers in parentheses are percentages.
* Data are the mean ± standard deviation.

Stent characteristics

The diameter of implanted stents ranged from 2.25 to 4.0 mm (mean, 3.4 mm ±0.3), and the length ranged from 8.0 to 33.0 mm (mean, 19.4 mm ±5.0). In total, 21 stents were positioned with partial overlap. Ten stent types were evaluated, and most were non–drug eluting stents (Vision, Guidant, Santa Clara, Calif [n=33]; Driver, Medtronic, Minneapolis, Minn [n=3]; Ave S7, Medtronic [n=2]; Ave S670, Medtronic [n=1]; Orbus, Orbus Medical Technologies, Fort Lauderdale, Fla [n=2]; Tristar, Guidant [n=2]; Bx Velocity, Cordis, Miami Lakes, Fla [n=1]; and Liberte´, Boston Scientific, Natick, Mass [n=1]). In addition, 31 drug-eluting stents (Cypher, Cordis, Miami, Fla [n=30]; Achieve, Guidant [n=1]) were included. Of these stents, the Cypher, Bx Velocity, and Tristar stents were considered to have thick struts (≥140 μm).

Data acquisition

Multi-section CT

Multi-section CT was performed (Aquilion 64; Toshiba Medical Systems, Tokyo, Japan), with 64 detector rows and a section thickness of 0.5 mm and a rotation time of 0.4, 0.45, or 0.5 seconds, depending on the heart rate. The tube current was 350 mA at 120 kV. Between 90 and 105 mL of nonionic contrast medium (Iomeron 400; Bracco, Milan, Italy) was administered into the antecubital vein with a CT injection system (Stellant; Medrad, Pittsburgh, Pa), depending on the total scanning time, and the flow rate was 5.0 mL/sec. Repetitive low-dose monitoring examinations (120 kV, 10 mA) were performed 5 seconds after the start of injection of contrast medium. After the preset contrast enhancement threshold level of baseline Hounsfield units plus 100 HU in the descending aorta was reached, multi-section CT was automatically initiated. After a 2-second delay, data acquisition was performed during an inspiratory breath hold of approximately 10 seconds; the electrocardiogram was recorded simultaneously to allow retrospective gating of the data.

For evaluation of the coronary arteries and intracoronary stents, data were reconstructed by using a segmented reconstruction algorithm at 75% of the R-R interval with a section thickness of 0.5 mm and a reconstruction interval of 0.3 mm. If motion artifacts were still present in this phase (as occurred in 23 patients), additional reconstruction was explored to obtain the reconstruction phase with the fewest motion artifacts. For this purpose, images were reconstructed at a single level throughout the R-R interval in 20-msec steps to obtain information on the individual patient’s pattern of cardiac motion. On the basis of these images, the time point to reconstruct the entire data set was chosen. Also, in all patients, an additional data set was reconstructed in the most optimal phase or phases by using a sharper reconstruction kernel (Q04 instead of Q05-07) to improve stent image quality.[14] Multi-section CT was performed successfully in all patients. The mean heart rate during the acquisition was 58 beats per minute ±10 (range, 38–86 beats per minute).

Conventional coronary angiography

Conventional coronary angiography was performed according to standard techniques by two experienced operators, one with 10 years of experience and the other (M.J.S.) with 15 years of experience. Vascular access was obtained by using the femoral approach with the Seldinger technique and a 6-F catheter.

Data analysis

Multi-section CT

For each coronary artery, the data set containing no motion artifacts or the fewest motion artifacts was transferred to a dedicated workstation (Vitrea2; Vital Images, Plymouth, Minn) for postprocessing.

Coronary stents were evaluated on both the standard-kernel and the sharper kernel reformations by using predominantly the original transverse multi-section CT images; manually obtained curved multiplanar reformations were used for verification of findings. Three dimensional volume-rendered reformations were not used. In addition, the transverse images and curved multiplanar reformations were viewed in three different window and level settings: The setting with a window width of 1000 HU and a window level of 200 HU was used as a standard window level, and settings with a window level and window width of 1600 HU and 300 HU and 2500 HU and 900 HU, respectively, were used to improve stent appearance. Assessment was performed with consensus reading by two experienced observers (J.W.J. and J.D.S.). Both readers were blinded to the conventional coronary angiographic results, and both had 3.5 years of experience in the evaluation of findings at multi-section CT coronary angiography. One (J.W.J.) also had extensive (15 years) experience with conventional coronary angiography and intervention.

First, images of each stent were assigned an image quality score of 1 (good image quality, no artifacts), 2 (moderate image quality, minor or moderate artifacts present but diagnosis possible), or 3 (uninterpretable, no diagnosis possible), as described elsewhere.[9,15] Also, the reviewers documented whether stents were positioned in partially overlapping positions. Overlapping stents were consequently considered to represent a single stent for the evaluation of in-stent or peri-stent stenosis.

Subsequently, the presence of significant restenosis (≥50% reduction of luminal diameter) was assessed for each stent, and the observation of nonsignificant (≥50% reduction of luminal diameter) neointimal hyperplasia within the stent was documented. Finally, since re-stenosis of the stent borders may also regularly occur, the presence of persistent stenosis (≥50% narrowing of luminal diameter 5.00 mm proximal and distal to the stent) was also evaluated, as described elsewhere.[9]

Conventional and quantitative coronary angiography

Conventional angiograms were evaluated in consensus by two experienced observers (G.P., J.C.T.) who had no knowledge of the multi-section CT data. First, the location of the intracoronary stents was identified on the images before injection of contrast medium. Subsequently, quantitative coronary angiography with automated vessel contour detection after catheter-based image calibration was performed in end-diastolic frames by two qualified observers (G.P. and J.C.T.) who had 2 and 10 years of experience, respectively, in quantitative coronary angiography. The observers used a standard algorithm dedicated to stent analysis (QAngio XA, QCA-CMS, version 6.0; Medis, Leiden, the Netherlands).[16] Quantitative coronary angiography of the stent and its proximal and distal (5.00 mm) lumina was performed, and the percentage reduction in diameter was determined. An in-stent luminal diameter that was narrowed by 50% or more (up to in-stent occlusion) was defined as significant restenosis.

Statistical analysis

Continuous variables are presented as means ±1 standard deviation, and categorical data are summarized as frequencies and percentages. To relate stent assessability to stent characteristics, stents were classified according to the location in the coronary tree and according to strut thickness. Stents with struts that were 140 μm thick or thicker were regarded as having thick struts, and stents with struts that were less than 140 μm thick were regarded as having thin struts, as described elsewhere.[9] We also distinguished between stents positioned in partially overlapping positions and stents that were not overlapping. The percentage of assessable stents was calculated for each category and was compared by using χ^2 analysis, with Yates correction. In addition, mean heart rate was compared between patients with images of stents that were interpretable and patients with images of stents that were uninterpretable because of attenuation artifacts or motion artifacts; for this comparison, the Student *t* test for independent samples was used. Logistic regression analyses were applied to correlate segment and patient characteristics to image quality by using the generalized estimating equation method developed by Liang and Zeger.[17] Two (dichotomous) outcome variables were considered: (a) good versus moderate or uninterpretable image quality and (b) good or moderate versus uninterpretable image quality. The generalized estimating equation analysis was performed with Proc Genmod, with a binomial distribution for the outcome variable, with the link function specified as logit, and with patients considered as separate subjects.

Odds ratios and 95% confidence intervals were reported. Sensitivity, specificity, and positive and negative predictive values (including 95% confidence intervals) for the detection of in-stent restenosis of 50% or greater, as determined with conventional angiography in combination with quantitative coronary angiography, were determined for each stent. In addition, diagnostic accuracy was also determined for the detection of significant (≥50%) narrowing of the peri-stent lumina (5.00 mm proximal and distal to the stent).

Statistical analyses were performed with software (SPSS, version 12.0, SPSS, Chicago, Ill; SAS, release 6.12, SAS Institute, Cary, NC). A p value of .05 was considered to indicate a statistically significant difference.

Results

Stent analysis: image quality

In 50 patients, a total of 76 stents (one to five stents per patient; mean number of stents, 1.5±0.87) were evaluated (Figure 1). Quality of images of 41 (54%) stents was good and quality of images of 24 (32%) stents was moderate; the stent lumen could not be visualized on images of the remaining 11 (14%) stents. The reasons for uninterpretability of images of these 11 stents were motion artifacts on images of five (45%) stents and attenuation artifacts on images of six (55%) stents.

Of the images of stents that were uninterpretable, images of six stents that were placed in the right coronary artery were among them, whereas images of three stents that were positioned in the left anterior descending artery and images of two stents that were placed in the left circumflex coronary artery were included. No significant differences were observed in interpretability of images of stents placed among the coronary arteries (p=0.35). The mean heart rate during data acquisition was significantly higher in patients with images of stents deemed uninterpretable because of motion artifacts (mean, 72 beats per minute ±9) than in patients with images of stents deemed uninterpretable because of attenuation artifacts (mean, 55 beats per minute ±2) (p=0.002). No significant difference in heart rate was observed between images of stents that were uninterpretable because of attenuation artifacts and images of stents that were interpretable (mean, 57 beats per minute ±9; p=0.62).

Among images of stents positioned without any overlap (n=55), quality was good in 31 (56%), moderate in 20 (36%), and nondiagnostic in four (7%). In contrast, quality of images of stents positioned with partial overlap (n=21) was significantly lower — quality in these images of stents was good in 10 (48%) and moderate in four (19%), whereas images of seven (33%) stents were uninterpretable (p=0.01).

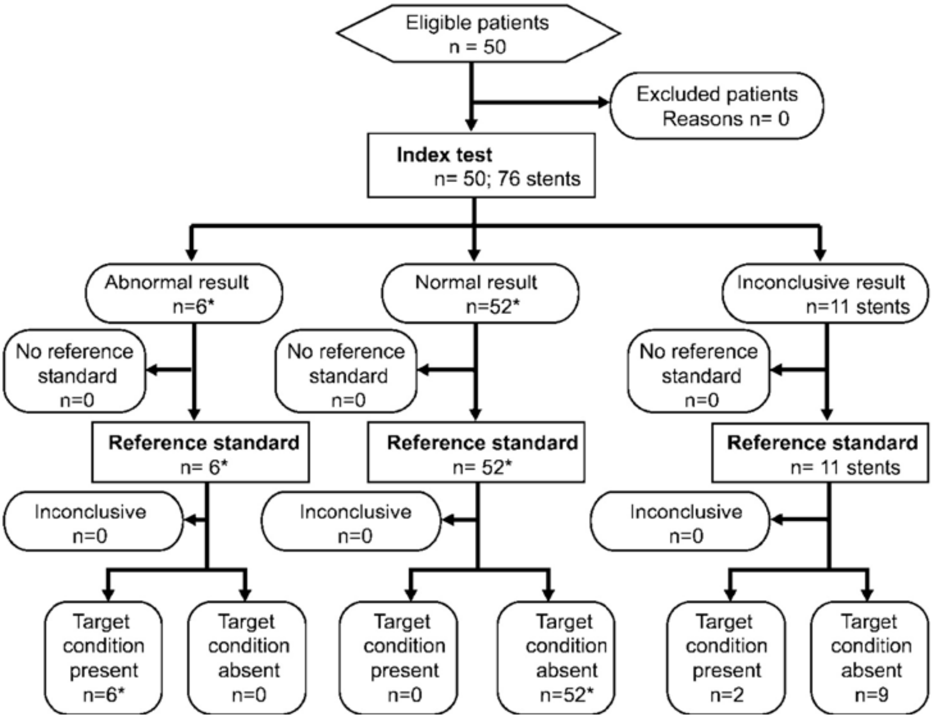

Figure 1. Flowchart.

* Total number of stents is lower than indicated in the boxes above because overlapping stents were considered to represent a single stent for the analysis of diagnostic accuracy.

A trend toward improved image quality for stents with thin struts (<140 μm thick, n=43) as compared with stents with thick struts (≥140 μm thick, n=33) could be observed. In the latter group, images of 14 (42%) stents were of good quality, those of 12 (36%) stents were of moderate quality, and images of seven (21%) stents were uninterpretable. In contrast, quality of images of 27 (63%) stents with thinner struts was good, and quality of images of 12 (28%) stents was moderate; images of four (9%) of the stents with thinner struts were uninterpretable. Still, no statistically significant difference was observed (p=0.15). Results from generalized estimating equation analysis are provided in Table 2.

Table 2. Results from generalized estimating equation analysis

Image quality	Odds ratio*
Good versus moderate or uninterpretable	
Heart rate†	0.98 (0.93, 1.05)
Overlapping stents (yes or no)	0.70 (0.17, 2.96)
Strut thickness (≥140 μm or <140 μm)	0.44 (0.15, 1.29)
Good or moderate versus uninterpretable	
Heart rate†	0.94 (0.86, 1.03)
Overlapping stents (yes or no)	0.16 (0.03, 0.87)
Strut thickness (≥140 μm or <140 μm)	0.38 (0.08, 1.77)

* Numbers in parentheses are the 95% confidence intervals.

† Odds ratio is expressed per beat per minute.

Stent analysis: diagnosis of significant in-stent restenosis

In seven patients, a total of 21 stents were placed in partially overlapping positions, thereby hampering individual evaluation of the presence of in-stent restenosis. Consequently, overlapping stents were considered as a single stent. As a result, 58 stents were available for the diagnosis of significant (≥50% reduction in luminal diameter) in-stent restenosis. Significant restenosis was correctly ruled out in all 52 stents that lacked significant in-stent restenosis, as determined with conventional coronary angiography in combination with quantitative coronary angiography (Figures 2, 3). The remaining six stents with significant in-stent restenosis were correctly identified at multi-section CT (Figure 4).

Table 3. Diagnostic accuracy for detection of significant in-stent or peri-stent restenosis

Statistic	≥50% In-stent restenosis	Peri-stent restenosis
Assessable stents*	65/76 (86)†	128/129 (99)‡
Sensitivity	6/6 (100)	5/5 (100)
Specificity	52/52 (100)	121/123 (98)§
Positive predictive value	6/6 (100)	5/7 (71)‖
Negative predictive value	52/52 (100)	121/121 (100)

Values are numbers of stents. Numbers in parentheses are percentages.

* Includes all available stents. For the calculation of diagnostic accuracy, partially overlapping positioned stents were considered as a single stent.

† The 95% confidence interval was 78% to 94%

‡ The 95% confidence interval was 97% to 100%,

§ The 95% confidence interval was 96% to 100%

‖ The 95% confidence interval was 37% to 100%.

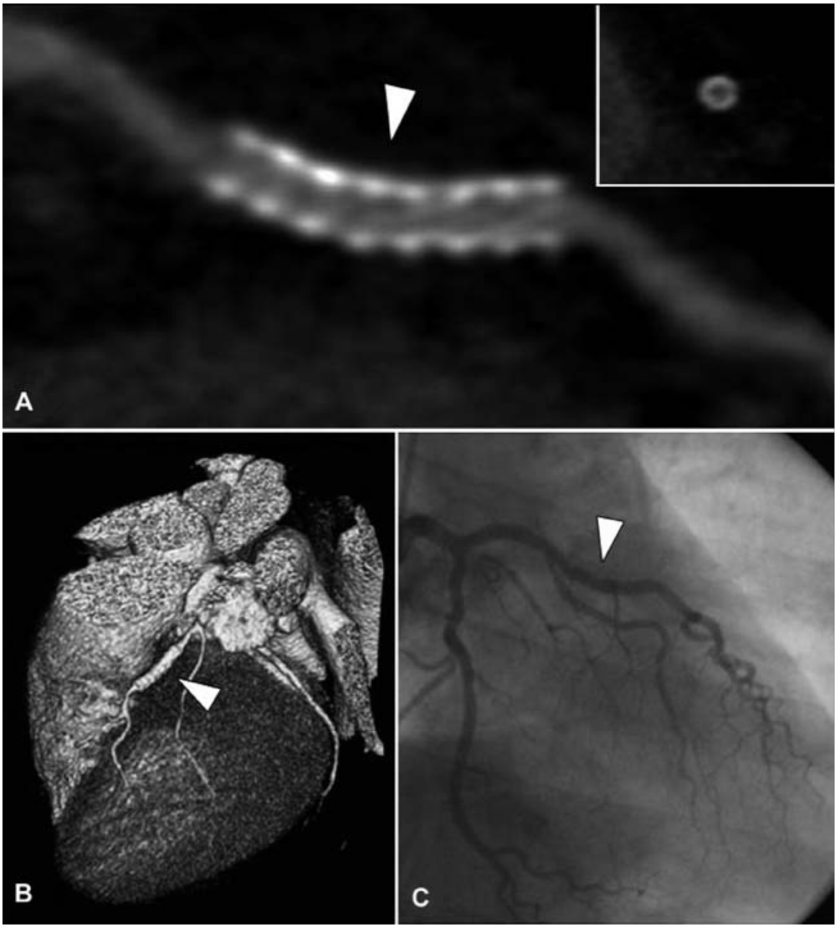

Figure 2. Patent thick-strut drug-eluting stent (diameter, 3.5 mm) placed in the left anterior descending coronary artery of a 53-year-old man. (A) Curved multiplanar and, (B) a three-dimensional volume-rendered reformation show the stent, with only limited neointimal hyperplasia (arrowhead, also on C). On the crosssectional image (inset on *A*), no significant in-stent restenosis was observed. (C) Corresponding conventional coronary angiogram.

Accordingly, the sensitivity and specificity for the assessment of significant in-stent restenosis were each 100% (Table 3). In the 52 stents without significant in-stent restenosis, the mean luminal narrowing as determined with quantitative coronary angiography was 23.4% ±8.6 (range, 4.3–42.4%). Nonsignificant restenosis could be observed at multi-section CT in 37 (71%) stents, whereas no neointimal hyperplasia could be observed at multi-section CT in 15 stents. In stents without neointimal hyperplasia visible at multi-section CT, the mean luminal narrowing as determined with quantitative coronary angiography was slightly but not substantially lower than that of stents with visible neointimal hyperplasia (20.6% ±11.7 versus 24.0% ±7.6).

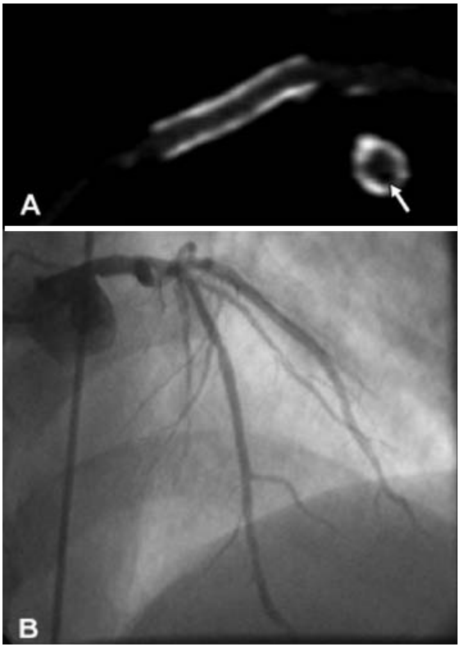

Figure 3. Patent thin-strut, non–drug-eluting stent (diameter, 3.5 mm) placed in the left anterior descending coronary artery of a 46-year-old man. (A) Curved multiplanar reformation shows the stent. At lower right-hand corner, cross-sectional image perpendicular to the stent helps confirm the presence of only minimal in-stent hyperplasia (appearing as a small rim of hypoattenuating tissue [arrow]). (B) Invasive coronary angiogram confirmed observations.

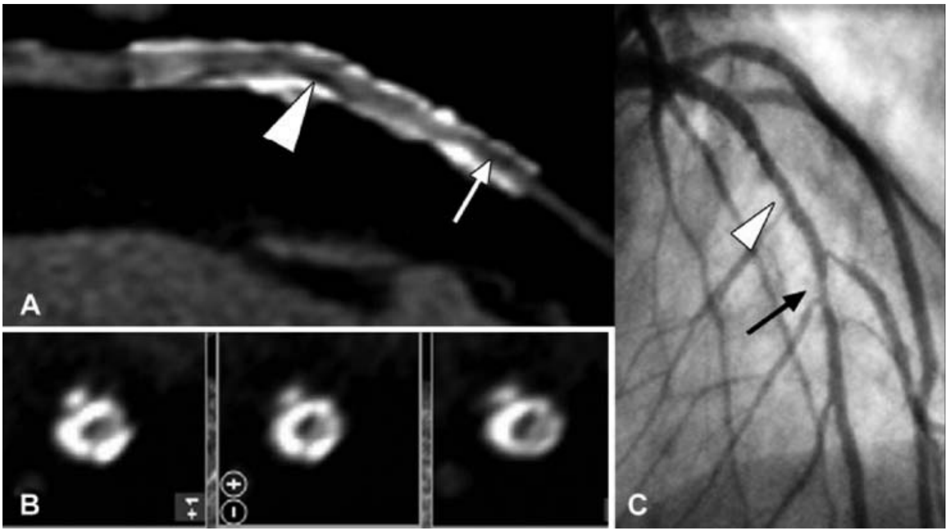

Figure 4: In-stent restenosis in two adjacent non– drug-eluting stents (diameters, 3.5 mm [proximal stent] and 3.0 mm [distal stent]) placed in the left anterior descending coronary artery of a 61-year-old man. (A) Curved multiplanar reformation shows in-stent restenosis (slightly exceeding 50% luminal diameter narrowing at the middle level (arrowhead, also on C) and more severe at the distal part of the stent (arrow, also on C)) in the two stents. (B) Three cross-sectional images obtained at the middle level show in-stent restenosis (appearing as hypoattenuating tissue). (C) Invasive coronary angiogram confirmed findings.

Peri-stent lumina

Of the 76 implanted stents, 21 were positioned in partially overlapping positions (Table 3). As a result, 55 single stents and 10 stents resulting from overlapping stents were available for evaluation. Also, one stent (located in the right coronary artery) originated directly from the aorta. Accordingly, 64 proximal stent lumina and 65 distal stent lumina were available for analysis. Images of all but one (1%) of the 129 peri-stent lumina were of sufficient quality to permit evaluation of the presence of significant narrowing. Conventional coronary angiography in combination with quantitative coronary angiography depicted the presence of significant stenosis in five peri-stent lumina. Stenoses in all five were correctly identified at multi-section CT. However, two lesions (one proximal and one distal) were overestimated with multi-section CT, resulting in a specificity of 98%.

Discussion

In our study, 76 coronary stents were evaluated by using 64-section CT, and 65 (86%) images of these stents were interpretable. Both elevated heart rate and overlapping positioning appeared to be associated with decreased interpretability, although no effect of stent type or location was observed. For the interpretable images of stents, sensitivity and specificity for detection of significant (≥50%) in-stent restenosis were each 100%, whereas the presence of nonobstructive in-stent restenosis was accurately identified in 71% of stents. In addition, the presence of peri-stent stenosis could be accurately detected, with a sensitivity and a specificity of 100% and 98%, respectively.

Our current observations compare favorably with those of previous studies of coronary stent imaging with 16-section CT. In an earlier study by Schuijf et al,[9] 21 patients with 65 previously implanted stents were evaluated. A moderate sensitivity of 78% and an excellent specificity of 100% for detection of in-stent restenosis were observed. However, only 50 (77%) stents were of sufficient image quality for evaluation. Exploration of the characteristics of images of 23% of the stents that were uninterpretable showed that predominantly images of stents with thicker struts (≥140 μm), as well as images of stents with smaller diameter (eg, ≤3.0 mm), tended to be affected by degraded image quality. The effect of thick struts was particularly pronounced; images of 41% of stents with thick struts were uninterpretable, as compared with images of 11% of stents with thinner struts. Diameter showed a less prominent effect; however, the percentage of images of stents that were uninterpretable was still substantially higher for those of stents with a diameter of 3.0 mm or less than it was for those of stents with a larger diameter (28% versus 11%). These observations were recently confirmed in a larger population (143 patients with a total of 232 stents).[6] In this study by Gilard et al, who also used 16-section CT, a substantial increase in interpretability — from 51% to 81%—was observed for images of stents with diameters of greater than 3.0 mm as compared with images of stents with diameters of 3.0 mm or less. In addition, sensitivity for detection of in-stent restenosis increased similarly from 54% to 86%. For all stents, regardless of diameter, the specificity was 100%. In the study by Gilard et al, the researchers did not explore the effect of strut thickness.

In our study, improved interpretability of images of stents was observed with 64-section CT, and image quality was sufficient on images in 86% of stents. Exploration of the characteristics of images of stents that were uninterpretable showed that, as in previous studies, in native coronary arteries, an elevated heart rate was an important cause of nondiagnostic image quality.[18] Images of 45% of stents could not be interpreted because of motion artifacts. Accordingly, these observations underline the need for adequate control of heart rate during multi-section CT coronary angiography.

Findings of further evaluation of the uninterpretable images of stents indicated that partially overlapping stents are also associated with deteriorated image quality. The increased metal content is likely to amplify high-attenuation artifacts, thereby increasing the artificial narrowing of the lumen of the stent. Although images of 93% of single stents were interpretable, images of 33% of partially overlapping stents were of nondiagnostic quality. Accordingly, in patients with partially overlapping stents, evaluation by means of a modality other than multi-section CT may be preferred. In contrast to previous studies, no pronounced effect of strut thickness was observed. The presence of thick struts tended to result in nondiagnostic image quality more often than did the presence of thin struts (21% versus 9%; $p=0.15$). Accordingly, the influence of strut thickness on image quality with 64-section CT should be evaluated in a larger cohort because our study may have been underpowered to demonstrate any effect.

On the interpretable images of stents, the presence or absence of significant (≥50%) in-stent restenosis was correctly identified in all stents. Also, the presence or absence of peri-stent restenosis could be detected with a diagnostic accuracy of 98%. In particular, the observed negative predictive value to exclude the presence of in-stent or peri-stent restenosis was extremely high. Accordingly, the technique may be well suited to help noninvasively rule out significant (≥50%) in-stent or persistent restenosis. Somewhat lower sensitivity and specificity were reported in a recent study in which 40-section CT was used.[19] In that study by Gaspar et al in which 65 patients with 111 implanted coronary stents were evaluated, the sensitivity and specificity for detection of 50% or greater in-stent restenosis were 89% and 81%, respectively.[19] In part, this discrepancy may be explained by the fact that Gaspar et al excluded only a small number (5%) of stents from the analysis, whereas we excluded a greater number. Still, a high negative predictive value (97%) was observed in the study by Gaspar et al, underlining the potential of multi-section CT as a noninvasive technique to rule out the presence of in-stent restenosis.

Another finding of our study was that, unlike the findings seen with 16-section CT,[9,14] the superior image quality of 64-section CT has improved visualization of nonsignificant in-stent hyperplasia in addition to significant in-stent restenosis. The presence of in-stent hyperplasia, albeit limited, was depicted with quantitative coronary angiography in all stents and was also correctly recognized in 71% of stents at multi-section CT. Our observations are agree with those of a recent study by Mahnken et al[20] in which 64-section CT was used in a phantom model. Comparison of 16-section CT with 64-section CT for imaging of eight 3.0-mm diameter stents positioned in a static chest phantom revealed superior visualization of stent lumina with 64-section CT because of significantly less artificial lumen reduction and image noise. Still, a considerable portion of stent lumina remained obscured even with 64-section CT; in our study, the presence of neointimal hyperplasia could not be observed at multi-section CT in 30% of stents. Accordingly, the value of multi-section CT to identify moderate in-stent hyperplasia appears to remain limited at present.

Our study does have some limitations. First, we evaluated a relatively small number of patients. As a result, the total number of stents and the number of patients with significant in-stent restenosis (12%) were relatively low as well. Nonetheless, a much higher prevalence of in-stent restenosis is not likely to be encountered in daily practice, and extrapolation of the current results to clinical practice may therefore be justifiable.[21,22] Second, the number of evaluated stents was low and the influence of stent and patient characteristics on interpretability of images of stents should be explored in larger patient cohorts to fully establish which characteristics should potentially be avoided in the evaluation of stents with multi-section CT. In particular, the range of stent diameters was limited in our study (mean, 3.4 mm ±0.3); as a result, we could not evaluate a potential effect of stent diameter. Thus, our study might best be regarded as a basis for further larger studies of image quality and diagnostic accuracy of 64-section CT in coronary stents. Third, despite the technologic advancements of 64-section CT, several limitations inherent to the technique remain. For example, as also observed in our study, a stable and low heart rate remains crucial for high-quality multi-section CT images, and administration of β-adrenergic blocking agents prior to the examination is therefore often required.[18] Another limitation of multi-section coronary angiography is the patients' exposure to a relatively high effective radiation dose (10–15 mSv). For this reason, dose-modulation protocols are currently in development.

In conclusion, in selected patients with previous stent implantation, the sensitivity and specificity of 64-section CT were 100% each for detection of significant (≥50%) in-stent restenosis and 100% and 98%, respectively, for detection of significant (≥50%) persistent stenosis. In particular, 64-section CT may be useful for noninvasive exclusion of in-stent or peri-stent restenosis and for avoidance of invasive imaging in a considerable number of patients.

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