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ORIGINAL ARTICLE

Evaluation of coronary stents using multidetector CT

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KEYWORDS

Multidetector CT;
Evaluation;
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Abstract *Background:* Recurrent ischemic symptoms after coronary stenting require imaging assessment to rule-out in-stent restenosis or occlusion.
Aim: To evaluate role of multi-detector computed tomography in assessment of coronary artery stents.
Patients and methods: Twenty-four patients were referred to assess coronary stents.
All were subjected to history taking, clinical examination and computed tomography angiography of coronary arteries using 320-row multi-detector computed tomography.
Results: There were totally sixty-three coronary artery stents. Only six stents were non-interpretable. Where forty-eight patent, while nine stents showed in-stent restenosis of significant degree ($\geqslant 50\%$), most stents 3.0 mm diameter.
Conclusion: Multi-detector computed tomography is considered convenient and reliably non-invasive imaging modality for assessment of suspected coronary stents with large diameter.

1. Introduction

Coronary artery stenting has become the most important non-surgical treatment for symptomatic coronary artery disease. However, in-stent restenosis occurs at a relatively high rate and this problem has led to the routine use of invasive angiography for assessing stent patency (1).

The clinical incidence of restenosis after coronary stent insertion is 20–35% for bare metal stents and 5–10% for drug-eluting stents, but it can be higher in certain subsets of lesions such as long stenosis, bifurcation lesions or lesions in small coronary arteries (2).

Abbreviations: MDCT, multi-detector computed tomography; CABG, coronary artery bypass graft; BMI, body mass index; LIMA, left internal mammary artery; RIMA, right internal mammary artery; OM, obtuse marginal; CTA, computed tomography angiography; LAD, left anterior descending; LCx, left circumflex; PDA, posterior descending artery; SVG, saphenous vein graft; RCA, right coronary artery; PCI, percuatneous coronary intervention.

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Although the use of recently introduced drug-eluting stents has resulted in further reductions in the occurrence of restenosis, in-stent thrombosis, however neointimal hyperplasia may still occur and cause partial or complete stent obstruction (3).

Whereas the clinical diagnosis of stent occlusion due to thrombosis is usually straightforward in patients with a recent stent implantation and with a subsequent onset of acute myocardial ischemia leading to acute myocardial infarction, the assessment of in-stent restenosis is more challenging (4).

Although coronary angiography is the clinical gold standard and it is a very effective diagnostic tool for detecting such in-stent restenosis, it's clearly an invasive procedure with its associated morbidity and mortality risks (5).

Therefore, a non-invasive, less expensive technique for detecting in-stent restenosis would be of great interest and used for following up (6).

Magnetic resonance imaging is a versatile cardiac imaging modality, and its ability to depict coronary artery stents is impaired by susceptibility artifacts induced by stent itself (7).

The latest generation of MDCT scanners, which offer a smaller voxel size, faster gantry rotation speed, higher spatial and temporal resolution as well as reconstruction of up to 320 sections per gantry rotation, provides an appealing alternative for non-invasive luminal assessment in patients with chest pain after coronary stent placement (8).

MDCT also can be useful to assess the condition of the whole coronary tree, as it provides information about the number, severity, and location of coronary lesions. MDCT enables reduction in further examinations such as stress echocardiography and scintigraphy needed because of a positive or inconclusive test result (9).

Beside demonstrating in-stent stenosis and thrombosis, MDCT can effectively evaluate other stent complications such as stent fractures, migrations, buckling, or collapse and other rare complications such as perforations and aneurysms (10).

The aim of our study was to evaluate the role of multidetector CT in the assessment of coronary artery stents in patients exhibiting recurrent chest pain or having positive results for myocardial ischemia on doing other non-invasive tests during their follow-up.

2. Patients and methods

A total number of 24 patients were enrolled in this study for multislice CT angiography of coronary arteries between January 2014 and October 2015. Those patients were referred to diagnostic radiology and medical imaging department at Tanta University Educational Hospital from cardiology department and private clinics (see Figs. 1–5).

Written informed consent was obtained from all patients participated in this study after full explanation of the benefits and risks of the procedure. They were informed about any unexpected risks that may appear during the course of this study. All patients' related information were kept confidential.

2.1. Inclusion criteria

- Patient having recurrent chest pain after previous coronary artery stenting.

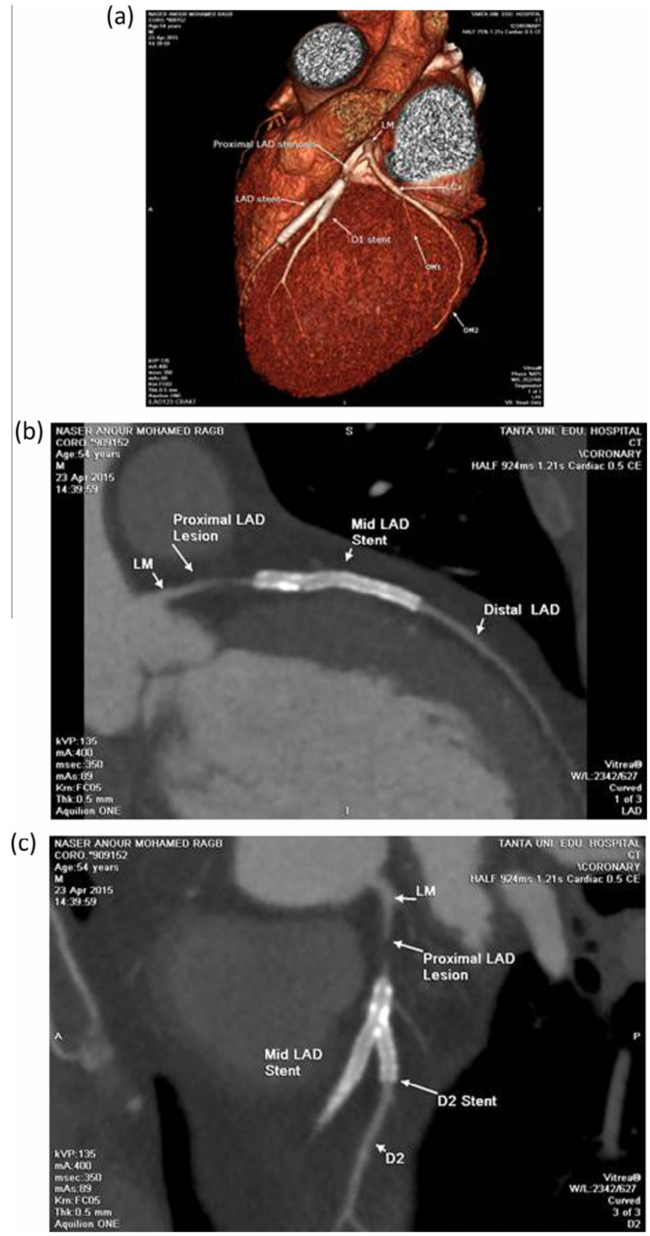

Fig. 1 54-years old male patient with recurrent typical chest pain 3 months after PCI to treat LAD bifurcation lesion. (a) Left anterior oblique view of 3D volume rendered image showing two kissing stents inserted at mid LAD and D2 with good contrast opacification of distal LAD and D2 beyond the stents. Severe proximal LAD stenosis is evident. The LCx and its obtuse marginal branches are patent without significant stenosis. (b) Curved planar reformatted image showing patent mid LAD stent with no in-stent restenosis. The distal LAD beyond the stent is patent. The proximal LAD shows severe stenosis by concentric soft plaque. (c) Curved planar reformatted image showing patent stent. Patent D2 segment.

- Asymptomatic patient underwent previous coronary stenting and shows positive results for myocardial ischemia during regular follow-up on doing non-invasive tests such as thallium scan, stress echocardiography or stress ECG.

2.2. Exclusion criteria

- Patient who is clinically unstable to withstand the duration of CT examination or cannot tolerate the required breath holding time for examination (10 s).
- Patient with history of allergy to IV contrast material or has impaired renal function.
- Patients with BMI > 40.

Every patient was subjected to the following:

- Proper history taking and clinical examination.
- Radiological examination Multi-slice CT angiography of coronary arteries.
- *Instructions:*
- Fasting 4–6 h before scan. Encourage water intake till one hour before scan.
- Avoid caffeine products and smoking and exercise one day before scan.
- Stop taking phosphodiesterase inhibitors used to treat erectile dysfunction or pulmonary hypertension.
- *Patient preparation:* Explanation of procedure with reassurance to relief anxiety.
- *Heart rate control:* optimum H.R. below 65 bpm (12patients), no medication given.
- Patients with higher H.R. were given oral B-blockers or 5.0 mg oral Ivabradine one hour before the scan.
- Eight patients with H.R. 65–75 bpm were given 50 mg oral Metoprolol *Four Patients with H.R. above 75 bpm were given 100 mg oral metoprolol.
- *At scanner room:* Patients were given gown to put on and then instructed to lie supine on scanner table with arms raised above their heads.
- ECG electrodes were applied to chest wall after skin preparation with alcohol and ECG trace was monitored
- Intra-venous canulla (16–22) in right anticubital vein was connected and test injection with saline was done
- 5.0 mg sublingual Isosorbid dinitrate was given.
- *Contrast media injection:*
- Non-ionic contrast media (Ultravist 370 mgI/ml; Bayer Healthcare, Berlin, Germany) was injected through the peripherally inserted IV cannula using dual-head powered automatic injector (Stellant D, Medrad, Indianola, PA, USA) followed by 50 cc saline flushing. The amount of contrast material and injection flow rate was adapted according to patient body habitus and scan time as follows:
- Contrast volume (in ml) = (scan time + 10) × injection flow rate.
- The injection flow rates were adapted according to kV used; 100 kV: 4.0 ml/s, 120 kV: 5.0 ml/s & 135 kV: 6.0 ml/s.
- *CT scan protocol:* All patients were scanned with 320-row multidetector CT scanner (Aquilion One, Toshiba Medical Systems, Otawara, Japan) installed at Tanta University Educational Hospital through these steps:
- Initial scanogram AP and lateral projection for automatic radiation dose calculation and for planning scan range from carina down to the apex of the heart.
- Automatic bolus tracking technique was used to detect the arrival of contrast material at descending aorta. The ROI was placed at descending aorta at mid heart level with trigger threshold set at 230 HU. Repetitive low-dose monitoring examinations (120 kV, 50 mAs, 0.5-s scanning time) were performed 10 s after contrast medium injection began. When trigger threshold was reached, scan started immediately after breath holding command.

2.3. Image acquisition

- *Acquisition parameters:* 0.35 s gantry rotation time, variable mA according to patient body habitus (range: 250–580 mA), variable kv according to patient body habitus (range: 80–135 kv).
- Prospective ECG gating was used with volume scanning method. Single heart beat acquisition was routinely performed in those with heart rate below 65 bpm and the scan window was set at 70–80% of R–R interval. In those with heart rate ranged from 65 to 70 bpm, the scanning window was set to 30–80% of R–R interval to include end systolic phase.
- Heart rate remained above 70 bpm at four (16.7%) patients due to suboptimal response to oral medications used and anxiety. In those patients, CT acquisition was done using multiple heart beats to improve temporal resolution with scanning window set manually to cover 30–80% of the R–R interval.

2.4. *Image-reconstruction

Images were reconstructed at 0.5 mm slice thickness and 0.5 mm interval with smooth and sharp reconstruction kernels (FC03 & FC05 respectively) at 75% of R–R interval and at the best diastolic phase. The scan field of view was set to as small as possible for better spatial resolution. Post processing: The reconstructed images were transferred to workstation (Vitrea Fx, Vital Images, USA) to form multiplanar reformatted images in axial, sagittal and coronal planes. Also maximum intensity projection, 3D volume rendered images and curved planar reformations were obtained.

2.5. Image-analysis

2.5.1. Assessment of image quality

A stent was considered assessable when the stent lumen was visible and contrast attenuation of the lumen could be evaluated qualitatively without the influence of partial volume effects, metal artifacts of stents, or cardiac motion artifacts. Each stent was assigned an image quality score of 1 (good image quality, no artifacts affecting evaluation of the stent), 2 (adequate image quality, mild to moderate artifacts, blurring but acceptable for clinical diagnosis), or 3 (poor image quality, uninterpretable with severe artifacts making stent evaluation impossible) according to the criteria used for assessability. Reduced image quality was evaluated in relation to stent location, diameter and strut thickness.

2.5.2. Assessment of stent lumen

Stent lumen was assessed at workstation using curved planar reformatted images while 3D volume rendered images were

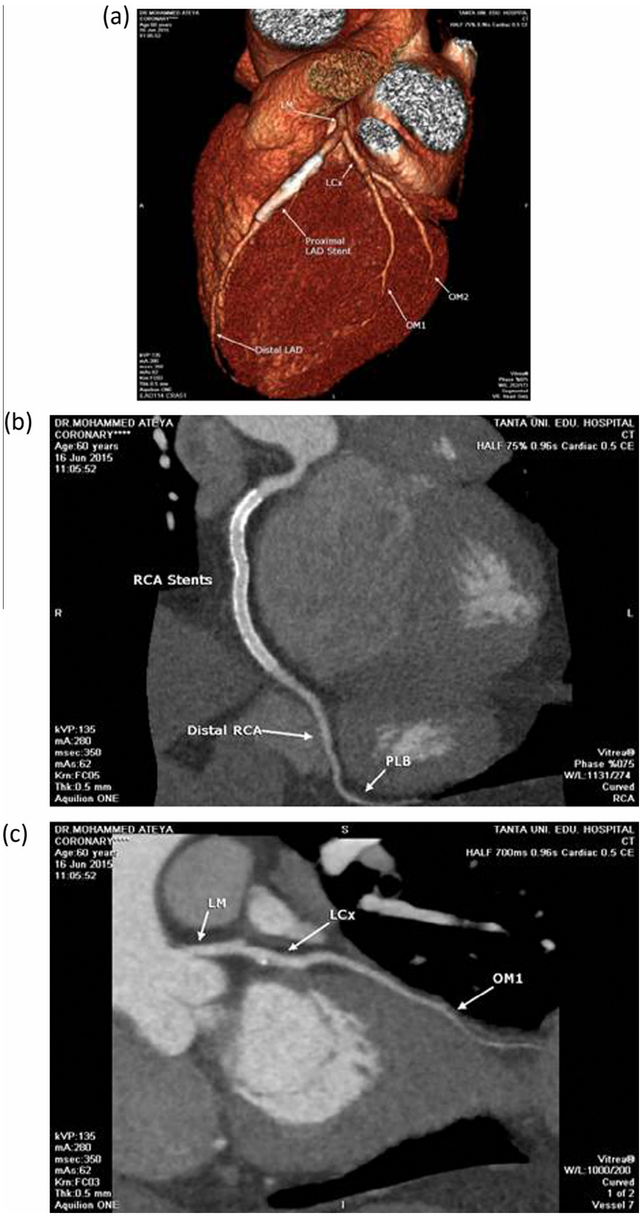

Fig. 2 60-year old male patient exhibits dyspnea and mild chest pain one year after PCI to treat RCA and LAD lesions. (a) Left anterior oblique view of 3D volume rendered image showing the stent inserted at proximal LAD with good opacification of mid and distal LAD beyond the stent. The visible segment of LM and proximal LAD as well as LCx and its obtuse marginal branches is well opacified. (b) Coronal curved planar reformatted image showing two patent stents inserted at mid and distal segments of RCA. The distal RCA and PLB are patent. (c) Coronal curved planar reformatted image showing patent LM, LCx and OM1 with proximal LCx mixed eccentric plaque exerting mild luminal stenosis.

used for global assessment of stent location and native coronary arteries.

Each stent was defined as follows:

- **Patent with no visible neointimal hyperplasia:* the absence of low-attenuation areas between stent wall and contrast enhanced lumen.
- **Patent with insignificant neointimal hyperplasia:* longitudinal low-attenuation areas along the stent wall observed as a rim of hypoattenuation between the stent and the contrast enhanced vessel lumen exerting $<50\%$ stenosis.
- **Patent with in-stent restenosis:* longitudinal and transverse low-attenuation areas along the stent wall exerting $\geqslant 50\%$ stenosis.
- **In-stent occlusion:* the complete absence of contrast material within stent lumen. *Evaluation of non-stented coronary arteries:* The non-stented coronary arteries were also evaluated to detect areas of significant stenosis ($\geqslant 50$) or occlusion that may contribute to recurrent patient's symptoms. The lumen assessment was done on looking through 3.0 mm axial MIP images and curved planar reformatted-images.

Conventional coronary angiography was done in 16 cases after MDCT on request of cardiologist and cardio-thoracic surgeon for confirmation and comparison.

Statistical analysis SPSS version 21 (IBM Inc.) was used which included the following:

- T test for comparison of means for numerical scaling variables e.g. body measurements.
- Cross tabulation with Fisher's exact test of significance for comparison of the nominal variables.
- F statistics for test of variance between and within our studied groups.

In all these tests, the statistical significance was considered at 5% level if ($P < 0.05$).

3. Results

Twenty-four patients were referred for coronary stents assessment, 18 (75%) patients were males while 6 (25%) patients were females. Their age ranged from 41 to 66 years with a mean of 56.13 ± 6.69 years.

Patient's weight and height and BMI measurements are displayed in Table 1. None of these body measurements between the studied groups showed any statistically significant differences ($P > 0.05$).

Different risk factors for coronary artery disease were present in studied patients including diabetes mellitus, hypertension, dyslipidemia and smoking. The distribution of risk factors among the studied groups was not statistically significant ($P > 0.05$) (Table 2).

Among the studied 24 patients, 12 (50%) patients required heart rate control prior to scan. Their baseline heart rate ranged from 70 to 96 bpm with a mean of 82.4 bpm. After giving heart rate control medications, their heart rate at time of scan ranged from 57 to 78 bpm with a mean of 63.71 bpm. Heart rate remained above 70 bpm at 4 (16.7%) patients due to suboptimal response to oral medications used and anxiety. In those patients, CT acquisition was done using multiple heart beats to improve temporal resolution with scanning window set manually to cover 30–80% of the R–R interval.

A total number of 63 coronary artery stents deployed within 24 patients were included in this study and were evaluated by MSCT. Both drug-eluting and bare metal stents were assessed with their outer diameter ranged from 2.5 mm to

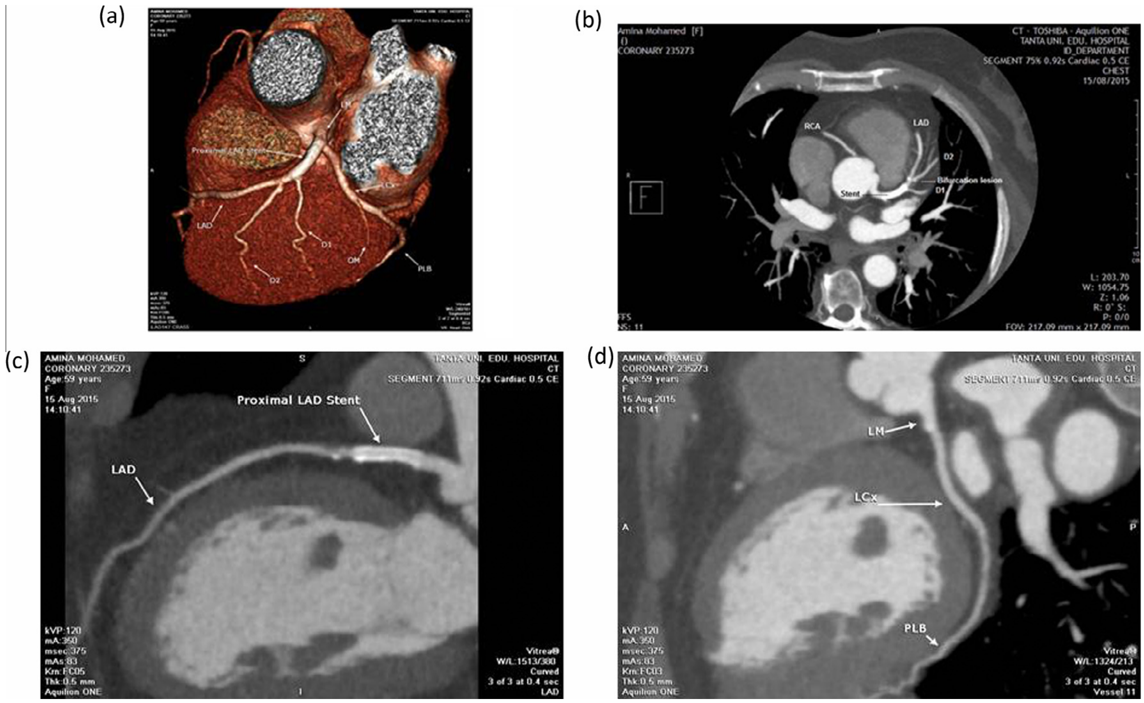

Fig. 3 59-year old female patient exhibits recurrent chest pain 7 months after PCI to treat severe proximal LAD lesion. (a) Left anterior oblique view of 3D volume rendered image showing the position of the proximal LAD stent that ends just beyond D1 takeoff which is still well opacified through the stent. Proximally, the stent encroaches upon LCx takeoff. LAD distal to the stent is patent and the visible segment of LCx as well. (b) Axial MIP image showing the position of proximal LAD stent. However, the lumen cannot be assessed from MIP image due to high density struts. A significant mid LAD bifurcation lesion is noted by two opposing mixed plaques exerting moderate luminal stenosis (50–70%) of mid LAD and D2 ostium. (c) Sagittal curved planar reformatted image showing patent proximal LAD stent. Mixed plaque is seen distal to stent exerting moderate luminal stenosis. The distal LAD is patent. (d) Coronal curved planar reformatted image showing patent dominant LCx and PLB. The dense proximal LAD stent is seen encroaching upon LCx takeoff.

Table 1 Body measurements.

	Weight (kg)	Height (m)	BMI
Stent group N = 24			
Mean	87.04	1.69	29.76
Std. deviation	9.37	0.04	3.01
Minimum	74	1.64	22
Maximum	110	1.76	38
Std. error	1.91	0.01	0.62

Table 2 Frequency of risk factors.

	DM		HTN		Dyslipidemia		Smoking	
	N	%	N	%	N	%	N	%
Stent group (N = 24)	6	25	6	25	9	37.5	12	50
P-value	0.469		0.133		0.075		0.366	

DM: diabetes mellitus, HTN: hypertension.

5.0 mm. The study included 9 (14.3%) stents with 2.5 mm diameter, 18 (28.6%) with 3.0 mm diameter, 18 (28.6%) with 3.5 mm diameter, 3 (4.8%) stents with 4.0 mm diameter, 9 (14.3%) stents with 4.5 mm diameter and 6 (9.5%) stents with 5.0 mm diameter.

The evaluated stents were deployed within different coronary arterial segments as shown in Table 3.

Among the 63 stents included in this study, only 6 (9.52%) stents were considered non-interpretable on evaluating MSCT images due to either small diameter or thick struts that interfere with luminal assessment. Four of those non-interpretable stents were of 2.5 mm diameter while the other two were of 3.0 mm diameter. The non-interpretable stents were distributed at mid LAD (2 stents), distal LAD (one stent) and proximal OM1 (3 stents). The remaining 57 (90.48%) stents were considered interpretable where 48 (76.19%) stents were reported as patent without neo-intimal hyperplasia while 9 (14.29%) stents showed significant in-stent restenosis ($\geqslant$50%).

According to stent diameter, the results of luminal assessment with MSCT can be classified as shown in Table 4.

According to their distribution at different coronary arterial segments, assessment of stent lumen with MSCT revealed the following: 9 (14.29%) patent stents at proximal RCA, 6 (9.52%) patent stents at mid RCA, 6 (9.52%) patent stents at distal RCA, 6 (9.52%) patent stents at proximal LAD, 9 (14.29%) patent stents at mid LAD, 3 (4.76%) patent stents and mid LCx, 6 (9.52%) patent stents at proximal D2 and 3 (4.76%) patent stents at proximal OM2. These patent stents showed no evidence of neo-intimal hyperplasia by MSCT.

Significant in-stent restenosis ($\geqslant$50%) was found at 3 (4.76%) stents at proximal LAD, 3 (4.76%) stents at mid

Fig. 4 56-year old male patient exhibits chest pain after multiple PCI settings with insertion of multiple drug eluting stents to treat multi-vessel disease. (a) Semitransparent 3D volume rendered image showing the position of proximal LAD stent with still opacified three diagonal branches through it. The mid and distal LAD segments are patent. Also noted the position of OM1 ostial stent, mid LCx stent and OM2 ostial stent. Both OM1 and OM2 are patent beyond the stents. (b) Curved planar reformatted image showing the entire course of RCA and PDA. Proximal and distal RCA stents are patent The remaining RCA segments and PDA are free of significant disease. (c) Curved planar reformatted image showing patent proximal LAD stent. The distal LAD segment as well as the left main coronary artery is patent. (d) Curved planar reformatted image showing inadequate luminal expansion of OM1 ostial stent with subsequent significant blooming artifact interfering with luminal assessment. OM1 distally is patent and free of disease. (e) Curved planar reformatted image showing patent LCx stent and OM2 ostial stent. OM2 distal to stent is patent.

LAD and 3 (4.76%) stents at proximal LCx. None of the evaluated stents in this study showed neither insignificant (< 50%) in-stent restenosis nor total occlusion. Six (9.52%) non-interpretable stents were found at 2 (3.17%) stents at mid LAD, one (1.6%) stent at distal LAD and 3 (4.76%) stents at proximal OM1.

Conventional coronary angiography was done in 16 cases after MDCT on request of cardiologist and cardio-thoracic surgeon for confirmation and comparison. In 16 patients (41 stents) with diameter more than 3 mm 31 stents were diagnosed correctly out of 32 diagnosed patents by MDCT and 8 stents out of 9 stenosed stents more than 50% diagnosed accurately by MDCT.

4. Discussion

Conventional coronary angiography has been considered the gold standard for evaluation of coronary artery stents and coronary artery bypass grafts. However, the main drawbacks of this method include invasiveness, patient discomfort, high radiation dose and risk of complications. A less invasive imaging modality is desirable for evaluation of patients suspected to have in-stent restenosis or occlusion and those who are suspected to have coronary artery bypass graft stenosis or occlusion (11).

It is not advisable to scan patients whose BMI is above 40 kg (12). In this study, the mean BMI for scanned patients

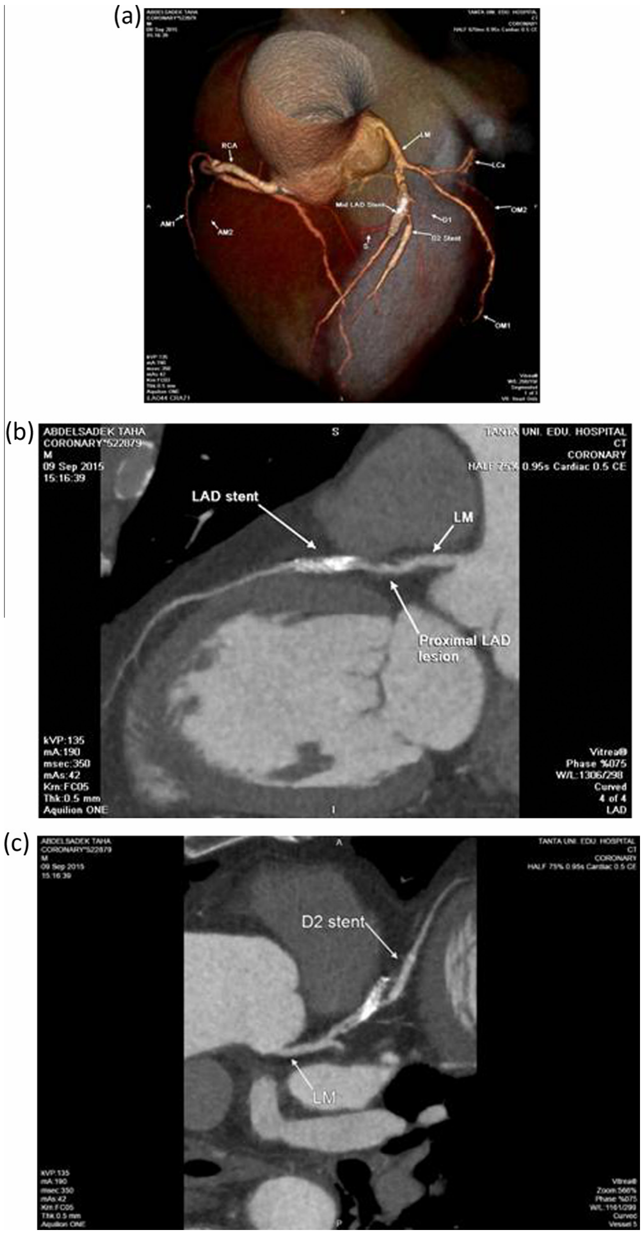

Fig. 5 59 year old male patient exhibits chest pain after PCI settings to treat mid LAD and D2 significant lesions. (a) Semitransparent 3D volume rendered image showing the position of mid LAD and proximal D2 stents. The distal LAD and D2 segments beyond the stents are patent. Incidentally noted dilated ascending aorta. (b) Curved planar reformatted image showing concentric soft plaque at proximal LAD segment exerting stenosis (60%). The mid-segment LAD stent has thick struts exerting significant blooming artifact interfering with luminal assessment. However, LAD segment distal to stent is patent a. (c) Curved planar reformatted image showing the proximal D2 stent that appears to be patent. D2 segment beyond the stent is patent. The mid-segment LAD stent shows significant blooming artifact interfering with luminal assessment.

was 29.76 kg with a range of 22–38. None of the performed scans was non-interpretable secondary to image noise as the BMI of the selected patients was still reasonable to perform coronary CTA.

Table 3 Distribution of stents within arterial segments.

Arterial segment	N	%
Proximal RCA	9	14.29
Mid RCA	6	9.52
Distal RCA	6	9.52
Proximal LAD	9	14.29
Mid LAD	14	22.22
Distal LAD	1	1.59
Proximal LCx	3	4.76
Mid LCx	3	4.76
Proximal D2	6	9.52
Proximal OM1	3	4.76
Proximal OM2	3	4.76
Total	63	100

Heart rate control is still essential even with the use of 320-row multislice CT scanner, not only to obtain good quality images, but also to lower radiation dose to the patients. The slower heart rate (⩽65 bpm) improves the temporal resolution and results in almost motion free images. It also permits the use of prospective ECG-gating (13).

In a pilot study done by Dewey et al. (14) on 30 patients who underwent both coronary angiography and coronary CTA, they found that radiation exposure reduction was greatest in patients with heart rates ⩽65 bpm, whereas the effective dose was significantly higher in those with higher heart rates because of the necessity of acquiring data over multiple cardiac cycles to increase temporal resolution, highlighting the importance of β-blockade.

In this study, heart rate control was achieved using oral medications: either Metoprolol or Ivabradine. With optimum heart rate control (⩽65 bpm), we were able to scan the patients with prospective gating method exposing only 70–80% of R–R interval using single beat acquisition at those with coronary stents. Only four cases (16.7%) failed to respond well to oral medications and their heart rate remained above 70 bpm at time of scan. So, we had to widen the scanning window to cover 30–80% of R–R interval and to use two beats volume scanning for those with coronary stents. Even though, the obtained image quality was not satisfactory and some of the native coronary arteries were non-interpretable.

The fast heart rate can also lead to failure of coronary stent lumen assessment and makes interpretation of bypass graft segments close to the heart difficult secondary to cardiac motion artifact (14).

Stent lumen visibility varies largely depending on stent type and diameter. The blooming effect is more disturbing in smaller coronary stents with thicker struts and is less disturbing in larger stents. Non-interpretable images tend to be obtained in stents that have thicker struts and/or a smaller diameter. When the stent diameter is more than 3 mm, lumen visibility is better. Regarding the type of stent, gold or gold-coated stents, along with tantalum made stents cause the most severe artifacts, while stainless steel and cobalt stents are better visualized (15).

Carbone et al. (16) evaluated the ability of 64- detector row CT to assess the coronary artery stent patency on fifty-five consecutive patients (age range 45–80 years) with 97 previously implanted coronary artery stents and the sensitivity, specificity, positive predictive value and negative predictive value were 75%, 86%, 71% and 89%, respectively. However, nine of

Table 4 MSCT findings according to stent diameter.

Stent diameter	2.5 (mm)	3.0 (mm)	3.5 (mm)	4.0 (mm)	4.5 (mm)	5.0 (mm)	Total
Patent	5	13	12	3	9	6	48
Stenosis (⩾50%)	0	3	6	0	0	0	9
Non-interpretable	4	2	0	0	0	0	6
Total	9	18	18	3	9	6	63
Total	14.3%	28.6%	28.6%	4.8%	14.3%	9.5%	100%

the 12 stented segments of 2.5 mm diameter and 10 of the 23 stented segments of 2.75 mm diameter were excluded from the analysis since these segments were considered as non-interpretable to blooming artifact.

In another study done by Oncel et al. (15) on thirty patients with 39 coronary stents using 64-slice CT scanner, nine of the 39 stents were shown to be totally occluded at conventional angiography. All of the occluded stents were correctly diagnosed with CT angiography. Nineteen of 20 patent stents were correctly demonstrated with CT angiography. Ten stents had in-stent restenosis; eight were correctly diagnosed with CT. The sensitivity, specificity, positive predictive value and negative predictive value were 89%, 95%, 94% and 90%, respectively. However, the stents with a diameter ⩽2.5 mm were excluded from their analyses and the average stent diameter was 3.1 ± 0.4 mm. This goes our results. (The sensitivity 89 and specificity 94.)

In another study by Rist et al. (17) twenty-five patients with 46 stents underwent 64-slice CT of the coronary arteries and coronary angiography after coronary artery stent placement. Significant in-stent restenosis or occlusion was detected on coronary angiography in 8 stents (⩾50% stenosis = 6 & occlusion = 2). Both of the two occluded coronary stents were correctly identified, while two of the six stents with non-occlusive stenoses were misdiagnosed as patent. The diameters of these two misdiagnosed stents were 2.5 and 3.0 mm, respectively. These findings indicated that non-occlusive in-stent restenoses were undetected in some cases, and especially for stents with a smaller diameter, even with using 64-detector row CT.

A recently done study by de Graaf et al. (8) using 320-row MDCT scanner on 53 patients with a total of 89 stents was available for evaluation. They concluded that stents with diameter <3 mm as well as stents with strut thickness ⩾140 mμm were associated with decreased CTA image quality and diagnostic accuracy.

Among the 63 stents that have been evaluated in this study, only 6 stents (9.52%) were considered non-interpretable. Four of them are 2.5 mm in diameter while the remaining two are of 3.0 mm diameter. The difficulty in interpretation of 2.5 mm stents in this study was due to small stent caliber that makes accurate lumen visualization difficult. Their struts were thin and did not exert significant blooming artifact. One stent of the same diameter was not interpretable secondary to inadequate stent expansion which is probably a technical error during stent deployment. On the other hand, the two stents with 3.0 mm diameter were not interpretable secondary to thick struts that exert much blooming and beam hardening artifacts making lumen visualization difficult even with bone window settings, sharp reconstruction kernel and high kV and mA setting.

The remaining 57 stents in this study were interpretable by MSCT and their lumen was clear enough to rule-out or diagnose in-stent restenosis. Some of those stents had thick struts that exert blooming artifact. However, the blooming artifact could be minimized by using sharp reconstruction kernel, bone window setting and small field of view and the lumen was clearly visualized.

A biodegradable stent with dense radio-opaque markers was evaluated by MSCT in this study, the blooming artifact exerted by those markers was not interfering with stent luminal assessment and in-stent restenosis was ruled out easily.

Based on stent location, stents located at proximal segments of RCA, LAD and LCx were better visualized than those deployed within the distal segments of the same arteries and also than those deployed within obtuse marginal and diagonal branches owing to large caliber of the former and small caliber of the later stents.

Cardiac motion artifact was not a contributing factor in difficult stent lumen evaluation in this study as the mean heart rate of stent group was 63 bpm which is considered slow enough to create motion free images and in the same studies that contain non-interpretable stent, the native coronary arteries were completely assessable. However, most authors (18) stated that heart rate should be kept below 60 bpm for better quality images when evaluating cases with coronary artery stents.

In this study, MSCT was capable not only of stent lumen evaluation to rule-out in-stent restenosis, but also was helpful in diagnosing significant disease at non-stented coronary arteries and detection of plaque composition either soft, calcified or mixed plaque. MSCT was capable of detecting serious incidental extracardiac findings such as ascending aortic aneurysm that could be missed during conventional coronary angiography. Another interesting finding was the detection of the site of myocardial infarction

A major drawback of retrospectively ECG-gated MDCT data acquisition is the radiation dose. Since the data are acquired with an overlapping helical pitch and continuous X-ray exposure, the applied radiation dose is higher than that in the prospectively ECG-triggered sequential acquisition. When compared with the mean effective dose values calculated for conventional coronary angiography, the mean effective dose with multi-detector row CT angiography was higher by a factor of about five. However, by reducing the tube current during cardiac cycle phases that are not likely to be used for image interpretation, a dose reduction of up to 48% is possible according to Jakobs et al. (18). To reduce radiation dose in this study, we used prospective helical acquisition only exposing 70–80% of R–R interval in those with heart rate below

65 bpm, and 30–80% of R–R interval in those with heart rate above 65 bpm.

Compared with conventional angiography, CT angiography is less costly, faster to perform, does not require assembly of an angiographic team to perform the study, generally available 24 h a day and can be considered as an outpatient procedure. It permits a wider variety of manipulations of the volumetric data set for image display and analysis in contrast to the limited projections routinely obtained during conventional angiography, and has fewer potential complications. Moreover, CT images can be reconstructed to yield 3D volume rendered images that give much anatomical and pathological details in contrast to conventional angiography that only visualizes lumen (19).

In our study using 320-row CT scanner, the mean scan time was about 5 s while it was 30 s with 16 section scanner and 20 s in 64 section scanner thus improving image quality by acquiring data from fewer heart beats and the study becomes tolerable by most patients due to short breath hold time. The shorter scan time also allowed much reduction in the volume of contrast material.

5. Conclusion

*Multi-detector CT is considered convenient and reliable non-invasive imaging modality for assessment of suspected coronary stents with large diameter

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