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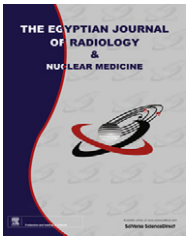

ORIGINAL ARTICLE

Diagnostic value of MDCT angiography in assessment of coronary artery bypass graft

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KEYWORDS

MDCT angiography;
Coronary artery bypass graft;
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Abstract *Purpose:* To evaluate the diagnostic value of MDCT angiography in assessment of coronary bypass grafts. We studied 51 patients from April 2008 to October 2011. All patients gave written informed consent, and the study protocol was approved by the Institutional Review Board. 96 grafts including 35 left internal mammary artery (LIMA) grafts, 5 radial artery grafts, and 56 saphenous vein grafts (SVG) were assessed by 64-MDCT and the results were compared with conventional coronary angiography as reference standard.

Results: The diagnostic value of multi-detector computed tomography for graft occlusion was: 100% sensitivity, 100% specificity, 100% positive predictive value, and 100% negative predictive value. The diagnostic power of multi-detector computed tomography for stenosis of the graft anastomosis was: 100% sensitivity, 96% specificity, 87.5% positive predictive value, and 100% negative predictive value, and 96.4% accuracy.

Conclusion: Multi-detector computed tomography has become an alternative to coronary angiography to diagnose graft occlusion and stenosis after coronary artery bypass. In addition, multidetector CT has the added advantage over traditional angiographic evaluation of simultaneously allowing evaluation for alternate postoperative complications that may also manifest with chest pain and dyspnea, thereby mimicking recurrent angina.

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1. Introduction

Postoperative assessment of bypass conduits and anastomoses after coronary artery bypass grafting (CABG) is important to evaluate the surgical technique (1,2). Coronary angiography (CAG) is the current gold standard for the evaluation of bypass graft patency and stenosis. However, CAG is invasive and associated with certain risks and complications, such as arrhythmia, graft dissection, myocardial infarction, and

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embolic events (3). These complications account for mortality rates of 0.14–0.28% and morbidity rates of 0.2–2.1% (4). Numerous studies that compared the accuracy of multidetector (64-row) computed tomography (64-MDCT) in assessment of coronary graft patency and stenosis with that of CAG have shown that 64-MDCT is a reliable diagnostic tool and less invasive than CAG (3,4). CAG is carried out in the first 2 days after CABG because it is easy to reopen the mediastinum without severe adhesions and repair graft problems such as occlusion, stenosis, and kinking (5,6).

2. Patients and methods

We studied 51 patients (35 males and 16 females, their age ranged between 50 and 70 years with the mean age of 62 years) from December 2008 to October 2010 (Table 1). All patients gave written informed consent, and the study protocol was approved by the Institutional Review Board. The interval between the bypass surgery and CT angiography ranges from 6 to 17 years, the mean interval is 9 years. The interval between CT angiography and invasive angiography is 8–15 days. There were 40 arterial grafts (35 left internal mammary artery (LIMA) grafts, 5 radial artery grafts), and 56 saphenous vein grafts (SVG) assessed by 64-MDCT and CAG. Of the 40 arterial grafts, 29 were single grafts and 11 had more than one coronary anastomosis. Of the 56 venous grafts, 36 were anastomosed to a single coronary branch and 20 were jump grafts with at least two consecutive coronary anastomosis. Patients with severe heart failure, unstable hemodynamics, significant renal dysfunction (serum creatinine >2.5 mg/L), or tachycardia (>80 beats/min) were excluded from the study. (See Tables 2 and 3)

3. MDCT

Multi-detector computed tomographic images were obtained using a 64-slice CT scanner (Light Speed VCT, General Electric Medical Systems, and Milwaukee, WI, USA) with retrospective electrocardiography gating. The scanning parameters were: 0.625-mm slice collimation pitch 11.2, 135 kV and 380 mA. We continuously injected 80–100 mL (according to the scanning area) of nonionic contrast material (iopamidol; 370 mg iodine/mL) at a rate of 5 mL/s^{-1}, followed by 50 mL saline solution. The CT scan started manually using the smart prep technique when ascending aortic enhancement is similar to the main pulmonary artery enhancement. The reconstructed multiphase images were transferred to a work station (Advantage Workstation 4.4; GE Healthcare) and the best cardiac phase was selected. All patients received 20–60 mg oral metoprolol tartrate according to body weight and blood pressure 1 h before the scan if the heart rate was >80 beats/min. We did not give nitroglycerine to the patients before the examination.

3.1. CT image analysis

CT images were reviewed by an experienced cardiothoracic radiologist who was informed about the previous surgical procedures, but blinded with respect to the invasive angiographic results. Image quality was graded on a 3-point scale as follows: grade 1, good (no artifacts); grade 2, acceptable image quality (minor limitations, such as mild artifacts); or grade 3, image quality insufficient because of artifacts.

All diseased graft and coronary segments were classified as occluded and significantly obstructed (50–99% luminal narrowing). Graft occlusion was defined as the absence of contrast material along the course of the graft, through the graft anastomosis to the native distal artery. Significant stenosis of the graft anastomosis in a patent graft was defined as $\geqslant 50\%$ reduction of luminal diameter.

The following vessels were assessed

1. Coronary grafts, all graft sections between the proximal anastomoses and each coronary insertion (graft segment) were separately assessed.
2. Post anastomotic native coronary arteries of patent graft.
3. Native coronary arteries of occluded or significantly stenosed grafts (including proximal and distal segments to the insertion of the graft).
4. Non grafted coronary arteries. Coronary artery diseases proximal to the insertion of patent grafts were not included in the analysis.

3.2. Conventional coronary angiography

Invasive CAG (ICA) was performed via a right femoral approach using a 4F catheter. Images were acquired at 12.5 frames per second. Selective imaging of bypass grafts was performed in 30° right anterior oblique and 60° left anterior oblique views. An experienced cardiologist, who was unaware of the CT results, analyzsed the angiographic findings. Using quantitative coronary angiography (QCA) evaluation (CAAS, Pie Medical Systems, Maastricht, The Netherlands), maximum diameter stenosis was determined out of at least two (orthogonal) projections. Graft occlusion was defined as the absence of contrast material along the course of the graft, through the graft anastomosis to the native distal artery. Native coronary artery was defined as the absence of contrast material along the course of the artery. Significant stenosis of the graft,

Table 1 MDCT evaluation of the coronary graft patency.

Type of graft	No of graft	Patency	Occlusion	Significant stenoses	Location of stenoses		
					Proximal	Mid	Distal
LIMA	35	27	2	6	2	2	2
Radial artery	5	3	1	1	0	1	0
Venous graft	56	29	10	17	5	6	6
Total	96	59	13	24	7	9	8

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graft anastomosis, or native coronary artery was determined if there was $\geqslant 50\%$ reduction in the mean diameter.

3.2.1. Statistical analysis

All data were expressed as mean ± standard deviation.

The results of MSCT and ICA were compared regarding the proximal anastomoses, central bypass, and distal anastomoses, post anastomotic native coronary arteries of patent graft, native coronary arteries of occluded or significantly stenosed grafts (including proximal and distal segments to the insertion of the graft), and non grafted coronary arteries' sensitivity, specificity, and positive as well as negative predictive values (NPVs) were calculated for patency rates and for the detection of significant stenosis and occlusion. The diagnostic accuracy of MSCT was compared with ICA as the standard of reference.

The percentage and 95% confidence interval were calculated for each value.

4. Results

Coronary angiography and 64-MDCT were performed without complications in any patient.

4.1. CT image quality

All 51 patients completed the CT examinations successfully, and all scans were interpretable. Image quality was graded good in 48 (94%) and acceptable in three (6%) of 51 examinations.

There were 96 grafts including 35 left internal mammary artery (LIMA) grafts, 5 radial artery grafts, and 56 saphenous vein grafts (SVG) assessed by 64-MDCT and the results compared with conventional coronary angiography as reference standard (Table 1).

MDCT correctly diagnosed 13 grafts to be occluded matching with the ICA results (Figs. 1 and 2,Table 2). 21 significant stenoses (5 LIMA, 1 radial artery and 15 venous grafts) (Figs. 2–5) of grafts were diagnosed by MDCT matching with the ICA findings. Of the 21 graft significant stenoses 7 showed the distal anastomosis of the graft with the coronary arteries (2 at the distal LIMA, 1 at the distal radial and 4 at the distal venous graft anastomosis). 3 cases of insignificant graft stenosis seen during ICA were falsely diagnosed by MDCT as significant stenosis (one at the LIMA (Fig. 6), and two at the distal venous grafts anastomosis) caused by artifact from surgical clips (Table 3).

In the current study there were mild angulations at 2 proximal arterial and 5 proximal venous anastomosis to the ascending aorta, all were correctly diagnosed as patent segments by MDCT (compared to invasive coronary angiography) after using curved planner, volume rendering and reformatted techniques.

MDCT coronary angiography correctly diagnosed the two occluded post anastomotic native coronary artery grafts seen by ICA. As regards the evaluation of post anastomotic native coronary artery significant stenosis (Fig. 7), MDCT falsely diagnosed two segments as significant stenosis caused by dense calcification (Table 4).

MDCT coronary angiography correctly diagnosed the 4 occluded native coronary artery segments seen by ICA. As regards the evaluation of native coronary artery significant stenosis, MDCT falsely diagnosed 2 segments as significant stenosis caused by dense calcification (Table 5).

As regards the non grafted coronary arteries, MDCT could correctly diagnose one patient with complete LAD occlusion by thrombus reported as non visualized LAD by ICA (Fig. 8). Also MDCT could diagnose one patient with plaque of the left main coronary artery which was missed by ICA (Fig. 9). MDCT falsely diagnosed 1 segment of significant stenosis at distal LAD (Table 6).

5. Discussion

Coronary artery bypass graft (CABG) surgery remains the standard of care in the treatment of advanced coronary artery disease. It is well recognized that the long-term clinical outcome after myocardial revascularization is dependent on the patency of the bypass grafts. Conventionally, invasive coronary angiography has been used to assess graft status and evaluate graft occlusion (2).

The body of the literature illustrating the value of computed tomography (CT) in the assessment of bypass grafts continues to grow with advances in CT technology (7,8). Multidetector CT scanners combine a high spatial resolution with the ability to demonstrate anatomy through volume-rendered images, thus producing a more sensitive evaluation over conventional or spiral CT (8). The addition of electrocardiographic gating minimizes cardiac and coronary graft motion, further improving the sensitivity and specificity of multidetec-

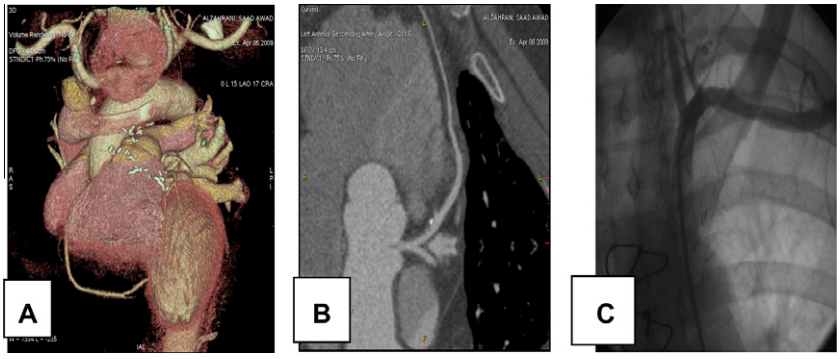

Fig. 1 (A) VR, (B) curved planar coronary angiography, (C) invasive angiography. Occluded LIMA. A Small calific plaque at proximal LAD.

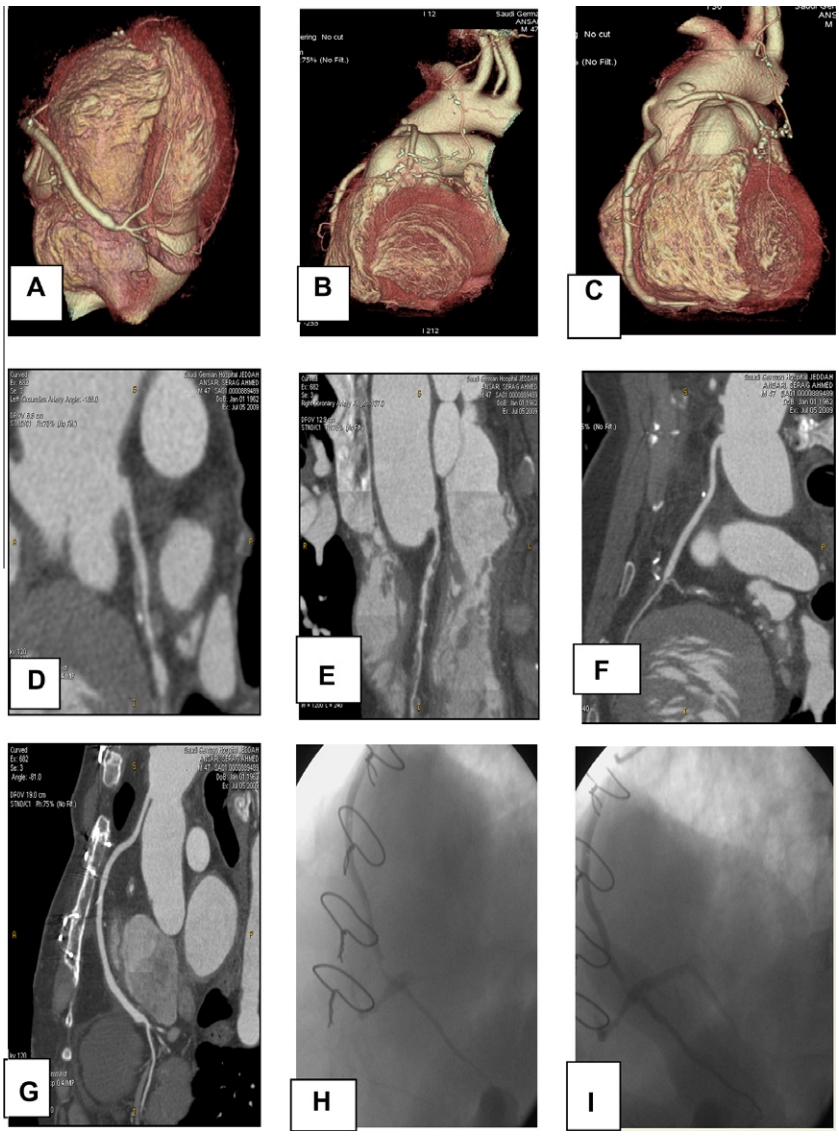

Fig. 2 (A, B), (C) VR, (D–G) curved planar, (H, I) invasive angiography) old man with recurrent angina pectoris on exertion. Significant distal anastomotic stenosis of arterial bypass graft to the distal RCA. Normal LIMA and venous graft to OM. Atherosclerotic changes of PDA. Occluded venous graft at its osteum.

tor CT evaluation of graft patency (9). These advances have also increased the ability to estimate the extent of intraluminal graft occlusion with noninvasive imaging techniques. With increased success in imaging grafts for patency, multidetector CT is being used more widely in the postoperative setting(9). Chest pain is common after CABG surgery and can have a variety of etiologies, including recurrent angina secondary to graft occlusion, sternal infection, pleural or pericardial effusion, and less common but potentially lethal complications such as pulmonary embolism or pseudo aneurysm formation. In this setting, multidetector CT can offer a rapid, convenient, and noninvasive means of discerning the correct underlying diagnosis. In addition, there are several recent reports on the merits of volume-rendered multidetector CT images in preoperative planning for repeat CABG surgery (10,11).

The best quality images are always obtained in patients with a low heart rate, but a recent report indicated that heart rate is not a crucial determinant of the quality of diagnostic accuracy by multisector reconstruction (12). In patients with rapid heart rates, multisector reconstruction was superior to half reconstruction in obtaining images with fewer motion artifacts. However, multisector reconstruction is not always appropriate because temporal resolution with this technique varies with the patient's heart rate. Therefore, we gave beta blocker if the heart rate exceeded 80 beats/min (13).

In the current study we have 13 graft occlusions equally detected by coronary angiography and MDCT coronary angiography. The diagnostic accuracy of MDCT was very high (Table 4), in agreement with previous reports (14).

Coronary angiography demonstrated significant stenosis of 21 grafts (5 LIMA, 1 radial artery and 15 venous grafts), all were correctly diagnosed by MDCT. Of the 21 graft significant stenoses 7 were seen in the distal anastomosis of the graft with the coronary arteries (2 at the distal LIMA, 1 at the distal

Table 2 Diagnostic accuracy of MDCT in evaluating graft occlusion.

	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
LIMA	100	100	100	100	100
Radial artery	100	100	100	100	100
Venous graft	100	100	100	100	100
Total	100	100	100	100	100

radial and 4 at the distal venous graft anastomosis). 3 cases of insignificant stenosis were falsely diagnosed by MDCT as significant stenosis (one at the LIMA, and two at the distal venous grafts anastomosis) caused by artifact from surgical clips. These results are in agreement with previous reports (15).

The rate of early graft occlusion was significantly higher in venous than in arterial grafts in the current study. Preoperative venous graft failure after off-pump CABG procedures is chiefly determined by the two factors of graft endothelial damage and patient hypercoagulability (including resistance to antiplatelet therapies) (15). High-pressure distention of venous grafts and their inherently weaker antithrombotic properties contributes to increased rates of early venous graft attrition. Specifically, too short of a graft may result in stretching of the vessel and damage to the endothelium, thereby initiating the cascade of thrombus formation (15).

In the current study the overall diagnostic accuracy of MDCT in evaluation of native post anastomotic coronary artery occlusion and stenosis was 100% sensitivity, 100% specificity, 100% PPV, 100% NPV, 100% accuracy for occlusion, and 100% sensitivity, 95.9% specificity, 83.3% PPV, 100%, NPV, and 96.6% accuracy for stenosis. These results are in agreement with previous reports (16,17).

Because there were no false negative results, we consider 64-MDCT to be the first choice for post-CABG graft assessment,

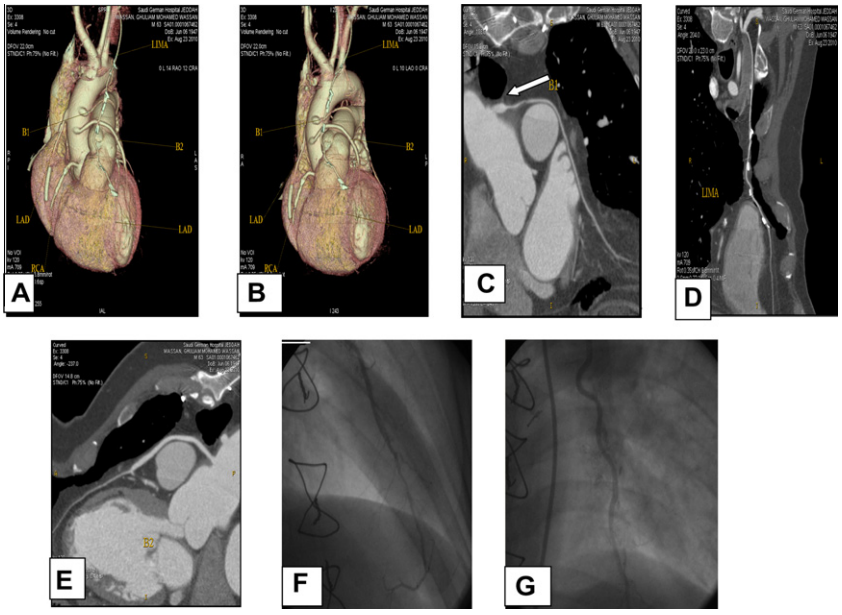

Fig. 3 (A, B) VR, (C–E) curved plannar, (F, G) invasive angiography. Significant luminal narrowing of proximal aspect of bypass arterial graft to LCX (arrow). Patent LIMA to LAD. Occluded bypass venous graft to RCA (containing stent) which is also occluded. Patent arterial graft to the first diagonal branch.

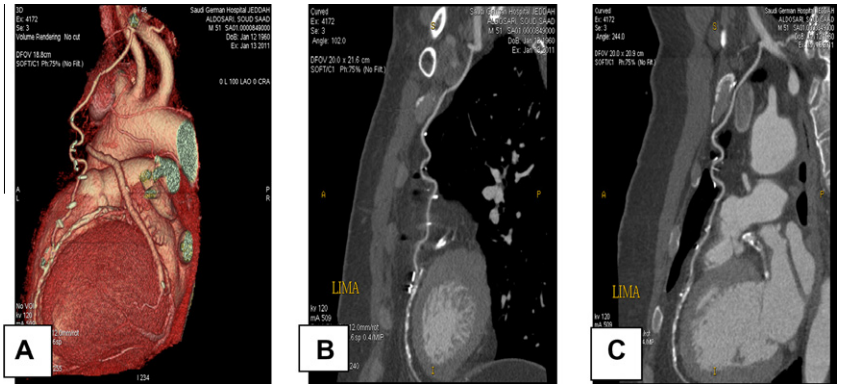

Fig. 4 (A) VR, (B, C) curved plannar. Significant stenosis at distal LIMA LAD anastomosis.

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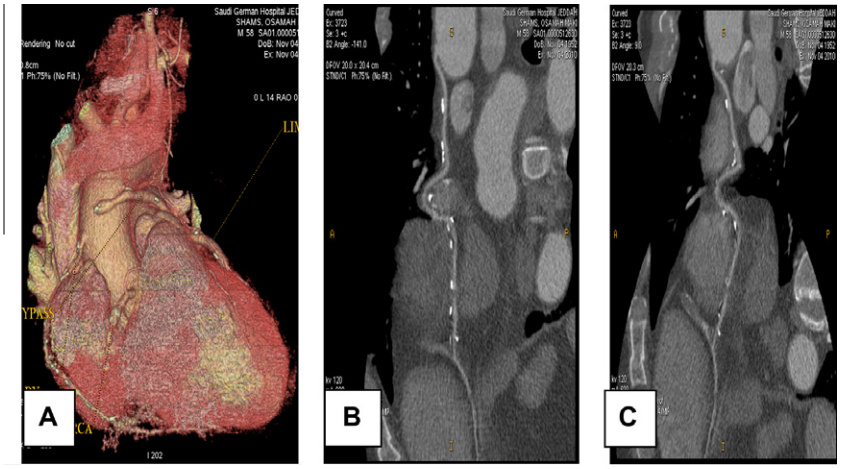

Fig. 5 (A) VR, (B, C) curved plannar coronary angiography atherosclerotic changes and areas of narrowings in the distal half of arterial by pass from ascending aorta to RCA.

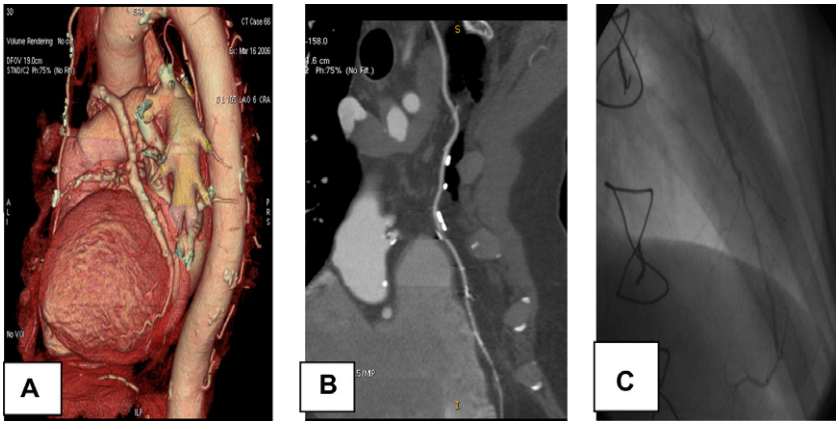

Fig. 6 (A) VR, (B) curved plannar, (C) invasive coronary angiography. Over estimation of stenosis of middle aspect of the LIMA caused by artifact from surgical clips. Atherosclerotic changes of the venous graft to LCX. Patent venous graft to RCA.

Table 3 Diagnostic accuracy of MDCT in evaluating graft significant stenoses.

	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
LIMA	100	96.6	83.3	100	97.1
Radial artery	100	100	100	100	100
Venous graft	100	95.1	88.2	100	96.4
Total	100	96	87.5	100	96.8

and the more invasive CAG as the 2nd choice when 64-MDCT shows graft occlusion or significant graft anastomosis stenosis, or if it cannot evaluate the state of the graft. Our results indicate the usefulness of MDCT as a screening modality for post-CABG evaluation.

In the current study, the diagnostic accuracy of MDCT in evaluating native coronary artery occlusion for occluded or significantly stenosed grafts showed nearly equal results with ICA (Table 5). As regards the evaluation of native coronary artery significant stenosis, MDCT falsely diagnosed 2 segments as significant stenosis caused by dense calcification. These are in agreement with previous studies (18), the difference between stenosis and complete occlusion of the native coronary arteries affects interventional options for treatment. We found that CT could exclude occlusion of native coronary arteries for patent and diseased grafts. (See Table 6)

As regards the non grafted coronary arteries in the current study, MDCT could identify a case of complete occlusion of the LAD at its osteum reported as non-visualized by invasive coronary angiography. Also MDCT could detect osteal narrowing of the LMCA caused by mixed plaque at its osteum not seen by invasive coronary angiography.

In the present study there were 4 patients with mild pleural effusion and 2 patients with pericardial sac collection. Pericardial effusions are common after coronary artery bypass, occurring with a reported prevalence of 22–85% (19). Important risk factors include postoperative anticoagulant therapy or coagulation abnormalities that are often related to the use of cardiopulmonary bypass. Despite their frequency, postoperative pericardial effusions rarely progress to become hemodynamically significant. Resultant cardiac tamponade has been reported in 0.8–6% of patients (20).

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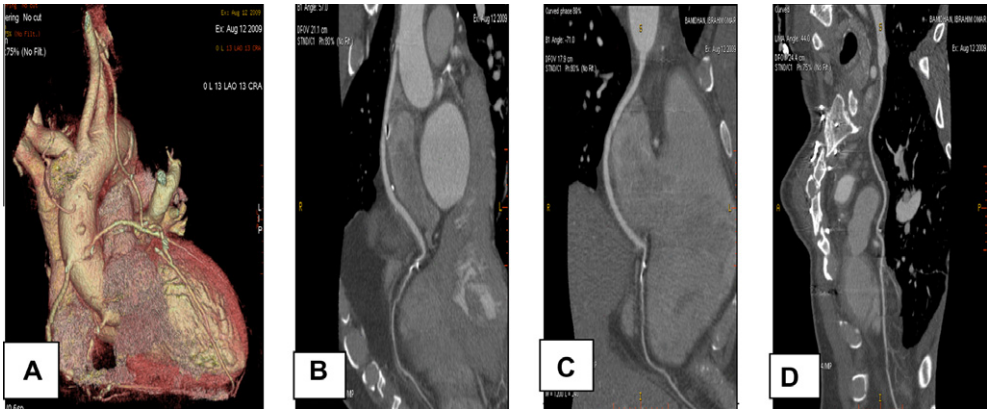

Fig. 7 (A) VR, (B–D)curved plannar coronar angiography. Patent LIMA to LAD, patent arterial graft to CXA and venous graft to RCA. Atherosclerotic changes of RCA distal to anastomosis. Patent CXA and LAD distal to the anastomosis. Occluded venous graft at its osteum.

Table 4 Diagnostic accuracy of MDCT in evaluating post anastomotic native coronary artery occlusion and significant stenoses of patent grafts.

	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Occlusion	100	100	100	100	100
Significant stenoses	100	95.9	83.3	100	96.6

Table 5 Diagnostic accuracy of MDCT in evaluating native coronary artery occlusion and stenoses for occluded or significantly stenosed grafts.

	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Occlusion	100	100	100	100	100
Significant stenoses	100	93.3	77.7	100	95

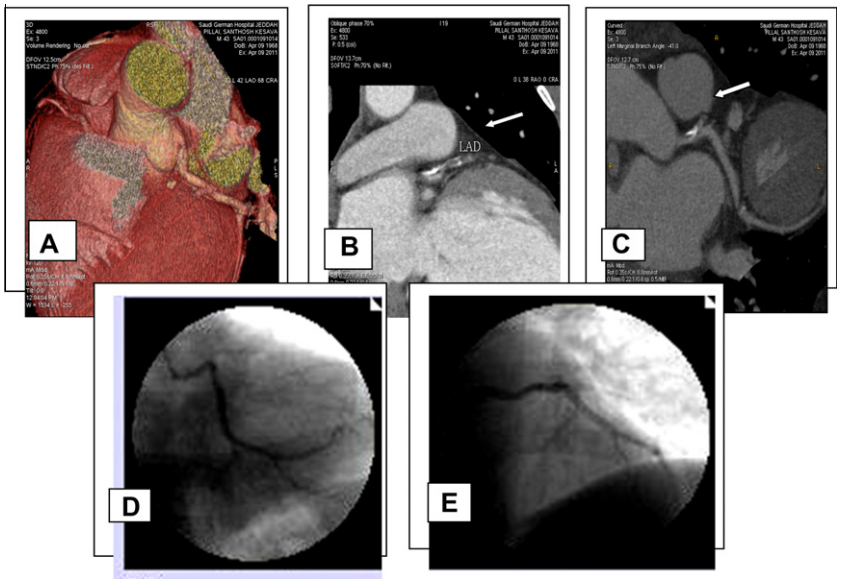

Fig. 8 (A) VR, (B, C) curved plannar, (D, E) invasive coronary angiography Occluded LAD at its origin by MDCT reported as non visualized by invasive coronary angiography.

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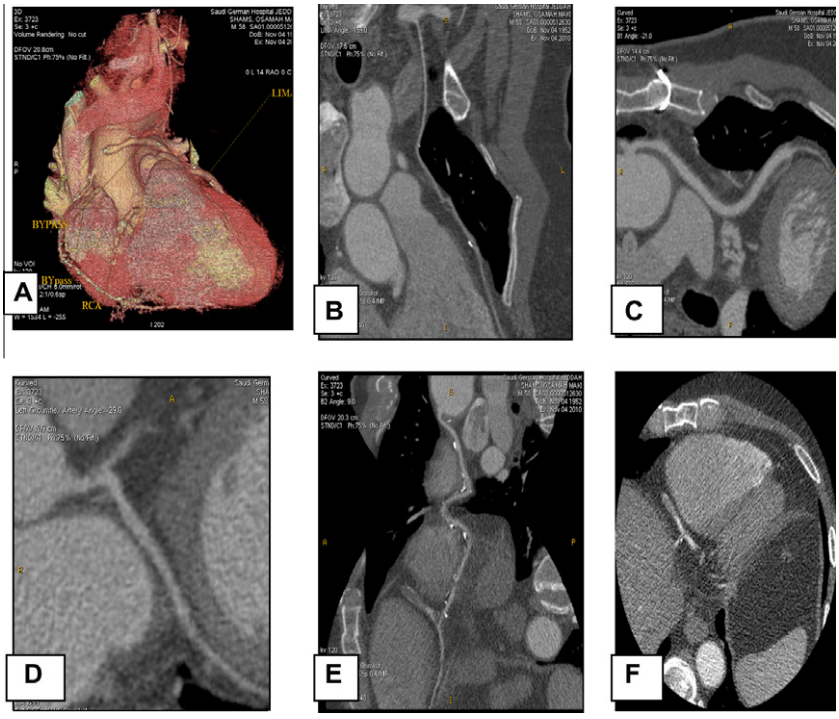

Fig. 9 (A) VR, (B–F) curved planar angiography. Patent LIMA to LAD. Patent venous to CX. Occluded RCA. Patent arterial graft to PDA. Atherosclerotic PDA. LMCA stenosis (arrow).

Table 6 Diagnostic accuracy of MDCT in evaluating non grafted coronary arteries occlusion and significant stenosis.

	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Occlusion	100	100	100	100	100
Significant stenoses	100	97.9	87.5	100	98.1

Most patients who undergo coronary artery bypass grafting develop pleural effusions; the prevalence is approximately 90% within the first week after surgery. These tend to be small, unilateral, and left sided with no relationship to an enlarged cardiac silhouette, atelectasis, or placement of a chest tube (21). Patients are generally asymptomatic, and the effusion usually resolves spontaneously over several weeks (22). Only 1–4% of CABG surgery patients proceed to develop clinically significant effusions that manifest with chest pain and dyspnea and require thoracocentesis. The pathophysiology of pleural effusion after CABG is unknown, but several etiologies have been postulated such as pericardial inflammation or intra operative pleural injury, which may lead to lymphatic drainage or increased fluid production (21).

Also we have 2 patients in the current study having pulmonary embolism 7–10 days after operation. A recent review of the literature regarding pulmonary embolism in the post-CABG surgery population showed an overall prevalence of 23% for deep vein thrombosis by 1 week after surgery, with less than 2% of these cases identified clinically (22).

5.1. Study limitations

There are some limitations to the present study. We included only patients able to maintain a breath hold of 30 s, because of the long duration of acquisition of CABG and post anastomotic coronary arteries with MDCT. For this reason, many patients, especially older patients and patients with chronic obstructive pulmonary disease were excluded.

Conventional CA is still the gold standard in the evaluation of both coronary artery and graft status, but its use is restricted by the invasive nature of the procedure.

6. Conclusion

The advantages of MDCT compared with ICA is that it is rapid and noninvasive, thus avoiding catheter-associated risk and, in the subset of patients with previous CABG, the problems and risks related to selective graft catheterization such as spontaneous or catheterization-related left IMA dissection, not an unusual occurrence, even in the absence of atherosclerotic plaque, particularly in segments treated with free-graft technique and in patients with acute coronary syndrome. During acute coronary syndrome, and especially in cases of complex previous coronary revascularization or cases for which historic data concerning the type and site of previous CABG are lacking, preliminary evaluation of the graft by MDCT enables easy determination of graft patency and the presence of significant stenosis and avoids diagnostic mistakes related to the difficult localization and selective catheterization of the graft. Our data suggest that MDCT, thanks to its very high negative predictive value, may eliminate the need for invasive

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coronary procedures in the presence of normal coronary imaging. In the case of graft occlusion or significant stenosis, ICA may be more correctly indicated and an oriented percutaneous coronary intervention performed.

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