Original article

Diagnostic accuracy of 64-slice multidetector computed tomography in evaluation of post-coronary artery bypass grafts in correlation with invasive coronary angiography

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KEYWORDS

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ABSTRACT

64-slice multidetector computed tomography (MDCT) allows more reliable and non-invasive evaluation of the coronary artery bypass grafts for occlusion or stenosis both in symptomatic and asymptomatic patients and also progression of disease in native coronary vessels.

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Introduction

Coronary artery disease (CAD) is a major cause of mortality and morbidity worldwide.¹ The prevalence of the disease is increasing dramatically in developing countries.² In India, the incidence of CAD ranges from 14.8 to 65.4 per 1000 population.³ Coronary artery bypass graft (CABG) surgery remains the standard of care in the treatment of advanced CAD.⁴ The various bypass conduits used for CABG surgery are harvested from veins and arteries of patients own body. Multidetector computed tomography (MDCT)—coronary angiography is the non-invasive imaging technique for the evaluation of CABG grafts with high temporal and spatial resolution and provides best alternative to the invasive coronary angiography (ICA).⁵ In the continuous technical evolution of the computed tomography (CT) scanners, it is now possible to scan the heart and the coronary bypass grafts with sub-millimeter slice thickness within a single breath hold.

In our study, we study prospectively the diagnostic accuracy of 64-slice MDCT coronary angiography in the detection of bypass graft occlusion and stenosis using ICA as the reference standard.

Materials and methods

The study was conducted prospectively in 36 post CABG patients using 64-slice MDCT (GE VOLUME CT-XT 64-SLICE), among these 36 patients, 25 were male and 11 were female. The age of the patients ranged from 40 years to 85 years (mean age: 67.33 years). Twenty-one patients had symptomatic chest pain and six patients had dyspnoea on exertion. Rest of the nine patients were asymptomatic and had come for routine follow-up. A total of 89 grafts including sequential grafts, analysed (arterial—34 and venous—55). The graft age was in the range of 1–15 years in 35 patients (Graph 1). Only one patient underwent CT coronary angiogram within 1 year of surgery due to recurrent chest pain. Patients with cardiac arrhythmias, ectopic heart beats, and claustrophobia are excluded from the study.

Computed tomography protocol

All the patients were prepared before the procedure. The patients were advised 4–6 hours of fasting prior to the procedure. All post CABG patients were on beta-blocker medication and the resting heart rate (HR) was between 60–70bpm. The renal function tests (creatinine < 1.2 mg) are also checked.

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Graph 1 Graph age since surgery.

Table 1

Method of acquisition.

Technique	ECG-gated retrospective technique
Slice thickness	0.625 mm
Gantry rotation time	0.35 sec
Pitch	Variable
Tube voltage	120 kv
Tube current	auto MA
Kernal	30
Recon interval	0.625 mm
Matrix	512 × 512

ECG: electrocardiogram, MA: motion artifacts.

After good intravenous access, non-ionic low osmolar contrast agent (visipaque –320 mg Iodine/mL) was injected at the rate of –5.5 mL/sec followed by saline chase at the rate of 5.5 mL/sec using dual pressure injector.

Method of acquisition (Table 1)

Procedure

After taking the scout, smart prep method was used to acquire the images (ascending aorta, threshold –100 HU). Image acquisition is usually done from the base of the heart to the thoracic inlet (caudo-cranial) using electrocardiogram (ECG)-gated retrospective technique.

After the procedure, the patient was advised to drink a lot of water for early washout of the contrast.

Image reconstruction

The retrospective ECG-data was used for image reconstruction. The first reconstruction was performed with the reconstruction window starting at 75% of R-R interval. If motion artifacts were present, additional reconstructions in 5% increments and decrements of the R-R interval is performed. This included data sets reconstructed in systole, if diastolic

data sets showed motion artifact. If no data set was entirely free of motion artifact, the data set with best image quality in the region of the graft was used for further analysis.

Reconstruction was done using advanced workstation (adw5). The reconstruction techniques used were maximum intensity projection (thin and thick-MIP), volume rendered technique (VRT), curved MIP, and tree view projections.

Data analysis

The coronary MDCT data sets were analysed with awareness of the previous surgical procedure, number, and location of bypass grafts.

Grafts were viewed in both long and short axis, parallel and perpendicular to the course of the vessel. The image quality was considered good if no artifacts and suboptimal if technical limitations, such as artifacts present.

Each bypass graft was divided into three segments-body of the graft, proximal, and distal anastomotic sites. The grafts then was assessed for the presence of occlusions. Patency of the graft, was demonstrated if its lumen showed uniform contrast enhancement without any filling defect or narrowing. The grafts which were considered patent were visually evaluated for the presence of stenosis afterwards. Significant stenosis was defined as a lumen reduction of 50–99%; lumen reduction of <50% was considered as non-flow limiting mild stenosis. Stenoses were subclassified on the basis of their location in the body of the graft or at the anastomotic sites (proximal or distal).

In situ grafts, namely the left internal mammary artery (LIMA) grafts can be traced from their origin at the subclavian arteries to their distal anastomotic sites and the overall patency of the grafts was assessed. Native coronary vessels were analysed for the progression of the disease.

Results and observations

A 64-slice coronary CT was performed without any complications in 36 (males–25 and female–11) patients. Most of them (21 patients) presented with symptomatic chest pain; six of them had dyspnoea on exertion. Rest of them were asymptomatic and had come for routine follow-up.

A total of 89 grafts (arterial–34 and venous–55) were studied. The technical quality was good in all cases except in two patients due to significant HR variation and inadequate patient breath hold during dynamic contrast scanning. However, due to additional reconstructions no graft was excluded from the study. Thirty-four patients had triple vessel disease. Two patients had double vessel disease.

The age of the bypass grafts varied from less than 1 year to more than 15 years since bypass surgery (Graph 1). All of them were evaluated after 1 year of surgery. Only one patient underwent CT coronary angiography within 10 months of surgery due to frequent intermittent chest pain. Among the 36 patients, two had only arterial grafts, six had only venous grafts, and the remaining 28 had both arterial and venous

grafts. The number of grafts were 1–5/patient. In our study, most of the patients had two grafts, accounting for 30.6% of the cases. The most commonly grafted vessel was left anterior descending artery (LAD) followed by other branches (Table 2). There were five sequential grafts studied (1 arterial and 4 venous). Each sequential graft was considered as a single graft with multiple distal anastomoses (Figure 1B).

Among the arterial grafts ($n=34$) in situ LIMA grafts (29) were used in most of (Figure 2A, B) the patients, two were free right internal mammary artery (RIMA) grafts (Figure 2A, B) and three free radial artery (RA) (Figure 1A) grafts. Among the 34 grafts, 30 were patent and four were occluded. There was one sequential arterial graft (Figure 1B) in our study and was patent. A total of 55 venous grafts analysed. Of these, 40 were patent and 15 were occluded. All 15 grafts were occluded at the proximal anastomosis to the ascending aorta (Figure 3A).

Among the patent grafts ($n=70$), four had some degree of stenosis. The stenosis was significant (50–99% diameter reduction) in 1 of 4 graft at distal anastomosis site. The remaining three grafts showed only mild stenosis (<50% diameter reduction). In 2 of 3 grafts, stenoses were located in the proximal part of the bypass graft (Figure 2A) and in the remaining

one, graft stenoses was located at the distal anastomotic site. Most of the arterial and venous grafts were (Figure 4A–D) patent, more significantly of former accounting for 88.2%. The occlusion rate was more in the venous grafts, constituted 27.3% (Table 3). In our study, the lifetime of the graft patency was considerably good in the arterial graft. The occlusion rate of the venous grafts increased with increasing graft age correlating with previous studies.⁶

The CT angiogram results correlated well with ICA (Table 4). Computed tomography had a diagnostic accuracy of 100% in identifying occluded ($n=19$) and patent grafts ($n=70$). Among the patent grafts ($n=70$) 66 had no stenosis on ICA as well. The degree of stenosis was mild in two grafts and significant in two grafts on ICA. The corresponding figures on MDCT were three and one, respectively. Multidetector computed tomography had falsely implicated stenosis in one graft. This could be attributed to suboptimal image quality in all these cases, due to significant variation in the HR during dynamic contrast scanning.

Thus, for the detection of bypass graft stenosis a sensitivity of 95%, specificity of 98.5%, positive predictive value of 75%, negative predictive value of 99.4% were found (Table 5).

Table 2

Distribution of grafts in individual patients.

Graft location	No. of grafts ($n=89$) (%)
Left anterior descending artery	29 (32.6)
Obtuse marginal	21 (23.6)
Right coronary artery	7 (7.9)
Posterior descending artery	13 (14.6)
Diagonal	10 (11.2)
Ramus intermedius	1 (1.1)
Posterior left ventricular artery	1 (1.1)
Posterior descending artery	1 (1.1)
Sequential grafts	6 (6.7)
Total no. of grafts	89

Discussion

64-slice MDCT with retrospective ECG technique and intravenous contrast agent has been promising non-invasive technique for the assessment of CABG. Recurrent cardiac ischaemia occurs in significant proportion of patients after CABG. Non-invasive investigations to identify graft occlusion and quantify graft stenosis are desirable due to the complications, cost and patient inconvenience of ICA.⁵

64-slice coronary CT was performed in 36 patients with total number of 89 grafts. All the grafts were evaluated.

Figure 1A,B VR images showing patent sequential arterial graft. D1: diagonal 1, ILA: intra-operative linear array, LAD: left anterior descending artery, LIMA: left internal mammary artery.

Figure 2A,B VR images showing patent arterial grafts. LAD: left anterior descending artery, LIMA: left internal mammary artery, RIMA: right internal mammary artery, OM: obtuse marginal.

Figure 3 (A) VR image, (B) invasive coronary angiography image showing occluded venous graft.

We found that 64-slice MDCT was extremely useful in the following aspects:

1. Decreased acquisition time.
2. Increased scan time and volume coverage.
3. Reduced amount of contrast agent.
4. Decreased artifacts due to metallic clips and arrhythmias.

64-slice MDCT provides improved temporal and spatial resolution with the simultaneous acquisition of 64-slices per rotation, the overall scan time and thus the breath hold time are significantly reduced.⁷ In our study, the overall scan time varied from 8 seconds to 12 seconds, significantly decreased as compared to the previous 4-slice (40 seconds) and 16-slice (30 seconds) scanners.^{8–10}

In our study, because of increased scan speed and volume coverage, in all patients we could cover the origin of LIMA grafts in spite of maintaining the breath hold within reasonable limits.

The amount of intravenous contrast agent needed for 64-slice coronary CT angiography has also been decreased as compared to previous scanners. In our study, we used 80–100 mL (average 90 mL) of non-ionic contrast agent for optimal opacification of the bypass grafts.

As a result of technical superiority of current scanner generation and with the use of advanced post processing techniques, we achieved 100% evaluability for all the bypass conduits, their proximal and distal anastomosis and the distal

Figure 4A–D Maximum intensity projection images showing patent SVGs to native arteries. LAD: left anterior descending artery, SVG: saphenous vein graft, OM: obtuse marginal, LCX: left circumflex, PDA: posterior descending artery.

Table 3
Correlation of graft type and patency.

Type of graft	Graft patency		Total
	Patent (%)	Occlusion (%)	
Arterial	30 (88.2)	4 (11.8)	34
Venous	40 (72.7)	15 (27.3)	55
Total	70 (78.6)	19 (21.4)	89

Table 4
Computed tomography angiogram, invasive coronary angiography results correlation.

Graft analysis	CTA (%)	ICA (%)
Patent	70 (78.6)	70 (77.9)
Occluded	19 (21.4)	19 (22.1)
Mild stenosis (among patent grafts)	3 (4.3)	2 (2.8)
Significant stenosis (among patent grafts)	1 (1.4)	2 (2.8)

CTA: computed tomography angiogram, ICA: invasive coronary angiography.

runoff vessels. None of the grafts had to be excluded from the analysis because of technical limitations such as artifacts.

Our study results are in accordance with the previous studies^{5–7,10–12} of 64-slice coronary CT, which demonstrated a higher diagnostic accuracy in the identification of graft stenosis and occlusion, compared with previous scanner generations.

Table 5
Diagnostic statistics of 64-slice multidetector computed tomography coronary angiography for graft stenosis and occlusion.

Statistics	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Occlusion	100	100	100	100
Stenosis	95	98.5	75	99.4

NPV: negative predictive value, PPV: positive predictive value.

In a study conducted by Ropers et al.,⁷ a total of 138 grafts were evaluated with 64-slice MDCT using ICA as a reference standard. They found that all bypass grafts could be evaluated for detection of patency and stenosis. The sensitivity and specificity for the detection of graft occlusion was 100%. Sensitivity for stenosis among the patent grafts was 100% with a specificity of 94%.

Malagutti et al.¹² has evaluated 52 patients with a total of 109 grafts using 64-slice MDCT. For the detection of occlusion, the sensitivity and specificity were 100% each. The sensitivity for stenosis was 100% and specificity was 98.3%.

In a study by Pache et al.,¹¹ the sensitivity and specificity were 100% each for the detection of occlusion. The sensitivity of the study for the detection of stenosis was 97.8% with specificity of 89.3%.

In our study, all the distal anastomosis and distal runoff vessels were evaluated. In one case, there was a mild

Figure 5A–C VR image (A) showing occluded SVG and RA grafts as confirmed with invasive coronary angiography (B,C). RA: radial artery, SVG: saphenous venous graft.

stenosis at the distal anastomotic site and was correctly identified by the MDCT. This observation correlates with other studies.^{6,7,11}

Earlier venous grafts were most commonly used. This is because of availability and ease of procurement of venous grafts. Compared to Saphenous venous grafts LIMA grafts have superior long term patency and was convincingly demonstrated in the 1980s, the LIMA to LAD grafting has become a fundamental part of CABG.^{13–16}

In our study, 19 of 89 bypass grafts were occluded; 15 of 55 (27.3%) venous grafts (Figures 3A,B and 5A,B) were occluded and 4 of 34 (11.8%) arterial grafts (Figure 5A,C) were occluded. This confirms that long-term patency of arterial grafts is better than venous grafts. Our study confirms that arterial grafts are associated with superior long-term patency compared with saphenous vein grafts. Our results are in concordance with the previous studies^{13,17,18} where arterial grafts were found to have better lifetime of graft patency than venous grafts.

When the graft patency was analysed with respect to native coronary artery to which they were anastomosed, it was found that the patency was highest when anastomosed to LAD. Twenty-five of 29 (86.2%) grafts anastomosed to LAD were patent. This was in part due to the fact that the vast majority (79.3%) was arterial grafts. Any graft used to bypass LAD has better patency because of technical ease of anastomosis to this anteriorly situated artery and higher outflow through this conduit. Two of four (50%) venous grafts anastomosed to the LAD were occluded. Though the patency of venous grafts anastomosed to LAD was less when compared to arterial grafts, it was still higher when compared to rest of the native coronary arteries which had venous grafts. The patency rate was 70% for the grafts anastomosed to diagonals; 66.6% for the grafts to obtuse marginals (OM), 71.4% for the grafts to right coronary artery (RCA), 76.9% for the grafts to posterior descending artery (PDA). Our study is in concordance with previous studies done by Desai et al.¹⁹ where it was found that the percentage of

occlusions to OMs, diagonals, PDA, and posterior left ventricular branches was higher because of the smaller size of the native arteries.

There were five sequential grafts in our study. Out of them one was arterial graft (LIMA → LAD, diagonal 1 [D1]) (Figure 1B) and four were venous grafts. One of the four sequential venous grafts (SVG → LAD, D1) was occluded. The remaining three sequential grafts (PDA, obtuse marginal (OM) 2; OM, ramus intermedius (RI); and PDA, D1) were patent.

In our study, all occluded grafts demonstrated occlusion at the proximal anastomotic sites (Figure 6A) to the ascending aorta (all were free saphenous venous and RA grafts). This may be due to any intimal injury occurred at the site of anastomosis during surgery, which predisposes to later development of occlusion. In addition, anastomosis to the aorta exposes the venous grafts to higher systemic pressures which may also predispose to graft occlusion.

Four patent grafts in our study had stenoses; one significant (50–99% diameter reduction) and three mild stenosis (<50% diameter reduction). In two of three grafts, stenoses were located in the proximal part of the bypass graft and in the remaining one graft stenosis was located at the distal anastomotic site.

The average effective radiation dose was 14.7 mSv in our study. The 64-slice coronary CT delivers an increased radiation dose compared to ICA, in the order of 12.2 mSv with tube modulation and 17.8 mSv without tube modulation,⁷ has been also demonstrated in previous studies by Feuchtner, Ropers, Martuscelli et al.^{6,7,20}

Limitations

The general limitations of MDCT are radiation exposure, contrast induced nephropathy and a prior exclusion of patients with atrial fibrillation. The evaluation of severely calcified lesions remain a drawback in the CT evaluation of patients after bypass surgery. Metal clips placed alongside bypass

Figure 6 (A) MIP image shows mild stenosis in the body of SVG to D2 graft in comparison with (B) invasive coronary angiography image showing severe stenosis. D2: diagonal 2, MIP: maximum intensity projection, SVG: saphenous venous graft.

grafts, especially internal mammary artery grafts, are known to cause artifacts. In our study, no bypass graft was unevaluable because of the presence of a clip, due to the high spatial and temporal resolution.

The evaluation of native coronary arteries is restricted due to ongoing atherosclerotic disease process with calcifications.

Conclusion

The 64-slice MDCT has high diagnostic accuracy for the detection of occlusion and stenosis of bypass grafts. However, the detection of graft occlusion is relatively better than detection of stenosis.

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