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ORIGINAL ARTICLE

Noninvasive evaluation of coronary artery bypass grafts and native coronary arteries: is 16-slice multidetector CT useful?

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PURPOSE
To investigate the diagnostic accuracy and limitations of 16-slice multidetector computed tomography (MDCT) in the detection of significant (>50%) stenosis of coronary artery bypass grafts (CABG) and native coronary arteries.

MATERIALS AND METHODS
One hundred two patients with 236 grafts were investigated by 16-slice MDCT. Native coronary arteries were also investigated. The image quality was assessed in terms of artifact, and the evaluable segments were screened for the presence of occlusion and significant (>50%) stenosis. MDCT results were compared with conventional coronary angiography.

RESULTS
The evaluability of MDCT was 90.4% for CABG and 71.2% for native coronary arteries. The most frequent causes of nonevaluable segments were motion artifact in venous grafts, metallic clip artifact in arterial grafts, and severe calcification in native coronary arteries. MDCT correctly diagnosed all of the 46 occluded grafts. The sensitivity, specificity, and the positive and negative predictive value of MDCT for the detection of significant CABG stenoses were 91.4%, 98.5%, 84.2%, and 99.2%, respectively. Including nonevaluable segments in the analysis, overall sensitivity was 84.2%. For the evaluation of native coronary arteries, MDCT had a sensitivity of 82.1% and a specificity of 75.3%, but evaluability was only 71.2%, resulting in overall sensitivity of 62.1%.

CONCLUSION
Use of 16-slice MDCT angiography allows very accurate evaluation of CABG patency and has high diagnostic accuracy in detecting graft stenoses. But evaluation of native coronary artery stenosis is limited, particularly in patients with advanced coronary artery disease with severe calcification.

Key words: • *coronary artery bypass grafting* • *multidetector computed tomography* • *angiography*

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Recurrent ischemic symptoms in patients with previous coronary artery bypass graft (CABG) surgery for advanced coronary artery disease (CAD) is a common problem. Conventional coronary angiography (CCA) is currently the reference standard technique for evaluation of status of CABG and coronary arteries. CCA, however, is expensive and has a small risk of potentially life-threatening complications, including arrhythmia, stroke, coronary artery or graft dissection, embolic events, and myocardial infarction; the morbidity rate is 0% to 2%, and the mortality rate is 0.14% to 0.28% (1). Therefore, a reliable, noninvasive imaging modality is preferable for evaluation of patients suspected of having graft stenosis or occlusion. During the past decade, considerable progress has been achieved in the field of noninvasive coronary imaging with magnetic resonance imaging, electron beam computed tomography, and, most recently, multidetector computed tomography (MDCT). Magnetic resonance imaging and electron-beam computed tomography have major limitations in reliability of coronary imaging (2–5). MCDT is a result of progress in the scanner technology, which led to improved spatial resolution through thinner slice collimation and to increased temporal resolution through faster gantry rotation. MDCT has become a robust technology for coronary imaging. To date, various studies have been published exploring the diagnostic performance of MDCT coronary angiography evaluation of CABG patency and stenosis using different scanner generations (6–22). Most studies performed with 16-slice MDCT have been restricted to the evaluation of bypass grafts. But noninvasive follow-up of patients who have undergone CABG surgery should also include assessment of native coronary arteries for the presence of significant de novo stenosis, which may explain ischemic symptoms if grafts are patent.

The purpose of the present study was to investigate the diagnostic accuracy and limitations of 16-slice MDCT in detecting significant stenosis in bypass grafts and native coronary arteries, using CCA as the standard of reference.

Materials and methods

Patient population

Study subjects included 102 consecutive patients (34 females, 68 males; mean age, 59 years; age range, 36 to 78 years) with previous CABG surgery, with a total of 236 grafts (1 to 5 grafts per patient; average, 2.3). The patients had been referred for CCA because of suspected progression of CAD and were investigated 2 to 240 months (mean, 71 months) after bypass operation. Only patients in stable clinical condition with sinus rhythm were included. Exclusion criteria were absence of sinus rhythm, renal failure (serum creatinine level >1.5 mg/dL) and known allergic reactions to iodine-containing contrast agent or contraindications to the administration of iodine.

Patients with pre-scan heart rate above 70 beats/min received a single oral dose of 100 mg metoprolol (Beloc, AstraZeneca, London, UK) 1 hour prior to the MDCT scan. If the heart rate was above 65 beats/min at the time of MDCT scanning, metoprolol (5–10 mg) was administered intravenously 5 min before the scan. In all patients, MDCT angiography was performed before CCA. The median interval between the MDCT and catheterization procedure was 5 days (range, 3–14 days). The study was approved by our institutional ethics committee, and all participating patients gave written informed consent.

MDCT scanning protocol

All MDCT examinations were performed by using a 16-slice MDCT scanner (GE Lightspeed Ultra 16, General Electrical Medical Systems, Milwaukee, USA). Monitoring of the electrocardiogram was performed continuously during the examinations, and all image acquisitions were performed during a single inspiratory breath-hold of 26 ± 2 seconds (mean ± SD), covering the distance from the aortic arch to the diaphragmatic face of the heart. The main acquisition parameters for MDCT angiography were: the use of retrospective ECG gating, craniocaudal scan direction, the detector collimation of 16 × 0.625 mm, tube voltage of 140 kV, tube current of 320–440 mA, table feed of 2.75–3.0 mm/rotation (depending on the patient's heart rate), gantry speed of 0.5 s/rotation and a pitch of 0.275–0.3.

Initially, an anteroposterior and lateral scout acquisition was obtained to determine the position of the heart and define the scan volume for further imaging. Scanning range included the entire course of the venous grafts, but not the proximal part of all internal mammary artery grafts, in order to maintain a manageable breath-hold period. For all examinations, 130 ml of iodinated contrast agent (Iodixanol, Visipaque 320 mgI/mL, GE Healthcare, Milwaukee, USA) was injected through an 18-gauge cannula positioned in an antecubital vein at a flow rate of 4 mL/s. Before the scan, each patient's individual circulation time was determined in the lumen of the ascending aorta using a test bolus of 30 mL of intravenous contrast agent at a flow rate of 4 mL/s. The time interval between the bolus injection and the maximal enhancement was measured, and the starting time of the enhanced scan was calculated as 3 seconds after the transit time of contrast agent.

Acquisition and initial reconstruction parameters varied according to the heart rate of the patients. For patients with a heart rate <60 beats/min, images were reconstructed using a snapshot algorithm from one cardiac cycle, providing a 250 ms temporal resolution (partial segment reconstruction). For patients with a heart rate of 60–65 beats/min, a snapshot burst algorithm was used with two cardiac cycles for image reconstruction and a temporal resolution of 125 ms (partial subsegmental reconstruction).

In all patients, the standard built-in reconstruction algorithm was used for image reconstruction. The data sets were reconstructed (with a slice thickness of 0.625 mm and 0.4-mm increments) during the mid-to-end diastolic phase, 65% to 75% of the R-R interval. If image quality in this data set was not optimal, additional reconstructions (35% to 85%) were performed, and the data sets with optimal images were chosen for further evaluation.

MDCT image analysis

All acquired data were transferred to a separate computer workstation (Advanced workstation 4.2, GE Healthcare, Milwaukee, USA) equipped with CardIQ software (GE Medical Systems). Depending on vessel morphology and quality of the MDCT data sets, different postprocessing techniques such as maximum-intensity projection, curved multiplanar reconstruction, and volume rendering were applied to assess arterial and venous bypass grafts and native coronary arteries. The images were evaluated by a single experienced investigator who was blinded to clinical history and results from CCA.

The quality of images was evaluated subjectively on a per segment basis. Using a three-point grading scale, the image quality was classified as good (no artifact present, optimal depiction of coronary arteries), sufficient (minor artifact present, acceptable image quality), and poor (severe artifact, luminal assessment impossible). Only data sets considered having good or sufficient image quality were evaluated further, and scans with poor image quality were excluded. The causes of nonevaluable segments were identified as the presence of motion artifact, calcified plaque, small arterial lumen (<1.5 mm) combined with poor opacification, and artifact due to surgical clips. After each bypass graft was classified as either evaluable or nonevaluable, bypass grafts were assessed for the presence of occlusion. All grafts considered patent were then evaluated for presence of significant stenosis. A visual estimate of diameter decrease was used to describe stenosis severity. Significant stenosis was defined as reduction in diameter of more than 50%. Bypass grafts were divided into three segments: 1, proximal anastomosis; 2, graft body; 3, distal anastomosis. Consecutive graft anastomoses were regarded as separate segments. The main analysis was performed on a per-segment basis, and significant stenosis (>50%) was classified on the basis of location in the body of the graft or at the anastomotic sites. In the per-patient analysis, patients were classified as positive for significant graft disease if there was significant stenosis in any bypass graft.

For the evaluation of the native coronary arteries, analysis was performed on segment basis according to the modified American Heart Association classification system. Right coronary artery (RCA): 1, proximal; 2, middle; 3, distal; and 4, combined posterior descending (PDA) and posterolateral (PL) branches. 5, left main artery (LMA). Left anterior descending artery (LAD): 6, proximal; 7, middle; 8, distal; 9, first diagonal branch (DB1); 10, second diagonal branch (DB2). Left circumflex artery (LCX): 11, proximal; 12, distal; 13, first obtuse marginal branch (OM). The evaluability of post-anastomotic recipient coronary arteries was assessed separately.

Conventional coronary angiography (CCA)

CCA (Axiom Artis; Siemens Medical Systems, Forchheim, Germany) was performed with standard techniques through a transfemoral approach. The angiograms were quantitatively assessed with quantitative coronary angiography software (QCA; Siemens Medical Systems, Forchheim, Germany) by an experienced interventional cardiologist unaware of the results of the MDCT examination. A diameter reduction more than 50% was defined as significant stenosis.

Statistical analysis

All statistical calculations were performed using the Statistical Package for the Social Sciences (SPSS Inc., Chicago, USA), version 10.1. Using CCA as the gold standard, diagnostic accuracy, sensitivity, specificity, positive predictive value, (PPV) and negative predictive value (NPV) were calculated for patency and significant stenoses of coronary artery or bypass grafts. If a coronary artery or graft segment contained more than one lesion, the most severe lesion determined the diagnostic accuracy of the assessment. In the patient-based analysis, patients were classified as positive for significant graft disease if there was significant stenosis in any bypass graft.

Results

All patients completed MDCT examinations without complications. The average heart rate during the scan was 60 ± 4 (52–76) beats/min.

Bypass grafts

A total of 236 grafts, 104 (44%) arterial and 132 (56%) venous, with a total of 248 distal anastomoses were examined. Eighteen patients had only venous grafts, 7 had only arterial grafts, and 77 had both venous and arterial grafts. Of 132 saphenous vein grafts, 121 were solitary, 10 sequential, and one a Y-graft with three anastomoses. Of 132 venous grafts with 144 distal anastomoses, 13 were to the LAD, 11 to the DB, 58 to the OM, 40 to the RCA, 17 to the PDA, and 5 to the PL. Of 104 arterial grafts, 86 (82.7%) were left internal mammary artery (LIMA), 6 (5.8%) were right internal mammary artery (RIMA), and 12 (11.5%) were radial artery (RA) grafts. All 86 LIMA grafts were to LAD. Of 6 RIMA grafts (4 of free arterial graft), 3 were to RCA and 3 to OM; and of 12 RA grafts, 4 were to LAD, 3 to OM, and 5 to RCA.

CCA of the bypass grafts showed that 190 bypass grafts (80.5%) were patent and 46 (19.5%) were occluded (40 venous grafts, 5 LIMA grafts, and 1 RA graft). Of the 46 occluded grafts, 7 were to LAD, 2 to DB, 16 to OM, 17 to RCA, and 4 to PDA. Of 190 patent grafts, 152 were free of stenosis, and 38 of significant stenosis in cardiac catheterization. All 190 angiographically patent grafts and all 46 occluded grafts were correctly detected by MDCT, with sensitivity and specificity of 100% (Table 1).

One hundred ninety patent grafts were evaluated for the presence or absence of significant stenosis. Each bypass graft was subdivided into three sections. Because of the scan range used, the ostium and proximal course of the internal mammary artery was not visualized and could not be evaluated for stenoses. Therefore, 190 patent grafts were subdivided into 499 sections (107 proximal anastomosis, 190 body of graft, and 202 distal anastomosis). The quality of images on a graft segment basis model was good in 416 sections (83.3%), sufficient in 35 sections (7.1%), and poor (insufficient) in 48 sections (9.6%). Forty-eight sections in poor image quality (28 arterial and 20 venous graft sections) in 32 grafts were not evaluable for the detection of stenosis, due to motion artifact in 22 cases (14 venous grafts, 7 LIMA, and 1 RA grafts), small diameter (<1.5 mm) combined with poor opacification in 5 LIMA grafts, metallic clips artifact in 15 arterial grafts (1 RIMA and 14 LIMA grafts), and calcifications in 6 saphenous vein grafts. Two of 48 nonevaluable sections were at the proximal anastomotic site, 6 at the body of the graft and 40 at the distal anastomotic site. Therefore, the evaluability was 98.1% (105 of 107) for the proximal anastomotic site, 96.8% (184 of 190) for the body of the graft, and 80.2% (162 of 202) for the distal anastomotic site (Table 2). After exclusion of 48 nonevaluable sections, 451 of 499 patent graft sections (90.4%) were found to be evaluable for presence or absence of significant stenoses. The separate evaluability of arterial and venous grafts was 86.7% (183/211) and 93% (268/288), respectively. If the number of grafts (rather than the number of graft sections) is considered, the overall evaluability was 83% (158/190).

In a total of 499 patent graft segments, CCA detected 38 significant stenoses (7 arterial, 31 venous); 9 were located at the proximal anastomotic site, 10 at the body of the graft, and 19 at the distal anastomotic site. Three of 38 lesions were in nonevaluable segments. Evaluation of those segments was hampered by metallic clips in distal anastomotic sites of one LIMA graft and calcifications in the body of the two venous grafts. In 451 evaluable graft segments, MDCT correctly assessed 32 of 35 (91.4%) significant lesions. All stenoses correctly diagnosed by MDCT were localized in the body and proximal anastomotic site, but three false-negative lesions located in the distal anastomotic site could not be defined by MDCT, probably because of metallic clips artifact in 1 LIMA graft and insufficient opacification of the distal anastomotic site in two venous grafts. Of 416 normal or nonsignificantly diseased segments, 410 (98.5%) were correctly diagnosed by MDCT. Six lesions were overestimated and classified as false positive. Three lesions were affected by metallic clips artifact in the distal anastomotic site of the LIMA grafts; one calcified lesion in the body of the venous graft was overestimated, and two lesions were affected by mo-

Table 1. Types of coronary artery bypass grafts and evaluation of patency and occlusion by 16-slice multidetector computed tomographic angiography and conventional coronary angiography

	Patent		Occluded		Diagnostic accuracy
	CCA	MDCT	CCA	MDCT	
All grafts (n = 236)	190	190	46	46	100%
LIMA (n = 86)	81	81	5	5	100%
RIMA (n = 6)	6	6	0	0	100%
RA (n = 12)	11	11	1	1	100%
VG (n = 132)	92	92	40	40	100%

CCA, conventional coronary angiography; LIMA, left internal mammary artery; MDCT, multidetector computed tomography; RA, radial artery; RIMA, right internal mammary artery; VG, venous grafts tion artifact in the distal anastomotic site of venous grafts. The sensitivity, specificity, PPV, and NPV of 16-slice MDCT in the detection of significant stenoses for the 451 evaluable patent graft sections were 91.4% (32 of 35), 98.5% (410 of 416), 84.2% (32 of 38), and 99.2% (410 of 413), respectively. When all sections (evaluable and non-evaluable) were included in the analysis, the overall sensitivity for significant stenosis detection was 84.2% (32 of 38). The diagnostic performance of MDCT for the detection of significant bypass graft disease (>50% stenosis) is detailed in Tables 2 and 3. On a patient basis, 28 of 30 patients with at least one significant stenosis on CCA were correctly identified by MDCT. In 66 of 72 patients, significant stenosis was correctly ruled out. On a patient-based model, the sensitivity, specificity, PPV, and NPV were 93.3%, 91.6%, 82.3%, and 97%, respectively. Five examples of MDCT coronary angiography of patients with bypass grafts are shown in Figs. 1–5.

Native coronary arteries

For the evaluation of the native coronary arteries, analysis was performed on a segment basis according to the modified American Heart Association classification system. Of a total of 1326 coronary segments in 102 patients, 116 segments distal to 48 occlusions were excluded from analysis. Therefore, 1210 coronary segments remained in the analysis. Image quality was as follows: good in 629 of 1210 (52%); sufficient in 233 of 1210 (19.2%); and poor in 348 of 1210 segments (28.8%). Causes of poor assessment of segments were severe calcification in 226 cases (64.9%), motion artifact in 65 cases (18.7%), and small arterial lumen (<1.5 mm) combined with poor opacification in 57 cases (16.4%). After exclusion of 348 segments with poor image quality, 862 segments (71.2%) were included in the study. Of the 862 segments which could be assessed on MDCT, 296 had significant disease on CCA. Of the 296 significantly diseased coronary artery segments, 241 (82.1%) were correctly detected; and 424 of 566 (75.3%) normal or nonsignificantly diseased segments were correctly ruled out by MDCT. The sensitivity was 82.1% (243/296), the specificity was 75.3% (424/566), the PPV was 63.1% (243/385), and the NPV was 88.9% (424/477) for the detection of significant stenoses in per-segment based evaluation. Including nonevaluable segments in the analysis, CCA identified 391 significant stenoses in 1210 segments. The overall sensitivity for significant stenosis detection was 62.1% (243/391). The diagnostic performance of MDCT for the detection of significant disease (>50%) in native coronary arteries is detailed in Table 3.

The evaluability of post-anastomotic recipient vessels by MDCT was analyzed separately. A total of 202 post-anastomotic recipient vessels (96 LAD, 9 DA, 48 OM, 31 RCA, 13 PDA, and 5 PL) were also examined for the evaluability. The quality of images on a segment basis model for post-anastomotic

Table 2. Diagnostic accuracy of 16-slice multidetector computed tomographic angiography for the detection of significant stenoses in the coronary artery bypass graft segments

	Proximal anastomosis	Body of graft	Distal anastomosis	Overall
Evaluability	105/107 (98%)	184/190 (96%)	162/202 (80%)	451/499 (90%)
Sensitivity	9/9 (100%)	9/9 (100%)	14/17 (82%)	32/35 (91%)
Specificity	96/96 (100%)	174/175 (99%)	140/145 (96%)	410/416 (98%)
Positive predictive value	9/9 (100%)	9/10 (90%)	14/17 (82%)	32/38 (84%)
Negative predictive value	96/96 (100%)	174/174 (100%)	140/143 (97%)	410/413 (99%)
Diagnostic accuracy	105/105 (100%)	183/184 (99%)	154/162 (95%)	442/451 (98%)
Overall sensitivity	9/9 (100%)	9/10 (90%)	14/19 (73%)	32/38 (84%)

Table 3. Diagnostic accuracy of 16-slice multidetector computed tomographic angiography for the detection of significant stenoses in coronary artery bypass grafts and native coronary arteries

	All grafts	Arterial grafts	Venous grafts	Native coronary arteries
Evaluability	451/499 (90%)	183/211 (86%)	268/288 (93%)	862/1210 (71%)
Sensitivity	32/35 (91%)	6/7 (85%)	29/31 (93%)	243/296 (82%)
Specificity	410/416 (98%)	173/176 (98%)	234/237 (98%)	424/566 (75%)
Positive predictive value	32/38 (84%)	6/9 (66%)	29/32 (90%)	243/385 (63%)
Negative predictive value	410/413 (99%)	173/174 (99%)	234/236 (99%)	424/477 (88%)
Diagnostic accuracy	442/451 (98%)	179/183 (97%)	263/268 (98%)	667/862 (77%)
Overall sensitivity	32/38 (84%)	6/8 (75%)	29/33 (87%)	243/391 (62%)

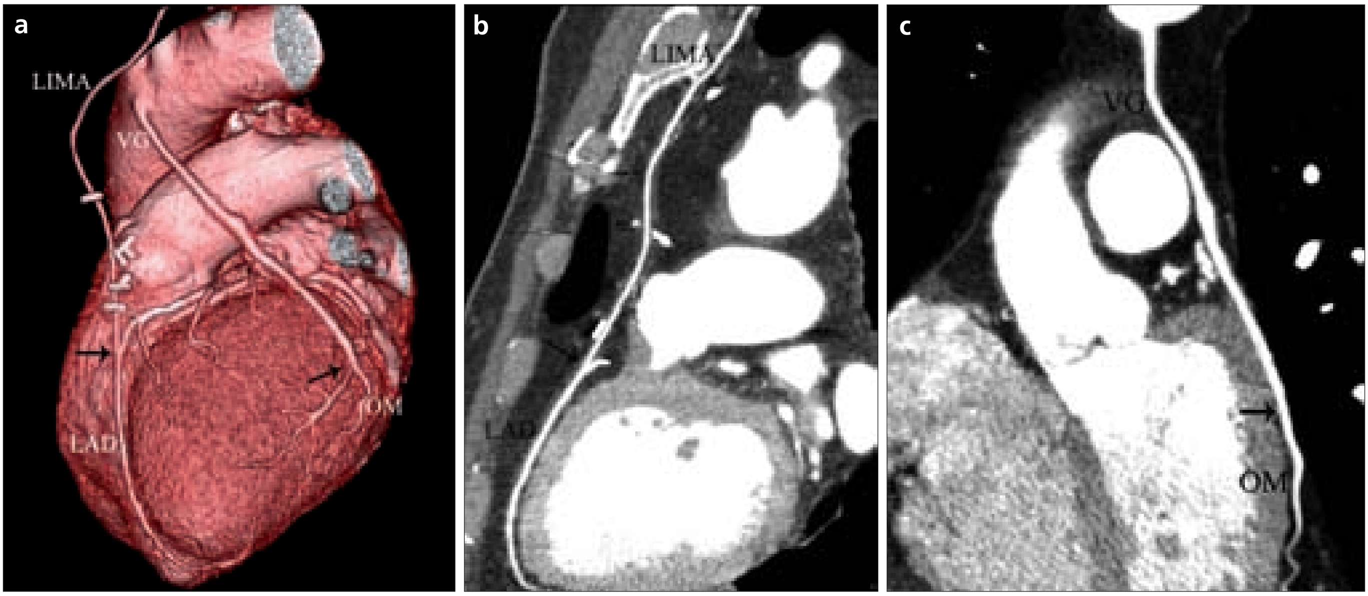


Figure 1. a–c. Volume rendering **(a)** and curved multiplanar reconstruction **(b, c)** MDCT images show patent left internal mammary artery (LIMA) to left anterior descending coronary artery (LAD) graft and patent aortocoronary venous graft (VG) to obtuse marginal artery (OM). Arrows indicate distal anastomotic sites.

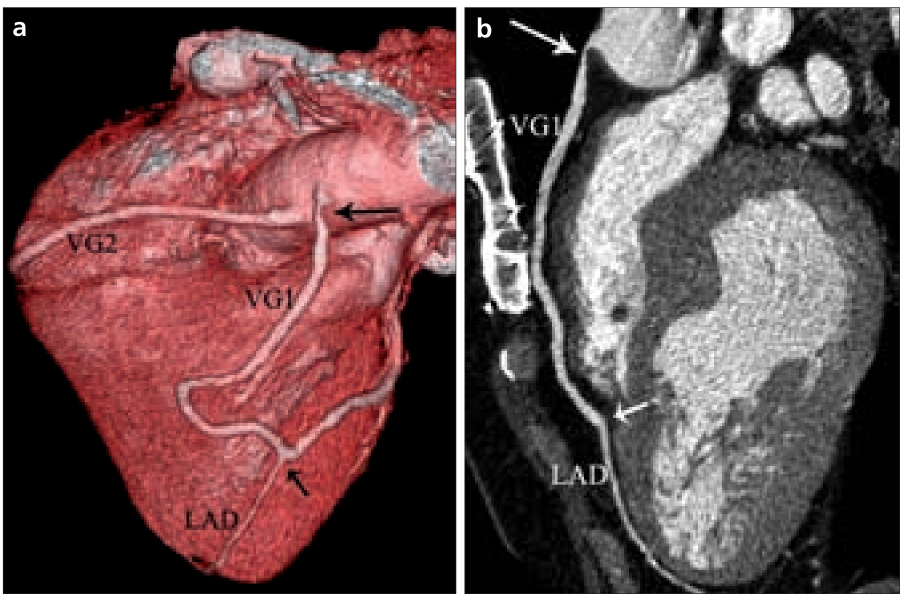


Figure 2. a, b. Volume rendering MDCT image **(a)** shows significant eccentric stenosis at the proximal anastomotic site *(long arrow)* of the sequential venous graft (VG1) to left anterior descending artery (LAD) and obtuse marginal artery. Patent aortocoronary venous graft (VG2) to right coronary artery is also seen. Curved multiplanar reconstruction MDCT image **(b)** shows hypodense noncalcifying plaque *(long arrow)* causing significant stenosis at the proximal anastomotic site of the venous graft to LAD. Short arrow indicates distal anastomotic site.

recipient vessels was good in 142 cases (70.3%), sufficient in 32 (15.8%), and poor in 28 cases (13.9%). The causes of poor image quality were identified as small arterial lumen (<1.5 mm) combined with poor opacification in 15 (53.6%) cases, motion artifact in 9 (32.1%) cases, and calcification in 4 cases (14.3%). Overall evaluability of 16-slice MDCT for post-anastomotic recipient coronary arteries was 86.1% (174/202).

Discussion

The small diameters and the constant and rapid movement of the coronary arteries make their visualization by CT challenging. The rotation speed of CT scanners has been a limiting factor in achieving sufficient temporal resolution. The feasibility of coronary artery imaging by CT was initially shown using 4-slice MDCT scanners with rotation times of 500 ms, using half-scan reconstruction algorithms that used data collected during approximately 180° of rotation to reconstruct one image. Nevertheless, with 4-slice MDCT scanners, image quality was inadequate for analysis in approximately 35% of patients studied, and it was shown that heart rate was a determinant of image quality (6–8). The subsequent development of 16- and 64-slice MDCT led to further decrease in rotation times and improved temporal resolution. With the development of gantry rotation speed of 370 ms, 16-slice MDCT achieved a temporal resolution of 188 ms, which has led to greater diagnostic accuracy (9–19). The 64-slice MDCT implemented a rotation time of 330 ms, resulting in a half-scan temporal resolution of 165 ms. Although 64-slice MDCT scanners were the first to allow highly accurate identification of significant CAD, regular (and preferably low) heart rates were still required (20–22). Most recently, dual-source CT has provided considerably increased temporal resolution of 83 ms to image the heart with reliably good image quality. Images with dual-source CT show less blurring, particularly at higher heart rates of 80–100 beats/min (23, 24).

As improvement of MDCT technology continues, this method is gaining increasing acceptance as a diagnostic

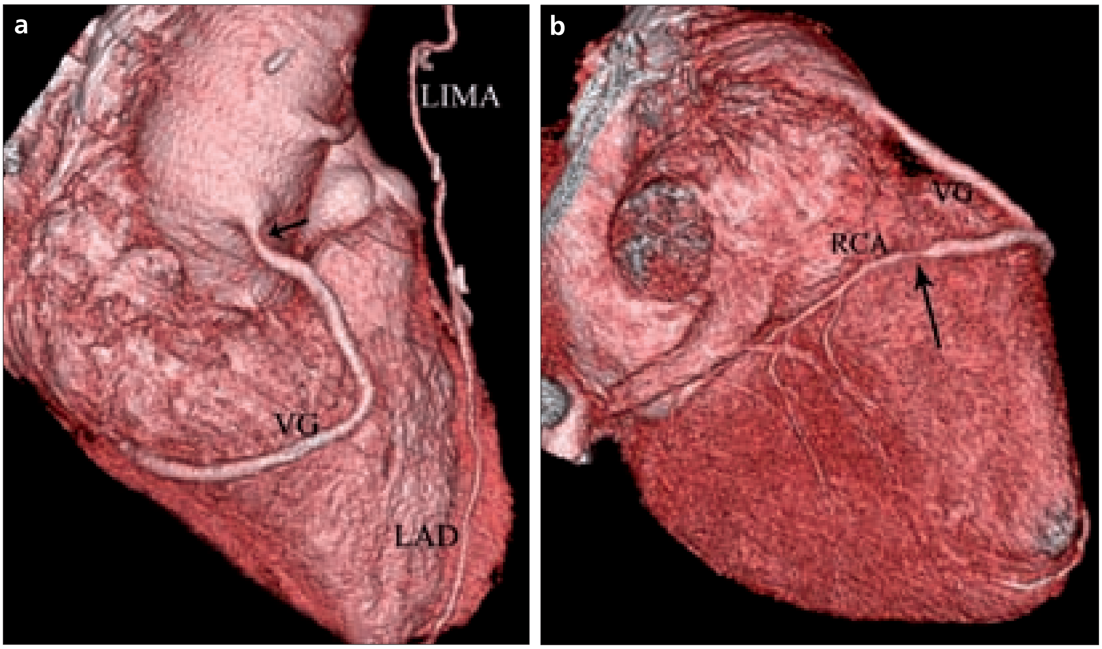


Figure 3. a, b. Volume rendering MDCT images **(a, b)** show nonsignificant stenosis at the proximal anastomotic site (*short arrow,* **a**) and significant stenosis at the distal anastomotic site (*long arrow,* **b**) of the aortocoronary venous graft (VG) to right coronary artery (RCA). Patent left internal mammary artery (LIMA) to left anterior descending artery (LAD) graft is also present.

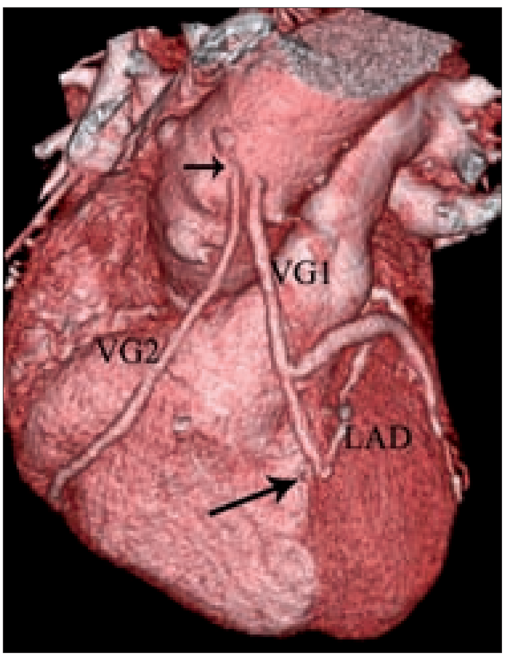
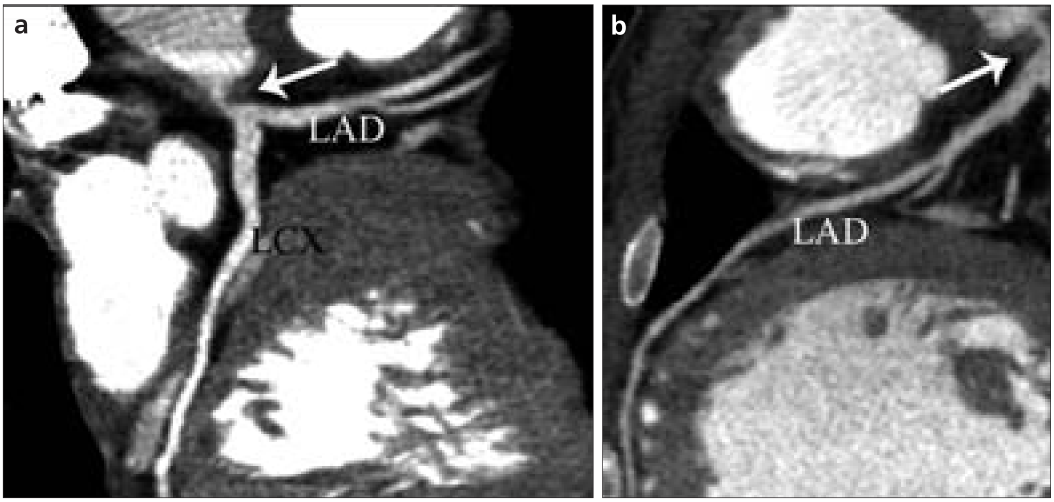


Figure 4. Volume rendering MDCT image shows venous sequential graft (VG1) to left anterior descending artery (LAD) and diagonal artery and venous graft (VG2) to right coronary artery (RCA). Distal anastomotic site of VG1 to LAD is occluded *(long arrow)*. Significant stenosis of the proximal anastomotic site of the VG2 to RCA is also seen *(short arrow)*.

cardiac imaging modality, allowing detection of native coronary artery and bypass grafts lesions with high spatial resolution. Earlier studies using 4-slice MDCT showed promising results regarding the assessment of significant bypass stenoses. However, because of artifact caused by residual motion, surgical clips, and insufficient opacification, a significant number of grafts (up to 38%) were unevaluable for the presence or absence of significant obstructive disease (6–8). The introduction of 16-slice MDCT increased the number of grafts that were able to be assessed, leading to increased diagnostic accuracy of significant stenosis. With the use of the 16-slice MDCT, sensitivity and specificity were between 95% and 100% in evaluation of bypass graft patency. For the evaluation of significant graft stenosis, sensitivities and specificities varied between 80% to 96% and 85% to 95%, respectively. Optimum performance was observed in patients with heart rates below 70 beats/min. Assessment of the distal anastomosis site, in particular, remained challenging with 16-slice MDCT (9–19). Recently, the introduction of 64-slice MDCT technology has provided increased spatial and temporal resolution compared with previous scanner generations, which may improve visualization of grafts and distal anastomoses, but coronary calcifications and surgical metallic clip artifact remain challenging issues (20–22). The most recently introduced dual-source CT scanner provides high diagnostic accuracy for the evaluation of coronary arteries without heart rate control (23, 24). Studies of the ability of dual-source CT angiography to evaluate CABG status have not yet been published.

Most studies performed with 16-slice MDCT have been restricted to the evaluation of the bypass grafts (9–12, 15, 16). But ischemic symptoms in patients after CABG surgery may be caused by obstruction of CABG or by progression of disease in the native coronary arteries. Therefore, evaluation cannot be limited to the bypass grafts but also requires assessment of native coronary arteries. However, evaluation of native coronary arteries in patients with CABG is hampered because of severe calcifications; in most cases, adequate imaging is not possible with MDCT,



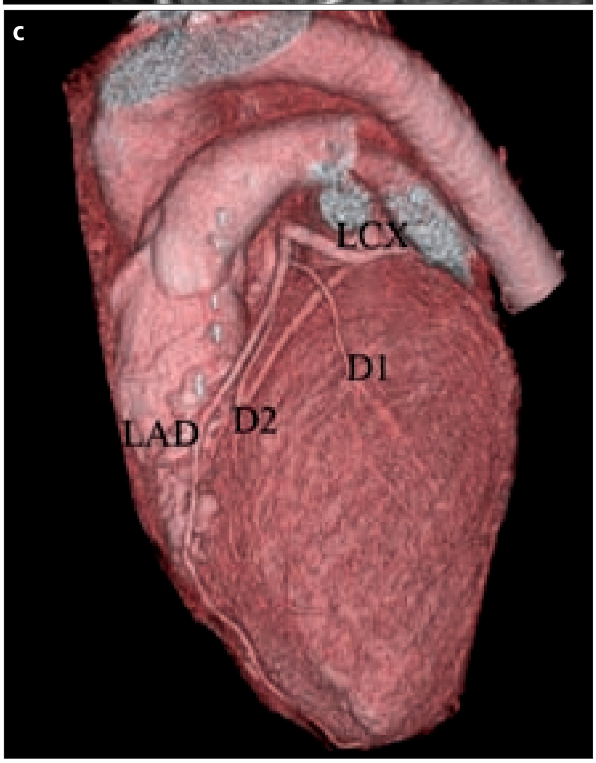


Figure 5. a–c. Curved multiplanar reconstruction MDCT images **(a, b)** show significant stenosis of the left main coronary artery *(arrow)*. Note the surgical clips along the path of the occluded left internal mammary artery graft to left anterior descending artery in volume rendering MDCT image **(c)**. (D1, first diagonal branch; D2, second diagonal branch; LAD, left anterior descending artery; LCX, left circumflex artery.)

despite technical advances such as 64-slice MDCT or dual-source CT (20–24).

Our study, using a scanner equipped with 16 × 0.625 mm collimation, showed high diagnostic accuracy (100%) in detection of complete graft occlusion. Overall evaluability of patent graft sections in a segment-based model was 90.4%. We demonstrated that the causes of nonevaluable segments were mostly motion artifact in venous grafts and surgical metallic clip artifact in arterial grafts, particularly in the distal anastomotic site of internal mammary artery grafts. For the assessment of significant graft stenosis, we found a sensitivity of 91.4% and specificity of 98.5% in evaluable segments. Including all segments in the analysis (evaluable and nonevaluable), the overall sensitivity was 84.2%. The main problem in using 16-slice MDCT was limited evaluation of distal anastomotic site in our study.

Saphenous vein grafts can easily be depicted by MDCT angiography because of their larger diameter, their relative spatial fixation, and their low incidence of severe calcification. However, evaluation of arterial grafts, particularly internal mammary artery grafts, may be limited because of the smaller vessel diameter and sometimes insufficient contrast enhancement. Moreover, surgical vascular clips in the proximity of bypass grafts have frequently caused beam hardening and partial volume artifact that hamper exact assessment of the graft. This sort of artifact is often aggravated by cardiac motion.

Ability to evaluate the proximal anastomotic site and the body of grafts is very good with 16-slice MDCT. However, evaluation of distal anastomotic site may be more difficult and time-consuming (9–19). These segments need to be assessed from different views, using additional image reconstruction modalities. Indirect signs, such as complete contrast enhancement of the post-anastomotic recipient vessels, may also be used to assess bypass status. Comprehensive post-bypass surgery evaluation should include assessment of the native coronary arteries which is difficult in these patients because of severe calcification and diffusely narrowed arteries associated with advanced atherosclerotic disease. Because 16-slice MDCT is insufficient to accurately delineate significant stenosis in small arteries (<1.5 mm), extensively diseased coronary segments are usually deemed nonevaluable, which may limit the diagnostic usefulness of 16-slice MDCT for ruling out significant CAD in clinical practice.

Disadvantages of MDCT are radiation exposure (6.4 ± 0.9 mSv with ECG pulsing for routine coronary 16-slice MDCT) (25), the need for iodinated contrast agents, and the fact that a reduction of heart rate using beta-blockade is still necessary.

In conclusion, 16-slice MDCT reliably reveals bypass graft anatomy, allows very accurate evaluation of graft patency, and has excellent diagnostic accuracy in detecting graft stenoses with high sensitivity and specificity. But the evaluation of distal anastomotic site remains challenging because of residual motion or clips artifact, especially with higher heart rates. Because of its inability to detect native coronary artery stenosis, 16-slice MDCT is not a replacement for CCA. But 16-slice MDCT can be used in clinical practice as a noninvasive alternative imaging modality if graft dysfunction is clinically suspected but CCA is not primarily indicated.

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