Assessment of Coronary Artery Bypass Graft Patency by Multislice Computed Tomography

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The recently developed multislice computed tomography (MSCT) is capable of rapid imaging of cardiac structures, including coronary arteries, during a single breath-hold. We evaluated coronary artery bypass graft (CABG) patency by comparing MSCT results to those of contrast angiography. MSCT and contrast angiography were performed in 39 patients (10 women, 29 men and mean age 60.0 ± 7.8 years) with a total of 115 bypass grafts including 36 left internal mammary arteries, 4 right internal mammary arteries, 19 radial arteries, 2 gastroepiploic arteries and 54 vein grafts. Patients were investigated for an average of 14 ± 27 months (range 1 - 108 months) after CABG surgery. Contrast angiography showed a patency rate of 87.0% (100/115). Ninety-nine of these 100 patent grafts by contrast angiography and 14 of the remaining 15 occluded grafts were correctly classified by MSCT (93.3% sensitivity and 99.0% specificity for bypass graft occlusion). The positive and negative predictive values for bypass graft occlusion were 93.3% and 99%, respectively, with an overall diagnostic accuracy of 98.3% (97.2% for left internal mammary artery, 100% for radial artery, 98.1% for vein graft and 100% for other grafts). In conclusion, MSCT is a useful and accurate diagnostic tool for the evaluation of bypass graft patency.

Key Words: Computed tomography, coronary disease, graft

INTRODUCTION

Coronary artery bypass graft (CABG) surgery is the standard therapy in the majority of diffuse coronary diseases or multivessel diseases. However, ischemic symptoms recur in 4% to 8% of patients/year following CABG.[1,2] Recurrence of ischemic symptoms and further limitations of life quality are closely related to the status of bypass grafts. Saphenous vein grafts (SVG) are found to be occluded with a rate of 7% in the first week and 15 to 20% in the first year after CABG.[2,3] At 10 years postoperatively, approximately half of all SVG conduits are occluded and only half of the remaining patent grafts are free of significant disease.[2,3]

Contrast angiography is currently the gold standard of diagnostic tools to assess bypass graft patency. However, it is an invasive and potentially harmful diagnostic method with a procedure-related mortality of 0.15% and a morbidity of 1.5%.[4] Therefore, it is recommended only on strict indications. Non-invasive imaging methods such as conventional computed tomography (CT), spiral CT, electron-beam CT (EBCT) or magnetic resonance imaging (MRI) have been evaluated for the assessment of bypass graft patency.[5-11] However, they have significant limitations in reliable visualization of the coronary arteries.[5-11] Recently developed multislice computed tomography (MSCT), with effective scan times up to 0.25 seconds and multi-row detector array systems, enables rapid imaging of cardiac structures including coronary arteries during one breath-hold. We investigated CABG patency by comparing MSCT results to those of contrast angiography of bypass grafts.

MATERIALS AND METHODS

Subjects

MSCT and contrast angiography of 115 bypass grafts were performed in 39 patients (10 women, 29 men and mean age 60.0 ± 7.8 years), with 36 left internal mammary arteries (LIMA), 4 right internal mammary arteries (RIMA), 19 Y-type radial arteries (RA), 2 gastroepiploic arteries (GEA) and 54 vein grafts including 4 sequential grafts. Patients were investigated for an average of 14 ± 27 months (range 1 - 108 months) after CABG surgery.

All patients had a sinus rhythm and were in a stable clinical condition. Patients with a history of contrast allergy or renal failure, as well as patients unable to comply with breath-hold commands, were excluded from this study. All patients gave written informed consent.

Multislice computed tomography

MSCT was performed with a LightSpeed Plus MSCT scanner (GE medical systems, Milwaukee, WI). All images were acquired in inspiratory breathhold during intravenous injection of contrast dye in 4 parallel slices (1.25 mm collimation) with a gantry rotation time of 500 ms. The tube current was 270 - 300 mA at 120-140 kV. Using the algorithm of 180° multislice cardiac interpolation, cross-sectional images were reconstructed with a slice thickness of 1.25 mm using retrospective ECG gating. For each patient, data sets were created routinely for 40% and 70% of the cardiac cycle (R wave-to-R wave interval). For each individual artery, the data set containing the fewest motion artifacts was used for further evaluation. On the basis of the cross-sectional images, 3D images of the heart structures with native coronary arteries and bypass grafts were reconstructed on an off-line workstation computer. The MSCT images were evaluated by two independent radiologists blinded to the contrast angiography findings of the bypass grafts. The bypass grafts were considered as occluded if grafts were not identified in both cross-sectional images and 3-dimensional MSCT images. Significant stenosis of bypass graft was defined as luminal diameter

stenosis ≥ 70%.

Contrast angiography of bypass grafts

Bypass graft contrast angiography was performed either before or after MSCT. The mean time interval between contrast angiography and MSCT was 17 ± 22 days, during which time no patients developed new ischemia-related symptoms or events such as hospital admission, unstable angina, myocardial infarct or stroke. In all patients, bypass graft contrast angiography was performed via the femoral artery or RA by the Judkins method. Contrast angiograms of bypass grafts were evaluated by two independent cardiologists. Failure to cannulate or visualize the graft even after aortic root injection was considered to indicate an occluded graft. Significant stenosis of bypass graft was defined as luminal diameter stenosis ≥ 70%.

Statistical analysis

All data were expressed as mean ± standard deviation. The sensitivity, specificity, accuracy and positive or negative predictive values for the detection of bypass graft occlusion of significant stenosis by MSCT were evaluated using conventional contrast angiography as a reference.

True-positive for the detection of either graft occlusion or significant narrowing was defined to exist when a bypass graft, judged to be occluded or significantly narrowed on MSCT, was also found to be occluded or significantly narrowed on coronary angiography, respectively. True-negative for the detection of graft occlusion or significant narrowing was defined to exist when a bypass graft, judged to be patent or have stenosis < 70% on MSCT, was also found to be patent or have stenosis < 70% on coronary angiography, respectively. False-positive for the detection of graft occlusion or significant narrowing was defined to exist when a bypass graft, judged to be occluded or significantly narrowed on MSCT, was also found to be patent or have stenosis < 70% on coronary angiography, respectively. False-negative for the detection of graft occlusion or significant narrowing was defined to exist when a bypass graft, judged to be patent or have stenosis

< 70% on MSCT, was also found to be occluded or significantly narrowed on coronary angiography, respectively.

Sensitivity was calculated as true positive/(true positive + false negative). Specificity was calculated as true negative/(true negative + false positive). Positive predictive value resulted from true positive/(true positive + false positive), and negative predictive value from true negative/(true negative + false negative). Accuracy was determined by (true positive + true negative)/total number of the grafts.

RESULTS

The MSCT investigation was completed successfully in all patients without any complications. A total of 115 bypass grafts were evaluated. Of the 36 LIMA and 4 RIMA grafts, 34 were to the left anterior descending coronary artery, 3 to the right coronary artery, two to a diagonal branch and one to an obtuse marginal branch. Of the 19 RA Y-grafts connected with LIMA, 9 were to an obtuse marginal branch, 8 to a diagonal branch and 2 to right coronary artery. Both GEA grafts were to the right coronary artery. Of the 54 vein grafts including 4 sequential grafts, 24 were to the right coronary artery, 14 to an obtuse marginal branch, 12 to a diagonal branch and 4 to the left anterior descending artery.

Invasive angiography of bypass grafts showed that 100 of 115 grafts were patent and 15 were

totally occluded (1 LIMA graft, 5 RA Y-grafts and 9 SVGs). Thus, the patency rate of the evaluated grafts was 87.0%

Ninety-nine of the 100 patent grafts and 14 of 15 occluded grafts on coronary angiography were correctly identified by MSCT (Fig. 1 - 3). Thus, the overall sensitivity and specificity of MSCT for the detection of bypass graft occlusion were 93.3% and 99.0%, respectively. The positive and negative predictive values for bypass graft occlusion were 93.3% and 99.0%, respectively. The overall diagnostic accuracy was 98.3% (97.2% for LIMA, 100% for RA, 98.1% for vein graft and 100% for other grafts) (Table 1).

One bypass graft which was falsely interpreted as occluded on MSCT was a LIMA graft to a diagonal branch (Fig. 4A). The angiography of this graft showed a competing counter blood flow from a native coronary artery (Fig. 4B). Also, one RA Y-graft, which showed a decreased blood flow on MSCT, was found to be patent but revealed a competing counter blood flow from a native coronary artery. Another bypass graft judged falsely as patent was a saphenous vein bypass graft to the right coronary artery.

As to the presence or absence of significant stenosis, four LIMA grafts could not be evaluated because of numerous metal clips along their course. However, other bypass grafts showed no technical limitation in diagnosing high-grade ($\geq$ 70%) stenosis. Whereas the overall specificity (97.8%), negative predictive value (97.8%), and diagnostic accuracy (95.8%) of MSCT for the

Table 1. Sensitivity, Specificity, and Negative and Positive Predictive Values for the Detection of Graft Occlusion on MSCT

| Values for the detection of graft occlusion	Overall (n=115)	LIMA Grafts (n=36)	RA Y-grafts (n=19)	Vein Grafts (n=54)	Other Grafts (n=6)
Sensitivity	93.30% (14/15)	100% (1/1)	100% (5/5)	88.90% (8/9)	(0/0)
Specificity	99.00% (99/100)	97.10% (34/35)	100% (14/14)	100% (45/45)	100% (6/6)
Positive predictive value	93.30% (14/15)	50% (1/2)	100% (5/5)	100% (8/8)	(0/0)
Negative predictive value	99.0% (99/100)	100% (34/34)	100% (14/14)	97.80% (45/46)	100% (6/6)
Diagnostic accuracy	98.30% (113/115)	97.20% (35/36)	100% (19/19)	98.10% (53/54)	100% (6/6)
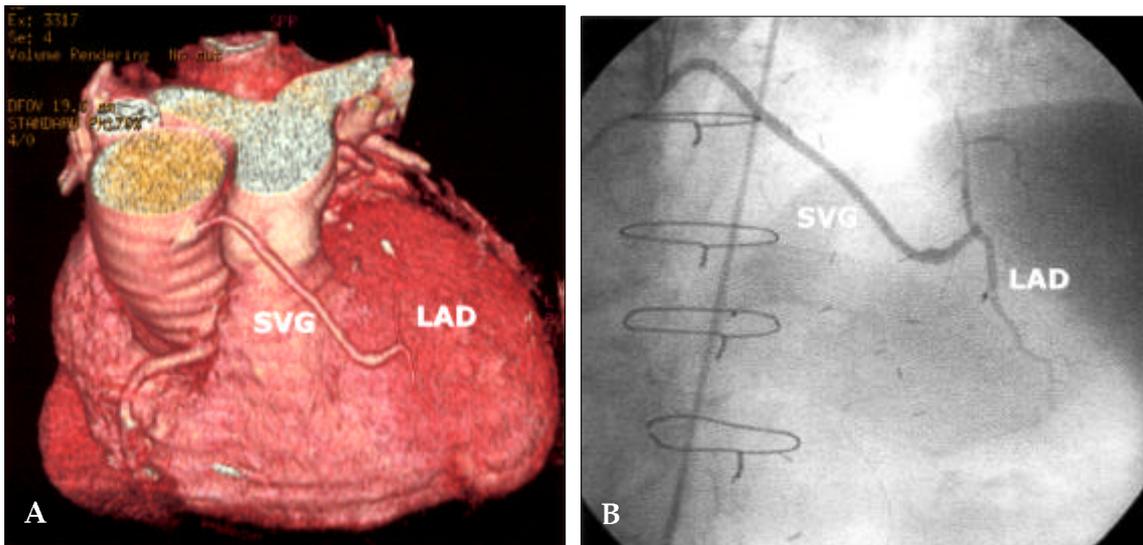
Fig. 1. A saphenous vein graft (SVG) from the aorta to the left anterior descending (LAD) artery on MSCT (A) and contrast angiography (B).
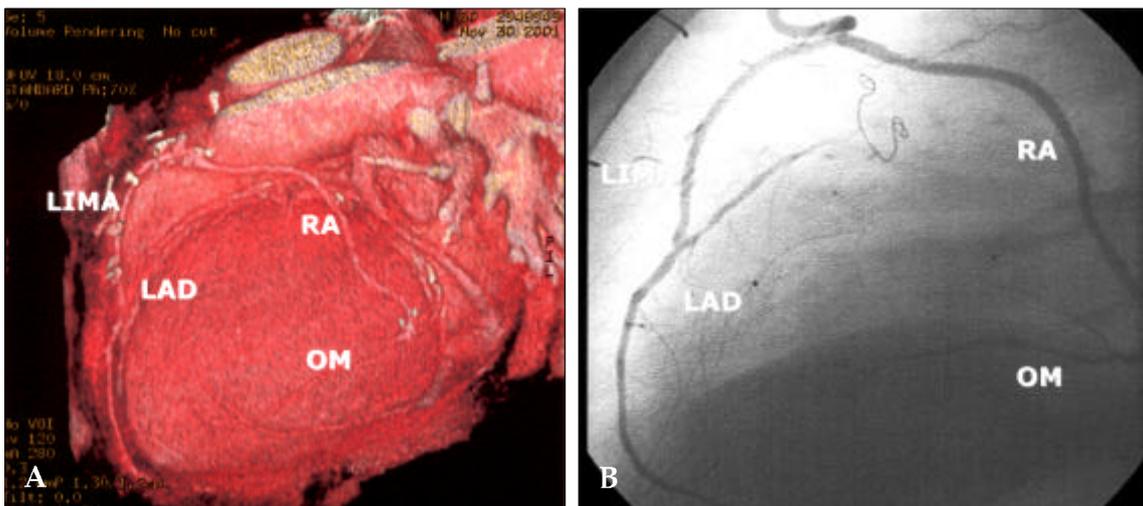

Fig. 2. A left internal mammary artery (LIMA) graft to the left anterior descending (LAD) artery and a radial artery (RA) Y-type graft from the LIMA to an obtuse marginal (OM) branch on MSCT (A) and contrast angiography (B).

detection of significant stenosis were comparable to those for the detection of graft occlusion, the overall sensitivity (66.7%) and positive predictive value (66.7%) for significant stenosis were lower than those for graft occlusion (Table 2).

DISCUSSION

Our study demonstrates that MSCT can be successfully applied to visualize the bypass grafts and assess their patency. There have been various studies comparing non-invasive imaging modalities such as conventional CT, EBCT, and MRI for evaluation of bypass patency. The first study which investigated bypass graft status with conventional CT was reported in 1980 by Brundage, et al.[5] However, the efficacy of the conventional CT was limited by cardiac and respiratory artifacts.

MRI showed sensitivities of 90-98% and specificities of 72-100% in identifying patent bypass
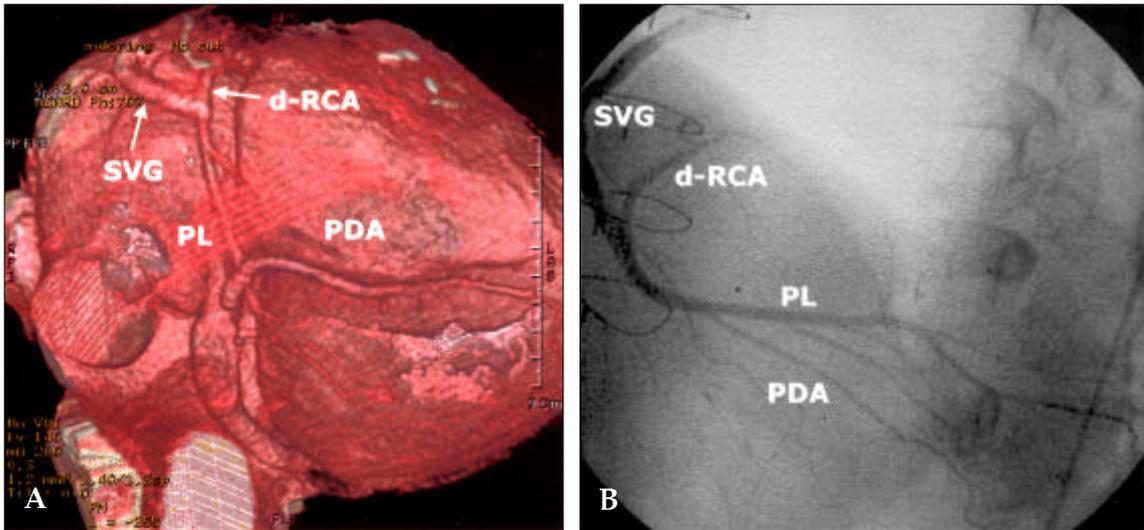
Fig. 3. A saphenous vein graft (SVG) from the aorta to the distal right coronary artery (d-RCA) on MSCT (A) and contrast angiography (B) (PL: posterior lateral branch, PDA: posterior descending artery).
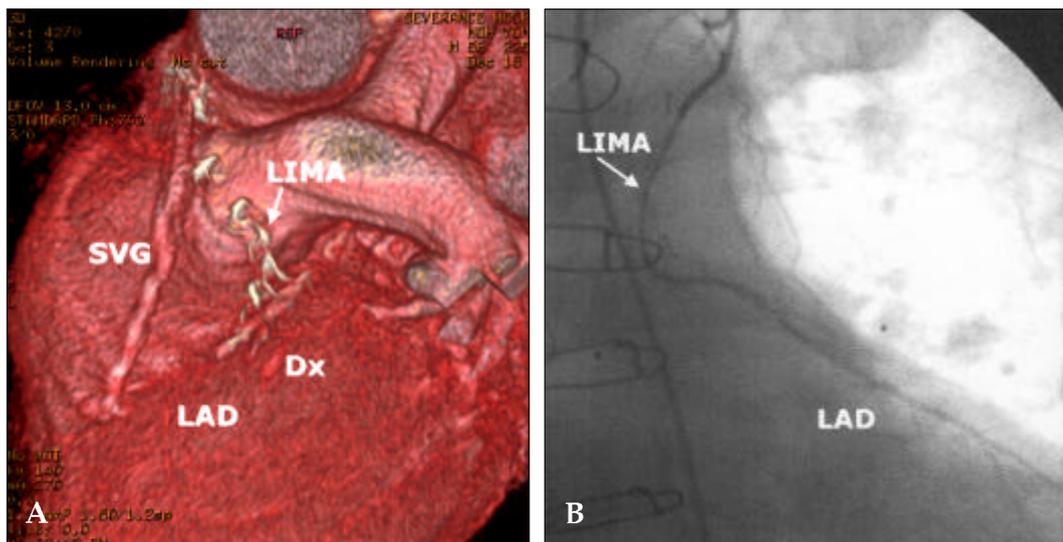

Fig. 4. A left internal mammary artery (LIMA) graft to the left anterior descending (LAD) artery was not visualized on MSCT (A) except metal clips. However contrast angiography (B) showed patent LIMA with competing counter flow from LAD. (Dx: diagonal branch).

grafts depending on different technical methods.[6-9] The most important advantage of magnetic resonance angiography is the absence of exposure to ionizing radiation and iodine contrast agents. However, this technique is still limited by poor spatial resolution, long scan times, image degeneration by metal objects (stents, sternal wires, pacemakers), and contraindications to magnetic resonance.[10]

The EBCT scanner is a non-mechanical, sequential CT scanner with a high temporal resolution (100 ms).[10,11] Several groups evaluated bypass graft patency with EBCT. Achenbach, et al.[11] and Ha, et al.[12] reported high values for the sensitivity and specificity of EBCT for the detection of graft patency. However, the in-plane spatial resolution is known to be slightly lower than in MSCT.[13] The EBCT scanner's configuration limits the number of

Table 2. Sensitivity, Specificity, and Negative and Positive Predictive Values for the Detection of High-degree Graft Stenosis on MSCT

High-grade stenosis (of patent grafts)	Overall (n=100)	LIMA Grafts (n=35)	RA Y-grafts (n=14)	Vein Grafts (n=45)	Other Grafts (n=6)
Evaluation possible	96% (96/100)	88.60% (31/35)	100% (14/14)	100% (45/45)	100% (6/6)
Sensitivity	66.70% (4/6)	100% (2/2)	100% (1/1)	33.30% (1/3)	(0/0)
Specificity	97.80% (88/90)	93.10% (27/29)	100% (13/13)	100% (42/42)	100% (6/6)
Positive predictive value	66.70% (4/6)	50% (2/4)	100% (1/1)	100% (1/1)	(0/0)
Negative predictive value	97.80% (88/90)	100% (27/27)	100% (13/13)	95.50% (42/44)	100% (6/6)
Diagnostic accuracy	95.80% (92/96)	93.50% (29/31)	100% (14/14)	95.60% (43/45)	100% (6/6)

cross sections to 40. The entire heart, a distance of about 12 cm, can be covered in one breathhold with a 3 mm protocol at the cost of a reduction in Z-axis resolution.[10,11] Furthermore, the imaging subject has to be positioned very carefully to avoid cutting off the bypass grafts either in their proximal or distal course.

The main advantages of MSCT compared with other non-invasive imaging modalities are the relatively rapid imaging time and the high spatial resolution attributable to the multi row detector system. MSCT has been investigated by two study groups for the accuracy of graft patency detection. Engelmann, et al.[14] compared the sensitivity and positive predictive value of MSCT for the detection of bypass graft patency with those of MRI. There were no significant difference between the two imaging modalities, although the positive predictive value of MSCT for vein graft patency was slightly higher than that of MRI (100% vs. 92%). Ropers, et al.[15] performed MSCT in 65 patients with 182 bypass grafts and found 97% sensitivity and 98% specificity for detecting by-pass occlusion. Compared to these studies, we included a greater variety of bypass graft types such as Y-graft using RA free graft, RIMA, GEA and sequential vein grafts. The results of our study showed that the values for diagnostic accu-racies are still comparable with those of previously reported studies.

Despite the high accuracy for graft occlusion detection, the correct diagnosis of high-degree graft stenosis using MSCT remains, however, associated with more technical limitations. Ropers, et al.[15] reported that 38% of grafts in their study could not be evaluated for the presence of high-degree stenosis because of metal clips and motion artifacts which impaired image quality and exact determination of graft stenosis grade. In our study, four of 100 patent bypass grafts, all LIMA grafts, were not evaluable mainly because of metal clip artifacts.

Another major technical limitation of MSCT is known to be the somewhat impaired temporal resolution resulting from its 250-ms acquisition time.[16] In patients with heart rates > 70 beats/ min, artifacts due to the greater diastolic motion, especially in the left circumflex and right coronary arteries, were noted. This limitation is usually minimized by using a retrospective electrocar-diographic (ECG)-trigger technique, which allows the reconstruction of cross-sectional images at any desired time point within the RR interval and thus permits optimization of axial image reconstruc-tion. With this technique, we had no difficulties diagnosing occlusion or high-degree stenosis of bypass grafts to left circumflex or right coronary arteries. However, since the ECG-triggered tech-nique requires a regular heart rhythm, MSCT is not applicable to patients with severe arrhythmia.

In this study, a LIMA graft falsely interpreted as occluded on MSCT showed a competing counter blood flow from a native coronary artery on contrast angiography. This false positive bypass occlusion can be explained by the delayed arrival of LIMA blood flow with contrast dye due to the competing counter flow. Therefore, moderate stenosis of the native coronary artery proximal to the anastomosis with a bypass graft can cause a competing counter flow to the graft and diminish the accuracy for graft occlusion detection in MSCT. Also, in cases of collateralized, totally obstructed vessels, side branches, distal segments or vessels with a lumen diameter of <2 mm, an accurate diagnosis of graft occlusion is known to be jeopardized.[16]

In conclusion, our study demonstrates that MSCT can properly visualize various types of bypass graft and provide accurate evaluation of the bypass patency.

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