

Noninvasive Evaluation of Coronary Artery Bypass Grafts with 16-Slice Multidetector Computed Tomography

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ABSTRACT

Background: The aim of this study was to investigate the diagnostic accuracy of 16-slice multislice, multidetector computed tomography (MDCT) angiography for the evaluation of grafts in patients with coronary artery bypass grafting (CABG).

Methods: Fifty-eight consecutive patients with CABG who underwent both MDCT and conventional invasive coronary angiography were included. The median time interval between the 2 procedures was 10 days (range, 1-32 days). The sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of MDCT for the detection of occluded grafts were calculated. The accuracy of MDCT angiography for detecting significant stenoses in patent grafts and the evaluability of proximal and distal anastomoses were also investigated.

Results: Optimal diagnostic images could not be obtained for only 3 (2%) of 153 grafts. Evaluation of the remaining 150 grafts revealed values for sensitivity, specificity, PPV, NPV, and diagnostic accuracy of the MDCT angiography procedure for the diagnosis of occluded grafts of 87%, 97%, 94%, 93%, and 92%, respectively. All of the proximal anastomoses were optimally visualized. In 4 (8%) of 50 patent arterial grafts, however, the distal anastomotic region could not be evaluated because of motion and surgical-clip artifacts. The accuracy of MDCT angiography for the detection of significant stenotic lesions was relatively low (the sensitivity, specificity, PPV, and NPV were 67%, 98%, 50%, and 99%, respectively). The number of significant lesions was insufficient to reach a reliable conclusion, however.

Conclusion: Our study showed that MDCT angiography with 16-slice systems has acceptable diagnostic performance for the evaluation of coronary artery bypass graft patency.

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INTRODUCTION

Coronary artery bypass grafting (CABG) is a surgical procedure commonly used for the treatment of coronary artery disease. Because graft patency is one of the most important factors influencing the survival of patients with a history of CABG, imaging techniques that demonstrate graft patency are of great importance in the follow-up of these patients [Garrett 1973; Campeau 1984; VACABG 1984; Bourassa 1991; Fitzgibbon 1996]. Conventional invasive coronary angiography is the current gold standard technique for the imaging of native coronary arteries and bypass grafts; however, because of the invasive nature and the rare but significant risks of conventional coronary angiography, new noninvasive imaging modalities for reliably visualizing the coronary anatomy are under investigation. Multislice, multidetector computed tomography (MDCT) angiography is a promising noninvasive imaging modality. The aim of this study was to evaluate the diagnostic accuracy of 16-slice MDCT angiography to demonstrate graft patency and to detect significant (>50% luminal stenosis) graft lesions in patients who have undergone CABG.

MATERIALS AND METHODS

Patient Characteristics

Fifty-eight consecutive patients (52 men, 6 women; mean \pm SD age, 61 \pm 9.1 years) who had undergone multislice computed tomography angiography and conventional invasive coronary angiography (ICA) with clinical indications were included in the study. ICA and MDCT angiography indications were assessed by evaluating symptoms, electrocardiography, exercise treadmill testing, and myocardial perfusion imaging results. The median time interval between MDCT and ICA investigations was 10 days (range, 1-32 days). None of the patients developed new ischemic symptoms or adverse cardiac events (such as worsening heart failure, need for hospitalization, myocardial infarction, and unstable angina pectoris) in the interval between the 2 angiographic studies. Only clinically stable patients in sinus rhythm were included in the study. Patients with atrial fibrillation, frequent premature

beats, renal dysfunction (serum creatinine >2.0 mg/dL), decompensated heart failure (New York Heart Association classes III and IV), unstable angina pectoris, and a known history of allergic reaction to iodine contrast material were excluded. The study protocol was reviewed and approved by the institutional ethics committee, and written informed consent was obtained from all patients.

MDCT Imaging

The MDCT examinations were performed with a 16-slice MDCT scanner (Sensation 16; Siemens, Erlangen, Germany). After an anteroposterior scout image was obtained (120 kV, 50 mA) with the patient in a supine position, the scanning range was planned individually for each patient, from the midclavicle to the apex of the heart (mean distance, 18.3 cm; range, 15.8–21.0 cm). Image acquisition was performed with an inspiratory breath hold. A total of 120 mL of iodinated contrast agent (300 mg/mL Iopamiro; Bracco, Milan, Italy) was injected into an antecubital vein via a 20-gauge catheter. Contrast was administered by a power injector (Envision CT; Medrad, Pittsburgh, PA, USA) at a flow rate of 4 mL/s. Optimal contrast enhancement was achieved by locating a region of interest on the ascending aorta. As soon as the density in the region of interest reached a threshold of 100 Hounsfield units, the patient was instructed to maintain an inspiratory breath hold, and scanning was started. Contrast-enhanced MDCT data were collected at a 1-mm slice thickness, a 420-millisecond rotation time (detector collimation, 0.75 mm; table feed, 3.4 mm/rotation), and 0.28 pitch. The tube current was 500 mA at 120 kV. Images were obtained by retrospective electrocardiography and half-scan techniques.

MDCT Image Evaluation

The MDCT images were evaluated on an offline workstation (Leonardo; Siemens) by 2 radiologists who were blinded to the ICA results and experienced in the field of MDCT-based coronary angiography. Images were also evaluated by a third radiologist when a consensus could not be reached. Besides the evaluation of axial images, contrast-enhanced scans were also investigated on the offline workstation by using multiplanar reconstructions, maximum-intensity projections, and volume-rendering reconstructions prepared with axial images.

Conventional ICA

Conventional ICA was performed with the Siemens Coroscop and Bicor Systems (Siemens Medical Systems, Munich, Germany). The Seldinger method was used for access via the right femoral artery, and selective angiography evaluations of native coronary arteries and bypass grafts were obtained by using 6F diagnostic catheters. All of the left internal mammary artery (LIMA) grafts were selectively catheterized. Aortography in the left oblique position was performed for nonselective visualization of saphenous vein grafts that could not have been shown selectively but were known from the operation records to have been used. Grafts that could not be visualized by aortography were accepted as occluded. Coronary angiograms were evaluated by 2 experienced cardiologists, and decisions were made by consensus.

Data Analysis and Statistics

MDCT angiographic images were investigated for visual evaluability of arterial and venous grafts, and grafts were classified as evaluable or nonevaluable. Then, evaluable grafts were investigated for patency and classified as either patent or occluded. Patent grafts were further evaluated for the presence of significant stenotic lesions (>50% luminal stenosis). Evaluability of distal and proximal anastomotic regions and the presence of significant stenotic lesions in these regions were also investigated in MDCT angiographic images, and the evaluability of anastomotic regions was defined as a percentage.

The results of MDCT angiography and ICA were compared with regard to graft patency and the presence of significant stenotic lesions in patent grafts. The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and diagnostic accuracy of MDCT coronary angiography were calculated by using ICA results as the reference gold standard.

RESULTS

A total of 153 grafts (56 arterial and 97 saphenous vein grafts) used in 58 patients were evaluated in the study. The median time interval between CABG and MDCT angiography was 6 years (range, 1–17 years). Of the 56 arterial grafts, 49 (87%) were LIMA grafts, 6 (11%) were radial artery grafts, and 1 (2%) was a right internal mammary artery graft. Forty-seven (96%) of the LIMA grafts were anastomosed to the left anterior descending coronary artery (LAD), 1 (2%) was grafted to the diagonal branch of the LAD, and 1 (2%) was grafted to the obtuse marginal (OM) branch of left circumflex coronary artery. Of 97 saphenous vein grafts, 9 (9%) were anastomosed to the LAD, 40 (41%) were anastomosed to the OM branch of the left circumflex coronary artery, 18 (19%) were anastomosed to the diagonal branch of the LAD, and 30 (31%) were grafted to the right coronary artery (RCA).

Of 153 venous and arterial grafts, 57 (37%) were occluded according to ICA. Arterial grafts showed a greater patency performance than venous grafts. Seven (13%) of 56 arterial grafts and 50 (53%) of 97 venous grafts were found to be occluded.

MDCT angiography was performed in all of the patients without any complications. The mean (\pm SD) heart rate was 63.4 ± 6.2 beats/minute (bpm), and 32 (55%) of the patients were on-blocker treatment prior to the investigation. Orally administered propranolol (20 mg) was used to control heart rate in 36 of the patients with a heart rate >70 bpm at the beginning of the investigation.

One hundred fifty (98%) of the 153 grafts could be evaluated optimally with MDCT angiography. Only 3 arterial grafts (2%) (2 LIMA-to-LAD grafts and 1 radial artery graft to the OM branch of the left circumflex artery) could not be evaluated because of motion and surgical-clip artifacts. All of the saphenous vein grafts were evaluable. Fifty of the 150 evaluable grafts were reported as occluded by MDCT. Evaluability was 100% (97/97) for venous grafts and 95% (53/56) for arterial grafts (Table 1).

Table 1. Comparison of Results of Multidetector Computed Tomography and Invasive Coronary Angiography

Graft Type	Total No.	True Positive	True Negative	False Positive	False Negative	Nonevaluable	Diagnostic Accuracy
Saphenous vein graft, n	97	44	44	3	6		88/97 (91%)
Arterial graft, n	56	3	49		1	3	52/56 (93%)
Total, n	153	47	93	3	7	3	140/153 (92%)

The diagnostic accuracy of MDCT angiography was calculated as 92% (140/153) when the results were analyzed with ICA results used as a reference. The diagnostic accuracy of MDCT angiography was 93% (52/56) and 91% (88/97) for venous and arterial grafts, respectively. The overall sensitivity, specificity, PPV, and NPV of MDCT angiography for graft occlusion were 87% (47/54), 97% (93/96), 94% (47/50), and 93% (93/100), respectively, when the results of 150 evaluable grafts were compared with the ICA results (Table 2).

Table 2. Comparison of the Results of Multidetector Computed Tomography and Invasive Coronary Angiography (Results for the 150 Evaluable Grafts)*

Graft Type	No. of Grafts	Sensitivity	Specificity	PPV	NPV
Saphenous vein graft	97	88% (44/50)	94% (44/47)	94% (44/47)	88% (44/50)
Arterial graft	53	75% (3/4)	100% (49/49)	100% (3/3)	98% (49/50)
Total	150	87% (47/54)	97% (93/96)	94% (47/50)	93% (93/100)

*PPV indicates positive predictive value; NPV, negative predictive value.

Forty-four of 47 venous grafts that were reported as occluded by MDCT angiography were confirmed as such by ICA. Three venous grafts (1 to the OM branch of the left circumflex artery, 1 to the diagonal branch of the LAD, 1 to the RCA) were misevaluated as occluded by MDCT angiography, and 6 grafts (2 to the LAD, 2 to the OM branch of the left circumflex artery, 1 to the diagonal branch of the LAD, and 1 to RCA) that seemed to be patent by MDCT angiography were shown to be occluded by ICA. Table 3 shows the detailed diagnostic performance of MDCT angiography according to

the coronary artery to which the saphenous vein graft had been anastomosed.

The analysis of the results of the evaluable LIMA grafts showed that in 45 of 46 LIMA grafts reported to be patent by MDCT angiography, the diagnosis was confirmed by ICA. MDCT incorrectly interpreted 1 of 2 occluded LIMA-to-LAD grafts as patent and accurately diagnosed the other. None of the LIMA grafts were falsely reported to be occluded by MDCT, and this result yields a specificity of 100% for the evaluation of LIMA graft patency.

Two of the 5 evaluable radial artery grafts were diagnosed as occluded by MDCT, and this result was confirmed by ICA. There were no false-positive or false-negative results for the evaluation of radial artery graft patency by MDCT angiography. The only right IMA graft evaluated in the study was correctly reported as patent by MDCT. The diagnostic performance of MDCT angiography for the evaluation of arterial graft patency is summarized in Table 4.

Three of the arterial grafts (2 LIMA-to-LAD grafts, 1 radial artery graft to the OM branch of the left circumflex artery) could not be optimally evaluated by MDCT angiography because of intense motion and surgical-clip artifacts. No contrast flow could be seen beyond a level on the CT images of these grafts, suggesting occlusion; however, these grafts have not been reported as occluded because of the nonoptimal image quality due to artifacts. Actually, these grafts have been proved occluded by ICA. If we accept these 3 nonevaluable but apparently occluded grafts as correctly diagnosed by MDCT, the sensitivity of MDCT angiography for arterial graft patency increases to 86% (6 of 7 grafts) from 75% (3 of 4 grafts). Likewise, the overall sensitivity, PPV, and diagnostic accuracy of MDCT angiography for the 153 grafts increases to 88% (50 of 57 grafts), 93% (50 of 53 grafts), and 93% (143 of 153 grafts), respectively.

Table 3. Performance of Multidetector Computed Tomographic Angiography for the Evaluation of Saphenous Vein Graft Patency*

Graft Type	No. of Grafts	Sensitivity	Specificity	PPV	NPV	Diagnostic Accuracy
Ao-LAD	9	60% (3/5)	100% (4/4)	100% (3/3)	67% (4/6)	78% (7/9)
Ao-OM	40	91% (19/21)	95% (18/19)	95% (19/20)	90% (18/20)	93% (37/40)
Ao-Dia	18	86% (6/7)	91% (10/11)	86% (6/7)	91% (10/11)	89% (16/18)
Ao-RCA	30	94% (16/17)	92% (12/13)	94% (16/17)	92% (12/13)	93% (28/30)
Total	97	88% (44/50)	94% (44/47)	94% (44/47)	88% (44/50)	91% (88/97)

*PPV indicates positive predictive value; NPV, negative predictive value; Ao, aorta; LAD, left anterior descending coronary artery; OM, obtuse marginal branch of the left circumflex artery; Dia, diagonal branch of the LAD; RCA, right coronary artery.

Table 4. Performance of Multidetector Computed Tomography Angiography for the Evaluation of Arterial Graft Patency (Results for the 53 Evaluable Grafts)*

Graft Type	No. of Grafts	Sensitivity	Specificity	PPV	NPV
LIMA-LAD	45	50% (1/2)	100% (43/43)	100% (1/1)	98% (43/44)
LIMA-Dia	1		100% (1/1)		100% (1/1)
LIMA-OM	1		100% (1/1)		100% (1/1)
Radial-OM	5	100% (2/2)	100% (3/3)	100% (2/2)	100% (3/3)
RIMA-RCA	1		100% (1/1)		100% (1/1)
Total LIMA	47	50% (1/2)	100% (45/45)	100% (1/1)	98% (45/46)
Total arterial	53	75% (3/4)	100% (49/49)	100% (3/3)	98% (49/50)

*PPV indicates positive predictive value; NPV, negative predictive value; LIMA, left internal mammary artery; LAD, left anterior descending coronary artery; Dia, diagonal branch of the LAD; OM, obtuse marginal branch of the left circumflex artery; RIMA, right internal mammary artery; RCA, right coronary artery.

The proximal anastomotic regions of all patent grafts ($n = 100$) could be optimally evaluated by MDCT angiography for the presence of significant stenoses. The proximal and distal anastomotic regions of all patent saphenous vein grafts ($n = 97$) were optimally imaged and evaluated. All proximal anastomoses of 53 evaluable arterial grafts were optimally evaluated; however, the distal anastomotic region in 4 (8%) of 50 patent arterial grafts could not be evaluated optimally for



Figure 1. Multidetector computed tomography (MDCT) angiographic image of a venous graft to the right coronary artery. Arrow shows a significant lesion that was accurately diagnosed by MDCT.

the presence of significant lesions because artifacts of metallic surgical clips impaired the image quality.

MDCT angiography revealed significant stenotic lesions (>50% luminal stenosis) in 4 saphenous vein grafts, and 2 of these lesions were confirmed by ICA. One of the venous grafts, which had 90% luminal stenosis but seemed to be patent by MDCT, was actually occluded according to ICA. The other significant lesion was not interpreted as significant by ICA. A lesion at the distal anastomotic region of a venous graft that seemed to be nonsignificant by MDCT was found significant by ICA. There were no significant lesions in arterial grafts that had been evaluable and judged as patent by MDCT angiography. A lesion in the distal anastomosis of a LIMA-to-LAD graft shown to be occluded by 50% to 60% according to ICA was accepted as nonsignificant by MDCT angiography. Considering these results, the sensitivity, specificity, PPV, and NPV of MDCT angiography for detecting significant stenoses were calculated as 67%, 98%, 50%, and 99%, respectively. Figures 1 and 2 show MDCT and ICA images of a significant lesion in a venous graft to an RCA, which was accurately diagnosed by MDCT angiography.

DISCUSSION

In this study, we evaluated the diagnostic accuracy of 16-slice MDCT angiography for the assessment of coronary artery bypass graft patency and for the presence of significant lesions in the patent grafts. Furthermore, the performance of MDCT in the evaluation of proximal and distal anastomotic regions of the grafts was also analyzed.

The median time interval between CABG operation and angiographic evaluation was 6 years, and as expected from the graft age, the proportion of occluded grafts was high. Fifty-seven (37%) of 153 grafts were shown to be occluded by ICA. The patency rate was relatively high for arterial grafts (88%);

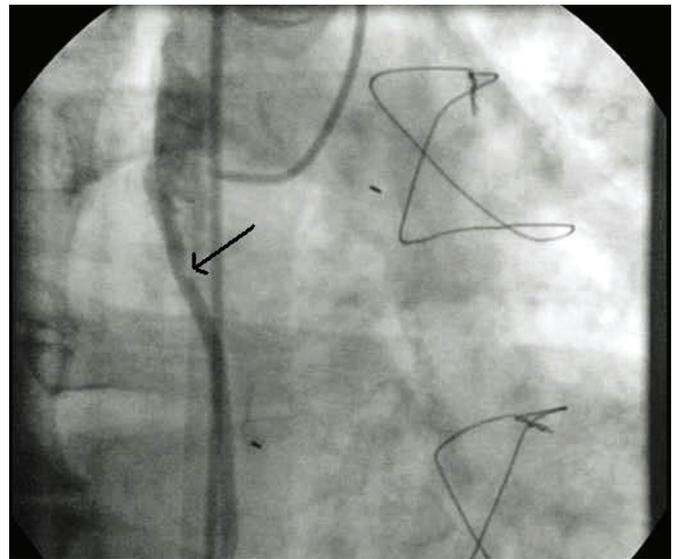


Figure 2. Invasive angiographic image of the same venous graft in Figure 1. Lesion (arrow) confirms the result of multidetector computed tomography angiography.

however, >50% of the venous grafts were occluded. These findings are compatible with the results of trials that have investigated long-term patency of bypass grafts and survival of the patients [Garrett 1973; Campeau 1984; VACABG 1984; Bourassa 1991; Fitzgibbon 1996].

Multislice MDCT angiography has been performed safely with no complications in any of the 58 study patients. Compared with native coronary arteries, bypass grafts are less affected by cardiac motion, have fewer calcifications, and exhibit wider luminal diameters. These factors contribute to the improved image quality and produce a better evaluation of bypass grafts by MDCT. In our study, 153 arterial and venous grafts were imaged by MDCT. Only 3 arterial grafts could not be evaluated because of suboptimal image quality, whereas all of the saphenous vein grafts were evaluable. Overall, the evaluability rate for the grafts was 98%. This rate is better than that of 4-slice systems and comparable with those found in studies that have used 16-slice and newer 64-slice systems [Ropers 2001; Schlosser 2004; Onuma 2007; Türkvatan 2009; Romagnoli 2010]. In contrast to many similar studies, none of the patients were excluded from our study by using an upper limit on the heart rate to diminish motion artifacts, but oral-blockers were given to patients whose basal heart rate was >70 bpm.

MDCT angiography with a 16-slice system showed a good performance in the present study for the evaluation of graft patency. The overall sensitivity and specificity of MDCT angiography for the detection of graft patency were 87% and 97%, respectively. Although the sensitivity was somewhat low (but acceptable), the specificity, PPV (94%), and NPV (93%) were comparable with the results of other studies that used 16-slice systems [Yamamoto 2006; Houslay 2007; Uva 2008; von Kiedrowski 2009]. The largest study thus far, which was conducted with 64-slice MDCT angiography in 138 patients, reported sensitivity and specificity values of 97% each for the evaluation of bypass graft occlusion and stenosis [Meyer 2007]. These results show that newer technology with improved image quality has superior diagnostic accuracy; on the other hand, the 16-slice system has an acceptable performance as well.

The visualization and assessment of a proximal bypass anastomosis is easier than for the distal anastomosis, because the image quality of this region is not affected by metallic-clip and calcification-related artifacts. Thus, evaluation of the distal anastomotic region usually is more problematic and may be time-consuming because of the suboptimal image quality. Accordingly, the proximal anastomoses of all patent saphenous vein grafts and all evaluable arterial grafts in our study were visualized with adequate image quality. On the other hand, the distal anastomoses of 4 (8%) of 50 patent arterial grafts could not be evaluated because of the presence of surgical clips. In contrast, all distal venous bypass anastomoses were evaluated with optimal image quality. Considering that studies conducted with 64-slice systems [Feuchtner 2007; Meyer 2007; Onuma 2007] revealed evaluability rates for anastomotic regions of 94% to 100%, the 92% evaluability rate of distal arterial grafts obtained in our study is acceptable for a 16-slice system.

The diagnostic performance of MDCT angiography for the evaluation of significant stenoses in bypass grafts was relatively low in the present study, compared with the results of similar studies that used 16-slice systems [Schlosser 2004; Türkvatan 2009; von Kiedrowski 2009]. Only 4 significant lesions were detected in 153 bypass grafts in the 58 patients included in our study, however, and this inadequate number of lesions is not sufficient to reach a correct interpretation regarding the accuracy of 16-slice MDCT angiography in detecting graft lesions. Nonetheless, the specificity (98%) and NPV (99%) of MDCT were nearly perfect for detecting significant graft lesions.

Sixteen-slice systems reveal bypass graft anatomy with good accuracy and are useful for patients for whom ICA has failed for assessing grafts. Sixteen-slice MDCT angiography can also be used as a noninvasive modality when graft dysfunction is suspected, other noninvasive methods are inconclusive, and invasive angiography is not certainly indicated. Impaired image quality due to motion and surgical-clip artifacts, poor evaluability of the native coronary arteries and the distal anastomotic regions of arterial grafts, and the relatively high radiation exposure are the main drawbacks of 16-slice MDCT angiography. The use of newer technology certainly improves the image quality and diagnostic accuracy of MDCT angiography but does not completely resolve problems related to surgical-clip artifacts and calcifications [Feuchtner 2007; Malagutti 2007; Onuma 2007]. Therefore, MDCT angiography remains far from being a perfect replacement for diagnostic ICA for now. Improvements in image quality and diagnostic accuracy, as well as minimization of radiation exposure, are the main goals for the development of future devices.

In conclusion, our study has shown that MDCT angiography with a 16-slice system has an acceptable diagnostic performance for the evaluation of coronary artery bypass graft patency and can still be used for this purpose if newer systems with improved performance are not available.

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