Evaluation of Venous and Arterial Conduit Patency by 16-Slice Spiral Computed Tomography

E. Martuscelli, MD; A. Romagnoli, MD; A. D’Eliseo, MD; M. Tomassini, MD; C. Razzini, MD; M. Sperandio, MD; G. Simonetti, MD; F. Romeo, MD; J.L. Mehta, MD, PhD

Background—Computed tomography has been shown to be useful in the evaluation of aortocoronary bypass grafts (CABG). This is the first prospective study to evaluate the accuracy of a new-generation scanner in the detection of patency and significant stenoses (>50% decrease in diameter) of venous and arterial grafts in patients with previous CABG.

Methods and Results—In 96 patients (80 males, mean age 62 years) with previous CABG, a multislice computed tomography (MSCT) scan was performed (collimation 16×0.625 mm). Patients with atrial fibrillation, renal failure, severe respiratory disease, severe heart failure, heart rate >70 bpm despite therapy, or unstable angina were excluded. A total of 285 conduits implanted on the native coronary arteries at the time of CABG were evaluated. MSCT data were analyzed by 2 independent radiologists and compared with the results of conventional angiography. Three patients were excluded from analysis. All conduits were judged evaluable in 84 patients. Among these patients, MSCT correctly diagnosed 54 occluded grafts and 4 significant stenoses on the body of the grafts. Of the 17 significant anastomotic lesions, MSCT correctly diagnosed 15. For these 84 patients, diagnostic accuracy was 99%, sensitivity was 97%, and specificity was 100%. When all 93 patients were considered, the sensitivity of MSCT in diagnosing significant stenoses was 96%.

Conclusions—MSCT with the new-generation scanner allows for accurate assessment of venous and arterial conduits in patients with previous CABG with a high degree of sensitivity and specificity. Exclusion criteria and radiation exposure remain limitations of the method. (Circulation. 2004;110:3234-3238.)

Key Words: computed tomography ▪ angiography ▪ bypass ▪ surgery

Conventional computed tomography (CT) has been investigated for noninvasive assessment of venous conduits after CABG since the early 1980s. The sensitivity and specificity of this method have been estimated to be between 80% and 100% and between 72% and 95%, respectively. Because of the presence of cardiac and respiratory artifacts, conventional CT has been restricted to the assessment of venous graft patency, with no possibility of detecting flow-limiting stenosis.1–5 The availability in the 1990s of the spiral multislice CT (MSCT) has allowed for ECG-gated reconstruction of images, the ability to analyze arterial conduits, and detection of significant stenoses.6–8

Venous and arterial conduits are ideal vessels for evaluation by MSCT because of their greater diameter, their direction with reference to the plane of the cross beam, and their relative spatial fixation. Arterial and venous conduits are usually free of severe calcification, which can impair assessment of the coronary lumen by this method.9 Several investigators have examined the potential of MSCT to detect bypass graft occlusion and stenosis. The first-generation MSCT scanner, which is able to acquire 4 slices with a subsecond rotation time, showed high sensitivity and specificity in the detection of venous and arterial occlusions, but identification of the presence or absence of significant stenoses was still inadequate (ie, 62%) for the application of this method in the clinical setting.10–16 The introduction of a new-generation MSCT scanner with an isodimensional voxel (isotropic resolution) and the ability to acquire up to 16 submillimetric slices provides more accurate detection of the vascular lumen with a shorter scan time and less occurrence of cardiac or respiratory artifacts. This new-generation MSCT challenges the value of conventional angiography in coronary artery imaging.17–21 In the present study, we examined the accuracy of the 16-slice MSCT scanner in the detection of patency and stenoses of arterial and venous conduits in patients who previously had CABG.

Methods

Patients
MSCT was performed on an outpatient basis in 96 consecutive patients (80 males and 16 females, mean age 62 years) with a previous history of CABG. The patients were referred for invasive
coronary and bypass angiography because of ischemia or suspected progression of coronary artery disease. Selective angiography of the bypass conduits was performed independently of the MSCT results in all patients 20±10 (mean±SD) days after MSCT. Mean time from CABG was 7 years (range 5 to 10 years). A total of 285 conduits had been implanted on the native coronary arteries at the time of CABG; of these, 96 were arterial and 189 were venous.

All patients received a β-blocker (atenolol 50 to 100 mg/d, based on body mass and basal heart rate) at least 3 days before MSCT to obtain a stable low heart rate. Exclusion criteria for inclusion in the study were presence of multiple ectopic beats, atrial fibrillation, heart rate ≥70 bpm despite therapy, renal insufficiency, severe lung disease, severe heart failure (Canadian Cardiac Society class IV), and unstable angina. The study protocol was approved by the institutional review board.

MSCT Scan Protocol
MSCT was performed with a General Electric LightSpeed-16 scanner. First, a noncontrast localization scan was performed that yielded an anteroposterior view of the chest; this allowed us to position the imaging volume, which extended from the distal tract of the ascending aorta to the inferior border of the heart. Next, a precise estimation of the contrast agent transit time was made with a bolus intravenous injection of 40 mL of nonionic low-osmolality contrast agent (Iopamiro 370, Bracco spa). In the third step, the volume data set was acquired in spiral mode with simultaneous acquisition of 16 parallel slices with collimation 16×0.625 mm. The gantry rotation time was 500 ms, peak tube voltage was 140 kV, tube current was 10 to 440 mA in 5-mA increments, and the table feed averaged 2.9 mm/rotation. Contrast agent (145 mL, 4 mL/s) was injected as a single injection, and CT scan was initiated with a delay based on the previously determined contrast agent transit time. Patients were instructed to hold their breath during the scan. To facilitate the relatively long period of breath holding, a short session of hyperventilation was performed before patients were scanned. ECG was digitized and recorded continuously in all patients. Depending on the covered volume (mean 146 mm, range 125 to 180 mm), the scan time was 25 to 32 seconds (mean 28 seconds), and the breath holding time was 27 to 33 seconds (mean 31 seconds).

Image Reconstruction
ECG-gated image reconstruction was made with a desktop environment (ImageWork, General Electric). We used 2 reconstruction algorithms depending on the heart rate. If the heart rate was <60 bpm, a single sector for image reconstruction was used with a temporal resolution of 250 ms; if the heart rate was between 60 and 70 bpm, 2 sectors for image reconstruction were used with a temporal resolution of 125 ms. Transaxial images were reconstructed with a slice thickness of 0.625 mm at 0.4-mm increments, optimizing the position of the reconstruction window by increment or decrement of 10% in a range between 40% and 80%.

The image data set was transferred to a dedicated work station (Advantage window 4.1, General Electric) for postprocessing. Depending on vessel morphology and quality of the data, several postprocessing techniques were applied to assess arterial and venous conduits. These included thin-slab maximum-intensity projection, reconstruction of multiple curved cross sections, vessel tracking, and 3D volume rendering. Two radiologists experienced in cardiac CT evaluated the images independently without knowledge of the coronary angiograms.

Data Analysis
Both readers classified arterial and venous conduits as evaluable or unevaluable by visual estimation. Evaluable conduits were classified as patent or occluded. In patent grafts, presence or absence of a significant stenosis (≥50% reduction in diameter) was identified. Stenoses were classified on the basis of their location in the body of the graft and at the anastomotic site. In case of disagreement between the 2 readers, a decision was reached by consensus.

Conventional Coronary Angiography
Conventional coronary angiography was performed with Philips Integris 5000 equipment (Medical Philips System [MPS]). Angiograms were evaluated by an expert cardiologist without knowledge of the MSCT results. Quantitative coronary analysis was performed offline by a resident MPS program that used the catheter tip for calibration. A diameter reduction ≥50% was defined as significant.

Statistical Analysis
Conventional coronary angiography was regarded as the standard of reference. Accuracy of MSCT was expressed in terms of sensitivity, specificity, positive predictive value, and negative predictive value. Concordance between readers 1 and 2 for the detection of occlusion or significant conduit stenosis by MSCT was calculated by the Cohen κ value, according to the formula κ=Io−Ie/Io+1−Ie, where Io is the observed concordance and Ie the expected concordance.

Results
All patients underwent MSCT without any complication. Mean heart rate during data acquisition was 58±5 bpm. In 3 patients (3%), analysis was not done; in 2, ECG gating was lost during acquisition, and in 1, the patient failed to understand the breathing instructions correctly. Ninety-three patients were available for analysis with 278 conduits (184 venous and 94 arterial). Among these 93 patients, 84 were judged fully evaluable (88% of the total), and 9 patients (9% of the total) were judged not fully evaluable. Among these 9 patients, 5 were unable to hold their breath until the end of data acquisition, and 4 patients had 1 or more ectopic beats during data acquisition. In these patients, some tracts of the conduits were imaged normally, but in others, the images were distorted by movement artifacts. The analysis in terms of patency was done in all conduits with 4 venous bypasses judged occluded both by MSCT and by angiography. The detection of significant stenoses was incomplete. One lesion was diagnosed by angiography analysis that was not detected by MSCT; this stenosis was localized to the distal anastomosis of a venous conduit judged evaluable by MSCT.

In the 84 fully evaluable patients, 251 conduits were available for analysis; of these, 85 were arterial and 166 venous (Table). Of the 85 arterial conduits, 12 were judged to be occluded (Figure 1A) and 73 patent by MSCT, with a sensitivity and specificity of 100%. Of the 166 venous conduits, 42 were judged to be occluded and 124 patent by MSCT (Figure 2), with a sensitivity and specificity of 100%. Relative to the detection of significant stenosis, 4 angiographic stenoses were localized in the body of the conduits (Figure 1B) and 17 at the anastomotic site (Figure 3). MSCT diagnosed correctly all stenoses localized in the body, but 2 of the 17 anastomotic site lesions could not be defined by MSCT, probably because of insufficient opacification of the distal anastomoses. Thus, sensitivity of MSCT was 90% and specificity 100% for assessment of conduit stenosis. Considering all data on occluded conduits and significant stenoses, sensitivity of MSCT was 97%, specificity was 100%, and diagnostic accuracy was 99%.

When all patients who were judged to be fully evaluable and those who were judged to be incompletely evaluable were considered together, MSCT identified 46 venous conduits as occluded and 12 arterial conduits as occluded, with a sensitivity and specificity of 100%. Relative to the detection
of significant stenoses, MSCT correctly identified all 4 significant stenoses localized in the body of the graft and 15 of the 18 significant stenoses localized on the anastomotic site. All 3 significant stenoses not identified by MSCT were on the distal anastomotic site. Overall sensitivity was 96%. The $\kappa$-value for interobserver variation in the detection of patency and significant stenoses of arterial and venous conduits was 0.95.

Discussion

CABG is performed around the world as a means to treat myocardial ischemia. For evaluation of bypass conduits, conventional coronary angiography remains the gold standard; however, limitations of this procedure include a small but definable risk, the need for multiple staff members, and the cost related to the procedure itself and the ensuing observational period. Because of this, alternative noninvasive methods have been investigated for imaging of venous and arterial conduits.\textsuperscript{23} Electron-beam CT, also known as ultrafast CT, allows for the generation of motion-free images with an ECG-triggered data acquisition within 100 ms, but limitation in spatial resolution does not allow for precise visualization of the distal anastomosis.\textsuperscript{7} MRI potentially meets the requirement of noninvasive follow-up procedures for patients with previous CABG, permitting flow mapping of the conduits as well.\textsuperscript{24} This technique is widely available and can be performed without any x-ray exposure; specificity of the MRI technique with regard to graft patency is reported to be 76% to 91%,\textsuperscript{24,25} with only 66% of distal anastomoses identified correctly.\textsuperscript{25}

Relative to the role of MSCT, Ropers et al\textsuperscript{16} performed a prospective comparison of MSCT with invasive coronary angiography in 65 patients with CABG, using a scanner able to acquire 4 parallel slices of heart of 1-mm collimation. Accuracy of MSCT in the detection of occluded conduits was very high, with sensitivity and specificity rates of 97% and

<table>
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<tr>
<th>Bypass Graft Type</th>
<th>No. of Bypass Grafts</th>
<th>Evaluability by MSCT, %</th>
<th>Patency, MSCT/CAG</th>
<th>Occlusion, MSCT/CAG</th>
<th>Graft Stenosis, MSCT/CAG</th>
<th>Proximal Anastomosis Stenosis, MSCT/CAG</th>
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<td>LIMA-LAD</td>
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CAG indicates coronary angiography; LIMA, left internal mammary artery; LAD, left anterior descending artery; I, intermediate branch; OM, obtuse marginal branch; RIMA, right internal mammary artery; RCA, right coronary artery; FG, free graft; AO, aorta; PD, posterior descending artery; PL, posterolateral branch; and DIA, diagonal branch.
98%, respectively; however, 38% of 124 patent grafts could be not evaluated by MSCT because of insufficient suppression of respiratory and motion artifacts (11 cases), arrhythmias (5 cases), poor opacification (7 cases), and metallic clips (17 cases). Within the limits of conduits judged evaluable, sensitivity and specificity in the detection of significant stenosis were 75% and 92%, respectively. When conduits judged unevaluable were included in the analysis, the overall accuracy for detection of stenoses was quite low, with a sensitivity of 48%.

To the best of our knowledge, the present study is the first prospective investigation of the new-generation scanner in the imaging of arterial and venous conduits. Compared with the old-generation 4-slice MSCT, this scanner presents many important technical improvements that can explain the high level of accuracy. For example, spatial resolution is greatly improved by simultaneous acquisition of 16 slices as thin as 0.625 mm and by the potential to have an isodimensional volume element (isotropic voxel). Furthermore, as with conventional x-ray equipment, image noise decreases and image quality improves as the number of photons received by the detector arrays increases. This scanner has an x-ray tube that is able to deliver a high tube current, which means a much better signal/noise ratio and much better quality of the images. Because of this, metal clips can be defined clearly (Figure 1A) and do not impair analysis of blood vessels. In the present study, 88% of patients were judged fully evaluable, and only 3 distal anastomotic stenoses were missed by MSCT, with an overall sensitivity of 96%. In spite of this, some limitations of the method are still present.

Limitations of the Method
Metal ceramic x-ray tubes able to deliver high tube current may be a concern in terms of exposure of the patient to radiation. We do not have specific data on radiation exposure, but it is likely that the effective dose is higher than 8 to 9 mSv, which is the mean dose for patients undergoing 16-slice MSCT for evaluation of native coronary arteries and is much higher than the dose received during conventional coronary angiography. Nonetheless, a roentgen-modulation ECG gating can reduce radiation exposure by up to 50%. Second, atrial fibrillation should be considered a contraindication to MSCT, but atrial or ventricular ectopic beats can impair quality of the images, rendering them useless. Third, flow characteristics of the bypass, including direction of the filling and runoff, are related to the integrity of the wall of the conduit and to resistance in the native coronary artery. Data acquisition by MSCT is not capable of providing information about flow characteristics and the functional state of the conduit. Fourth, infusion of a large amount of iodine contrast agent is a limitation of MSCT. Because of this, patients with severe heart failure or overt renal failure were excluded from the present study.

Presence of severe respiratory disease was also considered an exclusion criteria in the present study because of the duration of the breath holding required for data acquisition. In addition, patients with unstable angina were sent immediately for conventional coronary angiography. Heart rate >70 bpm is not a contraindication for MSCT evaluation; however, at low heart rates, a reconstruction algorithm with 1 or 2 sectors for reconstruction allows for better definition of the metal clips and distal anastomosis.

Figure 2. Occlusion of distal anastomosis of aorta to left anterior descending coronary artery venous graft diagnosed by volume rendering MSCT (A), advanced vessel analysis (B), and coronary angiography in left lateral projection (C).

Figure 3. Critical stenosis at proximal anastomotic site of aorta-obluse marginal branch venous graft diagnosed by volume rendering MSCT (A), advanced vessel analysis MSCT (B), and coronary angiography in right anterior oblique view (C).
It has been shown that 16-slice MSCT can be useful in the assessment of native coronary arteries. The evaluation of native coronary circulation was not the aim of the present study, and thus, we cannot provide detailed information on this aspect. It has been shown in previous studies with 4-slice MSCT that severe calcifications and extensive atherosclerotic disease of the native coronary arteries are frequently found in patients with previous CABG, and these factors impair the evaluability of the native coronary segments and limit the accuracy of the method.

Future Directions

Scanners able to acquire up to 64 slices with a slice thickness of <0.5 mm and served with a gantry rotation time <400 ms will soon be available for clinical use. These will greatly reduce the time required for data acquisition, reducing the duration of breath holding and reducing motion artifacts. This will also reduce the amount of contrast medium required for the scan. These factors are likely to translate into clinically significant improvements in diagnostic accuracy and applicability of the method.

Conclusions

The present study shows the potential of the MSCT with a scanner able to acquire 16 slices as thin as 0.625 mm in the assessment of venous and arterial conduits in patients with previous CABG, with an overall sensitivity of 96%. However, applicability of the method, at this time, is limited by the exclusion criteria and radiation exposure.

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References

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