Noninvasive assessment of coronary artery bypass graft patency by multislice computed tomography

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Computed tomography; Coronary artery bypass graft.

Background. **Follow-up of coronary artery bypass after cardiac surgery is routinely performed by means of X-ray coronary angiography. However, this is an invasive procedure, expensive and includes ionizing radiation exposure, hospitalization and a small risk of complications. Multislice computed tomography is a noninvasive diagnostic tool that permits the visualization of the cardiac structures, including the coronary arteries. The purpose of our study was to compare multislice computed tomography with conventional angiography for the evaluation of graft patency following cardiac surgery.**

Methods. **Forty-seven asymptomatic patients (44 men and 3 women, mean age 67 ± 7 years) who had undergone coronary bypass surgery at least 10 years previously, were retrospectively investigated by means of ECG-gated multislice computed tomography, within 6 months of coronary angiography.**

Results. **Overall, 116 out of the possible 127 (91.4%) grafts were assessable at computed tomography, including 87 saphenous vein grafts, 26 left internal mammary artery, 2 right internal mammary artery, and 1 gastroepiploic artery. Coronary angiography showed that 79 of 116 grafts (68.1%) were patent and that 37 (31.9%) were occluded. All grafts which were patent and occluded at coronary angiography were correctly identified at multislice computed tomography, with a sensitivity and specificity of 100%.**

Conclusions. **Multislice computed tomography with retrospective gating permits an accurate and noninvasive evaluation of coronary artery bypass patency, and could replace conventional angiography for the follow-up of asymptomatic, stable patients.**

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Introduction

Coronary artery bypass graft (CABG) surgery remains the most commonly performed revascularization procedure for diffuse or multivessel coronary disease. The late symptoms and clinical outcome after CABG are closely related to the status of the bypass grafts. In the first year after surgery, up to 20% of saphenous vein grafts (SVG) and 5% of internal mammary grafts may become occluded. 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[1]. Coronary artery angiography is, at present, the gold standard for the evaluation of graft patency[2]. However, it is a stressful invasive procedure for the patients with a procedure-related mortality of 0.15% and a morbidity of 1.5%[3]; therefore, it increases hospital costs. A minimally invasive or noninvasive imaging method for the evaluation of early and late postoperative graft patency is desirable. The assessment of coronary bypass patients with computed tomography was first reported in 1980[4]. In the following years, a number of studies described the application of conventional computed tomography, electron beam tomography and magnetic resonance imaging for the investigation of bypass graft patency[5-10]. However, none of these approaches has resulted in an accurate diagnostic procedure that is widely accepted. The recently developed multislice computed tomography (MSCT) with effective scan times up to 0.25 s and multirow detector array systems, enable rapid imaging of the cardiac structures, including the coronary artery lumen[11-13].

The purpose of our study was to compare MSCT with conventional angiography for the evaluation of graft patency following cardiac surgery in a population of stable, asymptomatic patients who had undergone CABG at least 10 years previously.

Methods

Subjects. Forty-seven asymptomatic patients (44 men and 3 women, mean age 67 ± 7 years) with multivessel coronary artery disease who had undergone CABG surgery at least 10 years previously, were investigated by means of MSCT within 6 months of coronary angiography, performed as part of our study design. Only patients in sinus rhythm, stable clinical conditions, without an implanted pacemaker, valve prosthesis or stent in bypass and without contraindications to the administration of iodinated contrast agent, were included in the study. All patients gave their written informed consent, and the study protocol was approved by the Ethical Committee of our University. The initial evaluation of the MSCT coronary angiography included the decision regarding the "assessability" of each graft. If motion artifacts or severe vessel calcifications had rendered the segment "nonassessable", it was not included in the analysis.

Multislice computed tomography. The patient was placed within the gantry of a multidetector row computed tomographic scanner (Light-Speed Plus, GE Medical System, Milwaukee, WI, USA), in a supine position. Leads were attached for simultaneous ECG and image recording necessary for inter-related image reconstruction. All images were acquired in inspiratory breath-hold. Our imaging protocol consisted of following steps. First, a noncontrast coronal view of the chest was taken to determine the position of the heart, define the scan volume for further imaging and identify any coronary calcification. Then, the individual contrast agent transit time from injection into a peripheral vein to the increase in density in the ascending aorta was measured: 20 ml bolus of contrast agent (Iomeron 350, Bracco Ltd, Milan, Italy) were injected. After a delay of 10 s, a sequence of 10 axial images were acquired at the level of the ascending aorta with an interval of 2 s between subsequent images. The contrast agent transit time was determined as the time interval between contrast agent injection and acquisition of the image with peak attenuation in the aortic root. The volume data set for coronary bypass imaging was finally acquired in spiral mode using four simultaneous parallel slices, 1.0 mm thick each, during intravenous injection of 140 ml of contrast agent at a rate of 3.5 ml/s. The gantry rotation time was 500 ms and the patient's table was continuously advanced at 1.5 mm/rotation. The tube current was 320 mA with a tube voltage of 120 kV. The scan was initiated with a delay based on the previously determined contrast agent transit time. Depending on the covered volume, the mean breath-hold time was 36 ± 4 s. All images were transferred to an external workstation (Advantage Windows 4.0, GE Medical System) to be elaborated using the CARDIO IQ program (GE Medical System). Axial, three-dimensional volume-rendered, and multiplanar reconstructed images were analyzed for evaluation of the number, location and patency of bypass grafts. To enable retrospective ECG-gating, the ECG was recorded continuously throughout the preparation and image acquisition period. The raw data were reconstructed at different percentages of the R-R interval (from 30 to 90%, using 10% increments).

Coronary angiography. Cardiac catheterization and contrast-enhanced X-ray coronary angiography were performed according to standard techniques. Multiple views of the coronary arteries were obtained and stored on a CD-ROM.

Graft analysis. The MSCT images were evaluated by two independent radiologists blinded to the angiography results; the number and location of bypass grafts, however, were known to the investigators. The bypass grafts were considered as occluded if they were not identified in both cross-sectional images and three-dimensional MSCT images. Analysis of all angiograms was performed by two independent experienced cardiologists, who scored arterial and venous grafts by flow, in accordance with the system used in the Thrombolysis In Myocardial Infarction trial[14]. Grade 0 or 1 were taken as occluded grafts, and all others as patent.

Statistical analysis. The sensitivity, specificity and accuracy of the graft patency were evaluated using conventional contrast angiography as a reference. The sensitivity was calculated as the number of true open/(true open + false occluded) grafts. The specificity was calculated as the number of true occluded/(true occluded + false open) grafts. The accuracy was calculated as follows: (true open + true occluded)/total number of grafts.

Results

MSCT was completed successfully in all patients, without any complications. The mean investigation time was 20 min, although reconstruction took another mean period of 20 min. The mean heart rate of the patients at the time of the MSCT examination was 62 ± 10 b/min (range 44 to 95 b/min). Twenty-nine patients (62%) were already using beta-blockers; no intravenous and/or oral beta-blockers were used before MSCT in our protocol. Overall, 116 out the possible 127 (91.4%) grafts were assessable at MSCT. The reasons for "nonassessability" were: motion artifacts caused by high heart rate in 1 patient with 5 bypass grafts, severe vessel calcification in 3 cases and artifacts caused by numerous metal clips along the course of three internal mammary artery grafts. Of 116 assessable bypass grafts for comparison with the coronary angiograms, 87 (75.0%) were SVG, 28 (24.1%) internal mammary artery grafts, including 26 left internal mammary artery and 2 right internal mammary artery grafts, and 1 (0.9%) gastroepiploic artery graft. Of 87 SVG, 36 were to the left anterior descending, 21 to the obtuse marginal, 10 to the right coronary, 8 to the diagonal branch, 7 to the left circumflex coronary arteries and 5 to the posterior interventricular branch. Of the internal mammary artery grafts, there was one sequential bypass to the diagonal branch and left anterior descending coronary artery and the remaining grafts were single grafts to the left descending anterior in 25 cases and to the diagonal branch in the remaining 2 cases. The gastroepiploic graft was to the right coronary artery.

Coronary angiography of the bypass graft showed that 79 of 116 grafts (68.1%) were patent and that 37 (31.9%) were occluded (9 left internal mammary artery and 28 SVG) (Figs. 1-3). All 79 patent grafts and 37 occluded grafts on coronary angiography were correctly identified at MSCT (Fig. 4). Thus, the overall sensitivity and specificity of MSCT for the detection of bypass graft patency were both 100%; the accuracy, consequently, was 100% too.

Discussion

Several noninvasive methods have been used to evaluate the "assessability" of the bypass graft patency following CABG. The first study which investigated the bypass graft status with conventional computed tomography was reported in 1980 by Brundage et al.[4]. The estimated sensitivity of this method ranged between 80 and 100%, with a consistently lower specificity (72 to 95%). Unlike conventional computed tomography, which uses a rotating X-ray tube, electron beam tomography uses a static row of detectors and a moving beam of electrons to produce X-ray photons. The advantage of this technique is a rapid image acquisition time of 50-100 ms per slice. In three studies, each including 25 to 45 patients, all grafts were assessable[5-7]. The sensitivity for detecting bypass occlusion, in these mentioned studies, was 95 to 100%, and the specificity 89 to 100%. The disadvantages of this technique are: a low spatial resolution, the use of contrast media, and the availability restricted to only a few centers compared with the more widespread MSCT. Magnetic resonance spin-echo and cine gradient-echo phase velocity mapping showed a high sensitivity (98%) and positive predictive value (97%) with a specificity ranging from 87 to 88%[8-10]. The most important advantage of magnetic resonance imaging is the lack of exposure to ionizing radiation and iodine contrast agent. However, this technique is still limited by its poor spatial resolution, long scan times, impaired graft visualization by

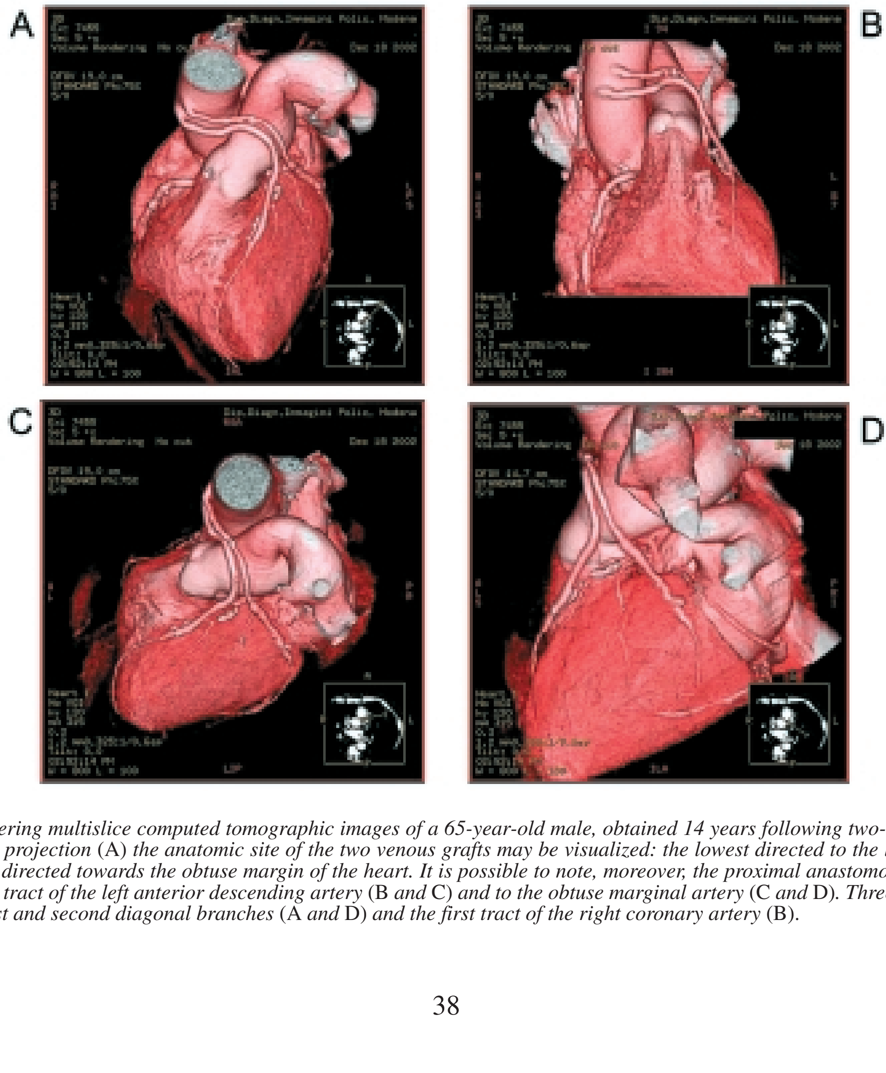

Figure 1. *Volume rendering multislice computed tomographic images of a 65-year-old male, obtained 14 years following two-vessel coronary bypass. In the antero-posterior projection* (A) *the anatomic site of the two venous grafts may be visualized: the lowest directed to the left anterior descending artery, and the highest directed towards the obtuse margin of the heart. It is possible to note, moreover, the proximal anastomosis to the aorta* (B) *and the distal to the middle tract of the left anterior descending artery* (B *and* C) *and to the obtuse marginal artery* (C *and* D). *Three native coronary arteries are also visible: first and second diagonal branches* (A *and* D) *and the first tract of the right coronary artery* (B).

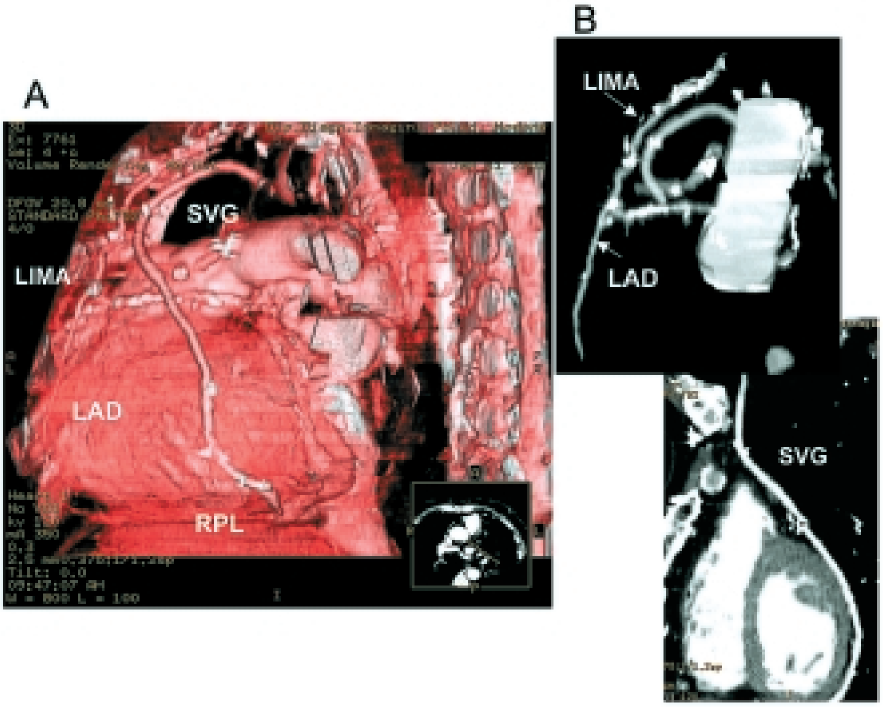

Figure 2. *Left posterior oblique volume rendering projection* (A) *and oblique and curved multiplanar reformat* (B) *of multislice computed tomography angiography. Patency of both venous and arterial coronary bypass: the left internal mammary artery (LIMA) is anastomosed to the left anterior descending artery (LAD); a saphenous vein graft (SVG) jumps to the postero-lateral branch (RPL).*

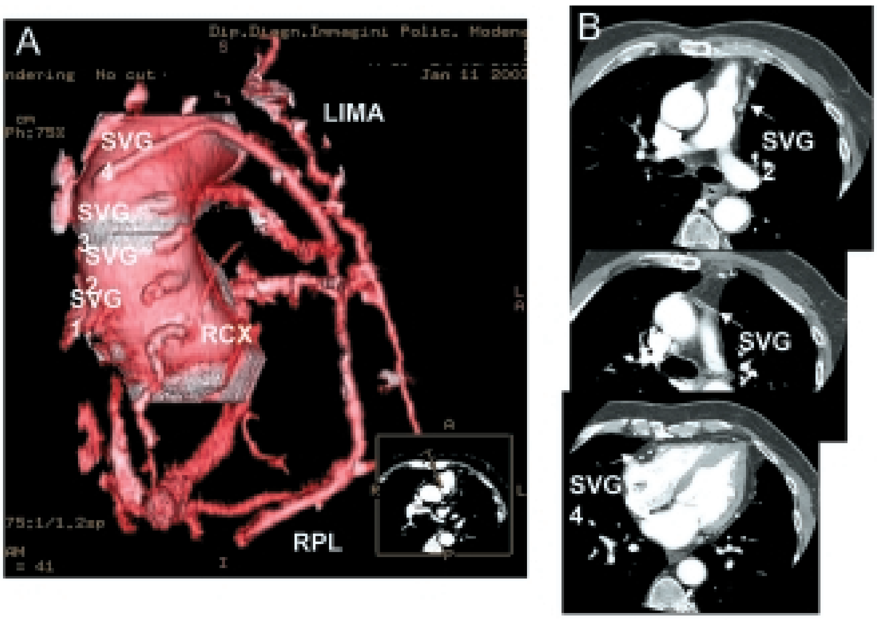

Figure 3. *Right anterior oblique volume rendering projection after subtraction of the cardiac chambers* (A) *and axial spiral multislice computed tomography angiography images at three different levels of the aortic arch* (B). *These images confirm the patency of the arterial bypass (left internal mammary artery-LIMA) and of the more cranial saphenous vein graft (SVG4); the lack of enhancement of the lumen of the remaining three venous grafts (SVG1, SVG2, SVG3) confirms that they are occluded at their origin. RCX = right coronary artery; RPL = postero-lateral branch.*

metal objects (stent, sternal wires) and contraindications. Compared to other noninvasive imaging methods, MSCT has good image quality due to the relatively rapid imaging time and the high spatial resolution attributable to the multirow detector system[12]. Ropers et al.[13] performed MSCT in 65 patients with 182 grafts and found a 97% sensitivity and 98% specificity for the detection of bypass occlusion. Nevertheless, to date, no study has used MSCT for the assessment of the long-term graft patency in asymptomatic patients. Most in-

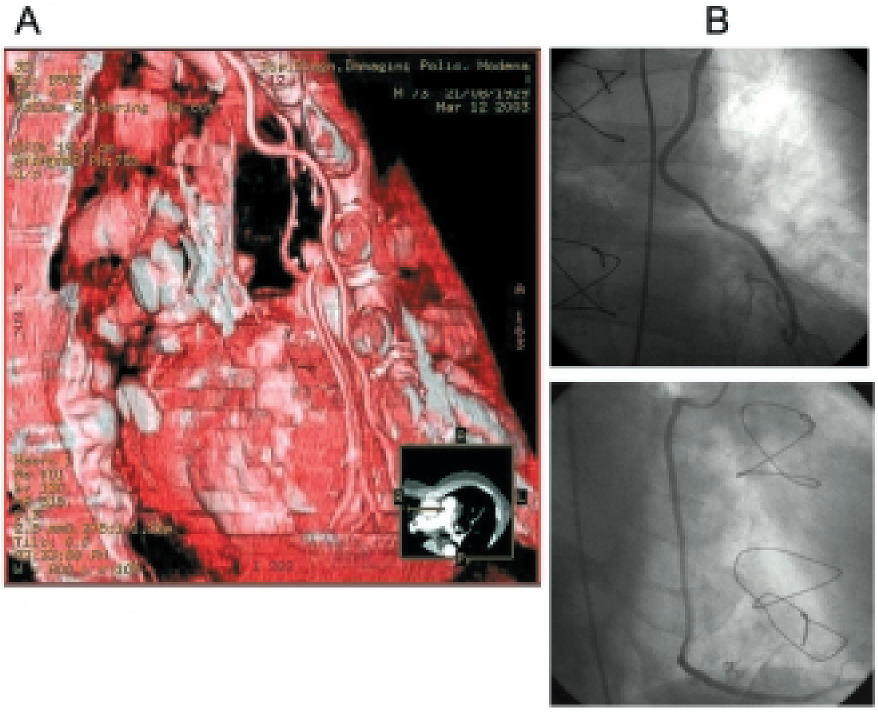

Figure 4. A: *this is a right oblique volume rendering image in a patient with two patent grafts; the arterial bypass, immediately below the sternum, is directed towards the left anterior descending artery, and the venous graft to the right coronary artery. It is possible to note the "perfect" correspondence between multislice computed tomography and coronary angiography in the assessment of the graft patency.* B: *antero-posterior projection* (top)*, with selective angiographic visualization of the left internal mammary artery, and right oblique projection* (bottom)*, with clear opacification of the bypass for the right coronary artery.*

vestigators have evaluated symptomatic patients presenting a wide range of time periods after surgery and others have examined the patients in the immediate postoperative period[15,16]. The objective of our study was the evaluation of stable, asymptomatic patients in the long-term follow-up; we have shown that in these patients MSCT allows for an accurate visualization and evaluation of various types of bypass graft.

Limitations. Despite these encouraging initial results, some technical limitations remain. In our study, 11 bypass grafts could not be evaluated because of artifacts due to high heart rate, severe vessel calcification and numerous metal clips along the course of the mammary artery grafts. One major drawback of MSCT is the impaired temporal resolution resulting from its 250 ms acquisition time. This appears to be adequate only at low heart rates (< 70 b/min). Although manual repositioning of the R-wave indicators during retrograde gating improves the synchronization of the acquisition intervals between consecutive heartbeats, cardiac motion artifacts cannot be entirely prevented. The scan quality, moreover, is improved by administering short-acting beta-receptor-blocking agents. Nevertheless, some of the problems may be overcome by using systems with a higher number of detectors. The presence of extensive calcifications may complicate correct assessment of the lumen of the bypass graft. The high-contrast calcium deposition cannot be sufficiently isolated from the contrast-enhanced vessel lumen and may result in the "nonassessability" of the segment or misinterpretation. Another limitation of MSCT is the fact that radiation is continuously applied, whereas image reconstruction is restricted to data acquired during only a fraction of the cardiac cycle. Several manufactures are prospectively introducing tube current modulation to reduce radiation exposure, currently estimated at around 6 mSv. Another drawback is the relatively long breath-hold. However, at the cost of an increased slice thickness the speed of tube movement could be increased, leading to a shorter overall scan duration to cover the volume of the heart. In spite of these technical problems we are convinced that MSCT, at least in CABG evaluation, could replace conventional angiography for the follow-up of asymptomatic patients.

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