Original Research

Imaging and Evaluation of Coronary Artery Bypass Graft Patency by 16-Slice Multidetector Computed Tomography

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Introduction: The purpose of this study was to evaluate the patency of coronary artery bypass grafts (CABGs) while assessing the capabilities and limitations of 16-slice multidetector computed tomography.

Methods: We studied retrospectively 19 patients (13 men, 6 women), over an 18-month period. All patients had undergone CABG surgery 3 months to 7 years earlier. Two patients were examined on an emergency basis for chest pain and their CABGs were evaluated simultaneously. The number of CABGs in each patient ranged from one to three. A total of 44 grafts were assessed. All scans were performed by a 16-row multi-slice scanner (Toshiba Aquilion). Maximum intensity projections, multiplanar reformations, and volume rendering techniques were performed on a Vitrea workstation. All 19 patients also underwent invasive catheter coronary angiography for confirmation of their status.

Results: Of the 44 grafts evaluated, 26 were classified as patent, 13 as not patent, and 5 as stenotic. In the bypass grafts with stenosis ≥50% there was a difference in the mean level of enhancement before and after the stenosis (265.38 ± 35.82 and 178.56 ± 9.32, respectively). Seventeen arterial and 27 venous grafts were imaged. Of the 13 non-patent grafts, 8 were venous. In 3 cases of arterial grafts the distal anastomoses were not delineated. The assessment of venous grafts was easier because of their larger diameter and lack of surrounding clips. One case of a carotid-subclavian shunt with a distal anastomosis of the left internal mammary artery to the left anterior descending branch was reported. Sensitivity, specificity, positive and negative predictive values for stenosis were evaluated.

Conclusions: Multidetector computed tomography is a fast and non-invasive modality for evaluating CABG patency that is gaining acceptance as an alternative method to invasive coronary angiography. Sensitivity and specificity are determined by the available and evolving technology.

Coronary artery bypass grafting (CABG), a surgical technique of considerable value in the therapy of coronary artery disease (CAD), aims to supply blood to ischaemic areas of the heart using a graft to bypass an occluded or stenotic coronary artery. The graft may be either an arterial conduit—such as the internal mammary artery, radialis, gastroepiploic, etc.—or a homologous venous graft. Generally speaking, patients experience a reduction in clinical symptoms and an improvement in their quality of life after revascularisation.[1] Indications are changing in light of newer techniques in percutaneous transluminal angioplasty (PTA) with coated stents, which have a lower restenosis rate. PTA is the first line of treatment because the procedure is minimally invasive. However, approximately 30-40% of patients treated in this way develop restenosis in the first year

and are more likely to need further medical treatment than are patients who have undergone CABG.[2]

Despite extensive experience (in 2001 a total number of 77,000 coronary artery bypass procedures were performed in Germany[3]), calculations show that the patency rate of bypass grafts is limited. One year after surgery, 16.7% of women and 12.4% of men have occluded venous bypass grafts,[4] while three years after surgery 20-30% of all bypass grafts are occluded.[5] Ten years post CABG, 15% of arterial grafts[6] and approximately 40-50% of venous grafts[7] are occluded. Studies have demonstrated that the sites of anastomoses are particularly prone to occlusion.[2,8] The postoperative course correlates highly with the patency rate of bypass grafts;[4] it is therefore essential to evaluate graft patency early and at regular intervals, regardless of clinical symptoms and before the occlusion of multiple graft vessels occurs.

At present, the diagnostic gold standard method in this situation is invasive catheter angiography (ICA) to investigate coronary artery and bypass status. However, in asymptomatic CABG patients such an invasive procedure for assessment of graft patency cannot be recommended in general because of its possible risks (0.1% mortality and risk of minor or even major complications[9]), inconvenience for the patient, and financial burden. All these considerations have triggered the quest to find an alternative, non-invasive method of bypass graft assessment. Multidetector computed tomography (MDCT) for non-invasive coronary bypass graft imaging and evaluation of graft patency is an emerging technique which has the potential to fulfil these requirements. Since 2002, second-generation MDCT scanners with faster gantry rotation speed and more detector rows have been available. Initial publications suggest vastly improved image quality and reliable detection of obstructive CAD.[10-13]

The aim of this study was to evaluate the patency of coronary artery bypass grafts while assessing the capabilities and limitations of multidetector CT using visualisation methods such as multiplanar reformations, maximum intensity projections, and volume-rendered techniques. Conventional coronary angiography was set as the standard of reference.

Materials and methods

Patient study

We studied retrospectively 19 patients (13 men, 6 women), age 55-76 years, who were examined with multidetector cardiac CT over an eighteen month period. All patients had undergone CABG 3 months to 7 years before being scanned. The patients' heart rates ranged from 60-95 beats per minute (bpm). Two patients were examined on an emergency basis for chest pain and their bypass grafts were evaluated at the same time. The number of grafts in each patient ranged from one to three. A total number of 44 grafts were evaluated, 17 arterial and 27 venous. Exclusion criteria for the study were known irregular heart rate, known allergy to iodinated contrast media, serum creatinine level >1.5 mg/dl, or substantial cardiac failure.

Multidetector-row computed tomography (MDCT)

MDCT examinations were performed using a 16-row detector scanner (Toshiba Aquilion). All patients were scanned at their original heart rate; beta-blockers were not administered. Patients were examined whilst in a supine position using the breath-hold technique. Scanning parameters were 135 kV, 300 mAs, 0.42 ms rotation time, 1 mm collimation and 1 mm table feed per rotation. A non-ionic iodinated contrast medium, 120 ml (370 mgI/ml) with a saline flush of 20-30 ml, was injected through an 18 G antecubital IV catheter by a single barrel injector with a flow rate of 3.2-3.5 ml/s. The start-delay time was determined by an automatic triggering system, Sure Start, with the threshold set at 130 HU in the ascending aorta. Scan direction was in a craniocaudal direction from the clavicles to the diaphragm. Mean scan time was 20 s.

Image reconstruction in all patients was performed using retrospective ECG gating, a technique that allows continuous image reconstruction from volume data sets during any phase of the cardiac cycle.[14,15] Multiple reconstructions were performed for each patient and each bypass graft. Bypass numbers and types were recorded. Subsequently, for each patient and each bypass graft, the single reconstruction that displayed the highest resolution and the smallest number of motion artefacts was chosen for interpretation.[16-19]

MDCT image interpretation

Evaluation of the bypass grafts was performed by dividing the grafts into three segments: a proximal, middle and distal segment. In addition, the sites of proximal and distal bypass anastomoses were evaluated. Images were obtained with the following reformations: thin MIPs (maximum intensity projections), MPRs (multiple projection reformats) and VRT (volume ren-

dering techniques. Image quality grading was based on a three point scale. Criteria were as follows: 1 = patent graft, 2 = ≥50% stenosis, 3 = thrombosed graft.

Invasive catheter coronary angiography

All 19 patients underwent invasive catheter coronary angiography. A total of 44 grafts, 17 arterial and 27 venous, were examined. The angiography procedure itself was carried out under routine conditions, and any clinical conclusions drawn and treatment decisions made were based solely on the angiographic results. Lesions with a lumen narrowing ≥50% were considered to be significant stenotic lesions.

Statistical analysis

The results of 16-slice multidetector-row computed tomography and of conventional coronary angiography were described by segment (venous or arterial) and by coronary artery: left internal mammary artery (LIMA) – left anterior descending branch (LAD); aortocoronary venous bypass (ACVB) – right coronary artery (RCA), ACVB – left circumflex artery (LCx). The diagnostic accuracy of the MDCT technique was evaluated by estimating the sensitivity, specificity, positive predictive value and negative predictive value for each category. The 95% confidence intervals (CI) were also calculated. Given the small number of grafts with stenosis ≥50%, this category was merged with the thrombosed grafts for purposes of analysis. The Pearson χ^2 and Fisher's exact tests were used in order to compare the aforementioned diagnostic accuracy estimates between type of graft and branches. In addition, similar comparisons were made between patients with low (<65 bpm) and high (≥65

bpm) heart rate during the MDCT procedure. The power analysis showed that our sample, which consisted of 44 grafts, was adequate to detect differences greater than 19% between the hypothesised and postulated proportion of stenosis at a significance level of p<0.05, achieving statistical power 74.5%. All reported p-values are based on two-sided tests and compared to a significance level of 5%. Data were analysed using STATA statistical software (Version 9.0, Stata Corporation, College Station, TX 77845, USA).

Results

Of the 44 grafts evaluated, 26 (62%) were classified as patent and 13 (29%) as not patent (Figure 1). Of the 13 non-patent grafts, 8 were venous. In three cases of arterial grafts, the distal anastomoses were not delineated. Occluded venous grafts at the proximal anastomoses created by nitinol implants reported were 4 (Figures 2, 3). The evaluation of venous grafts was easier because of their larger diameter and lack of surrounding clips. One case of a carotid-subclavian shunt with a proximal anastomosis of the LIMA to the subclavian artery and distal to the LAD was reported (Figure 4). One patient with a LIMA venous graft was examined post left aneurysmatectomy (Dor procedure). Concomitant findings were two cases with thrombi in the left ventricle, four cases with myocardial scars, three cases with pericardial or pleural effusions, two cases with aortic and mitral calcifications. All grafts were confirmed by coronary angiography (Figure 5). All total venous occlusions were observed in the proximal anastomosis, arterial occlusions in the distal anastomosis (Figure 6).

The baseline characteristics of the 19 patients are
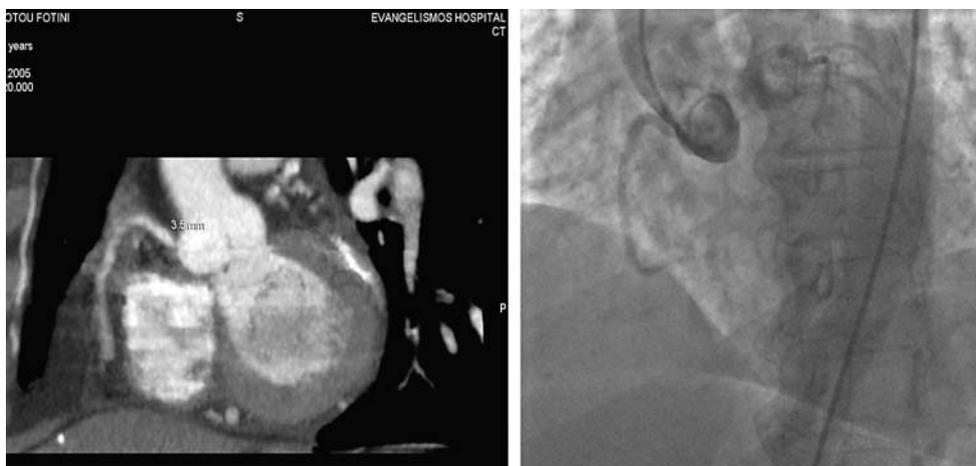
Figure 1. Depiction of stenosis >90% at the origin of the right coronary artery (RCA) during the patency study. Confirmation by invasive coronary artery angiography.
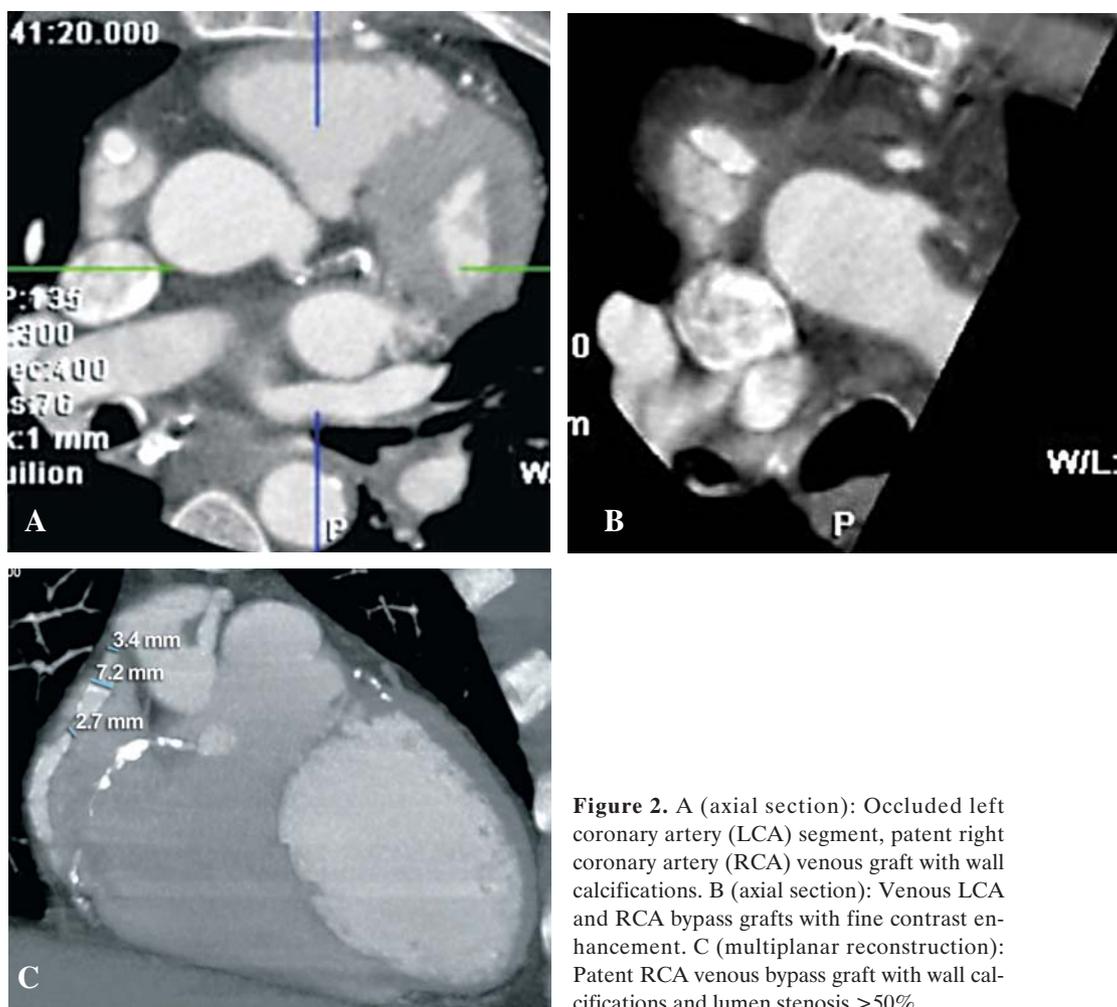
Figure 2. A (axial section): Occluded left coronary artery (LCA) segment, patent right coronary artery (RCA) venous graft with wall calcifications. B (axial section): Venous LCA and RCA bypass grafts with fine contrast enhancement. C (multiplanar reconstruction): Patent RCA venous bypass graft with wall calcifications and lumen stenosis >50%.
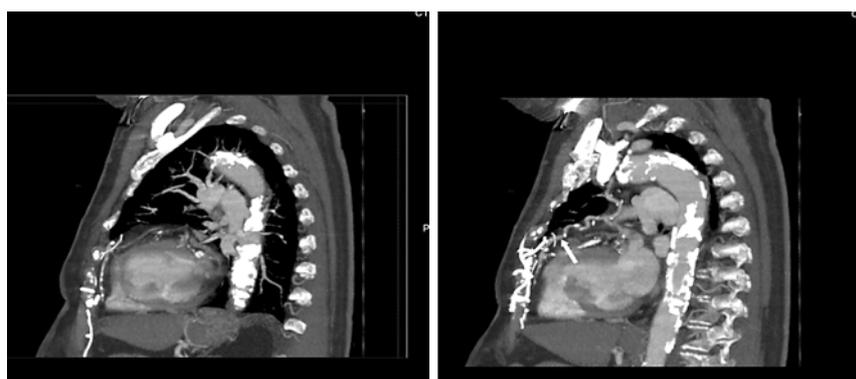

Figure 3. Depiction of a patent left internal mammary artery graft with increased width (6 mm) bypassing the anterior descending branch.

given in Table 1. The MDCT findings concerning graft patency were similar to the coronary angiography findings. In one stenotic lesion, CT demonstrated stenosis >50% while coronary angiography demonstrated stenosis 90% (selective catheterisation of the RCA in the patient was not successful), and in two other stenotic lesions CT reported a stenosis of 50% while coronary angiography gave 75-80% (Figure 7).

In two patients with grafts bypassing the LAD (LIMA) and LCx (venous) a high-grade bypassing stenosis was detected in the proximal RCA and a <50% stenosis was seen in the other patient in the mid portion of the RCA (Figure 8). The total sensitivity of MDCT for graft obstruction more than 50% was 83%, while its specificity ranged from 59% to 96% (Table 2).
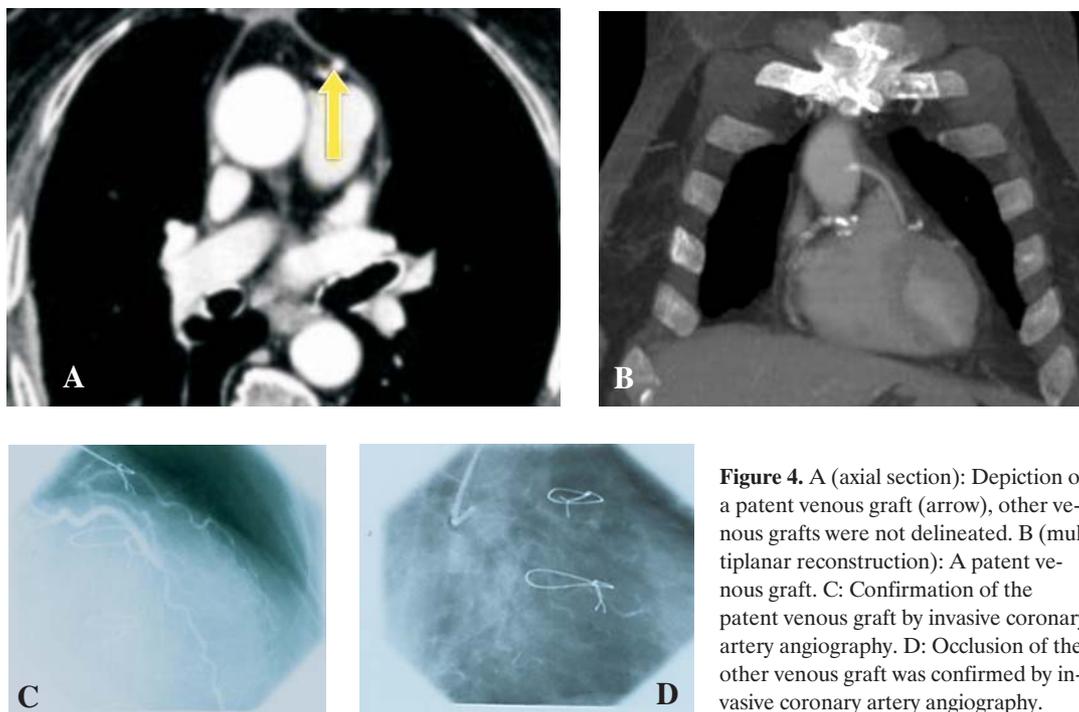
Figure 4. A (axial section): Depiction of a patent venous graft (arrow), other venous grafts were not delineated. B (multiplanar reconstruction): A patent venous graft. C: Confirmation of the patent venous graft by invasive coronary artery angiography. D: Occlusion of the other venous graft was confirmed by invasive coronary artery angiography.
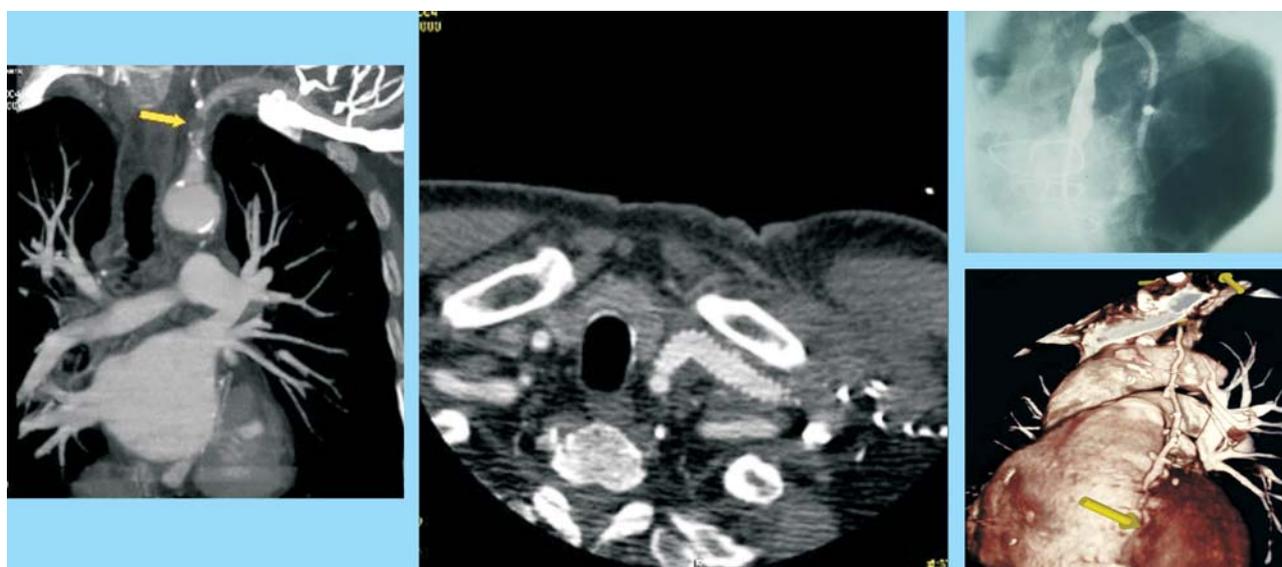
Figure 5. Simultaneous study of the patency of the left internal mammary artery graft, stenosis of the left subclavian artery and postoperative patency of a carotid-subclavian graft (Teflon). Confirmation of the internal mammary patency by invasive coronary artery angiography.

The sensitivity and specificity of MDCT were relatively high (more than 75%) for both venous and arterial grafts. No significant difference was found based on this categorisation (Table 3). This was also the case after comparing the aforementioned diagnostic value estimates by vessel branch (Table 4). Although MDCT was less sensitive and more specific in patients having a heart rate less than 65 bpm compared to those with more than this cut-off point (78% vs. 89%, 92% vs. 86%, respectively), this difference was not significant (Table 5). Similar results were found in patients who had systolic blood pressure greater or less than 140 mmHg at the time of MDCT. Based on the results, systolic blood pressure did not have a significant effect on the diagnostic value of MDCT.

Figure 6. Free patent venous graft, another thrombosed venous graft at the level of proximal anastomosis.

Table 1. Baseline characteristics of the study.

Patients	N	(%)	Graft type	N	(%)
Men	13	(68%)	LIMA→LAD (arterial graft)	17	(39%)
Women	6	(32%)	Venous graft→RCA	19	(43%)
			Venous graft→LCx	8	(18%)
Total	19	(100%)	Total	44	(100%)

Bypass grafts	Patent		Non-patent		Stenosis (>50%)		Total	
Venous	16	(62%)	8	(62%)	3	(60%)	27	(62%)
Arterial	10	(38%)	5	(38%)	2	(40%)	17	(39%)
Total	26	(100%)	13	(100%)	5	(100%)	44	(100%)

LAD – left anterior descending coronary artery; LIMA – left internal mammary artery; RCA – right coronary artery; LCx – left-circumflex artery.
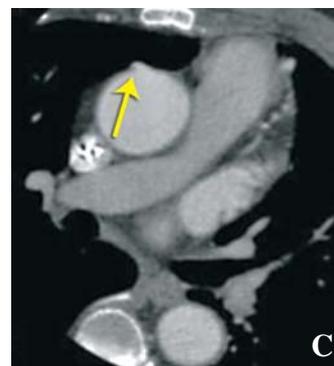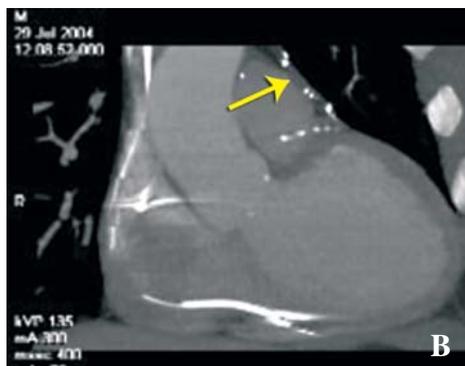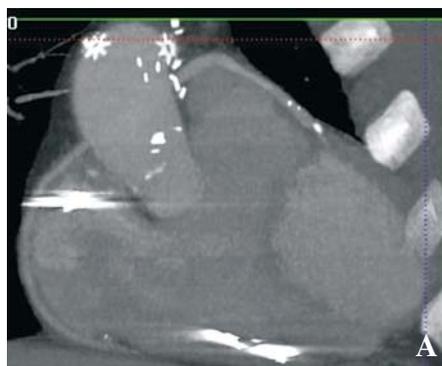
Figure 7. A (multiplanar reconstruction): Patent venous grafts to the right and left coronary arteries, clips at the ascending aorta level after unsuccessful anastomosis by automated aortic connector. B (multiplanar reconstruction): Occluded left internal mammary artery graft at the level of the distal anastomosis (arrow). C (axial section): Focal protrusion of the anterior wall of the ascending aorta; typical illustration of an occluded venous graft at its origin.

Discussion

The non-invasive follow-up of patients who have undergone CABG should include visualisation of bypass grafts and native coronary arteries. In daily practice, conventional angiography is considered the gold standard method for CABG evaluation. However, this procedure is invasive and cannot be recommended if there are no specific indications, because of the higher risk of complications in comparison to other imaging modalities, such as magnetic resonance imaging[20] or MDCT.

The most important findings of this study are that 16-slice MDCT technology provides excellent image quality and diagnostic accuracy in the detection of bypass graft patency. The results of several studies that used MDCT for non-invasive coronary and bypass angiography have been published.[10-13,21-27] Since the beginning of the 1980s CT has been used for the assessment of bypass grafts. Initial investigations without using the spiral technique could give information regarding patency only.[28] The development of the spiral technique was a major step in the technological progress of CT diagnostics. For single-slice spiral CT, sensitivities were 76% (internal mammary artery) and 100% (venous graft).[29] Imaging of jumped grafts was insufficient. Evaluation of graft stenosis or distal anastomoses was not possible.

Electron beam tomography revealed a sensitivity for graft patency ranging between 92% and 100% and a specificity between 83% and 100%,[20,30,31] while results were similar for arterial and venous grafts. Detection of venous graft stenosis is possible in a high
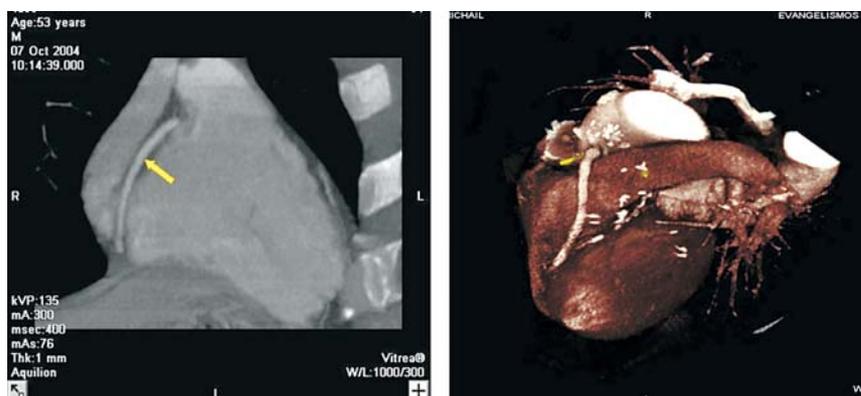
Figure 8. A patent venous graft and two other venous grafts that are thrombosed at the level of the proximal anastomosis.

Table 2. Diagnostic value estimates of multidetector computed tomography for detection of 50-100% graft obstruction.

Parameter	%	N/N	95% CI	
Sensitivity	83%	15/18	59%	96%
Specificity	88%	23/26	70%	98%
PPV	83%	15/18	59%	96%
NPV	88%	23/26	70%	98%

PPV – positive predictive value; NPV - negative predictive value

Table 3. Diagnostic value estimates of multidetector computed tomography for detection of 50-100% graft obstruction in relation to type of graft.

Parameter	Graft type				p
	Venous		Arterial		
	%	N/N	%	N/N	
Sensitivity	82%	9/11	86%	6/7	0.948
Specificity	94%	15/16	80%	8/10	0.790
PPV	90%	9/10	75%	6/8	0.797
NPV	88%	15/17	89%	8/9	0.990

Table 4. Diagnostic value estimates of multidetector computed tomography for detection of 50-100% graft obstruction in relation to vessel branch.

Parameter	Graft→Vessel						p
	LIMA→LAD		ACVB→RCA		ACVB→RCx		
	%	N/N	%	N/N	%	N/N	
Sensitivity	83%	5/6	78%	7/9	100%	3/3	0.999
Specificity	91%	10/11	90%	9/10	80%	4/5	0.999
PPV	83%	5/6	88%	7/8	75 %	3/4	0.999
NPV	91%	10/11	82%	9/11	100%	4/4	0.999

ACVB – aortocoronary venous bypass. Other abbreviations as in Table 1.

Table 5. Diagnostic value estimates of multidetector computed tomography for detection of 50-100% graft obstruction in relation to heart rate.

Parameter	Heart rate (bpm)				p
	<65 (N=21)		≥65 (N=23)		
	%	N/N	%	N/N	
Sensitivity	78%	7/9	89%	8/9	0.849
Specificity	92%	11/12	86%	12/14	0.907
PPV	70%	7/10	80%	8/10	0.845
NPV	85%	11/13	92%	12/13	0.879

percentage of patients, but only 84% of venous-graft segments were evaluated.[30] What remains unclear is the detection of relevant stenosis in arterial grafts and in distal graft anastomoses.

With ECG-gated MDCT, delineation of coronary arteries[25] and bypass grafts is possible directly.[24] The use of MDCT for evaluating bypass grafts has been examined in several studies.[22,23] Although the number of patients was rather small, our data revealed the efficacy of MDCT using the 16-row scanner in the detection of venous-arterial graft obstruction or patency, with a relatively high sensitivity and specificity (more than 75%) for both venous and arterial grafts. The grade of three stenotic lesions which were detected was not demonstrated accurately in MDCT in comparison to the angiographic results. Our findings suggest that MDCT using the 16-detector scanner for the detection of CABG obstruction and stenosis is a method that could be used in routine clinical practice as a non-invasive examination in patients with suspected CABG pathology.

The previously reported results on non-invasive lesion detection in coronary arteries were promising.[10,11,26,27] However, although MDCT imaging is becoming more accurate, complete visualisation of the

entire coronary tree still cannot be expected. Multidetector CT is gaining acceptance for the study of CABGs because the newer scanners, the 16-slice and the recently introduced 64-slice, have a higher temporal and z-resolution and are also faster, with a reported high sensitivity and specificity for graft occlusion (97% and 98%, respectively), but with a lower sensitivity in cases with stenosis (75% and 92%, respectively).[24]

With the MDCT technique some considerations must be underlined: acquisition must cover the entire thorax to observe the proximal anastomoses and the origin of the internal mammary artery. The use of beta-blockers improves the quality of images, particularly when the patient has a high heart rate.[32] Moreover, they dilate the coronary artery distal to the anastomosis, improving the distal flow visualisation. Beta-blockers were not used in this study, because it involved mainly outpatients and the presence of a cardiologist was not always possible. Iodinated contrast medium with a high concentration of iodine is also recommended, 350-370 mgI/ml. Retrospective ECG gating or prospective ECG triggering using different reconstructions improves the visualisation of vessels beyond distal anastomoses. The major drawbacks are the evaluation of distal anastomoses, usually respiratory motion artefacts, as well as vascular metal clips, particularly along the course of arterial grafts, which can cause partial volume effects or volume averaging. Despite all these disadvantages, sensitivities between 76% and 100% and specificities between 92% and 98% have been reported by several authors, depending on the evaluation of graft occlusion or substantial graft stenosis.[17,33,18] Studies have shown[34] that if the scanning direction is reversed from heart base to the origins of internal mammary artery grafts, within the first 20 s distal segments of native coronary arteries, CABGs and their anastomoses can be covered with fewer motion artefacts, while after 20 s, proximal segments of CABGs, which are less prone to cardiac and diaphragmatic motion, can be examined.

The mean level of CABG enhancement was 265.38 ± 35.82 HU. In the ascending aorta the level of enhancement was 285.56 ± 59.32 HU. In the stenotic bypass grafts there was a difference in the mean level of enhancement before and after the stenosis, 265.38 ± 35.82 versus 178.56 ± 29.32 HU, respectively, for stenosis ≥50%.

Limitations of MDCT are radiation exposure (8-12 mSv for the contrast-enhanced scan[35]), the need for an iodinated contrast agent, and the fact that a reduction of heart rate by using beta-blockers is still recommended. The initially high radiation dose dropped significantly to 4-6 mSv with the introduction of ECG-triggered scan modulation algorithms and is comparable to that of invasive coronary angiography. Published data regarding angiographic radiation exposure vary considerably and are examiner dependent. However, it is generally agreed that angiography has a lower radiation exposure than does MDCTA.[36]

Despite these technical limitations, MDCT allows accurate assessment of graft patency and, in addition, provides relevant information concerning the presence of substantial obstruction disease in bypass grafts, including distal anastomoses and coronary artery disease progression. The technique is easy to perform, well tolerated, and provides additional information regarding coronary arteries. Therefore, MDCT can be used as a non-invasive examination for graft patency in patients with an inconclusive stress test, angina, chest pain. etc.

Nieman et al[22] reported that thin-slab maximum intensity projections (MIP) were the best algorithm to assess an extended length of a bypass graft. In the presence of metal clips, the use of MIP resulted in an over-projection; in these cases the evaluation was completed using multiplanar reconstructions or transverse sections.[37] Volume rendering techniques (VRT) have been used for global orientation and for the presentation of results to the clinicians. In cases of complex revascularisation, in which the number and type of bypass grafts are sometimes unknown (usually in outpatients), it is very useful to get an overview of the bypass anatomy first using VRT (3D) before starting the evaluation of each segment.

Development in detector CT technology from single to 4-, 8-, 10- or 16- and 64-row detectors has broadened the spectrum of applications,[38] while every new generation of multislice scanners further boosts expectations. Moreover, some studies have suggested that 16-row in comparison to 4-row MDCT technology offered a better assessment of the proximal anastomoses (even in the presence of metal implants[39]), the proximal, middle, distal course and total course of the graft vessel, while not reporting better results for the evaluation of the distal anastomoses.[21]

The increased temporal and spatial resolution provided by 64-slice CT scanners allow better visualisation of distal anastomoses, irrespective of which coronary artery is being assessed. The image quality of proximal anastomoses and body segments of grafts is not significantly affected by the reconstruction

time-point during the cardiac cycle.[40] Technical improvements of 64-slice scanners have led to a reduction in beam hardening artefacts of metallic clips from arterial CABG.[41]

Conclusions

MDCT is a fast, non-invasive imaging modality for the evaluation of CABG patency. It is gaining acceptance as an alternative method to coronary angiography. Although 16-row technology may fall short of expectations with respect to distal anastomosis, the next generation of multidetector CT scanners with an increased temporal resolution, using faster rotation X-ray tubes and a smaller collimation, is likely to allow us to assess the distal anatomy of bypass grafts. MDCT scanning of venous bypass grafts and arterial grafts is a reliable method of detecting significant occlusions and stenoses and is becoming increasingly accurate as a non-invasive examination in patients with suspected graft dysfunction.[42]

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