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Clinical research
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Initial experience with 64-slice cardiac CT: non-invasive visualization of coronary artery bypass grafts

Gregor Pache[1*], Ulrich Saueressig[1], Alex Frydrychowicz[1], Daniela Foell[2], Nadir Ghanem[1], Elmar Kotter[1], Annette Geibel-Zehender[2], Christoph Bode[2], Mathias Langer[1], and Thorsten Bley[1]

[1] *Department of Diagnostic Radiology, University Hospital Freiburg, Hugstetter Strasse 55, 79106 Freiburg, Germany; and*
[2] *Department of Cardiology, University Hospital Freiburg, Hugstetter Strasse 55, 79106 Freiburg, Germany*

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KEYWORDS
Coronary angiography;
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Non-invasive visualization

Aims The aim of this study was to evaluate the diagnostic accuracy in the assessment of coronary artery bypass grafts using 64-slice computed tomography (CT) technology.
Methods and results CT coronary angiography was performed for 96 bypasses in 31 patients with suspected coronary artery disease using a Siemens Sensation 64-slice CT-scanner and compared with invasive coronary angiography (ICA). Patients with an irregular or fast heart rate despite β-blocker administration were not excluded from the study. All bypass grafts and 94% of the distal bypass anastomoses could be visualized by CT, non-evaluable distal arterial anastomoses were either due to clip material or calcification artefacts. Forty-two bypass graft occlusions and three significant stenoses were detected by CT and confirmed by ICA. Two venous grafts were missed and one arterial graft was not evaluable with ICA, but both were clearly depicted by multi-slice CT. One false negative and two false positive CT-findings resulted in a sensitivity of 97.8%, a specificity of 89.3%, a positive predictive value of 90%, and a negative predictive value of 97.7%.
Conclusion State-of-the-art 64-slice CT coronary angiography demonstrates high diagnostic accuracy in the assessment of arterial and venous bypass graft stenoses.

Introduction

Invasive coronary angiography (ICA) remains the gold standard in the evaluation of coronary artery bypass grafts (CABG).[1–4] As the lifetime of bypass patency is limited, follow-up examinations are inevitable.[5,6] However, patient discomfort with the examination, the cost considerations of a procedure unsuited for an outpatient setting, and the albeit small but real risk of serious complications have given the development of a reliable non-invasive method to rule out significant bypass stenosis particular urgency.[2–4,7]

Previous patient trials using 16-detector row computed tomography (CT) scanners have shown promising CT bypass coronary angiographic results. Compared with ICA, CT made reliable differentiation possible of patent and occluded grafts and high diagnostic accuracy in detecting graft stenoses with great sensitivity and specificity. However, the evaluation of distal graft patency and non-occlusive graft stenoses remains challenging because of residual motion or clip material artefacts, especially in patients with higher heart rates.[4,8–12]

The new 64-slice CT technology with a rotation time of 330 ms and 0.4 mm nearly isotropic voxels offer improved spatial and temporal resolution.[13] Initial 64-slice CT coronary angiographic results of native vasculature prove high diagnostic accuracy in assessing coronary artery stenoses of more than 50% with a sensitivity of up to 94%, including patient-based analysis, a specificity of 97%, and in the study by Leschka *et al.*,[14] a negative predictive value (NPV) of 99%.[15] The aim of the present study was to evaluate its diagnostic accuracy in the assessment of CABG compared with ICA.

* Corresponding author. Tel: +49 761 270 3802; fax: +49 761 270 3838.
E-mail address: pache@mrs1.ukl.uni-freiburg.de

Methods

Six months after implementation of a 64-slice CT system in our department, we had performed 237 cardiac CT examinations. Of these 46 patients had had previous CABG surgery. They had all been referred to our clinic for ICA evaluation because of suspected recurrent anginal symptoms after CABG surgery. None of these patients had to be excluded due to allergies to iodine contrast media, renal insufficiency, or hyperthyroidism. Fifteen patients were not eligible for inclusion in our study as a conventional catheter angiography had not been performed within 4 weeks of time. All of the remaining 31 patients were included in our study. Patient characteristics are summarized in *Table 1*.

The β-blocker metoprolol tartrate (50–100 mg) had been administered prior to the examination if a patient's heart rate was above 65 bpm and no contraindications for β-receptor blocking were present. Multi-slice CT (MSCT) angiography and ICA were performed within a mean interval time of 4.3 days (range 1–21 days). No cardiac events occurred between CT and ICA.

Table 1 Patient characteristics

Characteristic	Value
Patients	$n = 31$
Age (years)	
Mean ± SD	68.4 ± 8.4
Range	45 to 83
Sex	
Male	26
Female	5
Time interval after surgery (months)	92.8 ± 55.7
Cardiovascular risk factors	
Hypertension	30
Nicotine abuse	17
Hyperlipidaemia	24
Obesity (BMI index > 30 kg/m^2)	8
Mean ± SD	27.7 ± 4.6
Diabetes mellitus	8

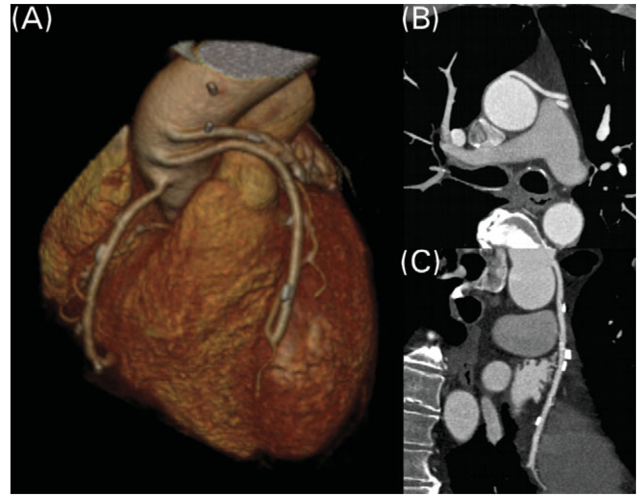

Figure 1 Example of MSCT coronary angiography image evaluation of a 66-year-old male CABG patient with three venous grafts using VRT (*A*); 3 mm thin-slab MIP (*B*); and cMPR (*C*). The demonstrated SVG to LCX (*B* and *C*) was classified patent and validated by ICA.

This study was approved by our local ethics committee and written informed consent was obtained from each patient prior to investigation.

MSCT coronary angiography

CT coronary angiography was performed with the latest 64-slice CT scanner (Siemens Sensation 64, Erlangen, Germany) using the following scan parameters: 330 ms gantry rotation time, detector collimation 0.6 mm, tube voltage of 120 kV at a maximum current of 800 mAs, craniocaudal scan direction. Electrocardiographic gated tube current modulation was applied to reduce radiation exposure. All patients received 0.2 mg of sublingual nitroglycerin shortly before the examination. After region of interest placement in the ascending aorta, patient circulation time was determined using a test bolus of 20 mL contrast agent (Ultravist 370, Schering AG) at a flow rate of 5 mL/s and a saline chaser bolus of 40 mL at a flow rate of 4 mL/s using a dual-head power injector (Injectron CT2; Medtron, Saarbrücken, Germany). For coronary angiography, 100 mL contrast agent was injected in an antecubital vein via an 18-gauge catheter at a flow rate of 5 mL/s, followed by a 60 mL saline chaser bolus at a flow rate of 4 mL/s.

Image reconstructions of the raw data were performed at 40, 50, 60, and 70% of the R-to-R interval using a medium-smooth convolution kernel of B25f. In case of uncertainty, segments were individually adjusted for reconstruction. Images were evaluated using 3 mm thin-slab maximum intensity projections (MIP), curved multiplanar reconstructions (cMPR), and volume-rendering techniques (VRT) on a post-processing workstation (Volume Wizard, Siemens Medical Solutions, Erlangen, Germany) (*Figure 1*).

Invasive coronary angiography

ICA was performed by an experienced cardiologist according to standard techniques. Sones technique via a brachial approach was applied in cases where vascular access was not possible via a femoral approach. An experienced cardiologist evaluated all coronary bypass angiograms by quantitative coronary analysis with automated vessel contour detection. Those stenoses with a luminal diameter >50% were defined as significant. Non-significant stenosis were defined as a luminal diameter reduction of 25–50%, stenosis with a luminal diameter reduction of 1–24% were evaluated as non-significant stenosis corresponding to wall irregularities.

Data analysis

Two experienced radiologists, blinded to the ICA results but aware of the operative procedure, evaluated the MSCT coronary bypass angiographies by consensus reading. Each bypass graft, and each consecutive anastomosis in case of sequential graft were counted as separate graft segments. Luminal diameter stenosis was analysed according to ICA with a luminal reduction >50% considered a significant stenosis. Non-significant stenosis were defined as a luminal diameter reduction of 25–50%, stenosis with a luminal diameter reduction of 1–24% were evaluated as non-significant stenosis corresponding to wall irregularities.

Diagnostic results from each of the two investigations were compared concerning proximal and distal anastomosis and bypass corpus. Sensitivity, specificity, positive predictive value (PPV), NPV, and the corresponding 95% CI were calculated for patency, significant stenoses (>50%), and bypass graft occlusion. ICA was regarded as the standard of reference.

Because of the possible interdependencies between different bypass grafts for one patient, an additional patient-based analysis was performed. In the patient-based analysis, sensitivity, specificity, and the corresponding 95% CI were calculated for patency or the presence of at least one significant stenosis (>50%) regardless of the number of bypass grafts of a patient. ICA was regarded as the standard of reference.

Results

All 31 patients underwent MSCT coronary angiography examinations without complications. Fourteen patients received an oral β-blocker prior to examination, 17 patients received no β-blockers due to presenting heart rates <65 bpm or contraindications. This resulted in a mean heart rate of 63.3 ± 7.3 bpm (range 29–164). Patients with irregular or fast heart rates despite β-receptor blocking were not excluded from the study.

A total of 96 bypass grafts were evaluated, of which 24% were internal mammary artery (IMA) and 76% were saphenous vein grafts (SVG). Twenty-two patients had SVG and IMA grafts, eight had only SVG, and one had only IMA grafts. There were seven SVG with sequential anastomoses.

One arterial graft had not been ICA-evaluated, because catheterization was expected to be very difficult because of a high-grade subclavian artery stenosis and a carotid-subclavian bypass. The graft was clearly demonstrated with MSCT and no significant stenosis was detected. Missed by ICA were two venous grafts, one to the left circumflex artery (LCX) and one to the right coronary artery (RCA). Both grafts were easily depicted and classified patent by MSCT. Although the image quality obtained by MSCT was good, the bypasses were excluded from statistical analysis because of the missing reference standard.

Table 2 shows the type and distribution of the 93 evaluable bypasses. With MSCT, 4/22 IMA grafts and 38/71 SVG were rated as occluded. All graft occlusions were confirmed by ICA.

Of the patent grafts, all bypass graft bodies and proximal-SVG anastomoses were evaluable by MSCT with diagnostic image quality. Forty-eight of 51 (94%) of the distal anastomoses were evaluable with MSCT. Two of the three non-evaluable distal anastomoses were IMA grafts, one to the left anterior descending artery (LAD) and one to the LCX (the SVG was to the LAD). All three non-evaluable cases were caused by metal clip artefacts.

MSCT correctly classified one significant IMA graft stenosis extending from the distal bypass corpus to the distal anastomosis. One significant IMA graft stenosis at the distal anastomosis was missed because of an intermediate-to-calcified plaque imitating a patent lumen (*Figure 2*). There were two false positive findings in the evaluation of IMA grafts with MSCT. Both were most likely due to poor opacification combined with small vessel size.

MSCT detected two significant SVG stenoses. One stenosis was located in the proximal graft body in an SVG to RCA (*Figure 3*), the other was located in an SVG to LCX. Both stenoses were confirmed by ICA. There were three non-significant stenoses (25–50%) one each in an SVG to the LAD, LCX, and RCA detected by both modalities. There were no false positive findings for SVG with MSCT.

MSCT findings are summarized in *Table 3*. The three unevaluable distal anastomoses were estimated as stenotic and were in contrast to earlier studies not excluded from statistical analysis.[4] From the data in *Table 3*, overall sensitivity for detecting significant stenoses was 97.8% (CI: 88.5–99.9), specificity was 89.3% (CI: 76.9–96.5), PPV was 90% (CI: 78.2–96.7), and NPV was 97.7% (CI: 87.7–99.9). Separate analysis for arterial and venous grafts resulted in a NPV of 92.3% (CI: 64–99.8) and 100% (CI: 88.4–100), respectively.

On a patient basis ($n = 31$) all 24 (sensitivity: 100%; CI: 85.8–100) patients with at least one stenosis >50% on ICA were correctly identified by MSCT. In five of seven (specificity: 71%; CI: 29–96.3) patients a stenosis >50% was correctly ruled out.

Discussion

The aim of this study was to evaluate the diagnostic accuracy of the latest 64-slice cardiac CT for the assessment of CABG.

Table 2 Bypass graft characteristics evaluated by MSCT

	Arterial grafts ($n = 22$)				Venous grafts ($n = 71$)			
	LAD	RD	LCX	RCA	LAD	RD	LCX	RCA
Graft anastomosis	16	4	2	0	12	7	29	23
Occluded grafts	3	0	1	—	7	4	17	10

MSCT CABG imaging has made a dramatic impact over the past few years.[2,3] Sensitivities and specificities of up to 96% and 95%, respectively, regarding graft occlusion detection were reported with 4-slice CT.[7,16,17] However, in a study by Ropers *et al.*[16] up to 38% of the bypass grafts had to be excluded owing to non-evaluability caused by poor 4-slice CT image quality. Introduction of 16-slice CT has led to an increase from 62 to 74% in the number of evaluable bypass grafts. Diagnostic accuracy in detecting graft stenosis improved, with a sensitivity of 96%, and after exclusion of non-evaluable segments, a specificity of 95% (4-slice CT 75% and 92%). A recent study even reported a specificity of 100% with a constant sensitivity of 96%.[11]

Our study using a new 64-slice cardiac CT shows improved diagnostic accuracy, with 94% of the distal bypass anastomoses being evaluable. Although, non-evaluable segments were not excluded, sensitivity and specificity were higher or comparable with 16-slice CT. The high NPV of 97.7% overall, and even 100% in a separate analysis for venous grafts highlights this technique's potential as a reliable, non-invasive tool in the evaluation of CABG. Moreover, on a patient-based analysis, all patients with at least one stenosis >50% on ICA were correctly identified by MSCT.

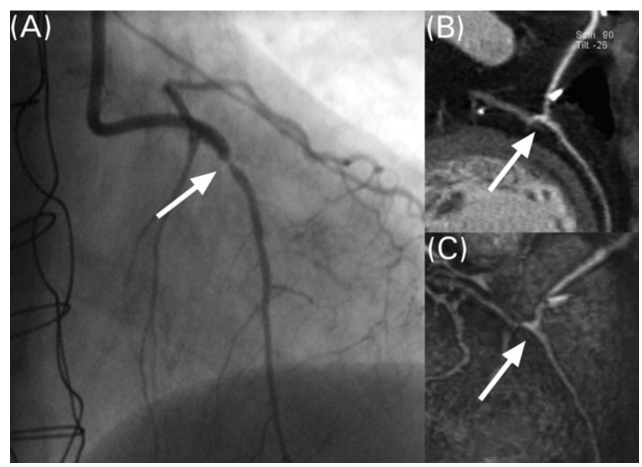

Figure 2 (*A*) ICA in a 69-year-old female CABG patient demonstrating a significant stenosis at the distal IMA anastomosis. This lesion was missed by MSCT because of an intermediate-to-calcified plaque imitating a patent lumen, as demonstrated by cMPR (*B*) and VRT (*C*) images (arrows).

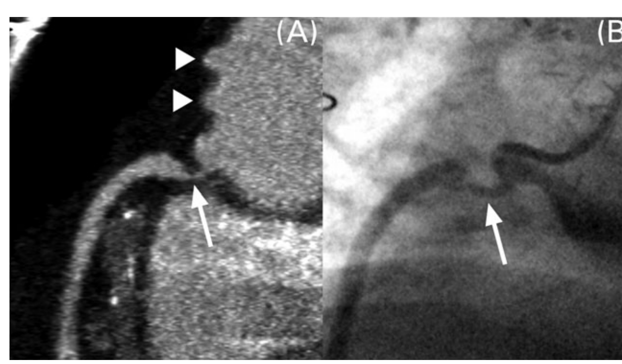

Figure 3 Cardiac CT MIP image demonstrating a significant lesion in a SVG to RCA of a 72-year-old male patient (*A*) (arrow). MIP image also demonstrates proximal occlusion of two venous grafts (arrowheads). The lesion was confirmed by ICA (*B*).

Table 3 Diagnostic accuracy of MSCT for the detection of significant stenosis or occlusion of bypass grafts

	Arterial grafts ($n = 22$)	Venous grafts ($n = 71$)
True positive CT	5	40
True negative CT	12	30
False positive CT	4[a]	1[a]
False negative CT	1	0

[a]False positive findings include three none evaluable grafts (two IMA, one SVG) that were estimated stenotic for this reason, although ICA showed all three grafts as patent.

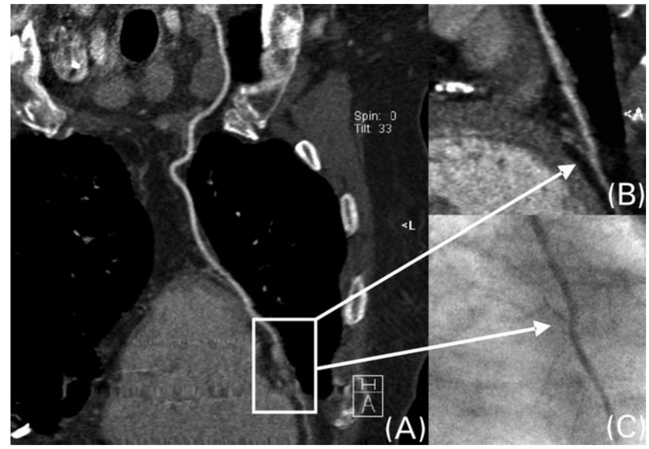

Figure 4 cMPR image demonstrating the course of the left IMA graft of a 73-year-old male patient to the LAD (*A*). In this reconstruction, the distal anastomosis remains unevaluable owing to motion artefacts (box). After individual adjustment of the reconstruction interval, cMPR image (*B*) now demonstrates the distal anastomosis with good, evaluable image quality. The graft was classified patent and validated by ICA (*C*) (arrows).

Numerous studies dealing with MSCT coronary bypass angiography have reported cardiac and respiratory motion artefacts as the most significant limitation in the reliable assessment of graft stenoses.[3,4] The introduction of 16-slice CT scanners improved diagnostic image quality by reducing cardiac and respiratory motion artefacts with faster gantry rotation times and shorter breath-hold times. However, optimum performance was observed primarily in patients with heart rates below 70 bpm. There were limitations in the evaluation of distal graft patency (74% evaluable bypass grafts reported by Schlosser *et al.*[4]) and non-occlusive graft stenoses, especially in cases of patients with higher heart rates.[3] CABG patients often present with arrhythmias. Such patients have been excluded from studies so far as being unsuitable for current MSCT technology because of the considerable changing of position of the bypass grafts throughout the cardiac cycle. In contrast to former studies, we did not exclude any patient with an irregular or fast heart rate. However, in our patient population no severe arrhythmia occurred, which may result in the degradation of image quality. We attempted to reduce the heart rate by administering additional β-blockers. It is well known that heart rate greatly influences image quality and stenosis detection.[18–20] Even with improved spatial and temporal resolution with 64-slice technology, additional administration of β-blockers is still justified.[21] Despite the use of β-blockers, we still observed a wide variety in heart range (29–164 bpm).

If graft segment image quality is disturbed by motion artefacts, additional image reconstruction intervals within the cardiac cycle can be evaluated for the time point of minimum motion artefact.[22] Especially, in arrhythmic patients, it may be often necessary to adapt the reconstruction window for different segments. In doing so, no bypass graft segment remained unevaluable and no significant stenosis was missed due to cardiac motion artefacts in our study population (*Figure 4*).

Coronary calcifications and metal clip artefacts still remain a challenging issue with 64-slice cardiac CT despite improvements with the use of curved MPRs.[3,4] In our study, an intermediate-to-calcified plaque imitated a true lumen, and led to our missing one significant stenosis (*Figure 2*). Evaluation of the distal anastomosis was hampered by metal clip artefacts in two of 18 arterial and in one venous bypass graft.

There were two false positive findings regarding IMA grafts with MSCT. The most likely reason for misinterpretation was poor opacification combined with very small vessel size. In one patient, poor opacification was probably due to severe heart failure and a left ventricular ejection fraction of 25%. In the other patient, we declared an ~50% stenosis as significant and, therefore, recommended ICA, as comparison with the right mammary artery's luminal diameter has revealed a significant difference.

One major advantage of cardiac CT is the easy depiction of even complex graft anatomy.[4] In our study, MSCT depicted two venous grafts that have been missed by ICA. We classified both grafts as patent, yet excluded them from statistical analysis because of the lack of a reference standard. Furthermore, one arterial graft was readily depicted and classified as patent by MSCT; ICA was not performed to display this particular graft due to complex vessel anatomy. The knowledge gained by graft anatomy evaluated by MSCT prior to ICA should enable the angiographer to reduce examination time, contrast media application, and radiation dose.

Study limitations

Recurrent anginal symptoms in CABG patients can be due to disease progression in the native vasculature. However, in this pilot study we focused on evaluating the diagnostic accuracy of CABG assessment as carried out in other studies with 4- and 16-slice CT.[4,16,17] Assessing the native vasculature of CABG patients is often extremely difficult because of widespread calcifications.[7] A larger patient study addressing this issue is already being conducted.

Many patients in our study population had had CABG surgery, a relatively long time ago. This might explain the high detection rate of occluded grafts compared with the relatively few significant stenoses we found. To determine whether a bypass graft is occluded acutely or chronically, Enzweiler *et al.*[23] differentiated the time point of bypass occlusion through diameter measurements by electron beam tomography. They have shown that in acute occlusions, the mean graft diameter is significantly larger than in chronic graft occlusions as a result of acute thrombosis. According to their results, the majority of our venous bypasses were chronically occluded grafts as they showed a narrow mean graft diameter of <1.5 mm (mean 0.3 ± 0.5 mm SD for 27 of 38 grafts). Six venous grafts showed a mean luminal diameter of >4 mm (mean 5.3 ± 0.7 mm SD) supposedly representing acute occlusion.[23] However, we did not focus on a study group presenting a relatively high pre-test probability, as did Leschka *et al.*,[14] who included patients already scheduled for CABG surgery. Therefore, our results instead represent the normal category of patients for whom the pros and cons of catheterization should be weighed. In addition, our data suggest that current 64-slice CT technology is also capable of reliably detecting non-significant stenoses with a luminal reduction of 25–50%. Three such stenoses were detected by CT and confirmed by ICA. To permit comparison with previous studies, we did not include non-significant lesions in our statistical analysis. To become a truly useful non-invasive screening method, MSCT must be able to reliably detect these non-significant lesions as well. Eventually, immediate catheterization will be avoidable, and a careful follow-up can be planned.

However, a limitation for close follow-up examinations is radiation exposure.[24–26] But radiation exposure from new generation scanners can be significantly reduced by prospective tube current modulation known as 'ECG pulsing'.[26–28] However, we applied no ECG pulsing in patients with arrhythmias or fast heart rates in order to allow reconstruction throughout the cardiac cycle without losing image quality.

Conclusions

State-of-the-art MSCT coronary angiography allows detailed evaluation of venous and arterial grafts with high diagnostic image quality even in patients with higher heart rates. CT reveals complex graft anatomy readily and reliably. Calcification, poor opacification, and clip material artefacts can still hamper the evaluation of distal arterial anastomoses despite improved spatial and temporal resolution.

Conflict of interest: none declared.

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