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Diagnostic Accuracy of Computed Tomography Angiography in Patients After Bypass Grafting

Comparison With Invasive Coronary Angiography

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OBJECTIVES We sought to evaluate the contribution of noninvasive dual-source computed tomography angiography (CTA) in the comprehensive assessment of symptomatic patients after coronary artery bypass grafting (CABG).

BACKGROUND Assessment of bypass grafts and distal runoffs by invasive coronary angiography is cumbersome and often requires extra procedure time, contrast load, and radiation exposure.

METHODS Dual-source CTA was performed in 52 (41 men, mean age 66.6 ± 13.2 years) symptomatic post-CABG patients scheduled for invasive coronary angiography. No oral or intravenous beta blockers or sedation were administered before the scan. Mean interval between CABG surgery and CTA was 9.6 ± 7.2 (range 0 to 20) years. Mean heart rate during scanning was 64.5 ± 13.2 (range 48 to 92) beats/min. Seventy-five percent of patients had both arterial and venous grafts. A total of 152 graft segments and 142 distal runoffs vessels were analyzed. Native coronary segments were divided into nongrafted (n = 118) and grafted segments (n = 289). A significant stenosis was defined as ≥50% lumen diameter reduction, and quantitative coronary angiography served as reference standard.

RESULTS The diagnostic accuracy of CTA for the detection or exclusion of significant stenosis in arterial and venous grafts on a segment-by-segment analysis was 100%. Sensitivity, specificity, positive predictive value, and negative predictive value to detect significant stenosis were 95% (95% confidence interval [CI]: 73% to 100%), 100% (95% CI: 96% to 100%), 100% (95% CI: 79% to 100%), 99% (95% CI: 95% to 100%) in distal runoffs respectively; 100% (95% CI: 97% to 100%), 96% (95% CI: 90% to 98%), 97% (95% CI: 93% to 99%), 100% (95% CI: 95% to 100%) in grafted native coronary arteries respectively; and 97% (95% CI: 83% to 100%), 92% (95% CI: 83% to 96%), 83% (95% CI: 67% to 92%), 99% (95% CI: 92% to 100%) in nongrafted native coronary arteries, respectively.

CONCLUSIONS Noninvasive CTA is successful for evaluating bypass grafts in symptomatic post-CABG patients, whereas invasive coronary angiography is still required for the assessment of significant stenosis in distal runoffs and native coronary arteries. (J Am Coll Cardiol Img 2009;2:816–24)

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Recurrent symptoms after surgical revascularization may be caused by progression of disease, either in the native coronary arteries or in the venous or, more rarely, arterial grafts (1). Therefore, comprehensive assessment of symptomatic patients after surgical revascularization should include arterial and venous bypass grafts, distal runoffs, and native coronary arteries.

Invasive coronary angiography (ICA) is often rather cumbersome, and the engagement and visualization of venous and arterial bypass grafts frequently prolongs procedure time and is associated with larger contrast use and increased radiation exposure.

Noninvasive computed tomography angiography (CTA) may be useful for reducing the additional invasive procedure time and contrast load if it were proven to be reliable for evaluating bypass grafts and distal runoffs before ICA.

Studies using 64-slice computed tomography (CT) scanners reported specificity values of 86% (2) and 76% (3), whereas up to 9% of nongrafted segments and distal runoffs were unevaluable because of presence of severe coronary calcifications, residual coronary motion, or metal clip artefacts.

Newer generation CT scanners may improve CT reliability. The dual-source 64-slice CT scanner is equipped with 2 tube-detector systems rotating simultaneously, resulting in an improved temporal resolution of 83 ms (4). Comparative studies demonstrated a high diagnostic performance of dual-source CT coronary angiography to detect significant obstructive coronary artery disease in patients without previous bypass surgery (4–6). We hypothesized that dual-source CTA allows more accurate detection or exclusion of significant stenoses, in particular, at the graft anastomosis site and smaller distal runoffs. We sought to evaluate whether CTA is complementary to ICA for the evaluation of patients after coronary artery bypass grafting (CABG).

METHODS

Study population. We studied 58 consecutive symptomatic patients after surgical revascularization that fulfilled the following criteria: sinus heart rhythm, able to breath-hold for 15 s, and no previous coronary intervention. All patients were scheduled for ICA, which was performed within 4 weeks after CTA. Six patients were excluded due to known allergy to iodinated contrast material (n = 1), impaired renal function (serum creatinine >120 μmol/l) (n = 2), atrial fibrillation (n = 2), and logistic inability to undergo a CT scan (n = 1) before ICA. Thus a total of 52 patients (41 male, mean age 66.6 ± 13.2 years) were included in the study. Our institutional review board approved the study, and all patients gave informed consent.

Patient preparation. No oral or intravenous beta blockers or sedation were administered before the scan. All patients received nitroglycerin (0.4 mg/dose) sublingually just before scanning.

CT scan protocol. All patients were scanned using a dual-source CT scanner (Somatom Definition, Siemens Healthcare, Forchheim, Germany). The system is equipped with 2 X-ray tubes and 2 corresponding detectors mounted on a single gantry with an angular offset of 90° (4). The CT angiography scan parameters were as follows: number of X-ray sources 2, detector collimation 32 × 0.6 mm with double sampling by rapid alteration of the focal spot in the longitudinal direction (Z-flying focal spot) (7), rotation time 330 ms, tube voltage 120 kV. The pitch varied between 0.2 for low heart rates (<40 beats/min) and 0.53 for high heart rates (>100 beats/min), with individually adapted pitch values for heart rates >40 and <100 beats/min. Automatic tube current modulation (ref mAs/rotation 380) in x-, y-, z-direction (Care Dose 4D, Siemens Healthcare), and adaptive electrocardiography (ECG) pulsing (full tube current during 30% to 65% of the RR interval, reduced tube current: 20% of maximum) was applied in all patients.

The scan range was extended to the level of the subclavian arteries in patients with internal mammary artery grafts. A bolus of iodinated contrast material (Ultravist 370, Schering AG, Berlin, Germany), which varied between 80 and 100 ml depending on the expected scan time, was injected in an antecubital vein followed by a saline chaser (40 ml; flow rate 4.0 to 5.0 ml/s).

The flow rate (4.0 to 5.0 ml/s) was adjusted to the scan range (presence of left internal mammary artery) and the expected scan time (pitch dependent). A bolus tracking technique was applied to synchronize the data acquisition with the arrival of contrast in the bypass grafts and native coronary arteries.

CT image reconstruction and evaluation. All CT datasets were reconstructed using a single-segment algorithm: slice thickness 0.75 mm; increment 0.4 mm; medium-to-smooth convolution kernel (B26f) and sharp kernel (B46f) resulting in a spatial resolution of 0.6 to 0.7 mm in-plane and 0.5 mm through-plane (8). Images were reconstructed fol-

ABBREVIATIONS AND ACRONYMS

CABG = coronary artery bypass grafting

CT = computed tomography

CTA = computed tomography angiography

E = effective dose

ECG = electrocardiography

ICA = invasive coronary angiography

QCA = quantitative coronary angiography

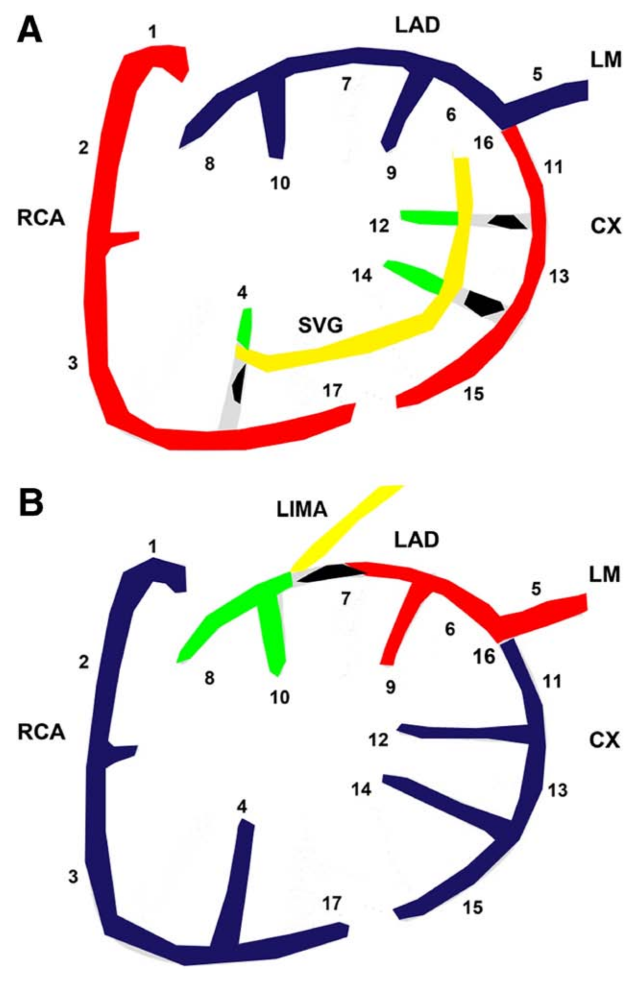

Figure 1. Schematic View of CTA Evaluation on a Per-Segment Level

(A) Saphenous venous graft (SVG) and **(B)** left internal mammary artery (LIMA) grafts **(yellow)**, distal runoffs **(green)**, native grafted **(red)**, and nongrafted **(blue)** coronary arteries were evaluated on a per-segment level according to the 17-segment modified American Heart Association classification (9). CTA = computed tomography angiography; CX = circumflex artery; LAD = left anterior descending artery; LM = left main artery; RCA = right coronary artery.

lowing a stepwise approach depending on the patient's heart rate during scanning as previously described (5). Two experienced radiologists, blinded to ICA findings, independently scored all CT datasets. In case of a jump graft (two or more anastomoses per arterial or venous graft), the graft was divided into graft segments. All graft segments between the proximal anastomoses and each coronary insertion were evaluated. Distal runoffs and native coronary arteries were evaluated on a per-segment level according to the 17-segment modified American Heart Association classification (9). The CT image evaluation of distal runoffs and native coronary arteries is illustrated in Figure 1. The distal runoff segments included the segment at which the graft was inserted and all segments located distally to the inserted segment. Native segments were divided into nongrafted and grafted segments. The grafted segments included all segments located proximal to the segment at which the graft was inserted. Volume-rendered images were initially used to visualize the course of the grafts in relation to the coronary arteries. Axial views and (curved) multiplanar reconstructions were used to identify and to classify lesions into significantly diseased (≥50% lumen diameter reduction) or not (<50% lumen diameter reduction). Interobserver disagreements were resolved in a joint session. One experienced observer evaluated image quality of all graft segments, distal runoff segments, and native coronary segments. Image quality was classified as good (defined as absence of any image-degrading artifacts related to motion, noise, and vascular clips), moderate (presence of artifacts but evaluation possible with moderate confidence), or poor (presence of image-degrading artifacts and evaluation possible with low confidence).

Quantitative coronary angiography (QCA). One experienced cardiologist, unaware of the results of CTA, identified all graft segments, distal runoffs, and native coronary segments. Segments were visually classified as normal or luminal irregularities (<20% lumen diameter reduction) or diseased (≥20% lumen diameter reduction). Diseased segments were evaluated using a validated quantitative coronary artery algorithm (QCA) (CAAS, Pie Medical, Maastricht, the Netherlands). Lesions with ≥50% lumen diameter reduction in 2 orthogonal planes were considered as significant stenoses. Distal runoff segments supplied by occluded grafts were classified as native grafted segments. All graft and native coronary segments located distally to a total occlusion (100% lumen reduction) and not supplied by collaterals were classified as post-occlusion segments and were excluded from analysis. In addition, native grafted segments with a lumen diameter <1.5 mm were excluded.

Effective dose. The effective dose (E) for CTA in each patient was estimated by the following equation, as proposed by the European Working Group for Guidelines on Quality Criteria in CT (10):

$$E = E_{DLP} \cdot \mathrm{DLP}$$

where DLP equals dose-length product (cm) and $E_{DLP} = 0.017\ \mathrm{mSv} \cdot \mathrm{mGy}^{-1} \cdot \mathrm{cm}^{-1}$.

Table 1. Patient and Scan Demographics (n = 52)

Male (%)	41 (79)
Age, yrs	66.3 ± 13.2
Body mass index, kg/m^2	27.2 ± 5.8
History (%)	
Family history of CAD	21 (40)
Nicotine abuse	10 (19)
Hypertension	16 (31)
Dislipidemia	31 (60)
Diabetes	19 (37)
Previous myocardial infarction	22 (42)
Long-term beta blockers	47 (90)
Graft anatomy per patient (%)	
Single graft	11 (21)
Two grafts	31 (60)
Three grafts	9 (17)
More than three grafts	1 (2)
Venous and arterial grafts	39 (75)
Venous grafts, no arterial grafts	6 (12)
Arterial grafts, no venous grafts	7 (14)
CT examination	
Heart rate during scanning, beats/min	64.4 ± 14.3
Scan time, s	15.2 ± 4.3
Pitch	0.26 ± 0.07
Scan length, cm	19.0 ± 5.8
Contrast volume, ml	92.6 ± 17.3
DLP, mGy·cm	1,726 ± 596
Effective dose, mSv	22.1 ± 2.8

CAD = coronary artery disease; CT = computed tomography; DLP = dose-length product.

Statistical analysis. Continuous variables are expressed as mean (standard deviation), and categorical characteristics are expressed as numbers and percentages. The diagnostic performance of CTA for the detection of significant stenosis as defined by QCA is presented as sensitivity, specificity, and negative and positive predictive values, with corresponding 95% confidence intervals, and positive and negative likelihood ratios were calculated. Comparison between CTA and QCA was performed on 2 levels: patient-by-patient and segment-by-segment analysis. Interobserver variability for the detection of significant stenosis was determined by kappa statistics.

RESULTS

Patient and scan demographics are summarized in Table 1. The mean body mass index was 27.2 ± 5.8 (range 22.0 to 34.5) kg/m^2. Forty-seven (90%, 47 of 52) patients used long-term beta blockers. The mean interval between CABG surgery and CTA was 9.6 ± 7.2 (range 0 to 20) years. The mean interval between CTA and ICA was 11.5 ± 14.3 (range 0 to 14.4) days. Mean scan time was 15.2 ± 4.3 (range 9.2 to 22.9) s. Mean heart rate during scanning was 64.5 ± 13.2 (range 48 to 92) beats/min. The mean effective dose of CTA was 22.1 ± 2.8 mSv.

Diagnostic performance of CTA: segment-by-segment–based analysis. The diagnostic performance of CTA for the detection of significant lesions in grafts, distal runoffs, and native coronary arteries on a segment-by-segment–based analysis is detailed in Table 2. A subanalysis was performed for distal runoffs and native coronary arteries in patients with low (≤65 beats/min) and high (>65 beats/min) heart rates (Table 3).

GRAFTS. Forty-five (87%, 45 of 52) patients had venous grafts, and 43 (83%, 43 of 52) patients had arterial grafts. In 1 patient, both the right and the left internal mammary arteries were used. A total of 63 venous grafts, including 33 jump grafts, representing 102 venous graft segments were evaluated. We observed good image quality in 87% (89 of 102) of venous graft segments, moderate image quality in 11% (11 of 102), and poor image quality in 2% (2 of 102). CTA correctly identified 15 of 15 occluded

Table 2. Diagnostic Performance of Dual-Source CTA to Detect Significant (≥50% Lumen Diameter Stenosis) Stenosis (Segment-by-Segment Analysis)

Segments	Prevalence of Disease (%)	N	TP	TN	FP	FN	κ	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	+LR	−LR
Bypass grafts	19	152	29	123	0	0	0.99	100 (85–100)	100 (96–100)	100 (85–100)	100 (96–100)	—	0
Native coronary arteries													
Distal runoffs	13	142	19	122	0	1	0.81	95 (73–100)	100 (96–100)	100 (79–100)	99 (95–100)	—	0.05
All grafted vessels	59	289	170	112	5	0	0.79	100 (97–100)	96 (90–98)	97 (93–99)	100 (95–100)	23.4	0
All nongrafted vessels	29	118	33	77	7	1	0.85	97 (83–100)	92 (83–96)	83 (67–92)	99 (92–100)	11.7	0.03

Values in parentheses represent upper and lower bound for 95% confidence interval.
FN = false negatives; FP = false positives; +LR = positive likelihood ratio; −LR = negative likelihood ratio; N = number of segments; NPV = negative predictive value; PPV = positive predictive value; TN = true negatives; TP = true positives.

Table 3. Heart Rate Subanalysis in Low (≤65 Beats/Min) and High (>65 Beats/Min) Heart Rates: Diagnostic Performance of Dual-Source CTA to Detect Significant (≥50% Lumen Diameter Stenosis) Stenosis (Segment-by-Segment Analysis)

Segments	HR (beats/min)	Prevalence of Disease (%)	N	TP	TN	FP	FN	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	+LR	−LR
Distal runoffs	≤65	10	74	7	67	0	0	100 (56–100)	100 (93–100)	100 (56–100)	100 (93–100)	—	0
	>65	19	68	12	55	0	1	92 (62–100)	100 (92–100)	100 (70–100)	98 (89–100)	—	0.08
Grafted natives	≤65	59	135	80	49	4	0	100 (94–100)	93 (81–98)	95 (88–99)	100 (91–100)	13.25	0
	>65	58	154	90	63	1	0	100 (95–100)	98 (91–100)	99 (93–100)	100 (93–100)	64.0	0
Nongrafted natives	≤65	19	43	8	34	1	0	100 (60–100)	97 (83–100)	89 (51–99)	100 (87–100)	35.0	0
	>65	35	75	25	43	6	1	96 (78–100)	88 (75–95)	81 (62–92)	98 (87–100)	7.85	0.04

Values in parentheses represent upper and lower bound for 95% confidence interval.
Abbreviations as in Table 2.

venous graft segments and 13 of 13 significant stenoses (Fig. 2). A total of 48 arterial grafts, including 2 jump grafts, representing 50 arterial graft segments were evaluated. We observed good image quality in 90% (45 of 50) of arterial graft segments, moderate image quality in 8% (4 of 50), and poor image quality in 2% (1 of 50). CTA correctly identified 1 of 1 occluded left internal mammary artery graft (Fig. 3). Agreement between CTA and QCA on a per-segment level was good (kappa value 0.99).

DISTAL RUNOFFS. ICA identified 136 patent graft segments, supplying a total of 142 distal runoff segments. The image quality was good in 79% (112 of 142), moderate in 17% (24 of 142), and poor in 4% (6 of 142). CTA correctly detected 19 of 20 significant stenoses (Figs. 4 and 5), and 1 significant

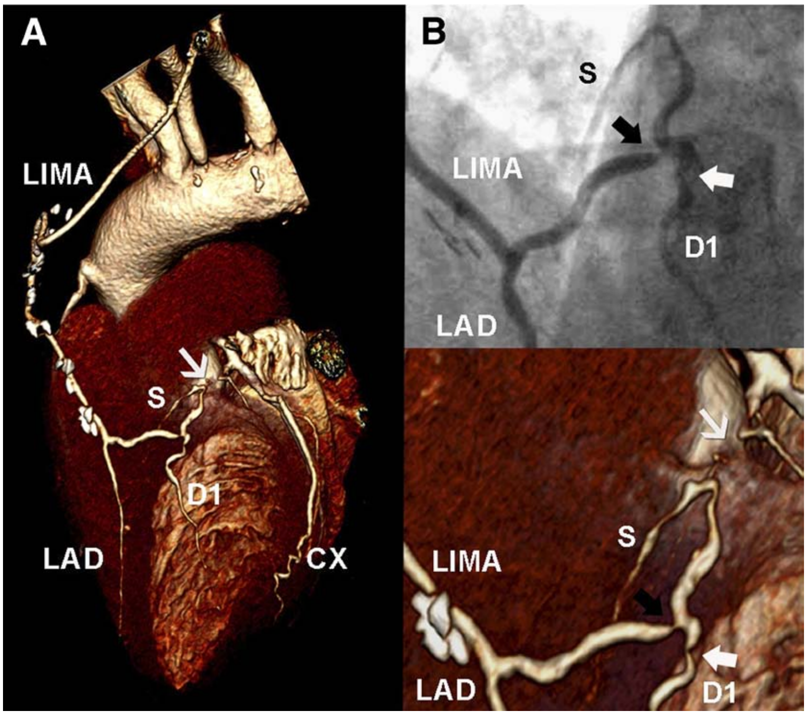

Figure 2. 58-Year-Old Man With Progressive Chest Pain and Inconclusive Stress Test

Volume-rendered computed tomography (CT) image **(A)** shows an occluded proximal LAD **(arrow)** and a patent LIMA to the distal LAD with a jump to first diagonal (D1). A more detailed view **(right lower panel)** shows a significant stenosis at the anastomosis site of D1 **(black arrow)**, with a second significant stenosis in the proximal D1 runoff **(white arrow)**. There is retrograde filling of a septal branch (S). Corresponding conventional angiogram **(B)** confirms CT findings. Abbreviations as in Figure 1.

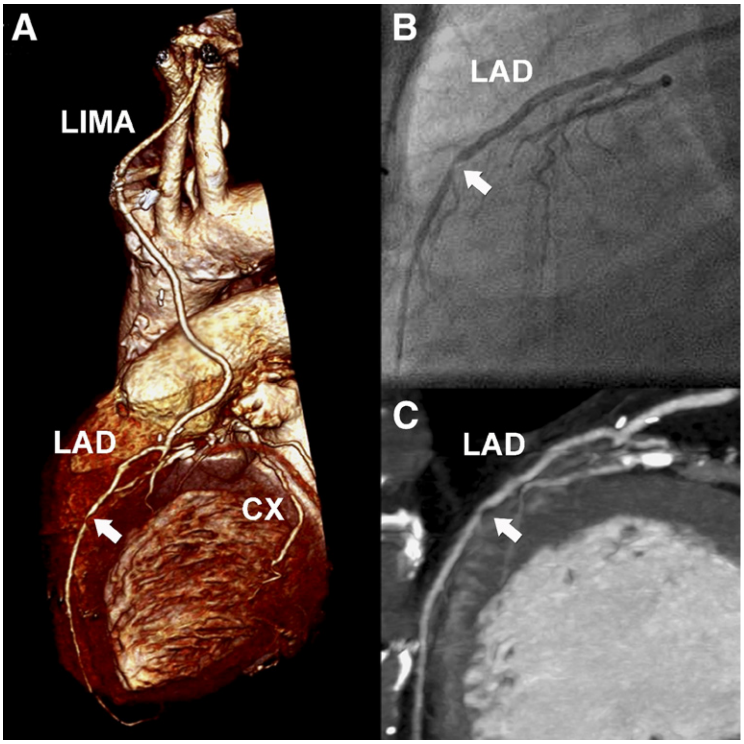

Figure 3. 81-Year-Old Man With Stable Angina Pectoris and a Positive Treadmill Test

Volume-rendered image **(A)** shows a patent LIMA to the distal LAD. The proximal LAD is occluded, and a lesion is present in the distal runoff **(white arrow)**. Corresponding curved multiplanar reconstructed image **(B)** and conventional angiogram **(C)** confirm the presence of a significant stenosis **(white arrow)**. Abbreviations as in Figure 1.

stenosis was missed in a marginal obtuse. The diagnostic performance of CTA in distal runoffs was lower in patients with heart rate ≥65 beats/min as compared with heart rate <65 beats/min. Agreement between CTA and QCA on a per-segment level was good (kappa value 0.81).

NATIVE CORONARY ARTERIES: GRAFTED. A total of 170 coronary arteries (right coronary artery 67%, 35 of 52; left main 94%, 49 of 52; left anterior descending artery 96%, 50 of 52; left circumflex artery 69%, 36 of 52) including 289 segments were revascularized by bypass grafting. The image quality was good in 73% (211 of 289), moderate in 22% (64 of 289), and poor in 5% (14 of 289) of segments. CTA detected 170 significant stenoses, including 44 (26%, 44 of 170) total occlusions, and 5 lesions were overestimated. A total of 37 (13%, 37 of 289) post-occlusion segments and 19 (7%, 19 of 289) segments <1.5 mm were excluded from analysis. The diagnostic performance was comparable in both heart rate groups. Agreement between CTA and QCA on a per-segment level was good (kappa value 0.79).

NATIVE CORONARY ARTERIES: NONGRAFTED. A total of 38 coronary arteries including 118 segments were not revascularized by bypass grafting. The image quality was good in 81% (96 of 118), moderate in 16% (19 of 118), and poor in 3% (3 of 118). CTA detected 33 significant stenoses, including 9 (27%, 9 of 33) total occlusions, and 7 lesions were overestimated. A total of 22 post-occlusion segments were excluded from analysis. The diagnostic performance was comparable in both heart rate groups. Agreement between CTA and QCA on a per-segment level was good (kappa value 0.85).

Diagnostic performance of CTA: patient-by-patient–based analysis. We observed a very high prevalence (98%, 51 of 52) of any significant obstructive disease on a per-patient level. The overall diagnostic accuracy of CTA for the detection of any significant stenosis was 100% on a per-patient level.

DISCUSSION

The diagnostic work-up of patients with recurrent angina after CABG remains challenging and

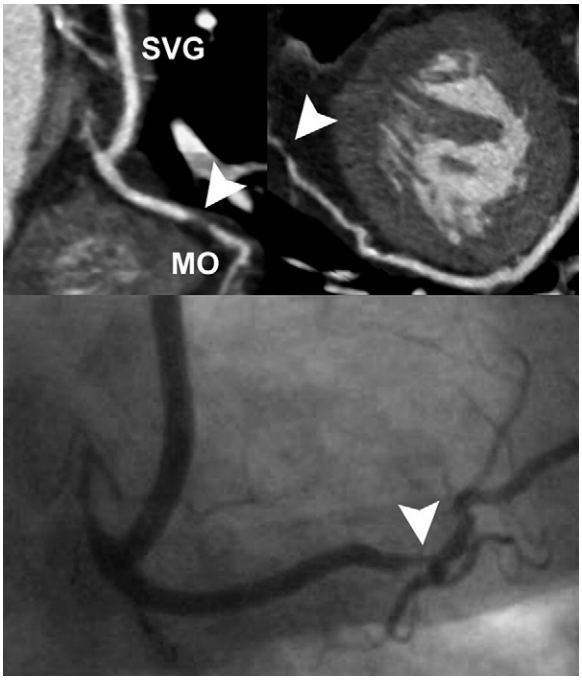

Figure 4. 72-Year-Old Woman Presenting With Typical Chest Pain and Previous Myocardial Infarction

Curved multiplanar reconstructed images show a significant lesion in a marginal branch. This focal lesion was missed at computed tomography evaluation and represents a false-negative finding. MO = marginal obtuse branch; SVG = saphenous venous graft.

should include complete assessment of bypass grafts and native coronary arteries.

Noninvasive 64-slice CTA demonstrated a very high diagnostic performance for the detection of obstructive graft disease, with sensitivities of 100% for occluded grafts and sensitivities ranging from 80% to 100% for the detection of significant stenosis (2,3,10–15). Few data are available reporting on the diagnostic performance of CTA for the detection of significant stenosis in the natives. Two studies (2,3) reported sensitivities for the detection of significant stenoses of 86% and 89% in distal runoffs and 86% and 97% in nongrafted arteries. Specificity in the two studies was 90% and 93% in distal runoffs and 76% and 86% in nongrafted coronary arteries. Importantly, 9% to 25% of native segments were unevaluable, and overestimation of stenosis frequently occurred.

The 64-slice dual-source CT scanner allows acquisition of images during a shorter time window (83 ms) of the heart cycle, resulting in images with less residual coronary motion and more precise delineation of stenoses (8), in particular at the graft distal anastomosis site and smaller distal runoffs. In addition, fast scanning of the whole thorax can be performed in short manageable breath holds (10 to 15 s), which is, in particular, important in the assessment of arterial grafts.

In our study, we sought to evaluate whether dual-source CTA would permit successful, reliable, noninvasive evaluation of bypass grafts and distal runoffs to obviate the need for invasive angiographic verification. For this evaluation, we performed a segment-by-segment analysis, rather than a per-patient analysis, to provide anatomic information about bypass grafts, distal runoffs, and native coronary segments. In our evaluation, we included all graft or native coronary segments in the analysis and did not exclude any segment due to motion artifacts or calcifications. We found a 100% sensitivity on a per-segment level for the detection of significant obstructive graft disease and a 95% sensitivity for the detection of significant lesions in distal runoffs. Importantly, the majority of distal anastomosis sites and smaller distal runoffs demonstrated good image quality and could be assessed with high confidence. Furthermore, it is noteworthy that on a per-patient analysis, all significant obstructive graft disease was correctly identified, and no false positives were encountered. According to the American College of Cardiology Foundation Appropriateness Criteria, routine use of 64-slice CT coronary angiography in post-CABG patients has been classified as an inappropriate/uncertain indication (16) or a Class IIb indication, Level of Evidence: C (17).

Our results indicate that successful, reliable, noninvasive evaluation of grafts with CTA may obviate the need for invasive angiographic verification, and CT angiography can be used for the assessment of graft patency only. If these results are verified in larger, multicenter studies, CTA evaluation of bypass grafts patency may be classified as an appropriate/certain indication. CTA may facilitate planning of subsequent percutaneous revascularization by providing accurate anatomical site of graft origin, saving considerable procedure time, contrast load, and radiation exposure. However, these hypotheses are purely conjectural and require clinical testing. Moreover, ICA is still required to confirm or refute CT evaluation of obstructive disease in distal runoffs and native coronary arteries.

The use of retrospective ECG gating or spiral CT scan mode resulted in a relatively high effective dose (22.1 mSv) as compared with diagnostic ICA (8.8 mSv), which is usually higher in the angiographic evaluation of venous and arterial bypass grafts (14). Our rather high patient dose was due to

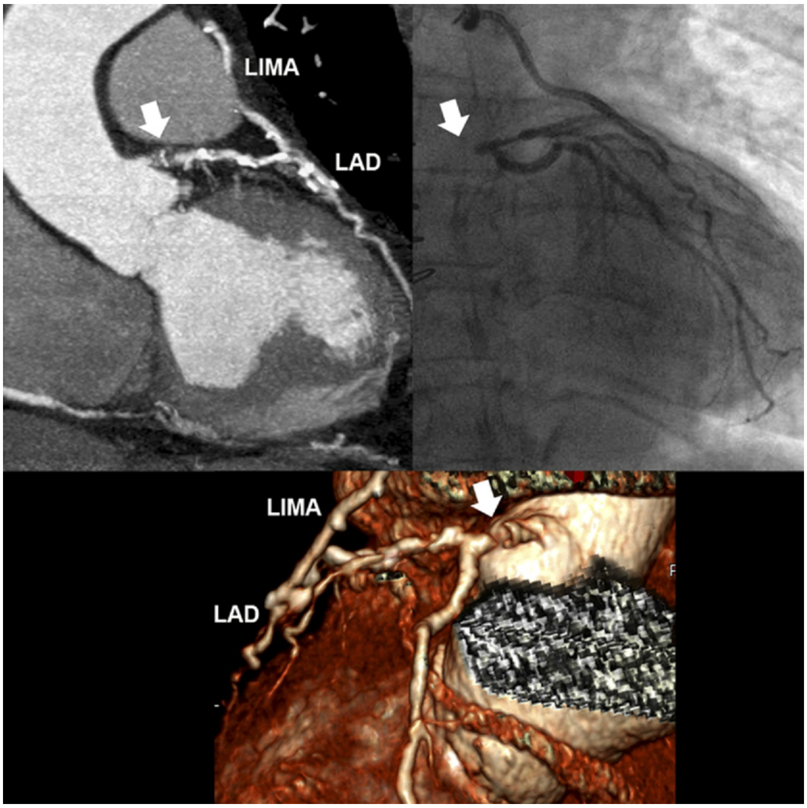

Figure 5. 70-Year-Old Women With Typical Chest Pain and Previous Myocardial Infarction 4 Years After CABG

The LIMA and distal runoff vessel were patent. The curved multiplanar reconstructed image **(upper right)** and volulme-rendered image **(color image)** demonstrated a total occlusion of the grafted left main **(arrow)**. Corresponding coronary angiogram confirms computed tomography findings **(upper left panel)**. Abbreviations as in Figure 1.

the fact that we began our study with a dual-source prototype scanner. At that time, we used a rather wide ECG pulsing window to be able to select optimal motion-free image reconstruction phases. Nowadays patient dose can be significantly reduced by the selection of short windows and the introduction of the possibility to select a very low tube current (4% of maximum tube current; Mindose, Siemens Healthcare) outside the ECG pulsing window, which can reduce effective dose up to 64% (18,19).

Recently, it has been shown that prospective ECG triggering or "step-and-shoot" CT scan mode can significantly reduce radiation exposure, with reported dose values of 1.0 to 3.0 mSv in patients without previous CABG, but requires a very regular heart rhythm (20,21).

To put dose concern into perspective, it is important to note that patients after CABG are generally older (± 60 years) and that this is associated with a lower, although not negligible, life-time attributable risk of cancer incidence or mortality (22).

CONCLUSIONS

We demonstrated that noninvasive CTA has a very high diagnostic performance to detect or exclude significant stenosis in bypass grafts. CTA should not be considered as a substitute for, but rather as complementary to ICA in the diagnostic work-up of symptomatic post-CABG patients, whereas ICA is still required to confirm or refute CT evaluation of obstructive native coronary artery disease.

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