Multimodality imaging of coronary artery bypass grafts

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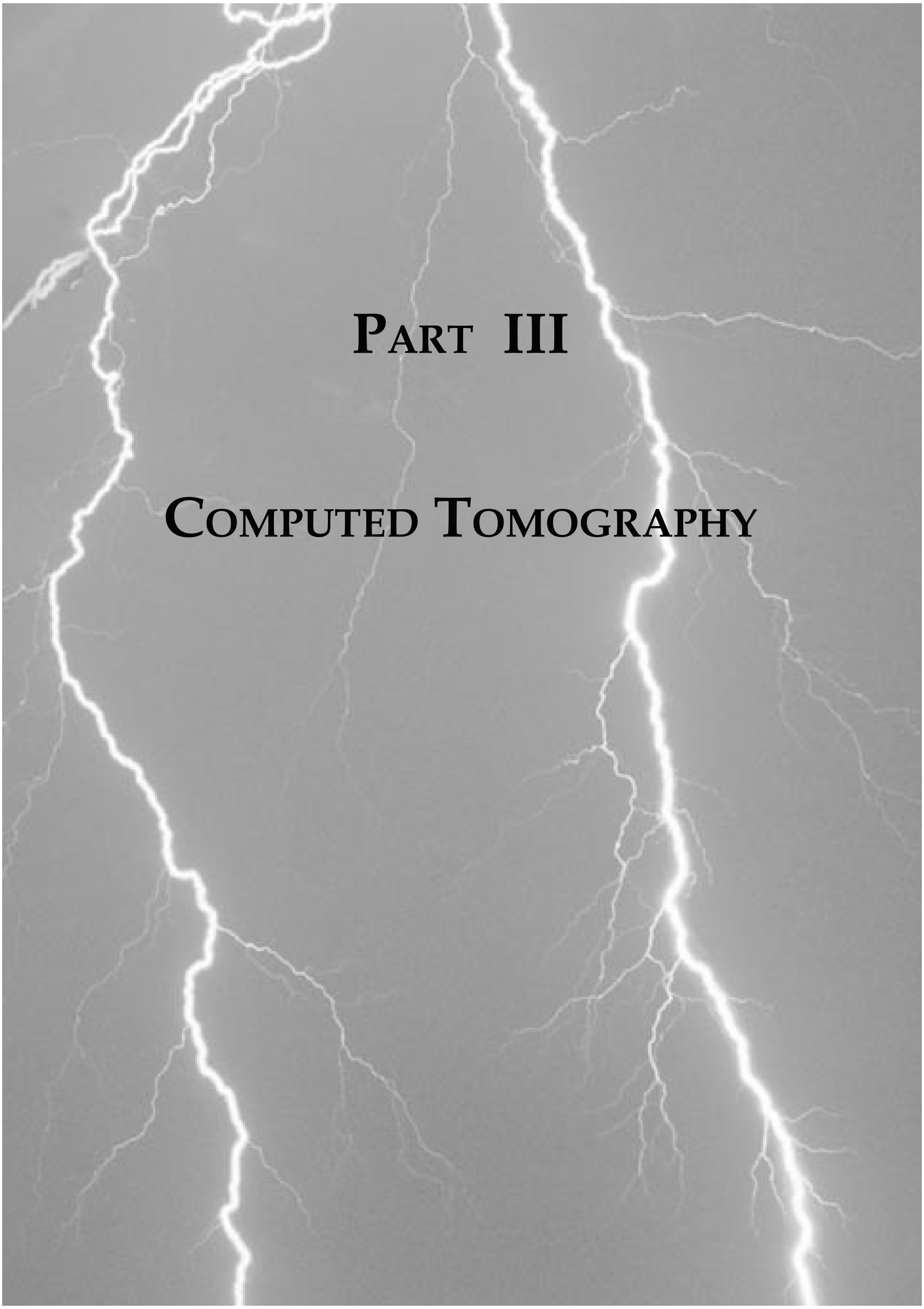

Part III

Computed Tomography

Chapter 7

Comprehensive assessment of patients after coronary artery bypass grafting by 16-detector row computed tomography

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Am Heart J 2005; 150, 4, 775-781

Abstract

Background: Multi-detector row computed tomography (MDCT) is a versatile modality to evaluate stenoses in native coronary arteries and bypass grafts. Acquired MDCT data can additionally be used to assess left ventricular ejection fraction (LVEF). The purpose was to use MDCT for the assessment of bypass graft and coronary artery disease combined with evaluation of LVEF.

Methods: Twenty-five patients underwent 16-detector-row CT examination and coronary angiography. Bypass grafts and nongrafted coronary artery segments at MDCT were evaluated on eligibility, patency and ≥50% stenosis. The MDCT data set was used to calculate LVEF and was divided into patients with no/subendocardial/transmural myocardial infarctions (MIs).

Results: Ninety vessels were evaluated: 14 arterial grafts/53 vein grafts/23 nongrafted vessels. Of 225 segments, 17 were ineligible for evaluation because of metal clips. With MDCT, patency in segments of arterial grafts/vein grafts/nongrafted vessels could be evaluated with high accuracy in 100%/100%/97% of segments. In arterial grafts stenoses ≥50% did not occur at angiography, which was for all eligible segments correctly diagnosed at MDCT. Stenosis ≥50% could be correctly detected by MDCT with a sensitivity/specificity of 100%/94% for vein grafts, and 100%/89% for nongrafted vessels. Negative predictive value was 100% for vein grafts and nongrafted vessels. In patients with transmural MI, MDCT revealed a significant lower LVEF as compared with patients without or with subendocardial MI ($p<0.05$).

Conclusion: Comprehensive assessment of bypass grafts, nongrafted vessels, and LVEF is feasible with MDCT. Owing to the high negative predictive value this noninvasive approach may be used as gatekeeper before coronary angiography.

Introduction

Recently, multidetector-row computed tomography (MDCT) has gained rapid acceptance as a diagnostic cardiac imaging modality, allowing noninvasive visualization of cardiac anatomy, coronary arteries, and coronary artery bypass grafts with high spatial resolution. With the introduction of 16-detector-row CT, significant stenoses (≥50%) in coronary arteries can be detected with high sensitivity and specificity (1;2). Earlier studies showed that 4-detector-row CT technology allows adequate detection of significant stenosis in both arterial and vein grafts, although with lower spatial resolution than the current state-of-the-art 16-detector-row technology (3;4). In addition, 16-detector MDCT technology has been used for bypass grafts visualization, although no direct comparison with coronary angiography was performed and nongrafted coronary arteries were not evaluated at the same time (5;6). As recurrent chest pain after coronary artery bypass graft surgery has a high prevalence and conventional coronary angiography has a small risk of potentially lethal complications, a noninvasive approach to evaluate both grafts and nongrafted coronary arteries in one comprehensive evaluation would be of great clinical benefit.

Furthermore, the acquired MDCT data set can additionally be used to assess global left ventricular (LV) function (7). Left ventricular ejection fraction (LVEF), and stroke volume, obtained with MDCT, have been shown to correlate well with cine magnetic resonance imaging (MRI) (8-10), echocardiography (11), and cine ventriculography (12). For patients with previous myocardial infarction (MI) measurement of LVEF is important for risk stratification, and adjustment of medical therapy in order to prevent congestive heart failure, as underscored in the practice guidelines for both non-ST-segment elevation and ST-segment elevation MI (13;14). In addition, LVEF was identified as an independent predictor of mortality in patients with previous bypass graft surgery (15;16). In patients with prior coronary artery bypass graft surgery presenting with recurrent chest pain, early risk stratification and adjustment of medical therapy based on measurement of LVEF would be important extra advantages of MDCT.

Accordingly, the purpose of the present study is to evaluate the use of 16-detector-row CT for the comprehensive assessment of bypass graft, as well as native coronary artery disease in conjunction with evaluation of global LV function.

Methods

Study Population

Consecutive patients with a history of bypass graft surgery, who were awaiting coronary angiography, were screened for participation in the study. Exclusion criteria were renal failure, allergy to contrast agents, irregular heart rhythm, and pregnancy. Included patients underwent coronary angiography for recurrent chest pain or a prior episode of severe arrhythmia and MDCT examination. No cardiac event occurred between angiography and MDCT. All patients gave written informed consent and the study was approved by the institutional ethical committee.

Coronary angiography was performed according to a standard procedure using the femoral approach. To determine stenosis severity in coronary arteries or bypass grafts objectively, quantitative coronary arteriography was performed by an independent,

experienced researcher. Quantitative coronary arteriography was performed according to standardized methods (17;18).
For all included patients, the presence of a prior MI was assessed, concerning patient history and electrocardiography criteria. Subendocardial infarctions were defined as non-Q-wave infarctions, transmural infarctions as Q-wave infarctions.

Multdetector-row Computed Tomography
Multdetector-row computed tomography examination was performed using a 16-detector-row CT scanner (Aquilion 16, Toshiba, Japan). None of the patients received additional β-blockers to reduce heart rate. A localizer scan was obtained to establish the scanning range, from proximal origin of the arterial graft from the subclavian artery to the heart base. When a patient had only vein grafts the top of the aortic arch was set as proximal boundary. The sure-start feature was used to determine the arrival of contrast agent in the ascending aorta. Data acquisition was initiated after the contrast agent (jobitridol, Guerbet, Aulnay sur Bois, France) appeared in the ascending aorta, and the patient was instructed to hold his breath. Additional scan parameters for arterial grafts were the following: 16 x 1.0-mm detector collimation, 0.4 to 0.5 seconds rotation time and 3.2 to 4.0 pitch dependent on patient's heart rate, 0.8 mm^3 pixel size, 120 kV at 320 mA tube voltage, 200 to 250 mm scanning range, administration of intravenous contrast agent at 4 ml/s to a total of 160 ml, and 25 to 30 seconds breath-hold duration. For vein grafts, because of a shorter scanning range (150-200 mm), 16 x 0.5 mm detector collimation was allowed, with 0.4 mm^3 pixel size. An electrocardiogram was simultaneously recorded, and data were retrospectively reconstructed using a segmental reconstruction algorithm, obviating the use of additional β-blockers to lower the heart rate. Axial images were reconstructed at intervals of 5% throughout the cardiac cycle with 0.8-mm increment for arterial grafts and 0.4 mm for vein grafts.
The reconstructed images were viewed on a Vitrea workstation (Vitrea 2, Vital Images, Plymouth, Minn) using 2D axial, 3D, and multiplanar reformat reconstructions. The cardiac phase with the least motion artifacts (mostly at 75%, 80% or 85%) was used for evaluation of bypass grafts, recipient vessels and nongrafted arteries. An experienced cardiologist and radiologist evaluated the scans in consensus. Bypass grafts were divided into segments. The course of the graft from its origin to the first anastomosis was regarded as one segment (graft body). If one graft had more recipient vessels (sequential grafts), the course of the graft from the first anastomosis to the second anastomosis was regarded as a separate segment (second graft body), and so on. The recipient vessels were regarded as separate segments. Proximal segments of coronary arteries receiving a graft were not assessed. Of nongrafted arteries, left main artery, left anterior descending artery, circumflex artery, and right coronary artery were distinguished as separate segments. All segments were evaluated on eligibility for assessment, and on patency. Eligible, patent segments of graft bodies and nongrafted arteries were further searched for the presence of a significant stenosis (≥50%).
Using the CT data set, a short-axis view of the left ventricle was reconstructed by multiplanar reformat (11). Endocardial contours were manually traced using cardiac analysis software (CT MASS, Medis, Leiden, the Netherlands), and LVEF was calculated.

Statistical Analysis

Computed tomography evaluation of vessel segments was compared with angiographic analysis. Sensitivity, specificity, diagnostic accuracy, positive predictive value (PPV) and negative predictive value (NPV) were based on their standard definitions. Agreements between the diagnostic modalities were assessed using κ statistics, with a κ value <0.4, between 0.4 and 0.75, and >0.75 representing modest, fair to good, and excellent agreement, respectively. Data of LVEF are presented as mean ± SD, and are compared using a Student t test.

Results

Study Population

A total of 30 consecutive patients were screened for inclusion in the study. Of these, 5 were excluded because of (supra)ventricular arrhythmias and/or renal insufficiency. Characteristics of the included 25 patients are shown in Table 7.1. A total of 90 vessels were evaluated; vessel characteristics are summarized in Table 7.2. The vessels were subdivided into 225 segments: in graft bodies 104 segments (22 in arterial, 82 in vein grafts), in recipient vessels 82 segments, in native, nongrafted arteries 39 segments. At coronary angiography, 187 (83%) segments were patent. Of these 187 segments, 17 (9%) were ineligible for evaluation of ≥50% stenosis because of metal clips used in arterial bypass grafting. Of the remaining 170 segments, 91 were segments of grafts bodies and nongrafted arteries and were screened for a stenosis ≥50%. In 14 (15%) segments a significant stenosis was present at coronary angiography.

Number of patients	25
Male/female	24/1
Age (years)	66.7 ± 9.4
Diabetes mellitus	8 (32%)
Currently smoking	3 (12%)
Hypertension	13 (52%)
Hypercholesterolemia	16 (64%)
Prior myocardial infarction	14 (56%)
Pacemaker or ICD	2 (8%)
Time after CABG (years)	9.2 ± 5.3
Medication	
β-blocker	14 (56%)
ACE-inhibitor	12 (48%)
Calcium antagonist	14 (56%)
Nitrate	12 (48%)
Diuretic	7 (28%)
Statin	19 (76%)
Oral anticoagulant	7 (28%)

Table 7.1
Patient Characteristics
ICD = intracardiac defibrillator; CABG = coronary artery bypass grafting;
ACE = angiotensin-converting enzyme

Number of vessels	90
Single arterial grafts	7
Sequential arterial grafts	7
Single vein grafts	25
Sequential vein grafts	28
Nongrafted arteries	23
Vascular territory perfused by vessel	
LAD	34
LCX	34
RCA	22

Table 7.2
Vessel Characteristics
LAD = left anterior descending artery; LCX = left circumflex artery; RCA = right coronary artery

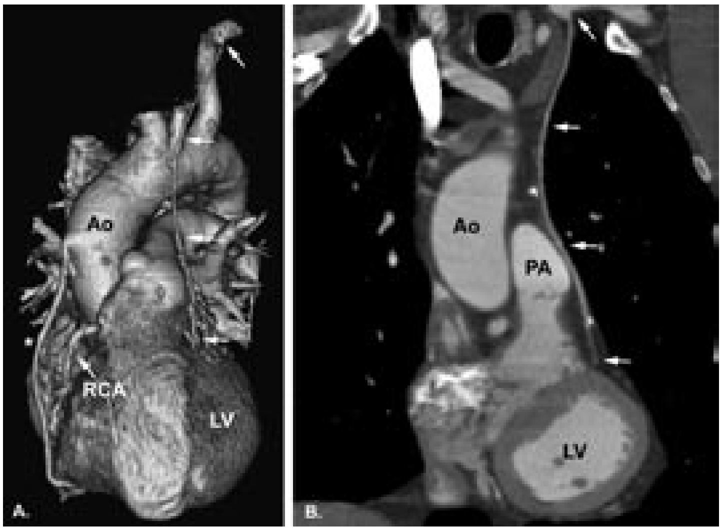

Figure 7.1
Example of an arterial and a vein graft. A, a 3D reconstruction of the heart and vessels. The white arrows highlight a left internal mammary artery graft to the left anterior descending artery from its left subclavian artery origin to the anastomosis. B, after the anastomosis the recipient vessel is occluded, also illustrated as multiplanar reformat reconstruction. The asterisk represents a vein graft to the posterior descending branch (anastomosis not shown). The native RCA is severely diseased. Ao = aorta; RCA = right coronary artery; LV = left ventricle; PA = pulmonary artery. A full colour version of this illustration can be found in the full colour section (page 167).

Comparison of MDCT and Coronary Angiography
Multidetector-row computed tomography examination was successfully accomplished in all patients. Heart rate varied from 53 to 85 beats/min (mean 64 ± 9 beats/min). Figures 7.1 and 7.2 depict typical examples of MDCT reconstructions of arterial and vein grafts. Patency on MDCT was scored in all 225 segments. When metal clips prevented adequate assessment of arterial graft segments, patency was evaluated by the presence or absence of contrast agent in the vessel in between the metal clip artifacts. All grafts were correctly identified as either patent or occluded by MDCT. Neither of the arterial graft segments (n = 22) were occluded. Accordingly, specificity, accuracy, and NPV were 100% for arterial grafts; sensitivity and PPV could not be calculated. Comparison of MDCT with coronary angiography for vein grafts, recipient and nongrafted vessels on vessel patency is illustrated in Table 7.3.
In patent graft bodies and nongrafted arteries the presence of a significant stenosis (≥50%) was evaluated by MDCT. All eligible arterial graft segments (n = 5) were not stenosed, which was correctly recognized by MDCT. Specificity, accuracy, and NPV were 100% for arterial grafts in the detection of a significant stenosis. Shown in Table 7.4 are the results of MDCT compared with angiography in the evaluation of significant stenoses for vein grafts and nongrafted vessels. κ values indicate a good to excellent agreement of MDCT and angiography. Particularly, NPV is high in all vessels when assessing patency or significant stenosis by MDCT.

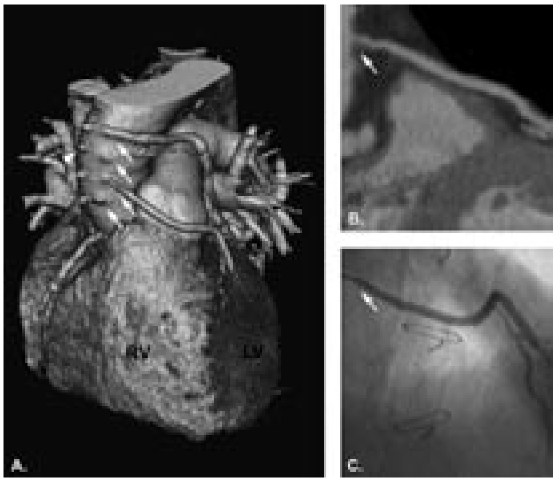

Figure 7.2

Example of a patient with multiple vein grafts. A, a 3D reconstruction of the heart, revealing 4 grafts (white arrows). Two patent grafts supply the obtuse marginal branch and the second diagonal branch, respectively; 2 grafts are totally occluded. Lateral from the graft origins, metal clips have been placed for identifying the graft locations (white arrowhead marks one of the clips). The vein graft to the second diagonal branch has a significant stenosis at its ostium. B and C, the multiplanar reformat reconstruction and coronary angiography of the ostium stenosis (arrow). RV = right ventricle; LV = left ventricle. A full colour version of this illustration can be found in the full colour section (page 168).

Vessel type	Sensitivity	Specificity	Accuracy	PPV	NPV	κ	p
Vein grafts	25/25 (100)	57/57 (100)	82/82 (100)	25/25 (100)	57/57 (100)	1.00	<0.001
Recipient vessels	2/3 (67)	77/79 (97)	79/82 (96)	2/4 (50)	77/78 (99)	0.55	<0.001
Nongrafted vessels	9/10 (90)	29/29 (100)	38/39 (97)	9/9 (100)	29/30 (97)	0.93	<0.001

Table 7.3

Comparison of MDCT and Coronary Angiography on Vessel Segment Patency
Values in parentheses are percentages. All arterial grafts were patent and correctly identified by MDCT. PPV = positive predictive value; NPV = negative predictive value

Vessel type	Sensitivity	Specificity	Accuracy	PPV	NPV	κ	p
Vein grafts	3/3 (100)	51/54 (94)	54/57 (95)	3/6 (50)	51/51 (100)	0.64	<0.001
Nongrafted vessels	11/11 (100)	16/18 (89)	27/29 (93)	11/13 (85)	16/16 (100)	0.86	<0.001

Table 7.4

Comparison of MDCT and Coronary Angiography on ≥50% Stenosis
Values in parentheses are percentages. Only patent vessels, eligible for evaluation, are included. Arterial grafts had no stenoses and were correctly identified by MDCT. Abbreviations as in Table 7.3

Global LV Function

Of the 25 patients, 14 had a prior MI in their medical history. Six patients had a subendocardial MI, 8 a transmural MI. In all patients LVEF could be derived from the MDCT examination. Mean LVEF for patients with no, subendocardial, and transmural infarctions were 51.1% ± 15.7%, 56.0% ± 17.7%, and 39.9% ± 9.1%, respectively (p = NS). Mean LVEF of patients without MI and with subendocardial MI demonstrated a significant difference compared with mean LVEF of transmural MI ($p<0.05$).

Discussion

In the present study a comprehensive 16-detector-row CT assessment of bypass grafts and native coronary arteries together with cardiac function has been shown to be feasible. With MDCT, patency and the presence of a significant stenosis in grafts or coronary arteries could be evaluated with high accuracy. Additional evaluation of LV function can be used in patients with previous MI for risk stratification or adjustment of medical therapy.

Computed Tomographic Angiography in Native Coronary Arteries
Multidetector-row computed tomography examination is a rapidly evolving, versatile technique, gaining acceptance as a diagnostic cardiac imaging tool. Four-detector-row CT already demonstrated promising results, when CT angiography was compared with coronary angiography, showing sensitivities of 81% to 93%, specificities of 76% to 97%, PPV of 57% to 66%, and NPV of 97% to 99% for the detection of ≥50% stenosis in eligible native coronary arteries (19-22). In these studies segments of vessels were excluded from analysis because of image artefacts from metal objects, calcification, coronary motion, or the patients' inability to perform the necessary breath-hold. With the introduction of the 16-detector-row CT technique, detection of significant stenoses in native coronary arteries improved because of higher spatial and temporal resolution, and shorter scanning time (23). Sensitivities of 92% to 95%, specificities of 86% to 95%, PPV of 79% to 80%, and NPV of 97% to 98% were reported for the detection of ≥50% stenosis, when compared with coronary angiography (1;2;24). If the heart rate exceeded 60 beats/min, additional β-blockers were administered in these studies to enhance image quality.
In the current study similar results were demonstrated for native coronary arteries in patients who had undergone bypass grafting. Segments were ineligible for evaluation by MDCT because of metal clip artifacts. All patients were able to sustain the necessary breath-hold, and none of the segments had to be excluded because of coronary motion artifacts or calcification. Vessel calcification was mostly observed in grafted arteries proximal to the first anastomosis and occluded grafts, proposing no difficulty for the eligible segments to be assessed.
Because of segmental reconstruction of the raw data sets, no prescan β-blockers were necessary. Heart rates varied to a maximum of 85 beats/min. Image quality was excellent and did not decline with higher heart rates.

Computed Tomographic Angiography in Bypass Grafts
Both arterial and vein grafts have been investigated with 4-detector-row CT and the results, compared with coronary angiography, showed fair diagnostic accuracies in the detection of ≥50% stenosis (3;4). However, there was a high number of unevaluable grafts in one study (3): only 62% of patent grafts could be assessed for the detection of significant stenoses because of metal and motion artifacts. In the study by Nieman et al. (4), assessability for the evaluation of stenoses was good for vein grafts (95%-100%), whereas for arterial grafts and nongrafted coronary arteries assessability was much lower (58%-73% and 66%-69%, respectively). Major causes of non-assessability were the patients' inability to sustain a long breath-hold (35-45 seconds) and cardiac motion artifacts. Heart rate had a significant influence on the assessment of nongrafted arteries. In patients with a heart rate ≥65 beats/min, assessability was 52% for nongrafted arteries. In both studies the proximal part of arterial grafts could not be included in the scan because of the limited scanning range.
Sixteen-detector-row CT technology has been used to assess the patency of arterial grafts within a short period (1 week to 12 months) after surgery (6). The entire arterial graft could be included in the scan, and graft patency was easily recognized. In addition, both arterial and vein grafts were investigated by 16-detector-row CT in one study, demonstrating the

ability of this technique to reliably depict grafts with fair diagnostic quality (5). However, both studies did not have a head-to-head comparison with coronary angiography, and native, nongrafted coronary arteries were not included in the analysis.
In the current study, arterial and vein grafts, recipient vessels, and native, nongrafted coronary arteries were evaluated by MDCT, compared in a head-to-head fashion with coronary angiography, demonstrating good diagnostic accuracy in the assessment of patency and in the detection of significant stenosis (≥50%). Owing to the high NPV (100% for nongrafted arteries, arterial and vein grafts) this approach may be used as gatekeeper before coronary angiography. For all arterial grafts the entire graft, from origin to the distal recipient vessel, could be assessed. Image quality was excellent for all patients; no motion artifacts were observed. Metal clips still proposed a difficulty in the evaluation of arterial grafts and recipient vessels, causing 9% of segments to be excluded from analysis. Because MDCT is becoming widely available and is gaining acceptance as a cardiac diagnostic tool, MDCT-compatible clips may be preferential to be used in bypass graft surgery.

Global LV Function with MDCT

Using 4-detector-row CT global LV function correlated well with cine MRI (8-10), echocardiography (11), and cine ventriculography (12). In a recent study, infarct volumes assessed by MDCT showed a negative correlation to LVEF measured by contrast ventriculography (25). The present study confirmed these findings by demonstrating that mean LVEF of patients with prior transmural MI was significantly lower than mean LVEF of patients with no or prior subendocardial MI. Both practice guidelines for non-ST-segment elevation and ST-segment elevation MI emphasize the need to determine LVEF for risk stratification and to adjust medical therapy to prevent congestive heart failure (13;14). Because an entire scan of the heart is required for the detection of significant stenoses in grafts or coronary arteries, determination of LVEF may be performed using the same CT data set, obviating the use of an additional diagnostic test. As cardiac CT software is still under development, more diagnostic potential of MDCT may be expected (7).

Comparison of MDCT with Established Noninvasive Modalities

Besides MDCT, the number of noninvasive modalities available for simultaneous assessment of stenoses in bypass grafts, nongrafted arteries, and LV function is limited. Currently, only cardiovascular magnetic resonance may suit this description. Accurate assessment of global and regional LV function with cine MRI has been described (26;27). However, magnetic resonance angiography still lacks the ability to evaluate stenoses in native coronary arteries and bypass grafts with high accuracy (28-30).
Other noninvasive modalities, such as gated single photon emission computed tomography and stress echocardiography (31;32), allow assessment of LV function and myocardial perfusion, which is an indirect marker of coronary artery disease; however direct visualization of bypass grafts and nongrafted arteries is impossible.

Limitations

Radiation exposure remains high for cardiac MDCT examinations, which is reported to be between 6.7 and 13.0 mSv (33;34). Because cardiac MDCT is becoming a robust diagnostic tool, future developments should focus on reducing radiation exposure.
The sample size of the current study is small. The results must be confirmed in a larger study before MDCT can be used as a gatekeeper in patients with prior bypass surgery.
No gold standard for the 16-detector-row CT LVEF measurements is available. Because LVEF measurements performed with a 4-detector row CT were proven to be very accurate in previous studies (8-12), differences from LVEF derived from 16-detector-row CT images are expected to be low. A study, which validates the 16-detector-row CT LV function by head-to-head comparison with an established modality, would be fitting.

Conclusion

Comprehensive assessment of bypass grafts, nongrafted vessels and global cardiac function is feasible with 16-detector-row CT. Good diagnostic accuracy in the detection of significant stenosis (≥50%) in comparison with coronary angiography was demonstrated. Owing to the high NPV, this noninvasive approach may be used as gatekeeper before conventional coronary angiography.

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