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Noninvasive Coronary Imaging

Noninvasive Visualization of Coronary Artery Bypass Grafts Using 16-Detector Row Computed Tomography

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OBJECTIVES The aim of this study was to evaluate the diagnostic accuracy of a 16-detector row computed tomography (CT) scanner for the assessment of coronary artery bypass grafts.

BACKGROUND A new generation of multislice spiral CT scanners, equipped with more and thinner detector rows, allows for reliable noninvasive detection of obstructive coronary artery disease.

METHODS The study included 51 consecutive patients. Three patients had to be excluded from the study due to arrhythmias or fast heart rates despite beta-blockade. A total of 48 patients with 131 coronary artery bypass grafts (internal mammary artery, n = 40; venous grafts, n = 91) were examined by computed tomography angiography (CTA) and by invasive coronary angiography (ICA) using a 16-detector row CT scanner. For cardiac protocols, only the 12 inner detector rings are applied. All CT examinations were performed with retrospective electrocardiogram gating at a mean heart rate of 64 ± 5 beats/min; 120 ml of Xenetix 300 (Guerbert GmbH, Sulzbach, Germany) were continuously injected. The bypass graft patency and the presence of stenoses as well as the proximal and distal anastomoses were evaluated by two experienced readers.

RESULTS All bypass grafts and 74% of the distal bypass anastomoses could be visualized by CTA; 21 bypass graft occlusions and 1 significant stenosis were detected by CTA and confirmed by ICA. Five false positive and one false negative finding resulted in a sensitivity of 96%, a specificity of 95%, a positive predictive value of 81%, and a negative predictive value of 99%.

CONCLUSIONS Sixteen-detector row CT scanner technology allows for the reliable visualization of coronary bypass grafts. Dysfunctional bypass grafts can be detected with high diagnostic accuracy. This technology can be used as a noninvasive test for patients with suspected graft dysfunction. (J Am Coll Cardiol 2004;44:1224–9) © 2004 by the American College of Cardiology Foundation

Myocardial ischemia induced by coronary artery disease represents the most common cause of premature death in industrial countries (1). The therapy of coronary artery disease aims to maintain myocardial blood flow using medical therapy, angioplasty with stent placement, or coronary artery bypass grafting. In Germany alone, 75,000 coronary bypass operations are performed every year. The patency of coronary bypass grafts is temporally limited.

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Thus, the 10-year patency rate for vein grafts lies around 60% (2–4), whereas arterial bypass grafts are characterized by a higher patency rate around 90% (4,5). Because clinical outcome is closely related to bypass graft patency (6), follow-up examinations are indispensable.

Conventional invasive coronary angiography (ICA) represents the gold standard in the follow-up of patients with coronary artery bypass grafts. Concerns about procedure-related risks and cost considerations have motivated the exploration of other less invasive means to assess coronary artery bypass grafts, including electron-beam computed tomography (CT), magnetic resonance angiography, and computed tomography angiography (CTA).

Recently published studies have shown that a new generation of multislice spiral computed tomography (MSCT) scanners, equipped with more and thinner detector rows, allows for reliable noninvasive detection of obstructive coronary artery disease (7). The aim of this study was to evaluate the diagnostic accuracy of a commercially available 16-detector row CT scanner for the assessment of coronary artery bypass grafts employing conventional ICA as the standard of reference.

METHODS

The study protocol was approved by the institutional review board, and written informed consent was obtained from all patients. Fifty-one consecutive patients with coronary artery bypass grafts (67 ± 75 months after surgery) who were scheduled for ICA were studied (39 men, 12 women; age range, 50 to 76 years; mean age, 64.6 ± 6.2 years). Only patients with sinus rhythm were included in the study.

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Abbreviations and Acronyms

CT = computed tomography
CTA = computed tomography angiography
EBCT = electron beam computed tomography
HR = heart rate
ICA = invasive coronary angiography
IMA = internal mammary artery
LAD = left anterior descending coronary artery
LCX = circumflex coronary artery
MRI = magnetic resonance imaging
MSCT = multislice spiral computed tomography
NPV = negative predictive value
PPV = positive predictive value
RCA = right coronary artery

Patients with renal insufficiency, hyperthyroidism, and allergy to iodine contrast media were excluded from the study; MSCT was performed one to four days before ICA.

MSCT coronary angiography. The MSCT exams were performed using a recently developed, commercially available 16-detector row CT scanner (Somatom Sensation 16, Siemens, Forchheim, Germany) with a gantry rotation time of 420 ms (collimation: 0.75 mm, table feed: 1.5 mm/rotation, reconstruction increment: 0.5 mm). For cardiac protocols, only the 12 inner detector rings are applied. Image acquisition was performed during an inspiratory breath-hold. To familiarize the patient with the protocol, the exam, including breath-holding, was practiced in advance. Beta-blockers (esmolol) were injected intravenously for heart rates (HRs) exceeding 70 beats/min.

A total of 120 ml of the iodinated contrast agent Xenetix 300 (300 mg iodine/ml, Guerbert GmbH, Sulzbach, Germany) was continuously injected into an antecubital vein via an 18-gauge catheter with an infusion rate of 3.5 ml/s. To find the suitable point of time for the beginning of the scan, a region of interest was placed into the ascending aorta. As soon as the signal intensity in the region of interest reached a threshold of 120 Hounsfield U, the patient was instructed to maintain an inspiratory breath-hold, and data acquisition was commenced.

Three separate data sets were reconstructed during different time instants of the cardiac cycle (−30%, −40%, −50% of the R to R interval). After reconstruction, CT raw data were transferred to a PC-based workstation (Wizard, Siemens Medical Solutions, Erlangen, Germany). Image interpretation was based on source as well as thin maximum intensity projection images. Furthermore, the three-dimensional data sets were viewed with volume rendering techniques.

ICA. Invasive coronary angiography was performed by an experienced cardiologist through a femoral approach including selective catheterization of the grafts or graft stumps. At least two orthogonal views were obtained for each bypass vessel. Before contrast injection into the left internal thoracic artery, 0.2 mg nitroglycerin was selectively injected. Nitroglycerin was not applied for assessment of venous bypass grafts. Narrowing ≥50% of the lumen diameter by visual assessment was defined as significant stenosis and documented for each bypass vessel. The localization was noted regarding proximal or distal anastomosis or central bypass.

Data analysis. The CT images were read by a radiologist and a cardiologist in consensus, blinded to the results of the coronary catheter angiography. The grade of a bypass graft stenoses was visually assessed and subdivided into: grade 0—no stenosis; grade 1—stenosis <50% diameter reduction; grade 2—stenosis >50% diameter reduction; and grade 3—bypass occlusion. Quantitative assessment of the vessel lumen was performed by an experienced cardiologist blinded to results of the MSCT examination using an automated vessel contour detection algorithm after catheter-based image calibration.

The results of MSCT and ICA were compared regarding the proximal anastomoses, central bypass, and distal anastomoses. Sensitivity, specificity, and positive as well as negative predictive values (NPVs) were calculated for patency rates of the bypass grafts and for the detection of significant stenoses and bypass occlusion. The diagnostic accuracy of MSCT was evaluated regarding ICA as the standard of reference.

RESULTS

Of 51 patients scheduled for MSCT, three had to be excluded from the study. In two cases intravenous administration of beta-blockers did not result in a sufficient reduction of the HR; in one patient, arrhythmias occurred during data acquisition. In the remaining 48 patients, ICA and MSCT could be performed without complications. A total of 40 internal mammary artery (IMA) grafts and 91 venous grafts could be compared. There were no right internal thoracic arteries used as bypass graft. The mean HR

Table 1. Diagnostic Accuracy of MSCT for the Detection of Bypass Graft Stenosis and Occluded Grafts in Evaluable Segments

	Total	IMA to LAD	SVG to LAD	SVG to LCX	SVG to RCA
Sensitivity (%)	96	75	100	100	100
Specificity (%)	95	100	100	100	87
PPV (%)	81	100	100	100	69
NPV (%)	99	97	100	100	100

IMA = internal mammary artery; LAD = left anterior descending coronary artery; LCX = circumflex coronary artery; MSCT = multislice spiral computed tomography; NPV = negative predictive value; PPV = positive predictive value; RCA = right coronary artery; SVG = saphenous vein graft.

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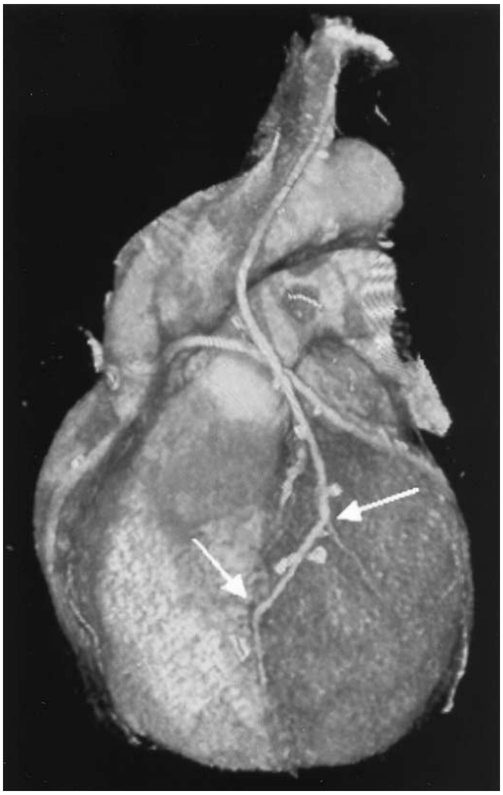

Figure 1. Three-dimensional multislice spiral computed tomography reconstruction (volume rendering) showing an internal mammary artery jump-graft to the left anterior descending coronary artery and to a diagonal branch. The **arrows** mark the region of the anastomoses.

Figure 2. Three-dimensional multislice spiral computed tomography reconstruction obtained with volume rendering technique showing an occluded internal mammary artery bypass. The bright clip material **(arrows)** marks the former course of the vessel.

of the patients was 64 ± 5 beats/min. An overview about the diagnostic accuracy of MSCT for the detection of significant stenosis and occluded grafts in evaluable segments is provided in Table 1.

Arterial grafts. Of the 40 IMA grafts, 35 (88%) were anastomosed to the left anterior descending coronary artery (LAD), and 5 were jump-grafts to the LAD and a diagonal branch (Fig. 1). All grafts could be visualized with diagnostic image quality, whereas only 28 of 37 (76%) of the distal anastomoses to the LAD and 3 of 5 (60%) of the distal anastomoses to the diagonal branches could be evaluated. A total of 11 of 42 (26%) of the distal IMA anastomoses were classified as unevaluable due to poor opacification (n = 7) and artifacts caused by metal clips (n = 4).

Based on MSCT and ICA, 3 of 40 (8%) IMA grafts were classified as occluded (Fig. 2), and 37 of 40 (92%) were classified as patent. One significant stenosis in the region of the IMA-LAD anastomosis was missed when analysis was based on MSCT. In one patient, MSCT revealed a nonsignificant IMA graft stenosis that was not confirmed by ICA.

Venous grafts. Of 91 venous grafts, 6 were anastomosed to the LAD, 41 to the circumflex coronary artery (LCX), and 44 to the right coronary artery (RCA). Five of six venous grafts to the LAD were classified as patent without stenosis by MSCT, and one graft was found to be occluded. These results were confirmed by ICA; MSCT permitted visualization of all proximal and distal anastomoses.

Invasive coronary angiography revealed 8 venous grafts to the LCX to be occluded. All 8 occlusions were correctly diagnosed by MSCT, which demonstrated 33 venous LCX grafts to be patent. Invasive coronary angiography showed only 32 patent grafts—1 venous LCX graft had a proximal anastomosis to the descendent aorta and was missed by ICA (Fig. 3). The patency of five grafts containing coronary stents was evaluated by MSCT and ICA. Two stented grafts were classified as occluded, and in one patient a significant in-stent restenosis was suspected, which was proven by ICA (Fig. 4). All proximal and 25 of 33 (76%) distal anastomoses in the LCX region were adequately seen on MSCT. The remaining 8 distal anastomoses (24%) were classified as unevaluable due to poor opacification and/or artifacts caused by cardiac motion.

A total of 44 venous grafts coursed to the RCA. Using MSCT, 9 to 44 (20%) grafts were found to be occluded, whereas 35 of 44 (80%) were patent. All findings were confirmed by ICA. One graft showed a distal hemodynamically relevant stenosis that was detected by both modalities (Fig. 5). Additionally, MSCT detected five grade-2 stenoses that were not confirmed by ICA. All proximal and 22 distal anastomoses (63%) could be visualized (Fig. 6). A total of 13 of 35 (37%) of the distal anastomoses were classified as

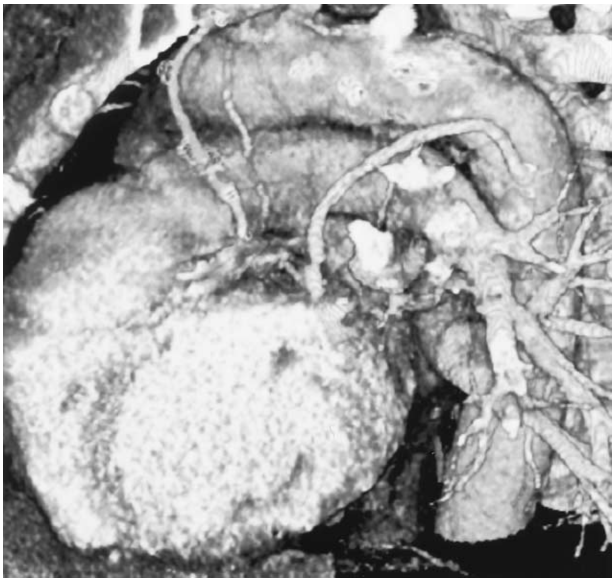

Figure 3. Three-dimensional multislice spiral computed tomography reconstruction (volume rendering) of a venous graft to the circumflex coronary artery with proximal anastomosis to the descending aorta. This graft was missed by invasive coronary angiography.

unevaluable due to small vessel diameter, poor opacification, and/or artifacts caused by cardiac motion.

Overall, 83 of 112 (74%) distal anastomoses could be evaluated. The unevaluable distal anastomoses were estimated as stenotic. This results in a lower specificity (68%) and positive predictive value (PPV) (37%) compared with the separate analysis of the evaluable segments (specificity 95%, PPV 81%). Sensitivity (96%) and NPV (99%) are identical for both analyses.

DISCUSSION

We evaluated the accuracy of retrospectively electrocardiogram-gated 16-slice MSCT for the assessment of coronary artery bypass grafts. This study carries three important messages:

1. The 16-detector row MSCT allows for a reliable differentiation between patent and occluded arterial and venous bypass grafts.
2. All proximal anastomoses of venous grafts and 74% of distal bypass anastomoses could be adequately assessed.
3. The 16-detector row MSCT can reliably detect and classify bypass stenoses with high diagnostic accuracy.

Coronary artery bypass grafts seem well suited for depiction by CTA. Compared with native coronary arteries, grafts are characterized by less cardiac motion, a wider luminal diameter, and fewer calcifications. All three factors contribute toward a reliable assessment of the bypass grafts by MSCT and electron-beam computed tomography (EBCT) (7,8). Thus, cardiac CT started more than 10 years ago assessing coronary arteries bypass grafts noninvasively using EBCT. Several studies investigated the patency of grafts. Sensitivity and specificity values varied between 80% to 98% and 82% to 91%, respectively (9–12). However, concerning the detection of bypass stenoses, only few data exist. Achenbach et al. (13) investigated bypass-stenoses with EBCT and detected 5 of 5 high-graded stenoses. The technique was limited by the fact that only 84% of grafts could be evaluated for the presence or absence of stenoses. Additionally, no attempts were made to evaluate the proximal and distal anastomoses.

Using single-slice spiral CT, a reliable noninvasive assessment of coronary artery bypass grafts was not possible, reflecting limited spatial and temporal resolution. Initial studies with four-slice MSCT revealed promising results regarding the evaluation of bypass grafts. Frohner et al. (14) demonstrated visualization of venous aortocoronary grafts and IMA bypasses in about 80% of cases. Ropers et al. (15) demonstrated, however, that only 77 of 124 patent grafts (62%) could be evaluated for the presence or absence of high-grade disease. Beyond arrhythmias, artifacts caused by

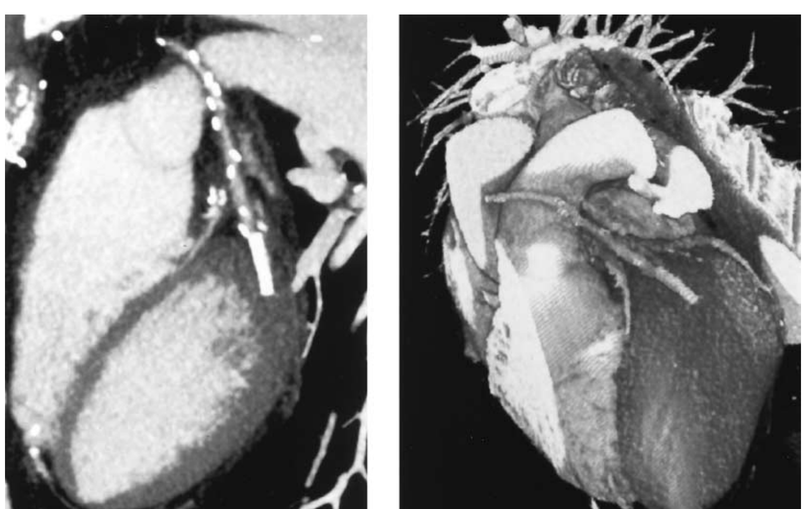

Figure 4. Stented graft that was classified as significant in-stent stenosis due to a lack of contrast distal of the stent. The diagnosis was approved by invasive coronary angiography (**left** = maximum intensity projection; **right** = volume rendering technique).

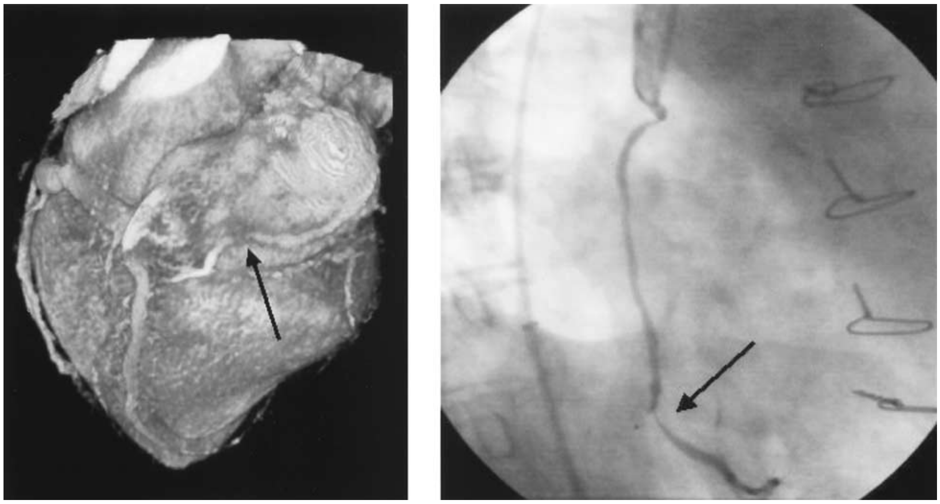

Figure 5. Three-dimensional multislice spiral computed tomography reconstruction (volume rendering) of a venous graft to the right coronary artery with a hemodynamically relevant stenosis **(left)** that was confirmed by invasive coronary angiography **(right)**.

respiratory and cardiac motion as well as metal clips was implicated as causes for the resultant poor image quality.

This study demonstrates the potential of the recently developed 16-detector row CT scanner for the assessment of coronary artery bypass grafts. Compared with the data reported by Ropers (15), the number of evaluable bypasses increased from 62% to 74% combined with improved diagnostic accuracy for the detection of stenosis (sensitivity 75% vs. 96%, specificity 92% vs. 95%). The major advantages of the 16-detector row system that result in improved image quality include: shorter breath-hold times, reducing respiratory artifacts; faster rotation of the gantry, reducing cardiac motion artifacts; and a decreased slice thickness, resulting in better spatial resolution.

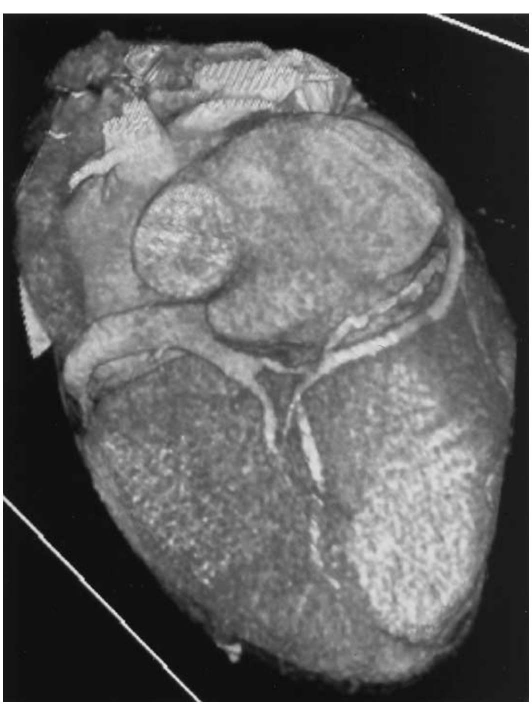

Figure 6. Three-dimensional multislice spiral computed tomography reconstruction (volume rendering) of a venous graft to the right coronary artery with a sufficient anastomosis.

The number of evaluable distal anastomosis might be further increased by scanning at lower HRs and using additional reconstructions. Recent studies have shown that HRs above 60 beats/min result in a poor image quality, especially of the distal parts of the coronary arteries (16,17). Using a 16-detector row scanner, Nieman et al. (7,18) have demonstrated that HRs below 60 beats/min permits visualization of all 15 coronary segments. It might hence be possible to improve visualization of distal anastomoses by decreasing the HR ($<$60 beats/min) before the MSCT examination. Furthermore, improvements may be associated with shifting the reconstruction interval. Herzog et al. (19) have demonstrated that shifting the reconstruction interval from end-diastole into end-systole is beneficial at increased HRs. Thus, assessment of end-systolic images might result in a more accurate evaluation of bypass anastomoses in some patients.

Although motion-free visualization of bypass grafts is less dependent on HR than the visualization of native coronary arteries, cardiac motion is still an issue. False positive findings were exclusively detected in grafts attached to the RCA, which shows the greatest amplitude of all coronary vessels during the cardiac cycle. All interpretations regarding bypasses in the LAD and the LCX territory, on the other hand, were correct. Beyond a high HR, MSCT visualization of coronary bypass grafts was limited by arrhythmias and surgical clips, which are mostly located in the region of IMA grafts.

A general drawback of MSCT relates to the necessity for contrast injection, the use of beta-blockers in a large number of patients, and the exposure to a relevant radiation dose. Recently, Hunold et al. (20) demonstrated that significantly higher radiation doses are delivered by cardiac MSCT compared with those delivered by EBCT or ICA. Hence, cardiac MSCT should be performed only in the presence of a strong clinical indication and the use of optimized and standardized MSCT imaging protocols. However, our initial data suggest that the lack of major complications and the ability to perform this noninvasive procedure without hospitalization combined with the excellent diagnostic accuracy compensate for the higher radiation exposure. Furthermore, most of the patients with suspected bypass dysfunction are in the 6th or 7th decade and, therefore, at lower risk for the development of radiation-induced cancers.

Void of any harmful side effects, including exposure to ionizing radiation, magnetic resonance imaging (MRI) represents a totally noninvasive alternative for assessing coronary artery bypass grafts. A recently performed study using steady state free precession sequences and gadolinium-enhanced three-dimensional MRI angiography reveals the methods' ability to differentiate between patent and occluded bypass grafts with moderate sensitivity (84%) and specificity (73%) values. Limited spatial resolution and motion artifacts prohibit the reliable evaluation of the anastomotic sites (21). Despite these limitations, MRI may play an important role in the evaluation of bypass grafts because, additional to the assessment of morphology, the technique allows for a functional approach to detect graft dysfunction. Langerak et al. (22) measured the blood flow using velocity-encoded cine MRI at rest and at stress. Scans were successful in only 80% of grafts, and calculating the flow reserve within the grafts, they detected significant stenoses with high sensitivity (94%) and moderate specificity (63%). Further, hardware and software developments combined with new contrast agents will certainly improve image quality, and the assessment of coronary bypass grafts by MRI may therefore offer an attractive alternative to invasive angiography and MSCT in the future.

Conclusions. The 16-detector row CT scanner technology allows for a reliable differentiation between patent and occluded coronary artery bypass grafts and an accurate detection of graft stenosis. The high sensitivity and the excellent NPV demonstrate that this technology can be used in clinical routine as a noninvasive test for patients with suspected graft dysfunction.

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