Bypass Graft and Native Postanastomotic Coronary Artery Patency: Assessment With Computed Tomography

Daniele Andreini, MD, Gianluca Pontone, MD, Giovanni Ballerini, MD, Erika Bertella, MD, Enrica Nobili, MD, Alessandro Parolari, MD, PhD, and Mauro Pepi, MD

Centro Cardiologico Monzino, IRCCS, Institute of Cardiology, University of Milan, Milan, Italy

Background. **Multidetector computed tomography has been shown to be useful in the evaluation of coronary artery bypass grafts in previous studies. We studied the accuracy of multidetector computed tomography in the detection of patency and significant stenosis of both grafts and native postanastomotic coronary arteries.**

Methods. **Ninety-six patients with 216 grafts (98 left mammary artery, 8 right mammary artery, 8 radial artery, and 102 venous grafts) were investigated by 16-slice computed tomography. Native postanastomotic coronary arteries were also evaluated. Patients unable to maintain a breath hold of 40 s were excluded. Computed tomography data were compared with the results of conventional angiography.**

Results. **On a segment-based model, the overall feasibility of computed tomography was 98.1% (212 of 216 grafts) for bypass grafts and 93.1% (201 of 216 segments) for postanastomotic coronary arteries. The leading cause of unfeasibility for postanastomotic coronary arteries was the small diameter of the examined vessel (<1.5 mm). Computed tomography correctly diagnosed all the 25 occluded grafts. Of the 33 significant stenoses of grafts, computed tomography correctly diagnosed 31. Sensitivity, specificity, positive predictive value, and negative predictive value were 100%, 98.5%, 96.5%, and 100%, respectively, for bypass graft; and 100%, 97.7%, 85%, and 100%, respectively, for coronary arteries. On a patient-based model, the feasibility, sensitivity, specificity, positive predictive value, and negative predictive value were 89.4% (86 of 96 patients), 100%, 93%, 86.4%, and 100%, respectively.**

Conclusions. **Multidetector computed tomography allows a very accurate assessment of arterial and venous conduits and of postanastomotic native coronary arteries in patients with previous bypass graft. Despite high feasibility (93.1%), limitations of the method were breath-hold duration (35 to 40 s) and postanastomotic assessment of small vessels (which, however, precluded the analysis in only 4.6% of cases).**

(Ann Thorac Surg 2007;83:1672–8)

Invasive coronary angiography (ICA) is currently the standard diagnostic method for imaging coronary arteries and coronary artery bypass grafts (CABG). The risk of adverse events is small but serious, and potentially life-threatening sequelae may occur, including arrhythmia, stroke, coronary artery dissection, and access site bleeding, with a total complication rate of 1.8% and a mortality rate of 0.1% [1, 2]. Furthermore, catheterization induces some discomfort for patients, mandates routine follow-up care, and is an expensive procedure. This situation constitutes the basis of the demand for a reliable noninvasive coronary imaging technique [3].

Arterial and venous conduits may be considered as the ideal vessels for evaluation by multidetector computed tomography (MDCT) because of their relative spatial fixation, their large diameter, and their low incidence of massive calcification that is considered, together with high heart rate, to be a negative predictive factor for assessability of the examination [4–8]. For these reasons, evaluation of CABG with computed tomography was first reported in 1980, despite the severely limited feasibility and accuracy of the method owing to the presence of cardiac and respiratory artifacts [9, 10]. The availability of the first four-detector-row MDCT in the 1990s enabled electrocardiographic-gated reconstruction of images, with adequate detection of significant stenosis in the venous and arterial grafts, despite the limitation of low spatial and temporal resolution [11, 12]. The latest generation of MDCT devices permits proper reconstruction of bypass grafts and the coronary artery tree. Indeed, many studies with at least 16-row MDCT have demonstrated good diagnostic accuracy for the detection of significant stenosis in assessable bypass grafts, with very high diagnostic accuracy (sensitivity between 96% and 99%, specificity between 95% and 100%) [13–20]. Therefore, MDCT could be proposed as a noninvasive test for the follow-up of CABG patency. On the other hand, the

Accepted for publication Jan 18, 2007.

Address correspondence to Dr Parolari, Via C. Parea 4, Milan 20138, Italy; e-mail: alessandro.parolari@ccfm.it.

Published by Elsevier Inc

0003-4975/07/$32.00
doi:10.1016/j.athoracsur.2007.01.030

feasibility and the diagnostic accuracy of MDCT in simultaneous evaluation of bypass graft and native postanastomotic coronary arteries are unknown. The importance of this complete evaluation is high because, although late survival after CABG surgery is largely dependent on graft patency, the role of native postanastomotic coronary arteries is not negligible [21].

The aim of our study was to evaluate the feasibility and diagnostic accuracy of MDCT compared with traditional ICA in the simultaneous evaluation of bypass graft and native postanastomotic coronary arteries in a large population of patients with previous CABG.

Material and Methods

Study Population

One hundred and thirty-two consecutive patients (101 male, mean age 63 ± 7 years) with 216 grafts (96 left mammary artery grafts, 8 right mammary artery grafts, 8 radial artery grafts, 2 gastroepiploic artery grafts, and 102 venous grafts), referred for ICA because of suspected progression of coronary artery disease (chest pain, positive exercise stress test), were prospectively screened to undergo 16-slice MDCT (GE Medical Systems Light Speed Pro 16, Waukesha, WI), collimation 16 mm × 0.625 mm. Thirty-six patients unable to maintain a breath-hold of 40 s were excluded. Therefore, 96 patients were included in the study. Invasive coronary angiography was performed in all the enrolled patients 6 ± 2 days after MDCT. The mean time between previous CABG and MDCT investigation was 72 ± 42 months (range, 22 to 134, median 61.5). All patients gave informed consent to participate in this study, which was approved by the Institutional Review Board of Centro Cardiologico Monzino IRCCS.

Patient Preparation

Each patient with a heart rate of 65 beats per minute or higher was treated with single or multiple intravenous doses of metoprolol about 15 minutes before the scan (49 patients = 51%, average dose 6.3 ± 1.5 mg), obtaining a mean heart rate of 61.3 ± 8.8 beats per minute.

Scan Protocol and Image Reconstruction

Multidetector computed tomography data were acquired using 16-slice CT with 16 mm × 0.625 mm collimation and a gantry rotation time of 400 ms. According to the electrocardiographic-pulsing technique, the tube current was modulated with a maximum current of 600 mA during a period between 40% and 80% of the R-wave to R-wave interval and a reduction by 80% during the remaining cardiac cycle. A tube voltage of 120 to 140 Kv was applied according to the patient's body weight.

During the scan, a variable dose of contrast agent (Iomeron 400 mg/mL; Bracco, Italy), average dose 110 mL ± 11 mL, was injected intravenously at a rate of 4.5 mL/s. The MDCT scan was acquired by the fluoroscopic bolus tracking technique during breath holding (36 ± 5 s), and evaluated by two independent expert readers with multiple approaches including volume rendering, multipla-

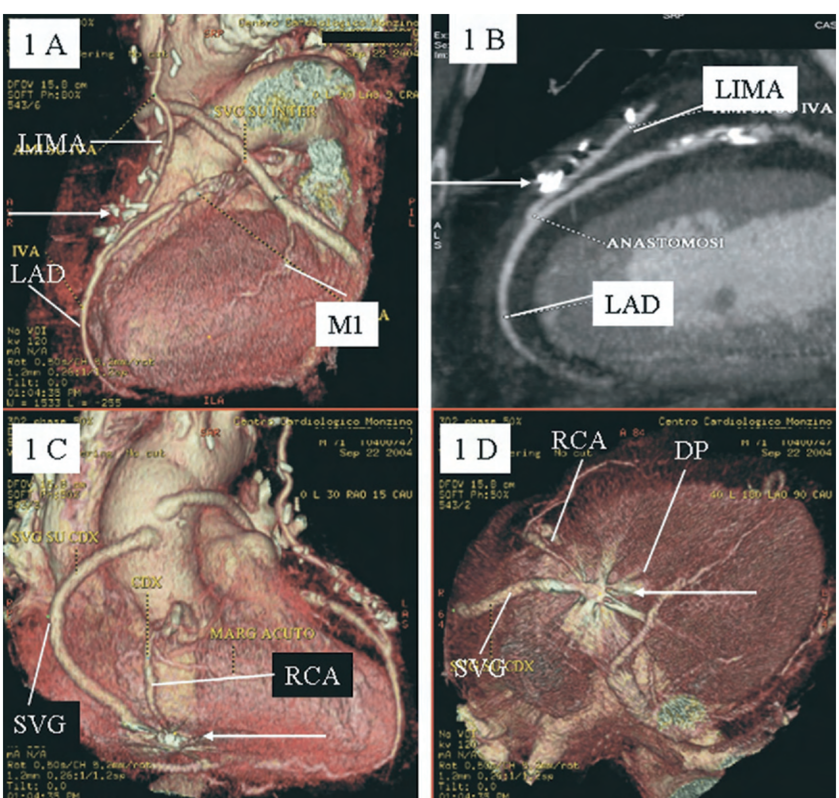

Fig 1. Examples of different causes of artifacts in coronary artery bypass graft evaluation. (A and B) Volume rendering reconstruction (1A) and multiplanar reconstruction (1B) of left internal mammary artery (LIMA) anastomosed on middle segment of left anterior descending artery (LAD): three closely spaced metallic clips on distal portion of LIMA (arrow). (C and D) Volume rendering reconstruction of saphenous vein graft (SVG) anastomosed on the distal right coronary artery (RCA) with magnetic device (arrow). (DP = posterior descending artery; LCX = left circumflex artery; M1 = first marginal branch.)

Table 1. Multidetector Computed Tomography Feasibility of Bypass Graft Imaging

Type of Graft	Number of Grafts	Number of Artifacts	Type of Artifact	Feasibility
Right IMA	8	0		100%
Left IMA	96	3	metallic clip	98.4%
Radial artery	8	0		100%
Gastroepiploic artery	2	0		100%
Vein graft	102	1	magnetic clip	99.1%
Total	216	4		98.1%

IMA = internal mammary artery.

nar reconstruction, and vessel analysis (CardioQ3 package; GE Medical Systems). On the basis of the "segment or burst reconstruction" algorithm, the temporal resolutions were, respectively, 200 and 100 ms.

MDCT Image Evaluation

The patency of all arterial and venous grafts was evaluated. Native distal postanastomotic coronary arteries including seven different coronary segments (distal left anterior descending, first and second diagonal branches, first and second marginal branches, distal right coronary artery, and posterior descending artery) of the 15-segment model of the American Heart Association [21] were also evaluated. The quality of images, judged on the basis of the absence of artifacts and on the possibility of correctly evaluating the vessel canalization (patency, presence of stenosis, occlusion) on the reconstructed image was graded as follows: good (absence of artifacts, possibility of correctly evaluating the vessel canalization); sufficient (presence of mild artifacts, possibility of evaluating the vessel canalization); or insufficient (presence of large artifacts, no possibility of evaluating the vessel canalization, cause of unfeasibility). Segments in which poor image quality did not allow evaluation of patency were classified as not assessable by two independent, blinded observers who also evaluated coronary grafts and native coronary segments for the presence of significant narrowing (≥50% diameter reduction). In case of disagreement among the two expert readers concerning the quality of images or the presence and severity of coronary artery disease, a consensus and final decision was obtained by involving a third expert.

Using a fixed image display setting (window 700 Hounsfield units, level 250 Hounsfield units), the image that displayed maximum luminal narrowing was identified by visual estimation and the outer vessel contour (border to low-signal epicardial fat) was manually localized to measure the vessel diameter. Similarly, the vessel diameter was determined in a reference segment without detectable plaque proximal to and as close as possible to the respective lesion. The causes of impaired image quality (unfeasibility) of native coronary artery imaging were classified as presence of massive calcified plaque, small diameter of the examined vessel (<1.5 mm), motion artifacts related to nonrespect of breath-hold or chest movement, misalignment of slices related to changes in heart rate during the scan, and presence of cardioverter/pacemaker leads. In detail, the artifact due to calcified plaque was defined as a large high-density lesion, extending along the wall, causing partial volume and beam-hardening artifacts; misalignments were defined as impairment of image quality caused by displacement of different vessel portions, resulting in out-of-phase vessel contours. The causes of impaired image quality (unfeasibility) of bypass graft imaging were classified as misalignment of slices related to changes in heart rate during the scan, motion artifacts related to nonrespect of breath-hold or chest movement, and artifacts due to surgical causes (metallic clips). Figure 1 shows some examples of these artifacts.

Invasive Coronary Angiography

Conventional ICA was performed with standard techniques using 6F catheters and after intracoronary injection of 0.2 mg of isosorbide dinitrate. The coronary arteries were divided into segments according to the American Heart Association classification used for MDTC analysis [15]. The angiograms were analyzed by two interventional cardiologists blinded to MDCT results using quantitative coronary angiography software (QuantCor QCA; Pie Medical Imaging, Maastricht, the Netherlands) and end-diastolic frames. The severity of coronary stenosis was quantified in two orthogonal views, and a stenosis was classified as significant if the lumen diameter reduction was greater than 50%.

Table 2. Multidetector Computed Tomography Evaluation of CABG Patency

					Location of Stenoses		
Type of Graft	Number of Grafts	Patency	Occlusion	Stenosis > 50%	Body Proximal	Body Middle	Anastomosis
Right IMA	8	6	2	0	0	0	0
Left IMA	96	86	7	3	0	0	3
Radial artery	8	4	4	0	0	0	0
Gastroepiploic artery	2	2	0	0	0	0	0
Vein graft	102	60	12	30	22	6	2
Total	216	158	25	33	22	6	5

CABG = coronary artery bypass graft; IMA = internal mammary artery.

Table 3. Multidetector Computed Tomography Diagnostic Accuracy in Evaluating All CABG and Native Postanastomotic Coronary Arteries

	CABG	Native Coronary Arteries
Sensitivity	100%	100%
Specificity	98.5% (96.7–100%)[a]	97.7% (95.5–99.9%)[a]
Positive predictive value	96.5% (92.8–100%)[a]	85 (70.1–99.9%)[a]
Negative predictive value	100%	100%
True positive	56	19
True negative	158	179
False positive	2	3
False negative	0	0
Area under ROC	0.994	0.995

[a] 95% Confidence interval.

CABG = coronary artery bypass graft; ROC = receiver operating characteristic curves.

Statistical Analysis

Statistical analysis was performed using a statistical software package (SPSS 13.0 for Windows; SPPS, Chicago, Illinois). All variables were expressed as mean ± SD. The feasibility of the MDCT scan was measured. An estimation of accuracy (sensitivity, specificity, positive predictive value, and negative predictive value) was also calculated on a segment-based and on a patient-based model (on a patient based-analysis, patients with at least one detected stenosis greater than 50% in a CABG or a native postanastomotic coronary arteries were classified as "positive"). The 95% confidence intervals (CI) for all diagnostic accuracy parameters were calculated using a conventional binomial estimator method. In a segment-based model, data were also presented as receiver-operating characteristic curves, and the areas under curves were reported for a quantitative coronary angiography cut-off value of 50%. Quantitative coronary angiography was used as the "gold standard." Moreover quantitative lesion severity (percentage of stenosis) was compared between MDCT and quantitative coronary angiography using Spearman correlation.

Results

Feasibility

All patients underwent a complete MDCT scan without complications. On a patient-based model, the overall feasibility was 89.4% (86 of 96 patients). On a segment-based model, the overall feasibility of MDCT was 98.1% (212 of 216 grafts) for CABG and 93.1% (201 of 216 segments) for native postanastomotic coronary arteries. The quality of images on a segment-based model was good in 195 cases (90.3%), sufficient in 17 cases (7.8%), and insufficient in 4 cases (1.9%) for CABG; and good in 170 cases (78.7%), sufficient in 31 cases (14.3%), and insufficient in 15 cases (6.9%) for native coronary arteries. Table 1 reports feasibility for the different types of graft and overall feasibility for the postanastomotic coronary arteries.

We judged only four of 216 graft cases not assessable, and all four artifacts were due to surgical technique: three internal mammary artery grafts with particularly long and closely spaced metallic clips and one saphenous vein graft because of anastomosis with a new-generation magnetic device (Fig 1). The leading cause of unfeasibility in postanastomotic coronary arteries was the small diameter of the examined vessel (<1.5 mm, 10 artifacts), followed by misalignment of slices related to variation of heart rate during the scan (three artifacts), and presence of massive calcified plaque (two artifacts).

Table 4. Multidetector Computed Tomography Diagnostic Accuracy for Different Types of CABG and for Different Segments of Postanastomotic Coronary Arteries

Type of Graft	Sensitivity	Specificity	Positive Predictive Value	Negative Predictive Value
Right IMA	100%	100%	100%	100%
Left IMA	100%	100%	100%	100%
Radial artery	100%	100%	100%	100%
Gastroepoploic artery	100%	100%	100%	100%
Vein graft	100%	96.8% (92.4–100%)[a]	95.2% (92.9–100%)[a]	100%
Coronary segment				
Distal LAD	100%	100%	100%	100%
D1	100%	92.3% (78.3–100%)[a]	75% (32.6–100%)[a]	100%
D2	100%	100%	100%	100%
M1	100%	95.8% (87.8–100%)[a]	50% (0–100%)[a]	100%
M2	100%	100%	100%	100%
Distal RCA	100%	94.4% (83.8–100%)[a]	87.5% (64.6–100%)[a]	100%
PD	100%	100%	100%	100%

[a] 95% Confidence interval.

CABG = coronary artery bypass graft; D1 = first diagonal; D2 = second diagonal; IMA = internal mammary artery; LAD = left anterior descending artery; M1 = first marginal; M2 = second marginal; PD = posterior descending; RCA = right coronary artery.

Diagnostic Accuracy

Table 2 reports the results of MDCT evaluation of CABG patency. Table 3 (segment-based model) shows the numbers of true positive, true negative, false positive, false negative, sensitivity, specificity, positive predictive value, negative predictive value, and the area under receiver-operating characteristic curves for all CABG and postanastomotic coronary arteries. Table 4 shows sensitivity, specificity, positive predictive value, and negative predictive value for different types of CABG and for seven different segments of postanastomotic coronary arteries. Overall, sensitivity and negative predictive value were 100% for both CABG and postanastomotic artery evaluation. On a patient-based model, the sensitivity, specificity, positive predictive value, and negative predictive value were 100%, 93%, 86.4%, and 100%, respectively.

Multidetector computed tomography correctly diagnosed all 25 grafts shown to be occluded by ICA. All 31 significant stenoses of grafts shown by ICA were correctly diagnosed by MDCT, with 2 cases of mild disparity in terms of the severity of the lesion (slight overestimation by MDCT) observed in two segments of venous grafts (classified as false positives). In 2 patients, MDCT was in perfect correspondence with a second ICA, after a previous ICA had shown different data versus MDCT. In 1 case, the first ICA (performed in a patient with acute myocardial infarction) showed ostial occlusion of one venous graft, not subsequently confirmed by MDCT (showing patency of the graft); and in the other case, the first ICA, performed on a patient with unstable angina, judged as not recognizable a venous graft with anastomosis on the left marginal branch; in that case, MDCT showed a subocclusive stenosis of the ostial segment of the venous graft. In both cases, the second ICAs were performed after MDCT because of the very high quality of CT imaging, leading to unequivocal CT diagnosis. On the basis of these results, 18 patients (56% of patients with stenosis greater than 50% on grafts or postanastomotic coronary arteries) underwent percutaneous coronary intervention (in 17 cases on grafts, in 1 case on native coronary arteries), without complications.

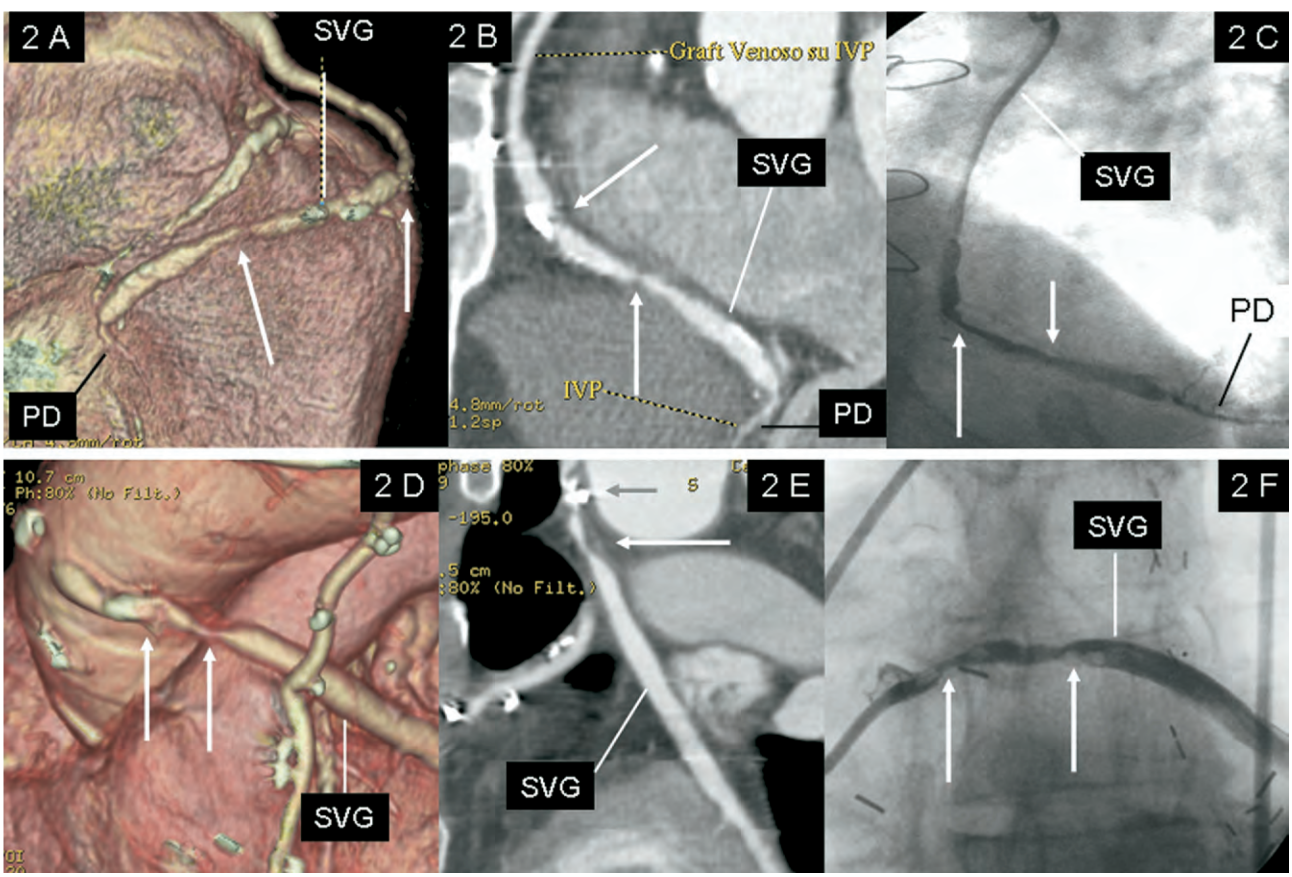

Fig 2. Examples of two cases showing head-to-head comparison of multidetector computed tomograhy (MDCT) and invasive coronary angiography in the evaluation of severe coronary artery bypass graft stenoses. (A) Multidetector computed tomography volume rendering reconstruction, (B) MDCT multiplanar reconstruction, and (C) coronary angiography in a case of severe stenoses (arrows) of saphenous vein graft (SVG), characterized by a calcified plaque proximally and a soft plaque distally. (D) Multidetector computed tomography volume rendering reconstruction, (E) MDCT multiplanar reconstruction, and (F) coronary angiography in a case of severe SVG stenoses (arrows). Multidetector computed tomography allows a very precise characterization of plaque morphology of the two stenotic segments. (PD = posterior descending artery.)

Figure 2 shows examples of cases in which MDCT correctly diagnosed graft pathologies (confirmed at ICA). Mean values of CABG significant stenosis (>50%) at MDCT were 83.2% ± 16.6%, with a very good correlation with ICA evaluation (80.5% ± 18.1%, $r = 0.82$, $p < 0.001$). Mean values of postanastomotic coronary artery significant stenosis (>50%) at MDCT were 76.2% ± 13.6%, with a high correlation with ICA evaluation (71.2% ± 15.1%, $r = 0.77$, $p < 0.001$).

Comment

This prospective study compared the feasibility and accuracy of high-resolution submillimeter MDCT and conventional ICA for the detection of patency and significant stenosis of arterial and venous grafts and native distal postanastomotic coronary arteries in consecutive patients with previous CABG. The main finding of this study is that MDCT is a feasible and accurate method for the detection of patency and significant stenosis (more than 50% decrease in diameter), not only of arterial and venous grafts (as demonstrated in previous studies) but also of distal postanastomotic coronary arteries.

The overall feasibility of complete evaluation of bypass graft patency in our population is very high (98.1%). Only 4 of 216 cases were judged not assessable, and all four artifacts were due to surgical causes: three IMA grafts were not assessable owing to the presence of metallic clips (metallic clips do not usually cause problems in the correct evaluation of MDCT, but in these 3 cases, they were particularly long and closely spaced), and one saphenous vein graft was not assessable as the anastomosis was performed with a new-generation magnetic device. The 98.1% feasibility could be even higher, because although four grafts were classified as not assessable, the artifacts involved only a small portion, localized in the body of the graft in the IMA and on the anastomotic site in the saphenous vein. Multidetector computed tomography correctly diagnosed all 24 grafts shown as occluded by ICA.

The diagnostic accuracy of CABG evaluation was very high (sensitivity 100%, specificity 98.5%), in agreement with previous reports [13–20]. Indeed, all 31 significant stenoses of grafts shown by ICA were correctly diagnosed by MDCT, with two cases of mild disparity in terms of the severity of the lesion observed in two segments of venous grafts. The overall feasibility of evaluation of native postanastomotic coronary arteries was high (93.1%, 201 of 216 segments), despite the small diameter of evaluated vessels, which is the leading cause of unfeasibility (10 segments with a diameter less than 1.5 mm). The diagnostic accuracy of native postanastomotic artery evaluation was also very high (sensitivity 100%, specificity 97.7%). These findings are in agreement with the very high diagnostic accuracy of MDCT coronary angiography (particularly in terms of sensitivity and negative predictive value) in vessels with a low or moderate risk for coronary artery disease [22, 23], as in the case of the distal portion of coronary arteries [24].

Clinical Implications

The appeal of MDCT compared with ICA is that it is rapid and noninvasive, thus avoiding catheter-associated risk and, in the subset of patients with previous CABG, the problems and risks related to selective graft catheterization such as spontaneous or catheterization-related left IMA dissection, a not unusual occurrence, even in the absence of atherosclerotic plaque [25], particularly in segments treated with free-graft technique and in patients with acute coronary syndrome. During acute coronary syndrome, and especially in cases of complex previous coronary revascularization or cases for which historic data concerning the type and site of previous CABG are lacking, preliminary evaluation of the graft by MDCT enables easy determination of graft patency and the presence of significant stenosis and avoids diagnostic mistakes related to the difficult localization and selective catheterization of the graft. Our data suggest that MDCT, thanks to its very high negative predictive value, may eliminate the need for invasive coronary procedures in the presence of normal coronary imaging. In the case of graft occlusion or significant stenosis, ICA may be more correctly indicated and an oriented percutaneous coronary intervention performed.

Study Limitations

There are some limitations to the present study. We included only patients able to maintain a breath hold of 40 s, because of the long duration of acquisition of CABG and postanastomotic coronary arteries with 16-slice MDCT. For this reason, many patients, especially older patients and patients with chronic obstructive pulmonary disease (mean age in our study was 61 ± 7 years), were excluded. Moreover, the spatial resolution of devices currently available (16 mm × 0.625 mm or 64 mm × 0.625 mm collimation) sometimes allows only a partial evaluation of distal coronary artery segments because of the small diameter of the examined vessel, which represents the leading cause of unfeasibility of postanastomotic coronary artery assessment in our study.

Future Directions

Sixty-four–row CT devices, available since 2005 and considered the gold standard, are able to greatly reduce the time required for data acquisition and thus the duration of breath holding. That allows a complete evaluation of grafts and postanastomotic coronary arteries in a larger cohort of patients. The further development of a new generation of scanners now under way (cardiac freeze-frame technique, dual-source CT, flat-panel CT), with further improved temporal resolution and the ability to acquire slices with a gantry rotation time of about 100 ms, abolishes the problem of breath holding and further reduces motion artifacts and artifacts related to variations of heart rate during the scan. Therefore, we may postulate that with these new devices, our conclusions could be further reinforced. Finally, thanks to the large reduction of X-ray dose with the new devices, the follow-up of patients with previous CABG could be made truly effective.

In conclusion, high-resolution submillimeter MDCT allows very accurate assessment of arterial and venous conduits and native postanastomotic arteries in patients with previous CABG. Despite its very high feasibility also for evaluating postanastomotic arteries (93.1%), the limitations of the method were breath-hold duration (35 to 40 s) and postanastomotic assessment of small vessels (which, however, precluded analysis in only 4.6% of cases).

References

1. Scanlon P, Faxon D, Audet A, et al. Society for Cardiac Angiography and Interventions. ACC/AHA guidelines for coronary angiography: a report of the American College of Cardiology/American Heart Association Task Force on practice guidelines (committee on coronary angiography). J Am Coll Cardiol 1999;33:1756–824.
2. Bashore TM, Bates ER, Berger PB, et al. American College of Cardiology/Society for Cardiac Angiography and Interventions. Clinical expert consensus document on cardiac catheterization laboratory standards: a report of the American College of Cardiology Task Force on clinical expert consensus documents. J Am Coll Cardiol 2001;37:2170–214.
3. Hoffmann U, Hadvar J, Dunn E, et al. Is CT angiography ready for prime time? A meta-analysis. J Am Coll Cardiol 2004;43(Suppl A):312A.
4. Cademartiri F, Marano R, Luccichenti G, et al. Anatomia normale del circolo coronarico con tomografia computerizzata multistrato a 16 canali. Radiol Med 2004;107:11–23.
5. Desjardins B, Kazerooni EA. ECG-gated cardiac CT. AJR Am J Roentgenol 2004;182:993–1010.
6. Achamnbach S, Moselewski F, Ropers D, et al. Detection of calcified and noncalcified coronary atherosclerotic plaque by contrast-enhanced submillimeter multidetector spiral computed tomography. Circulation 2004;109:14–7.
7. Kopp AF, Schroeder S, Kuettner A, et al. Non-invasive coronary angiography with high resolution multidetector-row computed tomography. Results in 102 patients. Eur Heart J 2002;23:1714–25.
8. Ferencik M, Moselewski F, Ropers D, et al. Quantitative parameters of image quality in multidetector spiral computed tomographic coronary imaging with submillimeter collimation. Am J Cardiol 2003;92:1257–62.
9. Brundage BH, Lipton MJ, Herfkens RJ, et al. Detection of patent artery bypass grafts by computed tomography: a preliminary report. Circulation 1980;61:826–31.
10. Moncada R, Salinas M, Churchill R, et al. Patency of saphenous aortocoronary-bypass grafts demonstrated by computer tomography. N Engl J Med 1980;303:503–5.
11. Engelmann MG, von Smekal A, Knez A, et al. Accuracy of spiral computer tomography for identifying arterial and venous coronary graft patency. Am J Cardiol 1997;80:569–74.
12. Ueyama K, Ohashi H, Tsutsumi Y, et al. Evaluation of coronary artery bypass grafts using helical scan computer tomography. Catheter Cardiovasc Interv 1999;46:322–6.
13. Martuscelli E, Romagnoli A, D'Eliseo A, et al. Evaluation of venous and arterial conduit patency by 16-slice spiral computed tomography. Circulation 2004;110:3234–8.
14. Salm LP, Bax JJ, Jukem W, et al. Comprehensive assessment of patients after coronary artery bypass grafting by 16-detector-row computed tomography. Am Heart J 2005;150:775–81.
15. Ropers D, Ulzheimer S, Wenkel E, et al. Investigation of aortocoronary artery bypass grafts by multislice spiral computed tomography with electrocardiographic-gated image reconstruction. Am J Cardiol 2001;88:792–5.
16. Anders K, Baumr S, Schmid M, et al. Coronary artery bypass graft (CABG) patency: assessment with high resolution submillimeter 16-slice multidetector-row computed tomography (MDTC) versus coronary angiography. Eur J Radiol 2006;57:336–44.
17. Marano R, Storto ML, Maddestra N, et al. Non-invasive assessment of coronary artery bypass graft with retrospectively ECG-gated four-row multi-detector spiral computed tomography. Eur J Radiol 2004;14:1353–62.
18. Rossi R, Chiurlia E, Ratti C, et al. Noninvasive assessment of coronary artery bypass graft patency by multislice computed tomography. Ital Heart J 2004;5:36–41.
19. Schlosser T, Konorza T, Hunold P, et al. Noninvasive visualization of coronary artery bypass grafts using 16-detector row computed tomography. J Am Coll Cardiol 2004;44:1224–9.
20. Chiurlia E, Menozzi M, Ratti C, et al. Follow-up of coronary artery bypass graft patency by multislice computer tomography. Am J Cardiol 2005;95:1094–7.
21. Bourassa MG, Fisher LD, Campeau L, et al. Long-term fate of bypass grafts: the Coronary Artery Surgery Study (CASS) and Montreal Heart Institute experiences. Circulation 1985;72(Suppl V):V71–8.
22. Leber WA, Knez A, Becker A, et al. Reply to quantification of coronary lesions by 64-slice computed tomography compared with quantitative coronary angiography and intravascular ultrasound. J Am Coll Cardiol 2006;47:892.
23. Nikolau K, Rist C, Wintersperger B, et al. Clinical value of MDCT in the diagnosis of coronary artery disease in patients with a low pretest likelihood of significant disease. AJR Am J Roentgenol 2006;186:1659–68.
24. Robbins S, Cotran R, Kumar V, et al. Pathologic basis of disease. 6th ed. Philadelphia: WB Saunders, 1999:645.
25. Moon CH, Nanavati VI. Multi-stent approach in the treatment of acute dissection of the left internal mammary artery. J Invasive Cardiol 1999;11:248–50.