

Open Heart Reoperations after Coronary Artery Bypass Grafting: the Role of Preoperative Imaging with Multidetector Computed Tomography

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ABSTRACT: **Background:** Injury to patent grafts or cardiac chambers may occur during reoperation after coronary artery bypass grafting. Preoperative spatial localization of bypass grafts with computed tomography may improve the safety of these procedures.

Objectives: To characterize patients who undergo CT before repeat operations after previous coronary artery bypass grafting, and evaluate its benefit in terms of surgical outcome.

Methods: We compared 28 patients who underwent cardiac gated CT angiography before reoperation (CT group) to 45 redo patients who were not evaluated with CT (no-CT group).

Results: The two groups were similar in most preoperative and operative characteristics. The CT group, however, included more patients with patent saphenous vein grafts and fewer with emergency operations, acute myocardial infarction and need for intraaortic balloon pump support. During mid-sternotomy, there was no injury to grafts in the CT group, while there were two patent grafts and three right ventricular injuries in the no-CT group. There was no significant difference in perioperative mortality (3.6% vs. 8.9%). The overall complication rate in the CT group was 21.4% compared to 42.2% in the no-CT group ($P = 0.07$). The only independent predictors of postoperative complications were diabetes mellitus, preoperative stroke and preoperative acute MI.

Conclusions: The patency and proximity of patent grafts to the sternum are well demonstrated by multidetector CT and may provide the surgeon with an important roadmap to avoid potential graft injury. A statistical trend towards reduced complications rate was demonstrated among patients who underwent CT angiography before their repeat cardiac operation. Larger series are required to demonstrate a statistically validated complication-free survival benefit of preoperative CT before repeat cardiac surgery.

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KEY WORDS: coronary artery bypass surgery, repeat surgery, spiral volumetric computed tomography

Open heart reoperations have gained an increasing role in the practice of cardiac surgery. The complication rate, however, is reported to be three to five times higher than for primary coronary artery bypass grafting [1,2]. The presence of patent grafts during reoperation presents a technical challenge and a significant risk of graft injury [3], with its associated grave consequences. Electrocardiographic-gated multidetector-row computed tomography of the heart has recently been applied for non-invasive imaging of coronary vessels [4], patency of bypass grafts [5], and demonstration of cardiac structures, including bypass conduits and their relation to the sternum [6]. Selective angiography, which is the standard diagnostic tool for evaluation of native and graft anatomy, provides insufficient information on the spatial relation of the bypass grafts to adjacent structures and to the planned median sternotomy. Moreover, the proximity of the right ventricle and the aorta to the sternum can hardly be determined by angiography, chest X-ray or fluoroscopy. We previously showed that in many cases three-dimensional imaging obtained from the new-generation MDCT warrants modification of the surgical plan during reoperative heart surgery after previous CABG procedures [7]. The purpose of the present study was to characterize patients who undergo MDCT before repeat operations after previous CABG and to evaluate the potential benefit of this new imaging tool in terms of surgical outcome.

PATIENTS AND METHODS

Between June 2003 and January 2006, 73 consecutive post-CABG patients were referred for reoperation. Preoperative demographic, clinical and surgical data are presented in Table 1. The various surgical procedures performed are detailed in Table 2. All patients who were post-CABG and candidates for repeat cardiac operations were considered for preopera-

MI = myocardial infarction

MDCT = multidetector computed tomography
CABG = coronary artery bypass graft

Table 1. Patients' characteristics

	CT angio (n=28)	No CT angio (n=45)	P
Interval to reoperation (yrs)*	8.8 ± 5.3	9.1 ± 6.7	0.86
Mean age (yrs)	72.4 ± 8.9	68.5 ± 9.3	0.08
Females	6 (21.4%)	7 (15.6%)	0.52
Diabetes	9 (32.1%)	20 (44.4%)	0.30
Patient with ITA	22 (78.6%)	27 (60%)	0.10
Patient with SVG	19 (67.9%)	20 (44.4%)	0.05
Right ITA to LAD	3 (10.7%)	2 (4.4%)	0.30
Patient with patent grafts**	27 (96.4%)	37 (82.2%)	0.07
COPD	3 (10.7%)	5 (11.4%)	0.93
CRF (Cr > 1.5)	7 (25%)	16 (35.6%)	0.35
Peripheral vascular disease	7 (25%)	10 (22.2%)	0.78
Acute MI (7 days)	1 (3.6%)	9 (20%)	0.04
Ejection fraction <40%	7 (25%)	15 (33.3%)	0.45
Prior stroke	2 (7.1%)	8 (17.8%)	0.20
Emergency	4 (14.3%)	18 (40%)	0.02
Cerebrovascular disease	6 (21.4%)	11 (24.4%)	0.77
IABP	0 (0%)	8 (17.8%)	0.02

CRF = chronic renal failure (Cr > 1.8), COPD = chronic obstructive pulmonary disease, MI = myocardial infarction, CABG = coronary artery bypass grafting, IABP = intraaortic balloon pump, ITA = internal thoracic artery, SVG = saphenous vein graft, Cr = creatinine, OPCAB = off-pump coronary artery bypass surgery.

* Interval in years between CABG and repeat operation

** ITA+SVG

Table 2. Surgical procedures

	CT angio (n=28)	No CT angio (n=45)	P
CABG	16 (57.1%)	30 (66.7%)	0.412
AVR	13 (46.4%)	15 (33.3%)	0.263
MVR*	7 (25%)	6 (13.3%)	0.205
CABG + valve	8 (28.6%)	4 (8.9%)	0.027
DVR	1 (3.6%)	3 (6.7%)	0.572
Any valve replacement	19 (67.9%)	18 (40%)	0.021
Aorta	3 (10.7%)	1 (2.2%)	0.121
CEA	1 (3.6%)	0 (0%)	0.275
Axillary cannulation	6 (21.4%)	1 (2.2%)	0.03
Femoral cannulation	1 (3.6%)	3 (6.7%)	0.572

CABG = coronary artery bypass grafting, AVR = aortic valve replacement, DVR = double valve replacement (patients included in AVR and MVR), aorta = replacement of ascending aorta, CEA = open heart procedure + carotid endarterectomy.

*Including one mini-thoracotomy with femoral cannulation.

tive CT angiography. Emergency operations, renal failure, non-availability of CT scanner, or non-availability of qualified personnel, however, precluded the performance of CT angiography in all the patients.

The patients (CT group) were scanned using a multidetec-

tor CT scanner with ECG gating. Twenty-two were scanned with a 16-channel MDCT (Mx8000 IDT, Philips Medical Systems, Cleveland, OH, USA), and 6 were scanned with a 40-channel MDCT (Brilliance 40, Philips). The remaining 45 patients underwent reoperation without preoperative CT evaluation (no-CT group).

CT DATA ACQUISITION, IMAGE RECONSTRUCTION AND PROCESSING

A total of 130–150 ml (100 ml using the 40-channel MDCT) of contrast material at a concentration of 370 mg iodine/ml (Ultravist, Schering, Berlin, Germany) were injected at a rate of 4.0 ml/sec. To optimize vessel visualization, an automated bolus-tracking technique was used with the region of interest placed within the aortic arch. Scanning began in the cephalo-caudal direction 5 seconds after reaching a threshold of 200 Hounsfield Units. When the 40-channel MDCT was used, a 40 ml saline chaser was injected at a rate of 4.0 ml/sec following the contrast administration. All studies were performed during one breath-hold and with ECG gating. The scanning volume covered the region between the thoracic inlet to the apex of the heart, with total scan time ranging from 16 to 37 seconds (28 ± 6). The CT images were reconstructed at diastole and at 80% or 75% of the R-R interval. Since all patients had a recent coronary angiography, stenosis assessment using CT was not performed for either the grafts or the native coronary vessels. In addition, since most of the patients had complicated cardiac and non-cardiac medical conditions that were carefully balanced by multiple drugs, their heart rate was not lowered, nor was sublingual nitroglycerin administered for the CT exam. The range of heart rate was 55–93 beats/minute (65 ± 10).

The scanning parameters were: tube voltage 140 (120) kV, 400 (700) mAs, and pitch 0.2–0.298. Gantry rotation time was 0.42 seconds. Detector collimation was 16 x 0.75 mm (or 40 x 0.625 mm), and the reconstructed slice thickness was 1.0 mm with an increment of 0.5 mm.

The image processing and data analysis was performed on a separate workstation (MxView, Philips). Imaging of the heart, bypass grafts, and their spatial location with respect to the sternum were assessed using axial images, multiplanar reformation, thin-slab maximal intensity projection, and three-dimensional volume-rendered images. First, 3D images were created for a global overview of the heart, grafts and their relation to the sternum, after removal of all bony structures excluding the sternum. The radiologist then located the grafts and right ventricular wall on the multiplanar reformation and thin-slab MIP images and measured their distance from the midline of the sternum using electronic calipers.

MIP = maximal intensity projection

STATISTICAL ANALYSIS

Data are presented as mean ± standard deviation for continuous variables and as number and percent for categorical variables. Comparison between groups was performed using the Student *t*-test for continuous variables, and chi-square or Fisher's exact test for categorical variables as appropriate. Multivariable logistic regression was used to identify group association and risk factors for other specified endpoints. Analysis was performed with the SPSS 13 statistical package.

RESULTS

The two groups were similar in most preoperative characteristics [Table 1]. The CT group, however, included more patients with patent saphenous vein grafts, while the prevalence of acute myocardial infarction, emergency patients and patients supported preoperatively with an intraaortic balloon pump was higher in the no-CT group.

The various surgical procedures are presented in Table 2. The use of preoperative CT-angiographic imaging was more common among patients who underwent valve surgeries, especially combined procedures of valve + CABG.

When using the multivariable logistic regression model, preoperative non-use of IABP (*P* = 0.004), patent SVG (*P* = 0.002) and CABG+valve procedure (*P* = 0.001) were also factors found to be independent predictors of preoperative selection to the CT group.

The following patent bypass grafts were present in the CT group: 22 left internal thoracic arteries, 6 right ITAs, one gastroepiploic artery graft, one radial artery graft, and 23 SVGs. MDCT enabled spatial localization of patent grafts and their proximity to the sternum, which was shown to be precise and reliable at surgery. Since the postsurgical right ventricular wall and the grafts are surrounded with connective tissue that causes their adhesion to the sternum, we defined critical proximity or adhesion when the distance between the right ventricular anterior wall, the ascending aorta or the graft to the sternum was less than 3 mm. Critical proximity to the planned mid-sternotomy line of the left ITAs [Figure 1] and SVGs was demonstrated by the CT in six and two patients, respectively. The left ITAs and SVGs were adherent to the sternum close to the midline, but lateral to the mid-sternal line by 3 to 12 mm in four and two additional patients, respectively. Mid-sternotomy was safe in these patients; knowledge of the exact distance between the mid-sternotomy line and the adherence point of the patent graft enabled safe separation of this conduit from the sternum, its control during cross-clamping of the aorta, and during positioning of the sternal retractor.

IABP = intraaortic balloon pump
 SVG = saphenous vein grafts
 ITA = internal thoracic artery

Figure 1. Preoperative assessment of a 64 year old man who had undergone a previous CABG, before repeat CABG and AVR. The left ITA is adherent to the sternum at the midline behind the manubrium adjacent to the highest sternal suture (arrow-left ITA); further down it continues to be adherent to the sternum in a torturous way toward its anastomosis with the LAD.

[A] Axial thin-slab MIP reconstruction. **[B]** Three-dimensional volume-rendered reconstruction of the heart and grafts. ITA = internal thoracic artery, LAD = left anterior descending artery, MIP = maximal intensity projection.

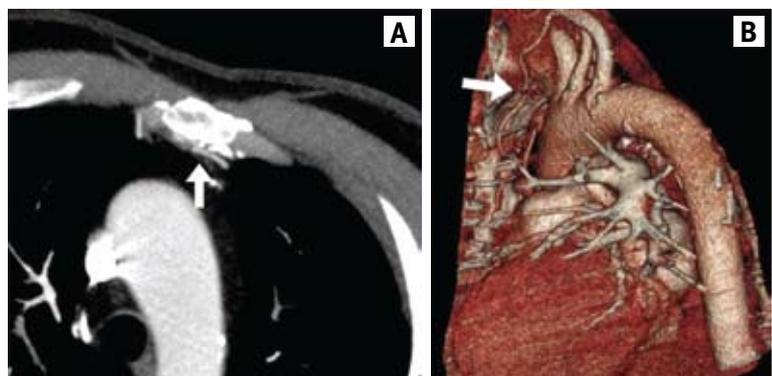


Table 3. Operative results

	CT angio (n=28)	No CT angio (n=45)	P
30 day mortality	1 (3.6%)	4 (8.9%)	0.38
Patent graft damage**	0 (0%)	2 (4.4%)*	0.5
RV damage	1 (3.6%)	3 (6.6%)*	0.8
Postoperative renal dysfunction	2 (7.1%)	10 (22.2%)	0.09
Reexploration for bleeding	1 (3.6%)	4 (8.9%)	0.38
Prolonged ventilation	4 (14.3%)	9 (20%)	0.53
Postoperative stroke	0 (0%)	1 (2.2%)	0.43
Overall complications	6 (21.4%)	19 (42.2%)	0.07

RV = right ventricle.

*One of the patients with patent graft injury also had RV laceration during sternotomy.

** Patent graft damage was associated with perioperative MI.

MDCT also clearly showed the exact spatial location of the three right ITAs that were adherent to the sternum when crossing the midline in their course to the left anterior descending anastomotic site [Table 1].

MDCT demonstrated adherence of the right ventricle and aorta to the sternum in 16 and 2 patients, respectively. During surgery, dissection was performed according to MDCT findings in the CT group. Table 3 presents the operative results. There was no injury to cardiac structures or grafts during mid-sternotomy, although there was one case of small right ventricle laceration during its separation from the chest wall. There were two cases of patent graft injury and three cases of right ventricular laceration that occurred during mid-sternotomy in the no-CT group [Table 3].

Based on MDCT findings, the operative plan was changed in 10 patients. Four patients underwent thoracotomy or partial sternotomy instead of mid-sternotomy. One patient's sternum was divided between 0.5 and 1.2 cm laterally to the right of the midline. Axillary cannulations were used in six patients and femoral arterial cannulation in one patient. Two patients underwent mid-sternotomy after being connected to the cardiopulmonary bypass circulation with remote arterial and femoral venous cannulation.

Perioperative mortality was not significantly different between the CT and no-CT groups. The preoperative MDCT was not associated with a reduced rate of complications when using the multivariable regression model. The differences in overall postoperative complications, however, nearly reached a level of significance (21.4% vs. 42.2%, $P = 0.07$) [Table 3].

The only independent predictors of postoperative complications were diabetes mellitus ($P < 0.001$), preoperative stroke ($P < 0.001$) and preoperative acute myocardial infarction ($P = 0.002$).

DISCUSSION

Reoperation after a previous CABG is common [8]. Most patients are referred to re-CABG due to ischemia caused by progression of arteriosclerosis in native coronary disease or SVGs [7]. In addition, repeat operations are often required in elderly patients who develop senile calcific aortic stenosis or other valvular disease requiring surgical reintervention. The mixture of surgical procedures in our study population is typical for the type of patients referred nowadays for reoperative procedures after CABG. With the current policy of extensive arterial revascularization with ITAs [10] at primary operation, many of the patients referred to repeat open-heart procedures have patent ITA grafts due to better long-term patency of this conduit [11]. The need to protect the ITA graft from injury during reoperation is a challenging task. Injury to these grafts creates a specific risk, which can increase operative mortality and morbidity due to inadequate myocardial preservation or a perioperative MI [12]. ITA damage can occur during sternotomy or later during its separation from the sternum and chest wall. Patients who had undergone bilateral ITA grafting with right ITA to the LAD coronary artery across the midline are at additional risk [13]. In all the above situations involving patent ITA or even with patent SVG, it is most helpful for the surgeon to know the exact spatial location of patent grafts and their proximity to the sternum and chest wall before initiating surgery. This information is reliably provided by MDCT. Indeed, analysis of the preoperative characteristics in this

study shows that there had been a marked inclination to refer patients with patent grafts for preoperative evaluation with MDCT during the study period. Many of these patients were valve cases, which are usually operated electively. On the other hand, acute MI patients, emergency patients and patients treated with IABP were less likely to undergo preoperative MDCT due to logistic problems with their transfer to the CT unit before surgery and concerns regarding nephrotoxicity from contrast material injected shortly after their diagnostic coronary angiography.

The complication rate and mortality rate in the CT group were relatively low. Nevertheless, the preoperative performance of MDCT did not emerge as an independent predictor for mortality or morbidity. The only independent predictors for postoperative complications were the commonly known ones, such as preoperative stroke, preoperative acute MI, and diabetes mellitus.

STUDY LIMITATIONS

A major limitation of the study was the lack of homogeneity between the two groups. Unstable and emergency patients were less likely to undergo CT before their operation, thus significantly more patients in the no-CT group were emergency patients, acute MI patients or those supported by IABP. Another limitation was the relatively small number of patients who underwent preoperative CT. More post-CABG patients scheduled for repeat open heart surgeries who undergo preoperative CT angiography are required for improved statistical power.

CONCLUSIONS

The patency and proximity of ITA, SVG, and the right ventricle to the sternum are well demonstrated by MDCT and may provide the surgeon with an important roadmap to avoid potential harm to these grafts. However, the use of MDCT is mostly limited to non-emergency patients with normal renal function. The trend towards reduced mortality and complication rate among the patients who underwent MDCT angiography before cardiac reoperation in this small study group implies that larger series are required to demonstrate statistically the benefits of preoperative use of MDCT before reoperative procedures.

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MI = myocardial infarction

LAD = left anterior descending

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