Evaluation of Coronary Artery Bypass Grafts in the Early Postoperative Period Using 64-Slice MDCT[1]

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Purpose: The aim of this study was to evaluate the accuracy of 64-slice multidetector row CT (MDCT), as compared with conventional coronary angiography (CCA), for assessing coronary artery bypass grafts (CABG) in the early (< 1 month) postoperative period.

Materials and Methods: Twenty-four patients underwent both 64-slice MDCT (0.6 mm collimation, 0.37s gantry rotation) and CCA within 15 days after CABG. Sixty-five bypass grafts (20 venous grafts and 45 arterial grafts) and 67 distal runoff arteries in 24 patients were included in the analysis. The bypass grafts and distal runoffs were evaluated for the presence of significant stenosis, including obstruction. The CT findings were compared with the CCA findings.

Results: CCA confirmed that 62 of the 65 grafts were patent and that 3 had significant stenosis or obstruction. Sixty of the 62 patent grafts were correctly identified by MDCT. One of the three grafts that had significant stenosis was misinterpreted on the MDCT images. The sensitivity, specificity and positive and negative predictive values for detecting stenosis were 67%, 97%, 50% and 98%, respectively, with an overall diagnostic accuracy of 95%. MDCT also correctly detected all the stenotic distal runoff arteries (4 of 67).

Conclusion: 64-slice MDCT is a promising alternative diagnostic modality for evaluating a CABG in the early postoperative period.

Index words : Tomography, X-ray computed
　　　　　　 Coronary angiography
　　　　　　 Coronary artery bypass graft
　　　　　　 Graft occlusion, vascular

Coronary artery bypass graft surgery (CABG) has been widely used for patients with multivessel coronary artery disease. The post-operative patency of the bypass graft is important to predict the clinical outcome (1-3). Postoperative myocardial infarction is a rare, but potentially severe complication after CABG. So, the early recognition of the failure of a bypass graft on the early postoperative imaging is necessary to evaluate the quality of the surgical anastomosis and the graft patency (4, 5).

Conventional coronary angiography (CCA) is currently the standard diagnostic modality that's used to assess the status of bypass grafts. However, it is an invasive

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procedure requiring a long procedure time, it can cause graft injury or spasm, and it has the risk of complications (6–10), and especially in the early postoperative period. Therefore, a less invasive imaging modality would be desirable for evaluating the patency of a graft. MDCT has recently gained increasing acceptance for noninvasive cardiac imaging. Several recent studies have shown that 64-slice MDCT angiography achieved excellent image quality and high diagnostic accuracy for evaluating coronary arterial bypass grafts, as compared with CCA (11–17). However, to the best our knowledge, there have been no studies that have reported on the value of 64-slice MDCT for evaluating bypass grafts in the early postoperative period.

The purpose of this study was to investigate the accuracy of 64-slice MDCT, as compared with CCA, for the assessment of the patency of a CABG in the early (< 1 month) postoperative period. In addition to the assessment of a CABG, we also assessed the distal coronary runoff arteries in this study.

Materials and Methods

Patient Population

From March 2005 to February 2006, eighty one patients underwent CABG at our hospital due to triple vessel coronary artery disease. Overall, seventy patients underwent postoperative imaging within 15 days after CABG. Forty six patients (46/70, 65.7%) underwent CCA to assess their graft's patency. The patients who had a regular heart beat without difficulty when holding their breath participated in this study, and they underwent additional 64-slice coronary MDCT within 7 days (mean: 2 days, range: 1–7 days) after CCA. The patients with a history of renal insufficiency, contrast allergy or atrial fibrillation were excluded. Overall, twenty four patients (13 men and 11 women, mean age: 61.8 years, range: 42 to 74 years) were included in this comparative study. This study was approved by the hospital institutional review board, and informed consent was obtained from all the patients for the CCA and MDCT.

MDCT Angiography

The scans were performed on a 64-slice multidetector system (Somatom Sensation 64; Siemens, Erlangen, Germany). The patients were positioned in the gantry in the supine position with electrocardiographic leads placed on the anterior thorax to enable a retrospectively gated scan. The scan parameters were 800-900 effective mA, 120 kV, a gantry rotation time of 0.37s, a detector collimation of 64 × 0.6 mm and a pitch of 0.24. Scans were performed in the craniocaudal direction, with a scan range from the thoracic inlet through the lung bases. For the cases with a gastroepiploic arterial graft, the scan range was expanded into the upper abdomen. All the scans could be performed within one single breath-hold. A total of 70–100 mL of contrast media (Visipaque 320; Amersham Health, Cork, Ireland) was injected at a rate of 5.0 ml/second, and this was followed by an injection of 40 ml saline at a rate of 5.0 ml/second. A test bolus technique was used to optimize graft visualization. A small amount of contrast material (20 mL) was intravenously injected during the acquisition of a series of dynamic low-dose monitoring scans at the level of the ascending aorta. The scan delay time was determined by calculating the peak time plus 2 seconds. The patients with a heart rate exceeding 70 beats per minute (bpm) received 40 mg–80 mg of oral β - blocker (propranolol), unless underlying contraindications were present. In addition, 0.6 mg oral nitroglycerin was given to all the patients immediately before MDCT scanning.

In order to optimally visualize the coronary arteries, image reconstruction was performed between 30% and 70% relative to the RR interval by using 5% increments. The best phases with the least cardiac motion for the image analysis were determined on the basis of the preview series of scans that were reconstructed at 9 different R-R interval positions. A slice thickness of 0.6 mm with increments of 0.4 mm each and a B25f smooth + + Kernel were used for the reconstruction. The reconstructed data of the MDCT was transferred to a workstation (Wizard; Siemens, Erlangen, Germany) for further processing.

Table 1. Graft Types

	Graft Type	$n = 65$
Arterial ($n=45$)	Left IMA to the LAD or a diagonal branch	22
	Left IMA to the OM	1
	Right IMA to the LAD or a diagonal branch	9
	Right IMA to the OM	7
	Right IMA to the ramus intermedius	1
	Right GEA to the RCA	2
	RA to the OM or the ramus intermedimus	3
Venous ($n=20$)	SV to the RCA or the PDA	17
	SV to the LAD	1
	SV to the OM	2

IMA = internal mammary artery; LAD = left anterior descending artery; OM = obtuse marginal branch; GEA = gastroepiploic artery; RCA = right coronary artery; RA = radial artery; SV = saphenous vein; PDA = posterior descending artery

Conventional Coronary Angiography

Arterial catheterization and selective conventional angiography of the coronary arteries and the bypass grafts were performed according to standard techniques. Quantitative coronary angiography was performed on two orthogonal projections of the coronary arteries (Coroskop, Siemens, Erlangen, Germany) to identify the segments larger than 2.0 mm in diameter. An experienced interventional cardiologist and a thoracic surgeon reviewed the angiographic images for stenotic lesions or occlusions in the bypass grafts and in the runoff arteries that were distal to the grafts.

Analysis

Two radiologists working in consensus reviewed the conventional contrast enhanced axial slices, as well as the three-dimensional images, including the volume rendered (VR), curved multiplanar reformatted (MPR) and maximum intensity projection (MIP) images, to evaluate graft patency and the runoff arteries distal to the grafts on the MDCT images. The image quality of an exam was grade as 'good', 'adequate' or 'poor'. Each bypass graft was visually classified as either 'evaluable' or 'unevaluable', according to the vessel size (>2 mm) or the presence of motion artifacts. The evaluable bypass grafts were assessed for the presence of significant stenosis or occlusion. Significant stenosis was defined as a reduction in the luminal diameter of more than 50%. All the coronary branches that were supplied by a patent bypass graft were also assessed for significant luminal narrowing. The CT findings were compared with those findings of the CCA. Based on the findings of the CCA, the sensitivity, specificity, positive and negative predictive values and the accuracy of 64-slice MDCT were calculated. The 95% confidence intervals (CIs) were calculated using binomial proportions.

Results

Among the eighty one postoperative patients, fifty seven patients were referred to undergo MDCT, but nine patients (9/57, 15.8%) failed to undergo MDCT because of arrhythmia. There were twenty four patients who didn't undergo CCA, but they did undergo MDCT because they refused to receive invasive procedures. All 24 patients enrolled in this study completed their MDCT examination successfully without serious complications. The mean heart rate during the scan was 66 bpm (range: 57–86). In 3 of the 24 patients, the cardiac rhythm was regular, but the heart rate was over 70 bpm after the administration of oral β-blockers.

The image quality of each exam was graded as 'good' for 12 (50%) examinations and 'adequate' for 12 (50%) examinations. No patient was excluded from the analysis because of poor image quality.

There were five sequential grafts and eighteen composite grafts. Each consecutive anastomosis in the cases of composite grafts was regarded as a separate graft seg-
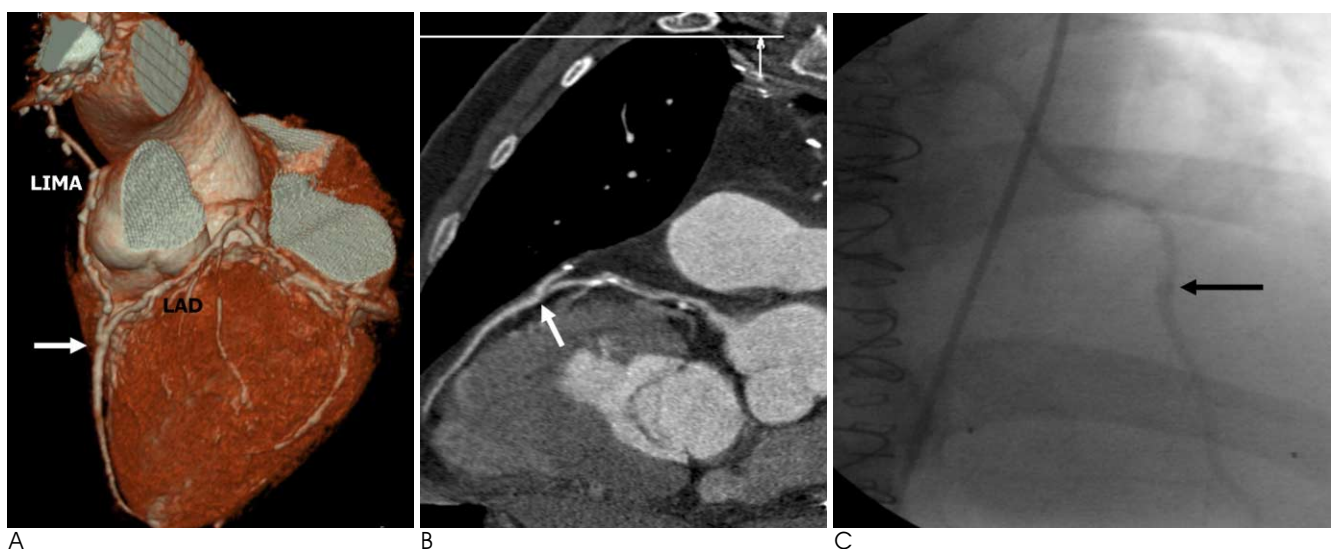

A   B   C

Fig. 1. Representative images from a 70-year-old male with a patent left internal mammary artery (LIMA) graft to the left anterior descending artery (LAD).
A, B. The anastomotic site (arrow) is well visualized on a volume rendering image and on a MPR image.
C. The corresponding CCA shows a patent LIMA graft (arrow).

ment. Therefore, the 24 patients had a total of 68 bypass grafts (21 venous grafts and 47 arterial grafts). One of the 68 grafts was classified as 'unevaluable' and this was excluded from the analysis due to motion artifact on MDCT. Two of the 68 grafts were excluded because of catheterization failure during CCA, although both of them were well visualized on MDCT; 1 graft was a right gastroepiploic artery grafted to a posterolateral branch, and the other graft was a saphenous vein graft connected to a diagonal branch. So, 65 grafts in 24 patients were finally included in the comparative analysis, of which 45 were arterial grafts and 20 were venous grafts (Table 1).

CCA confirmed that 62 of the 65 grafts were patent and that 3 had significant stenoses or obstruction. Sixty of the 62 patent grafts were correctly identified by MD-

CT (Fig. 1, 2). Two cases of graft stenoses or occlusions were erroneously suspected on MDCT, but this was not present on CCA. The reviewers correctly identified two of the three grafts that had significant stenoses or obstructions on the CCA (Fig. 3, 4); one was a radial artery graft to an obtuse marginal branch, and the other was saphenous vein graft to the right coronary artery. Only one case of significant stenosis (a right internal mammary artery (RIMA) to the left anterior descending artery (LAD)) was missed on 64-slice MDCT (Fig. 5).

According to the CCA, there was a total of 69 distal coronary runoff arteries supplied by 62 patent grafts. Of these, 68 distal runoffs could be assessed with MDCT, except for one due to motion artifact. Four of them had significant stenosis on the CCA, and CT detected all these lesions (Fig. 6). Therefore, with regard to the as-
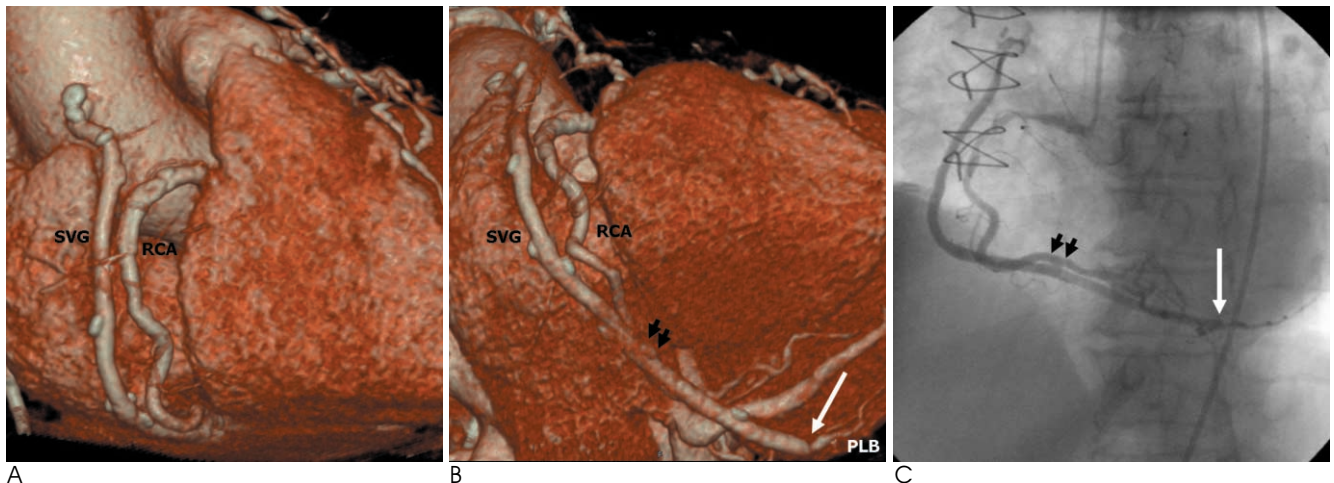

Fig. 2. Representative images from a 64-year-old male with a patent saphenous vein graft (SVG).
A. The SVG originated from the ascending aorta.
B, C. The SVG is first anastomosed (black short arrows) to the distal segment of the right coronary artery (RCA) and then it consecutively jumps to the posterolateral branch (secondary anastomosis) (white long arrow). The findings of the MDCT angiograms concurred with those of the CCA.
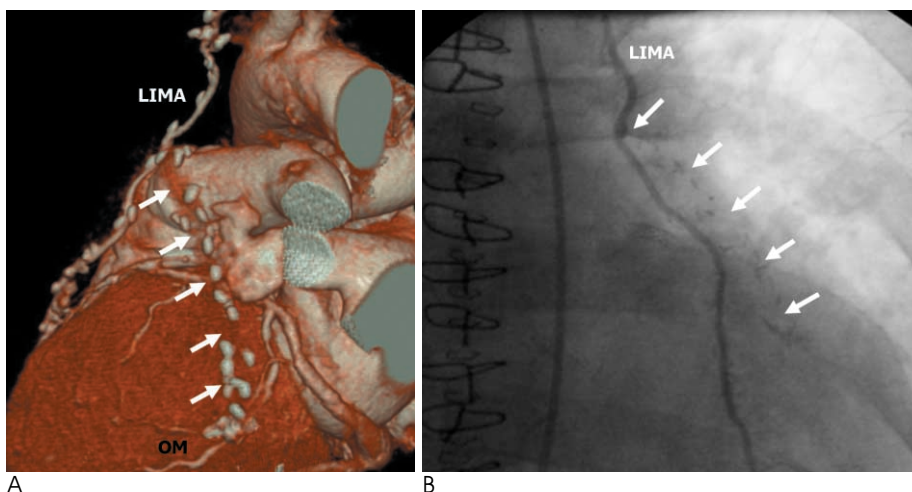

Fig. 3. A 62-year-old male with a radial artery (RA) graft from the LIMA to an obtuse marginal branch (OM).
A. The arterial graft shows total occlusion (arrows) from the anastomotic site with the LIMA.
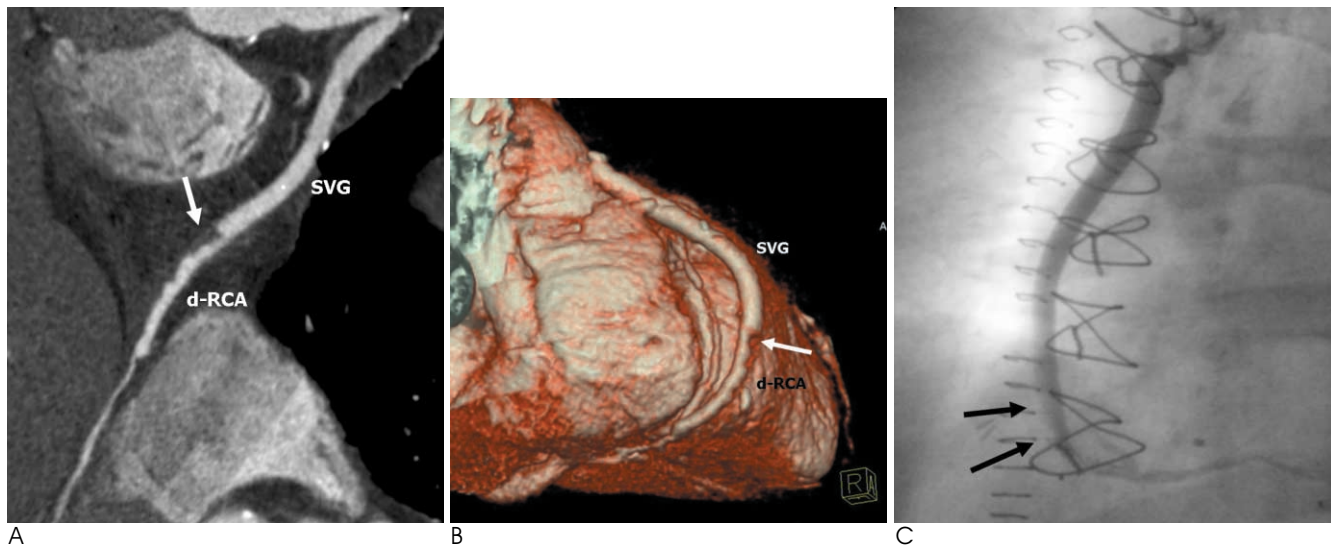B. The corresponding CCA confirmed the RA graft occlusion (arrows).

A B C

Fig. 4. An example of graft body stenosis in a SVG connected to the distal RCA (d-RCA) in a 59-year-old female. On the MIP and 3-D volume rendering images (A, B), there seems to be significant stenosis of the distal SVG graft with luminal irregularity. Intraluminal thrombus (white arrow) is suggested by these CT images.

C. The CCA shows sluggish blood flow and a filling defect (black arrows) at the distal graft body, and this is also suggestive of intraluminal graft thrombus. However, it was initially missed by a cardiologist.
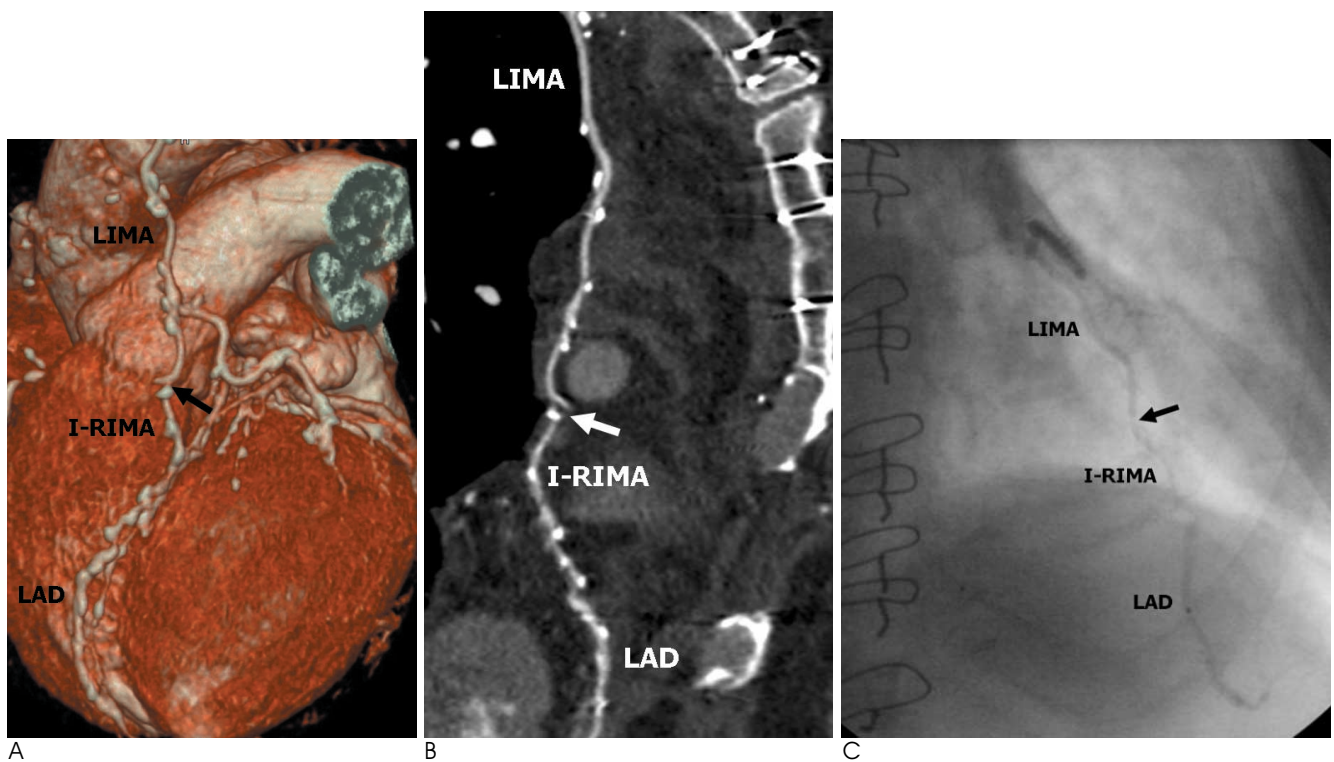

A B C

Fig. 5. Mismatch between the MDCT and CCA in a 61-year-old male with a LIMA connected to the LAD via a fragment of the right internal mammary artery (I-RIMA).

A, B. The volume rendered and MIP images show focal discontinuity (arrow) just proximal to a clip. The reviewers considered that it was due to beam-hardening artifact that developed due to a metallic clip and the graft was considered as patent.

C. The CCA shows about 70% stenosis (arrow) at the same site that is the anastomosis between the LIMA and the I-RIMA.

sessment of the distal runoff coronary arteries, our study demonstrated 100% diagnostic accuracy without any cases of false interpretation.

Evaluation of the competitive flow was limited on MDCT. One of the two patent bypass grafts that was erroneously interpreted as occluded by MDCT was a left internal mammary artery (LIMA) attached to the LAD (Fig. 7). The LIMA was faintly visualized on MDCT, and so it was considered to be a diffusely stenotic graft. The graft was patent with competitive flow between the LIMA and the LAD on the CCA, although 70% stenosis was present in the LAD.

Using the CCA findings as the standard of reference, the sensitivity and specificity of MDCT for the detection of significant stenosis or obstruction of bypass grafts were 67% (95% CI: 9.43–99.16%) and 97% (88.83–99.61%), respectively. The positive and negative predictive values were 50% (6.76–93.24%) and 98% (91.20–99.96%), respectively, with an overall diagnostic accuracy of 95% (Table 2).

Discussion

The patients with a CABG require follow-up evaluations to monitor the patency of their grafts because it is known from previous studies that the clinical outcome of a CABG primarily depends on the graft's integrity (1–3). The patency of the bypass graft in the early postoper-
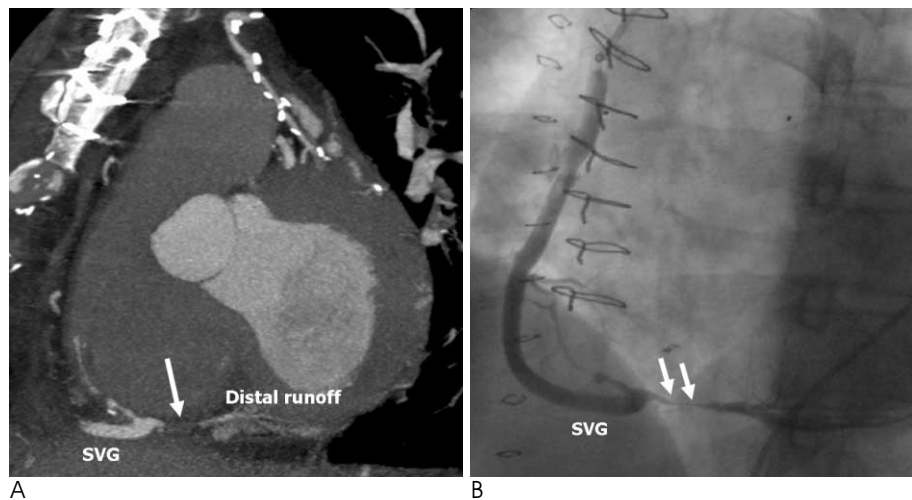

Fig. 6. A. Significant stenosis of the distal runoff artery (the distal RCA) at just the distal portion of the anastomotic site and the SVG is well visualized on MDCT.
B. The CCA also revealed stenosis of the distal runoff artery.

Fig. 7. A 53-year-old male with a LIMA connected to the LAD.
A. On a volume rendered image, the distal segment of the LIMA is poorly visualized (arrows).
B. An MIP image shows diffuse narrowing (arrows) of the graft from just distal to the junction between the LIMA and the RIMA. Therefore, we thought that the graft was diffusely stenotic.
C. The CCA shows a patent graft with a relatively small diameter and competitive blood flow.

Table 2. Diagnostic Results of MDCT Angiography for the Bypass Graft Patency, as Compared with Catheter Angiography, in 65 Coronary Artery Bypass Grafts

Graft		No.	MDCT Angiography*				Accuracy (%)
			TP	TN	FP	FN	
Arterial	IMA	40	0	38	1	1	95
	GEA	2	0	2	0	0	100
	RA	3	1	2	0	0	100
Venous	SV	20	1	18	1	0	95
Total**		65	2	60	2	1	95

TP = true positive; TN = true negative; FP = false positive; FN = false negative; IMA = internal mammary artery; GEA = gastroepiploic artery; RA = radial artery; SV = saphenous vein
* The positive result was defined as significant stenosis or occlusion. Significant stenosis means a reduction in the luminal diameter of more than 50%.
** Based on these results, the sensitivity, specificity and the positive and negative predictive values are 67% (95% CI: 9.43–99.16%), 97% (88.83–99.61%), 50% (6.76–93.24%), and 98% (91.20–99.96%), respectively.

ative period is also associated with the long-term outcome after CABG (18). Early stenosis or occlusion of the bypass graft is rare, but this may cause significant postoperative complications, including myocardial ischemia. A study by Berger et al. reported that early stenosis or occlusion was reported in 9.1% of the patients in whom a LIMA was anastomosed to the LAD with a CABG (19). Another study revealed that the immediate-term postoperative coronary angiography detected graft failure or occluded native vessels in 13 of 40 patients (32.5%), although that study was performed on patients who had clinically suspected myocardial ischemia after CABG (20).

During the early postoperative period, the primary mechanism of graft failure is thrombosis. Early graft thrombosis is related to technical issues, including failure to reverse the vein graft, a tight suture at the anastomosis, poor targets with poor runoff, injury to the graft during harvesting and the occasional grafting of vessels for which the proximal stenosis is less than 70% (2, 21). Graft closure from thrombosis at one month postsurgery has been reported in 10–15% of cases (2). However, many patients with occluded grafts have no signs of trouble during the early postoperative period (6). The signs (e.g., electrocardiography alteration and elevation of the cardiac enzymes) and symptoms (e.g., chest pain and dyspnea) are nonspecific in the postoperative condition. Thus, early complications such as graft closure from thrombosis, graft malposition and kinking must be detected by postoperative imaging to plan the

appropriate management such as interventional coronary procedures or additional surgery (22–24). So, this current investigation was carried out to assess the diagnostic accuracy of 64-slice MDCT for the assessment of patients in the early postoperative period after CABG.

Although some non-invasive diagnostic tools such as MDCT and MRI have been reported on, CCA is currently considered the gold standard for postoperative imaging (23, 25, 26). However, selective catheterization of the coronary artery bypass graft is invasive and it may be difficult; complications can occur during the early postoperative period and these are due to an irregular heart beat, a small vessel size, graft spasm or graft injury (6–8). Coronary artery spasm or graft spasm may severely complicate the immediate postoperative period of patients who underwent CABG, and this can result in circulatory collapse or cardiac arrest. The catheterization of the small grafts may initiate or aggravate the graft spasm. On rare ocassions, serious complications of CCA can occur such as conduit dissection, embolism, myocardial infarction, stroke and death (7, 9, 10). Therefore, the use of highly sensitive and non-invasive diagnostic modalities for evaluating bypass grafts would be of great clinical benefit to decrease graft injury and the complications of CCA during the early postoperative period.

MDCT has recently been used for noninvasive imaging of coronary artery disease and for determining the patency of bypass grafts. Several studies have reported that 64-slice MDCT achieved good imaging quality and high diagnostic accuracy in assessing coronary artery bypass grafts, as compared with CCA (11–17). However, those studies were performed in the late postoperative setting. In contrast, our study was performed in the early postoperative setting in which the patients complain of respiratory difficulty or they have irregular heart beats. Therefore, 64-slice MDCT is a convenient tool to evaluate bypass grafts in postoperative patients because it allows more rapid image acquisition than CCA and even 4- or 16-slice MDCT (27).

For the detection of bypass graft stenosis or occlusion after CABG, as compared with CCA, the sensitivity with using 64-slice MDCT has been reported to range from 85% to 100% and the specificity is between 91.4% and 100% (11–17). In this current study, 64-slice MDCT also achieved favorable overall diagnostic accuracy (95%), high specificity (97%) and a high negative predictive value (98%), although the sensitivity (67%) and positive predictive value (50%) were relatively low. This is be-

cause of the paucity of true positive cases (only three grafts) in this study. Yet the high negative predictive value suggests that MDCT can rule out the presence of significant bypass graft failure in postoperative patients.

The 64-slice MDCT is superior to conventional angiography in that it shows the cardiac structure, the global function of the left ventricle and the coronary vasculature, as well as non-cardiac structures (28–30). In addition, not only luminal evaluation, but also demonstration of neointimal plaque or thrombus is possible with the increased spatial resolution of 64-slice MDCT.

During conventional angiography, the direction of blood flow may be changed and it may even be reversed by catheter engagement or by the rate of injecting the contrast material. So CCA may not be a standard of reference in some cases. Therefore, MDCT and CCA should be complementary diagnostic tools for the evaluation of postoperative graft patency.

Despite the marked technical improvements, the previous studies have reported that there are still some limitations of 64-slice MDCT. First of all, the major drawback of retrospective ECG-gated MDCT is its high radiation dose. A previous study revealed that the mean effective dose for coronary MDCT was significantly higher than that for CCA (31). Dill et al reported that the mean effective dose for 16-slice coronary MDCT is 2.1 times higher than that for CCA in the patients with bypass grafts (32). They described the cause of MDCT's higher radiation dose in bypass patients as the increased length to the through-plane (z-axis), which is particularly needed in patients with IMA grafts. Therefore, for reducing the radiation dose, the ECG-correlated tube current modulation and a reduced tube voltage can be applied (33). Otherwise, image acquisition by prospective ECG-triggering can reduce the radiation exposure while maintaining the diagnostic performance of retrospective ECG-gated MDCT (34).

Evaluating the blood flow is limited with MDCT, which is unlike that for coronary angiography, and the MDCT results for this can be misleading. After CABG, there may be competitive blood flow when an arterial grafts is used to bypass a coronary artery that has only moderate proximal stenosis (35). Alterations in the flow patterns in the graft occur during competitive flow and the total graft flows are notably decreased during competitive flow (36). According to these phenomena, the patent graft can be rated as stenosed or occluded on MDCT. Actually, in one of the false positive case in this study, there was competitive blood flow between the LI-MA graft and the LAD. So, the LIMA graft was presumed to be stenosed on MDCT. Because an arterial graft's patency decreases as the coronary competitive flow increases (37), another limitation of coronary MDCT is that it cannot detect the competitive flow. Further, beam hardening artifacts caused by surgical clips or previously inserted stents in the neighboring native vessels can distort the images of 64-slice MDCT.

The limitations of our study need to be addressed. First, the number of patients included in this study was quite small. The lack of hemodynamically significant stenosis in this series is responsible for the relatively low sensitivity and the low positive predictive value. Second, there may be a selection bias in this study. Because the patients with arrhythmia and severe respiratory difficulty were not included in this study, good or adequate image quality was achieved in all the examinations and MDCT showed results that were comparable to CCA. However, our current study is worthy of note because it was performed in the early postoperative setting with using 64-slice MDCT.

Many problems such as respiratory difficulty and a fast, irregular cardiac rhythm are present during the early recovery period after CABG. Although a small number of patients were studied, 64-slice MDCT achieved favorable diagnostic imaging quality and it showed high diagnostic accuracy and a high negative predictive value as compared the standard invasive CCA. In conclusion, coronary 64-slice MDCT allows physicians to reliable evaluate bypass grafts and the distal arteries, and it can exclude the presence of significant bypass graft failure in the postoperative patients. A future study with a larger population of CABG patients will be needed to further evaluate the value of performing postoperative MDCT angiography for assessing graft patency.

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64절편 MDCT를 이용한 관상동맥우회이식편의 수술 후 초기 평가[1]

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목적: 본 연구의 목적은 관상동맥우회술(coronary artery bypass graft, CABG) 후 한 달 이내의 초기 관상동맥 이식편을 평가하는 방법으로 고식적 관상동맥 조영술과 64-다절편 전산화 단층촬영의 정확도를 비교하고자 하였다.

대상과 방법: 24명의 환자가 이식편을 평가하기 위하여 수술 후 15일 이내에 고식적 관상동맥 조영술과 64-다절편 전산화단층촬영을 모두 시행 받았다. 총 65개(정맥이식편 20개, 동맥이식편 45개)의 이식편과 67개의 문합원위부 혈관이 본 연구의 분석에 포함되었다. 64-다절편 전산화 단층촬영으로 이식편과 문합원위부혈관에 의미 있는 협착이나 폐쇄 소견이 있는지를 평가하고, 고식적 관상동맥 조영술과 그 소견을 비교하였다.

결과: 고식적 관상동맥 조영술 상, 분석에 포함된 총 65개의 이식편 중, 62개의 이식편은 개통성이 좋았으나, 3개의 이식편이 의미있는 협착 또는 폐쇄를 보였다. 64-다절편 전산화 단층촬영상, 62개의 개통된 이식편 중 60개는 고식적 관상동맥 조영술과 그 소견이 일치하였다. 또한, 의미 있는 협착 또는 폐쇄를 보인 3개의 이식편 중 한 개의 이식편은 전산화단층촬영에서 협착이 보이지 않았다. 민감도, 특이도, 양성예측도와 음성예측도는 각각 67%, 97%, 50%, 98%였으며, 진단적 정확도는 97%였다. 전산화단층촬영상, 문합원위부혈관의 협착은 모두 발견되었다.

결론: 관상동맥우회술 후 초기 이식혈관을 평가할 때 64-다절편 전산화단층촬영이 유용한 대체 검사방법이 될 것으로 기대된다.