Early angiographic evaluation after off-pump coronary artery bypass grafting

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Objectives: One of the potential drawbacks of off-pump coronary artery bypass is reduced patency compared with conventional coronary artery bypass. This study examined the systematic angiographic evaluation after off-pump coronary artery bypass.

Methods: Of the 1604 consecutive patients who underwent off-pump coronary artery bypass over 6 years, 1422 (89%) who underwent postoperative angiography were analyzed. Generalized estimating equations logistic analyses were used to investigate potential predictors of graft failure (FitzGibbon B or O).

Results: Bilateral internal thoracic arteries were used in 78% of the patients. The mean number of distal anastomoses was 3.7 ± 1.2 . The in-hospital mortality rate was 0.4%. Recipient coronary diameter less than 1.5 mm (odds ratio [OR], 1.62; 95% confidence interval [CI], 1.24-2.11) was an independent predictor of graft failure, whereas percent stenosis diameter greater than 75% (OR, 0.71; 95% CI, 0.53-0.93), sequential graft (OR, 0.69; 95% CI, 0.51-0.94), and left main disease (OR, 0.72; 95% CI, 0.53-0.96) were protective factors. In the sub-analyses for each conduit, percent stenosis diameter was protective against left internal thoracic artery failure (OR, 0.61), whereas smaller recipient coronary diameter was associated with right gastroepiploic artery and saphenous vein graft failure (OR, 2.37 and 2.36, respectively). Left circumflex artery was associated with gastroepiploic artery graft failure, whereas sequential graft was again protective for the gastroepiploic artery (OR, 4.39 and 0.33, respectively).

Conclusions: Smaller coronary diameter would be a predictor of graft failure, whereas percent stenosis diameter greater than 75%, sequential graft, and left main disease would be protective factors for off-pump bypass grafts. (J Thorac Cardiovasc Surg 2013;146:1119-25)

Considerable knowledge has been accumulated since off-pump coronary artery bypass (OPCAB) gained resurgent interest among cardiac surgeons. However, contrary to surgeons' expectations, major outcomes have not been demonstrated to be better with OPCAB than with conventional coronary artery bypass (CCAB).^{1,2} Several studies³ showed that patients undergoing OPCAB experienced reintervention more frequently at follow-up than those undergoing CCAB. Reduced patency in OPCAB may, in part, account for the higher rate of reintervention at follow-up, because OPCAB is a more technically demanding procedure than CCAB.⁴ Although some investigators¹ reported equivalent patency rates for OPCAB and CCAB, 2 randomized controlled studies^{2,5}

have shown that OPCAB was associated with an increased risk of graft failure than CCAB. Shroyer and colleagues⁵ demonstrated that the patency rate of the OPCAB arm was lower than that of the on-pump arm on 12-month angiography, and the 1-year composite adverse outcome rate (death from any cause, nonfatal myocardial infarction, and any reintervention procedure) was higher for OPCAB than for CCAB. Several meta-analyses concerning graft patency also showed similar results.⁴

Graft failure is one of the major determinants of clinical prognosis.⁶ However, the optimal graft choice for OPCAB has not been determined, and, at present, it is derived from extrapolation of the previous findings in CCAB.⁷ High patency rates of arterial conduits at long-term follow-up have been well described in the literature, and attrition seems to be limited to within a few months after the operation.⁸ Thus, the early patency of off-pump bypass grafts needs to be evaluated. This study was conducted to examine the findings of the systematic angiographic evaluation done after OPCAB surgery to identify predictors of graft failure.

MATERIALS AND METHODS

Study Design

This was a database study based on Kokura Memorial Hospital patients' medical records. The primary objective of this study was to identify the independent predictors of graft failure on the basis of the postoperative

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Abbreviations and Acronyms

BITA	= bilateral internal thoracic artery
CCAB	= conventional coronary artery bypass
CI	= confidence interval
LAD	= left anterior descending
LCx	= left circumflex
LITA	= left internal thoracic artery
GEA	= gastroepiploic artery
GEE	= generalized estimating equation
MDCT	= multidetector computed tomography
OPCAB	= off-pump coronary artery bypass
OR	= odds ratio
RCA	= right coronary artery
SVG	= saphenous vein graft

angiography. In the subanalyses, risk factors for failure of each conduit were explored. This study was approved by the Kokura Memorial Hospital Institutional Review Board, with patient consent waived.

Patients

From January 2000 to December 2005 inclusive, 1604 consecutive patients underwent isolated OPCAB by a single surgeon at Kokura Memorial Hospital. Of these, 1521 patients (95%) underwent systematic angiographic evaluation by means of catheter-based angiography (1422 patients, 89%) or multidetector computed tomography (MDCT; SOMATOM Sensation 16; Siemens AG, Munich, Germany; 99 patients, 6%) before discharge. Because 16-detector row CT has some limitations (eg, lower spatial and temporal resolution), patients who underwent catheter-based angiography comprised the study cohort. Perioperative data were collected prospectively and entered into the institutional database. The definitions of data concerning baseline characteristics conformed to those reported in the European System for Cardiac Operative Risk Evaluation.⁹ The definitions of perioperative factors were delineated previously.¹⁰

Target territories were defined as the left anterior descending (LAD) artery, left circumflex (LCx) artery, or right coronary artery (RCA) on the basis of their anatomy. Percent stenosis diameter was qualitatively assessed by the operating surgeon and dichotomized as greater than 75% or 75% or less in this study.¹¹ Recipient vessel diameter was determined from an assessment at surgery by means of 1.0-, 1.5-, or 2.0-mm probe insertion.

Surgical Technique

OPCAB was the intended procedure, except for patients with acute myocardial infarction who were in a hemodynamically unstable state even with an intra-aortic balloon pump. There were 77 patients who underwent intended CCAB during the study period. Approximately half of them were in a hemodynamically unstable condition, even with an intra-aortic balloon pump; the remaining patients had previous cardiac surgery and required cardiopulmonary bypass for re sternotomy and exposure. All OPCAB procedures were performed under general anesthesia with pulmonary artery pressure monitoring. The heart was approached via median sternotomy. Heparin (100 KIU/kg and an additional dose) was administered to achieve and maintain the activated clotting time at more than 250 seconds. Graft selection was based on the following strategies: (1) Patients with significantly stenosed ($\geq 75\%$) multivessel disease involving the left coronary arteries received bilateral internal thoracic arteries (BITAs); (2) for the left coronary arteries with less than 75% stenoses, saphenous vein grafts (SVG) or radial arteries were used as additional conduits; (3) for less than 75% and 75% or more stenosed RCAs, SVG and right

gastroepiploic arteries (GEAs) were used, respectively. Internal thoracic arteries and GEAs were harvested in a skeletonized fashion using an ultrasonic scalpel (Harmonic Scalpel; Ethicon Endo-Surgery, CVG, Cincinnati, OH) by trained surgeons. Diluted papaverine hydrochloride (1:20) was injected into the arterial conduits from the distal end. The conduits were wrapped in a papaverine-soaked gauze until anastomoses. SVG and radial arteries were dissected using the conventional open harvest technique. SVG was gently dilated by injection of heparin-added blood.

The left internal thoracic artery (LITA) was usually anastomosed to the LAD region, and the right internal thoracic artery (RITA) was anastomosed to the LCx via the transverse sinus. When the RITA was not long enough to reach the LCx system, (1) the proximal portion of the RITA was cut and anastomosed to the side of the LITA graft in a Y-shaped fashion as a composite graft (30% of RITA anastomoses) or (2) the pedicled RITA was directed to the LAD system, whereas the LITA was anastomosed to the LCx system (14% of RITA anastomoses). The choice of BITA configurations was based on the surgeon's preference. Heart positioning was achieved with the help of deep pericardial sutures, suction-type devices (Octopus system, Medtronic, Inc, Minneapolis, Minn; and Acrobat SUV system, Guidant Corporation-Cardiac Surgery, Santa Clara, Calif), and table tilting. Of the sequential grafts, the distal anastomosis was done in end-to-side fashion. Side-to-side anastomoses were made in a diamond shape for SVGs and in a parallel fashion for the arterial grafts. Endarterectomy was performed if a coronary artery had long, calcified plaque. Proximal anastomoses of SVGs and radial arteries were made under a single tangential clamp. When the ascending aorta was not eligible for clamping, proximal anastomotic devices were applied (Symmetry Aortic Connector System, St Jude Medical, Inc, St Paul, Minn; and PAS-Port System, Cardica, Redwood City, Calif).¹² Grafts were intraoperatively evaluated with flowmetry (CardioMeds; Medi-Stim, Oslo, Norway) to detect bypass dysfunction, although the data were not recorded in our database. Intraoperative decisions (eg, re-anastomosis) were made on the basis of the results of the flowmetry. Heparin was reversed with a half-reversal dose of protamine sulfate after completion of all anastomoses. Subcutaneous heparin at a dose of 100 KIU/kg was given twice per day on postoperative days 1 to 4 in every patient to prevent postoperative stroke.¹² Oral aspirin (100 mg) was started on postoperative day 1 and continued thereafter. Other antiplatelets (eg, clopidogrel) were not used.

Angiographic Evaluation

Catheter-based angiography was performed before discharge in the patients, all of whom provided their written informed consent. Postoperative angiography was performed as routine evaluation and is standard of care in Japan. Patients with cerebrovascular disease, renal dysfunction, or respiratory failure were excluded for clinical reasons (83 patients). Most patients underwent angiography within 2 weeks after surgery. The experienced interventional cardiologists who performed angiography reviewed the results. Both native coronary arteries and conduits were selectively visualized, and in at least 2 orthogonal views, the conduit was reviewed and scored on the worst appearance of the proximal anastomosis, body of the conduit, and distal anastomosis according to the FitzGibbon classification.⁶ When grafts could not be selectively intubated, an aortogram or a subclavian arteriogram was obtained. Each anastomosis was analyzed separately. A string sign was recorded as FitzGibbon grade B. A patent graft was defined as a graft without 50% or greater stenosis (ie, FitzGibbon A).

Statistical Analysis

Continuous data are expressed as means ± 1 standard deviation or medians (interquartile range), and categorical variables are expressed as numbers (proportions). Because the graft patency of multiple anastomoses within a patient cannot be assumed to be independent,¹³ generalized estimating equation (GEE) logistic analyses were used to evaluate the influence of the potential predictors (Main Analysis).¹⁴ An event was defined as FitzGibbon grade B or O. The working correlation matrix was set to

exchangeable, and the robust variance estimators were adopted for constructing confidence intervals (CIs) of the odds ratios (ORs). Model variables used in the multivariable analyses were selected a priori on the basis of the previous reports.^{15,16} Grafting techniques also were included in the model on the presumption that these were clinically relevant. The following 20 factors were included in the analysis: age (>75 years), sex (female), New York Heart Association classification (≥ 3), recent myocardial infarction (within 90 days), left ventricular ejection fraction (<50%), chronic renal failure (creatinine >200 $\mu\text{mol/L}$), hypertension, hypercholesterolemia, diabetes mellitus, left main disease ($\geq 50\%$), extracardiac arteriopathy, previous cardiac surgery, emergency, operator's experience (first 100 consecutive cases), percent stenosis diameter (>75%), recipient coronary diameter (<1.5 mm), number of anastomoses (continuous), conduits (LITA, RITA, GEA, SVG, and radial artery), territories (LAD, LCx, and RCA), and grafting techniques (sequential, composite, and endarterectomy). In the subanalyses for each conduit, cases with exceptional anastomoses (eg, GEA-LAD anastomosis) were excluded from the GEE models. Subanalysis for the radial artery graft was not performed because there were only 76 radial artery anastomoses (1.4% of all anastomoses). All analyses were performed using SAS version 9.2 (SAS Institute, Inc, Cary, NC). All *P* values quoted are 2-sided.

RESULTS

Patients' Characteristics and Operative Results

The patients' baseline and perioperative characteristics are shown in Tables 1 and 2. Univariate analyses for graft occlusion revealed estimates of naïve ORs by the GEEs. The patients' average age was 68 ± 9 years; 20% of the patients were aged more than 75 years (75% were male, 25% were female). Left main disease 50% or greater was present in 44% of patients. The mean number of distal anastomoses was 3.7 ± 1.2 . BITA grafts were used in 78% of patients, and SVGs were used in 41% of patients. Sequential grafting was performed in 76% of patients. Of the 5262 anastomoses, 63% had proximal stenoses greater than 75%. The recipient coronary diameter was less than 1.5 mm in 35% of anastomotic sites. Postoperative morbidity included perioperative myocardial infarction in 33 patients (new Q-wave and creatine kinase-myocardial band >50 IU/L), low output syndrome in 7 patients, new-onset atrial fibrillation in 370 patients, stroke in 8 patients, renal failure necessitating dialysis in 18 patients, and prolonged ventilation (>48 hours) in 42 patients. Operative (within 30 days) and in-hospital mortality were 0.1% and 0.4%, respectively.

Angiographic Evaluation: Main Analysis

Table 3 shows the distribution and patency rate for each graft (FitzGibbon A). The patency rates of the LITA and RITA grafts were comparable (95.6% and 95.5%, respectively), whereas those of the SVG in the LCx and RCA systems were slightly lower (92.4% and 92.9%, respectively). The patency rate of the GEA grafts when used in the LCx system was markedly low (86.7%); there were only 60 anastomoses with this configuration.

By using the GEE logistic model, 4 variables were found to be independent predictors of overall graft fate (ie, failure or patency; Table 4). Recipient coronary diameter less than

TABLE 1. Preoperative characteristics

Variable	Total, N = 1422 No. (%)	Univariate analysis*		
		OR	95% CI	P value
Age (y)	68 $\pm$ 9			
Age > 75 y	290 (20)	1.39	1.02-1.90	.039
Female sex	379 (25)	1.45	1.08-1.95	.014
NYHA class ≥ 3	265 (19)	0.88	0.62-1.25	.468
Unstable angina	318 (22)	0.81	0.57-1.16	.256
Emergency	109 (8)	0.86	0.50-1.48	.582
Previous MI	614 (43)	0.99	0.75-1.30	.924
Recent MI (<90 d)	140 (10)	1.21	0.76-1.82	.371
LV dysfunction				
Fair (LVEF > 50%)	1093 (77)	Reference		
Moderate	299 (21)	0.75	0.52-1.07	.113
(LVEF 30%-50%)				
Poor (LVEF < 30%)	30 (2)	0.93	0.38-2.25	.865
Diseased vessels				
1- or 2-vessel disease	450 (32)	Reference		
3-vessel disease	972 (68)	1.20	0.58-2.48	.518
Left main disease	619 (44)	0.69	0.51-0.91	.010
Previous PCI	619 (44)	0.97	0.73-1.28	.815
Previous cardiac surgery	33 (2)	1.64	0.81-3.35	.172
CRF (creatinine > 200 $\mu\text{mol/L}$)	94 (7)	0.61	0.31-1.19	.145
ESRF on dialysis	70 (5)			
Diabetes mellitus	659 (46)	1.04	0.79-1.38	.771
Taking insulin	163 (11)			
Hypertension	951 (67)	0.93	0.70-1.23	.601
Hypercholesterolemia	793 (56)	1.07	0.81-1.42	.635
COPD	36 (3)	1.16	0.60-2.26	.658
Extracardiac arteriopathy	296 (21)	0.85	0.61-1.19	.350
CVA	240 (17)	1.04	0.71-1.51	.837

OR, Odds ratio; CI, confidence interval; NYHA, New York Heart Association; MI, myocardial infarction; LV, left ventricle; LVEF, left ventricular ejection fraction; PCI, percutaneous coronary intervention; CRF, chronic renal failure; ESRF, end-stage renal failure; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident. *Univariate analysis for graft occlusion. Estimates of naïve ORs by the GEEs.

1.5 mm was a risk factor for graft failure (OR, 1.62; 95% CI, 1.24-2.11), whereas percent stenosis diameter greater than 75% (OR, 0.71; 95% CI, 0.53-0.93), sequential graft (OR, 0.69; 95% CI, 0.51-0.94), and left main disease (OR, 0.72; 95% CI, 0.53-0.96) protected against graft failure. Other baseline variables, such as LVEF and diabetes mellitus, or operative factors such as type of conduit and target territory, were not associated with graft failure in the multivariable analysis. Although the patency rate of those patients with coronary endarterectomy was relatively low (82.1%), this technique was not associated with graft failure.

Angiographic Evaluation: Subanalysis for Each Conduit

For LITA grafts, percent stenosis diameter greater than 75% was the only predictor of patency (OR, 0.61; 95% CI, 0.40-0.94; Table 5). None of the variables were

TABLE 2. Perioperative characteristics

Variable	Total, N = 1422	Univariate analysis*		
	No. (%)	OR	95% CI	P value
First 100 cases	90 (6)	0.92	0.53-1.60	.765
No. of anastomoses	3.7 ± 1.2	1.01	0.88-1.16	.853
Incomplete revascularization	187 (13)	0.89	0.57-1.39	.607
Conversion to CCAB	4 (0.3)	—	—	—
Operation time (min)	288 ± 72	1.13	1.01-1.27	.032
Conduit				
LITA	1365 (96)	Reference		
RITA	1083 (76)	1.04	0.73-1.48	.836
GEA	476 (33)	1.27	0.82-1.95	.285
SVG	586 (41)	1.68	1.17-2.43	.005
Radial artery	47 (3)	0.95	0.29-3.11	.936
Territory				
LAD	1400 (98)	Reference		
LCx	1237 (87)	1.20	0.87-1.65	.273
RCA	962 (68)	1.39	0.99-1.94	.056
Grafting technique				
Sequential graft	1076 (76)	0.80	0.61-1.04	.099
Composite graft	345 (24)	1.36	0.91-2.04	.128
Endarterectomy	31 (2)	2.23	0.65-7.68	.202
Proximal anastomotic devices	83 (5)	0.46	0.20-1.06	.068
Recipient coronary (N = 5262)				
Stenosis >75%	3293 (63)	0.73	0.56-0.95	.019
Diameter <1.5 mm	1860 (35)	1.61	1.25-2.09	<.001
<1.0 mm	21 (0.4)			
1.0 mm	2462 (47)			
1.5 mm	2613 (50)			
>1.5 mm	166 (3)			
Max CK-MB IU/L (N = 1402)	13 (8.6-24)†	1.02	1.00-1.03	.026
CK-MB > 50 IU/L	148 (10)	1.66	1.12-2.47	.012
Mortality				
Operative (within 30 d)	1 (0.1)			
In-hospital	5 (0.4)			

OR, Odds ratio; CI, confidence interval; CCAB, conventional coronary artery bypass; LITA, left internal thoracic artery; RITA, right internal thoracic artery; GEA, gastroepiploic artery; SVG, saphenous vein graft; LAD, left anterior descending; LCx, left circumflex; RCA, right coronary artery; CK-MB, creatine kinase-myocardial band isoenzyme. *Univariate analysis for graft occlusion. Estimates of naïve ORs by the GEEs. †Median (interquartile range).

associated with RITA graft failure. Smaller recipient coronary diameter (<1.5 mm) showed a trend to correlate with GEA graft and SVG failure (OR, 2.37 and 2.36; 95% CI, 1.08-5.20 and 1.32-4.19, respectively). Of note, the LCx system was a predictor of GEA graft failure (OR, 4.39; 95% CI, 1.66-11.61), whereas sequential graft was a protective factor for GEA graft patency (OR, 0.33; 95% CI, 0.15-0.70).

Patients Who Did Not Undergo Angiography

Among the patients who did not undergo postoperative angiography, all but 1 had no sign of ischemia during the

TABLE 3. Graft distribution and patency rate

Conduit	Territory	Total no.	FitzGibbon			Patency rate†
			A	B*	O	
LITA	LAD	1925	1841	70 (13)	14	95.6%
	LCx	227	218	7 (1)	2	96.0%
	RCA	4	2	0	2	50.0%
	Total	2156	2061	77 (14)	18	95.6%
RITA	LAD	231	220	10 (1)	1	95.2%
	LCx	1145	1093	31 (3)	21	95.5%
	RCA	37	36	1	0	97.3%
	Total	1413	1349	42 (4)	22	95.5%
GEA	LAD	7	7	0	0	100%
	LCx	60	52	2	6	86.7%
	RCA	585	557	16 (3)	12	95.2%
	Total	652	616	18 (3)	18	94.5%
SVG	LAD	88	84	3	1	95.5%
	LCx	288	266	4	18	92.4%
	RCA	588	546	16 (1)	26	92.9%
	Total	964	896	23 (1)	45	92.9%
Radial artery	LAD	4	4	0	0	100%
	LCx	49	48	1	0	98.0%
	RCA	23	21	1	1	91.3%
	Total	76	73	2	1	96.1%

LITA, Left internal thoracic artery; LAD, left anterior descending; LCx, left circumflex; RCA, right coronary artery; RITA, right internal thoracic artery; GEA, gastroepiploic artery; SVG, saphenous vein graft. *Numbers in parentheses represent string sign. †FitzGibbon A.

hospital stay. One death occurred in a 69-year-old woman. Vasospasm of the radial artery graft was suspected to be the cause.

Postangiography Outcomes

Eight patients (0.6%) experienced complications of postoperative angiography: limb thrombosis in 2 patients, ventricular arrhythmia in 1 patient, dissection of the aorta in 1 patient, transient ischemic attack in 2 patients, and cerebral infarction in 2 patients. The 2 patients with cerebral infarction showed neurologic dysfunction, but all 8 patients were discharged.

Of the 216 patients with at least 1 suboptimal graft (FitzGibbon B or O), 25 underwent repeated interventions as staged procedures (24 percutaneous coronary interventions and 1 surgery) after scintigraphy.

DISCUSSION

One of the possible drawbacks of OPCAB surgery is reduced patency compared with CCAB.^{2,4,5} Graft failure is relevant to the clinical prognosis of patients undergoing CCAB,⁶ and it is logical to think that this association may fit the OPCAB cohort. Many studies have been published concerning graft patency in CCAB. However, few reports have specifically dealt with this issue in OPCAB surgery.¹⁷ In addition, the results from these studies should be interpreted cautiously, because few of them took clustering into account,^{1,17} and the findings of most studies were derived from symptom-driven angiography.

TABLE 4. Multivariable analysis: Predictors of graft occlusion (FitzGibbon B or O)

Variable	OR	95% CI	P value
Age > 75 y	1.37	0.98-1.90	.064
Female sex	1.24	0.91-1.68	.183
NYHA class $\geq$ 3	0.89	0.60-1.35	.592
Recent MI (<90 d)	1.25	0.82-1.91	.301
LVEF < 50%	0.79	0.56-1.12	.181
CRF	0.67	0.34-1.33	.253
Hypertension	0.93	0.69-1.25	.627
Hypercholesterolemia	1.07	0.79-1.44	.668
Diabetes mellitus	1.06	0.79-1.40	.712
Left main disease	0.72	0.53-0.96	.028
Extracardiac arteriopathy	0.86	0.61-1.22	.401
Previous cardiac surgery	1.25	0.57-2.75	.580
Emergency	0.88	0.48-1.61	.683
First 100 cases	1.00	0.58-1.73	.995
Recipient coronary			
Stenosis > 75%	0.71	0.53-0.93	.013
Diameter < 1.5 mm	1.62	1.24-2.11	<.001
No. of anastomoses	1.04	0.89-1.21	.618
Conduit			
LITA	Reference		
RITA	0.75	0.45-1.26	.275
GEA	1.16	0.57-2.38	.684
SVG	1.37	0.78-2.40	.275
Radial artery	0.70	0.20-2.48	.579
Territory			
LAD	Reference		
LCx	1.06	0.69-1.61	.805
RCA	0.88	0.48-1.60	.668
Grafting technique			
Sequential graft	0.69	0.51-0.94	.018
Composite graft	1.61	0.98-2.62	.058
Endarterectomy	1.96	0.62-6.24	.254

OR, Odds ratio; CI, confidence interval; NYHA, New York Heart Association; MI, myocardial infarction; LVEF, left ventricular ejection fraction; CRF, chronic renal failure; LITA, left internal thoracic artery; RITA, right internal thoracic artery; GEA, gastroepiploic artery; SVG, saphenous vein graft; LAD, left anterior descending; LCx, left circumflex; RCA, right coronary artery.

In 1604 consecutive patients who underwent OPCAB, 89% received systematic catheter-based angiography before discharge. GEE logistic analysis was performed to identify the independent predictors of graft failure, and percent stenosis diameter (>75%), recipient coronary diameter (<1.5 mm), sequential graft, and left main disease were found to be predictors.

Percent Stenosis Diameter

When arterial grafts are used to bypass a low-grade stenosis, competitive flow may increase from the native coronary vessel.¹⁸ Several authors also noted an association between decreased severity of stenosis and frequency of the string sign.¹¹ Miwa and colleagues¹⁹ reported that the string sign of patent radial arteries was a consequence of competitive flow. The current authors and Desai and colleagues¹⁵

have speculated that arterial remodeling to maintain shear stress against the endothelium in the setting of low flow may lead to graft failure.

Recipient Coronary Diameter

Desai and colleagues¹⁵ noted that the distal run-off was strongly correlated with the size of the distal target vessel. Similar to percent stenosis diameter, recipient coronary diameter is deemed to influence the flow through the bypass conduits. Grafting small target vessels may be more technically demanding, especially on the beating heart. On the basis of the results of the subanalysis of each conduit (Table 5), an internal thoracic artery conduit could be expected to have excellent patency for the left coronary arteries even with small target-vessel size.

Sequential Graft

Sequential graft was revealed to be a determinant of graft patency. The primary advantages of this technique include a higher blood flow through the sequential graft than through the individual graft.²⁰ Intraoperative velocity studies showed a higher velocity of blood flow in the sequential graft.²¹ Although a sequential graft may be technically difficult in OPCAB surgery, several authors have reported excellent results.²²

Left Main Disease

The reason why left main disease served as a protective factor for graft patency was not identified from this retrospective study. When the study cohort was divided as to the sides of the coronary arteries grafted (left or right), left main disease was associated with graft patency in the left coronary arteries, not in the RCAs (data not shown). This result may imply that left main disease, in addition to percent stenosis diameter, decreased the risk of competitive flow. It is also conceivable that patients who have significant left main disease are good candidates for not only CCAB²³ but also OPCAB surgery. However, noncritical, isolated left main stenosis may cause competitive flow. Relationships between graft patency in OPCAB surgery and left main disease (eg, ostial, mid-shaft, and noncritical lesions) need to be evaluated in the future.

Subanalysis: Left Internal Thoracic Artery

In our subanalyses, less severe percent stenosis diameter was associated with LITA graft failure. Doppler studies suggested that severity of stenosis is associated with flow and size of the LITA graft.¹⁸ However, adaptive shrinkage of the arterial conduits may be reversible as the native coronary stenosis progresses.

Subanalysis: Gastroepiploic Artery

Recipient coronary diameter influenced the patency of the GEA. The GEA may be more susceptible to having

TABLE 5. Subanalysis of each conduit

Variable	LITA			RITA			GEA			SVG		
	OR	95% CI	P	OR	95% CI	P	OR	95% CI	P	OR	95% CI	P
Recipient coronary												
Stenosis > 75%	0.61	0.40-0.94	.025	0.77	0.45-1.31	.331	0.91	0.93-2.11	.826	0.96	0.53-1.73	.878
Diameter < 1.5 mm	1.14	0.71-1.82	.591	1.65	0.98-2.80	.061	2.37	1.08-5.20	.032	2.36	1.32-4.19	.004
Territory												
LAD	Reference			1.22	0.66-2.25	.531	—	—	—	—	—	—
LCx	0.85	0.37-1.97	.706	Reference			4.39	1.66-11.61	.003	1.25	0.70-2.26	.449
RCA	—	—	—	—	—	—	Reference			Reference		
Grafting technique												
Sequential graft	0.99	0.59-1.67	.968	0.94	0.53-1.69	.845	0.33	0.15-0.70	.004	0.76	0.41-1.40	.375
Composite graft	—	—	—	0.86	0.44-1.72	.676	—	—	—	1.46	0.64-3.30	.369
Endarterectomy	—	—	—	—	—	—	—	—	—	3.45	0.75-15.88	.111

LITA, Left internal thoracic artery; RITA, right internal thoracic artery; GEA, gastroepiploic artery; SVG, saphenous vein graft; OR, odds ratio; CI, confidence interval; LAD, left anterior descending; LCx, left circumflex; RCA, right coronary artery.

a contractile response in the low-flow situation than the LITA because of their different histologic characteristics.²⁴ We preferentially used the GEA grafts for the RCA system with severe stenosis (>75%). This may partly explain the reason why recipient coronary diameter, not percent stenosis diameter, influenced GEA patency. On the other hand, a sequential graft seems advantageous with GEA grafts, as shown in the subanalysis (Table 5). This technique may help increase the graft flow.

The LCx system was associated with graft failure. In our experience, by harvesting in a skeletonized fashion, the GEA grafts could reach the LCx in some cases. The higher failure rate of this configuration may be attributed to spasm of the distal portion of the GEA and tension on the graft. We have abandoned this configuration and adopted the SVG and the RITA for mild and severe lesions of the LCx, respectively.

Subanalysis: Saphenous Vein Graft

SVG failure was associated with smaller recipient coronary diameter. Goldman and colleagues¹⁶ reported that the smaller diameter of the recipient vessel was a determinant in both early and long-term vein graft patency. Schwartz and colleagues²⁵ noted that the SVG was a risk factor for graft occlusion in the Bypass Angioplasty Revascularization Investigation study, whereas the type of conduit was not associated with graft patency in our series. This discordance may be, in part, ascribed to routine heparin use.¹² Presumably, an increase in coagulability may account for the early graft occlusion. Therefore, we believe that high-risk patients may require aggressive anticoagulation in addition to antiplatelet therapy after OPCAB.

In 83 cases, proximal anastomotic devices were applied. We previously reported that the early patency rate of these SVGs was 100%.¹² As a result, these devices did not adversely influence the graft patency in this study.

Study Limitations

First, percent stenosis diameter was derived from qualitative assessment by one observer. Other investigators drew conclusions similar to ours in that small target vessel size adversely affected graft patency, although the size of the target vessel was derived from single-observer visual assessment at the time of patient enrollment and not quantitative angiography.¹⁵ Second, all procedures were performed by a single surgeon, and the results of the angiography were derived from the OPCAB surgery on the basis of our grafting strategy, limiting the generalizability of these results. Third, catheter-based angiography was performed in only 89% of the consecutive patients, because MDCT took the place of catheter-based angiography after 2 patients experienced cerebral infarction. Because 16-detector row CT has some limitations (eg, lower spatial and temporal resolution), patients who underwent MDCT were omitted from the study cohort. In addition, the angiography results were read by several cardiologists. Fourth, we did not evaluate long-term patency rates. However, we agree with Goldman and colleagues¹⁶ in that initial patency at 1 week after surgery is an important predictor of long-term graft patency. Fifth, we could not compare the angiographic results between OPCAB and on-pump coronary artery bypass grafting, because only 77 patients underwent on-pump coronary artery bypass grafting in Kokura Memorial Hospital (Kokura, Japan) during the study period. Sixth, we cannot reach any conclusions regarding the radial artery graft because of the small sample size. Finally, the quality of the recipient coronary arteries, the size of the conduits, and the flow data were not recorded in our database. Despite these limitations, the findings of this study were derived from the largest angiographic study to date of OPCAB surgery. In addition, the analyses were based on rigorous statistical methodology.

CONCLUSIONS

Severe percent stenosis diameter and small recipient coronary diameter were associated with graft patency in

OPCAB surgery. A better patency rate would be expected when anastomosing the LITA to a coronary artery with severe stenosis. Sequential grafting technique could be expected to improve the patency rates of off-pump bypass grafts, especially for the GEA. Patients with significant left main disease may be good candidates for OPCAB surgery.

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