Statistical Methods

All values are expressed as the mean ± standard deviation. The discrete variables were analyzed with Fisher's exact test between two groups and Kruskal-Wallis rank test for more than three groups. Scheffé's test was performed when a significant difference was recognized in the results of Kruskal-Wallis test. All statistical analyses were performed using the software package SPSS 10.0 for Windows (SPSS Inc., Chicago, IL, USA). The differences were considered statistically significant when the p value was less than 0.05.

Results

Angiographic Study

From 223 (94.9%) patients, informed consent was obtained and follow-up angiography was performed before hospital discharge by cardiologists in our hospital. By means of the Cardiovascular Measurement System (QCA-CMS, version 4.1; Medical Imaging System, Leiden, The Netherlands), the stenotic percentage of anastomosis was calculated by comparing the diameter of anastomosis with that of the proximal portion of the graft at the view of the minimum lumen when stenosis existed. Successful revascularization was defined as a percentage stenosis diameter of the anastomosis of less than 50%.

The success rates of revascularization for coronary distribution, graft materials and anastomotic fashions are shown in Table 5. The overall success rate of revascularization was 97.7% (810/829). Stratifiedly the coronary distribution, the success rate of revascularization was 98.2% in LAD, 96.5% in diagonal (DG), 98.6% in obtuse marginal (OM), 97.4% in posterolateral (PL), 97.6% in posterior descending (PD), and 100% in right coronary artery (RCA). The success rate of revascularization was 98.3% with the left ITA, 98.1% with the right ITA, 98.1% with the RA, and 87.0% with the GEA. The success rate of revascularization was 97.1% with the end-to-side fashion, and 98.9% with the side-to-side fashion. The success rate of revascularization with GEA was significantly lower than that of the other graft materials (left ITA versus GEA, p=0.002, right ITA versus GEA, p=0.009, RA versus GEA, p=0.002).

Five of 269 composite grafts (1.9%) showed kinking or stenosis of the left ITA just proximal to the composite graft anastomosis site with RA. Four of 334 ITAs (1.2%) showed stenosis in the middle of the vessel probably due to intraoperative injury.

Evident flow competition was observed in 36 patients. Of those, 24 RA composite grafts and 12 of the left ITA distal from the anastomotic site of the composite graft to the target coronary artery were not opacified in angiography of in situ graft, although the target coronary artery and its anastomotic site were clearly opacifed in the native coronary angiography.

Early and Late Mortalities and Morbidities

Table 3 lists the early and late complications. Early death occurred in 3 patients (1.3%) due to intracranial bleeding, aspiration pneumonia and intestinal hemorrhage. There was no clinical underperfusion syndrome or new intra-aortic balloon pumping (IABP) insertion although perioperative myocardial infarction (new Q waves in electrocardiogram (ECG), creatinekinase-MB (CK-MB) > 50 with ECG change or CK-MB > 70 without ECG change: normal value <11 IU/l in our institute) occurred in 6 patients (2.6%). Only one patient suffered stroke during the postoperative angiographic study.

Eleven patients underwent successful percutaneous catheter intervention, although they were asymptomatic. The cause of intervention were the obstruction of the left ITA just proximal to the Y-composite graft anastomotic site with the RA in 3 patients, obstruction of the right ITA just proximal to the I-composite graft anastomotic site with the RA in 1 patient, obstruction of the middle of the left ITA in 5 patients, and the native coronary artery of unsuccessful revascularization in 2 patients. One patient received redo OPCAB before discharge due to occlusion of the graft to the LAD.

One patient died suddenly 6 months after the operation due to unknown causes. Two patients whose angiography showed anastomotic stenosis of LAD without symptom returned to the hospital for recurrent angina and performed successful PCI at 5 months after the operation. One patient with poor left ventricular function readmitted for congestive heart failure.

Comments

Complete arterial revascularization using the OPCAB technique is the goal of coronary artery bypass surgery. Revasucularization of the LAD with the ITA is a gold standard because of its long-term advantages. Therefore, the other arterial graft should be used to revascularize the right coronary, diagonal, and circumflex artery territories. Of these territories, the right coronary artery territory can be revascularized with the RA or GEA because the right ITA is usually not long enough to reach. We prefer the RA to the in situ GEA because of the long-term patency of the GEA as reported by Suma et al. was suboptimal.[7] Indeed, the success rate of revascularization with the GEA was significantly lower than that of the other graft materials. Recently, we have used skeletonized GEA using an ultrasonic scalpel to facilitate visual inspection, when the GEA was essential for revascularization.[8] In addition, the RA appears to have advantages over the GEA because it can be harvested while the left ITA is being dissected and laparotomy with its associated morbidity can be avoided. Moreover, the excellent size, length, and handling characteristics make the RA a versatile arterial conduit allowing an uncompromised distal anastomosis beyond any stenosis.

For two major reasons, the RA is now used widely as a composite graft with increasing number of OPCAB operations although it can be used either as a free graft proximally anastomosed to the ascending aorta or as a composite graft anastomosed to the ITA. One reason is the late patency of the arterial free grafts proximally anastomosed to the aorta which is similar to that of the saphenous vein.[9,10] The second is the possibility of perioperative stroke which may occur in OPCAB using free grafts anastomosed to the ascending aorta with partial clamping.[11]

We use the RA emerging as a Y, I, K, T, or X in combination with one or both ITAs.[5] With this approach, arterial revascularization up to 7 coronary targets is possible with maximum graft economy (i.e., two arterial grafts) and reduction of the operative trauma and time.

A potential disadvantage of this approach may result from the fact that coronary bypass flow is totally dependent on the flow of the proximal ITA. Reduction of flow in the left ITA, caused by vasospasm or trauma, may result in a hypoperfusion syndrome with glabal ischemia and its catastrophic consequences.

Multiple clinical and experimental studies have examined the potential ability of the ITA as a blood source of arterial composite graft.[12-17] Markwirth et al.[14] reported that the functional and morphologic adaptability of the LITA was sufficient to meet the higher flow-volume requirements by measurement of the quantitative flow and coronary flow reserve (CFR) of the left ITA in a T graft using a Doppler guidewire. Wendler et al.[16] concluded that the flow reserve of the proximal ITA is adequate for multiple coronary anastomoses irrespective of the choice of the second arterial grafts from the results of flow measurement using a Doppler guidewire at one week and six months after the operation. On the other hand, Sakaguchi et al.[17] stated that positron emission tomography detected a significant difference in the CFR between the arterial composite Y graft group and the independent grafts group. They concluded that the composite Y graft was not as effective as the independent grafts for improving the CFR soon after bypass grafting. However, they mentioned that the clinical importance of the CRF difference between the Y graft and the independent grafts is unclear because the coronary flow reserve in the Y graft group might still be sufficient for revascularization of the left coronary system.

Hypoperfusion syndrome related to the conventional CABG generally occurs typically 30 to 40 minute after discontinuation of cardiopulmonary bypass.[18] It is conceivable that the reactive hyperemia of the myocardium which presents after removal of aortic clamp[19-21], may require greater conduit flow while the oxygen debt is repaid. This situation might produce a drastic imbalance between graft flow and myocardial demand, resulted in the hypoperfusion syndrome.[15,22] Even in our 127 patients whose bypass flow depended on single ITA, the hypoperfusion syndrome was neither detected nor expected, which was reflected by no IABP implantation and low mortality rates in our series.

With our procedure, the LAD was revascuralized at first by the ITA because it was the most important coronary artery which supplies about 50% of the left heart ventricle with blood and exposure of the LAD has no major hemodynamic consequences.[23] After the revasucularization of the LAD, the coronary artery was anastomosed in the order of the diagonal, obtuse marginal, and posterolateral to posterior descending arterial branches with only local ischemia of the target vessel. We believe that these techniques avoiding intraoperative global myocardial ischemia contributed at least partially to avoid the hypoperfusion syndrome in our patients.

It is no wonder that meticulous graft harvesting and precise anastomotic technique are key components in this approach. In our early cases, 9 patients had obstruction of the ITA as a blood source. Of these patients, 2 patients had severe stenosis in the middle of the LITA, although they were asymptomatic. Angiography showed coronary-coronary bypass which might act to avoid global myocardial ischemia (Fig.1). We think that predischarge angiography is important to visualize technical problems that surgeon can learn from and avoid in future operations until enough experience is gained.

The competitive flow between the native coronary artery and bypass graft is another concern in any composite graft attached to the ITA.[24] This phenomenon was induced by graft-receipient artery mismatch. In 38 patients with composite grafts, the target coronary artery and its anastomotic site were clearly opacifed in the native coronary angiography, although the bypass graft to the target coronary artery (i.e., the composite graft or the distal ITA from the connection) was not opacified in angiography of the situ graft. Diffuse narrowing of the distal left ITA, from the anastomotic site of the composite graft, was recognized in 13 patients who had competitive flow in the distal left ITA to the

LAD.However, no ischemia has been detected by stress nuclear imaging or doppler flow reserve measurement in these patients. No definite conclusion has been reached concerning the relationships between the competitive flow, diffuse narrowing, and the true graft failure.[25-29]It still remained to be determined whether a particular coronary artery with non-critical lesion should be grafted prophylactically using the arterial graft for the future progression.[30] We prefer grafting to a coronary artery with mild stenosis in a side-to-side fashion, and the termination of this conduit was to the coronary artery of severe stenosis. When the posterior descending coronary artery had only mild stenosis, we anastomosed the side of the RA composite graft anastomosed to the end of the right ITA to that branch and the end of the RA to the circumflex branches.

In our study, no patient with competitive flow of bypass grafts was readmitted for angina or congestive heart failure. Although late follow-up angiography was performed in only 2 cases with competitive flow of the RA composite graft, the RA was patent at more than 1 year after the operation. These results prompted us to believe that the RA had a possibility to work as a physiologically functional arterial graft that can be recruited on demand of the progression of the native coronary artery disease.

In conclusion, the total arterial OPCAB has provided excellent success rate of revascularization for the total coronary system and showed good clinical results. Consequently, we propose that predischarge angiography is necessary to avoid the potential risk of blood source obstruction until enough experience is gained.These results have inspired us to continue performing complete arterial revascularization, although long-term studies are waiting to provide evidence of the validity to use our technique.

Table 1. Preoperative Characteristics (n=235)

	n	
Age (y)		
Mean	66.2 ± 8.7 (range 42-84)	
65 y and 74 y	99	42%
75 y	45	19%
Male / Female	193 / 42	
LVEF<0.35	40	17%
Preoperative IABP	7	3%
Acute MI	4	2%
Emergency case	7	3%
Reoperation	7	3%
History of PCI	46	20%
Diabetes mellitus	83	35%
Cerebrovascular disease	51	22%
Chronic renal failure	8	3%
Hemodialysis	6	3%
COPD	7	3%
Higgins Score		
Mean	3.3 ± 2.8	
5	61	26%

IABP: intra-aortic balloon pumping, LVEF: left ventricular ejection fractin, MI: myocardial infarction, PCI: percutaneous coronary intervention, COPD: chronic obstructive pulmonary disease

Table 2. Pattern of Blood Sources and Composite Arterial Grafts

	n	No. of Distal Anastomoses	Mean
Single blood source	127 (54%)	439	3.5
LITA + Y-composite	103	349	3.4
LITA + K-composite	19	74	3.9
RITA + Y-composite	4	12	3.0
RITA + K-composite	1	4	4
Double blood source	101 (43%)	403	4.0
In situ LITA RITA + I-composite	16	60	3.8
In situ LITA RITA + Y-composite	19	67	3.5
In situ RITA LITA + Y-composite	9	38	4.2
In situ LITA RITA + X-composite	3	15	5.0
LITA + Y-composite RITA + I-composite	36	141	3.9
LITA + K-composite RITA + I-composite	7	40	5.7
LITA + Y-composite RITA + T-composite	1	6	6
LITA + Y-composite In situ GEA	6	23	3.8
RITA + Y-composite In situ GEA	1	3	3
In situ LITA + in situ RITA	1	3	3
In situ LITA + in situ GEA	2	7	3.5
Triple blood source	7 (3%)	30	4.3
In situ LITA + in situ RITA + in situ GEA	7	30	4.3

LITA: left internal thoracic artery, RITA: right internal thoracicartery, GEA: gastroepiploic artery

Table 3. Bypass Distribution, Graft Material and Anastomotic fashion

	Graft Material									
	LITA		RITA		RA		GEA		Total	
	E-S	S-S	E-S	S-S	E-S	S-S	E-S	S-S	E-S	S-S
LAD	213	1	18	1	1	0	0	0	232	2
DG	6	12	7	0	38	23	0	0	51	35
OM	8	0	2	0	22	40	1	0	33	40
PL	5	4	5	6	91	162	8	1	109	173
PD	0	0	4	0	128	34	9	5	141	39
RCA	0	0	13	1	3	0	0	0	16	1
Total	232	17	49	8	283	259	18	6	582	290

LITA: left internal thoracic artery, RITA: right internal thoracic artery, RA: radial artery, GEA: gastroepiploic artery, E-S: end-to-side anastomosis, S-S: side-to-side anastomosis, DG: diagonal, OM: obtuse marginal, PL: posterolateral, PD: posterior descending, RCA: right coronary artery.

Table 4. Early and Late Results

Early Results	
Hospital mortality	3 (1.3%)
Morbidity	
Perioperative MI	6 (2.6%)
Postoperative IABP	0 (0%)
Early coronary intervention	12 (5.1%)
Reexploration for bleeding	2 (0.8%)
Sternal	
Dehiscence	6 (2.6%)
Infection	0 (0%)
Cerebral infarction	2 (0.8%)*
Renal failure with dialysis	2 (0.8%)
Forearm	
Circulatory injury	0 (0%)
Infection	1 (0.4%)
Paresthesia	0 (0%)
Late Results	
Late death	1 (0.4%)
Cardiovascular event	
Admission for angina or CHF	3 (1.3%)
Coronary intervention	2 (0.8%)
Cerebral infarction	4 (1.7%)

MI: myocardial infarction, CHF: congestive heart failure

*: One occurred during postoperative angiographic study

Table 5. Success Rate of Revascularization forBypass Distribution, Graft Material and Anastomotic fashion

	Graft Material									
	LITA		**RITA**		**RA**		**GEA**		**Total**	
	E-S	S-S	E-S	S-S	E-S	S-S	E-S	S-S	E-S	S-S
LAD	198/201 (98.5%)	1*	17/18 (94.4%)	1*	1*	0	0	0	216/220 (98.2%)	2*
DG	6*	12*	7*	0	34/37 (91.9%)	23*	0	0	47/50 (94.0%)	35*
OM	7/8 (87.5%)	0	2*	0	21	38*	1*	0	31/32 (96.9%)	38*
PL	5*	4*	4*	5	86/89 (96.6%)	148/150 (98.7%)	6/8 (75.0%)	1*	101/106 (95.3%)	158/160 (98.8%)
PD	0	0	4*	0	118/120 (98.3%)	32*	8/9 (88.9%)	4/5 (80.0%)	130/133 (97.7%)	36/37 (97.3%)
RCA	0	0	13*	1*	2*	0	0	0	15*	1*
Total	216/220 (98.2%)	17*	47/48 (97.9%)	7*	262/270 (97.0%)	241/243 (99.2%)	15/18 (83.3%)	5/6 (83.3%)	540/556 (97.1%)	270/273 (98.9%)

*: 100% of success rate

LITA: left internal thoracic artery, RITA:right internal thoracic artery, RA: radial artery, GEA: gastroepiploic artery, E-S: end-to-side anastomosis, S-S: side-to-side anastomosis, DG: diagonal, OM: obtuse marginal, PL: posterolateral, PD: posterior descending,RCA: right coronary artery.

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Legend

Figure 1. left upper circle: The LITA was occluded.

Right upper arrow: Thecoronary-coronary bypass (The left anterior descending artery was supplied from theobtuse marginalbranch through the radial artery composite graft.)

left and right lower PCI was performed successfuly.