A. Administrative

Participant ID: ....

Hospital name: ....

B. Demographics

Date of Birth: 19...... / ...... (yyyy/mm)

Gender: ○ Male ○ Female

C. Baseline status of Diabetes

Treatment: ○ None ○ Diet ○ Oral ○ Insulin

HbA1c : .... %

Duration of Diabetes: ....years ......months

Medication: ....

Nephropathy: ○ No ○ Yes

Retinopathy: ○ none ○ NPDR ○ PDR

D. Risk Factors

Weight: .... kg Height: .... cm BMI: (Auto Calculation)

CTR: .... %

Smoker: ○ No ○ Yes → Current Smoker: ○ No ○ Yes

Family History of CAD: ○ No ○ Yes

Anemia: ○ No ○ Yes → Hb: ....

Hypercholesterolemia: ○ No ○ Yes

Hypertension: ○ No ○ Yes

Chronic Lung Disease: ○ No ○ Yes → Degree: ○ Mild ○ Moderate ○ Severe

Liver Dysfunction: ○ No ○ Yes

Renal Failure: ○ No ○ Yes →Dialysis: ○ Yes ○ No → BUN: .... Cr: ....

Aortic Aneurysm: ○ No ○ Yes

Peripheral Vascular Disease: ○ No ○ Yes

Cerebrovascular Accident: ○ No ○ Yes →When: ○ Recent (<= 2 weeks) ○ Remote (> 2 weeks)

Cerebrovascular Disease: ○ No ○ Yes → Type: ○ Coma ○ CVA ○ RIND ○ TIA ○ Non Invasive >75%

E. Previous Interventions

Prior Coronary Intervention: ○ No ○ Yes

Thrombolysis: ○ No ○ Yes →Interval: ○ <= 6 hours ○ >6 hours

Previous Cardiac Surgery: ○ No ○ CABG ○ Valve ○ Aortic ○ Others

Cerebrovascular Surgery: ○ No ○ Yes

Peripheral Vascular Surgery: ○ No ○ Yes

F. Cardiac Status

Myocardial Infarction: ○ No ○ Yes
- → When: ○ <=6 hours ○ 1-7 days ○ >21 days ○ >6 hours but <24 hours ○ 8-21 days
- → Rythm: ○ non-Q ○ Q →Q rythm: □ I, aVL □ II, III, aVF □ V1-V3

Congestive Heart Failure: ○ No ○ Yes → CHF history: ○ No ○ Yes

Angina: ○ No ○ Yes → Type: ○ Stable ○ Unstable → Unstable Type: ○ Rest Angina ○ Variant Angina ○ New Class 3 ○ Non-Q MI ○ Recent Accel ○ Post-Infarct Angina

Arrhythmia: ○ No ○ Yes → Type: ○ VF ○ af ○ VT ○ PAT

Classification CCS: ○ 0 ○ I ○ II ○ III ○ IV NYHA: ○ I ○ II ○ III ○ IV

G. Medications

Digitalis: ○ No ○ Yes Beta Blockers: ○ No ○ Yes Nitrates - I.V.: ○ No ○ Yes Anticoagulants: ○ No ○ Yes

Diuretics: ○ No ○ Yes Inotropic Agents: ○ No ○ Yes Steroids: ○ No ○ Yes Aspirin: ○ No ○ Yes

Participant ID: .... Hospital name: .... Gender: ○ Male ○ Female
Date of Birth: 19...... / ......

H. Pre Operative Hemodynamics and Catheterization

Diseased Coronary Vessels: ☐ LMT>50% ☐ LAD ☐ Dx ☐ LCX ☐ RCA

LVG : LVEDVI: .... LVESVI: .... LVEF: .... %
UCG : LVDd: .... LVDs: .... FS: .... %

Aortic Stenosis: ○ No ○ Yes Insufficiency: ○ 0 ○ 1 ○ 2 ○ 3 ○ 4
Mitral Stenosis: ○ No ○ Yes Insufficiency: ○ 0 ○ 1 ○ 2 ○ 3 ○ 4
(None=0, Trivial=1, Mild=2, Moderate=3, Severe=4)

I. Operative

Surgery date: 20...... / ...... (yyyy/mm)
Admission date: 20...... / ...... (yyyy/mm)
Discharge date: 20...... / ...... (yyyy/mm)
Operation time: ...... hours ...... min
Perfusion time: .... min
Cross Clamp time: .... min
Status of the procedure: ○ Elective ○ Urgent ○ Emergent

Memo:

Bypass Grafting:

Number of Distal Anastomoses total: ....
Completeness of Revascularization: ○ complete ○ incomplete

Graft	Coronary Branch	Inflow	Diameter	Stenosis (%) Severity of Stenosis proximal native coronary

IABP: ○ No ○ Yes → When Inserted: ○ Preop ○ Intraop ○ Postop
→ Indication: ○ Hemodynamic Instab ○ Unst. Angina ○ Prophylatic ○ PTCA Support ○ CPB Wean

PCPS: ○ No ○ Yes → When Inserted: ○ Preop ○ Intraop ○ Postop
→ Indication: ○ Hemodynamic Instab ○ Unst. Angina ○ Prophylatic ○ PTCA Support ○ CPB Wean

J. Cardiopulmonary Bypass

Cardiopulmonary Bypass: ○ No ○ Yes
↓
○ Elective ○ Conversion from Off-pump
→ Reason: ○ Hypotension ○ Rhythm ○ Bleeding ○ Anatomical ○ Others

K. Transfusion

Blood Products Used during Operation: ○ No ○ Yes
Blood Products Used after Operation: ○ No ○ Yes
Autologous Blood Transfusion: ○ No ○ Yes

Participant ID: .... Hospital name: .... Gender: O Male O Female

Date of Birth: 19...... / ......

L. Pre Intervention Hemodynamics and Catheterization

Diseased Coronary Vessels: ☐ LMT>50% ☐ LAD ☐ Dx ☐ LCX ☐ RCA

LVG : LVEDVI: .... LVESVI: .... LVEF: .... %

UCG : LVDd: .... LVDs: .... FS: .... %

Aortic Stenosis: O No O Yes Insufficiency: O 0 O 1 O 2 O 3 O 4

Mitral Stenosis: O No O Yes Insufficiency: O 0 O 1 O 2 O 3 O 4

(None=0, Trivial=1, Mild=2, Moderate=3, Severe=4)

M. Coronary Intervention (I)

PCI date: 20...... / ...... (yyyy/mm) Admission date: 20...... / ...... (yyyy/mm)

Discharge date: 20...... / ...... (yyyy/mm)

Memo:

PCI site	PCI times	Material type	Vessel diameter Proximal (mm)	MLD (mm)	Distal (mm)	Lesion Length (mm)	post MLD(mm)
	O 1st O 2nd or more						
	O 1st O 2nd or more						
	O 1st O 2nd or more						
	O 1st O 2nd or more						
	O 1st O 2nd or more						
	O 1st O 2nd or more						
	O 1st O 2nd or more						

N. Coronary Intervention (II)

PCI date: 20...... / ...... (yyyy/mm) Admission date: 20...... / ...... (yyyy/mm)

Discharge date: 20...... / ...... (yyyy/mm)

Memo:

PCI site	PCI times	Material type	Vessel diameter Proximal (mm)	MLD (mm)	Distal (mm)	Lesion Length (mm)	post MLD(mm)
1:	O 1st O 2nd or more						
2:	O 1st O 2nd or more						
3:	O 1st O 2nd or more						
4:	O 1st O 2nd or more						
5:	O 1st O 2nd or more						
6:	O 1st O 2nd or more						
7:	O 1st O 2nd or more						

O. Coronary Intervention (III)

PCI date: 20...... / ...... (yyyy/mm) Admission date: 20...... / ...... (yyyy/mm)

Discharge date: 20...... / ...... (yyyy/mm)

Memo:

PCI site	PCI times	Material type	Vessel diameter Proximal (mm)	MLD (mm)	Distal (mm)	Lesion Length (mm)	post MLD(mm)
1:	O 1st O 2nd or more						
2:	O 1st O 2nd or more						
3:	O 1st O 2nd or more						
4:	O 1st O 2nd or more						
5:	O 1st O 2nd or more						
6:	O 1st O 2nd or more						
7:	O 1st O 2nd or more						

Participant ID: ________ Hospital name: ________ Gender: ○ Male ○ Female
Date of Birth: 19____ / ____

P. Complications in Hospital

Complications: ○ No ○ Yes

Intraoperative
○ No
○ Yes → ☐ Bleeding
☐ Arrhythmia → Type: ☐ VF ☐ VT ☐ af ☐ PAT
☐ Other
memo : ________

Operative
○ No Date: 20____ / ____ (yyyy/mm)
○ Yes → ☐ Perioperative Myocardial Infarction
☐ Need Reoperation
↓
Reason : ☐ Bleeding
☐ Valvular Dysfunction
☐ Graft Occlusion
☐ Coronary Occlusion
☐ Other Cardiac Problem
☐ Non Cardiac Problem
memo : ________

Neurologic
○ No Date: 20____ / ____ (yyyy/mm)
○ Yes → ☐ Stroke
☐ Transient
☐ Continuous Coma >=24Hrs

Renal Failure
○ No Date: 20____ / ____ (yyyy/mm)
○ Yes → BUN : ________
Cr : ________
↓
Dialysis : ○ No
○ Yes → ○ Transient
○ Permanent

Vascular
○ No Date: 20____ / ____ (yyyy/mm)
○ Yes → ☐ Aortic Dissection
☐ Illiac/Femoral Dissection
☐ Acute Limb Ischemia

Infection
○ No Date: 20____ / ____ (yyyy/mm)
○ Yes → ☐ Sternum-Deep
☐ Wound-Chest
☐ Wound-Arm
☐ Wound-Leg
☐ Septicemia

Pulmonary
○ No Date: 20____ / ____ (yyyy/mm)
○ Yes → ☐ Prolonged Ventilation
☐ Pneumonia
☐ Pulmonary Embolism

Others
○ No Date: 20____ / ____ (yyyy/mm)
○ Yes → ☐ Heart Block
☐ Cardiac Arrest
☐ Atrial Fibrillation
☐ Anticoagulant Complication
☐ Tamponade
☐ Gastro-Intestinal Complication
☐ Multi-system Failure
☐ DIC
☐ Liver Dysfunction
↓
AST : ________
ALT : ________
T-Bil : ________

Q. Mortality

Status: ○ No ○ Yes
Mortality date: 20____ / ____ (yyyy/mm)
Cause of Death: ☐ Cardiac ☐ Renal ☐ Infection ☐ Valvular
☐ Neurological ☐ Vascular ☐ Pulmonary ☐ Other
Memo: ________

Participant ID: .... Hospital name: .... Gender: ○ Male ○ Female

Date of Birth: 19...... / ......

P. Follow-up data

Latest follow-up Date: 20...... / ...... (yyyy/mm)

Event: ○ No ○ Yes ——— Date: 20...... / ...... (yyyy/mm)

↓

- ☐ Follow-up examination
- ☐ Ischemia by RI
- ☐ Scheduled

- ☐ CHF
- ☐ MI
- ☐ Recurrent Angina
- ☐ Cerebrovascular Accident
- ☐ VT/VF
- ☐ Punctured effusion Tamponade
- ☐ Vascular Accident

★ Coronary data

Coronary Branch	Stenosis (%)	Treatment	Bypass Graft	Branch	Stenosis (%)	Treatment

★ Hemodynamics and Catheterization

CAG Date : 20...... / ...... (yyyy/mm)

Diseased Coronary Vessels: ☐ LMT>50% ☐ LAD ☐ Dx ☐ LCX ☐ RCA

LVG : LVEDVI: .... LVESVI: .... LVEF: .... %

UCG : LVDd: .... LVDs: .... FS: .... %

Aortic Stenosis: ○ No ○ Yes Insufficiency: ○ 0 ○ 1 ○ 2 ○ 3 ○ 4

Mitral Stenosis: ○ No ○ Yes Insufficiency: ○ 0 ○ 1 ○ 2 ○ 3 ○ 4

(None=0, Trivial=1, Mild=2, Moderate=3, Severe=4)

★ Diabetes status

Treatment: ○ None ○ Diet ○ Oral ○ Insulin

HbA1c : .... %

Medication: ....

Nephropathy: ○ No ○ Yes

Retinopathy: ○ none ○ NPDR ○ PDR

Memo: ________________________________

____

____

研究成果の刊行物・別刷

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Graft design strategies with optimum antegrade bypass flow in total arterial off-pump coronary artery bypass

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Abstract

Objective: In arterial conduits, graft flow is one of the major determinants of long-term patency. We sought to delineate the effect of strategy for graft arrangement and design to three-vessel disease by evaluation of the dominant flow direction in each segment of a bypass graft. **Materials and methods:** We reviewed coronary angiograms of 1571 bypass grafts in 395 patients who underwent total arterial off-pump coronary revascularization without aortic manipulation for three-vessel disease since December 2000. The graft flow graded as A (antegrade), B (competitive), C (reverse), and O (no flow = occlusion). The current arrangement and design has been introduced since March 2003, and consists of the in-situ left internal thoracic artery (ITA) to the anterior descending artery and the composite I-graft of the right ITA and radial artery to the left circumflex (LCX) and right coronary artery (RCA) territories. Either clockwise or counterclockwise orientation, the I-graft was chosen to achieve a sufficient antegrade flow. Group I consisted of 181 patients with a single in-situ ITA as a composite Y-graft. Group II consisted of 214 patients with bilateral in-situ ITAs, which subdivided into Subgroup II-A consisted of 80 patients with bilateral in-situ ITAs until February 2003, and Subgroup II-B consisted of 134 patients with bilateral in-situ ITAs since March 2003. **Results:** The number of distal anastomoses was 3.52 ± 0.63 in Group I, and 4.36 ± 0.83 in Group II, respectively ($p < 0.0001$). The overall graft patency rate was 98.6% (1549/1571), and there was no significance different between the groups. The rate of grade A in Group II was 863/933 (92.5%) and was significantly higher ($p = 0.049$) than that of Group I 572/638 (89.7%). The rate of functioning bypass in Subgroup II-B was (95.8%) 568/593, and was significantly higher ($p = 0.03$) than that in Subgroup II-A (92.4%) 314/340. In Subgroup II-B, 233/268 (86.9%) of the conduits had completely grade A bypass flow, and this ratio was significantly higher ($p = 0.04$) than that in Subgroup II-A (79.4%) 127/160. Conclusion: Usage of bilateral ITAs and selecting the orientation of the I-graft to LCX and RCA branches provide maximal distal anastomotic sites with satisfactory graft patency rate, and simultaneously minimized the incidence of reverse and competitive flow.

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Keywords: Off-pump; CABG; Arterial graft; Angiography

1. Introduction

Coronary artery revascularization was first performed on beating hearts [1]. Off-pump CABG combined with a no-aortic-touch technique has been accepted as an effective procedure to avoid the neurologic and aortic complications, and to reduce the operative risk. A composite graft using in-situ and free grafts is necessary for complete revascularization in patients with multi-vessels disease, and the arterial graft is commonly used because of its beneficial characteristics in terms of expectancy of both graft patency and improved late outcome [2].

In the arterial graft, circumstances of the blood flow in the graft lumen may be an important determinant for the durable patency. It has been reported that occlusion or string sign in the arterial graft is closely correlated with the insufficiency of the bypass flow, which represents competitive and reverse flow. It can occur either when the pressure capacity of the bypass graft is not enough; or the intraluminal pressure in the native coronary artery is relatively high due to the moderate stenosis of the native coronary artery. The previous study showed that reverse flow in the non-individual conduit had a significant correlation with the presence of moderately stenotic right coronary artery (RCA) and more than four target coronary branches for a single in-situ internal thoracic artery (ITA) [3]. In addition, the management of a coronary branch with critical stenosis and the strategy for the graft arrangement play essential roles for blood flow distribution [4].

The objectives of this study were (1) to compare the bypass flow in different bypass graft configurations for complete revascularization of the three-vessel territories

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using the flow grading system and (2) to evaluate the different strategy for graft arrangement and design.

2. Materials and methods

2.1. Study population

Between December 2000 and June 2005, 395 consecutive patients (male; 321, female; 74, mean age; 66.1 ± 9.1 years) underwent off-pump complete revascularization for three-vessel disease with arterial grafts (Table 1). Patients were excluded if they (i) had a bypass graft of the in-situ gastroepiploic artery or the saphenous vein, (ii) had individual grafts only, or (iii) did not undergo postoperative coronary angiography.

All patients underwent pre- and 2-week postoperative coronary angiographies, which were evaluated by the cardiologist for the native coronary artery stenosis and the graft patency, respectively.

The evaluation of graft patency is based on the concept of flow grading system (Table 2). A patent graft meant that the graft had a complete continuity of the graft lumen in the overall length from the subclavian artery to the target coronary branch, irrespective of the flow direction.

Grade O; (occlusion) was defined as the continuity of the graft lumen was interrupted at any level until the target coronary branch.

Grade A; means that antegrade graft flow was found in most of the multi-plane ITA angiography. Grade B; (competitive flow) defined as a situation in which the target vessel was slightly opacified from the ITA injection, and the bypass graft did fill by retrograde flow from the native coronary artery injection. Grade C; (reverse flow) the distal anastomotic sit was not opacified from the ITA graft injection at all, but it did fill clearly by retrograde flow from the native coronary artery injection. Flow grade was recorded for each target coronary branch. Any bypass graft graded as occluded or having reverse flow was considered not functioning because it did not contribute to coronary perfusion and relief of ischemia in the target region. A patent bypass without reverse flow was graded as functioning, and the rate of functioning grafts was defined as the proportion of functioning bypass grafts to the total number of bypass grafts. The definition of terms used in the present study is as follow. The in-situ ITA graft is an ITA, which was divided only at its distal portion. A composite graft is a bypass conduit consisting of one in-situ graft and a free graft anastomosed to it (in an end to end, end to side, or side to side fashion). An individual bypass was defined as a bypass conduit having one distal anastomoses and one in-situ graft. This included the straight composite grafts; i.e. I-graft, to one target coronary branch. A bypass conduit having two or more distal anastomosis, such as a sequential, Y-, or K-graft, was defined as non-individual.

Table 1
Baseline characteristics

	Group I (single ITA)	Group II (bilateral ITAs)	*p* value, Group S versus B
No. of patients	181	214	
Age (years)	70.3 ± 7.3	62.5 ± 9.0	<0.0001
Male/female	140/41	181/33	0.07
Hypertension	106 (59%)	108 (50%)	0.11
Hyperlipidemia	89 (49%)	117(55%)	0.28
Diabetes	76 (42%)	84 (39%)	0.58
End-diastolic volume index of LV (ml/m^2)	84.4 ± 23.8	89.4 ± 33.3	<0.0001
Ejection fraction of LV (%)	48.0 ± 10.8	46.0 ± 12.9	0.005
Total distal anastomoses	638	933	
Bypass conduits used			
Individual (target banch = 1)	0	142	
Non-individual (target branches>2)	181	286	
In situ ITA sequential	0	36	
Composite Y-graft	160	88	
Composite K-graft	21	15	
Composite I-graft	0	147	
Total	181	428	

ITA; internal thoracic artery LV; left ventricle.

Table 2
Concept of flow grading

	Flow grade			
	A	B	C	O
Flow direction	Antegrade	Competitive	Reverse	No-flow
Patency	Patent	Patent	Patent	Occluded
Function	Functioning	Functioning	Non-function	Non-function
Durability	Yes	No	No	No

Table 3
Baseline characteristics

	Subgroup II-A (~Feb. 2003)	Subgroup II-B (Mar. 2003~)	p value, Group B-1 versus B-2
No. of patients	80	134	
Age (years)	60.6 ± 8.2	63.6 ± 9.4	0.02
Male/Female	68/12	113/21	0.90
Hypertension	43 (54%)	65 (49%)	0.46
Hyperlipidemia	49 (61%)	68(51%)	0.14
Diabetes	32 (40%)	52 (39%)	0.86
End-diastolic volume index of LV (ml/m^2)	92.9 ± 35.1	87.7 ± 32.0	0.27
Ejection fraction of LV (%)	46.5 ± 13.9	45.6 ± 12.2	0.67
Total distal anastomoses	340	593	
Bypass conduits used	160 (100%)	268 (100%)	
Individual (target banch = 1)	44 (27.5%)	98 (36.6%)	0.053
In situ ITA	27 (16.9%)	93 (34.7%)	<0.0001
Composite I-graft	17 (10.6%)	5 (1.9%)	<0.0001
Non-individual (target branches >1)	116(72.5%)	170 (63.4%)	0.053
In situ ITA sequential	10 (6.3%)	26 (9.7%)	0.21
Composite Y-graft	49 (30.6%)	39 (14.6%)	<0.0001
Composite K-graft	13(8.1%)	2 (0.7%)	<0.0001
Composite I-graft	44 (27.5%)	103 (38.4%)	0.02
ITA-RA-LCX-RCA (clockwise)	0	67 (25.0%)	<0.0001
ITA-RA-RCA-LCX (counterclockwise)	44 (27.5%)	36 (13.4%)	0.0003

ITA; internal thoracic artery LV; left ventricle LCX; left circumflex artery RA; radial artery RCA; right coronary artery.

The design and arrangement of the bypass conduits were primarily determined by the operative risk and special relationship of the target sites (Tables 1 and 3). Group I consisted of 181 patients with single in situ ITA graft as Y- or K- graft. In Group II, 214 patients had bilateral in situ ITA in the combination of individual, Y-, K- or I-graft. Group II was divided into two subgroups by the date of surgery, because the current standard strategy has been introduced in March 2003, aiming at preventing high-risk situations of reverse and competitive flow [4]. Subgroup II-A consisted of 80 patients until February 2003, and Subgroup II-B consisted of 133 patients between March 2003 and June 2005 (Table 3). In the standard technique in Subgroup II-B, one in-situ ITA, usually the left, supplies to the left anterior descending artery (LAD) territory and an I-graft of the contra lateral ITA, usually the right, and the radial artery to the circumflex (LCX) and the right coronary artery (RCA) in a clockwise orientation, which meant a side to side anastomosis with the LCX branch and an end to side anastomosis to the RCA branch (Fig. 1). The counter-clockwise orientation was occasionally chosen to avoid grafting to the RCA branch with 75% stenosis at the end of the conduit, because reverse flow is commonly found at the distal end of the conduit [4]. In Subgroup II-A, the I-graft was used only in a counterclockwise orientation for the safety of redo operation in the future (Table 3). When the bypass conduits had grade A bypass flow to all target coronary branches, we considered that the design of the bypass conduit was successful.

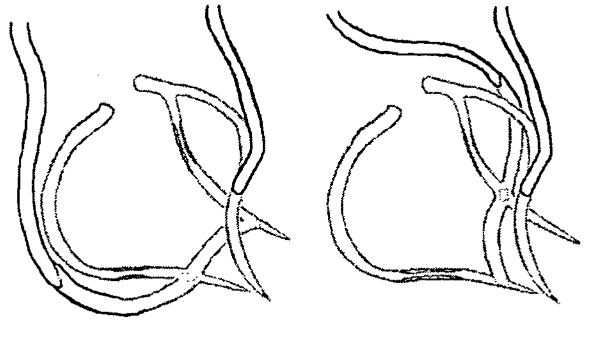

Fig. 1. A composite I-graft in the clockwise (right) and counterclockwise orientation (left).

Through a standard median sternotomy, the pericardial cavity was widely opened and deep pericardial sutures were placed for traction. Heparin was administered and activated coagulation time was maintained at more than 300 s until completion of anastomosis. In the present study, the ITA was harvested using either conventional (combined with vein and fascia), or semiskeletonized (partially combined with vein), or skeletonized technique [5]. All the distal portion of ITA grafts were larger than 1.5 mm in diameter assessed by insertion of 1.5 mm flexible probe. Allen's test was routinely performed before harvesting the radial artery and capillary refilling of the palm within 10 s was judged as negative [6]. Irrespectively to patient's age, the radial artery of non-dominant forearm was harvested by using an ultrasonic scalpel, treated with a papaverin hydrochloride solution [7], and was divided into two pieces when necessary. In the side-to-side anastomosis, a longitudinal arteriotomy of 6–10 mm was performed on both native coronary artery and arterial graft, and it was long enough for anastomosis without turbulence. The angle of the graft placement was adjusted to 0–90 degree to save the length and avoid kinking.

The distal anastomoses were carried out while stabilizing the coronary vessels using Octopus II+ or III stabilizer (Medtronic, Minneapolis, MN) and a retract-O-tape (Quest Medical, Inc., Allen, TX) was placed for temporary proximal occlusion. The surgical field was maintained by CO_2 blower and an intracoronary shunt; Anastsflo (Edwards Lifesciences, Irvine, CA) for coronary artery of 1.5 and 2.0 mm in diameter, Clearview (Medtronic, Minneapolis, MN) for coronary artery 1.25 and 1.0 mm in diameter, was used.

Continuous infusion of diltiazem was started during the operation and continued until oral medication was started, usually on the first postoperative day. It was terminated and replaced by nicardipine hydrochloride if sufficient heart rate could not be obtained. In the intensive care unit, heparin was administrated continuously for 24 h, and replaced by oral administration of aspirin.

2.2. Statistical analysis

The continuous variables are expressed as mean ± stan-standard deviation, and compared by the unpaired Student's t-test between the two groups. The data of two independent groups were compared by Fisher's exact probability test. The differences in the outcomes were considered statistically significant at a probability value <0.05.

3. Results

The over graft patency rate was 98.6% (1549/1571). The number of distal anastomoses in Group II was 4.36 ± 0.83, and it was significantly greater than in Group I (3.52 ± 0.63) ($p < 0.0001$) (Table 2). In Group I, 572 (89.7%) bypass were grade A, whereas 20 (3.1%), 36 (5.6%), and 10 (1.6%) were grade B, C and O, respectively. The graft patency rate in Group II was 98.7% (921/933), and was comparable with that in Group I (98.4%) (628/638). However, the rate of grade A bypass flow in Group II was 92.5% (863/933), and was significantly higher than that of in Group I (89.7%) (572/638) ($p = 0.049$). In Group I, the number of bypass conduits of grade A bypass flow to all target coronary branches was 122/181 (67.4%), and was significantly less than that in Group II (360/428) (84.1%) ($p < 0.0001$) (Table 4).

In the comparison of Subgroup II-A to Subgroup II-B, there was no significant difference in the graft patency rate (Table 5). However, the functioning rate in Subgroup II-B was (95.8%) (568/593) and was significantly higher than that in Subgroup II-A (92.4%) (314/340) ($p = 0.03$). In Subgroup II-B, the number of bypass conduits with the grade A bypass flow to all target coronary branches was (233/268) (86.9%), and was significantly higher than that in Subgroup II-A (127/160) (79.4%) ($p = 0.04$) (Fig. 2).

The characteristics of the native coronary branches according to anatomical location and the grade of coronary stenosis, LAD and diagonal had 92.9 and 95.9% grade A from the total number of anastomoses, respectively. The grade A flow of the graft performed for 91–100% stenosis of native coronary branches was 98.8%, while in 76–90% coronary stenosis the grafts had grade A flow in 92.9% and when the grade of coronary stenosis is 51–75%, the graft grade A was 86.0% (Table 6).

Table 4
Angiographic results

	Group I (single ITA)	Group II (bilateral IT As)	p value
No. of patients	181	214	
Distal anastomoses	3.52 ± 0.63	4.36 ± 0.83	<0.0001
Flow grade			
A	572 (89.7%)	863 (92.5%)	
B	20(3.1%)	19(2.0%)	
C	36 (5.6%)	39 (4.2%)	
O	10(1.6%)	12(1.3%)	
Total	638	933	
Antegrade flow rate			
A	572 (89.7%)	863 (92.5%)	0.049
Functioning rate			
A + B	592(92.8%)	882 (94.5%)	0.16
Patency rate			
A + B + C	628 (98.4%)	921 (98.7%)	0.64
Bypass conduits	181	428	
Flow grade in the bypass conduits			
A only	122 (67.4%)	360(84.1%)	<0.0001
Non-A (+)	59 (32.6%)	68 (15.9%)	

ITA; internal thoracic artery LV; left ventricle non-A; grade B, C, or O.

Table 5
Angiographic results

	Subgroup II-A (~Feb. 2003)	Subgroup II-B (Mar. 2003~)	p value
No. of patients	80	134	
Distal anastomoses	4.25 ± 0.83	4.42 ± 0.83	0.07
Flow grade			
A	307 (90.3%)	556 (93.8%)	
B	7(2.1%)	12 (2.0%)	
C	19 (5.6%)	20 (3.4%)	
O	7(2.1%)	5 (0.8%)	
Total	340	593	
Antegrade flow rate			
A	307 (90.3%)	556 (93.8%)	0.05
Functioning rate			
A + B	314(92.4%)	568 (95.8%)	0.03
Patency rate			
A + B + C	333 (97.9%)	588 (99.2%)	0.11
Bypass conduits	160	268	
Flow grade in the bypass conduits			
A only	127 (79.4%)	233 (86.9%)	0.04
Non-A (+)	33 (20.6%)	35 (13.1%)	

IT A; internal thoracic artery LV; left ventricle non-A; grade B, C, or O.

4. Discussion

Avoidance of cardiopulmonary bypass and manipulation of the aorta can decrease the incidence of preoperative complications. In this aorta no-touch technique, the usage of the in-situ ITA graft is almost essential and it provides a favorable long-term survival with an excellent graft patency because it has a lower incidence of atherosclerotic graft disease than the saphenous vine graft [2,8]. In previous reports, the early and midterm graft patency rates of the radial artery were equivalent to those of the ITA [9–11]. The radial artery in the composite graft may provide a better durability than that proximally anastomosed to the ascending aorta because the exposure to an excessive pressure of the aorta and wall stress and the mismatch of the wall thickness can be avoided [11,12].

On planning the configuration and design of the arterial grafts in off-pump CABG without aortic manipulation, consciousness for the anticipated direction of bypass flow

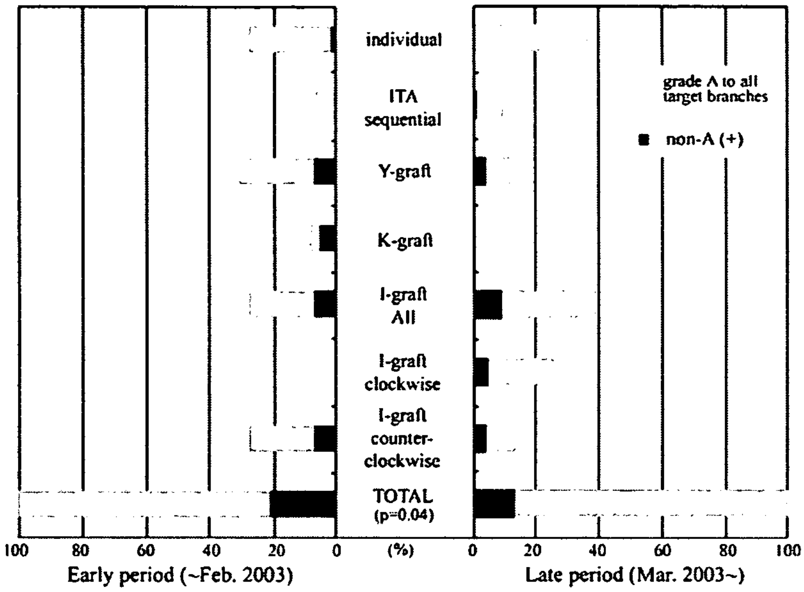

Fig. 2. Comparison of the proportion of bypass conduits used in the early and the late periods, and the rate of the conduits having only grade A, in various configurations.

may be mandatory. It was reported previously that reverse flow in the non-individual graft have significant correlations with the moderately stenotic RCA and the number of distal anastomotic sites of the composite graft [3]. Interaction of the coronary branches, which were connected to each other by a sequential or composite graft, and management of the coronary branches with moderate and severe stenoses play crucial roles in the occurrence of competitive and reveres flow. On the contrary, the graft material and size of the target branch does not correlate with the direction of bypass flow [4]. Additionaly, the patency rate of the graft with sufficient antegrade bypass flow was significantly higher than those of the graft presenting reverse and competitive flow, and the bypass grafts graded B or C were prone to close the graft lumen in the intermediate term [13,14]. It is generally believed that the long-term graft patency can be highly expected whenever arterial materials are exclusively used. However, the arterial graft without a sufficient antegrade flow has no obvious advantage regarding the long-term patency rate, as compared with the venous graft. A composite graft allows total arterial revascularization with an excellent graft patency rate and a lower incidence of cardiac events, especially for patient with atherosclerosis of the ascending aorta [15,16]. Although different arrangements and designs of the in-situ and free arterial grafts have already been reported [8,17], no optimal strategy for graft arrangement has been established yet. The decision of the configuration actually depends on the surgeon's preference or the custom of each group.

FitzGibbon et al. examined the venous conduits angiographically using the grading system of the luminal size at the narrowest portion, and the intimal irregularity as well. [18,19]. This grading system predicted the late atherosclerotic graft occlusion, which is considered as a major determinant of the long-term patency of the venous grafts. However, in the ITA graft, atherosclerosis hardly developed [20,21]. Additionally, the luminal size of the anastomotic site is not precisely measurable in the sequential fashion,

Table 6
Early angiographic results

Characteristics of coronary branches	Number of anastomoses	Grade			
		A (%)	B (%)	C (%)	O (%)
Location					
LAD main trunk	397	369 (92.9)	14 (3.5)	10 (2.5)	4 (1.0)
Diagonal	196	188 (95.9)	2 (1.0)	5 (2.6)	1 (0.5)
LCX	461	424 (92.0)	6 (1.3)	26 (5.6)	5(1.1)
RCA	517	454 (87.8)	17 (3.3)	34 (6.6)	12 (2.3)
Stenosis (%)					
51–75	727	625 (86.0)	31 (4.3)	61 (8.4)	10 (1.4)
76–90	410	381 (92.9)	8 (2.0)	14 (3.4)	7 (1.7)
91–100	434	429 (98.8)	0	0	5 (1.2)
Overall	1571	1435 (91.3)	39 (2.5)	75 (4.8)	22 (1.4)

LAD; left anterior discending artery, LCX; left circumflex artery, RCA; right coronary artery.

especially when the angle of the graft and coronary branch is near to 90 degrees, or when the contrast medium dose fills only incompletely due to mixture with the blood flow from the native coronary artery. Furthermore, although inadequate surgical maneuvers during the operation strongly affect the luminal size by unsuccessful anastomosis or graft kinking, regression of the stenosis and the increase or growth of the diameter were relatively common finding in the arterial grafts [22]. Thus, we consider that the angiographic luminal size or graft patency may be not relevant for pure comparison of graft arrangement and design of the arterial conduits.

In the present study, the configuration and design of the arterial graft were compared not only by classifying the anatomical patency or occlusion, but also by the dominant flow direction in the arterial composite and sequential grafts. Although there was no significant difference in the graft patency rate among the groups, the use of bilateral ITAs enabled more distal anastomosis with reduced competitive and reverse flow. We considered that the appropriate pressure slope in each segment of the bypass conduit should be higher at the proximal than that at the end of the conduit to achieve an antegrade flow. The anastomosis of the bypass conduit end with a moderately stenotic coronary branch is unfavorable in most cases. Thus, the composite I-graft is useful because the target coronary branch at the end of the conduit can be chosen by determining its orientation. In the composite Y-graft, the adequate pressure slope to the both ends should be made and the indication for Y or K graft should be more carefully decided. On the other hand, the Y-graft has an advantageous in terms of increased flow capacity [23] and availability to the distant target branches, as compared with the I-graft. For the diagonal, LCX, and RCA branches, the Y- or K-graft is preferred when all target branches have severe stenosis, target diagonal branch is located at the anteroapical portion, or remarkable cardiomegaly exists. Also, selection of suitable candidates for this procedure is a major concern.

Since the bypass grafts with reverse flow do not contribute to the coronary perfusion in the grafted territory, the efficacy of CABG may be unpromising, even when the bypass graft is anatomically patent. When non-functioning or occluded graft is highly predicted at early period, an alternative therapeutic strategy should be considered such as hybrid therapy with drug eluting stent implantation for conservation of the arterial grafts for the future redo operation.

In previous study, sequential anastomoses with more than two moderately stenotic coronary branches including one at the end of the conduit were highly associated with flow insufficiency and late occlusion. Although the gastroepiploic artery is an option of choice for the RCA and LCX territories, it is unsuitable for moderately stenotic coronary branch because its pressure potential is inferior to that of the in-situ ITA [24,25].

This study has some limitations as it is not randomized. Peripheral vascular resistance in the myocardial tissue also has an important role in the coronary perfusion. Grade B flow probably includes insufficient graft flows due to both strength of the native coronary flow and poor vascularity with high resistance in the severely impaired myocardium. Although no bypass graft may be required for the latter, we could not predict the insufficient antegrade flow caused by the critically damage vasculature.

5. Conclusion

The use of bilateral ITAs significantly increased the bypass grafts with sufficient antegrade flow, and the I-graft to LCX and RCA branches with avoidance of anastomosis with moderately stenotic coronary branch at the end of the graft was effective for reduction of reverse and competitive flow by selecting its orientation. Flow consciousness in the graft arrangement and design may be a major concern to confirm the advantage of the arterial material and complete revascularization when the arterial grafts are exclusively used.

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Predictive factors for the intermediate-term patency of arterial grafts in aorta no-touch off-pump coronary revascularization

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Abstract

Objective: Graft flow is one of the important determinants of the arterial graft patency. To establish the optimal graft design, we examined detailed characteristics of the arterial composite and sequential grafts, and sought to delineate the risk factors of graft occlusion due to insufficient bypass flow. **Methods:** Angiograms of 2547 bypass grafts in 677 consecutive patients who underwent total arterial off-pump CABG without aortic manipulation followed by early postoperative angiography since December 2000 were reviewed. The angiographic flow was graded as A (antegrade), B (competitive), C (reversal), and O (occlusion). **Results:** The overall early graft patency rate was 98.2% (2502/2547). The rate of grade A was 91.3% (2325/2547), while the rates of grades B and C were 2.9% (73/2547) and 4.1% (104/2547), respectively. For the main trunk of the anterior descending branch (LAD), the graft patency rate was 99.3% (674/679). The grade A rate of the internal thoracic artery (ITA) grafts to LAD in an individual fashion was 99.5% (203/204), being comparable with that in the sequential or composite grafting which had two distal anastomoses (98.1%, 159/162; $p = 0.33$). The actuarial patency rates at 3 years were 84.7% for the bypass grafts with grade A flow and 33.9% for those with grade B/C flow, respectively ($p < 0.0001$). The multivariate Cox-regression analysis demonstrated that grade B/C ($p < 0.0001$, HR = 4.19) and 51—75% stenosis of the native coronary artery ($p = 0.02$, HR = 2.86) were significant predictors of graft occlusion. **Conclusions:** For the LAD, the results of graft flow in sequential ITA grafting or composite grafting with two distal anastomoses were comparable with that in individual ITA grafting. Prediction and prevention of competitive and reverse flow are mandatory for achieving the advantages of the arterial materials.

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Keywords: Coronary disease; Surgery; Angiography; Off-pump CABG; Arterial graft

1. Introduction

The arterial grafts have beneficial characteristics in terms of expectancy of long-term patency and improved late outcome after coronary artery bypass grafting (CABG) [1—3]. For the arterial grafts, the circumstance of the blood flow in the graft lumen is considered an important determinant of the patency. It has been reported that occlusion or string sign in the arterial grafts can typically occur when the stenosis in the native coronary artery is moderate, and that these physiologic changes in the luminal diameter occurred within 2 years [4—7]. We previously reported that reverse flow in the sequential or composite graft was commonly associated with the moderately stenotic right coronary artery (RCA) and composite or sequential grafting to more than four target branches [8]. In addition, the management of a coronary branch with critical stenosis played definitive roles [9].

The objectives of this study were (1) to delineate the effects of detailed characteristics of the target coronary branches and the bypass grafts on the occurrence of competitive flow, (2) to delineate the risk of graft occlusion, and (3) to establish a theoretical basis for optimizing the strategy for graft arrangement to the left anterior descending artery (LAD) and to non-LAD branches, which include the diagonal branch, left circumflex artery (LCX), and RCA.

2. Methods

The pre- and postoperative coronary angiograms of 2547 bypass grafts in 677 consecutive patients, who underwent off-pump complete revascularization for coronary artery disease using only the internal thoracic artery (ITA) with or without the radial artery between December 2000 and May

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Table 1
Baseline characteristics

No. of patients	677
Age (years)	66.1 ± 9.1
Male/female	563/114
Hypertension	357 (52.7%)
Hyperlipidemia	332 (49.0%)
Diabetes	260 (38.4%)
Left ventricular end-diastolic volume index (ml/m^2)	84.9 ± 29.0
Left ventricular ejection fraction (%)	48.1 ± 11.7
Total distal anastomoses	2547
Distal anastomoses per patient	3.76 ± 1.01
Bypass conduits used	1023
In-situ ITA	293
Composite Y-graft	391
Composite I-graft	273
Composite K-graft	66

ITA, internal thoracic artery.

2006, were reviewed. The patients who had a bypass of the gastroepiploic artery, the inferior epigastric artery or the saphenous vein, those with individual grafts only, and those who did not undergo early postoperative coronary angiography were excluded. All patients provided written informed consent after explanation of the potential risks. All procedures were performed under social insurance coverage, and institutional approval was obtained. There were 563 men and 114 women, and their mean age was 66.1 ± 9.1 years. The number of distal anastomoses was 3.76 ± 1.01 per patient (Table 1).

Early postoperative coronary angiography was performed within a month after surgery. Cardiologists independently evaluated the native coronary artery stenosis and the graft patency. The maximal severity of stenosis was recorded for all target branches. The definitions of terms used in the present study are as follows. A patent graft meant that the graft had a complete continuity of the graft lumen throughout its entire length from the origin of the ITA to the target coronary branch, irrespective of the flow direction. Whenever the continuity of the graft lumen from an in-situ ITA graft to the anastomosis with the target coronary branch was interrupted at any level, or when repeated angioplasty was performed, they were defined as Grade O (occlusion). Grade A was defined as a situation in which antegrade graft flow was found in most of the multi-plane ITA angiographs. Grade B (competitive) was defined as a situation in which the target vessel was slightly opacified from the ITA graft injection, and the bypass graft did fill by retrograde flow from the native coronary injection. Grade C (reverse flow) was defined as a situation in which the distal anastomotic site was not opacified from the ITA graft injection at all, but it did fill clearly by retrograde flow from the native coronary injection. Flow grade was recorded for each target coronary branch, and these data were collected prospectively.

An individual bypass is defined as a bypass conduit having one in-situ ITA and one distal anastomosis. A non-individual bypass graft means a bypass conduit having two or more distal anastomoses, such as sequential or composite grafting. The in-situ ITA is ITA divided only at its distal portion.

2.1. Graft design strategy

The arrangement of the bypass conduits was primarily determined by the operative risk and positional relationship of the target sites. Our current standard technique since March 2003 was based on our previous angiographic studies and introduced for minimizing competitive and reverse flow. One in-situ ITA, usually the left, supplies the LAD territory, while an I-graft of the contralateral ITA, usually the right, and the radial artery supply the LCX and RCA territories in a clockwise orientation, via a side-to-side anastomosis with LCX and an end-to-side anastomosis with RCA. The counterclockwise orientation was occasionally chosen to avoid grafting to RCA branch with 75% stenosis at the end of the conduit, because reverse flow was commonly found at the distal end of the conduit with the end-to-side anastomosis [8,9]. Before introduction of this strategy, the I-graft was used only in a counterclockwise orientation for the safety of redo operation in the future. For patients aged more than 75 years or with considerable operative risks, such as chronic obstructive pulmonary disease or diabetes mellitus treated by insulin therapy, we harvested only a single ITA. In the present series, all ITA grafts were greater than 1.5 mm in diameter at the distal end.

2.2. Late angiographic results

Follow-up angiography was performed between 3 and 66 months after the operation for 325 bypass grafts in 91 patients with recurrent angina, or ischemic findings on electrocardiography or scintigraphy. The mean follow-up period was 29 ± 19 months.

2.3. Statistical analysis

The continuous variables are expressed as the mean values ± standard deviation (SD). The data of two independent groups were compared by Fisher's exact probability test. Longitudinal data were estimated by the Kaplan–Meier method and the difference of two groups was compared by log-rank method. Cox regression analysis was used to examine the significance of the variables in predicting graft occlusion. Statistical analyses were performed using SPSS software (SPSS 8.0 Inc., Chicago, IL). The differences in the outcomes were considered statistically significant when the p-value was less than 0.05.

3. Results

The overall graft patency rate was 98.2% (2502/2547), and the grade A rate was 91.3% (2325/2547). The actuarial graft patency rates at 3 years were 84.7% for the bypass grafts graded A and 33.9% for the bypass grafts graded B/C ($p < 0.0001$). The early patency rate of the bypass grafts to 51–75% stenotic coronary branches was 98.1% (1140/1162), and their grade A rate was 85.1% (989/1162), being significantly lower than that of the bypass grafts to 76–100% stenotic branches (96.5%, 1336/1385; $p < 0.0001$). For 75% stenotic branches, the actuarial graft patency rates at 3

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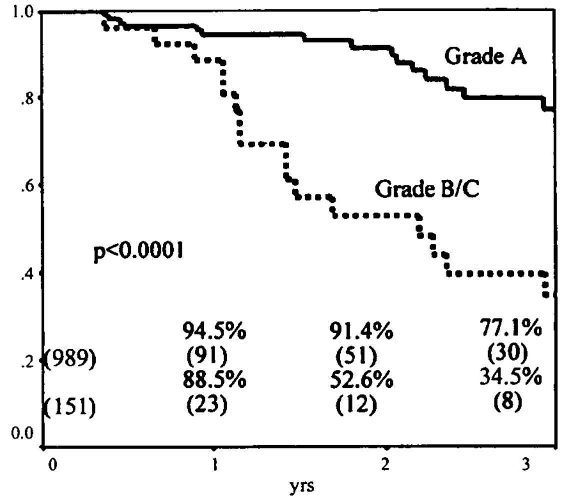

Fig. 1. The actuarial graft patency rate of the bypass grafts to 51–75% stenotic branches. Grade A vs grade B/C.

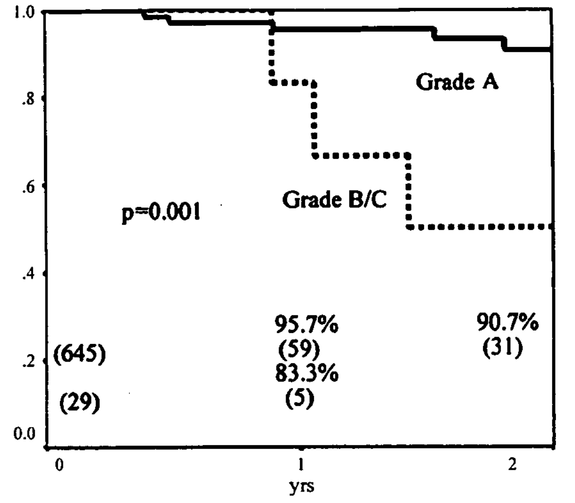

Fig. 2. The actuarial graft patency rate of the bypass grafts to the main trunk of LAD. Grade A vs grade B/C.

years were 77.1% for the bypass grafts graded A and 34.5% for the bypass grafts graded B/C ($p < 0.0001$) (Fig. 1).

Regarding the main trunk of LAD, the grade A rate of the in-situ ITA in individual fashion was 99.5% (203/204), and was significantly higher than that of non-individual conduit grafting (93.1%, 442/475; $p = 0.0001$), whereas the patency rates were similar ($p = 0.99$). The grade A rate of the conduit with two distal anastomoses was comparable with that of the individual grafting ($p = 0.33$) (Table 2). For the bypass grafts to LAD, the actuarial graft patency rates at 1 year were 95.7% for the bypass grafts graded A and 83.3% for the bypass grafts graded B/C ($p = 0.001$) (Fig. 2). The actuarial graft patency rates of the bypass graft to the LAD with 51–75% stenosis and those with 76–100% stenosis at 2 years were 79.9% and 96.7%, respectively ($p = 0.16$).

For the non-LAD branches, including the diagonal, LCX, and RCA branches, the grade A rate of the in-situ ITA was comparable to that of the Y- or K-graft or I-graft (90.8% vs 89.9%; $p = 0.87$), and the grade A rate of the individual grafts was comparable to that of the sequential and composite grafts (91.9% vs 89.9%; $p = 0.99$) (Table 3). The patency rate of the bypass grafts to 51–75% stenotic branches was similar

Table 2
Early angiographic results: flow grading of bypass grafts to main trunk of left anterior descending artery

		No. of anastomoses	Grade A	Grade A rate (%)	Grade B	%	Grade C	%	Grade O	Patency rate (%)
Native coronary stenosis	51–75%	313	288	92.0 [1]	16	5.1	6	1.9	3	99.0 [3]
	76–90%	205	196	95.6 [2]	2	1.0	5	2.4	2	99.0 [4]
	91–100%	161	161	100 [2]	0	0	0	0	0	100 [4]
Diameter of target branch	<1.5 mm	72	68	94.4 [5]	2	2.8	1	1.4	1	98.6
	≥1.5 mm	546	523	95.8 [6]	10	1.8	10	1.8	3	99.5
	Not recorded	61	54	88.5	6	9.8	0	0	1	98.4
Graft material anastomosed	ITA	679	645	95.0	18	2.7	11	1.6	5	99.3
	RA	0	0	–	0	–	0	–	0	–
	Free ITA	0	0	–	0	–	0	–	0	–
Anastomotic fashion	End-to-side (graft end)	675	642	95.1	17	2.5	11	1.6	5	99.3
	Side-to-side (sequential)	4	3	75.0	1	25.0	0	0	0	100
Conduit type	In-situ ITA	275	272	98.9 [7]	1	0.4	0	0	2	99.3
	Y-graft	343	318	92.7 [8]	17	5.0	5	1.5	3	99.1
	K-graft	61	55	90.2 [8]	0	0	6	9.8	0	100
	I-graft	0	0	–	0	–	0	–	0	–
No. of distal anastomoses of conduit	1 (individual)	204	203	99.5 [9,13]	0	0	0	0	1	99.5 [11]
	2	162	159	98.1 [10,14]	2	1.2	0	0	1	99.4 [12]
	3	204	188	92.2 [10]	12	5.9	2	1.0	2	99.0 [12]
	4~	109	95	87.2 [10]	4	3.7	9	8.3	1	99.1 [12]
Total		679	645	95.0	18	2.7	11	1.6	5	99.3

ITA, internal thoracic artery; RA, radial artery. [1] vs [2], $p = 0.001$; [3] vs [4], $p = 0.67$; [5] vs [6], $p = 0.54$; [7] vs [8], $p = 0.0001$; [9] vs [10], $p < 0.0001$; [11] vs [12], $p > 0.99$; [13] vs [14], $p = 0.33$.

Table 3
Early angiographic results: flow grading of bypass grafts to diagonal branch, LCX, and RCA

		No. of anastomoses	Grade A	Grade A rate (%)	Grade B	%	Grade C	%	Grade O	Patency rate (%)
Target branch	Diagonal	391	368	94.1 [1]	9	2.3	7	1.8	7	98.2 [4]
	Circumflex	804	738	91.8 [2]	19	2.4	36	4.5	11	98.6 [5]
	Right coronary	673	574	85.3 [3]	27	4.0	50	7.4	22	96.7 [6]
Native coronary stenosis	51–75%	849	701	82.6 [7]	48	5.7	81	9.5	19	97.8 [9]
	76–90%	500	469	93.8 [8]	7	1.4	12	2.4	12	97.6 [10]
	91–100%	519	510	98.3 [8]	0	0	0	0	9	98.3 [10]
Diameter of target branch	<1.5 mm	614	553	90.1	15	2.4	27	4.4	19	96.9
	>1.5 mm	1121	1015	90.5	34	3.0	57	5.1	15	98.7
	Not recorded	133	112	84.2	6	4.5	9	6.8	6	95.5
Graft material anastomosed	ITA	166	147	88.6 [11]	4	2.4	7	4.2	8	95.2
	RA	1654	1488	90.0 [12]	51	3.1	83	5.0	32	98.1
	Free ITA	48	45	93.8	0	0	3	6.3	0	100
Anastomotic fashion	End-to-side (graft end)	869	709	81.6 [17]	48	5.5	80	9.2	32	96.3
	Side-to-side (sequential proximal)	999	971	97.2 [18]	7	0.7	13	1.3	8	99.2
Conduit type	In-situ ITA	109	99	90.8 [13]	1	0.9	1	0.9	8	92.7
	Y-graft	842	749	89.0 [14]	25	3.0	50	5.9	18	97.9
	K-graft	185	161	87.0 [14]	10	5.4	13	7.0	1	99.5
	I-graft	732	671	91.7 [14]	19	2.6	29	4.0	13	98.2
No. of distal anastomoses of conduit	1 (individual)	37	34	91.9 [15]	0	0	0	0	3	91.9
	2	360	319	88.6 [16]	15	4.2	12	3.3	14	96.1
	3	780	701	89.9 [16]	26	3.3	40	5.1	13	98.3
	4∼	691	626	90.6 [16]	14	2.0	41	5.9	10	98.6
Total		1868	1680	89.9	55	2.9	93	5.0	40	97.9

ITA, internal thoracic artery; LCX, left circumflex artery; RA, radial artery; RCA, right coronary artery. [1] vs [3], $p < 0.0001$; [2] vs [3], $p < 0.0001$; [4] vs [6], $p = 0.18$; [5] vs [6], $p = 0.02$; [7] vs [8], $p < 0.0001$; [9] vs [10], $p = 0.87$; [11] vs [12], $p = 0.59$; [13] vs [14], $p = 0.87$; [15] vs [16], $p > 0.99$; [17] vs [18], $p < 0.0001$.

to that of the bypass grafts to 76–100% stenotic branches (97.8% vs 97.9%; $p = 0.87$), while the grade A rate of the bypass grafts to 51–75% stenotic branches was significantly lower than that of the bypass grafts to 76–100% stenotic branches (82.6% vs 96.1%; $p < 0.0001$). The actuarial graft patency rates at 2 years were 94.5% for the bypass grafts graded A and 57.6% for the bypass grafts graded B/C ($p < 0.0001$). The actuarial graft patency rate of the bypass grafts to branches with 76–100% stenosis at 2 years was 89.8%, being significantly higher than that of the bypass grafts to branches with 51–75% stenosis (82.2%; $p = 0.009$). The actuarial graft patency rate of the bypass grafts in the end-to-side fashion at 2 years was 80.5%, being significantly lower than that of the bypass grafts in the side-to-side fashion (91.4%; $p = 0.01$) (Fig. 3A). The actuarial graft patency rates at 2 years were 85.6% for the I-grafts graded A and 88.8% for the bypass grafts graded B/C ($p = 0.31$) (Fig. 3B).

As shown in Table 4, the univariate Cox regression analysis demonstrated that the RCA territory, 51–75% stenosis, small coronary branch (diameter < 1.5 mm), and grade B/C were significant predictors of graft occlusion. The multivariate Cox regression analysis identified 51–75% stenosis (HR = 2.86, $p = 0.02$) and grade B/C (HR = 4.19, $p < 0.0001$) as significant predictors.

4. Discussion

A composite graft allowed total arterial revascularization with excellent graft patency rate and lower incidence of perioperative cardiac and cerebrovascular events [10,11]. Although various arrangements of the in-situ and free arterial grafts have already been reported [3,12,13], no optimal strategy for graft arrangement has been established yet. We have applied our grading system of angiographic graft flow for 5.5 years. The results of the present study imply some suggestions regarding the strategy for graft arrangement.

For the main trunk of the LAD, the use of the in-situ ITA graft has been generally accepted as a standard strategy, which provides a long-term patency and improves the late survival after CABG. The in-situ ITA in an individual fashion may be ideal for the main trunk of the LAD; however, sequential and composite grafting to the LAD and a diagonal branch is an important option of choice. Dion et al. reported that the long-term patency of sequential grafting with the in-situ ITA to the LAD and a diagonal branch was identical to that of the individual in-situ ITA [14]. We previously reported that early angiographic results of the Y-graft to the LAD and a diagonal branch were similar to that of sequential grafting [9]. As shown in Table 2, our present study demonstrated that, in the LAD region, the sequential graft and the Y-graft to two distal anastomoses were as reliable as individual grafting. We consider that the in-situ ITA, which is anastomosed to the LAD, can be connected with at least one diagonal branch by sequential or composite grafting without disturbance of graft flow to the main trunk of the LAD. Different from bypass grafts to LCX or RCA, the difference between the patency rate of bypass grafts to LAD 51–75% and that of bypass grafts to 76–100% stenosis was not significant. The in-situ ITA grafts could confidently supply the

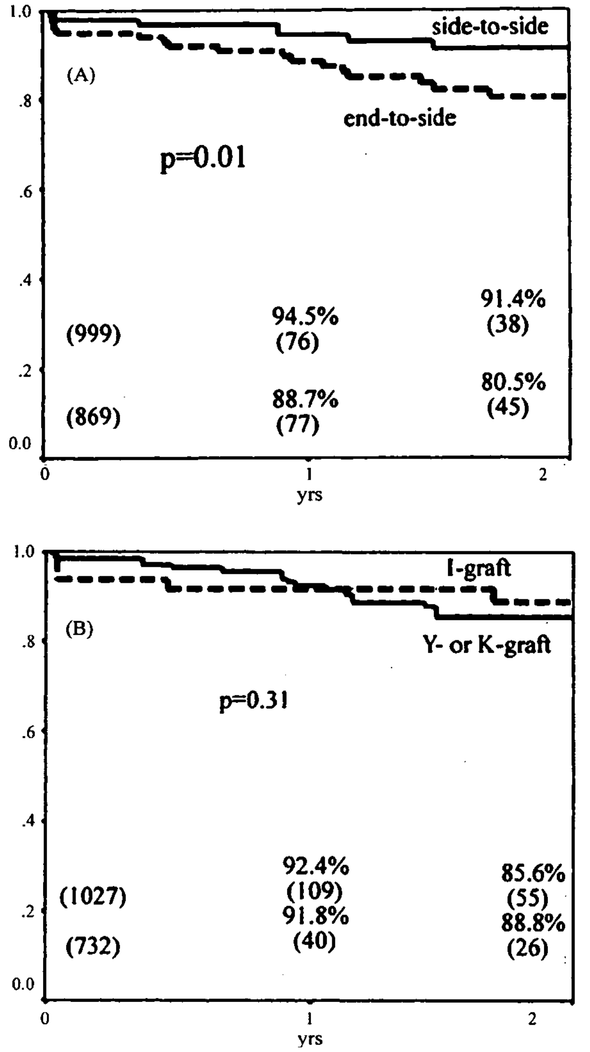

Fig. 3. (A) The actuarial graft patency rate of the bypass grafts to the non-LAD branches. End-to-side anastomoses (graft end) vs side-to-side anastomoses. (B) The actuarial graft patency rate of the bypass grafts to the non-LAD branches. I-graft vs Y- or K-graft.

sufficient antegrade flow to the LAD territory, even with moderate stenosis.

For the coronary branches besides LAD, there was no obvious disadvantage of the composite grafts versus the individual graft and the in-situ ITA. In addition, native coronary stenosis had stronger impact on the bypass grafts to the non-LAD branches than on the bypass grafts to the LAD in the follow-up angiographic results. For the bypass grafts to the non-LAD regions, both grade B/C and 51–75% stenosis in the native coronary branch significantly correlated with graft occlusion.

One of the possible explanations for these differences between the grafts to LAD and those to non-LAD branches may be the difference in the graft materials. About 90% of the anastomoses were performed with the composite radial artery. The radial artery may be more sensitive for the blood flow in the lumen than the ITA graft. More severe stenosis will be necessary for the long-term patency of the radial artery, as compared with the ITA graft.

Regarding the conduit type, no significant difference was found between the I-graft and the Y- or K-graft in the non-LAD regions. We consider that the appropriate pressure slope in each segment of the bypass conduit, highest at the proximal and lowest at the end of the conduit, was the most important for antegrade bypass flow to all target vessels. The bypass grafts with the side-to-side anastomoses presented better graft patency than those with the end-to-side anastomoses. Therefore, when the positional relationship of the target sites allows, the I-graft would be favorable, because it has only one end-to-side anastomosis and the target coronary branch at the end of the conduit can be changed by simply determining its orientation. On the other hand, the Y-graft has the advantages of increased flow capacity [15] and availability to the distant target branches.

Dion et al. reported that the patency rate of end-to-end grafting was comparable with side-to-side grafting with excellent long-term patency of sequential grafting using the ITA graft [14]. In their report, the target branches of 78% of bypass graft restudied were the LAD and a diagonal branch, whereas, in the present study, sequential ITA grafting to the LAD and a diagonal branch was only 9%, and sequential grafting to four or more target branches was performed in about 11% of patients. We consider that the difference is owing to differences in target site, graft material, and probably the number of target coronaries in sequential anastomoses.

Selection of patients suitable for this procedure would be a next concern. It has been widely accepted that the patients with severe atherosclerosis of the ascending aorta are the most suitable candidates for composite and sequential grafting [10,11]. We would suggest herein new patients' selection criteria from a viewpoint of preventing competitive flow and maximizing durability of arterial grafts. According to the results of the present study and our previous investigations, the decisive risks of competitive and reverse flow are as follows: (1) a RCA branch with 51–75% stenosis, (2) a LCX branch with 51–75% stenosis, (3) a bypass conduit with four or more distal anastomoses, and (4) three high-risk situations reported in [9]. Of 677 patients in this study, 147 (21.7%) patients had none of these risks and/or all risky situations were successfully avoided. The actuarial graft patency rate of patients who have none of the above risks at 3 years was significantly higher than that of patients with any of the risks (92.6% vs 69.7%; $p < 0.0001$). They were the best candidates for this procedure. On the other hand, when competitive or reverse flow is highly predicted, alternative strategies, such as the aortocoronary bypass, which provides the highest bypass pressure [16], may be reasonable, especially for the non-LAD regions.

The present study had some limitations. First, the patients who underwent follow-up angiography were biased toward clinically evident graft failure. Second, the peripheral vascular resistance in the myocardial tissue, which has an important role in the coronary perfusion, was not taken into account. Third, the capacity of the ITA graft was not considered. The pressure and flow capacity as the blood source of the bypass conduit and potentiality of growth or thinning and adaptability to the graft flow may also play important roles in the occurrence of insufficient flow and resultant occlusion. At the beginning of 2004, we started to harvest ITA in a skeletonized fashion to maximize the

Table 4
Predictors of graft occlusion in the intermediate-term follow-up period

Variables	Hazard ratio	95% CI	p-Value
Univariate analysis			
Female	1.17	(0.55–2.47)	0.68
Distal anastomoses of the conduit	1.00	(0.78–1.29)	0.99
Early period (Dec. 2000–Feb. 2003)	0.91	(0.50–1.66)	0.76
Type of the conduit, Y- or K-graft (vs in-situ ITA)	0.66	(0.31–1.42)	0.29
Type of the conduit, I-graft (vs in-situ ITA)	1.02	(0.45–2.32)	0.96
Graft material anastomosed, radial artery (vs in-situ ITA)	1.39	(0.81–2.38)	0.23
Graft material anastomosed, free ITA (vs in-situ ITA)	2.51	(0.74–8.55)	0.14
Location, LCX territory (vs LAD territory)	0.98	(0.51–1.90)	0.95
Location, RCA territory (vs LAD territory)	2.44	(1.41–4.23)	0.001
Stenosis (51–75%)	2.28	(1.35–3.83)	0.002
Diameter of coronary branch (<1.5 mm)	1.94	(1.12–3.36)	0.01
End-to-side anast. (graft end) (vs side-to-side = sequential proximal)	1.48	(0.87–2.53)	0.15
Grade B/C in early angiography	6.46	(3.64–11.47)	<0.0001
Multivariate analysis			
Graft material anastomosed, radial artery (vs in-situ ITA)	0.51	(0.10–2.70)	0.43
Graft material anastomosed, free ITA (vs in-situ ITA)	1.24	(0.14–11.35)	0.84
Location, LCX territory (vs LAD territory)	1.88	(0.37–9.57)	0.45
Location, RCA territory (vs LAD territory)	3.27	(0.65–16.35)	0.15
Stenosis (51–75%)	2.86	(1.17–6.99)	0.02
Diameter of coronary branch (<1.5 mm)	1.57	(0.78–3.14)	0.20
End-to-side anast. (graft end) (vs side-to-side = sequential proximal)	1.12	(0.53–2.33)	0.77
Grade B/C in early angiography	4.19	(2.02–8.69)	<0.0001

CI, confidence interval; LAD, left anterior descending artery; LCX, left circumflex artery; RCA, right coronary artery; ITA, internal thoracic artery; RA, radial artery.

capacity of the in-situ ITA graft [17,18]. This technique will extend the application of the bilateral ITA grafting to patients with a substantial operative risk [19]. Fourth, the effects of the luminal size of arterial conduits on the long-term patency remain unclear. Previously, the grading system of the luminal size at the narrowest portion, and intimal irregularity was reported [20,21]. It was reported useful for assessment of degeneration of bypass grafts in a conventional technique. However, the luminal size of the side-to-side anastomosis in the sequential fashion is not precisely measurable, especially when the angle between the graft and the coronary branch is near 90 degrees, or when the contrast medium only fills incompletely due to mixture with the blood flow from the native coronary artery. Moreover, the regression of stenosis and the increase of the diameter were relatively common findings in the arterial materials [22,23]. At last, high-pressure injection of contrast medium may induce reverse and competitive flow and may interfere with evaluation of graft flow direction. This may be a methodological limitation. This flow grading system is not necessarily practical for postoperative evaluation for each patient and each bypass graft. In the present study, flow grading was performed independently from the catheterization team. We utilized this grading system for comparison of graft configurations and optimizing the strategy for design of the arterial grafts, based on data of a considerable number of patients and bypass grafts, and examined significance of correlations between characteristics of the bypass grafts and the occurrence of competitive and reverse flow. For these purposes, flow grading is considered useful.

In conclusion, prediction and prevention of competitive and reverse flow may be necessary to enhance the advantage of multivessel revascularization using exclusively arterial materials because insufficiency of the antegrade flow would spoil the advantage of arterial grafts.

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