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

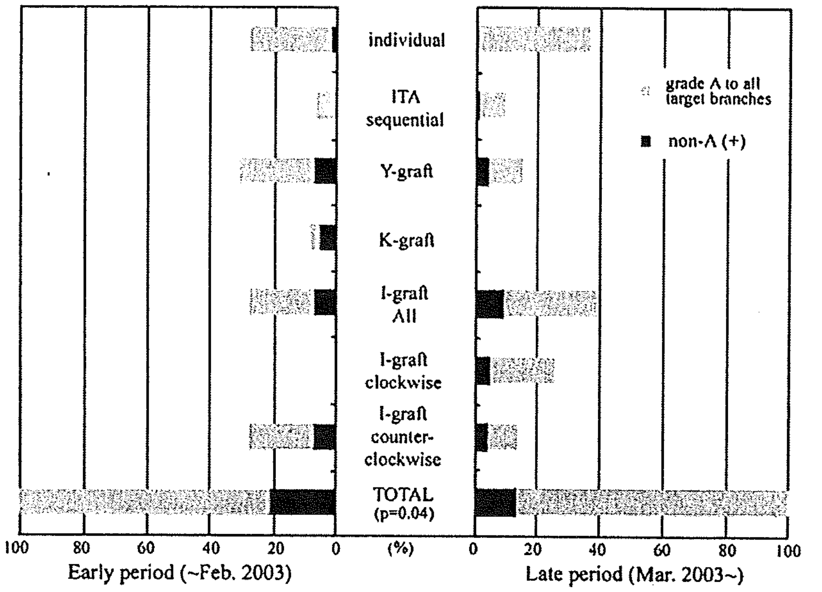

Fig. 2. Comparison of the proportion of bypass conduits used in the early and the late periods, and the rate of the conduits having only grade A, in various configurations.

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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Safety and efficacy of sequential and composite arterial grafting to more than five coronary branches in off-pump coronary revascularization: assessment of intraoperative and angiographic bypass flow

short title: sequential and composite grafting to 5 vessels

Hiroyuki Nakajima MD,
Junjiro Kobayashi MD,
Koichi Toda MD,
Tomoyuki Fujita MD,
Yutaka Iba MD,
Yusuke Shimahara MD,
Shunsuke Sato MD,
Soichiro Kitamura MD.

From The Department of Cardiovascular Surgery
National Cardiovascular Center, Osaka, Japan

Correspondence to: Hiroyuki Nakajima MD, Department of Cardiovascular Surgery,
National Cardiovascular Center, 5-7-1 Fujishirodai, Suita, Osaka 565-8565, Japan,
Tel: 81-6-6833-5012, Fax: 81-6-6872-7486.
E-mail: hnakajim@hsp.ncvc.go.jp

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Off-pump CABG, Complete revascularization, Arterial graft, Graft flow, Angiography.

Abstract

Objective: To assess the safety and efficacy of sequential and composite coronary artery bypass grafting (CABG) with exclusively arterial grafts to more than 5 coronary branches including small coronary vessels.

Methods: We reviewed the clinical records and angiograms of 633 consecutive patients with 2617 bypass grafts who underwent total arterial off-pump complete revascularization for 3-vessel disease without aortic manipulation. Group I consisted of 263 patients with a single in-situ internal thoracic artery (ITA), while group II consisted of 370 patients with bilateral in-situ ITA. Subgroups I-A and I-B consisted of 242 patients with 3 or 4 distal anastomoses and 21 patients with more than 5 distal anastomoses, respectively. Subgroups II-A and II-B consisted of 199 patients with 3 or 4 anastomoses and 171 patients with more than 5 anastomoses, respectively.

Results: There were no significant differences in the early mortality and morbidity between group I and group II. The angiographic graft patency rates in the two groups were similar (98.5%, 703/714, vs. 97.7%, 1429/1460, p=0.35), while the rate of antegrade flow in group II (92.4%, 1349/1460) was significantly higher than that in group I (89.4% 638/714, p=0.02). Intraoperative graft flow measured at proximal portion of in group II (79±35ml/min) was significantly larger that that in group I (53±31ml/min, p<0.0001). The patency rate of bypass grafts to small coronary vessels (1.25mm in diameter or less) was 97.4% (626/643).

The early mortality rates in subgroup I-A and subgroup I-B were 1.2% (3/242) and 0% (0/21), respectively (p=0.61). The graft flow in subgroup I-A was comparable to that in subgroup I-B (53±31ml/min vs. 55±33ml/min, p=0.42). The early mortality rates in subgroup II-A and subgroup II-B were 0.5% (1/199) and 0.6% (1/177), respectively (p=0.91). The graft flow in subgroup II-B (81±35ml/min) was greater than that in subgroup II-A (76±35ml/min, p=0.07).

Conclusions: For more than 5 target branches, sequential and composite arterial grafting was safe and reliable, even when the target vessels were small. Bilateral in-situ ITA would be feasible for the patients with multiple stenotic lesions, because of abundant bypass flow

and less incidence of competitive flow. Durable completeness of revascularization can be expected.

Introduction

Complete revascularization is considered as the important determinant of freedom from adverse cardiac events after coronary artery bypass grafting (CABG). For rationale of off-pump coronary revascularization, functional complete revascularization, which was defined as at least one bypass graft to each of the three major vascular regions, may be essential (1,2,3). On the other hand, the efficacy of 4 or more distal anastomoses for 3-vessel disease is still controversial. It may be deleterious in the conventional surgical technique (4), probably because the increase of anastomoses would necessitate longer cardiopulmonary bypass and cardiac arrest time.

Recently, not only the left anterior descending artery (LAD), but also the left circumflex (LCX) and right coronary (RCA) arteries are commonly bypassed with the internal thoracic artery (ITA) or other arterial grafts to achieve long-term patency and improve the clinical outcome (5,6,7).

It has been widely accepted that off-pump CABG reduces the operative morbidity and mortality, and that avoidance of manipulation of the ascending aorta is effective for prevention of perioperative complications, such as stroke. In addition, it was previously reported that the arterial grafts were advantageous for grafting to small coronary vessels, even in off-pump CABG (8). Moreover, we suppose that it is technically demanding in conventional CABG to adjust the graft length and to create sequential grafting to two or more coronary vessels in the LCX and the RCA regions, as compared with off-pump CABG. Accordingly, off-pump sequential and composite grafting may be advantageous, especially for the patients who require 5 or more distal anastomoses.

In the present study, we sought to delineate the safety and efficacy of sequential and composite arterial grafting for five or more coronary branches without cardiopulmonary bypass by examining the clinical results and intraoperative and angiographic bypass flow.

Materials and methods

We reviewed the coronary angiograms of 633 consecutive patients with 2617 bypass grafts, who underwent off-pump CABG for 3-vessel disease using totally arterial grafts between December 2000 and September 2007. Functional complete revascularization with the in-situ ITA and a free arterial graft, mostly a radial artery, was performed in all cases. The patients who underwent incomplete revascularization, who had an in-situ gastroepiploic artery or saphenous vein graft, or had individual bypass graft only, were excluded. The clinical and angiographic data were based on the cardiovascular surgery database in our institution, which was approved by our institutional review board. All patients provided written informed consent giving them after explanation of the potential risks. There were 501 men and 132 women, and their mean age was 67 ± 9 years.

Group I consisted of 263 (41.5%) patients who had a single in-situ ITA, while group II consisted of 370 (58.5%) patients with the bilateral in-situ ITAs. Each group was divided into two subgroups. Subgroup I-A consisted of 242 patients who had 3 or 4 distal anastomoses, and subgroup I-B consisted of 21 patients who had 5 or more distal anastomoses. As shown in Table 1, there were no significant differences between subgroup I-A and subgroup I-B in the preoperative patients' characteristics. Subgroup II-A consisted of 199 patients who had 3 or 4 distal anastomoses, and subgroup II-B consisted of 171 patients who had 5 or more distal anastomoses. Regarding the preoperative characteristics, there were significant differences in the age at operation, ratio of female gender and distal anastomotic sites (Table 2).

Operative techniques and perioperative management

The details of our surgical technique were described previously (9,10). In the present series, all ITA grafts were harvested with semi-skeletonized or skeletonized technique, and were larger than 1.5 mm in diameter at the distal anastomotic site. The radial artery was harvested from the non-dominant forearm irrespective of the patient's age. It was divided into two pieces when necessary. In the side-to-side anastomosis, we made a longitudinal arteriotomy both on the native coronary artery and the arterial graft long enough for anastomosis without turbulence. The angle of the graft placement was adjusted between 0 to 90 degrees to save the length and avoid kinking. After completion of anastomoses, the graft flow was measured at the proximal portion of each in-situ ITA using a transit-time flow meter at approximately 90-120 mmHg of arterial pressure.

Total arterial CABG with aorta no-touch technique using one or two in-situ ITAs and radial artery has been our standard technique. The configuration of the bypass conduits were primarily determined by the operative risk and positional relationship of the target sites. The bilateral ITAs were preferably used for patients who were in active life and were less than 75 years of age with neither severe chronic obstructive pulmonary disease nor insulin-dependent diabetes mellitus. As shown in Table 1 and 2, the radial artery was used as a free graft in 607 (95.9%) of these patients.

In the patients with the bilateral in-situ ITAs, one in-situ ITA, usually the left, was anastomosed with LAD and an I-graft of the contralateral ITA, usually the right, and the radial artery was anastomosed with LCX and RCA in a clockwise orientation, which meant a side-to-side anastomosis with LCX and an end-to-side anastomosis with RCA, or in a counterclockwise orientation, which meant a side-to-side anastomosis with RCA and an end-to-side anastomosis with LCX. The orientation was chosen to avoid grafting to the coronary branch with 75% stenosis at the end of the I-graft, because competitive and reversal flow was commonly found at the distal end of the conduit (8,9).

Early postoperative coronary angiography was performed about 2 weeks after surgery. The severity of the native coronary artery stenosis and the graft patency were independently evaluated by cardiologists. The maximal severity of stenosis was recorded for all target branches. The terms in this paper were defined as follows. In brief, a 'patent' graft meant that the graft had a complete continuity of the graft lumen throughout its entire length from the subclavian artery 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, it was defined as 'occluded' (Grade O). Grade A was defined as a situation in which antegrade graft flow was found in most of the multi-plane ITA angiograms. Grades B and C were competitive and reversal, respectively. Flow grade was recorded for each target coronary branch. In the present paper, the flow grades were judged as "antegrade flow" (=grade A) and "competitive flow" (=grades B and C).

Statistical analysis

The continuous variables are expressed as the mean values ± standard deviation. These variables were compared by unpaired t-test between the two groups. The data of two independent groups were compared by Fisher's exact probability test. Longitudinal data were estimated by Kaplan-Meier method, and the difference of two groups was compared by the log-rank method. 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.

Results

Comparisons of group I vs. group II

The early mortality rates in group I and group II were 1.1% (3/263) and 0.5% (2/370), respectively (p=0.40). There were no significant differences in the early complications between the two groups (p=0.93).

Intraoperative graft flow, which was measured at the proximal portion of in-situ ITA, in group II (79±35ml/min) was significantly larger that that in group I (53±31ml/min, p<0.0001). In early postoperative angiography, the graft patency rates in these two groups were similar (98.5% (703/714) vs. 97.7% (1429/1460), p=0.35), while the rate of antegrade flow in group II was significantly higher than that in group I (89.4% (638/714) vs. 92.4% (1349/1460), p=0.02).

Comparisons of subgroup I-A vs. subgroup I-B

Three patients (1.2%, 3/242) in subgroup I-A died, whereas there was no early mortality in subgroup I-B (Table 3). Perioperative myocardial infarction occurred in 6 patients (2.5%) of subgroup I-A.

Intraoperative measurement showed that graft flow in subgroup I-A and I-B were 53±31 ml/min and 55±33 ml/min, respectively (p=0.42) (Figure 1). Early postoperative coronary and graft angiography were performed in 187 patients (77%, 187/242) with 643 distal anastomoses in subgroup I-A and 14 patients (14/21, 67%) with 71 distal anastomoses in subgroup I-B. Angiography revealed that the graft patency rates were 98.3% (632/643) in subgroup I-A and 100% (71/71) in subgroup I-B (p=0.27). The rate of antegrade flow in subgroup I-B was significantly higher than that in subgroup I-A (91.5% vs. 89.1%, p=0.048).

Comparisons of subgroup II-A vs. subgroup II-B

The early mortality rates in subgroup II-A and subgroup II-B were 0.5% (1/199) and 0.6% (1/177), respectively (p=0.91). Perioperative myocardial infarction occurred in 5 patients (2.5%) of subgroup II-A and 3 patients (1.7%) of subgroup II-B. There were no significant differences in the early morbidities between the two subgroups (p=0.89) (Table 4).

Measuring the intraoperative graft flow revealed that the total graft flow in subgroup II-B was relatively larger than that in subgroup II-A (81±35 ml/min vs. 76±35 ml/min, p=0.07) (Figure 2). Early postoperative angiography was performed in 175 (87.9%) patients of subgroup II-A and 148 (86.5%) patients of subgroup II-B. The graft patency rates were 97.3% (648/666) in subgroup II-A and 98.4% (781/794) in subgroup II-B, respectively (p=0.16). There was no significant difference in the rates of antegrade flow between subgroups II-A and II-B (p=0.21) (Table 4).

Discussion

The in-situ ITA graft to LAD is a significant predictor for the survival and freedom from the repeated revascularization, because atherosclerotic changes are rarely found in the ITA graft by histological investigation and its intimal cells have functional superiority to venous grafts regarding nitric oxide or prostacyclin release (11). Especially in the patients who have no considerable operative risks, the use of the bilateral ITAs and more arterial graft is considered as a favorable graft material to LCX and RCA.

Completeness of revascularization to all three major vascular regions is also reported as one of the independent predictors of improved short- and long-term survival after CABG (12,13,14,15,16). Complete revascularization can be more successfully achieved by surgical treatment, as compared with catheter intervention, and this fact supported the clinical benefit of surgical treatment. On the other hand, it was reported that off-pump CABG could be the cause of fewer bypass grafts and incomplete revascularization, which would be explanation of increased recurrence of angina and repeated coronary intervention (17). In the previous reports, the most common reason for incomplete revascularization was too small vessel size (14). The other reasons were severely diseased vessel, non-dominant RCA, presence of prior infarcted tissue (17), and unavailability of proximal anastomosis to ascending aorta (14).

The clinical outcomes and efficacy of bypass grafting to 5 or more coronary branches in excess of functional complete revascularization have not been proved, yet. Vander Salm and colleagues reported that the MI-free survival rate of patients with multiple anastomoses to the non-LAD system was significantly lower than that of patients with no more than one graft insertion to a non-LAD system (4). They reported that there was no independent survival advantage for traditional or functional complete revascularization as compared with incomplete revascularization, and that surgical construction of more than one graft to the LCX and RCA territories could be deleterious (4).

The present study demonstrated that the safety of CABG to 5 or more target branches by sequential and composite grafting, which consisted of an individual in-situ ITA to LAD and sequential anastomoses of the radial artery to the LCX and RCA regions. The immediate operative results for patients with 5 or more targets were similar to those of patients with 3 or 4 targets, in spite of extensive stenotic lesions and their significantly high age. In addition, the graft patency rate and the incidence of competitive flow were not affected by increasing the target branches, irrespective of the same blood source and graft materials. From the viewpoint of blood supply for the myocardium, the bilateral in-situ ITAs would be feasible in the patients with 3-vessel disease, especially for more than 5 target branches, because the amount of the bypass flow was not increased as compared with that for 3 or 4 target branches.

These results may be explained as follows. First, in contrast to conventional CABG, the increase of distal anastomotic sites in off-pump CABG does not bring about prolongation of cardiopulmonary bypass time or cardiac arrest time. Second, the arterial materials were advantageous for the small coronary vessels. The graft patency rate for the small vessels; i.e., having diameter of less than 1.5 mm, was similar to that for larger branches, 1.5mm or more diameter. This fact could improve the success rate of complete revascularization.

Third, sequential bypass grafting played an important role in current procedure. Previously, Dion and colleagues reported the efficacy of sequential grafting with the ITA graft to LAD and diagonal branch with excellent graft patency concomitant with economizing the length of the graft (18,19). Farsak and colleagues documented the importance of run-off of the most distally located target coronary branch on a sequential venous graft to secure patency of the entire sequential conduit (20), and we reported that the distal end of the sequential radial artery graft should be anastomosed to the near-occluded coronary branch (21). We consider that even if the flow demand of a small coronary vessel is not enough to maintain patency of each arterial graft in an individual fashion, sequential grafting concomitant with the appropriate target vessel for the distal end would avoid physiological narrowing of the entire graft. Moreover, in off-pump CABG, we suppose that adjusting the graft length and angle of anastomosis for prevention of kinking or angulation would be relatively easy, as compared with the arrested heart. Consequently, no additional graft material was necessary even for several target branches in the LCX and RCA regions in our patients.

This study has some limitations. First, this study is retrospective and not randomized. There were some differences in the preoperative patients' characteristics. Randomization is extremely difficult, because the number of distal anastomotic sites mostly depends on the configuration of coronary artery system and locations of the stenotic lesions. However, the operative procedure and graft materials were comparable between these subgroups, and all patients underwent functional complete revascularization for 3-vessel disease. Second, regarding decision of single or bilateral in-situ ITA, rapid adaptability to blood flow in the lumen and reparability of the stenotic ITA was not taken into account (22, 23). Bilateral in-situ ITA provided greater bypass flow than the single in-situ ITA, but less than twice of the single in-situ ITA. As far as competitive flow is avoided, the single in-situ ITA can be durable as compared with the bilateral in-situ ITA, as the case may be. This may be a paradox on the subject of blood supply and durability of arterial grafts.

In conclusion, total arterial off-pump CABG with sequential and composite grafting is safely applicable and useful for the patients with 5 or more target coronary branches. Since the rate of graft occlusion and competitive flow did not increase, irrespective of the same graft materials, durable completeness of revascularization can be expected. To achieve abundant bypass flow, the bilateral in-situ ITAs would be mandatory in CABG for more than 5 target branches.

Table 1

Baseline characteristics of patients with a single in-situ ITA

	Subgroup I-A	Subgroup I-B	p value
No. of patients	242	21	
Age (yrs)	72 ± 8	71 ± 7	0.37
Male/Female	172 / 70	16 / 5	0.62
Hypertension	139 (58%)	15 (71%)	0.21
Hyperlipidemia	115 (48%)	12 (57%)	0.39
Diabetes	108 (45%)	10 (48%)	0.79
LVEDVI (ml/m2)	82 ± 24	81 ± 30	0.43
Ejection fraction (%)	48 ±11	48 ± 14	0.49
Distal anastomoses			
3	131	0	-
4	111	0	-
5	0	17	-
6~	0	4	-
Graft materials used			
in-situ ITA	242 (100%)	21 (100%)	1.0
free ITA	18 (7%)	0	0.22
RA	224 (93%)	21 (100%)	0.22
Conduit shape			
composite Y-graft	223 (91%)	15 (71%)	0.002
composite K-graft	19 (9%)	6 (29%)	
Total distal anastomoses	837	110	-

ITA; internal thoracic artery LVEDVI; left ventricular end-diastolic volume index
RA; radial artery

Table 2

Baseline characteristics of patients with bilateral in-situ ITA

	Subgroup II-A	Subgroup II-B	p value
No. of patients	199	171	
Age (yrs)	63 ± 9	66 ± 7	0.004
Male/Female	144 / 33	154 / 17	0.03
Hypertension	96 (48%)	79 (46%)	0.69
Hyperlipidemia	102 (51%)	81 (47%)	0.46
Diabetes	91 (46%)	67 (39%)	0.32
LVEDVI (ml/m2)	82 ± 24	81 ± 30	0.39
Ejection fraction (%)	48 ±13	47 ± 11	0.41
Distal anastomoses			
3	44	0	-
4	155	0	-
5	0	116	-
6~	0	55	-
Graft materials used			
in-situ ITA	398	342	1.0
free ITA (distal part of ITA)	1	7	-
free GEA	2	1	-
RA	193	169	0.22
Total distal anastomoses	752	918	-

ITA; internal thoracic artery LVEDVI; left ventricular end-diastolic volume index
RA; radial artery

Table 3

Early results -subgroup I-A vs. subgroup I-B-

	Subgroup I-A	Subgroup I-B	p value
Angiographic Results			
Patients angiography performed	187 (77%)	14 (67%)	-
Distal anastomoses	643	71	
Antegrade flow	573 (89.1%)	65 (91.5%)	0.048
Competitive flow	59 (9.2%)	6 (8.5%)	0.84
Patency rate	632 (98.3%)	71 (100%)	0.27
Diameter of target branch and patency rate	643	71	
1.0 or 1.25 mm	160/166 (96.4%)	30/30 (100%)	0.29
1.5 mm~	420/424 (99.1%)	40/40 (100%)	0.54
not recorded	52/53 (98.1%)	1/1 (100%)	-
Early results			
Mortality	3/242 (1.2%)	0	0.61
Cardiac	0	0	
non-cardiac	3	0	
Morbidity	10/242 (4.1%)	1/21 (4.8%)	0.89
MI (CKMB>100)	6	0	
stroke	1	1	
deep wound infection	2	0	
reoperation for bleeding	1	0	

MI; myocardial infarction, CKMB; Creatinine kinase MB

Table 4

Early results -subgroup II-A vs. subgroup II-B-

	Subgroup II-A	Subgroup II-B	p value
Angiographic Results			
Patients angiography performed	175/199 (88%)	148/171 (85%)	-
Distal anastomoses	666	794	
Antegrade flow	609 (91.4%)	740 (93.2%)	0.21
Competitive flow	39 (5.9%)	41 (5.2%)	0.56
Patency rate	648 (97.3%)	781 (98.4%)	0.16
Diameter of target branch and patency rate			
1.0 mm	14/15 (93.3%)	49/52 (94.2%)	0.90
1.25 mm	151/156 (96.8%)	222/224 (99.1%)	0.10
1.5 mm~	428/436 (98.2%)	498/506 (98.4%)	0.76
not recorded	55/59 (93.2%)	12/12 (100%)	-
Early results			
Mortality	1/199 (0.5%)	1/171(0.6%)	0.91
Cardiac	0	1	
non-cardiac	1	0	
Morbidity	9/199 (4.5%)	7/171 (4.1%)	0.89
MI (CKMB>100)	5	3	
stroke	3	1	
deep wound infection	1	2	
reoperation for bleeding	0	1	

MI; myocardial infarction, CKMB; Creatinine kinase MB

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