Off-Pump Multivessel Revascularization
Efficacy Of Suction Type Of Coronary Stabilizer

Objective: **Off-pump coronary artery bypass grafting (CABG) has come into widespread use with the availability adequate coronary stabilization devices. We studied the efficacy of second-generation coronary stabilization devices (suction device) comparing to the first-generation device (compression device).** *Methods:* **We prospectively analyzed consecutive patients who underwent isolated off-pump CABG via a midline sternotomy at Shin-Tokyo Hospital Group between July 1, 1996, and August 31, 2000, comparing perioperative, and follow-up data in the group using a suction device (group S) to that in the group using a compression device (group C).** *Results:* **Preoperative risk factors were identical between the two groups, with the exception of a higher incidence of three vessel disease in group S. Complete revascularization increased from 47.3% in group C to 88.1% in group S, and the number of distal anastomoses from 2.1 ± 0.6 in group C to 2.9 ± 0.9 in group S. Revascularization of the circumflex artery was achieved in 21.7% of group S patients, which was significantly higher than that in group C (2.2%). Postoperative recovery, mortality, and morbidity did not differ significantly between groups. Calculated event-free rates at 2 years was 88.7% in group C and 92.0% in group S (p = NS).** *Conclusions:* **Anastomosis to the posterior wall of the heart using the suction device is safe. An increased number of distal anastomoses may reduce the occurrence of cardiac events related to incomplete revascularization.**
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Key words: coronary artery disease, off-pump coronary artery bypass graft, operative device, prospective study

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Coronary artery bypass grafting (CABG) can be performed under cardiac arrest with cardiopulmonary bypass (CPB) or under beating heart. Off-pump CABG (OPCAB) is technically demanding and local coronary stabilization is an essential part ensuring a steady operating field. To reduce anastomosis-related failure, different devices have been developed. We reported our early experience of OPCAB using first-generation coronary stabilization system: compression devices,[1] in which early results of OPCAB were favorable with early recovery and low mortality and morbidity.[2,3] Using compression coronary stabilization system, we bypassed the anterior aspect of the heart without difficulty. Anastomosis on the posterior wall of the heart using the compression device was, however, difficult due to hemodynamic instability.[1] New OPCAB devices have ~~on obtaining a~~ steady operative field and free of hemodynamic change. The new-generation coronary stabilizers, suction devices, reduce hemodynamic deterioration even when it was applied to the posterior wall of the heart, which allowed us to perform multivessel revascularization. By the end of August, 2000, we have conducted over 200 OPCAB using the second-generation device. In this report, we compare the early results of OPCAB using the two dif-

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ferent devices and analyze the feasibility of multivessel revascularization using this suction device.

Methods

Between July 1, 1996, and August 31, 2000, a total of 1,174 patients underwent isolated CABG at Shin-Tokyo Hospital Group (Shin-Tokyo Hospital and Kobari General Hospital). Among them, 264 patients (22.5%) underwent off-pump CABG approached via midline sternotomy, and their perioperative data were prospectively collected. Patients undergoing minimally invasive direct coronary artery bypass (MIDCAB) approached via anterolateral mini-thoracotomy were excluded as were those undergoing concomitant general or vascular surgery.

Subjects were divided into two groups by the type of coronary stabilization device used; group C using the compression device from the early study phase between July 1, 1996, and March 31, 1999, and group S using the suction device from the late study phase between April 1, 1999, and August 31, 2000. The compression device used in this study was a Ring system (US Surgical, Norwalk, CT) and the suction device was an Octopus 2 (Medtronic, Minneapolis, MN).

The heart was approached via midline sternotomy. After harvesting of the appropriate conduits, a local coronary stabilizer (Ring or Octopus system) was applied onto the target coronary artery. Anastomosis was performed in the following sequence: posterior, lateral, anterior, then inferior wall. If the left anterior descending artery (LAD) was the only collateral supply to the other coronary arteries, the LAD was first anastomosed with one of the internal mammary arteries to avoid global ischemia. The posterior aspect of the heart was exposed with four retropericardial suspension sutures applied behind the heart,[4] and it was further supported using the Trendelenburg position. No coronary preconditioning was done. Proximal and distal control of the target coronary artery was achieved using silicone occlusion tape. An intracoronary shunt tube was utilized in selected cases, such as severely stenotic but unoccluded coronary arteries without a collateral blood supply. A shunt tube was also utilized when EKG changes were observed during the local coronary clamping. A carbon dioxide gas blower provided a bloodless operative field and facilitated anastomosis. Coronary anastomoses were performed using 8-0 or 7-0 polypropylene sutures. In aortocoronary bypass, the proximal anastomoses was performed in last, using 6-0 polypropylene sutures under the side biting clamp applied to the ascending aorta.

The following parameters were collected: patient age, gender, preoperative risk factors, cardiac profile, coronary lesions, regional coronary artery anastomosis time, number of grafts, operation time, intubation period, intensive care unit (ICU) stay, and postoperative stay. The definitions of the preoperative risk factors, postoperative complications, and the remote cardiac events have been detailed elsewhere.[5] Complete revascularization was defined as having all territory of the coronary artery (the right coronary artery, LAD, and circumflex artery) with stenosis $\geq$ 75% revascularized with at least one arterial or venous conduit. Follow-up was completed by telephone by medical professionals.

Postoperative angiography was performed in selected patients with informed consent: the first 100 patients systematically underwent coronary angiography within 3 months of surgery, and thereafter early coronary angiography was performed either due to the poor quality of native coronary arteries or at the request of referring cardiologists.

Statistical analysis was performed using the Student's t-tests or Mann-Whitney's u-tests as appropriate for continuous variables, or the chi-square tests (Fisher's exact test if $n < 5$) for categorical variables. Postoperative survival and the event-free rates were constructed by the Kaplan-Meier method and compared with Mantel-Cox's logrank test. A p-value less than 0.05 was considered significant. Results were expressed as the mean $\pm$ standard deviation. All analyses were performed using Statview version 5.0 (SAS Intstitute, Cary, NC).

Results

Patient demographics: Group C consisted of 63 patients (44 males and 19 females with a mean age of 68.3 $\pm$ 6.9 years), and group S of 201 patients (145 males and 56 females with a mean age of 67.9 $\pm$ 9.8 years). The preoperative data are described in Table I. There was no significant difference between two groups, except for a higher frequency of three vessel disease in group S.

Operative results: Operative data are shown in Table II. Number of distal anastomoses was 2.1 $\pm$ 0.6 in group C and 2.9 $\pm$ 0.9 in group S. Complete revascularization rate was 47.6% in group C and 88.1% in group S. The radial artery and saphenous vein graft were used more frequently in group S than in group C. The coronary anastomosis time per vessel in group S was shorter than in group C. The target vessels of each graft are displayed in Table III. Anastomosis to the circumflex artery was significantly more frequently

Table I. *Preoperative risk factors*

	Compression device (n = 63)		*Suction device (n = 201)*		*p*
Clinical characteristics					
Age	68.3 ± 6.9	(52-82)	67.9 ± 9.8	(31-81)	NS
Age over 75	11	17.5%	54	26.9%	NS
Female sex	19	30.2%	56	27.9%	NS
Cardiac profile					
Unstable angina	6	9.5%	28	13.9%	NS
Acute myocardial infarction	3	4.8%	10	5.0%	NS
Previous myocardial infarction	44	69.8%	125	62.2%	NS
History of congestive heart failure	8	12.7%	29	14.4%	NS
Poor ejection function (< 40%)	3	4.8%	19	9.5%	NS
Atrial fibrillation	2	3.2%	10	5.0%	NS
Redo surgery	3	4.8%	5	2.5%	NS
Emergency surgery	3	4.8%	17	8.5%	NS
Angiographic profile					
Left main disease	16	25.4%	57	28.4%	NS
Number of diseased vessels	2.5 ± 0.6	(1-3)	2.6 ± 0.6	(1-3)	NS
Three vessel disease	30	47.6%	129	64.2%	< 0.05
Coronary risk factors					
Hypertension	44	69.8%	127	63.2%	NS
Diabetes	25	39.7%	88	43.8%	NS
Insulin user	4	6.3%	20	10.0%	NS
Hyperlipidemia	30	47.6%	88	43.8%	NS
Obesity	3	4.8%	22	10.9%	NS
Family history	7	11.1%	27	13.4%	NS
Comorbidity					
Cerebral vascular accident	13	20.6%	44	21.9%	NS
Calcified ascending aorta	9	14.3%	19	9.5%	NS
Peripheral vascular disease	4	6.3%	12	6.0%	NS
Renal dysfunction	13	20.6%	33	16.4%	NS
Hemodialysis	3	4.8%	7	3.5%	NS
Chronic pulmonary obstructive disease	5	7.9%	10	5.0%	NS

Table II. *Surgical results*

	Compression device (n = 63)		*Suction device (n = 201)*		*p*
Number of distal anastomosis	2.1 ± 0.6	(1-4)	2.9 ± 0.9	(1-6)	< 0.0001
Complete revascularization	30	47.6%	177	88.1%	< 0.0001
Coronary anastomosis time/vessel	15.4 ± 6.0	(9-45)	11.5 ± 2.9	(8-24)	< 0.0001
Operation time (minutes)	248.6 ± 44.3	(160-390)	298.0 ± 77.0	(120-675)	< 0.0001
Left internal mammary artery	59	93.7%	194	96.5%	NS
Right internal mammary artery	31	49.2%	89	44.3%	NS
Radial artery	14	22.2%	97	48.3%	< 0.0005
Gastroepiploic artery	23	36.5%	99	49.3%	NS
Inferior epigastric artery	0	0.0%	2	1.0%	NS
Saphenous vein	6	9.5%	48	23.9%	< 0.05
Blood transfusion	10	15.9%	27	13.4%	NS

Table III. *Distribution of distal anastomoses*

	Compression device						
	LAD	*Diagonal*	*HL, OM*	*PL*	*RCA*	*I graft*	*Total distal anastomoses*
Left internal mammary artery	58	2	0	0	0	0	60
Right internal mammary artery	1	11	2	0	13	4	31
Radial artery	0	0	1	2	11	0	14
Gastroepiploic artery	0	0	0	0	22	1	23
Inferior epigastric artery	0	2	0	0	0	0	2
Saphenous vein	1	0	2	1	3	0	7
Total	60	15	5	3	49	5	137
	43.8%	10.9%	3.6%	2.2%	35.8%	3.6%	100.0%

	Suction device						
	LAD	*Diagonal*	*HL, OM*	*PL*	*RCA*	*I graft*	*Total distal anastomoses*
Left internal mammary artery	181	21	3	18	0	1	224
Right internal mammary artery	1	11	2	0	13	4	31
Radial artery	0	15	13	61	21	0	110
Gastroepiploic artery	0	1	1	11	91	0	104
Inferior epigastric artery	0	3	0	0	0	0	3
Saphenous vein	1	4	6	25	21	0	57
Total	183	55	25	115	146	5	529
	34.6%	10.4%	4.7%	21.7%	27.6%	0.9%	100.0%

LAD, Left anterior descending artery; *HL,* high lateral branch; *OM,* obtuse marginal branch; *PL*, posterolateral branch; *RCA,* right coronary artery.

Table IV. *Postoperative outcomes*

	Compression device (n = 63)		*Suction device (n = 201)*		*P*
Intubation (hours)	7.2 ± 8.8	(1-60)	6.9 ± 11.8	(0-115)	NS
ICU stay (days)	2.0 ± 1.6	(1-12)	2.3 ± 2.2	(1-24)	NS
Postop stay (days)	15.0 ± 6.8	(7-53)	13.6 ± 7.4	(4-66)	NS
Major complication (patients)	5	7.9%	17	8.5%	NS
Low output syndrome	0	0.0%	2	1.0%	NS
Postoperative myocardial infarction	2	3.2%	2	1.0%	NS
Cerebral vascular accident	0	0.0%	1	0.5%	NS
Mediastinitis	0	0.0%	5	2.5%	NS
Re-exploration for bleeding	0	0.0%	0	0.0%	NS
Postoperative hemodialysis	0	0.0%	4	2.0%	NS
Pneumonia	2	3.2%	2	1.0%	NS
Ventilator support ≥ 5days	0	0.0%	3	1.5%	NS
Others	1	1.6%	2	1.0%	NS
Inhospital Death	0	0.0%	3	1.5%	NS

performed in group S (115 anastomoses, 21.7%) than in group C (3 anastomoses, 2.2%), $p < 0.0001$ with Bonferroni's correction.

Postoperative results: Postoperative course is displayed in Table IV. Postoperative recovery and the incidence of morbidity and mortality did not differ significantly between two groups.

Follow-up results: Excluding hospital mortalities, the collection of long-term data was completed in all patients (Table V). Due to the availability of coronary stabilization devices, follow-up was significantly longer in group C (2.5 ± 0.8 years) than in group S (1.2 ± 0.4

Table V. *Remote results*

	Compression device	*Suction device*
Number of patients followed	63/63 (100%)	198/198 (100%)
Follow up period (years)	2.5 ± 0.8	1.2 ± 0.4
Total outpatient cardiac events	9 (14.3%)	12 (6.1%)
Angina	4	5
Congestive heart failure	1	2
PTCA	4	1
Arrhythmia	0	3
Others	0	1
Sudden death	0	0
1 year event-free rate	92.0%	96.4%
2 year event-free rate	88.7%	92.0%
3 year event-free rate	84.1%	
Distant death	8 (12.7%)	10 (5.1%)
Cardiac death	2 (3.2%)	2 (1.0%)
Non-cardiac death	6 (9.5%)	8 (4.1%)
1 year survival rate	95.2%	99.0%
2 year event-free rate	88.8%	93.0%
3 year survival rate	86.3%	

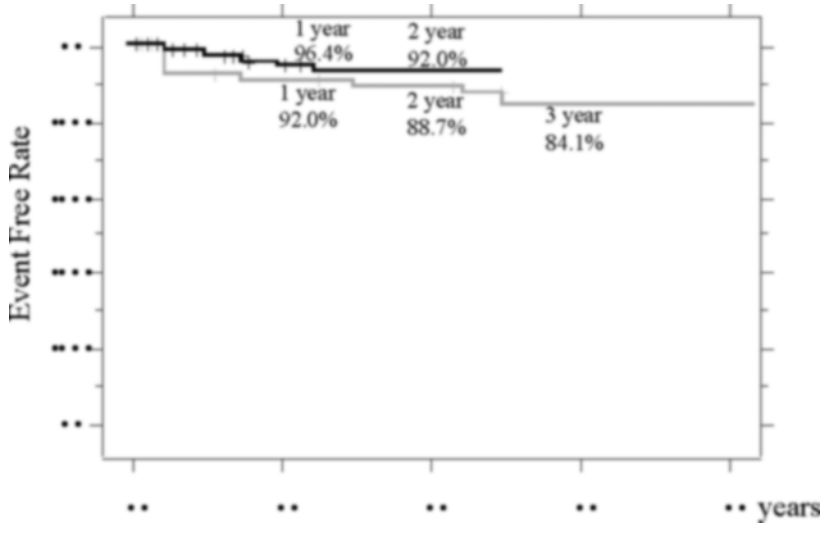

Fig. 1. The black line indicates the event-free curve of patients treated with the suction device and the gray line that for the compression device. There were no significant differences between two groups (p = 0.27).

years). Actuarial 1- and 2-year event-free rates were 92.0% and 88.7% in group C and 96.4% and 92.0% in group S, showing no significant difference during limited follow-up (Fig. 1). Late death occured in 8 patients (12.7%) in group C and 10 (5.1%) in Group S. Actuarial 1- and 2-year survival rates were 95.2% and 88.8% in group C and 99.0% and 93.0% in group S, showing no significant difference (Fig. 2).

Angiographic results: Postoperative angiography was performed for 41 patients in group C and 112 patients in group S. There were no significant differences between the two groups in graft patency (Table VI).

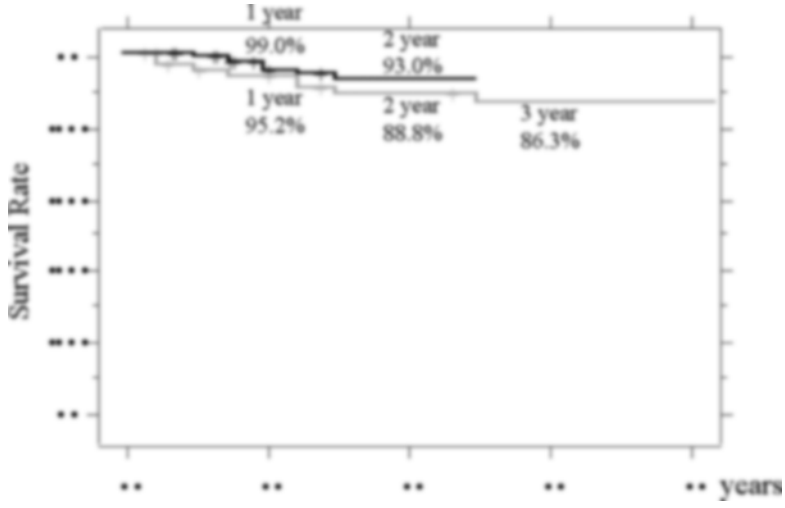

Fig. 2. The black line indicates the survival curve of patients treated with the suction device and the gray line that for the compression device. There were no significant differences between two groups (p = 0.26).

Table VI. *Postoperative angiographic results*

	Compression device 41 patients examined				*Suction device 112 patients examined*			
Type of graft	*Number of distal anastomoses*	*Stenosis free anastomosis (N)*	*(%)*	*Graft occlusion (N)*	*Number of distal anastomoses*	*Stenosis free anastomosis (N)*	*(%)*	*Graft occlusion (N)*
Left internal mammary artery	36	35	97.2	0	123	116	94.3	1
Right internal mammary artery	21	19	90.5	0	56	52	92.9	0
Radial artery	11	9	81.8	1	66	58	87.9	0
Gastroepiploic artery	17	16	94.1	1	56	53	94.6	0
Inferior epigastric artery	0	0		0	3	3	100.0	0
Saphenous vein	4	4	100.0	0	22	22	100.0	0

Discussion

Compression device: The indication for OPCAB varied with the coronary stabilization device. Patient hemodynamics were difficult to maintain when the compression device (first-generation device) was applied to the posterior wall of the heart. During anastomosis of the posterior wall, combination of the rotation of the heart and the use of compression device decreases venous return, deceases cardiac output, and results in hemodynamic instability.[6,7] Thus, the indication for OPCAB using the compression devices was limited to the revascularization of the anterior surface of the heart, such as the LAD and/or right coronary artery. If the heart is small, anastomosis to the high lateral or obtuse marginal branch can be performed using the compression system; however, anastomosis to the posterolateral branch is practically not possible. In our OPCAB series, only 3 patients had the posterolateral branch of the circumflex artery bypassed using a compression device. In the era of the compression device, revascularization of the circumflex artery was contraindicated, and patients with significant lesions on the circumflex artery were commonly referred for on-pump CABG instead.

During the period when only compression devices were used, patients with three vessel disease who underwent OPCAB may have ended up with incomplete revascularization, or undergone on-pump CABG with accepting the risks related to CPB: including stroke and distal emboli related to aortic cannulation,[8] or decreased or altered immune function and inflammatory response.[9,10] Three out of 4 remote incidences of percutaneous transluminal angiography (PTCA) among

group C patients were related to incomplete revascularization.

Suction device: After, the suction device was introduced, revascularization of the circumflex artery was no longer a contraindication to OPCAB. Using the suction device and retropericardial suspension, bypass to the circumflex artery was achieved in almost all patients if there is a significant lesion in the circumflex artery. Since the circumflex artery was not difficult to access, lesions in the left main coronary artery could also be safely revascularized using a suction coronary stabilizer; enabling safe complete revascularization for patients with 3-vessel disease or left main disease by OPCAB.[11] By the use of the suction type of stabilizer, complete revascularization was more frequently achieved and it potentially reduce late cardiac events, such as reoccurrence of angina or the incidence of PTCA. With expanded indications of OPCAB, the number of OPCAB increased dramatically: 63 OPCAB (7.5%) performed among 840 isolated CABG when only the compression device was available, while 201 OPCAB (60.2%) were performed among 334 isolated CABG after the suction device was introduced.

Contraindications: The contraindication to OPCAB is now limited to intramyocardial coronary artery and severely calcified coronary artery. Denudation of the intramyocardial coronary artery on beating heart is unsafe due to the risk of ventricular perforation.[12] Bypassing to the intramyocardial coronary artery should be performed under cardiac arrest with CPB. Anastomosing to the calcified coronary artery under beating heart is technically difficult, because a suture needle cannot be easily pass through the calcified artery. Furthermore, local clamping of the calcified coronary artery using silicone snare loops are not easy and forceful application of the snare loops may result in coronary dissection.

Study limitations: Our study was performed prospective manner but the coronary stabilizer was not randomly assigned. The suction device was available only after the compression device, thus, the results may be biased due to differences in study period. Surgeon' s experience with off-pump procedures and the modification of surgical techniques, such as the introduction of retropericardial sutures may influence improved surgical results in later phase of OPCAB using a suction device.

Due to the recent introduction of OPCAB, long-term results remain unknown, although mid-term results are favorable. Our study was performed with a single surgical group, which may also bias operative data. The majority of patients were referred from outside of the hospital. Only 15% of the patients were followed-up at our outpatient clinic and the others were by local hospitals or private cardiologists, which may also influence late results.

Summary: In OPCAB, use of a coronary stabilization device played a key role in improving early results. Advances in coronary devices are expected to increase the range of patients being referred for OPCAB. Using the suction coronary stabilization device, off-pump multi-vessel coronary revascularization, including the posterior wall of the heart, has been proven to be safe and more complete revascularizations were performed. Therefore, OPCAB using the suction device would potentially reduce the late cardiac events.

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