Original Article

Assessment of On-Pump Beating Coronary Artery Bypass Surgery Performed after Introduction of Off-Pump Approach

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Objective: To clarify the position of on-pump beating coronary artery bypass (CAB) and to define preoperative indicators of intentional conversion to the procedure in the era of advancement of off-pump CAB (OPCAB), we assessed on-pump beating CAB performed after the introduction of OPCAB.

Subjects and Methods: We assessed 130 patients who underwent single CAB [117 (90%) with OPCAB and 13 (10%) with on-pump beating CAB] between August 1999 (when OPCAB was selected as the first-line surgical procedure) and December 2004.

Results: No significant differences were seen between the groups in the number of coronary lesions or the prevalence of left main trunk (LMT) lesion. Reduced left cardiac function, cardiac dilatation, and mitral regurgitation (MR) were more remarkable in the on-pump beating CAB group. Preoperative ischemic condition was generally unstable in the both groups. A conversion to on-pump beating CAB occurred at anastomosis for the left anterior descending (LAD) branch in 61% and for the left circumflex (LCX) branch in 15%. LAD patients had more severe left cardiac dysfunction and cardiac dilatation than LCX patients.

Conclusion: To perform safe and reliable CAB surgery, cardiovascular surgeons should define preoperative indicators of difficult OPCAB and convert OPCAB to on-pump beating CAB intentionally without hesitation when unstable hemodynamics is detected. (Ann Thorac Cardiovasc Surg 2006; 12: 324–32)

Key words: off-pump coronary artery bypass, on-pump beating coronary artery bypass, acute coronary syndrome, severe left cardiac dysfunction, ischemic mitral regurgitation

Introduction

Treatment strategies for ischemic heart diseases are complicated by the development of off-pump coronary artery bypass (OPCAB) surgery and drug-eluting stents. Since percutaneous coronary intervention is indicated in a wider range of cases and the remaining severe cases are subject to surgical revascularization, the best surgical approach should be selected carefully among OPCAB, on-pump beating coronary artery bypass (CAB), and conventional CAB performed on non-beating hearts. While OPCAB that is advanced by improved surgical techniques and the development of new devices is introduced aggressively even in high-risk patients for cardiopulmonary bypass (CPB) (e.g., patients with severe calcification of the ascending aorta, elderly patients, and those complicated by cerebrovascular disorder, malignancy, multiple atheroscle-

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rosis, renal failure, and/or respiratory failure), on-pump beating and conventional CAB surgery remain as widely-used revascularization approaches even after the appearance of such a new procedure.[1)] To clarify the position of on-pump beating CAB involving more invasive procedures with CPB than OPCAB and to define the criteria for performing on-pump beating CAB, we compared cases of on-pump beating CAB performed after the introduction of OPCAB with cases of OPCAB.

Subjects and Methods

Since the introduction of OPCAB as the first line revascularization procedure at our hospital, 130 patients underwent single CAB surgery between August 1999 and December 2004. They consisted of 117 patients (90%) treated with OPCAB and 13 (10%) treated with on-pump beating CAB. The three objectives of this study were: 1) to trace the history of CAB surgeries and to assess the revascularization ratio of each surgery; 2) to compare pre-, peri-, and postoperative factors in on-pump beating CAB cases with those in OPCAB cases; and 3) to assess characteristics of patients treated with on-pump beating CAB.

Surgical procedure

The OPCAB system consisted of a heart positioner, a stabilizer, elastic suture, a coronary shunt tube, and a carbon dioxide blower. The left internal thoracic artery (LITA) was initially anastomosed to the left anterior descending (LAD) artery. Bilateral internal thoracic or radial arteries were used as arterial grafts. Venous bypass grafting was performed with proximal anastomosis, by means of a proximal anastomosis device. Intra-aortic balloon pumping (IABP) application is the status of unstable hemodynamics [ST change, frequent atrium or ventricular arrhythmia, pulmonary-to-systemic pressure (Pp-Ps) ratio of more than 0.5, decrease of cardiac index] due to coronary ischemia. The increased frequency of use of the intra-aortic balloon pumping is attributed to the improvement of various devices, coronary shunt tubes and advanced surgical skills. On-pump beating CAB was performed in patients with unstable hemodynamics (Pp-Ps ratio of more than 0.5, refractory arrhythmia) requiring circulatory support mostly attributed to dilated heart due to ischemic remodelling, cardiogenic shock due to acute coronary syndrome (ACS) and reversible ischemic mitral regurgitation. CPB was established by delivering the blood from the superior and inferior vena cava to the ascending aorta. Blood flow was controlled with preserved intrinsic pressure according to the presence or absence of multiorgan disorder. Devices used, grafts selected, and anastomosis procedures used were the same as those for OPCAB.

Statistical Analysis

To compare the OPCAB and on-pump beating CAB groups, data expressed as the mean ± standard deviation (SD) were analyzed with Student's t test, chi-square for independence test, and Fisher's exact probability test. The level of significance was $p<0.05$.

Results

History of CAB surgeries and revascularization ratio

The history of CAB surgeries at our hospital from 1999 when OPCAB was introduced is described below. In 1999, conventional CAB grafting accounted for 16.7% of all cases, intraaortic balloon pump-supported OPCAB for 33%, and OPCAB for 50%. No on-pump beating CAB was performed. In 2000, the proportion of conventional CAB cases decreased. In 2001 and thereafter, no conventional CAB was performed. However, the proportion of on-pump beating CAB and OPCAB cases increased with the reduced frequency of IABF (Fig. 1). These changes are mostly attributed to the improvement of various devices advancing surgical skills.

The revascularization ratio is computed with the number of CAB cases divided by the number of coronary lesions. In 2001 and thereafter, the ratio was elevated to 1.0 or more (Fig. 2). This elevation seems to be related largely to the appearance of a coronary shunt tube. A swift conversion from OPCAB to on-pump beating CAB for total revascularization in patients with unstable hemodynamics can also have played a role in the elevation.

Comparison of pre-, peri-, and postoperative factors in on-pump beating CAB cases with those in OPCAB cases

a. Preoperative factors

The mean age (±SD) was 65.7±8.6 years in the OPCAB group and 63.5±9.0 years in the on-pump beating CAB group. The male/female ratio was 86/31 in the OPCAB group and 11/2 in the on-pump beating CAB group. With regard to risk factors, no statistically significant differences were found between the groups in the prevalence of diabetes mellitus (DM) (51.6% in the OPCAB group

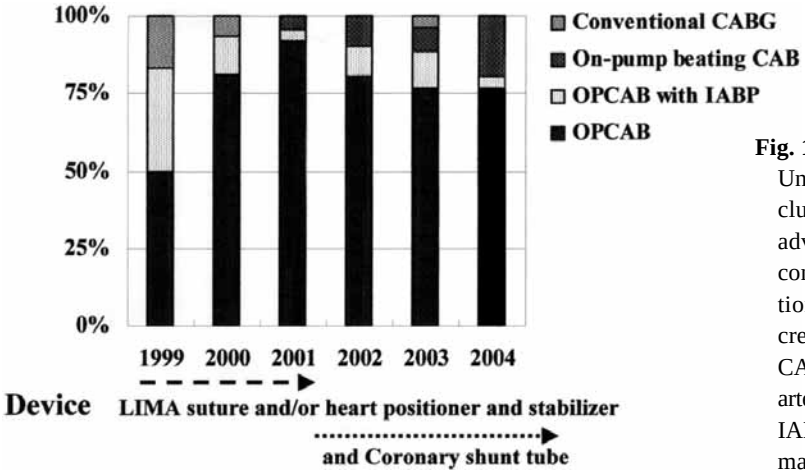

Fig. 1. History of CAB grafting at our hospital.
Under the impact of improvement of various devices including a heart positioner and a heart stabilizer and an advance in surgeon's skills, in 2001 and thereafter, no conventional CAB was performed, whereas the proportions of on-pump beating CAB and OPCAB cases increased with reduced use frequency of IABP.
CABG, coronary artery bypass grafting; CAB, coronary artery bypass; OPCAB, off-pump coronary artery bypass; IABP, intra-aortic balloon pumping; LIMA, left internal mammary artery.

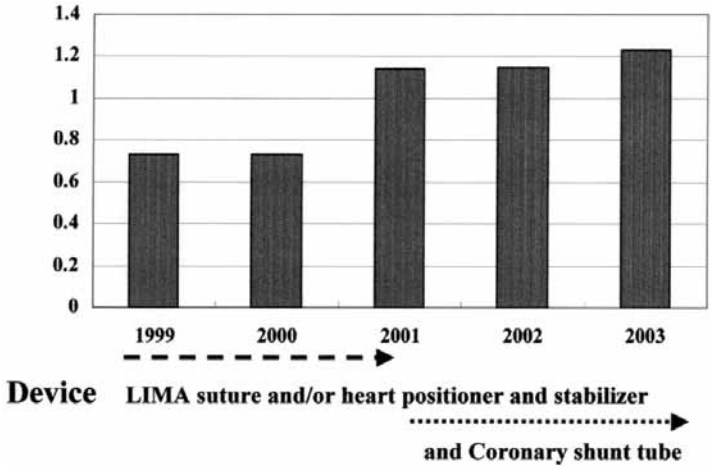

Fig. 2. Changes in revascularization ratios.
(Revascularization ratio = number of CAB cases/number of coronary lesions)
Owing to the appearance of a coronary shunt tube as well as to the improvement of various devices and an advance in surgeon's skills, the ratio was elevated to 1.0 or more in 2001 and thereafter. This elevation is also related to a swift conversion from OPCAB to on-pump beating CAB for total revascularization in patients with unstable hemodynamics.

versus 69.2% in the on-pump beating CAB group), that of cerebrovascular disorder (CVD) (22.2% versus 15.4%), or the rate of hemo dialysis (HD) (17.9% versus 23.0%). Whereas the prevalence of renal dysfunction with increased serum creatinine (S-Cr) levels was significantly higher in the on-pump beating CAB group (76.9%) than in the OPCAB group (38.0%)($p<0.05$).

No statistically significant differences were seen between the OPCAB and on-pump beating CAB groups in the number of coronary artery lesions (2.5 ± 0.7 versus 2.6 ± 0.5) or the proportion of patients with a left main trunk (LMT) lesion (23% versus 38%). Reduced left cardiac function and cardiac dilatation due to remodelling were significantly more remarkable in the on-pump beating CAB group than in the OPCAB group. This is evident by the left ventricular (LV) ejection fraction (LVEF; 0.62 ± 0.12 in the OPCAB group versus 0.45 ± 0.12 in the on-pump beating CAB group; $p<0.01$) and the LV end-diastolic diameter (LVEDD; 51.8 ± 7.0 mm versus 59.5 ± 6.9 mm; $p<0.01$). The proportion of patients with moderate or severe mitral regurgitation (MR) was significantly higher in the on-pump beating CAB group (23%) than in the OPCAB group (0%) ($p<0.01$)(Table 1).

The preoperative ischemic condition was unstable angina pectoris in many patients in both groups. In the OPCAB group, the condition was unstable angina pectoris in 52.7% of all patients, stable angina pectoris in 30.1%, acute myocardial infarction (AMI) in 8.6%, and impending myocardial infarction (IMI) in 8.6%. In the on-pump beating CAB group, the condition was unstable angina pectoris in 38.6% of all patients, AMI in 7.6%, and ischemic heart failure (IHF) in 53.8%. IHF accompanied by ischemic MR was significantly more frequent

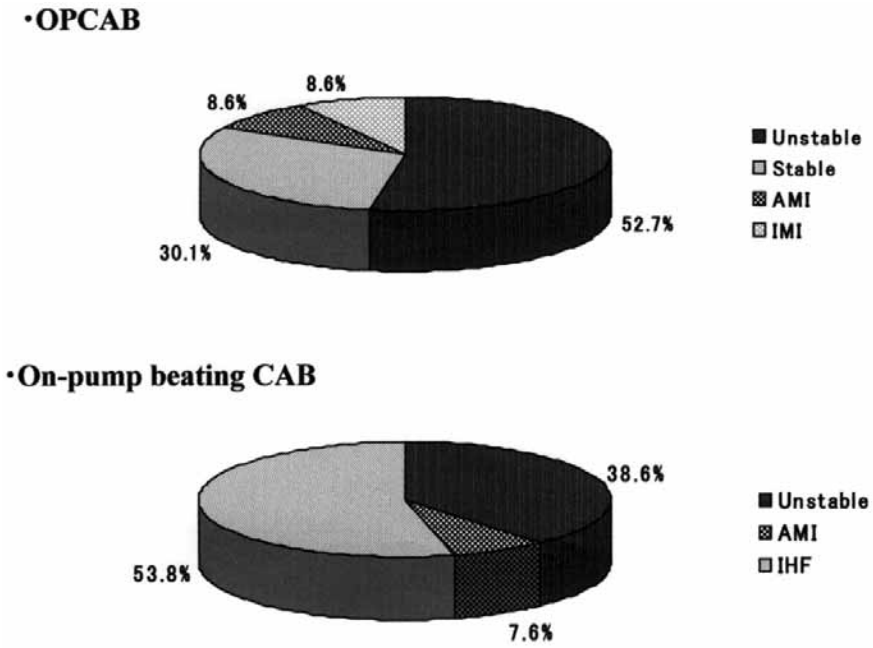

Fig. 3. Preoperative ischemic condition.
Unstable angina pectoris was found in many patients in both groups. IHF accompanied by ischemic MR was more frequent in the on-pump beating CAB group than in the OPCAB group.
OPCAB, off-pump coronary artery bypass; unstable, unstable angina pectoris; stable, stable angina pectoris; AMI, acute myocardial infarction; IMI, impending myocardial infarction; CAB, coronary artery bypass; IHF, ischemic heart failure.

in the on-pump beating CAB group (23%) than in the OPCAB group (0%) ($p<0.01$)(Fig. 3).

b. Perioperative factors

No significant differences were noted between the OPCAB and on-pump beating CAB groups in the number of bypasses (2.5±1.1 versus 2.8±1.1) or the coronary revascularization ratio (CRR)(1.1±0.4 versus 1.0±0.3) (Table 2).

c. Postoperative factors

No findings suggesting myocardial disorder were obtained in either group, as shown by the postoperative maximum creatinine kinase MB (Max CK-MB) fraction of 19.3±7.3 IU/l in the OPCAB group and 20.6±6.0 IU/l in the on-pump beating CAB group (excluding patients with preoperative AMI). After surgery, no serious complications nor perioperative death occurred in either group. Postoperative results were favorable, except for a hospital death that occurred in 0.8% of patients in the OPCAB group.

Table 1. Preoperative factors

	OPCAB	On-pump beating CAB	p value
Number	117	13	
Age (year)	65.7±8.6	63.5±9.0	NS
Gender (M/F)	86/31	11/2	NS
DM (%)	51.6	69.2	NS
CVD (%)	22.2	15.4	NS
HD (%)	17.9	23.0	NS
Renal dysfunction (S-Cr>1.0 mg/dl) (%)	38.0	76.9	<0.05
Coronary artery lesion	2.5±0.7	2.6±0.5	NS
LMT (%)	23	38	NS
LVEF	0.62±0.12	0.45±0.12	<0.01
LVEDD (mm)	51.8±7.0	59.5±6.9	<0.01
MR (>moderate) (%)	0	23	<0.01

Patients in the on-pump beating CAB group showed an increase in serum creatinine levels ($p<0.05$ in comparison with the OPCAB group), reduced cardiac function due to remodelling, cardiac dilatation, and moderate mitral regurgitation ($p<0.01$ in comparison with the OPCAB group).
M, male; F, female; DM, diabetes mellitus; CVD, cerebrovascular disorder; HD, hemodialysis; S-Cr, serum creatinine; LMT, left main trunk; LVEF, left ventricular ejection fraction; LVEDD, left ventricular end-diastolic diameter; MR, mitral regurgitaion; OPCAB, off-pump coronary artery bypass; CAB, coronary artery bypass; NS, not significant.

Characteristics of patients treated with on-pump beating CAB

Before surgery, IHF was frequent in the on-pump beating CAB group. The mean brain natriuretic peptide level was 545.6±358.9, and 61.5% of the patients used catecholamine preoperatively. In the patients in the on-pump beating CAB group, OPCAB was attempted initially for revascularization but was converted intentionally or accidentally to on-pump beating CAB for various reasons. Intentional conversion occurred in 92.3% of the patients, and accidental conversion in 7.7%. This finding indicates that the practicability of OPCAB was determined quickly, resulting in intentional conversion to avoid accidental conversion.

To use CPB, blood flow was controlled with preserved intrinsic pressure according to the presence or absence of multiorgan disorder. Of the patients under the CPB support, 61.5% received 100% support, 7.6% received 60–70% support, and 30.9% received 30–50% support. To maintain coronary flow, IABP was used in 38.4% of the patients, and a coronary shunt tube in 92.3% (Fig. 4).

As regarding the timing of conversion from OPCAB to on-pump beating CAB, it occurred with the Pp-Ps ratio exceeding 0.5 at anastomosis for the LAD branch in 61% of the patients, with the Pp-Ps ratio exceeding 0.5 at anastomosis for the left circumflex (LCX) branch in 15%, with the Pp-Ps ratio exceeding 0.5 at pericardotomy in 8%, with abnormal intramuscular coronary artery in 8%, and with severe LV adhesion in 8%.

When preoperative factors were assessed for patients with the Pp-Ps ratio exceeding 0.5 at anastomosis for the LAD (LAD subgroup) and those with the Pp-Ps ratio exceeding 0.5 at anastomosis for the LCX (LCX subgroup), the LAD subgroup had significantly severe cardiac dilatation due to remodelling, as evidenced by the LVEF of 0.43±0.13% in the LAD subgroup versus 0.54±0.16% in the LCX subgroup ($p<0.05$), the LVEDD of 58.2±5.6 mm versus 54.0±1.3 mm ($p<0.05$), and the LV end-diastolic volume (LVEDV) of 179.6±34.1 ml versus 142.0 ±7.1 ml ($p<0.05$)(Fig. 5).

The above results indicate that on-pump beating CAB was performed in patients with unstable hemodynamics associated with ACS, chronic ischemia, cardiac dilatation associated with remodelling due to infarction, reduced left cardiac function, ischemic MR, abnormal intramuscular coronary artery, severe calcification, or coronary narrowing.

Table 2. Peri- and postoperative factors

	OPCAB	On-pump beating CAB	p value
IABP (%)			
Pre	11.7	30.8	NS
Peri	17.6	38.5	<0.05
Post	11.7	41.7	<0.05
CAB	2.5±1.1	2.8±1.1	NS
CRR	1.1±0.4	1.0±0.3	NS
Max CK-MB (IU/l)	19.3±7.3	20.6±6.0	NS
Severe complication (%)	0	0	NS
Perioperative death (%)	0	0	NS
Hospital death (%)	0.8	0	NS

Findings suggesting myocardial disorder, serious complications, or perioperative death were not observed in either group. Postoperative results were favorable, except a hospital death that occurred in 0.8% of patients in the OPCAB group.
IABP, intra-aortic balloon pumping; CAB, coronary artery bypass number; CRR, coronary revascularizaion ratio (coronary artery bypass number/coronary lesion); Max CK-MB, maximum creatinine kinase-MB; OPCAB, off-pump coronary artery bypass; CAB, coronary artery bypass; NS, not significant.

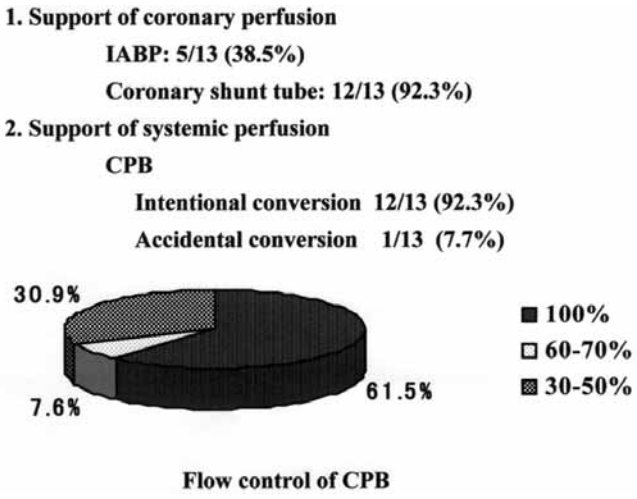

Fig. 4. Coronary perfusion support and CPB in on-pump beating CAB cases.
To use CPB, blood flow was controlled with preserved intrinsic pressure according to the presence or absence of multiorgan disorder.
IABP, intra-aortic balloon pumping; CPB, cardiopulmonary bypass; CAB, coronary artery bypass.

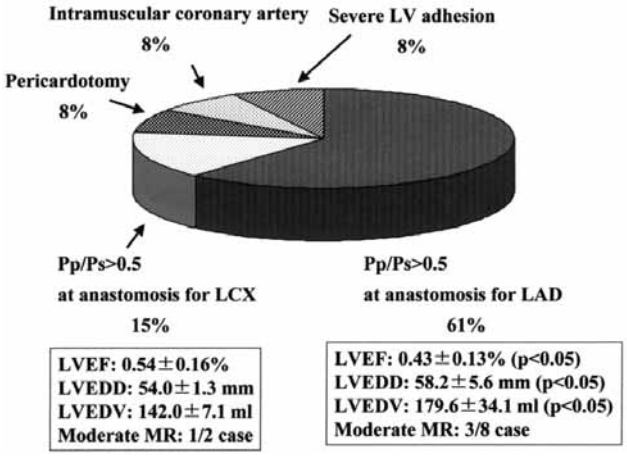

Fig. 5. Timing of conversion to on-pump beating CAB and patient characteristics.
Patients with the Pp-Ps ratio exceeding 0.5 at anastomosis for the LAD had severe cardiac dilatation due to remodelling and a more frequent conversion to on-pump beating CAB than those with the Pp-Ps ratio exceeding 0.5 at anastomosis for the LCX. LV, left ventricular; Pp/Ps, pulmonary-to-systemic pressure; LCX, left circumflex; LAD, left anterior descending; LVEF, left ventricular ejection fraction; LVEDD, left ventricular end-diastolic diameter; LVEDV, left ventricular end-diastolic volume; MR, mitral regurgitaion.

Discussion

Among a total of 14,947 cases of single CAB grafting in Japan, OPCAB cases have increased in number at an accelerating pace since 1996 and have reached 7,853 cases (52.5%). However, the number of bypasses is clearly greater for on-pump beating CAB than for OPCAB, based on the mean number of bypasses (3.02 versus 2.55), according to nationwide survey results from cardiovascular surgeons in 2003.[1)] Through comparisons between OPCAB and off-pump beating CAB,[2,3)] the usefulness of OPCAB was proposed in every respect.[4–10)] The efficacy of OPCAB has been verified since 2000 in the era of advancement of OPCAB with ever-increasing cases. The advancement is definitively attributed to six factors: 1) improved graft selection and harvest; 2) appearance of a heart positioner and a stabilizer for the expansion of visual field and the achievement of stationary field; 3) appearance of a coronary shunt tube; 4) appearance of a proximal anastomosis device for grafting; 5) improved anastomosis techniques of surgeons;[11,12)] and 6) cooperation of anesthesiologists, medical engineers, and operating room staff who can take appropriate measures against changes in hemodynamics on a case-by-case basis. At our hospital, the validity of OPCAB as a standard procedure was discussed based on the revascularization ratio and postoperative results. We found that OPCAB can achieve total arterial revascularization with the use of various devices, and postoperative results did not vary according to surgical urgency, the presence or absence of DM, that of renal dysfunction, or the severity of coronary lesions. OPCAB is thus considered appropriate as a standard coronary revascularization procedure.

Some patients, however, require a conversion from OPCAB to on-pump beating or conventional CAB because of unstable hemodynamics. The safety of surgical revascularization procedure, revascularization ratio, and development of perioperative complications may depend on the type of conversion, namely, accidental or intentional conversion. At present when safer and more reliable surgery is sought, cardiovascular surgeons should quickly determine the necessity of conversion from OPCAB to on-pump beating or conventional CAB with a proper analysis of pre- and perioperative hemodynamics. Advisability of OPCAB is discussed in terms of methods of graft harvest, expansion of visual field and achievement of stationary field by means of various devices, and each surgeon's skill. For OPCAB to become a standard procedure in the future, more definite preoperative indicators are required. At present, a conversion to on-pump beating CAB is often associated with the following conditions: 1) poor hemodynamics due to ACS; 2) severe left ventricular function due to myocardial remodelling resulting from myocardial infarction and/or chronic ischemia; 3) mitral valve tethering due to reversible myocardial ischemia; and 4) severe coronary calcification, abnormal intramuscular coronary artery, or coronary narrowing.

The use of CPB causes problems in the following patients: 1) elderly patients; 2) those with cerebrovascular disorder; 3) those with previous cerebral infarction; 4) those with severe aortic sclerosis; 5) those with malignancy; 6) those with obstructive ventilatory disturbance; and 7) those with renal dysfunction. Most coronary disorder patients have cerebrovascular disorder concomitantly, which is regarded as a major issue. Stamou et al.[13)] reported that the risk of postoperative cerebral infarction was 1.8 times higher for on-pump beating CAB than for OPCAB through a study of 2,320 OPCAB and 8,069 on-pump beating CAB cases. Another report suggested a decrease in neurocognitive function associated with pump use.[14)] Maintenance of pulse pressure with no use of CPB

is reported to be effective in cases of preoperative multiorgan disorder, such as those complicated by obstructive ventilatory disturbance or by renal dysfunction.[15] Furthermore, OPCAB is reported to allow the avoidance of acute pulmonary disorder associated with systemic inflammatory reactions to CPB.[16]

Poor hemodynamics due to ACS

Conventional CAB grafting performed on non-beating hearts within 48 hours after the onset of acute myocardial infarction resulted in a markedly high operative mortality at 8.3%.[17] Locker et al.[18] reported that the operative mortality after emergency CAB for AMI was higher for on-pump beating CAB (24%) than for OPCAB (5%), while the incidences of late death, recurrent angina, and re-intervention were higher for OPCAB than for on-pump beating CAB. These late results seem to reflect reduced anastomotic accuracy and total revascularization ratio in patients who underwent OPCAB. Effectiveness of on-pump beating CAB in patients with ACS or cardiogenic shock is uncontroversial; on-pump beating CAB performed on beating hearts is reported to be more effective than conventional CAB without reduced quality of revascularization in patients with poor hemodynamics that precludes OPCAB.[19] On the other hand, OPCAB for LAD lesions is reported to be possible when reflection at anastomosis is mild and has a minor effect on cardiac function and when preoperative hemodynamics is acceptable.[20] In any case, for patients with unstable hemodynamics, OPCAB should be converted intentionally to on-pump beating or conventional CAB without hesitation, or on-pump beating or conventional CAB should initially be planned, to preserve perioperative perfusion of other organs.

Severe left ventricular dysfunction due to myocardial remodelling resulting from myocardial infarction and/or chronic ischemia

Among ischemic heart diseases, multivessel lesions with reduced left cardiac function are often related to poor prognosis. Treatments for these lesions include drug therapy, percutaneous coronary intervention, and CAB grafting. Of those, CAB grafting is the most effective in terms of late results; it is reported to improve long-term vital prognosis and to relieve clinical symptoms.

Some investigators reported the successful use of OPCAB in patients who had multivessel lesions with reduced left cardiac function with the LVEF of 0.3 or less.[21,22] On the other hand, Al-Ruzzeh et al.[23] reported that the use of CPB did not increase risks in cases of reduced left cardiac function. They compared operative results of OPCAB with those of on-pump beating CAB in 305 CAB patients with the LVEF of less than 3.0. While the operative mortality was 6.6% for OPCAB and 14.1% for on-pump beating CAB, risk factors included ventricular tachycardia and fibrillation but did not include the use of CPB in the patients with reduced left cardiac function. This report suggests that CPB can be used without hesitation in patients with reduced left cardiac function to maintain favorable hemodynamics and to achieve safe and reliable revascularization.

Mitral valve tethering due to reversible myocardial ischemia

Marked LV dilatation due to remodelling resulting from myocardial infarction and/or chronic ischemia and MR due to tethering should be treated aggressively with left ventriculoplasty, LV volume reduction surgery, or mitral annuloplasty, whereas MR associated with transient myocardial ischemia can be relieved with revascularization. However, cardiac reflection in such a case may cause an unstable condition with the Pp-Ps ratio exceeding 0.5, which may preclude safe and reliable revascularization. Cardiac output at anastomosis of the circumflex region is reported to have a 20% reduction.[18] In such a case, on-pump beating CAB should be selected.

Severe coronary calcification, abnormal intramuscular coronary artery, or coronary narrowing

Measures for coronary arteries with difficult anastomosis are often dependent on the surgeon's skill. Various methods are attempted for detecting embedded coronary arteries.[24,25] These embedded arteries cannot be stabilized with devices securely and lead to difficult anastomosis in many cases.

In the present study, we assessed cases of CAB performed by the same surgeon between August 1999 (when OPCAB was introduced and selected as the first-line surgical revascularization procedure in principle at our hospital) and December 2004. Operative results of OPCAB as well as the surgeon's leaning curve are satisfactory. Safe and reliable revascularization was achieved with a conversion from OPCAB to on-pump beating or conventional CAB according to circumstances. A conversion to on-pump beating CAB occurred in the following conditions: 1) poor hemodynamics due to ACS; 2) reduced left cardiac function due to myocardial remodelling resulting from myocardial infarction

and/or chronic ischemia; 3) mitral valve tethering due to reversible myocardial ischemia; and 4) severe coronary calcification, abnormal intramuscular coronary artery, or coronary narrowing. The conversion allowed total arterial revascularization and caused neither serious complications nor operative death.

Potential preoperative indicators of a conversion to on-pump beating CAB include the following: 1) ACS; 2) LVEF of 0.45 or less, LVEDD of 60 mm or more, and/or LVEDV of 180 ml or more because of remodelling; 3) moderate mitral regurgitation secondary to IHF requiring catecholamine; and 4) severe coronary calcification in the circumflex region, abnormal intramuscular coronary artery, or coronary narrowing.

Through the development of drug-eluting stents, coronary surgery is indicated more frequently in difficult cases, such as those complicated by diffuse lesions, coronary narrowing with calcification, renal dysfunction, reduced cardiac function, LV dilatation, or ischemic MR. Safe and reliable revascularization is needed for these technically difficult cases. In the past, OPCAB was performed by necessity in patients in whom CPB was contraindicated, but at present and in the future, on-pump CAB will be selected in cases with difficulties in performing OPCAB. While the usefulness of OPCAB is being established, cardiovascular surgeons can obtain the trust of patients and internists by converting OPCAB to on-pump beating CAB without hesitation.

Conclusion

Results of our assessments indicate that on-pump beating CAB can allow high-quality revascularization with the use of excellent devices, IABP to avoid myocardial ischemia, a coronary shunt tube, CPB for hemodynamic stabilization, and blood flow control to avoid organ disorders. To perform safe and reliable CAB surgery, cardiovascular surgeons should define preoperative indicators of difficult OPCAB and convert OPCAB to on-pump beating CAB intentionally without hesitation when unstable hemodynamics are detected.

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