Original Article

Systematic Off-pump Coronary Artery Bypass

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Purpose: We assessed the feasibility of systematic off-pump coronary artery bypass (OPCAB) and identified risk factors for on-pump conversion.

Methods: Between July 1, 2002 and December 31, 2003, OPCAB was attempted for all patients who required isolated coronary artery bypass in our institution. The perioperative results of patients were prospectively entered into a structured database, the results were analyzed to identify the risks of requirement of cardiopulmonary bypass.

Results: OPCAB was performed in all but 4 patients, giving an OPCAB success rate of 98.3% (229/233). The reason for cardiopulmonary bypass was hemodynamic instability occurring during reoperative surgery in 3, and cardiogenic shock in 1. The isolated risk factor for on-pump conversion was reoperation (relative risk 11.6). Mean number of distal anastomoses performed under OPCAB was 3.7±1.2, and the complete revascularization rate was 92.1% (211/229). There was one hospital death (0.4%). During a mean follow-up period of 1.0±0.4 years, two patients developed angina, which were treated with catheter intervention; otherwise, there was no death, or other cardiac events observed.

Conclusion: Systematic OPCAB was feasible except in patients undergoing reoperative surgery or patients with on-going deep cardiogenic shock. Systematic OPCAB provided successful complete revascularization and its short term results were acceptable. (Ann Thorac Cardiovasc Surg 2005; 11: 172–7)

Key words: coronary artery bypass, mortality and morbidity, off-pump

Introduction

Off-pump coronary artery bypass (OPCAB) has theoretical advantages to on-pump coronary artery bypass (ONCAB), including less inflammatory effect, avoidance of distal emboli related to cannulation, and more physiologic myocardial preservation.[1)] Practically, the expected advantages of OPCAB include lower of myocardial enzyme release, less postoperative systemic inflammatory reactions, better neurological outcome, fewer blood transfusions, and shorter length of postoperative recovery. A number of retrospective studies have pointed out better outcomes after OPCAB,[2-4)] and the advantage of OPCAB has been more clearly demonstrated in high risk patients,[5,6)] although a randomized study of the OPCAB versus ONCAB failed to identify the clear outcome benefits of OPCAB.[7)] There are disadvantages of OPCAB related to technical limitations, such as incomplete revascularization especially bypass for the posterior or lateral wall of the heart, and there are questions about anastomosis quality. However, with the development of new devices and techniques, multivessel OPCAB has been conducted safely by our surgical team.[8)] Since we moved into the current institution in July 2002, OPCAB has been performed systematically, regardless of the anatomy of

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the coronary lesions, urgency of surgery, or status of reoperations. This study investigated the feasibility of systematic OPCAB and identified the risk factors of on-pump conversion.

Methods

Patients

Perioperative and remote data of patients who underwent cardiac surgery at Juntendo University Hospital were prospectively entered into a structured database, since staff surgeons moved to Juntendo University in July 2002. All patients, except for those requiring valvular or left ventricular surgery, were scheduled for OPCAB rather than ONCAB. Informed consent was obtained from patients prior to surgery, and it included the possibility of intraoperative conversion to ONCAB. Patients who underwent minimally invasive direct coronary artery bypass (MIDCAB) via mini-sternotomy or subxiphoid incision for single vessel revascularization were excluded from this study. No other patients were excluded from this study on the basis of pattern of coronary artery disease, urgency of surgery, or status of reoperation. Between July 1, 2002 and December 31, 2003, a total of 233 consecutive isolated coronary artery bypass grafting (CABG) were performed in our institution and the demographics are shown in Table 1. There were no patients in deep cardiogenic shock requiring salvage operation in our series. The mean EuroSCORE[9] was 4.2±3.4 (range 0-17), and the predicted mortality rate was 5.1±9.0% (range 0.8-70.7).

Table 1. Preoperative patient demographics

n	233	
Clinical characteristics		
Age	65.8±9	(37-87)
Age over 75	44	18.9%
Female sex	41	17.6%
Cardiac profile		
Unstable angina	70	30.0%
Acute myocardial infarction	16	6.9%
Intra-aortic balloon pump	19	8.2%
History of congestive heart failure	17	7.3%
Poor ejection fraction (<40%)	22	9.4%
Atrial fibrillation	6	2.6%
Redo surgery	14	6.0%
Urgent surgery	31	13.3%
Emergent surgery	25	10.7%
Left main disease	80	34.3%
Three vessel disease	153	65.7%
Coronary risk factors		
Hypertension	160	68.7%
Diabetes	122	52.4%
Insulin user	39	16.7%
Hyperlipidemia	125	53.6%
Smoking	121	51.9%
Obesity	49	21.0%
Family history	38	16.3%
Peripheral vascular disease	18	7.7%
Cerebral vascular accident	38	16.3%
Chronic pulmonary disease	2	0.9%
Calcified ascending aorta	54	23.2%
Active malignancy	8	3.4%
Renal dysfunction	24	10.3%
Hemodialysis	13	5.6%
EuroSCORE	4.2±3.4	0-17

Surgery

All patients underwent midline sternotomy. Cardiopulmonary bypass and perfusionists were standing-by without priming the pump. After appropriate conduits were harvested, the target vessels were examined. Distal anastomoses were performed using a suction type coronary stabilizer (Octopus III or IV, Medtronic, Minneapolis, MN). Posterior wall exposure was facilitated with the placement of retropericardial sutures and with the patient in a Trendelenburg position. The order of a bypass was posterior wall first, then lateral wall and lastly anterior wall. For unstable angina with a culprit lesion in the left anterior descending artery (LAD) and for a left main lesion, the LAD was first anastomosed to one of the internal mammary arteries (IMAs) before performing revascularization of the posterior wall. EKG changes during local occlusion or high flow coronary arteries were an indication for intracoronary shunt. The bypass conduits and targets were based on the patients coronary anatomy; however, in general, the LAD was bypassed with one of the IMAs, the right coronary artery was bypassed with the gastroepiploic artery, and the circumflex artery was bypassed with the radial artery or saphenous vein, as described previously.[10]

Data collection

Perioperative data were prospectively collected. Outpatient follow-up was completed by the end of February 2004 by medical record or contact with the primary cardiologist of the patient. Incomplete revascularization was defined as if at least one territory of the diseased coronary arteries (LAD, circumflex, and right coronary artery) was not revascularized. Remote myocardial infarction, angina, arrhythmia requiring hospitalization, congestive heart failure requiring hospitalization, coronary reintervention, and sudden death were defined as cardiac

Table 2. Surgical results

n	229	
Number of distal anastomosis	3.7±1.2	(2-7)
Bilateral internal mammary artery	73	31.9%
Total arterial revascularization	175	76.4%
Aorta non-touch surgery	98	42.8%
Complete revascularization	211	92.1%
Blood transfusion	41	17.9%
Left internal mammary artery	221	96.5%
Right internal mammary artery	78	34.1%
Radial artery	158	69.0%
Gastroepiploic artery	128	55.9%
Saphenous vein	54	23.6%
Area of revascularization		
Anterior territory (LAD or diagonal)	229	100.0%
Leteral territory (circumflex)	182	79.5%
Posterior territory (right coronary)	167	72.9%
Reasons for incomplete revascularization		
Total occluded or hypoplastic system	5	
Small coronary artery (<1 mm)	11	
Mild stenosis (<75%)	2	

Table 3. Postoperative results

n	229	
Intubation (hours)	6.5±8.1	(0-60)
ICU stay (days)	2.3±1.8	(0-11)
Postop stay (days)	12.8±9.4	(2-121)
In-hospital death	1	0.4%
Postoperative congestive heart failure	2	0.9%
Postoperative myocardial infarction	1	0.4%
Respiratory failure (intubation more than 24 hours)	2	0.9%
Pneumonia	1	0.4%
Severe arrhythmia	1	0.4%
Cerebral vascular accident	1	0.4%
Re-exploration for bleeding	1	0.4%
Postoperative hemodialysis	2	0.9%
Mediastinitis	2	0.9%

events. Catheterization at 1 year was recommended for the patients followed-up at out institute regardless symptoms.

Statistical analysis

Results are expressed as mean ± standard deviation or number and percentage, as appropriate. Statistical analysis was performed using Student's *t*-test for continuous variables or Chi-square tests (Fisher's exact tests if n<5) for categorical variables. Logistic regression analyses were performed to identify the risk factors for ONCAB conversion. The variables entered into the logistic regression analysis included preoperative and intraoperative factors described in Table 1 and Table 2. A *p*-value less than 0.05 was considered significant. All statistics were carried out by JMP version 5 (SAS, Cary NC).

Results

OPCAB

Among 233 consecutive patients, 4 patients required conversion to ONCAB, giving OPCAB a success rate of 98.3% (229/233). Of these cases requiring cardiopulmonary bypass support, 3 were reoperation (2 patients sustained graft injury during chest re-entry, and the other one had dense adhesion preventing dissection of the heart without decompression using cardiopulmonary bypass.) and another patient developed cardiogenic shock after anesthesia induction due to abrupt occlusion of the LAD. The 3 reoperative patients were cannulated from the groin but the last patient was cannulated from the ascending aorta and right atrium in a standard fashion. All 4 patients who required cardiopulmonary bypass completed CABG without clamping the aorta and recovered without any postoperative complications. The only significant risk factor of on-pump conversion was reoperation (relative risk 11.6, 95% confident level 5.7-619.1). The OPCAB success rate was significantly higher in primary CABG (99.5%, 218/219) than in reoperative CABG (78.6%, 11/14), p<0.001.

Surgical results

Surgical results of 229 patients who completed OPCAB are shown in Table 2. The mean number of distal anastomoses of these patients was 3.7±1.2, and the complete revascularization rate was 92.1% (211/229). The details of incomplete revascularization are also shown in Table 2.

There was one hospital death (0.4%) due to arrhythmia related to perioperative myocardial infarction. The major complications are listed on Table 3. The incidences of each major complication were less than 1%. One patient with severe carotid disease (total occlusion on the right and 90% stenosis on the left carotid artery), who underwent all in-situ bypass, developed a stroke on postoperative day 2. Intubation time, ICU stay, and postoperative stay were 6.5±8.1 hours, 2.3±1.8 days, and 12.8±9.4 days, respectively. The mean in-hospital rehabilitation was 5.4±5.3 days.

Remote results

Postoperative follow-up was completed in all patients with a period of 1.0±0.4 years. There was no remote

Table 4. Follow-up results

Number of patients followed	228	100%
Follow-up period (years)	1.0±0.4	
Angina	2	0.9%
Catheter intervention or reoperation	2	0.9%
Congestive heart failure	0	0.0%
Arrhythmia	0	0.0%
Death	0	0.0%

death, but 2 patients developed angina recurrence related to graft failure, which was successfully treated by catheter interventions. There was no myocardial infarction, congestive heart failure or arrhythmia observed. Overall cardiac event-free rate was 99.1% (226/228). 33 patients (2 symptomatic patients and 31 asymptomatic volunteers) underwent postoperative angiography at 1 year (0.9±0.2). This study evaluated a total of 140 distal anastomoses and found 4 occlusions (left IMA in 1, radial artery in 2, and gastroepiploic artery in 1), giving an overall anastomosis patency rate of 97.1% (the left IMA 97.5% [39/40], right IMA 100% [8/8], radial artery 96.3% [52/54], gastroepiploic artery 93.1% [27/29], and saphenous vein 100% [9/9]).

Discussion

Previously published propensity matched retrospective studies demonstrated partial advantages of the OPCAB compared to ONCAB.[11,12] These studies showed similar or decreased mortality rates in the OPCAB group, and similar or better results in the OPCAB group in terms of postoperative transfusion, sternal infection, encephalopathy, and renal failure than in the ONCAB group. However, the OPCAB group had fewer numbers of distal anastomoses than the ONCAB group, as shown by Boening[12] (2.39±0.7 in the OPCAB group versus 3.4±0.9 in the ONCAB group) and by Sabik[11] (2.8±1.0 versus 3.5±1.1). The number of the distal anastomoses may have been difficult to match by propensity scores. The results of these propensity matched retrospective studies could be limited because of the inclusion of the early learning phase of OPCAB surgery.

A recent prospective randomized OPCAB study by Puskas (Surgical Management of Arterial Revascularization Therapies [SMART] study) successfully demonstrated a similar completeness of revascularization in the OPCAB group compared to the ONCAB group.[13] In the SMART study, 200 patients were randomized under strict criteria-driven protocols, and the number of grafts per patient was 3.39±1.04 in the OPCAB group and 3.40±1.08 in the ONCAB group. There were no significant differences in the completeness of revascularization between the two groups. The SMART study also demonstrated favorable postoperative outcomes in the OPCAB group, including lower myocardial enzyme release, fewer transfusions, earlier extubation, and shorter length of hospital stay than in the ONCAB group. This SMART study was performed after the initial learning curve of OPCAB surgery.

Our number of distal anastomoses (3.7±1.2 per patient) and the revascularization rate (92.1%) were more than satisfactory. Incomplete revascularization was observed in only 18 patients, and none of these should have been considered target vessels regardless of the type of surgical revascularization. In our study, the LAD was always revascularized with one of the IMA without exception regardless of size. The non-revascularized vessels were either right coronary artery or the circumflex artery. Patients with a small diameter coronary artery (11 patients), totally occluded artery with poor distal run-off (4 patients) or hypoplastic coronary system (1 patient) had no graftable target vessel, which was impossible to bypass even under on-pump cardiac arrested. Two patients with a mildly stenosed artery were not revascularized because of the lack of appropriate conduits. We considered that all targets had been appropriately bypassed under off-pump beating heart.

Failures of OPCAB in our study were due to hemodynamic instability, but not related to target vessels. We performed OPCAB with success even in emergent (operation performed within 12 hours after referral due to ongoing ischemia with optimized medical support) or urgent cases (operation performed within 24 hours after referral), as long as the patient was hemodynamically stable with medical support. However, we do not recommend OPCAB for salvage surgery, although there were no such patients in our series. Patients experiencing deep cardiogenic shock despite cardiopulmonary resuscitation should be cannulated immediately and placed on cardiopulmonary bypass. One patient who collapsed during anesthesia induction may fall into this category. Left main stenoses are not contraindications for OPCAB in our practice.[14] For patients with left main disease, to avoid hemodynamic collapse during posterolateral exposure, the LAD was first anastomosed with one of the IMA and allowed to perfuse. This maneuver was also applied for patients who cannot tolerate the initial exposure of the posterolat-

eral wall. Patients with poor left ventricular function (ejection fraction <30%) and valvular disease, especially mild mitral valve regurgitation, and atrial fibrillation were sometimes difficult to maintain the hemodynamics during displacement of the heart for posterolateral revascularization.[8] However, their hemodynamics usually stabilized once IMA-LAD bypass was completed.

In reoperation, hemodynamics collapse may occur due to injury of patent previously placed vessels. These should be treated with immediate placement of cardiopulmonary bypass, otherwise abrupt hemodynamic collapse will occur. Reoperation was an independent predictor of on-pump conversion; thus, cardiopulmonary bypass should always be standing by during reoperative OPCAB. Our conversion rate to ONCAB was 1.7% including reoperation, and 0.5% in primary surgery. These numbers are within the acceptable range: 2% in SMART study with patients who have undergone primary operation only[13] and 9.8% by the European randomized OPCAB study including reoperation.[15]

Perioperative mean EuroSCORE in our study was 4.2±3.4 and its calculated mortality rate was 5.1%. Our morality rate after OPCAB (0.4%) was far below the calculated rate and other postoperative complications were minimal. Our study showed that stroke may occur in high risk patients despite optimal surgical technique such as no cross clamping, no manipulation of the aorta, or no cardiopulmonary bypass. Within our limited follow-up, angina recurrences were rare. A previous randomized study showed a lower distal anastomosis patency rate in the OPCAB group than the ONCAB group, suggesting a possible poor anastomosis quality by OPCAB compared to that in ONCAB.[16] However, our angiographic results at one year were satisfactory (overall patency rate of 97.1%). We believe a greater number of distal anastomoses and excellent angiographic results may have contributed to good remote clinical outcomes.

This study of OPCAB has several limitations. First, this was a retrospective non-randomized single center study, although the data was collected in a prospective manner. In fact, our policy of systematic OPCAB prohibited randomization of the patients to ONCAB. Second, the number of patients requiring on-pump conversion in this study was small, which may limit the analysis of risk factors for on-pump conversion. Third, we did not compare the results of OPCAB with the historical cohort of on-pump CABG, because the staff surgeons had moved to the current hospital in July 2002, and patient management by the previous house staff may have differed from ours. Fourth, the postoperative stay in Japan may be longer than that in reports from western countries. However, differences in cultural background and insurance policies between countries should be taken into account. Patients, except for a few patients who were referred from a chronic rehabilitation facility, were kept in-hospital until completion of in-hospital rehabilitation. Fifth, the number of the participants for postoperative angiography at 1 year was small. This may be due to most patients remains asymptomatic.

Conclusion

In conclusion, systematic OPCAB is feasible and its clinical outcome was satisfactory. Conversion to ONCAB can be expected in reoperation. Patients in deep cardiogenic shock requiring cardiopulmonary resuscitation should undergo immediate placement of cardiopulmonary bypass for life saving purpose.

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