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Risk Factors of On-Pump Conversion during Off-Pump Coronary Artery Bypass Graft

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Background: Off-pump coronary artery bypass grafting (OPCABG) procedures can avoid the complications of an on-pump bypass. However, some cases unexpectedly require conversion to cardiopulmonary bypass during OPCABG. The risk factors associated with a sudden need for cardiopulmonary bypass were analyzed. **Methods:** This retrospective study included 283 subjects scheduled for OPCABG from 2001 to 2010. These were divided into an OPCABG group and an on-pump conversion group. Preoperative, operative, and postoperative variables were compared between the 2 groups. **Results:** Of the 283 patients scheduled for OPCABG, 47 (16%) were switched to on-pump coronary artery bypass grafting (CABG). The mortality of the both the OPCABG and on-pump conversion groups was not significantly different. The major risk factors for conversion to on-pump CABG were congestive heart failure (CHF) (odds ratio [OR], 3.5; p=0.029), ejection fraction (EF) <35% (OR, 4.4; p=0.012), and preoperative beta-blocker (BB) administration (OR, 0.3; p=0.007). The use of intraoperative (p=0.007) and postoperative (p=0.021) inotropics was significantly higher in the conversion group. The amount of postoperative drainage (p<0.001) and transfusion (p<0.001) also was significantly higher in the conversion group. There were no significant differences in stroke or cardiovascular complications between the groups over the course of short-term and long-term follow-up. **Conclusion:** Patients who undergo OPCABG and have CHF or a lower EF (<35%) are more likely to undergo on-pump conversion, while preoperative BB administration could help prevent conversions from OPCABG to on-pump CABG.

Key words: 1. Off-pump coronary artery bypass grafting
2. Coronary artery bypass
3. Myocardial ischemia
4. Hemodynamic instability
5. On pump conversion

Introduction

Performing coronary artery bypass grafting (CABG) procedures without cardiopulmonary bypass (CPB) can reduce unwanted complications, such as myocardial ischemia (MI), inflammatory responses, and neurological complications in elderly and high-risk patients. Following the successful clinical application of off-pump CABG (OPCABG) by Borst et al. [1] in 1996, revascularization was initially limited to the vessels of the anterior wall. However, complete revascularization of the left lateral and inferior wall of

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the heart is now possible with the development of cardioplegic technology and improved hemodynamic understanding of the heart vasculature. There are considerable difficulties in performing coronary perfusion without CPB in patients with poor left ventricular (LV) function, evolving MI, severe congestive heart failure (CHF), or very small epicardial vessels. In these cases, the emergent use of CPB may result in complications and an adverse outcome. Deterioration of cardiac function due to manipulation of the heart during an operation can result in the obstruction of the right ventricular outflow tract and a change in LV pumping action. These changes have been shown to lead to decreased cardiac output, cardiac insufficiency, and hypotension [2]. Thus, if the probability of needing CPB can be accurately predicted preoperatively, then unwanted risk can be reduced with an elective on-pump CABG. In this study, we retrospectively analyzed patients who were switched from OPCABG to on-pump CABG in order to develop safer surgical procedures.

Methods

Of 451 patients scheduled for isolated OPCABG between March 2001 and December 2010, 283 were selected for possible outpatient follow-up in this study to analyze long-term complications and survival rates. Out of these 283 patients, 47 (16%) were switched to on-pump CABG (the on-pump conversion group); these were compared to the remaining 236 (84%) in the OPCABG group. Patients with unstable vital signs secondary to cardiogenic shock who required an intraaortic balloon pump (IABP) preoperatively and patients with a history of valve repair, aortic graft replacement surgery, or revision surgery were excluded from this study.

Of the 283 patients in the study, 163 (58%) were taking beta-blockers (BBs) until the day before surgery (carvediolol, 6.25 mg twice a day). Data on cardiomegaly, ejection fraction (EF), recent MI, presence or absence of CHF, number of diseased coronary arteries, comorbid diseases, and renal function were recorded. Comorbid diseases included hypertension, chronic obstructive pulmonary disease, hyperlipidemia, and diabetes mellitus. Hypertensive patients were identified as those taking at least one antihypertensive drug, and patients with diabetes mellitus were identified as those taking insulin therapy either orally or by injection. Patients with a recent MI were identified by a cardiologist, based on reported symptoms, elevated cardiac enzymes, or the results of an electrocardiogram (ECG) taken within 3 months before surgery. Patients with cardiomegaly were identified as those with an elevated cardiothoracic ratio (above 0.5). The Framingham criteria were used to identify patients with CHF.

Postoperative MI was defined as a new onset Q-wave after operation on an ECG or significant cardiac enzyme elevation accompanied by symptoms. Postoperative stroke was defined as a new focal neurologic deficit and a persistent postoperative change in mental status. Renal failure was defined as a 50% increase in postoperative serum creatinine level compared to baseline serum creatinine levels. Postoperative atrial arrhythmia was defined as the occurrence of new atrial arrhythmia in the absence of preoperative persistent or paroxysmal atrial arrhythmias over 24 hours.

Conversion from OPCABG to on-pump CABG took place when, despite corrective measures, including the loosening of deep pericardial sutures and administering myocardial stabilizers, administering inotropics and plasma, and changing the patient's position, a patient had (1) a systolic blood pressure that has fallen to 70 mm Hg; (2) a persistent ventricular arrhythmia; (3) a persistent change in ST segments; and (4) left ventricle distension with bradycardia. When these conditions were met, CPB was applied promptly.

1) Surgical method

All patients were kept normothermic and in the supine position. OPCABG was attempted with CPB on standby. For patients with a low EF, the right femoral artery site was reserved for an IABP, in case it was necessary, and a Swan-Ganz catheter was placed in 35% of the patients. A median sternotomy was performed to harvest the internal thoracic artery graft. If needed, radial artery and great saphenous vein grafts also were harvested. Prior to ligation of the internal thoracic artery, 8,000–10,000 units of heparin were administered, and the activated clotting time during the operation was maintained between 200 and 300 seconds. After the pericardial incision was made, a right pleurotomy and a deep vertical

Table 1. Characteristics of the 283 patients in the OPCABG group and on-pump conversion groups

Characteristic	OPCABG	On-pump conversion	p-value
No. of patients	236 (84)	47 (16)	
Age (yr)	60.3±9.0	65.2±7.5	0.001
Male gender	165 (85)	29 (15)	0.268
Body surface area (m^2)	1.71±0.2	1.65±0.2	0.019
New York Heart Association class	3.0±0.7	3.4±0.6	0.000
No. of diseased vessels	2.9±0.8	3.2±0.7	0.688
Left main coronary artery disease	83 (35)	21 (45)	0.217
Congestive heart failure	28 (12)	18 (38)	0.000
Cardiomegaly	66 (28)	22 (47)	0.011
Left ventricle ejection fraction	56.9±12.6	48.0±15.7	0.000
Hypertension	139 (59)	24 (51)	0.321
Diabetes mellitus	86 (36)	20 (43)	0.429
Hypercholesterolemia	25 (11)	4 (9)	0.661
Chronic obstructive pulmonary disease	7 (3)	1 (2)	0.751
Recent myocardial infarction	51 (22)	17 (36)	0.033
Preoperative	18 (8)	9 (19)	0.014
Peripheral vascular disease	8 (3)	4 (9)	0.113
Chronic kidney disease	7 (3)	3 (6)	0.249
Preoperative beta blockeradministration	146 (62)	17 (37)	0.005

Values are presented as number (%) or mean±standard deviation.
OPCABG, on-pump coronary artery bypass grafting.

pericardiotomy were performed to secure a space for entering the heart from the right thoracic cavity. One or 2 deep pericardial sutures were placed between the upper left pulmonary vein and the inferior vena cava, and then the heart was elevated. Either a pressure-type myocardial stabilizer (Guidant Axius Vacuum 2 Stabilizer System; Guidant Corp., Santa Clara, CA, USA) or a vacuum-type myocardial stabilizer (Guidant Axius XposeTM Device 3, Guidant Corp.) was used to secure the area of anastomosis, and then the coronary artery was exposed. Prior to dissection of the artery, pressure was applied with a 5-0 polypropylene suture if there was incomplete occlusion of the surrounding area of anastomosis. After dissection, a coronary arterial shunt (intracoronary shunt, Flo-Thru, internal diameter 1.5–2.0 mm; Bio-Vascular Inc., St. Paul, MN, USA) was inserted to maintain distal perfusion during surgery. Carbon dioxide spray (Guidant Axius Blower/minister, flow rate <5 L/min; Guidant Corp.) was used to secure visibility of the anastomosis. For any evidence of hemodynamic instability, additional intravenous heparin was administered (with an activated clotting time of 400 seconds), and the procedure was converted to CPB, using a venous catheter without cardioplegia. All anastomoses were performed on a beating heart.

The left ascending artery was always bypassed first. Second, any vessel with a more-critical stenosis was bypassed and an anastomosis was performed. A proximal anastomosis was completed before beginning the anastomosis of the next stenosed vessel. The guiding principle was that more cardiac displacement was better tolerated with increasingly complete revascularization. The order of the anastomosis of the different vessels was decided for individual patients depending on various factors, particularly hemodynamic status after heart manipulation. Continuous suturing with 8-0 polypropylene was used for arterial grafts, and 7-0 polypropylene was used for venous grafts. In cases where proximal aortic anastomosis was necessary, suturing with 6-0 polypropylene was performed after side-clamping. After all anastomoses were completed, blood flow (mL/min) within the vessel graft was measured with Doppler ultrasound and protamine neutralization was performed.

2) Statistics

Data were expressed as mean±standard deviation. Statistical analysis was performed using IBM SPSS ver. 20.0 (IBM Corp., Armonk, NY, USA). Univariate

Table 2. The intraoperative data of 283 patients with OPCAB group and on-pump conversion group

Variable	OPCAB	On-pump conversion	p-value
No. of anastomosis	3.5±1.0	4.1±1.1	0.000
Left anterior descending artery territory[a)]	1.6±0.6	1.9±0.7	0.367
Right coronary artery territory[b)]	0.9±0.6	1.2±0.5	0.413
Left circumflexterritory[c)]	1.0±0.6	1.0±0.7	0.383
Completeness of revascularization[d)]	1.3±0.5	1.4±0.5	0.395
Rate of conduit type			
Left internal mammary artery	230 (97)	44 (94)	0.171
Right internal mammary artery	7 (3)	0	0.232
Radial artery	169 (72)	25 (53)	0.013
Great saphenous vein	175 (74)	43 (91)	0.010
Gastroepiploic artery	2 (1)	0	0.545
Operation time (min)	293.4±55.3	365.6±69.9	0.000
Inotropics[e)] (μg/kg/min)	1.9±2.1	2.6±3.2	0.007
Transfusion (mL)	1,154±866	2,035±1,019	0.000

Values are presented as mean±standard deviation or number (%).
OPCAB, off-pump coronary artery bypass graft.
[a)]Including left anterior descending artery, diagonal artery, and ramus intermedius. [b)]Including posterior descending artery and postero-lateral branches. [c)]Obtuse marginal branches. [d)]As measured by the mean number of distal anastomoses divided by the mean number of diseased vessel system. [e)]Average dose of dobutamine which is the first choice of the inotropic agent intraoperatively.

analyses were performed to assess factors associated with study outcomes. The chi-square test or the Fisher exact test was used to compare categorical variables. The Student t-test was used to compare continuous variables. We constructed a multivariate logistic regression model for risk factors. The stepwise elimination method was used, including the variables CHF, recent MI, cardiomegaly, EF＜35%, stroke, and preoperative use of a BB. The odds ratios (ORs) and 95% confidence intervals were also calculated. All results with a p-value less than 0.05 were considered statistically significant.

Results

In the 283 patients scheduled for an isolated OPCABG, 47 (16%) were converted to an on-pump CABG. The risk-factor analyses of the 29 males (15%) in the on-pump conversion group and 165 males (85%) in the OPCABG group indicated there was no significant difference between the groups based on gender (p=0.268) (Table 1). The analyses also indicated that the on-pump conversion group patients had a higher frequency of CHF (p=0.000), cardiomegaly (p=0.011), recent MI (p=0.033), and previous stroke (p=0.014). Low cardiac function was also present in the on-pump conversion group, which had, for example, significantly more low left ventricle EFs (p=0.000) and were in higher New York Heart Association (NYHA) classes (p=0.000).

The patients in the on-pump conversion group underwent conversion for the following reasons: LV dysfunction from pressure created by heart manipulation (40 cases), electrical disturbances such as bradycardia and ST-segment elevation from heart manipulation for the anastomosis of inferior wall vessels (5 cases), and anatomically narrow or curving target vessels that prevented insertion of a shunt into the vessel incision (2 cases).

During the operation, the on-pump conversion group had significantly larger packed red blood cell transfusion volumes than the OPCABG group (p=0.000). The on-pump conversion group also used a significantly larger average amount of dobutamine (p=0.007) and had significantly more surgical anastomosis sites (p=0.000) than the OPCABG group (Table 2).

An IABP was used postoperatively in 6 patients, with significantly more in the on-pump conversion group (4, 9%) than the OPCABG group (2, 1%) (p=0.001). The use of the IABPs was deferred for up to 44 hours without difficulty. The chest tube drainage (p=0.000) and transfusion (p=0.000) volumes were significantly different between the 2 groups. On Pump conversion group was more large. Three early

Table 3. The postoperative and follow-up data of patients with OPCAB group and on-pump conversion group

Variable	OPCAB (%)	On-pump conversion (%)	p-value
Drainage during ICU (mL)	745±457	1,144±606	0.000
Transfusion (mL)	336±528	698±685	0.000
Inotropics[a)] (μg/kg/min)	0.6±1.5	1.2±2.3	0.021
Intraaortic balloon pump	2 (1)	4 (9)	0.001
Early death	2 (1)	1 (2)	0.434
Postoperative myocardial infarction	2 (1)	1 (2)	0.436
Stroke	1	0	0.654
Sternal wound infection	10 (4)	4 (9)	0.220
Renal failure	10 (4)	3 (6)	0.525
Atrial fibrillation	8 (3)	1 (2)	0.649
Ventilation time (hr)	18.9±12.0	25.4±20.0	0.030
ICU stay time (hr)	71.2±31.6	86.1±37.5	0.050
Admission time (day)	16.5±9.0	18.3±10.0	0.206
Late stroke	21 (9)	3 (6)	0.618
Reoperation	5 (2)	2 (4)	0.362
Late death	22 (9)	4 (18)	0.920
Late New York Heart Association class	1.7±0.6	1.6±0.5	0.372

Values are presented as mean±standard deviation or number (%).
OPCAB, off-pump coronary artery bypass graft; ICU, intensive care unit.
[a)]Average dose of dobutamine which is the first choice of the inotropic agent during ICU stay.

deaths were noted, including 2 deaths in the OPCABG group and 1 death in the on-pump conversion group, but there was no significant difference between the 2 groups (p=0.434). The incidence of complications after surgery, such as wound infection, renal insufficiency, and atrial fibrillation, were not significantly different between the 2 groups (p=0.220, p=0.525, p=0.649) (Table 3). One case of postoperative MI was reported in the on-pump conversion group (p=0.436), but no neurological complications were reported (p=0.654).

During outpatient follow-up, 4 cases (8%) of late death were reported in the on-pump conversion group. One patient died from pulmonary embolism, and 3 died from a cardiac problem, such as CHF and a sudden onset of ventricular fibrillation. In the OPCABG group, a total of 22 patients (9%) died. Among them, 17 patients' deaths were noncardiac in origin, such as cancer, trauma, pulmonary thromboembolism, chronic kidney disease, or sepsis. Five patients' deaths were cardiac in origin, including CHF and MI. There was no statistically significant difference between the 2 groups (p=0.920).

There were 3 cases (6%) of late-stage stroke in the on-pump conversion group and 21 cases (9%) in the OPCABG group (p=0.618). Revision surgery for graft occlusion was performed in 2 patients (4%) and 5 patients (2%) in the on-pump conversion and OPCABG group, respectively (p=0.362). Mean follow-up duration was 99.7±38 months (range, 2 to 159 months) in the OPCABG group and 70.4±25 months (range, 34 to 138 months) in the on-pump conversion group.

Multivariate logistic regression analysis of the risk factors of on-pump conversion during OPCABG revealed that preoperative CHF (p=0.029; OR, 3.2), EF <35% (p=0.012; OR, 4.4), and preoperative use of BB (p=0.077; OR, 0.3) affected on-pump conversion, but recent MI, previous stroke, preoperative NYHA class and cardiomegaly did not have a significant effect on-pump conversion (Table 4).

Discussion

Coronary reperfusion after cardiac arrest imposed by CPB is usually performed in patients with multivessel coronary artery disease. However, CPB may induce systemic inflammatory responses that, in turn, cause various complications and may lead to adverse neurological events upon arterial cannulation. Many CABG procedures have been performed without CPB or by using minimally invasive methods using skills

Table 4. Logistic regression analysis: risk factors for on-pump conversion during off-pump coronary artery bypass graft		
Variable	p-value	Odds ratio (confidence interval)
Congestive heart failure	0.029	3.236 (1.125–9.314)
Recent myocardial infarction	0.542	1.393 (0.479–4.050)
Ejection fraction <35	0.012	4.426 (1.380–14.199)
Cardiomegaly	0.471	1.467 (0.518–4.150)
Stroke	0.077	3.510 (0.873–14.120)
Preoperative beta blocker administration	0.007	0.269 (0.103–0.702)

and technology that have been developed for stabilizing and manipulating the heart. These methods allow complete revascularization of the coronary arteries of not only the anterior walls, but also the lateral and posterior walls, and have been especially effective in elderly or high-risk patients with comorbidities [2-5]. However, there are reports of patients with severe left main coronary artery disease and cardiac hypertrophy experiencing a drop in ventricular filling pressure due to the manipulation of the heart in order to access the area of anastomosis, as well as a subsequent reduction in cardiac output and hemodynamic instability [6]. In this study, hemodynamic instability was observed in 47 patients whose surgery was converted to on-pump CABG. Vassiliades et al. [7] reported that 1.65% of 1,420 cases of OPCABG were converted to on-pump intraoperatively. On-pump conversion was significantly more common in patients with a higher preoperative NYHA class, severe cardiomegaly (in particular, LV hypertrophy), smaller body surface area, distal anastomosis of the right coronary artery, and recent MIs. A higher incidence of complications, such as postoperative MI and renal insufficiency, also was reported.

Mathison et al. [8] reported hemodynamic instability in 4.8% of subjects and indicated that the significant risk factors were EF<25%, CHF, and recent MI. In these cases, IABP procedures were useful.

In the present study, hemodynamic instability was significantly more common in patients with a smaller body surface area, a higher preoperative NYHA class, recent MIs, CHF, and echocardiographic findings of LV hypertrophy.

Dewey et al. [9] reported that the frequency of postoperative use of myocardial stimulants and the volume of transfusion were significantly higher in an on-pump CABG group than in an OPCABG group. CPB was a significant risk factor for postoperative mortality.

Edgerton et al. [10] reported that revision surgery was a risk factor for the emergent use of CPB and that lower mortality and fewer incidences of postoperative complications were associated with earlier rather than later conversion to CPB.

Hemodynamic instability during OPCABG could arise from anatomical factors such as the presence of narrow vessels or severe asymmetric ventricular hypertrophy. However, hemodynamic instability occurs frequently during the process of heart manipulation in order to access the area of anastomosis. More cases are performed using an inferior or posterior rather than an anterior vessel approach. In order to gain access to the left ascending artery or diagonal branch, the cardiac apex needs to be elevated and the heart rotated toward the midline. Eventually, the right ventricle becomes trapped between the bulky LV muscle and the right pericardium, resulting in a drop in right ventricular cardiac output. This can be corrected by supplementing fluid to the right side of the heart or with a Trendelenburg maneuver. However, when approaching an inferior vessel, the patient's head is typically placed downward and the apex of the heart is elevated, which could result in the closing of the tricuspid valve. When approaching a posterior vessel, the right ventricle receives more pressure, which can lead to transient low cardiac output. Moreover, an electrical conduction disorder may occur due to the occlusion of the coronary blood flow during the operation.

In the present study, 2 cases had narrow or curving vessels that made shunt insertion difficult, 5 cases had LV compression that resulted from a posterior vessel approach, and 5 cases had electrical conduction abnormalities due to a right coronary artery anastomosis. Such cases can usually be managed with a reverse Trendelenburg position, administration of cardiotonic drugs, and administering fluids to increase ventricular filling pressure. Other methods that can be used for operative safety include minimizing the reduction of cardiac output by transferring the apex to the right pleural cavity through a right pleural incision [11-13], inserting an IABP through mechanical means or a shunt implantation technique [14,15], using a right ventricular assist device to provide mechanical support for the right ventricle [16,17], and performing a perfusion-assisted direct coronary artery bypass [18,19]. In this study, all patients with a systolic blood pressure below 70 mm Hg, despite fluid therapy, inotropes, positional changes, and repositioning of the heart, were switched to on-pump CABG with CPB.

Postoperative complications and mortality are reportedly higher in patients with hemodynamic instability who underwent a delayed switch to an on-pump CABG [7,8]. In the present study, statistical significance was observed with intraoperative (p=0.007) and postoperative (p=0.021) use of inotropes, amount of transfusion (intraoperative, p=0.000; postoperative, p=0.000). Intraoperatively, there was a significant increase in operation time (p=0.000) and number of anastomoses (p=0.000) in the on-pump conversion group compared to the OPCABG group. IABP procedures were more frequent and the length of stay in the intensive care unit was longer in the on-pump conversion group than in the OPCAGB group. However, the postoperative incidence of MI, stroke, wound infection, renal failure, atrial fibrillation, and death were not significantly different between the 2 groups.

A low rate (range, 1.1% to 16.3%) of intraoperative hemodynamic instability has been reported in many studies [10]. However, its incidence is associated with high risk, and careful preoperative selection of patients is required to prevent complications. When treating patients with preoperative CHF and an EF＜35%, the on-pump CABG option should be considered, and when opting for an OPCAGB, a BB should be administered preoperatively to prevent an on-pump conversion.

1) Limitations

The size of the on-pump conversion group was small and the size difference between the 2 groups was large, which placed some limitations on the statistical analyses. However, no other problems were encountered when conducting the statistical analyses.

A more detailed analysis of the risk factors related to on-pump conversion, using intraoperative ECG [20], Swan-Ganz catheter monitoring, and transesophageal echocardiography to assess cardiac output changes [21], is needed. In the present study, Swan-Ganz catheter monitoring was used for only 35% of the on-pump conversions; however, we currently use it with all CABG procedures, and in the future, we will use these data to reanalyze the risk factors related to on-pump conversion.

Finally, due to surgeons' preferences, early CPB was applied instead of an IABP procedure. This preference resulted in a high rate of on-pump conversion (16%) during OPCABG.

2) Conclusions

OPCABG has many advantages, such as avoiding CPB complications and reducing operative time and length of stay in the intensive care unit. However, conversion to on-pump CABG is unavoidable in certain patients, and emergent pump use may be disadvantageous to the patient. In this study, CHF and an EF＜35% were significant risk factors for on-pump conversion during OPCABG. Although the surgeon's experience probably has the greatest influence on the outcome, careful attention must be paid during surgery to patients with CHF and an EF＜35%. In addition, the preoperative administration of a BB could have a positive effect in preventing the need for conversion to an on-pump CABG during OPCABG.

Conflict of interest

No potential conflicts of interest relevant to this article are reported.

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