

On-pump with beating heart or cardioplegic arrest for emergency conversion to cardiopulmonary bypass during off-pump coronary artery bypass

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Ann Saudi Med 2014; 34(4): 314-319

DOI: 10.5144/0256-4947.2014.314

BACKGROUND AND OBJECTIVES: Intraoperative conversion, especially under emergent circumstances during off-pump coronary artery bypass (OPCAB), is associated with a significantly higher rate of hospital mortality. This study compared the clinical early outcomes of patients emergently converting to cardiopulmonary bypass (CPB) with or without cardioplegic arrest and evaluated the efficacy of an on-pump beating heart technique for these critically ill patients.

DESIGN AND SETTINGS: A retrospective study of patients treated at The First Affiliated Hospital of China Medical University over an 8-year period (2005 to 2013).

PATIENTS AND METHODS: Between January 2005 and September 2013, 104 patients were emergently converted to CPB during OPCAB. In the first 55 patients (53%), the cardioplegic arrest was performed. In the most recent 49 patients (47%), the on-pump beating heart procedure was used without cardioplegic arrest.

RESULTS: There were no significant differences in their baseline clinical characteristics, number of anastomoses performed per patient, and reasons for conversions ($P>.05$). A significant reduction occurred in the observed mortality between the cardioplegic arrest group and the on-pump beating heart group (25.6% vs 6.1%, $P=.008$). A statistical difference was found between the cardioplegic arrest group and the on-pump beating heart group in the time of CPB, peak cardiac troponin I, duration of inotropic support, time to extubation, intensive care unit stay, postoperative hospital stay, incidence of new intra-aortic balloon pump support, and pulmonary complications ($P<.05$). The incidence of blood requirements, postoperative myocardial infarction, new-onset atrial fibrillation, hemodialysis, stroke, infective complications, and resurgery for bleeding were lower in on-pump beating heart group, but the difference did not reach statistical significance ($P>.05$).

CONCLUSION: The on-pump beating heart technique is the preferred method of emergency conversion to CPB during OPCAB. It has lower postoperative mortality and morbidity than the cardioplegic arrest.

Conventional coronary artery bypass grafting (CABG) is one of the most commonly performed procedures and a very well-established treatment for coronary artery diseases. This procedure with cardiac arrest allows the performance of coronary artery anastomosis in a steady, bloodless surgical field.¹ Nevertheless, a significant morbidity remains mostly because of the whole-body response to the nonphysiologic nature of on-pump, leading to the propagation of a systemic inflammatory response syndrome, such

as cytokines and complements.^{2,3} Over the last decade, interest has reemerged in off-pump coronary artery bypass (OPCAB) surgery, which avoids cardiopulmonary bypass (CPB), cardioplegic arrest, and, consequently, the global ischemic time.

However, one of the main limitations of OPCAB is the occasional need to convert to CPB. This may occur because the surgeon anticipates difficult coronary anastomoses, hemodynamic instability during regional ischemia, or poor tolerance of cardiac positioning.

Emergent conversion to CPB support can also occur during grafting or positioning, or in patients with acute ischemia in whom hemodynamic collapse or ventricular arrhythmias occur. This occurrence is associated with a significantly increased risk of mortality and postoperative morbidity, and negates any potential benefit of OPCAB.^{4,7}

The incidence of conversion decreases with the increasing experience of surgeons in performing OPCAB and the increasing use of a cardiac positioning device. However, emergency conversion is an unpredictable event and cannot be completely avoided. To reduce the mortality and postoperative morbidity, we adopted the technique of on-pump beating heart when converting to CPB during OPCAB. In this study we compared the clinical outcomes and laboratory data of patients undergoing cardioplegic arrest and on-pump beating heart for emergency conversion to CPB during OPCAB and evaluated the efficacy of the on-pump beating heart technique.

PATIENTS AND METHODS

Study design and patients

From January 2005 through September 2013, there were 3255 consecutive OPCAB performed at the first affiliated hospital of China Medical University, of which 104 (3.2%) were emergently converted to CPB during OPCAB. In 55 patients (53%) seen from January 2005 through November 2009, the cardioplegic arrest was performed during emergency conversion. Considering the significantly higher postoperative morbidity and mortality, the most recent 49 patients (47%), treated between December 2009 and September 2013, underwent on-pump beating heart without cardioplegic arrest during emergency conversion.

Emergency conversion

Emergency conversion was defined as the use of CPB after the initial intent of performing OPCAB if the reason for using CPB was any of the following: hemodynamic compromise, hemorrhage, ischemic episodes, and cardiac arrest. We did include patients who had any of the above, even while manipulating the heart to assess the coronary anatomy. We did not include patients who underwent CPB semielectively because of coronary anatomy (diffusely diseased vessels, small-caliber vessels, and intramyocardial vessels).

Surgical technique of off-pump revascularization

Median sternotomy was used as the surgical access in all cases. Conduits were harvested, and patients were

partially heparinized to maintain the activated clotting time at approximately 300 seconds. Deep pericardial sutures, Trendelenburg position, and right tilt were used to facilitate the exposure of lateral, posterior, and inferior vessels of the heart. The target vessels were exposed and controlled with silastic sling. The chosen devices for coronary artery stabilization were the Medtronic Octopus device, apical suction positioning device, and apical suction positioning device (Medtronic, Minneapolis, Minn). The target vessel was then opened and an intracoronary shunt (Medtronic, Minneapolis, Minn) was put in to maintain distal perfusion during the performance of anastomoses. The visualization of the operative field was achieved with a carbon dioxide surgical blower system. All proximal anastomoses were performed with the use of a side-biting aortic clamp.

Conversion to CPB

The decision to convert was made by the treating surgeon, and the reason for conversion was recorded. A primed ready-to-use CPB circuit was arranged in all cases to minimize delay in instituting CPB. When conversion to CPB was necessary after full heparinization, patients were started on CPB with an aortic cannula in the ascending aorta and a single 2-stage venous cannula in the right atrial appendage. The surgery was then continued on the assisted beating heart or with aortic cross-clamping utilizing antegrade and retrograde cold blood cardioplegia. In the case of ventricular fibrillation or cardiac arrest, the patient was immediately defibrillated and the cardiac massage was initiated if necessary. All patients were placed on CPB, during which the mean arterial pressure was maintained between 60 and 70 mm Hg with pharmacological manipulation as necessary. In the cardioplegic arrest group, myocardial protection was obtained with 1 L of cold blood cardioplegia delivered antegradely and repeated every 30 minutes as necessary. In the on-pump beating heart group, we used our OPCAB technique described earlier.

Strategy for revascularization

Surgical revascularization was mainly started using left internal mammary artery for the grafting of left anterior descending (LAD). Following this, the right coronary system was approached, and finally the circumflex territory was revascularized. In patients with left main disease, LAD and circumflex arteries were always grafted regardless of the degree of stenosis. All other vessels with significant lesions (>70%) were identified preoperatively in the angiogram and selected as a target for revascularization.

Table 1. Clinical characteristics of the patients.

Variables	On-pump eating-heart group (n=55)	Cardioplegic rest group (n=49)	P value
Mean age (Y [SD])	66.2 (7.3)	65.8 (7.3)	.747
Sex ratio (M/F)	35/20	30/19	.800
Hypertension (%)	33 (60.0%)	31 (63.3%)	.733
Diabetes (%)	22 (40.0%)	20 (40.8%)	.933
COPD (%)	6 (10.9%)	8 (16.3%)	.419
Previous MI (%)	35 (63.6%)	29 (59.2%)	.641
Acute MI (%)	5 (9.1%)	5 (10.2%)	.848
CHF (%)	33 (60.0%)	31 (63.3%)	.733
Peripheral artery disease (%)	7 (12.7%)	8 (16.3%)	.602
History of smoking (%)	29 (52.7%)	31 (63.3%)	.278
Dyslipidemia (%)	38 (69.1%)	35 (71.4%)	.795
Left main stenosis >50% (%)	16 (29.1%)	14(28.6%)	.953
Double-vessel disease	7 (12.7%)	7 (14.3%)	.816
Triple vessels	48 (87.3%)	42 (85.7%)	.816
Previous stroke (%)	16 (32.7%)	16 (32.7%)	.694
Previous PCI (%)	16 (32.7%)	11 (22.4%)	.445
Ejection fraction (mean [SD])	43.6 (9.4)	42.4 (10.5)	.513
BMI (kg/m ²)	24.35 (4.23)	24.59 (4.42)	.773
Renal failure (%)	4 (7.3%)	3 (6.1%)	.815
Creatinine (mg/dL)	1.2 (0.5)	1.2 (0.5)	.721
NYHA class III-IV (%)	21 (38.2%)	20 (40.8%)	.784
AF (%)	5 (9.1%)	5 (10.2%)	.848
Preoperative IABP (%)	7 (12.7%)	5 (10.2%)	.538
Carotid stenosis >50%	20 (36.4%)	18 (36.7%)	.508
Emergency surgery (%)	4 (7.3%)	4 (8.2%)	.865

BMI: Body mass index; COPD: chronic obstructive pulmonary disease; MI: myocardia infarction; CHF: congestive heart failure; NYHA: New York Heart Association; PCI: percutaneous coronary intervention; BMI: body mass index; AF: atrial fibrillation; SD: standard deviation; IABP: intra-aortic balloon pump.

Postoperative management

All postoperative cardiac surgery patients were taken to a dedicated cardiac intensive care unit (ICU). Each patient was required to meet standard criteria before extubation. Patients were generally transferred from the cardiac ICU if they were considered at risk clinically for decreased oxygen delivery. All patients received intravenous nitroglycerin (0.1-8 µg kg⁻¹ min⁻¹) and

dobutamine (1-8 µg kg⁻¹ min⁻¹) infusions for the first 24 hours. Oral routine medications included daily aspirin and resumption of cholesterol-lowering agents, β-blockers, and angiotension-converting enzyme inhibitors as appropriate.

Statistical Analysis

The data were managed and analyzed by SPSS version 16.0 (SPSS In., Chicago, Illinois, USA). The results for categorical variables were expressed as numbers (percentages). Continuous variables were presented as the mean (standard deviation). The Fisher exact test or the chi-square test was used to compare categorical variables. The continuous variables were compared by using the Student *t* test. A *P* value of less than .05 was considered to be statistically significant.

RESULTS

Preoperative characteristic

Table 1 shows preoperative characteristics in both patient groups. No significant preoperative differences were observed between the 2 groups with regard to age, sex, diabetes, hypertension, chronic obstructive pulmonary disease, previous myocardia infarction (MI), acute MI, congestive heart failure, peripheral artery disease, history of smoking, dyslipidemia, left main stenosis >50%, double-vessel disease, triple-vessel disease, previous stroke, previous percutaneous coronary intervention, ejection fraction, carotid stenosis >50%, body mass index, renal failure, creatinine, New York Heart Association (NYHA) class III-IV, atrial fibrillation (AF), preoperative intra-aortic balloon pump (IABP), or emergency surgery.

Perioperative data

Table 2 shows the perioperative data of the patients. The CPB time was significantly longer in the cardioplegic arrest group than in the on-pump beating heart group (129.25 [39.24] vs 104.96 [35.64] minutes, *P*=.001). The number of anastomoses/patients was similar (3.33 [0.82] vs 3.18 [0.63] hours, *P*=.317). Because of hemodynamic instability, 47 patients (85.5%) converted in the cardioplegic arrest group vs 44 patients (89.8%) in the on-pump beating heart group (*P*=.504). Because of cardiac arrest, 5 patients (9.1%) converted in the cardioplegic arrest group vs 3 patients (6.1%) in the on-pump beating heart group (*P*=.571). Because of hemorrhage, 2 patients (3.6%) converted in the cardioplegic arrest group vs 1 patients (2.0%) in the on-pump beating heart group (*P*=.627). Because of graft occlusion, 1 patients (1.8%) converted in the cardioplegic arrest

group vs 1 patient (2.0%) in the on-pump beating heart group ($P=.491$). The postoperative peak cardiac troponin I (cTnI) values in the cardioplegic arrest group were higher than those in the on-pump beating heart group (11.97 [18.13] ng/mL vs 4.9 [9.76] ng/mL, $P=.017$). A statistical difference was found between the cardioplegic arrest group and the on-pump beating heart group in the duration of inotropic support, time to extubation, ICU stay, postoperative hospital stay, incidence of new IABP support, and pulmonary complications ($P<.05$). The incidence of blood requirements, postoperative MI, new-onset AF, hemodialysis, stroke, infective complications, and reoperation for bleeding were lower in the on-pump beating heart group, but the difference did not reach statistical significance ($P>.05$). A remarkable reduction occurred in the observed mortality between the cardioplegic arrest group and the on-pump beating heart group (25.6% vs 6.1%, $P=.008$).

DISCUSSION

CABG with CPB on the one hand allows controlled hemodynamics with superior graft quality while on the other hand carries inherent risks of CPB that have renewed interest in OPCAB. Recently, a ROOBY and 2 CORONARY trials demonstrated that 30-day and 1-year outcomes would be no different between on-pump and OPCAB8-10. However, a study consisting of 21 640 patients compared between on-pump and OPCAB and concluded that OPCAB was associated with less morbidity, shorter length of stay, and similar mortality compared with on-pump procedures, suggesting that OPCAB can be a safe and effective alternative to on-pump.¹¹ Nevertheless, today the global percentage of surgeons using less invasive OPCAB procedures is estimated only at 20%, although it is expected that the procedure could be beneficial for high-risk patients.¹² Although the controversy is still continuous, OPCAB has been used as the primary mode of treatment for patients with multivessel coronary artery disease in our center. Additionally, the economical condition in our country makes it necessary to reduce cost as much as possible, and OPCAB in our setting significantly reduces the surgical cost.

Certain maneuvers may avoid some of the potentially deleterious hemodynamic consequences during OPCAB that may lead to conversion. At our institution, certain intraoperative techniques can facilitate OPCAB even during challenging cases. The sequence of grafting (anastomosing the LAD first may maintain cardiac performance), timing of proximal anastomoses, grafting collateralized vessels first, use of cardiac stabilizing device in combination with an apical suction

positioning device, use of intracoronary shunts, trials of temporary regional ischemia before arteriotomy, judicious use of inotropic agents, widely opening the right pleura, minimizing compression during cardiac

Table 2. Perioperative data.

Variables	Cardioplegic Arrest group (n=55)	On-pump beating-heart group (n=49)	P value
Number of anastomoses/patient	3.33 (0.82)	3.18 (0.63)	.317
CPB time (min)	129.25 (39.24)	104.96 (35.64)	.001
Reason for conversion			
Hemodynamic instability	47 (85.5%)	44 (89.8%)	.504
Cardiac arrest	5 (9.1%)	3 (6.1%)	.571
Hemorrhage	2 (3.6%)	1 (2.0%)	.627
Graft occlusion	1 (1.8%)	1 (2.0%)	.491
Maximum cTnI (ng/mL)	11.97±18.13	4.9±9.76	.017
Blood requirements (%)	19 (34.5%)	12 (24.6%)	.263
New IABP (%)	19 (34.5%)	8 (16.3%)	.034
Postoperative MI (%)	10 (18.2%)	6 (12.2%)	.402
New-onset AF (%)	12 (21.8%)	11(22.4%)	.938
Pulmonary complications (%)	17 (30.9%)	7 (14.3%)	.045
Hemodialysis (%)	8 (14.5%)	3 (6.1%)	.163
Stroke (%)	2 (3.6%)	1 (2.0%)	.627
Infective complications (%)	9 (16.4%)	4 (8.2%)	.207
Duration of inotropic support (d)	5.07 (2.81)	3.49 (1.99)	.001
Reoperation for bleeding (%)	4 (7.3%)	1 (2.0%)	.213
Time to extubation (h)	95.9 (67.4)	50.0 (45.5)	.000
ICU stay (d)	6.8 (2.8)	5.0 (2.2)	.001
Postoperative hospital stay (d)	15.6 (5.5)	11.8 (4.5)	.000
In-hospital mortality (%)	14 (25.6%)	3 (6.1%)	.008

CPB: Cardiopulmonary bypass; cTnI: cardiac troponin I; IABP: intra-aortic balloon pump; MI: myocardial infarction; AF: atrial fibrillation; ICU: intensive care unit.

positioning, and immediate perfusion of any free graft soon after distal anastomosis can all be used to make OPCAB a successful OPCAB. Randomized controlled trials reported that a high off-pump to on-pump conversion rate (>9%) was often associated with the low experience of surgeons participating in OPCAB.¹³⁻¹⁶ The “CPB-readiness” or “safety measures” include the following: a perfusionist on standby, a primed CPB pump or “dry-ready” (unprimed) pump, pre-inserted CPB cannulae, and preinserted purse string sutures. The use of one or more of these standby measures can be beneficial to enable swift conversion to CPB, if necessary. In our hospital, the entire cardiac surgical staff is, therefore, highly familiar with the OPCAB technique. Less experienced centers and centers still in the process of establishing off-pump programs should start out with standard patients with good target vessels. Subsequently, the experience thus gained can be transferred to high-risk cases, aiming for excellent results in that challenging population.

Hemodynamic instability and intraoperative dysrhythmias are major procedural complications of OPCAB, threatening conversion to emergency on-pump surgery. Conversion is, in general, an underexplored phenomenon of which there are few available studies. As previously reported,^{4,7} outcomes for converted patients were worse than those for nonconverted patients. Conversion to CPB was associated with an increase in hospital mortality and postoperative stroke compared with nonconverted patients. Conversion to CPB during an attempted off-pump procedure, especially under emergent circumstances, essentially negates the potential benefits of OPCAB. Even at an experienced OPCAB center with a conversion rate of less than 3%, this complication is associated with adverse outcomes. Based on our data, the consequences of conversion may also impact postoperative mortality and morbidity.

We believe that the patients who require conversion to CPB on an emergency basis for situations like hemodynamic compromise, hemorrhage, ischemic episodes, and cardiac arrest represent true conversions. These are the situations in which conversion to CPB after attempted OPCAB might be a necessity rather than a choice. However, patients requiring the use of CPB semielectively because of coronary anatomy (e.g., diffuse coronary artery disease or intramyocardial vessels) are not true conversions because they depend on the surgeon's preference. When emergency conversion cannot be avoided, it was very important to know how to reduce the postoperative mortality and morbidity. The aim of our study was to investigate retrospectively

two different techniques for conversion to CPB, with or without cardioplegic arrest under emergent circumstances during OPCAB.

Recently, beating heart and noncardioplegic CABG without cross-clamping or cardioplegic arrest have been used as alternative surgical techniques in high risk patients.¹⁷ The avoidance of cardioplegic arrest can eliminate intraoperative global myocardial ischemia, which might contribute to myocardial protection.¹⁸ The beating heart can preserve native coronary blood flow, which might reduce myocardial injury.¹⁹ Perrault et al¹⁸ described on-pump beating heart coronary surgeries as an acceptable tradeoff between conventional CABG and OPCAB in high-risk patients. Experimentally, it has been demonstrated that maintaining the heartbeat results in minimal myocardial edema and better left ventricular function.²⁰ Cardioplegic arrest may, therefore, have a direct adverse effect on the heart that gives rise to an increase in morbidity and mortality, especially for high-risk patients.

Despite the use of CPB in both groups, CPB time was shorter in the on-pump beating heart group. The shortening of the duration of CPB may reduce the visceral injury. In our study, the peak cTnI value after surgery was significantly lower, suggesting a lesser impact of the on-pump beating heart technique on the myocardial injury in the perioperative period. In addition, the systemic heat of patients was approximately 36°C in the on-pump beating heart group, whereas the patients were cooled to 30°C in the conventional group. Therefore, the visceral damage that may have occurred due to systemic cooling would have been more significant in the cardioplegic arrest group. The Duration of inotropic support, incidence of new IABP support, and pulmonary complications were significantly lower in the on-pump beating heart group than in the cardioplegic arrest group. This could be because of the smaller myocardial injury in the on-pump beating heart group. Similarly, postoperative time to extubation, ICU stay, and postoperative hospital stay decreased in the on-pump beating heart group. In-hospital mortality was significantly lower in the on-pump beating heart group than in the cardioplegic arrest group. These considerations may all be related to the elimination of cardioplegic arrest, which is the main difference between the techniques. No significant differences were detected between the groups in relation to incidence of blood requirements, postoperative MI, new-onset AF, hemodialysis, stroke, infective complications, and resurgery for bleeding. These are all believed to be related to the use of CPB itself. Our data suggests that on-pump beating heart can be performed safely even in patients who

might suffer hemodynamic collapse during surgery. The number of cases is too small, but the maintenance of some cardiac output and elimination of global ischemia might be important in preventing deterioration of cardiac function even if emergently converting to CPB during OPCAB.

Study Limitations

The present study is one of the few studies comparing the TWO techniques used in emergency conversion to CPB during OPCAB. The study carries several limitations, being a retrospective study among a small number of patients, which made the validity of the clinical results limited. First, patients were not assigned to the

two groups randomly, and hence a historical difference existed between the two groups. Other factors, such as the learning curve of the whole team, the time of conversion, and the decision criteria, which varied between the first and the second cohort might have impacted the outcome. Second, the single-surgeon, single-center nature of the trial design also limited the generalizability of the surgical outcome.

In conclusion, intraoperative emergency conversion is associated with a significantly higher rate of hospital mortality and morbidity. The on-pump beating heart technique is the preferred method of emergency conversion to CPB during OPCAB. It has lower postoperative mortality and morbidity than the cardioplegic arrest.

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