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A Comparison of Consecutive Off-Pump Versus Conventional Coronary Artery Bypass

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ABSTRACT

Background: Coronary revascularization on the beating heart is an attractive alternative to conventional coronary artery bypass grafts (CCABG), but remains controversial. Our study compares the outcomes of consecutive patients undergoing off-pump CABG (OPCABG) with a group of similar patients undergoing consecutive CCABG.

Methods: A retrospective analysis of 268 patients who underwent elective CABG between July 1998 and July 1999 at St. Michael's Medical Center yielded 134 consecutive patients who underwent OPCABG and 134 consecutive patients who had CCABG. Patients' medical charts were reviewed for age, preoperative risk factors, operative findings, postoperative complications, and length of stay (LOS).

Results: The two cohorts were well matched, with similar ages (66.4 ± 11.2 for OPCABG vs. 65.8 ± 10 for CCABG, $p = 0.66$) and preoperative ejection fractions (EF) (44 ± 13 vs. 44 ± 12, $p = 0.85$). There were no hospital mortalities, and there were five conversions to cardiopulmonary bypass. The OPCABG group had a significantly shorter ICU and postoperative LOS.

Conclusions: Our data suggests that a fair number of patients are potential candidates for OPCABG, the only contraindications being technical limitations or the surgeon's comfort level. Six- to twelve-month follow-up indicates that OPCABG can be performed safely with a decrease in LOS, and should be part of the surgeon's armamentarium.

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INTRODUCTION

Conventional coronary artery bypass grafts (CCABG) have been performed with reproducible success, but complications cause significant morbidity. Some of these complications may be secondary to cardiopulmonary bypass (CPB) and include stroke [Reed 1988] and a systemic inflammatory response syndrome [Steinberg 1993]. Since these complications are multifactorial, avoidance of CPB may not translate into clinical benefit.

Nevertheless, advocates of off-pump CABG have proposed that theoretical advantages of avoiding cardiopulmonary bypass are a decreased incidence of neurologic dysfunction, postoperative myocardial infarction (MI), bleeding, renal failure and respiratory failure [Savageau 1982, Shaw 1987b, Bouchard 1998, Ascione 1999]. Critics argue that the primary unaddressed concern of OPCABG, long-term graft patency, needs to be evaluated [Gundry 1998, Mack 1998, Calafiore 1999, Mack 1999, Bull 2000]. These controversial, unresolved issues led us to evaluate our experience with two cohorts of consecutive patients undergoing conventional CABG and the off-pump procedure.

MATERIALS AND METHODS

Patients

We conducted a retrospective analysis of 268 patients that underwent elective CABG at St. Michael's Medical Center. Starting in February of 1999, after a learning period in which we selected patients to be done with or without cardiopulmonary bypass, we decided that all patients would be done without cardiopulmonary bypass. This rep-

Table 1A. Preoperative Risk Factors (Non-cardiac)

	OPCABG (n = 134)	CCABG (n = 134)	p value
Age (years)	66.4 ± 11.1	65.8 ± 10.0	0.66
Gender (% male)	63.4	66.4	NS
COPD (%)	12.1	11.1	0.57
Renal Insuff. (%)	5.9	4.0	0.75
CVD (%)	12.6	8.1	0.84
CVA (%)	8.0	8.9	0.61
Diabetes (%)	34.3	42.2	0.16
Reoperations (%)	5.9	8.2	0.47

Table 1B. Preoperative Risk Factors (Cardiac)

	OPCABG	CCABG	p value
Hypertension (%)	70.8	67.4	0.59
CHF (%)	14.9	5.6	0.05
Preop MI (%)	38.8	29.1	0.09
Preop A fibril. (%)	5.9	4.4	0.58
Unstable angina (%)	47	43	NS
Preop EF (%)	44.0 ± 12.9	44.2 ± 11.7	0.85
Previous PTCA (%)	19.4	26.1	0.24
Thrombolysis (%)	2.2	0.7	0.31
Hemo. instability (%)	1.4	0.7	0.56

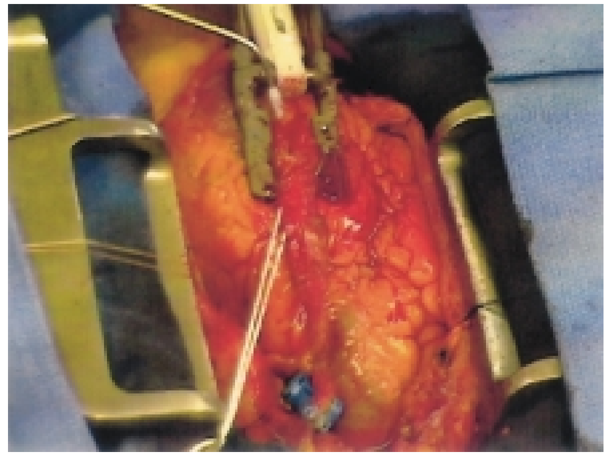

Figure 1. Left anterior descending exposure.

resented the first 134 consecutive patients, which were all patients who underwent coronary artery bypass without exclusion or selection. The only patients done on cardiopulmonary bypass were the five patients that were converted from off-pump to on-pump intraoperatively.

As a comparative group, we counted backwards 134 patients done immediately prior to the first patient's off cardiopulmonary bypass during our learning phase. These patients represented all patients who underwent coronary artery bypass in a consecutive, and therefore, unselected fashion. Therefore, each group included all patients who underwent coronary artery bypass procedures, none of which were selected for either on- or off-pump. Consequently, there was no selection bias or patient exclusion. All procedures between February 1999 and July 1999 were approached with the intent to perform them without cardiopulmonary bypass. One hundred thirty-four consecutive off-pump CABGs were performed and compared with a group of 134 consecutive CABGs done with CPB between July 1998 and January 1999. Both cohorts were well matched for age, sex, and preoperative risk factors according to the STS criteria (Table 1a, ◎, and 1b, ◎).

Postoperative MI was defined as EKG changes, i.e., new Q wave and/or Troponin I (TnI) levels > 11.6 ng/ml up to 24 hours postoperatively. Respiratory insufficiency was defined as prolonged mechanical ventilation (> 24 hours) postoperatively. Renal insufficiency was defined as an increase in serum creatinine > 2.0 mg/dl, an increase in serum creatinine more than two times baseline, and/or a new requirement for hemodialysis or peritoneal dialysis.

Patients were evaluated postoperatively for neurologic events such as documented cerebrovascular accidents (CVAs), transient ischemic attacks (TIAs), seizures, and delirium.

Statistical Analysis

Data was expressed as mean ± standard deviation. All statistical analyses were performed as two-tailed tests using the students' t-test for continuous variables and chi-square for categorical variables. A multiple linear regression analysis was performed to evaluate the outcome of both groups with regards to postoperative and ICU length of stay. In all cases significance was defined as $p < 0.05$.

Surgical Technique

OPCABG

After induction of anesthesia, the internal mammary arteries were harvested along with the other conduits. After partial heparinization (10,000 units) an activated clotting time (ACT) was noted and rechecked every 30 minutes and heparin was given to maintain ACT > 300 seconds. Depending on the target, exposure was carried out using a variety of techniques. The left anterior descending (LAD) artery and the diagonal branches were exposed by placing a deep pericardial suture to elevate and rotate the targets into the surgeon's view (Figure 1, ◎). For exposure of the lateral vessels—the obtuse marginal and the postero-lateral branches of the circumflex—we employed pericardial traction sutures at the left superior and inferior pulmonary veins (Figure 2, ◎), the posterior descending artery (PDA) being exposed with placement of a suture near the inferior vena cava. These traction sutures, along with placing the patient in Trendelenberg position, exposed the lateral coronary arteries adequately without significant hemodynamic compromise. A shunt may be selectively placed to facilitate distal perfusion during performance of the anastomoses. Stabilization is carried out with the help of a mechanical stabilizer.

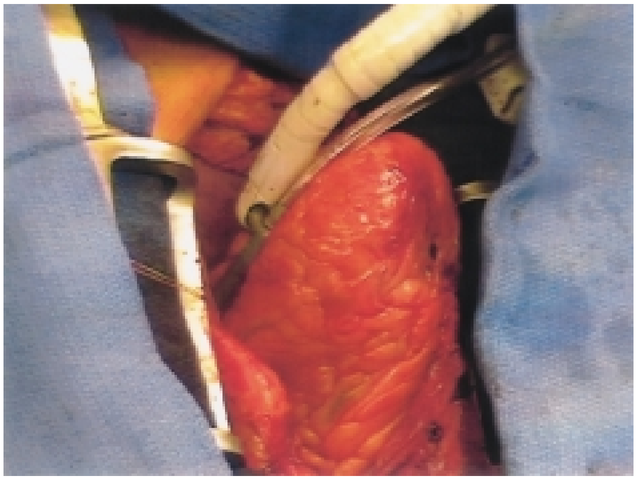

Figure 2. Obtuse marginal exposure.

Table 2A. Operative Findings

	OPCABG	CCABG	p value
Skin-skin time (hrs)	4.49 ± 1.35	4.79 ± 1.35	0.07
Number of distals	4.00 ± 1.20	3.94 ± 1.28	0.69
Aortic calcification (%)	2.9	8.9	0.03
Endartrectomy (%)	0.7	5.2	0.03
Evolving MI (%)	1.4	0.7	0.56
Intraop IABP (%)	3.7	2.9	0.73
Transfusion (% patients)	23.13	27.60	NS
Total # PRBC	77 ± 1.16	80 ± 1.12	0.84
FFP	38 ± 0.79	24 ± 0.58	0.22
Platelets	230 ± 4.81	129 ± 3.30	0.14
Cryo-ppt.	4.00 ± 0.35	4.00 ± 0.00	0.32

Table 2B. Conversions to Cardiopulmonary Bypass

Patient Number	Preoperative Diagnosis	Cause of Conversion	Operative Procedure	Outcome
1	Unstable angina	Asystolic arrest	CABG x 5	Discharged
2	CAD	Hemodynamic instability	CABG x 5	Discharged
3	Unstable angina, Redo	V. fibrillation/MI	CABG x 1	Discharged
4	Unstable angina	Hemodynamic instability	CABG x 4	Discharged
5	Unstable angina	Hemodynamic instability	CABG x 4	Discharged

CCABG

Standard CPB with mild to moderate systemic hypothermia was used with cold-blood antegrade and retrograde cardioplegia to arrest the heart. The anastomoses were performed on a stationary heart. Both partial and total aortic clamping were used for the proximal anastomoses.

RESULTS

There were no mortalities in either group. Total myocardial revascularization was achieved in all patients with a mean number of 4.0 ± 1.2 distal anastomoses in the OPCABG group and 3.9 ± 1.2 in the CCABG group. Both groups had a similar proportion of arterial grafts (2.3 ± 1.3 in the OPCABG group and 2.2 ± 1.5 in the CCABG group, p = NS) and vein grafts (1.6 ± 1.4 in OPCABG and 1.5 ± 1.5 in CCABG, p = NS). Operative findings were similar with respect to the transfusion of blood and blood products, evolving MI, and intraoperative intra-aortic balloon pump (IABP) support. Shorter skin to skin operative times in the OPCABG group approached significance (p = 0.07) (Table 2A, ◎). There were five conversions to cardiopulmonary bypass (Table 2B, ◎).

No significant differences in postoperative complications were found in either group, including MI, new onset atrial fibrillation, and neurologic dysfunction (3.7% vs. 6.7%, p = NS). There were three TIAs and two strokes in the OPCABG group and five TIAs with three strokes in the CCABG group. There were no significant differences with respect to renal failure; respiratory failure, and deep sternal wound infections (Table 3, ◎). We found a higher average chest tube output in the OPCABG group, but this did not translate into an increased number of transfusions (p = 0.9).

A multiple linear regression analysis revealed a significantly shorter length of stay both in the ICU (2.0 ± 4.0 days vs. 3.0 ± 5.4 days; p = 0.0044) and postoperatively in the hospital (7.0 ± 8.0 vs. 9.0 ± 10.0, p = 0.006) (Figure 3, ◎).

Follow-up at six months and twelve months revealed a 0% reintervention rate.

DISCUSSION

The whole-body inflammatory response has been attributed to cardiopulmonary bypass, with an increased morbidity risk that is potentially avoided by off-pump CABG [Boyle 1999]. This systemic inflammatory response begins with the activation of complement, both coagulation pathways, and the fibrinolytic and kallikrein cascades. Monocytes adhere to the CPB circuit modulating the release of cytokines, i.e., TNF-a and a variety of interleukins, while the activation and degranulation of neutrophils results in the release of proteolytic enzymes and oxygen radicals culminating in end-organ injury and postoperative morbidity [Butler 1993, Gu 1998]. This complex set of interactions can have serious sequelae and have prompted physicians to seek improved patient management alternatives through less invasive procedures. Though beating heart surgery has been in existence since the inception of coronary revascularization [Kolessov 1967, Trapp 1975] concerns over long-term graft patency have limited its universal appeal. Nevertheless, theoretical disadvantages of CCABG have prompted renewed interest in this approach.

Neurocognitive dysfunction associated with CPB has been attributed to both microembolization and cerebral

Table 3: Postoperative Complications

	OPCABG	CCABG	p value
MI (%)	2.2	4.4	0.72
A fibrillation	23.1	21.6	0.79
IABP (%)	3.7	5.2	0.54
PTCA (postop) (%)	0.7	6.7	0.37
Reop for bleeding (%)	1.4	1.4	NS
Mechanical vent. (days)	173 ± 4.62	159 ± 0.82	0.10
Re-intubations (%)	11.1	6.7	0.40
Renal failure (%)	5.9	6.7	0.79
Chest tube drainage (ml)	826 ± 711	641 ± 603	0.04
PRBC (units)	158 ± 2.76	163 ± 2.46	0.98
FFP (units)	93 ± 2.88	67 ± 1.46	0.56
Platelets (units)	324 ± 9.93	226 ± 4.95	0.45
Cryoprecipitate (units)	31 ± 1.37	30 ± 1.47	0.97
Sternal infections (%)	0.7	7.4	0.32

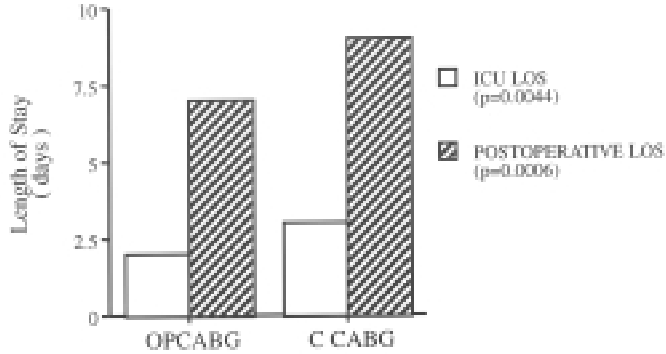

Figure 3. ICU and postoperative length of stay.

ischemia. Long- and short-term cognitive deficits probably secondary to microembolization have been described after CPB [McKhann 1997] ranging from 30-79% in the first two postoperative weeks [Savageau 1982, Shaw 1987] and from 24-57% after six months [Savageau 1982, Shaw 1987a]. In theory, avoidance of aortic cannulation, cross-clamping, and the jet stream from the pump could reduce this often unheralded complication.

Perioperative myocardial dysfunction and myocardial infarction in CABG patients has also been associated with CPB and aortic cross-clamping. Significantly lower Troponin I levels, arrhythmias, and inotropic requirements were observed in OPCABG patients in one prospective randomized study [Ascione 1999]. An additional study showed a lower perioperative MI rate for OPCABG (2.5% vs. 12.5%), but the CPB group of patients in this study had a higher than usual incidence of MI [Bouchard 1998].

Finally, avoidance of CPB may reduce end-organ injury elsewhere in patients. Less postoperative renal insufficiency for OPCABG patients was observed in a prospective randomized study which revealed a significantly worse glomerular filtration rate and renal tubular function in the CPB group [Ascione 1999]. Pulmonary dysfunction associated with CPB has also been demonstrated with evidence of longer duration of ventilatory support [Gu 1998].

These findings have prompted several studies comparing the two methods. A lower mortality for OPCABG (0% vs. 1.6%) was observed in a retrospective study at Emory University with shorter LOS (p = 0.01), fewer transfusions (50% decrease, p = 0.0001), no MI's, no strokes, and a decrease in hospital cost of 33% (p = 0.05) [Puskas 1998]. A larger follow-up study by the same group found a significantly reduced length of stay (5.5 vs. 3.6 days), hospital cost decrease (24%), and fewer transfusions (27.3% vs. 61%) [Puskas 2000].

Although these studies showed a decreased morbidity and mortality in patients undergoing off-pump CABG, our study found no significant differences in postoperative morbidity and mortality between the off-pump and the on-pump CABG groups. However, graft patency and long-term follow-up were not assessed in our study.

The only study examining long-term graft patency results revealed a lower patency rate and a higher reintervention rate at seven years for the OPCABG procedure. [Gundry 1998]. However these operations were performed prior to the creation of modern stabilization devices and exposure techniques. A prospective study undertaken after these devices and techniques became available revealed a 97% graft patency at 48 hours, with no significant difference in mortality or morbidity between the two groups [Bull 2000]. However the number of subjects was small (n = 50) and significantly fewer vessels were bypassed in the off-pump group (2.8 ± 0.6 vs. 3.7 ± 0.8) [Bull 2000]. Prospective studies have shown an early angiographic patency of 99% overall, with 98.2% for the marginal branches [Calafiore 1999, Mack 1999]. In the recent Emory study, 126 patients had an early angiographic patency of 97.8% [Puskas 2000]. A large meta-analysis of 37 peer-reviewed publications concluded that early graft patency was greater than 90% [Mack 1998]. While we await long-term graft patency results, these studies show acceptable early graft patency with the introduction of stabilization devices. Benefit has also been shown in high-risk groups, including those requiring reoperative CABG.

A retrospective evaluation of the New York state data base revealed a significant reduction in stroke (0% vs. 3.8%), cardiovascular complications (4.8% vs. 15.8%), and mortality (1.3% vs. 2.7%) in reoperative patients undergoing off-pump CABG [Bergsland 1998]. Revascularization in this patient population has provided symptomatic improvement but no demonstrated survival benefit. A lower morbidity and mortality observed in reoperative patients undergoing off-pump CABG in comparison with CCABG in the New York state data base support it's use in this patient population [Fanning 1993].

Another proposed benefit of OPCABG is a shorter in-hospital length of stay [Puskas 1998]. A significant reduction in ICU as well as postoperative length of stay in primary OPCABG patients has also been shown [Zenati 1997]. However, other retrospective comparisons showed no statistically significant difference in length of stay between the two groups [Jansen 1997, Ott 1999]. In our patients we found a statistically significant decrease in postoperative ($p = 0.0044$) and ICU length of stay ($p = 0.0006$). While we saw no decrease in postoperative morbidity and no mortalities in either group, both groups had significantly lower rates of morbidity and mortality when compared with STS or New York state rates (2.5% mortality; 15% morbidity). Furthermore, we had a 0% reintervention rate at 12-month follow-up.

A decrease in perioperative bleeding has been shown in a previous study [Nader 1999]. However, while our study found an increase in total chest tube drainage in the OPCABG group (predominantly serous), this did not result in a higher transfusion rate.

Although our study was retrospective, the results yielded were the same for similar groups of patients covering all ranges of ejection fractions and ages. We believe this to be a valid comparison. Though not as good as prospective randomization, it is comparable if not better than a retrospective case-matched study.

While our early 12-month follow-up indicates uniform clinical success, we await long-term graft patency results. With the rapidly progressing interest in minimally invasive surgery and the recent explosion of technological advances, beating heart surgery has evolved into a valuable alternative in coronary revascularization.

CONCLUSION

Our data indicates that a fair number of patients are potential candidates for the off-pump coronary artery bypass procedure, the only contraindications being technical limitations or the surgeon's comfort level. Prospective randomized trials with long-term follow-up are required to evaluate long-term graft patency and to define the real benefits of this approach. Until then, although OPCABG has given us excellent early results and should be part of the surgeon's armamentarium, it cannot be proclaimed as a salutary advance over CCABG.

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