

# Off-Pump Versus On-Pump Coronary Artery Bypass Surgery: A Case-Matched Comparison of Clinical Outcomes and Costs



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## ABSTRACT

**Background:** Results of off-pump coronary artery bypass (OPCAB) surgery have demonstrated trends toward fewer complications, faster recoveries and lower costs compared with on-pump coronary artery bypass (ONCAB) surgery. The validity of such comparisons, however, may be impacted by differences in preoperative risk factors between the two surgeries.

**Methods:** A total of 76 OPCAB surgery patients were case-matched (by age, sex and Society of Thoracic Surgeons' risk scores) with an equal number of patients who underwent ONCAB surgery by the same surgeon. Postoperative clinical parameters (time on mechanical ventilation, number of blood transfusions, peak cardiac enzyme levels and metabolic acidosis) and outcomes data (intensive care unit and overall in-hospital lengths of stay, perioperative myocardial infarction, atrial fibrillation, stroke, reoperation for bleeding and mortality) were analyzed, and the variable and total costs for each patient were calculated.

**Results:** OPCAB patients required less mechanical ventilation and fewer blood transfusions and had lower peak creatinine phosphokinase levels, as well as a reduced incidence of metabolic acidosis. There were trends toward both shorter intensive care unit and overall in-hospital lengths of stay for OPCAB patients. The average total cost for this group was 20.5% less than for ONCAB patients. There were no differences in rates of

atrial fibrillation, myocardial infarction, reoperation for bleeding, stroke or mortality.

**Conclusions:** By reducing the need for mechanical ventilation, transfusions and intensive care unit and overall in-hospital lengths of stay, OPCAB surgery decreases the use of limited and costly resources without increasing risks. These advantages do not appear to be related to patient selection.

## INTRODUCTION

The advent of cardiopulmonary bypass in the latter half of the last century enabled cardiac surgeons to perform a wide range of procedures that had previously been technically impossible. Extracorporeal circulation, however, elicits a series of physiologic derangements including the activation of a systemic inflammatory response as well as detrimental hematologic effects that hinder normal hemostasis. These effects appear to be more clinically significant in elderly patients and in others with underlying organ system dysfunction.

Over the past decade, the use of less-invasive techniques in open heart surgery has expanded. For coronary revascularization, minimally invasive direct coronary artery bypass procedures were developed and refined. Access to the lateral and posterior wall vessels to facilitate complete revascularization evolved, accompanied by technical advances in the instrumentation for stabilization of the heart. The use of off-pump or beating-heart coronary artery bypass (OPCAB) surgery has since become more popular and widely used. Theoretically, by eliminating the use of cardiopulmonary bypass, many of the adverse systemic sequelae associated with extracorporeal circulation may be lessened. As a result, recovery may be hastened and a number of well-documented side effects present in those undergoing on-pump coronary artery bypass (ONCAB) surgery may be decreased.

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Early application of OPCAB surgery was at first undertaken by only a few centers and was limited primarily to grafting vessels on the anterior wall and diaphragmatic surfaces [Buffolo 1990, Benetti 1991]. With time, others began to report successful results in high-risk patients who underwent this procedure. When compared with ONCAB patients (historical controls) at the same institutions, reductions in postoperative complications [Bergsland 1998] and faster recovery [Calafiore 1998] were noted.

As important as documenting the benefits of OPCAB surgery is the need to confirm the safety of this technically demanding procedure by evaluation of clinical outcomes. It is therefore incumbent upon those performing the procedure to maintain accurate data aimed at documenting successful high-quality results. Comparing these outcomes along with the examination of recovery times, resource utilization and costs will hopefully provide an accurate answer to whether these new techniques are clinically beneficial to those patients requiring coronary bypass surgery.

## MATERIALS AND METHODS

At our center, OPCAB surgical techniques were instituted in the latter half of 1998. Seventy-six patients, who underwent OPCAB surgery in our initial experience with this procedure from August 1998 to August 1999, were case-matched with an equal number of patients operated on by the same surgeon (R.A.L.) during the 15-month period before off-pump surgery was undertaken. The two groups were matched by age, sex and Society of Thoracic Surgeons (STS) risk scores (an expected mortality risk based on preoperative characteristics such as ejection fraction, diabetes, renal failure, hypertension, hemodynamic instability, recent myocardial infarction and intra-aortic balloon pump use). Patients were matched by age within five years and by STS risk score within 0.5%.

Patients who underwent ONCAB surgery were cannulated in the distal ascending aorta and right atrium using the standard technique and were heparinized at 4 mg/kg, with additional heparin given to maintain an activated clotting time (ACT) of greater than 400 seconds. Patients were systemically cooled to 32°C, with cardiac standstill obtained using cold blood potassium cardioplegia. A single cross-clamp method was utilized, with distal anastomoses performed prior to proximal anastomoses. Heparin was fully reversed with protamine sulfate at the conclusion of the cardiopulmonary bypass run.

In some off-pump surgery patients, exposure of the heart was facilitated by placement of deep pericardial traction sutures in the oblique sinus and, in others, by incising the right pericardium to allow displacement of the heart into the right pleural space. The Genzyme cardiac stabilizing device (Genzyme-OPCAB Stabilization System, Genzyme Surgical Products, Cambridge, MA) was utilized in all patients. Systemic heparinization was initially delivered at 3 mg/kg, with additional bolus doses to maintain an ACT

of greater than 400 seconds. Body temperature was maintained at greater than 36.5°C by using a constant ambient room temperature of 24°C. Distal anastomoses were performed prior to proximals in the vast majority of patients, with the left internal mammary artery-left anterior descending coronary artery anastomosis performed last. Protamine sulfate was administered to correct for the ACT after the final anastomosis was completed.

All patients in both groups were transported to the Intensive Care Unit (ICU) postoperatively. Enteric coated aspirin was administered beginning on the first postoperative day and patients in both groups were extubated as per standard procedure (with documentation of adequate levels of awakening, ability to oxygenate and lack of hypercarbia). Chest drains were removed when drainage was less than 100 mL over an eight-hour period. All patients were subjected to the same postoperative recovery protocols both in the ICU and on the ward, including criteria for transfusion of blood products.

Data was collected prospectively and examined retrospectively on all patients, focusing on preoperative characteristics as well as clinical outcomes such as time on mechanical ventilation, ICU and overall postoperative length of stay (LOS), number of blood transfusions, incidence of metabolic acidosis (as defined by  $\text{HCO}_3^- < 21$  mm/L) and peak levels of creatinine phosphokinase (CPK) in the first 24 hours. The occurrence of atrial fibrillation, reoperation for bleeding, stroke, perioperative myocardial infarction and mortality were recorded. Fixed and variable costs for each patient were obtained and were evaluated for their association to age and STS risk scores within each group.

Continuous data was analyzed using a paired t test, while categorical values were analyzed using a McNemar chi-square test. Both tests took into account that patients were matched prior to statistical analysis, with significance indicated by p values less than 0.05. Cost differences between the two groups, as well as relationships between age and cost, and preoperative risk score and cost were examined using a t test.

## RESULTS

There were 56 males and 20 females in each group and because of the case-matched criteria, both groups were similar in preoperative clinical characteristics (Table 1, ⊙). They did however differ in the average number of distal anastomoses performed (OPCAB: 2.8; ONCAB: 3.7;  $p = 0.00001$ ), which appeared to be related to the presence of three-vessel coronary artery disease (OPCAB 65%; ONCAB 81%;  $p = 0.051$ ). There was also no significant difference between the two groups in the number of patients who had undergone a previous coronary artery bypass operation (OPCAB: 3; ONCAB: 1).

Incision-to-dressing operating room time was on the average 25 minutes shorter with OPCAB operations. Average time on the ventilator was significantly lower for the OPCAB group (Table 2, ⊙), with 52.6% of the OPCAB

Table 1. Preoperative characteristics of patients who underwent off-pump coronary artery bypass (OPCAB) compared with those who underwent on-pump coronary artery bypass (ONCAB)

	Mean	p value
Age, y		
OPCAB	64.4	0.170
ONCAB	64.0	
STS risk score, %		
OPCAB	2.07	0.950
ONCAB	2.07	
Parsonnet risk score, %		
OPCAB	7.15	0.520
ONCAB	6.77	
Ejection fraction, %		
OPCAB	50.3	0.099
ONCAB	47.3	

STS indicates Society of Thoracic Surgeons.

patients extubated in the operating room versus none of the ONCAB patients. Both the mean ICU stay and the overall postoperative LOS were reduced for the OPCAB group, although fell short of statistical significance. The median postoperative LOS for the OPCAB group was four days—one day shorter than the LOS for the ONCAB group.

The average number of packed red blood cell transfusions and the mean peak CPK levels were significantly lower for the OPCAB group on both of the first postoperative days (Table 2, ⊙). The incidence of metabolic acidosis was significantly less in the OPCAB group compared with the ONCAB group (53% and 72%, respectively;  $p = 0.026$ ). No significant differences were found in the incidences of atrial fibrillation (OPCAB: 23.9%; ONCAB: 26.3%;  $p = 0.845$ ), stroke, perioperative myocardial infarction, reoperation for bleeding or mortality (Table 3, ⊙).

Mean variable costs were found to differ significantly in favor of OPCAB surgery; mean total costs did not differ significantly in the ONCAB group (Table 4, ⊙), but this was due to a large standard deviation. In the OPCAB group, there was no association between either age or STS risk score and cost of care. For the ONCAB group, however, both age and STS risk score were significantly associated with costs, with an increase of one year of age being associated with a mean increase in variable cost of \$122.40 ( $p = 0.01$ ) and with a mean increase in total cost of \$329.30 ( $p = 0.006$ ). For the STS risk score, an increase of 1% of STS risk was associated with a mean increase in variable cost of \$428.70 ( $p = 0.07$ ) and with a mean increase in total cost of \$1706.40 ( $p = 0.004$ ).

## DISCUSSION

By eliminating the need for cardiopulmonary bypass, off-pump surgery has theoretical clinical advantages over con-

Table 2. Postoperative characteristics of patients who underwent off-pump coronary artery bypass (OPCAB) compared with those who underwent on-pump coronary artery bypass (ONCAB)

	Mean	p value
Time on ventilator, d		
OPCAB	0.26	0.007
ONCAB	0.77	
Postoperative ICU LOS, d		
OPCAB	1.80	0.144
ONCAB	2.41	
Postoperative LOS, d		
OPCAB	5.17	0.112
ONCAB	6.24	
PRBC, POD 1, units		
OPCAB	0.25	0.00001
ONCAB	0.88	
PRBC, POD 2, units		
OPCAB	0.05	0.040
ONCAB	0.18	
Peak CPK, POD 1, u/L		
OPCAB	565	0.009
ONCAB	834	

ICU indicates intensive care unit; LOS, length of stay; PRBC, packed red blood cell transfusion; POD, postoperative day; CPK, creatinine phosphokinase.

ventional on-pump procedures, in part due to the absence of the marked systemic inflammatory response elicited by extracorporeal circulation during on-pump procedures [Wan 1999, Matata 2000]. This phenomenon may theoretically lead to a reduction in specific organ system dysfunction related to cardiopulmonary bypass, especially in high-risk populations (e.g., those with chronic obstructive pulmonary disease or renal dysfunction). Limiting the physiologic trauma of the operation would thus promote faster recovery, particularly in susceptible populations with a relatively greater number of co-morbidities, such as the elderly.

Off-pump surgery has been shown to produce less organ-specific dysfunction than on-pump surgery. For instance, glomerular filtration rates were better in OPCAB patients than in those subjected to cardiopulmonary bypass [Ascione 1999a]. Our finding of a lower incidence of metabolic acidosis in OPCAB patients, also noted by Bouchard et al. [Bouchard 1998], may suggest better end-organ perfusion during the operation, although more in-depth studies are needed before this can be stated with assurance.

Some data have suggested better myocardial protection and subsequent performance after OPCAB surgery. Lower rates of postoperative CPK leak and of myocardial infarction [Bouchard 1998, Arom 2000], as well as reduced requirements for inotropic support [Ascione 1999b, Boyd 2000] and less frequent need for postoperative intra-aortic balloon pump use [Puskas 1998] when compared with ONCAB surgery have been reported. In our study there was a significant difference in cardiac enzyme leak, but

Table 3. Postoperative complications

	OPCAB, n (%)	ONCAB, n (%)
Atrial fibrillation	18 (23.9)	20 (26.3)
Cerebrovascular accident	1 (1.3)	0 (0)
Postoperative MI	1 (1.2)	1 (1.3)
Reoperation for bleeding	0 (0)	1 (1.3)
Mortality	1 (1.3)	3 (3.9)

OPCAB indicates off-pump coronary artery bypass; ONCAB, on-pump coronary artery bypass MI, myocardial infarction.

there was no difference in the rate of myocardial infarction. It is therefore unclear whether the CPK leak reflects ischemia-related myocyte loss, mechanical trauma to the heart by avoidance of cannulation or other factors.

Although we did not find significant differences in the rates of postoperative complications between the two groups, this may be due to our small sample size. Whereas some have found significantly lower rates of atrial fibrillation after off-pump surgery [Arom 2000, Boyd 2000], the incidences of stroke and mortality are not consistently lower in OPCAB patients. However, Arom et al. did find significantly fewer episodes of renal failure as well as lower mortality when comparing OPCAB to ONCAB results in patients with STS risk scores greater than 10% [Arom 2000].

Our finding of a reduction in the use of limited and costly resources has been consistent with other reports of OPCAB surgery. Lowering costs in coronary artery bypass surgery patients through earlier extubation and by utilizing "fast track" protocols has been shown to be safe, without producing an increase in morbidity or mortality [Engleman 1994, Arom 1995]. By virtue of eliminating the need for extracorporeal circulation and hastening recovery, OPCAB surgery costs are reduced when compared with ONCAB costs. The need for fewer blood transfusions has been well-documented [Calafiore 1998, Puskas 1998, Arom 1999, Ascione 1999b], as has a decrease in the need for reoperation for bleeding when compared with ONCAB patients [Ascione 1999b, Arom 2000]. The shorter average operating room time noted in our study has been reported by others [Arom 1999, Arom 2000] and is likely due to a combination of both fewer grafts being performed as well as less or no time required for cannulation, cardioplegia delivery, rewarming the patient and achieving hemostasis. Significant reductions in time on mechanical ventilation and ICU length of stay have been noted previously [Arom 2000, Boyd 2000] as have significant reductions in overall postoperative lengths of stay of up to three days [Puskas 1998, Arom 2000, Boyd 2000].

Cost savings with OPCAB surgery have also been documented, with reductions in costs ranging from 14% to 30% [Puskas 1998, Arom 1999, Boyd 2000]. Ascione et al. found significant cost reduction due to lower bed occupancy rates, nursing expenses, the need for transfusions and perioperative complications (specifically, fewer chest wound infections and less need for inotropic support) [Ascione 1999b].

Table 4. Comparison of variable and total costs of off-pump coronary artery bypass (OPCAB) compared with on-pump coronary artery bypass (ONCAB)

	OPCAB	ONCAB	p value
Mean variable costs, \$	7706.99	9730.67	<0.01
Mean total costs, \$	15041.68	18943.73	>0.05

Similarly, we found a significant cost savings utilizing off-pump techniques with a reduction in total costs of just over 20%. A more detailed analysis of this difference by our Financial Office showed the savings to be most pronounced in specific areas. The average cost of blood transfusions per patient dropped by 87.4% and by limiting the time on mechanical ventilation (or avoiding it entirely), respiratory care costs were reduced by 67.7%. Operating room costs were lower by virtue of not using the cardiopulmonary bypass circuit (67.3% less for equipment) and by a reduction in operative time (17.6% reduction in cost). Lower costs were also generated by both the pharmacy (64.2%) and the ICU (44.2%).

The major concern regarding clinical outcomes not addressed in this report centers around long-term patency with this technically more difficult procedure. Although some reports have documented excellent early patency with OPCAB techniques [Calafiore 1998, Puskas 1998, Cartier 1999, Boyd 2000], Arom et al. recently reported higher rates of reoperation for graft occlusion in OPCAB patients as well as more frequent subsequent re-admissions for angina and reinterventions [Arom 2000]. Accurate follow-up over time is thus essential and will provide answers to these concerns.

The average age of those undergoing coronary artery bypass surgery has been increasing over the past two decades. As the incidence of comorbidity rises with increasing age [Stamou 2000], mortality and morbidity rates with coronary artery bypass surgery also increase with age [Weintraub 1991]. The institution of "fast track" protocols in the elderly, however, has been shown to be safe and effective [Lee 1999]. Boyd et al. have demonstrated improved outcomes and cost savings in this patient subpopulation using off-pump techniques [Boyd 2000]. These observations suggest that those who may potentially benefit greatly from off-pump surgery may indeed turn out to be the elderly population, as well as others with more comorbidities.

Our data suggest that the cost savings is most notable in older, sicker patients because increases in age and in STS risk scores were significantly associated with costs in ONCAB patients but not in OPCAB patients. This is likely due to an attenuation of clinically obvious (and perhaps not-so-obvious) pathophysiologic changes that accompany ONCAB surgery and delay recovery, because we found no significant differences in rates of major complications which would account for significant cost differences.

The relatively small number of patients examined limits our study. With our total off-pump experience now near-

ing 300 patients, a similar case-matched study is planned to see if these trends have persisted or even improved as both surgeons and the institution as a whole becomes more familiar with the postoperative care of these patients. Ideally, large randomized prospective studies comparing the two techniques will more reliably answer the questions of clinical benefits (several of which have begun at other centers in the past year).

Although both groups were managed clinically by the same team of physicians and nurses, using standard postoperative protocols that did not differ between the two groups, we recognize that there may be an element of bias regarding overall time on mechanical ventilation. No effort was made to extubate OPCAB patients in such a manner, as previous attempts to do so at our institution have routinely failed. Use of a lighter anesthetic protocol for OPCAB patients combined with a degree of expectation that these patients would extubate earlier may thus have introduced bias into this data. For OPCAB patients who were not extubated in the operating room, however, shorter intubation times (0.42 days) were still present when compared with ONCAB patients.

By case-matching patients for preoperative characteristics that would have impact on length of stay, our data suggest that the use of OPCAB surgery has decreased the use of limited and costly resources without compromising safety for those who undergo this operation.

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