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Resource Utilization in Off-Pump versus Conventional Coronary Artery Bypass Grafting in a Community Hospital: A Comparative Analysis Using Propensity Scoring

Scot C. Schultz, MD,[1,2] Scott Woodward, CRNA,[1,2] George Ebra, EdD[1,2]

[1]Gulf Coast Cardiothoracic and Vascular Surgeons, Naples, Florida; [2]Naples Community Hospital, Naples, Florida, USA

ABSTRACT

Background: At a time when cost containment in health care is under increased scrutiny, coronary artery bypass grafting remains the most widely performed cardiac surgical procedure in the world. This study compares 30-day mortality, morbidity, and resource use for off-pump coronary artery bypass (OPCAB) versus conventional coronary artery bypass (CCAB) revascularization.

Methods: From January 2000 through December 2008, 1003 patients underwent OPCAB grafting by a single surgeon (S.C.S.). Data were prospectively collected, entered into a Society of Thoracic Surgeons adult cardiac surgery database, and analyzed retrospectively. We used propensity-matching techniques to match this cohort to a group of 1003 patients who underwent CCAB.

Results: The hospital mortality rate was lower for the OPCAB patients than for the CCAB patients: 2.0% (20/1003) versus 2.8% (28/1003). Predictors of hospital mortality for the entire cohort included age (P = .001), cardiogenic shock (P = .001), congestive heart failure (P = .019), history of myocardial infarction (P = .001), and reoperation (P = .007). The overall incidence of morbidity was lower for the OPCAB patients (reoperation for bleeding, P = .011; prolonged ventilation, P = .035; stroke, P = .045; cardiac arrest, P = .004). OPCAB patients experienced significantly reduced procedure times (P = .001), postoperative ventilation times (P = .035), postoperative lengths of stay (P = .035), and blood product use (intraoperative, P = .001; postoperative, P = .001).

Conclusion: These outcomes clearly demonstrate that OPCAB is a safe and effective procedure for myocardial revascularization. This retrospective, nonrandomized observational study has shown that the patients who underwent OPCAB had reduced morbidity and mortality, as well as decreased resource use, compared with those who underwent CCAB.

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Correspondence: Dr. Scot C. Schultz, Gulf Coast Cardiothoracic and Vascular Surgeons, Naples Community Hospital, Naples, Florida, USA; 239-649-0440; fax: 239-649-1905 (e-mail: canes99@yahoo.com).

INTRODUCTION

Coronary artery bypass grafting (CABG), the most widely performed cardiac surgical procedure in the world today, was made possible through the development of cardiopulmonary bypass (CPB). The advantage of using CPB during CABG is the ability to operate on a still heart devoid of blood while providing exposure of all coronary vessels. Despite its widespread use in cardiac surgery, CPB is well recognized to be nonphysiological and associated with deleterious and damaging side effects.

Introduced in the 1960s [Kolessov 1967; Favaloro 1969], off-pump CABG (OPCAB) remains a controversial alternative to conventional CABG with CPB (CCAB) and has endured intense scrutiny by the cardiac surgical community [Parolari 2005]. The literature has clearly defined the safety and benefits of OPCAB, which include less brain injury [Patel 2002], reduced myocardial damage [Penttila 2001], diminished renal failure [Ascione 1999a], fewer blood transfusions [Puskas 1998], a lesser degree of complement activation [Vallely 2001], and significant cost savings to the institution [Ascione 1999b], along with uncompromised graft patency [Puskas 1999]. Only a relatively small number of surgeons have embraced the procedure since it is estimated that approximately 20% of surgical revascularizations worldwide are performed on a beating heart [Lytle 2004]. With the advent of improved cardiac stabilizers, refinements in surgical and anesthesia techniques, and increasing surgical experience, OPCAB surgery can be safely performed in essentially all patients who undergo myocardial revascularization.

This study examines the safety and efficacy of OPCAB versus CCAB in a community hospital. We used propensity scoring and a propensity-matching algorithm in a comparative analysis of in-hospital clinical outcomes and resource use for a group of patients undergoing OPCAB and a control group of patients undergoing CCAB.

MATERIALS AND METHODS

Patient Population

The surgical group's computerized Society of Thoracic Surgeons (STS) Adult Cardiac Surgery Database (version 2.61) was used to identify all patients who underwent isolated CABG between January 2000 and December 2008.

Table 1. Comparison of Preoperative Clinical Variables and Risk Factors by Patient Group*

Variables	OPCAB Group	CCAB Group	*P*
Patients, n (%)	1003 (100.0)	1003 (100.0)	
Sex, n (%)			
Male	814 (81.2)	791 (78.9)	.199
Female	189 (18.8)	212 (21.1)	
Age, y†	68.1 ± 9.6 (27-90)	67.5 ± 9.8 (31-89)	.164
Age group, n (%)			
<50 y	35 (3.5)	56 (5.6)	
51-59 y	147 (14.7)	134 (13.4)	
60-69 y	347 (34.6)	352 (35.1)	
70-79 y	367 (36.6)	370 (36.9)	
≥80 y	107 (10.7)	91 (9.1)	
Coronary risk factors, n (%)			
Family history of CAD	447 (44.6)	455 (45.4)	.720
Hypertension	733 (73.1)	735 (73.3)	.920
Dyslipidemia	705 (70.3)	709 (70.7)	.845
Smoking history	149 (14.9)	168 (16.7)	.245
Diabetes mellitus	285 (28.4)	288 (28.7)	.882
Perioperative risk factors, n (%)			
Renal dysfunction	22 (2.2)	19 (1.9)	.636
Chronic lung disease	74 (7.4)	82 (8.2)	.505
Cerebral vascular disease	91 (9.1)	99 (9.9)	.542
Peripheral artery disease	174 (17.3)	176 (17.5)	.906
Prior myocardial infarction	381 (38.0)	384 (38.3)	.890
History of congestive heart failure	101 (10.1)	100 (10.0)	.941
Unstable angina	894 (89.1)	911 (90.8)	.206
Cardiogenic shock	16 (1.6)	20 (2.0)	.501

*OPCAB indicates off-pump coronary artery bypass grafting; CCAB, coronary artery bypass grafting with cardiopulmonary bypass; CAD, coronary artery disease.

†Age data are presented as the mean ± SD (range).

We identified 3107 patients, of which 1003 underwent OPCAB and 2104 underwent CCAB. The patients who underwent OPCAB represent the experience of a single surgeon (S.C.S.). Following propensity matching, on- and off-pump patients were comparable with respect to the measured demographic and preoperative variables. The remaining 2006 patients constitute the clinical material for this comparative analysis. Table 1 summarizes the baseline characteristics of the 2 study groups. This study was presented to the Institutional Review Board, which waived the requirement for informed consent because of the study's retrospective nature.

Preoperative angina symptoms were defined by the Canadian Cardiovascular Society (CCS) classification system. There were 199 patients (19.8%) in the OPCAB group who had previously undergone percutaneous coronary intervention and 214 patients (21.3%) in the CCAB group. Moreover, 22 patients (2.2%) in each group had previously undergone CABG. There were no statistically significant differences between the 2 groups with respect to CCS class, percutaneous coronary intervention, or prior CABG.

Preoperative Angiographic Findings

Before their operations, all patients underwent selective coronary arteriography evaluation. In the OPCAB group, 830 patients (82.9%) demonstrated triple-vessel disease, 134 patients (13.4%) had double-vessel disease, and 38 patients (3.8%) had single-vessel disease. In the CCAB group, 826 patients (82.4%) had triple-vessel disease, 163 patients (16.3%) had double-vessel disease, and 14 patients (1.4%) had single-vessel disease. Left main coronary artery disease (>0.50 stenosis) was present in 259 patients (25.8%) in the OPCAB group and 242 patients (24.1%) in the CCAB group.

In the OPCAB group, the ejection fraction as determined by left ventriculography or echocardiography was >0.50 in 572 patients (57.0%), between 0.30 and 0.50 in 378 patients (37.7%), and <0.30 in 53 patients (5.3%). In the CCAB group, the ejection fraction was >0.50 in 566 patients (56.4%), between 0.30 and 0.50 in 393 patients (39.2%), and <0.30 in 44 patients (4.4%).

Surgical Technique

OPCAB Group. The techniques used in this group have evolved over the course of the study, although all procedures were performed via a median sternotomy. Intravenous heparin (200 U/kg; activated coagulation time target, >300 seconds) was administered following internal mammary artery (IMA) harvesting. The pericardium was incised with an inverted-T incision, and a full right pleuropericardiotomy was created down to the inferior vena cava. A single deep pericardial 2-0 Ethibond 36-in suture was placed as previously described [Bergsland 1999]. We used various stabilizers, including compression stabilizers (Guidant/Maquet, Wayne, NJ, USA) Genzyme/Teleflex Medical, Research Triangle Park, NC, USA) and suction stabilizers (Estech, San Ramon, CA, USA; Guidant/Maquet). In general, the distal anastomosis was performed before the proximal anastomosis. Exceptions to this distal-first sequence were for actively ischemic patients and those in whom proximal anastomotic devices (Symmetry Bypass System [St. Jude Medical, St. Paul, MN, USA], PAS-Port [Cardica, Redwood City, CA, USA]) were used. In general, the IMA anastomosis was the last distal anastomosis to be performed, and collateralized vessels were grafted before collateralizing vessels. To facilitate the proximal anastomosis, we placed a side-biting aortic partial-occlusion clamp in the majority of patients. When an aortic clamp was deemed too risky to apply, proximal anastomoses were constructed with other arterial sources (such as T-grafts off the left IMA or the innominate artery) or with proximal anastomotic devices. At the completion of the procedure, heparin was fully reversed with protamine sulfate.

Table 2. Coronary Arteries Grafted and Types of Conduits in Patients Undergoing Coronary Artery Bypass Grafting according to Patient Group*

Conduit	OPCAB Group	CCAB Group
Internal mammary artery, no. of grafts		
LAD	714	875
DIAG	112	76
OM/CX	23	26
RCA	5	2
PDA/PL	0	2
Radial artery, no. of grafts		
LAD	132	19
DIAG	142	118
OM/CX	339	348
RCA	38	32
PDA/PL	78	49
Vein, no. of grafts		
LAD	104	78
DIAG	264	310
OM/CX	599	874
RCA	165	211
PDA/PL	491	489
Total, no. of grafts	3206	3509

*OPCAB indicates off-pump coronary artery bypass grafting; CCAB, coronary artery bypass grafting with cardiopulmonary bypass; LAD, left anterior descending artery; DIAG, diagonal artery; OM, obtuse marginal branch; CX, circumflex artery; RCA, right coronary artery; PDA, posterior descending artery; PL, posterior lateral branch.

CCAB Group. Intravenous heparin (350 U/kg, activated coagulation time target >450 seconds) was administered following IMA harvesting. Standard CPB techniques with ascending aorta cannulation and 2-stage venous cannulation of the right atrium were routinely performed. The CPB circuit consisted of a centrifugal pump, and the patients were cooled to 28°C to 32°C, with mean arterial pressures maintained between 55 and 75 mm Hg. Myocardial protection was maintained with antegrade and/or retrograde cold blood cardioplegia (surgeon preference). Proximal anastomoses were created with single-clamp and side-biting clamp techniques (surgeon preference). At the completion of the procedure, heparin was fully reversed with protamine sulfate.

Data Sources

Perioperative data were obtained by prospective review of the patient's hospital record. The Patient Registration Form allowed standardized reporting in accordance with the guidelines and definitions of the STS Adult Cardiac Surgery Database (version 2.61) for each patient's clinical status.

The Social Security Death Index database (available at http://genealogy.rootsweb.com) was used to obtain patient 30-day mortality data. The capability to identify deaths in the Social Security Death Index is between 92% and 99%, according to the unique identifiers available [Williams 1992].

Statistical Analyses

Demographic and clinical data are presented as frequency distributions and simple percentages. Values for continuous variables are expressed as the mean ± SD. Univariate analyses of selected preoperative, intraoperative, and postoperative discrete variables were accomplished by chi-square analysis, continuity-adjusted chi-square analysis, or a 2-tailed Fisher exact test, with the appropriate degrees of freedom used to test for the equality of proportions in the case of categorical variables. Two-sample Student t tests (2-tailed) were used to test for the equality of means for continuous variables. A hierarchical logistic regression model was developed to examine the relationship between pre- and intraoperative variables with respect to hospital mortality.

Propensity score technology applying logistic regression and based on selected demographic and preoperative clinical variables was used to calculate the probability of each patient to undergo OPCAB. This calculation generated a propensity score between 0 and 1, which summarized a collection of covariates and indicated the likelihood of a given patient to undergo an OPCAB procedure. We used Rosenbaum's optimal matching algorithm [Rosenbaum 1989] to match the pool of patients who underwent CCAB with the OPCAB patients. This approach, which minimizes the overall distance between observations, was conducted with the Mahalanobis distance within propensity score calipers (no matches outside the calipers). The application of this matching technique controls for potential confounding variables.

The collected data were subjected to both quantitative and qualitative analysis with the biostatistical capabilities of the Number Cruncher Statistical Systems software (NCSS, Kaysville, UT, USA). A difference between measurements with a P value ≤.05 was defined as statistically significant.

Operative Data

We performed 3206 coronary artery grafts (mean, 3.2 per patient; range, 1-6) in the OPCAB group, compared with 3509 (mean, 3.5; range, 1-8) in the CCAB group (P = .001). During the last 4 years of the study, the 2 groups were comparable with respect to the number of grafts per patient. There were 375 sequential grafts in the OPCAB group and 346 in the CCAB group. Table 2 summarizes the types of conduits used and the corresponding recipient arteries.

RESULTS

Hospital Morbidity Rate

The overall incidence of major morbidities for the 2 groups was low. A majority of the patients experienced no in-hospital complications (P = .107): 899 patients in the OPCAB group (89.6%) and 920 patients in the CCAB group (91.7%).

Table 3. Comparison of Hospital Complications by Patient Group*

Complications	OPCAB Group, n (%)	CCAB Group, n (%)	P
Patients	1003 (100.0)	1003 (100.0)	
Reoperation for bleeding	22 (2.2)	42 (4.2)	.011
Prolonged ventilation	58 (5.8)	82 (8.2)	.035
Cerebrovascular accident	4 (0.4)	12 (1.2)	.045
Perioperative myocardial infarction	3 (0.3)	5 (0.5)	.479
Renal dysfunction	70 (7.0)	49 (4.9)	.047
Cardiac arrest	4 (0.4)	17 (1.7)	.004
Gastrointestinal	34 (3.4)	27 (2.7)	.363
Deep sternal infection	7 (0.7)	6 (0.6)	.781

*OPCAB indicates off-pump coronary artery bypass grafting; CCAB, coronary artery bypass grafting with cardiopulmonary bypass.

Postoperative complications were defined in accordance with the STS guidelines. A between-group comparison for each of the hospital complications (Table 3) revealed significant differences in reoperation for bleeding (P = .011), prolonged ventilation (P = .035), cerebrovascular accident (P = .045), and cardiac arrest (P = .004). The incidence of renal dysfunction favored CCAB; however, there was no significant difference between the groups in the number of patients requiring hemodialysis.

Placement of an intra-aortic balloon pump was required in 54 patients (5.4%) in the OPCAB group and in 56 patients (5.6%) in the CCAB group.

Hospital Mortality Rate

The hospital mortality rate was 2.0% (20 of 1003) for OPCAB patients and 2.8% (28 of 1003) for CCAB patients. The elective mortality rates of 2.3% (17 of 741) in the OPCAB group and 2.2% in the CCAB group were not significantly different; however, a comparison of the mortality rates for nonelective surgery achieved statistical significance (P = .022). The mortality rate for urgent surgery was 0.0% (0 of 221) for the OPCAB patients, versus 2.1% (5 of 238) for the CCAB patients; the mortality rate for emergent/salvage surgery for OPCAB patients was 7.3% (3 of 41), versus 21.9% (7 of 32) for CCAB patients.

The mortality rate for first operation was 1.7% (17 of 981) for the OPCAB patients and 2.7% (26 of 981) for the CCAB patients. The mortality rate for reoperation was 13.6% (3 of 19) for the OPCAB patients and 9.1% (2 of 22) for the CCAB patients.

We entered 25 preoperative and intraoperative variables into a forward stepwise logistic regression model for the entire cohort in order to identify independent correlates of hospital mortality. Of the variables entered into the multivariate model, 5 preoperative variables were significant predictors of increased hospital mortality (Table 4): age, P = .001; cardiogenic shock, P = .001; history of congestive heart failure, P = .019; prior myocardial infarction, P = .001; and reoperation, P = .017. The surgical approach (OPCAB versus CCAB) was not a predictor of hospital mortality.

Resource Utilization

To assess the impact of resource utilization on the 2 groups, we compared 6 commonly used measures (Table 5). Procedure times were significantly shorter for OPCAB patients than for CCAB patients (mean ± SD, 147.1 ± 34.0 minutes versus 185.2 ± 55.1 minutes; P = .001). There was a trend toward a reduction in ventilator dependence in the OPCAB group (mean, 17.1 ± 53.2 hours versus 22.9 ± 71.9 hours; P = .053). Moreover, prolonged ventilation (>24 hours) was less frequent in the OPCAB group than in the CCAB group (5.8% versus 8.2%, P = .035).

The postprocedure length of stay (LOS) in the intensive care unit was shorter for the OPCAB group (42.9 ± 39.7 hours) than for the CCAB group (51.0 ± 83.3 hours; P = .095). The OPCAB patients also had significantly shorter hospital LOSs (6.5 ± 5.0 days versus 7.1 ± 5.7 days, P = .035). Seventeen percent of the patients in the OPCAB group and 35.4% of the patients in the CCAB group required intraoperative administration of one or more blood products (P = .001). A similar pattern of blood product use was observed postoperatively, with 39.4% of the patients in the OPCAB group and 55.0% of the patients in the CCAB group requiring administration of one or more blood products (P = .001).

Table 4. Multivariate Analysis of Demographic and Preoperative Clinical Variables Associated with Hospital Mortality in Patients Undergoing Isolated Coronary Artery Bypass Grafting with and without Cardiopulmonary Bypass*

Predictor	Beta Estimate	SE	X^2	P†	Odds Ratio	95% CI
Age	0.0861	0.0198	22.46	.001	1.1	1.0-1.1
Cardiogenic shock	1.9689	0.4982	12.17	.001	7.2	2.7-19.0
Chronic heart failure	0.8742	0.3514	5.53	.019	2.4	1.2-4.8
History of myocardial infarction	1.0601	0.3245	11.17	.001	2.9	1.5-5.5
Reoperation	1.6482	0.5179	7.39	.007	5.2	1.9-14.3

*SE indicates standard error; CI, confidence interval.

†Only significant variables (P < .05) are listed.

Table 5. Comparison of Resource-Utilization Variables by Patient Group*

Variables	OPCAB Group	CCAB Group	*P*
Procedure time, min	147.1 ± 34.0	185.2 ± 55.1	.001
Postoperative ventilation time, h	17.1 ± 53.2	22.9 ± 71.9	.053
Intensive care unit stay, h	42.9 ± 39.7	51.0 ± 83.3	.095
Postoperative LOS, d	6.5 ± 5.0	7.1 ± 5.7	.035
Intraoperative blood product use, n (%)	60 (17.0)	149 (35.4)	.001
Postoperative blood product use, n (%)	395 (39.4)	552 (55.0)	.001

*Data are presented as the mean ± SD where indicated. OPCAB indicates off-pump coronary artery bypass grafting; CCAB, coronary artery bypass grafting with cardiopulmonary bypass; LOS, length of stay.

DISCUSSION

Advances in surgical techniques, anesthesia management, and the application of other adjunctive technologies have all contributed to improved clinical outcomes in OPCAB surgery during the last decade. With the current cost-containment environment, reduced health care resources, and the need to eradicate or ameliorate the adverse effects of CPB, a simpler and less invasive myocardial revascularization procedure has evolved. As with most innovative surgical techniques, OPCAB is a technically demanding procedure that involves a steep learning curve. It is well documented that OPCAB surgery in experienced hands can be accomplished with excellent clinical outcomes [Song 2003; Puskas 2008; Chen 2009].

This study represents one of the largest reported series of consecutive OPCAB cases by a single surgeon in a community hospital. The experience demonstrates a commitment to OPCAB surgery at a time when there was a degree of uncertainty as to the efficacy and safety of the procedure. The study has compared prospectively collected data with standardized methods applying STS guidelines and definitions.

The results of this study clearly demonstrate that OPCAB can be safely performed in a community hospital setting with reduced mortality, morbidity, and resource utilization, compared with CCAB. In the present study, hospital mortality was lower in the OPCAB group than in the CCAB group. Furthermore, OPCAB procedures were associated with significantly lower rates of reoperation for bleeding, prolonged ventilation, postoperative cerebrovascular accident, and cardiac arrest. These outcomes are comparable to those reported in the literature [Ascione 2001; Stamou 2002; Berson 2004; Carlson 2007]; in the present series, however, we observed an increased risk for renal dysfunction in the OPCAB patients, but not for renal failure requiring hemodialysis. This finding was unexpected, because several investigators have reported a reduced occurrence of renal failure after OPCAB surgery [Puskas 1998; Arom 2000]. Our experience may be related to our tolerance of brief periods of intraoperative hypotension and our use of ketorolac for postoperative pain management.

This study has also demonstrated a significant reduction in resource utilization in the OPCAB group, with significantly shorter procedure times, reduced postoperative ventilation times, and shorter stays in the intensive care unit. Furthermore, CCAB patients had a longer mean overall hospital LOS than OPCAB patients, a finding that supports outcomes previously reported for OPCAB surgery [Cheng 2005]. This difference in postoperative LOS represents a significant cost savings and reduced use of health care resources. Moreover, there was a dramatic difference between the 2 groups in blood product use, with OPCAB patients requiring significantly fewer blood products intra- and postoperatively. This finding represents an important factor in minimizing the occurrence of morbidity and confirms the findings described in previous reports [Reston 2003].

This study has shown that a commitment to OPCAB surgery can produce excellent outcomes, with reduced mortality, morbidity, and the use of fewer hospital resources. With the current emphasis on cost containment, reduced health care resources, and the need to minimize complications, these results cannot be overlooked and clearly demonstrate the benefits that can be derived with the use of OPCAB for myocardial revascularization.

Limitations of the Study

This study provides valuable information concerning a comparative analysis of OPCAB and CCAB; however, a series of caveats regarding the study outcomes must be considered. The retrospective, nonrandomized, and observational nature of the study imposed some limitations on the comparability of the groups. Despite the application of sophisticated statistical algorithms to control for biases in patient selection, the study design has inherent limitations. However, observational, nonrandomized, retrospective studies have the advantage that they are representative of what actually occurs in a community-based practice and are generally better powered to identify significant differences in outcomes and are more open to generalization.

The results of the propensity analysis and the application of an optimal-matching technique based on a series of known demographic and clinical characteristics did not suggest the presence of any patient-selection bias (Table 1). The application of propensity score analysis in the present study adjusted for baseline differences and allowed homogeneous groups to be compared with respect to 2 different approaches to myocardial revascularization.

CONCLUSION

In today's health care environment, the focus of myocardial revascularization is on less-invasive techniques that reduce costs, decrease resource use, and minimize morbidity and mortality. This single-surgeon experience has demonstrated that OPCAB surgery can be accomplished with reduced morbidity and mortality. In an era of health care reform with an increasing emphasis on value, not volume, this study clearly demonstrates a reduction in resource use with enhanced clinical outcomes.

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