Off-pump coronary surgery: Effect on early mortality and stroke

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Background: Avoiding cardiopulmonary bypass in coronary artery bypass grafting is thought to reduce early mortality and morbidity.

Methods: We used our prospective database to compare all patients having off-pump coronary surgery ($n = 389$) with those having on-pump coronary surgery ($n = 2412$) between March 15, 1995, and November 1, 2000. Patients were grouped by age (years) in decades (>90 , 80-89, 70-79, 60-69, <60 years). The Northern New England risk model was applied. Thirty-two independent variables were entered into a stepwise logistic regression analysis with the end points being surgical mortality and postoperative stroke.

Results: Patients undergoing off-pump operations were older (70.9 ± 12 vs 68.1 ± 11 years; $P < .001$), and their Northern New England predicted risk was higher ($11.9\% \pm 13\%$ vs $9.2\% \pm 10\%$; $P < .001$). However, patients having on-pump bypass had significantly more bypass grafts constructed (3.3 ± 0.8 vs 1.9 ± 0.8 ; $P < .001$) and triple-vessel coronary artery disease (58% vs 28% ; $P < .001$). There were no significant differences in postoperative mortality, stroke rate, complications, and length of stay between the groups. Logistic regression analysis did not show that cardiopulmonary bypass was a risk factor for either surgical mortality (odds ratio, 1.08; $P = .83$) or stroke (odds ratio, 1.59; $P = .27$).

Conclusion: Off-pump coronary bypass did not reduce early mortality and morbidity. Early and late results should be compared in a prospective randomized study.

Beating-heart surgery was originally the only approach to myocardial revascularization.¹ In 1967, Kolessov² reported a left internal thoracic artery (LITA) to left anterior descending (LAD) coronary artery anastomosis through a left thoracotomy on a beating heart, as a method of treatment for angina pectoris. However, this was quickly abandoned in favor of coronary artery bypass grafting (CABG) via median sternotomy with modern cardiopulmonary bypass (CPB) techniques because of the improved safety and ease of suturing on a still, bloodless field.

Off-pump coronary surgery (OPCAB) has been reintroduced in the past few years and now accounts for nearly 20% of all CABG operations performed in the United States.¹ This is despite the lack of prospective randomized studies documenting proven mortality or morbidity benefits in the short or long term.

Cardiac surgeons endure less favorable operative exposure, safety, and a steep learning curve to perform arterial bypass grafting on a "beating" heart because of the

belief that avoiding CPB improves end organ function by diminishing microembolic activation of inflammatory cascades and mechanical trauma to blood elements.

Patients and Methods

Between March 15, 1995, and November 1, 2000, 2801 patients had isolated CABG with 389 patients having OPCAB, 368 via a median sternotomy and 21 through a small anterior thoracotomy. Another 2412 patients had on-pump CABG. All patients' data were entered into our cardiac surgical database, which follows 576 preoperative, intraoperative, and postoperative variables. Patients were grouped by age (years) in decades (>90, 80-89, 70-79, 60-69, and <60 years). The Northern New England (NNE) risk model was used to predict surgical mortality.³

Statistical Analysis

Results for continuous variables are expressed as mean $\pm$ standard deviation. Results for categorical variables are expressed as number (percent). The Student *t* test for independent samples was used to determine statistically significant differences between the 2 groups for the continuous variables. The χ^2 test was used to determine statistically significant group differences for the categorical variables. Stepwise logistic regression was used to select the predictor variables for the outcomes surgical mortality and postoperative cerebrovascular accident (CVA). (See the appendix for the list of potential predictor variables that were considered). The final logistic regression models included only those variables that were significant in the stepwise logistic regression models. In the final models, the independent variables are expressed as odds ratios with 95% confidence intervals, and the corresponding *P* value is also given. An α level of .05 was used to determine statistical significance. Statistical calculations were performed by means of SAS version 8.1 (SAS Institute, Cary, NC).

Incomplete revascularization was derived by comparing significantly obstructed coronary arteries at cardiac catheterization with coronary arteries surgically grafted. Nongrafting of any significantly obstructed coronary artery was considered an incomplete revascularization. Grafting of all diseased vessels was considered complete revascularization.

Learning Curve

All operations involved 2 surgeons, as surgeon and first assistant surgeon, who performed the proximal and distal anastomoses. The 6 surgeons, present during the entire period of the study, participated in a minimum of 95 to a maximum of 149 cases. There was a gradual adoption of off-pump techniques with 3.5% of OPCABs performed in 1996, 9% in 1997, 15.2% in 1998, 28.1% in 1999, and 26.4% in 2000.

Patient Selection

The choice of OPCAB versus on-pump CABG was surgeon preference. Factors favoring OPCAB included patients with suitable anatomy, epicardial target vessels 1 mm or larger, which were noncalcified and easy to expose, patients considered at high risk for CPB, elderly patients with multiple preoperative morbidities, and especially patients with significant calcification of the ascending aorta and vascular disease.

Contraindications to OPCAB included technical issues such as small, calcified, intramyocardial coronary targets. Difficulty in vessel exposure and unstable condition of the patient also precluded an off-pump approach.

Four hospitals were used by the group with 90% of all cases at Cedars-Sinai Medical Center.

Surgical Technique

OPCAB. A median sternotomy or small anterior thoracotomy (minimally invasive direct coronary artery bypass, MIDCAB) was used. For the small anterior thoracotomy, internal thoracic artery (ITA) harvest was with one of two specialized retractors (LIMA lift; Cardiothoracic Systems, Inc, Cupertino, Calif, or Thoralfit, United States Surgical Corp, Norwalk, Conn). Proximal and distal coronary artery flow was controlled with silicone rubber loops (Retract-O-Tape; Quest, Allen, Tex). Blood was cleared from the anastomotic site with a commercial carbon dioxide saline-blower (Clearview blower/mister kit; Medtronic, Inc, Minneapolis, Minn). Commercial stabilizers included suction stabilizers (Medtronic Octopus I and II; Medtronic, Inc) and U-shaped foot stabilizers (Universal Stabilizer System; Esteche Systems, Inc, Danville, Calif). A heparin dose of 10,000 units was given before vessel occlusion, and the activated clotting time (ACT) was maintained at twice control ACT. Heparin was fully reversed before sternal closure.

We selectively used coronary shunts (Flo-Thru intraluminal shunt; Bio-Vascular, Inc, St Paul, Minn), primarily in constructing bypass grafts to dominant right coronary arteries. Exposure for lateral and inferior wall vessels was achieved by a combination of deep pericardial stitches, an opening of the right side of the pericardium to the inferior vena cava-right atrial junction, and a right decubitus Trendelenberg position. Proximal anastomoses were made to the ascending aorta with the systolic blood pressure between 70 to 80 mm Hg and a curved vascular clamp. If significant aortic calcification precluded safe clamp placement, proximal anastomoses were made to the side of the ITA.

Conventional CABG

CABG was performed through a median sternotomy under moderate hypothermia (28°C-32°C) and CPB support. Single-dose, antegrade, cold blood cardioplegia was supplemented with cold continuous retrograde crystalloid cardioplegia and topical iced slush to protect the myocardium. Proximal anastomoses were performed during a single period of aortic crossclamping. The CPB circuit consists of a roller pump (Jostra Bentley Corp, Irvine, Calif) and membrane oxygenator (Avecor Affinity, Medtronic, Inc). Both OPCAB and on-pump CABG patients were discharged receiving either aspirin or warfarin sodium (Coumadin) if their heart rhythm was atrial fibrillation.

Results

The OPCAB patients were significantly older (70.9 ± 12 years vs 68.1 ± 11 years; $P < .001$) than on-pump CABG patients (Table 1). There were more 90-year-old patients (11 vs 5) and a greater percentage of 80-year-old patients (20.7% vs 11.4%; $P < .05$) in the OPCAB group. The OPCAB patients tended to be more urgent in acuity level

TABLE 1. Patient clinical characteristics

Characteristic	OPCAB (n = 389)	On-pump (n = 2412)	P value
Age (y)			
Mean	70.9 ± 12	68.1 ± 11	<.001
≥90	11 (2.9)	5 (0.2)	
80-89	81 (20.7)	275 (11.4)	
70-79	134 (34.5)	914 (37.9)	
60-69	91 (23.3)	673 (27.9)	
<60	72 (18.6)	545 (22.6)	
Male	279 (71.6)	1815 (75.3)	.165
LVEF(%)	54 ± 13	53 ± 14	.150
Acuity			
Elective	254 (65.4)	1734 (71.9)	.005
Urgent	116 (29.8)	523 (21.7)	
Emergency	17 (4.3)	142 (5.9)	
Angina CCS			
I	(7.4)	(10.2)	.002
II	(28.9)	(31.0)	
III	(38.4)	(27.6)	
IV	(25.4)	(31.2)	
NNE risk (%)			
Age (y)			
Mean	11.9 ± 13	9.2 ± 10	<.001
≥90	31.2 ± 23	21.7 ± 12	NS
80-89	20.3 ± 14	19.8 ± 14	NS
70-79	14.0 ± 13	11.5 ± 9	.004
60-69	6.0 ± 6	6.5 ± 6	NS
<60	2.6 ± 3	3.1 ± 4	NS

Variables are expressed as mean ± SD or n (%). CCS, Canadian classification system; LVEF, left ventricular ejection fraction; NNE, Northern New England; NS, not significant.

(29.8% vs 21.7%; $P < .05$). Their anginal symptoms tended to be more severe (Canadian Cardiovascular Society class III or IV, 63.8% vs 58.8%; $P < .05$). Their overall predicted risk by the NNE risk model was significantly greater (11.9% ± 13% vs 9.2% ± 10%; $P < .001$).

This increased predicted risk in OPCAB patients is reflected in a comparison of preoperative risk factors (Table 2). Prior carotid endarterectomy (7.5% vs 4%; $P = .002$), chronic obstructive pulmonary disease (14.7% vs 11.3%; $P < .05$), creatinine concentration more than 2.0 mg/dL (8.6% vs 5.2%; $P = .008$), symptoms of congestive heart failure (17.5% vs 13.7%; $P < .05$), and peripheral vascular disease (26.2% vs. 19.7%; $P = .003$) were all more prevalent in OPCAB patients. On-pump CABG patients had a higher incidence of cigarette use (51.6% vs 45.8%; $P = .03$), diabetes (31.7% vs 24.7%; $P = .006$), and previous myocardial infarction (35.9% vs 29.2%; $P = .01$).

However, on-pump patients differed significantly from the OPCAB patients in the extent of their preoperative coronary artery disease (CAD) and the number and location of coronary arteries bypassed (Tables 3 and 4). On-pump CABG patients had significantly more triple-vessel CAD (58% vs 28%; $P < .001$) and less single-vessel CAD (11%

TABLE 2. Preoperative risk factors

Variable	OPCAB	On-pump	P value
Prior surgery	35 (9.0)	284 (11.8)	NS
CEA	29 (7.5)	96 (4.0)	.002
CVA	41 (10.5)	211 (8.8)	NS
Cigarettes	178 (45.8)	1245 (51.6)	.03
COPD	57 (14.7)	273 (11.3)	.05
DM	96 (24.7)	763 (31.7)	.006
HTN	237 (60.9)	1490 (61.8)	NS
Creatinine > 2.0 mg/dL	31 (8.6)	124 (5.2)	.008
PVD	102 (26.2)	474 (19.7)	.003
MI	115 (29.2)	865 (35.9)	.01
CHF	68 (17.5)	331 (13.7)	.05
LVEF < 30%	24 (6.8)	196 (8.3)	NS
LM	(30.0)	(28.6)	NS

Variables are expressed as n (%). CEA, Carotid endarterectomy; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CVA, cerebral vascular accident; DM, diabetes mellitus; HTN, hypertension; LM, left main coronary; LVEF < 30%, left ventricular ejection fraction less than 30%; MI, myocardial infarction; NS, not significant; PVD, peripheral vascular disease.

TABLE 3. Number of distal anastomoses and diseased vessels

Variable	OPCAB	On-pump	P value
Distal anastomosis (No.)			
Age (y)			
Mean	1.9 ± 0.8	3.3 ± 0.8	<.001
≥ 90	1.2 ± 0.9	2.8 ± 0.4	
80-89	2.0 ± 0.7	3.1 ± 0.7	
70-79	1.9 ± 0.8	3.3 ± 0.7	
60-69	1.9 ± 0.9	3.4 ± 0.9	
< 60	1.9 ± 0.8	3.4 ± 0.8	
Diseased vessels (%)			
1 VD	33	11	<.001
2 VD	38	31	
3 VD	28	58	
Incomplete revascularization (%)	28.5	14.6	<.001

Variables are expressed as mean ± SD or n (%). 1 VD, One-vessel disease; 2 VD, two-vessel disease; 3 VD, three-vessel disease.

vs 33%; $P < .001$). As a result, they received more bypass grafts (3.3 vs 1.9; $P < .001$), which was consistent in all age groups. However, LITA and radial artery use was not different, with right internal thoracic artery (RITA) use showing a modest increase (18.3% vs 12.4%; $P = .005$) in on-pump CABG patients. There were significant differences in location of coronary arteries grafted, with circumflex and posterior descending coronary arteries more commonly grafted in the on-pump CABG patients.

Revascularization was incomplete significantly more often in the OPCAB patients than in the on-pump CABG group (28.5% vs 14.6%; $P < .001$). Surgical mortality was 2.5% when the revascularization was complete versus 3.0% when incomplete ($P = .5$). Postoperative CVA was 2.3%

TABLE 4. Arterial conduits and arteries bypassed

Variable	OPCAB	On-pump	P value
ITA			
Overall	368 (94.7)	2303 (95.5)	NS
LITA	355 (91.3)	2228 (92.4)	NS
RITA	48 (12.4)	441 (18.3)	.005
Radial artery	114 (29.2)	760 (31.5)	NS
Coronary artery anastomosis			
LAD	356 (91.5)	2303 (95.5)	.001
Diagonal	80 (20.5)	943 (39.1)	<.001
PDA	55 (14.1)	1345 (55.8)	<.001
Circumflex	202 (51.9)	2119 (87.9)	<.001
RCA	112 (29)	676 (28)	NS
Intermediate	15 (4)	376 (16)	<.001

Variables are expressed as n (%). *ITA*, Internal thoracic artery; *LAD*, left anterior descending; *LITA*, left internal thoracic artery; *NS*, not significant; *PDA*, posterior descending artery; *RCA*, right coronary artery; *RITA*, right internal thoracic artery.

versus 2.2% ($P = .89$) when comparing complete with incomplete revascularization. Surgical mortality before and after 1999 was 2.5% versus 2.7% ($P = .71$). Postoperative CVA before and after 1999 was 2.3% versus 2.5% ($P = .66$).

Increased age, creatinine concentration greater than 2.0 mg/dL, ejection fraction less than 30%, prior CABG, increased New York Heart Association class, acute myocardial infarction, and increased surgical acuity were found to be independent variables increasing surgical mortality. Disease of the LAD vessel was found to decrease surgical mortality. Increased age, surgical acuity, creatinine level greater than 2.0 mg/dL, and presence of peripheral vascular disease were found to increase the incidence of postoperative CVA. However CPB did not increase either surgical mortality or postoperative CVA (Table 6).

There were no significant differences in mortality between the groups overall or by age in decades (Table 5). Incidence of stroke, likewise, was not significantly different. Of note, there were no strokes in the OPCAB patients who were octogenarians, but there were 5 in the septuagenarian group. Neither group, however, was significantly different from their same-decade on-pump CABG peers. Of the 12 deaths in the OPCAB group, 5 died of cardiac related events, including arrhythmias, pump failure, and myocardial infarction. One died of a stroke, 3 died of small bowel necrosis, and 3 died of sepsis resulting from pneumonia or intravascular catheters.

New atrial fibrillation, reoperation for bleeding, deep sternal infection, sepsis, prolonged intubation, and readmission within 6 weeks were not significantly different between groups (Table 7). Twelve-hour postoperative blood loss and any blood product usage were not different. New dialysis was slightly more prevalent in the OPCAB group, but the difference was small. Not surprisingly, the percentage of

TABLE 5. Postoperative complications

Variable	OPCAB	On-pump	P value
Surgical mortality			
Age (y)			
Overall	12 (3.1)	60 (2.5)	NS
≥ 90	3 (27.3)	0 (0.0)	NS
80-89	6 (7.7)	14 (5.1)	NS
70-79	2 (1.5)	22 (2.4)	NS
60-69	1 (1.1)	16 (2.4)	NS
<60	0 (0.0)	7 (1.3)	NS
CVA			
Age (y)			
Overall	7 (1.8)	55 (2.3)	NS
≥ 90	1 (9.1)	0 (0.0)	NS
80-89	0 (0.0)	7 (2.6)	NS
70-79	5 (3.9)	31 (3.4)	NS
60-69	1 (1.1)	13 (1.9)	NS
<60	0 (0.0)	5 (0.9)	NS

Variables are expressed as n (%). *CVA*, Cerebrovascular accident; *NS*, not significant.

OPCAB patients with no complications (72%) closely matched the on-pump CABG patients (70%). Overall postoperative length of stay was not different between OPCAB and on-pump CABG patients. However, OPCAB patients less than 60 years old had a shorter length of stay than on-pump patients (4.9 ± 2.2 days vs 6.2 ± 4 days; $P = .02$), and septuagenarians in the on-pump group had a shorter length of stay than the off-pump group. Note, this is the only group, when examined by decade, in which the off-pump patients were at significantly higher risk than the on-pump patients.

Discussion

Conventional coronary surgery through a median sternotomy with CPB support is the standard for myocardial revascularization. Having a clear, still operative field enabled the widespread adoption of cardiac surgical techniques for both myocardial revascularization and valvular replacement and repair under “safe” conditions. However, the introduction of less invasive catheter-based techniques and the general aging of the population has forced cardiac surgeons to apply cardiac surgical techniques to an increasingly older and sicker population.^{4,5}

Tuman and associates⁶ reported that the risk of end-organ dysfunction in patients having isolated on-pump CABG increased exponentially with age. Patients 65 years of age and younger had a low incidence of neurologic events ($<1\%$), but patients older than 75 years had a 9-fold increase (8.9%). However, cardiac related morbidity, such as low cardiac output and postoperative myocardial infarction, was unrelated to advanced age in the stepwise logistic regression analysis. They forecast that the use of coronary revascularization techniques without extracorporeal circula-

TABLE 6. Results of logistic regression

Risk factors	Surgical mortality			CVA		
	OR	95% CL	P value	OR	95% CL	P value
Age (continuous)	1.05	(1.03-1.08)	.001	1.04	(1.01-1.07)	.009
Creatinine $\geq$ 2.0 mg/dL	3.02	(1.56-5.83)	.001	2.52	(1.23-5.18)	.012
EF $\leq$ 30%	2.18	(1.16-4.09)	.015			
Prior CABG	2.29	(1.22-4.29)	.010			
NYHA class	1.27	(1.07-1.51)	.006			
MI, this	2.2	(1.28-3.79)	.005			
Surgical acuity	1.98	(1.44-2.72)	.001	1.94	(1.41-2.69)	.001
Cath LAD	0.36	(0.20-0.65)	.001			
PVD				2.42	(1.42-4.10)	.001
CPB	1.08	(0.54-2.17)	.830	1.59	(0.70-3.57)	.267

CABG, Coronary artery bypass grafting; Cath LAD, cardiac catheterization, left anterior descending coronary artery disease; CL, confidence limits; CPB, cardiopulmonary bypass; EF, ejection fraction; MI, this, myocardial infarction, this admission; NYHA class, New York Heart Association classification; OR, odds ratio; PVD, peripheral vascular disease.

tion or aortic crossclamping may decrease the neurologic risk of CABG.^{7,8} Several groups in South America and the United States reported good results with OPCAB in the early and middle 1990s.⁹⁻¹¹ However, it was not until the introduction of increasingly sophisticated mechanical stabilizers that OPCAB enjoyed a renaissance. Presently, despite the lack of any long-term, prospectively randomized studies to prove the benefit of beating-heart surgery, nearly 20% of patients in the United States are undergoing myocardial revascularization without CPB support.¹ Among cardiac surgeons, the argument is increasingly not whether patients should have beating-heart surgery, but why all patients are not having beating-heart surgery.

Our series of 389 patients represents a selective use of beating-heart techniques in our cardiac surgical population. It is a retrospective, nonrandomized experience and includes all patients having only myocardial revascularization by our group during a 5-year period. Our beating-heart surgery patients were significantly older, with a higher percentage of patients aged 80 years and older than our on-pump patients. There are 2 comparable series of octogenarians having OPCAB. The Washington Hospital Center experience differs in that they report a total of 71 patients over a 12-year period from January 1987 to May 1999.¹² Thirty-four percent of the patients underwent an anterior thoracotomy approach to single-vessel off-pump CABG (MIDCAB). Among our series of 81 octogenarians and 11 nonagenarians, only 2 patients had an anterior thoracotomy approach. Their operative mortality (6%) and postoperative length of stay (9 ± 6 days) for octogenarians was similar to our results (7.7% mortality and 8.6 ± 4.5 days, length of stay).

A more comparable series is the experience of Ricci and associates¹³ in octogenarians. They compared 97 OPCAB patients with 172 conventional CABG patients from January 1995 to May 1999. They report a variety of surgical

approaches (median sternotomy, left anterior small thoracotomy, left posterior thoracotomy, and subxiphoid access), although they favored median sternotomy to obtain complete myocardial revascularization. Our 81 OPCAB octogenarians were compared with 275 octogenarians having conventional on-pump CABG. Average number of bypass grafts of OPCAB patients between our series and theirs was similar (2.0 vs 1.8), as was the number having conventional CABG (3.1 vs 3.3 grafts per patient). Their reported mortality was higher than ours (10.3% vs 7.7%) for OPCAB but was similar for on-pump CABG (5.2% vs 5.1%). We found no difference in risk profile between our off-pump and on-pump octogenarian CABG patients. As in their series, we report no episode of stroke in our octogenarians. However, we did not find a significant difference in stroke rate compared with our conventional CABG patients. This is due to the low incidence of stroke seen in our on-pump CABG patients overall (2.3%), and in our on-pump octogenarian patients (2.6%). They reported a significant reduction in stroke rate as their conventional CABG patients had a stroke rate of 9.3%. They also reviewed angiographic data to determine the severity and distribution of CAD. They observed an important trend to more extensive multivessel involvement in the CPB cohort. They speculate that this may explain the difference in graft-patient ratio observed between the CPB cohort (3.3) compared with the off-pump cohort (1.8). We also found a trend toward significantly more extensive CAD in our on-pump patients. The presence of triple-vessel CAD was twice as often seen in the on-pump group (58%) versus the off-pump group (28%). This explains the fewer grafts per patient seen in the OPCAB (2.0) versus on-pump patients (3.1). This is also consistent with the less frequent lateral and inferior wall bypass grafts seen in our OPCAB patients when compared with our on-pump CABG patients.

Arom and colleagues¹⁴ also noted this difference of

TABLE 7. Postoperative complications

Variable	OPCAB	On-pump	<i>P</i> value
Postop LOS (d)			
Age (y)			
Overall	7.7 ± 11.0	7.4 ± 7.0	NS
≥ 90	9.6 ± 5.4	10.8 ± 4.7	NS
80-89	8.6 ± 4.5	9.3 ± 7.4	NS
70-79	9.5 ± 7.7	7.8 ± 7.1	.05
60-69	6.2 ± 7.0	7.0 ± 6.4	NS
<60	4.9 ± 2.2	6.2 ± 4.4	.02
New dialysis	8 (2.1)	22 (0.9)	.04
New atrial fibrillation	80 (20.6)	511 (21.2)	NS
Reoperative bleeding	7 (1.8)	56 (2.3)	NS
Deep sternal infection	1 (0.3)	14 (0.6)	NS
Prolonged intubation	10 (2.6)	84 (3.5)	NS
Twelve-hour blood loss (mL)	511 ± 438	503 ± 519	NS
Blood product use (%)	57.8	57.3	NS
Patients with no complications (%)	(72)	(70)	NS
Readmission 6 weeks	49 (12.6)	306 (12.7)	NS

Variables are expressed as mean ± SD or n (%). LOS, Length of stay; NS, not significant.

grafts per patient between OPCAB and on-pump patients. They reported 2.1 grafts per patient in the OPCAB group versus 3.2 grafts per patient in the on-pump CABG group. This difference was magnified in the high-risk subgroup (1.6 vs 3.1 grafts per patient; $P < .001$). In short-term follow-up, there was a trend to increased recurrent angina and need for reinterventional procedures in the OPCAB patients.

Gundry and associates¹⁵ reported a 7-year follow-up on a cohort of patients having OPCAB from 1989 to 1990, before the current era of commercial stabilizers. They noted twice as many recatheterizations (30% vs 16%) and three times the reintervention rate (20% vs 7%) when compared with a group of patients having on-pump CABG. Their patients in the OPCAB group received fewer grafts (2.4 ± 0.9 vs 3.2 ± 1.1 vessels per patient) and a much lower proportion of lateral and inferior wall bypass grafts.

The possibility of incomplete revascularization and early failure resulting from technical difficulties in constructing bypass grafts to the lateral or inferior wall must be considered. Incomplete revascularization was nearly twice as common in our OPCAB patients (28.5% vs 14.6%). This did not affect early outcomes. However, we may encounter increased recurrent angina and future interventions on continued follow-up.

There are several published series addressing arterial graft patency in OPCAB surgery. They report excellent short-term patency for arterial grafting to the anterior wall.^{16,17} However, angiographic documentation of successful lateral and inferior wall grafting is lacking.

Bhan and coworkers¹⁸ reported on 96 OPCAB patients who underwent coronary angiography before hospital discharge. They found 97.9% patency of their LITA to LAD

grafts, but they found only 81% patency of their saphenous vein grafts, which were predominantly placed to lateral and inferior wall bypass targets.

We were expecting to see decreasing morbidity with an off-pump approach. However, our series is notable for a lack of significant differences in postoperative outcomes between OPCAB and on-pump CABG patients. There were no significant differences in mortality or stroke rate. Blood product usage and 12-hour blood loss were not significantly different between on-pump and OPCAB patients, despite differences noted by other groups of less bleeding and blood product usage in OPCAB patients.¹⁹ Although not followed in our database, the increased bleeding and blood product usage in our series may reflect a selection bias to perform OPCAB on patients we believe have significant bleeding risk (ie, patients with prior thrombolytic and antiplatelet inhibitor use). There were significantly more OPCAB patients with preoperative renal insufficiency. We did not follow postoperative creatinine in our database. However, the incidence of new dialysis was greater in the OPCAB group (2.1% vs 0.9%; $P < .04$).

Our series is similar to others in comparing treatment groups retrospectively adjusted for predicted preoperative risk. However, biases were introduced including less extensive coronary artery disease and fewer bypass grafts in OPCAB patients. A multivariable logistic regression analysis was performed to minimize these biases, but we were unable to demonstrate any negative effect of CPB on short-term outcomes. Calafiore and associates²⁰ reported a series of 1843 patients nearly equally divided between OPCAB and on-pump CABG. They found in a stepwise logistic regression analysis that CPB was an independent risk factor for higher mortality (odds ratio, 2.2; $P = .0217$).

Randomized multi-institution studies seem to be the only solution to answering the question whether CPB affects outcomes in coronary revascularization.

Can these make a difference? The Bypass Angioplasty Revascularization Investigation (BARI) is a prospective, randomized study comparing balloon angioplasty (PTCA) with conventional CABG in multivessel coronary artery patients.¹⁸⁻²⁰ In BARI, they found significant differences in outcomes for mortality and reintervention rate favoring conventional CABG for the randomized patient population with diabetes. However, these favorable differences in outcomes for conventional CABG patients who had diabetes disappeared when examining the BARI registry patients who had PTCA. This is because the registry patients were not randomized. They were followed by the BARI investigators, and the decision to undergo PTCA versus CABG was made by the cardiologist. The diabetic registry patients who underwent PTCA tended to have less extensive CAD (ie, more double-vessel disease, less left main and triple-vessel disease) than patients referred for CABG. Moreover, unfavorable lesions for PTCA tended to be referred for CABG. It is not hard to imagine that diabetic patients with subjectively better vascular runoff and distal bypass targets were more frequently referred for PTCA. BARI warns us that all nonrandomized comparisons of OPCAB versus on-pump CABG will have selection biases, particularly in terms of extent of CAD and quality of distal targets. As we have seen, this may affect the rate of recurrent angina and reinterventions in the future.

In conclusion, our prospective, nonrandomized series comparing OPCAB with on-pump CABG demonstrates that we can select slightly higher risk patients for OPCAB with similar outcomes in the short term. However, a randomized, prospective study with sufficient numbers of elderly, high-risk patients is needed to answer questions of short- and long-term benefit.

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See Appendix on page 320.

Appendix. List and definition of the variables

Preoperative		Preoperative	
Age	Continuous (y)	Peripheral vascular disease	Dicotomous/indicator
Age $\geq$ 70 years old	Dicotomous/indicator	Angina (CCS)	Quasi-continuous at 5 levels
Sex	Dicotomous/indicator	Congestive heart failure (NYHA)	Quasi-continuous at 5 levels
Body surface area	Continuous (m ²)	Myocardial infarction	Dicotomous/indicator
Body mass index	Continuous (kg/m ²)	Acute myocardial infarction	Dicotomous/indicator
Chronic obstructive pulmonary disease	Dicotomous/indicator	Surgical acuity	Quasi-continuous at 4 levels
Diabetes mellitus	Dicotomous/indicator	Cerebrovascular accident	Dicotomous/indicator
Creatinine	Continuous	Carotid endarterectomy	Dicotomous/indicator
Creatinine > 2.0 mg/dL	Dicotomous/indicator	Total diseased vessels	Quasi-continuous at 4 levels
Dialysis	Dicotomous/indicator	Circumflex disease	Dicotomous/indicator
Ejection fraction	Continuous	Left anterior descending disease	Dicotomous/indicator
Ejection fraction < 30%	Dicotomous/indicator	Left main disease	Dicotomous/indicator
Prior CABG	Dicotomous/indicator	Right coronary artery disease	Dicotomous/indicator
Prior PTCA	Dicotomous/indicator	Height	Continuous (m)
Hypertension	Dicotomous/indicator	Weight	Continuous (kg)
Cholesterol	Continuous (mg/dL)	Cardiopulmonary bypass	Dicotomous/indicator

CABG, Coronary artery bypass grafting; CCS, Canadian Cardiovascular Society; NYHA, New York Heart Association; PTCA, Percutaneous transluminal coronary angioplasty.

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