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Clinical Outcomes in Coronary Artery Bypass Graft Surgery: Comparison of Off-Pump and On-Pump Techniques

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ABSTRACT

Background: A consecutive series of patients undergoing first-time coronary artery bypass graft (CABG) surgery were analyzed and the impact of off-pump surgery was evaluated.

Methods: From January 1, 2000 to December 31, 2000, 367 patients underwent isolated first-time CABG surgery. One hundred and twenty underwent off-pump CABG (Group A, 32.7%) and 247 underwent conventional on-pump CABG (Group B, 67.3%). Five patients were converted during operation and were included in Group A. The pre-operative characteristics, intra-operative details, and post-operative course were analyzed in the two groups. All patients were followed up between 11 and 23 months (median 18 months) after operation by telephone interviews or questionnaire survey.

Results: Early mortality was 2.1% (group A, 0.83%; group B, 2.83%), with the difference not being statistically significant. The incidence of post-op stroke (group A, 1.66%; group B, 3.66%), renal failure (group A, 2.5%; group B, 5.66%), and gastrointestinal complications (group A, 1.66%; group B, 1.21%) was likewise not significantly different in the two groups. However, the patients in group A had a statistically significant lower incidence of low cardiac-output (group A 13.3%; group B 29.5%; p = 0.002), atrial fibrillation (group A 11.66%; group B 30.36%; p<0.001), blood product transfusion (group A 39.66%; group B 89.87%; p<0.001), time on ventilator (group A, 5.96 hrs; group B, 10.31 hrs; p<0.001), and post-op hospital stay (group A, 7.79 days; group B, 9.81 days, p<0.001). Medium-term results (recurrence of angina, late mortality, cardiovascular events, and need for revascularization) were similar in the two groups.

Conclusions: Off-pump CABG results in a decreased incidence of complications in the immediate post-op period with comparable results in the medium term.

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INTRODUCTION

In recent years, off-pump coronary artery bypass grafting (CABG) has experienced a resurgence, and many surgery units and surgeons have adopted this technique to some extent. There is evidence from small randomized controlled trials that off-pump CABG is associated with a decrease in the systemic inflammatory response associated with the bypass procedure and a decrease in resulting morbidity [Ascione 1999, Ascione 2000]. In non-randomized series, off-pump CABG appeared to reduce post-operative mortality among high risk, elderly patients [Al-Ruzzeh 2001].

However, off-pump CABG still has not been widely adopted. In the year 2000, less than 20% of CABG procedures in the United States were performed off-pump [Mack 2000]. Our institution started performing off-pump CABG in 2000, and this report analyzes the results of all 367 patients who underwent CABG by either method at our facility in the calendar year 2000.

MATERIALS AND METHODS

Patients:

In the year 2000, 367 patients underwent first-time CABG at our institution. The patients were divided into two groups: 120 patients (group A, 32.7%) underwent off-pump CABG and 247 patients (group B, 67.3%) underwent CABG with cardiopulmonary bypass (CPB) and cardioplegic arrest. Five patients were converted during operation and were included in group A. The technique used was entirely at the discretion of the operating surgeon.

Operative Techniques

Off-pump CABG

All operations were performed via median sternotomy. The internal mammary artery and saphenous vein were harvested using standard techniques. Half-dose heparin (150 units/kg body weight) was given and the activated clotting time (ACT) was maintained above 250 seconds. The Lima stitch was used to elevate the left posterior pericardium, and the Octopus 2+ (Medtronic, Inc., Minneapolis, MN) stabilizer was used to stabilize the coronary artery. The left internal mammary artery (LIMA) to left anterior descending (LAD) coronary anastomosis was usually the first to be constructed, unless the LAD was the major collateralizing artery. All distal anastomoses were

Table 1. Pre-Operative Characteristics and Risk Factors

Variable	Off-Pump N = 120 N (%)	On-Pump N = 247 N (%)	p value
Age (years)	62.83 ± 9.20	62.80 ± 9.52	NS
Gender (male)	99 (82.5%)	193 (78.13%)	NS
Angina CCS 0	3 (2.5%)	3 (1.2%)	NS
1	2 (1.6%)	5 (2.0%)	
2	31 (25.8%)	55 (22.2%)	
3	61 (50.8%)	120 (48.5%)	
4	23 (19.1%)	64 (25.9%)	
Dyspnea NYHA 1	21 (17.5%)	61 (24.6%)	NS
2	70 (58.3%)	115 (46.5%)	
3	28 (23.3%)	67 (27.1%)	
4	1 (0.8%)	4 (1.6%)	
Previous Q wave infarct	48 (40%)	78 (31.5%)	NS
Diabetes mellitus	25 (20.8%)	49 (19.83%)	NS
Hypertension	67 (55.8%)	139 (67.6%)	NS
Hypercholesterolemia	93 (77.5%)	190 (76.9%)	NS
Renal impairment	4 (3.3%)	6 (2.4%)	NS
COPD	19 (15.8%)	32 (12.9%)	NS
H/o CVA/TIA	5 (4.1%)	10 (4.0%)	NS

COPD = chronic obstructive pulmonary disease; CVA = cerebrovascular accident; TIA = transient ischemic attack

constructed prior to the proximal anastomoses. During the construction of the obtuse marginal (OM) branch and the posterior descending branch (PDA) anastomoses, the patients were placed in the Trendelenburg position. The proximal coronary artery was snugged with 4/0 pledgetted Prolene (Ethicon, Somerville, NJ). Distal snares were never used. Shunts (Medtronic, Inc., Minneapolis, MN) were used only if there was hemodynamic compromise or excessive back-bleeding. The proximal anastomoses were constructed with the single application of a side-biting clamp. At the end of the procedure, heparin was neutralized with protamine.

CABG with CPB

A median sternotomy was used in all cases. The conduits were harvested using standard techniques. Heparin (300 units/kg body weight) was given and ACT was maintained above 480 seconds. CPB was initiated by cannulating the ascending aorta and the right atrium. Antegrade cardioplegia was then administered. All distal anastomoses were constructed during a single period of cross-clamping, and the proximal anastomoses were constructed with the help of a side-biting clamp.

Post-Op Care

All patients were admitted to the cardiac intensive care unit. Post-operative care followed standard protocols for extubation, transfer to the wards, gradual mobilization, and discharge.

Follow-Up

All patients were seen in the clinic at six to eight weeks postoperatively by the surgeon and at three to four months postoperatively by the cardiologist. In December 2001, all patients were followed up with a telephone interview or questionnaire survey.

Statistical Techniques

Data (continuous variables) was expressed as mean ± standard deviation. Continuous variables were analyzed using the student's t-test or Mann-Whitney U test. Categorical variables were analyzed using the chi-square test or Fisher's exact test, as appropriate. A p value of <0.05 was considered statistically significant. The SPSS 10 (SPSS Inc., Chicago, IL) statistical package was used for the statistical analysis.

RESULTS

The preoperative characteristics of the patients in Groups A and B are shown in Table 1 (). The groups were well-matched and showed no statistically significant difference in risk variables. Table 2 () shows the extent of coronary artery disease (CAD), left ventricular (LV) function, and priority of surgery. There was a greater proportion of 1- and 2-vessel disease patients in the off-pump group than in the on-pump group (p <0.001). There was no significant difference in the LV function between the two groups. Patients in the off-pump group had a statistically significant greater proportion of urgent surgery. Table 3 () shows the number of distal anastomosis according to the extent of CAD.

No patient with 1-vessel disease was operated upon on-pump. For patients with 2-vessel disease, there was no significant difference in the number of grafts in the two groups. However, in patients with 3-vessel disease, the patients who had off-pump surgery received a mean of 2.75 ± 0.71 grafts compared to 3.02 ± 0.72 per patient in the on-pump group (p = 0.004). Table 4 () shows the target arteries grafted in patients with 3-vessel disease.

The proportion of left anterior descending (LAD), obtuse marginal (OM), posterior descending (PDA), acute marginal

Table 2. Coronary Artery Disease Extent, Ejection Fraction and Priority of Surgery

	Off-Pump N = 120 N (%)	On-Pump N = 247 N (%)	p value
CAD extent			p <0.001
1 vd	11 (9.1%)		
2 vd	30 (25%)	25 (10.1%)	
3 vd	79 (65.8%)	222 (89.8%)	
Ejection fraction			NS
Good	70 (58.3%)	166 (67.2%)	
Fair	44 (36.6%)	72 (29.1%)	
Poor	6 (5%)	9 (3.64%)	
Priority			p <0.001
Elective	43 (35.8%)	117 (47.3%)	
Urgent	70 (58.3%)	109 (44.1%)	
Emergency	7 (5.8%)	21 (8.5%)	

CAD = coronary artery disease; vd = vessel disease

Table 3. Number of Distal Anastomoses According to CAD Extent

	Off-Pump	On-Pump	p value
1 vd	1.36 ± 0.5 (11 patients)		
2 vd	2.13 ± 0.5 (30 patients)	2.44 ± 0.8 (25 patients)	NS
3 vd	2.75 ± 0.71 (79 patients)	3.02 ± 0.72 (222 patients)	p = 0.004

(AM) and distal right coronary (RCA) arteries grafted in the two groups was not statistically different. However, 15.1% of patients in the off-pump group had a diagonal artery grafted compared to 29.7% in the on-pump group (p = 0.04).

Postoperative results are shown in Table 5 (). One patient in the off-pump group developed mesenteric ischemia on day 7 and succumbed to it. Seven patients (2.83%) in the on-pump group died in the hospital, four of cardiac failure, two of stroke, and one of multi-organ failure. There was no statistically significant difference in the incidence of postoperative stroke, new renal failure, or major gastrointestinal (GI) complications. The incidence of low cardiac output (CO), atrial fibrillation (AF), and transfused patients was lower in the off-pump group. Sixteen patients (13.3%) in the off-pump group required inotropes compared to 75 patients (29.5%) in the on-pump group (p = 0.002). None of the patients in the off-pump group required an intra-aortic balloon pump (IABP) postoperatively, while five in the on-pump group did.

Two patients in the off-pump group required re-exploration. One of the re-explorations was for bleeding from the lung surface, which had been grazed during placement of the LIMA stitch. This complication has been described previously [Zamvar 2001]. In the second patient, the bleeding was from a side branch of the left internal mammary artery. Nine patients in the on-pump group required re-exploration. A surgical cause was found in seven of these patients. The two patients for which no surgical cause was found were treated with platelets and fresh frozen plasma for coagulopathy.

The patients in the off-pump group required ventilation for a mean time of 5.96 ± 3.44 hours compared to 10.31 ± 10.36 hours for patients in the on-pump group (p <0.001). Postoperative hospital stay was 7.79 ± 4.97 days for the off-pump group and 9.81 ± 5.34 days for the on-pump group (p = 0.001).

In December 2001, all patients were followed up by telephone interviews or questionnaire surveys. Table 6 () shows the results of the follow-up. There was no statistically significant difference between the two groups for any of the variables studied in the follow-up.

Table 4. Target Arteries in Patients With 3-Vessel Disease

	Off-pump N = 79 N (%)	On-Pump N = 222 N (%)	p value
LAD	77 (97.4%)	217 (97.7%)	NS
Diagonal	12 (15.1%)	66 (29.7%)	0.04
OM	66 (83.5%)	200 (90.0%)	NS
PDA	55 (69.6%)	166 (74.7%)	NS
Distal RCA	5 (6.32%)	24 (10.8%)	NS
Ac Marginal	2 (2.5%)	1 (0.4%)	NS

LAD = left anterior descending artery; OM = obtuse marginal artery; PDA = posterior descending artery; RCA = right coronary artery; Ac = acute

Table 5. Post-Operative Data

	Off-Pump N = 120 N (%)	On-Pump N = 247 N (%)	p value
Mortality	1 (0.83%)	7 (2.83%)	NS
Low cardiac output	16 (13.3%)	73 (29.5%)	0.002
Atrial fibrillation	14 (11.6%)	75 (30.3%)	<0.001
Transfused patients	47 (39.1%)	222 (89.8%)	<0.001
Re-exploration	2 (1.6%)	9 (3.6%)	NS
CVA	2 (1.6%)	9 (3.6%)	NS
Renal failure	3 (2.5%)	14 (5.8%)	NS
GI complications	2 (1.6%)	3 (1.2%)	NS
Drainage(mls)	529 ± 368	848 ± 393	<0.001
Ventilation (hrs)	5.96 ± 3.44	10.31 ± 10.36	<0.001
Discharge (days)	7.79 ± 4.97	9.81 ± 5.34	0.001

DISCUSSION

This is a retrospective analysis of all patients who underwent CABG surgery in our institution in the calendar year 2000. We introduced off-pump surgery in this year and there was no prior experience with it in the institution.

Analysis of the patient risk factors showed no difference between the two groups. However, there was a greater proportion of 1- and 2-vessel disease patients in the off-pump group, since surgeons learning the off-pump technique initially use the technique on these patients. Nevertheless, 65.8% of patients in the off-pump group had 3-vessel disease. A greater proportion of patients in the off-pump group had urgent surgery because one of the surgeons, who

Table 6. Follow-Up (Median 18 Months)

Variable	Off-Pump N = 119 N (%)	On-Pump N = 240 N (%)	p value
Completeness of follow-up	119 (100%)	240 (100%)	
Recurrence of angina	19 (15.9%)	39(16.25%)	NS
Death	2 (1.68%)	4 (1.66%)	NS
MI	0	4 (1.66%)	NS
Stroke	0	5 (2.08%)	NS
Repeat angiogram	4 (3.36%)	7 (2.91%)	NS
Angioplasty	1 (0.84%)	1 (0.41%)	NS
Repeat CABG	1 (0.84%)	0	NS

MI = myocardial infarction; CABG = coronary artery bypass graft

preferentially used the off-pump technique, dealt with a larger proportion of in-house referrals.

Off-pump patients generally receive fewer grafts than on-pump patients [Kshettry 2000]. In our series, the patients with 3-vessel disease undergoing off-pump surgery received a mean number of 2.75 ± 0.71 grafts compared with 3.02 ± 0.72 grafts per patient in the on-pump group (p = 0.004). This is probably attributable to the "learning curve" phenomenon for a newly introduced technique. However, analysis of the target vessels (Table 4,) showed that there was no significant difference in the proportion of LAD, OM, PDA, distal RCA, or AM arteries receiving grafts. A significantly higher proportion of patients in the on-pump group (29.7% vs. 15.1%, p = 0.04) received grafts to the diagonal artery. Complete revascularization should, no doubt, be the goal. However, it is not the number of grafts so much as the distribution that indicates the completeness of revascularization.

The incidence of mortality, re-exploration, post-operative stroke, and new renal failure, though less in the off-pump group, were not statistically significant in the two groups. However, the off-pump group showed a decrease in blood transfusion requirements, AF rate, need for inotropes and IABP, and time on ventilator. Similar experiences have been reported by others [Ascione 1999, Nader 1999, Kshettry 2000].

We also observed a small decrease in post-operative hospital stay (off-pump, 7.79 days ± 4.97; on-pump, 9.81 days ± 5.34; p = 0.001). The length of stay is longer than that reported by others [Ott 1997, Boyd 1999, Calafiore 2001], but many of our patients remain in the hospital for non-medical reasons, such as lack of home support or lack of convalescent facilities nearer home.

The quality of anastomosis is often questioned in off-pump surgery. A compromised anastomosis will result in a recurrence of angina and the need for reintervention. Routine angiography to check for patency is neither economically feasible in our set-up nor ethically justifiable. Information obtained from an immediate postoperative angiogram is of doubtful physiological relevance [Zehr 2000] and not predictive of long-term patency [Gundry 1998]. Careful follow-up of all patients provides important information and can serve as a surrogate measure of graft patency. We have been able to follow up all of our patients at a median period of 18 months (range 11-23 months). The incidence of death and of recurrence for angina, stroke, and MI was not significantly different in the two groups.

Gundry et al. [Gundry 1998] have reported a seven-year follow-up of patients operated upon off-pump and on-pump in 1989. Survival and cardiac death rates were similar in the two groups, but there was a threefold increase in the reintervention rate in the off-pump group. However, these patients did not have the benefit of modern stabilizers. The surgeons at that time used silicone-rubber tapes around the coronary artery as a means of vessel stabilization, an expedient that has been shown to result in significant endothelial damage [Hangler 2001]. It is the availability of reliable stabilizers that accounts for the recent increase in popularity of off-pump CABG. Patency in off-pump CABG has been shown to be in the range of 85-96% at many institutions [Jansen 1996, Wiklund 2000, Lund 2001], a rate which compares favorably with patencies following CABG with CPB [Gerola 1996, Royse 2000].

This study has some limitations. First, it was a non-randomized study. Patient selection for off-pump surgery was entirely at the discretion of the operating surgeon. Even though the pre-operative variables are similar in the two groups, some selection bias must have occurred. There are also many variables (for example, diffusely diseased coronary arteries, poor quality veins for grafting) that do not have a place in the risk stratification system but likely have an impact on outcome. Experienced surgeons understand their potential impact very well.

Randomization is not necessarily the answer. In the BARI trial, there was a significant difference between the patients who accepted randomization and those who did not (but were followed up in the register) with regard to ethnicity, smoking history, education level, and left ventricular ejection fraction [BARI 1997, Detre 1997]. Randomized trials very seldom report the proportion of eligible patients recruited, and, in some instances (as in the ARTS trial), this proportion may be as low as 5% [Moses 2000, Serruys 2001].

Randomized trials may shed light on the actual effects of therapeutic interventions, but these have to be followed up with observational studies, like ours, to reflect real life situations. In fact, two recent reports [Benson 2000, Concato 2000] found that observational studies did not overestimate the size of the treatment effects compared to their randomized counterparts. Calafiore et al. [Calafiore 2001] argue that selection is as important as the technique of operation for a good outcome.

CONCLUSION

The results of our "real-life" series indicate that the technique of off-pump surgery can be applied to a significant proportion of patients undergoing CABG surgery, and a decrease in immediate morbidity can be expected, with comparable results in the medium term.

Definitions used in this report

All clinical data were collected prospectively in line with the minimum data set (MDS) defined by the Society of Cardiothoracic Surgeons of Great Britain and Ireland. The current MDS, and its associated definitions, is compatible with all existing initiatives in the UK such as the UK heart valve registry, the Central Cardiac Audit Database, and the British Cardiac Intervention Society database [Keogh 2000]. For *operative mortality*, we used the definition proposed by the Society of Thoracic Surgeons and included "death from any cause during or after an operation within 30 days if the patient is discharged or within any interval if the patient is not discharged." *Low cardiac output* was defined as use of the intra-aortic balloon pump (IABP) or inotropes at any stage post-operatively (dopamine <5 mcg/kg/min. excluded). *Re-exploration for bleeding* included any patient who underwent surgical re-exploration for this complication or for hemopericardium postoperatively. *Renal failure* included patients who had normal renal function preoperatively and required hemodialysis or hemofiltration postoperatively. *Major gastrointestinal (GI) complications* included GI hemorrhage requiring blood transfusion and mesenteric ischemia. *Atrial fibrillation (AF)* was identified by cardiac monitoring and confirmed by standard 12-lead ECG.

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