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Selective Use of Off-Pump Coronary Bypass Surgery Reduces Mortality and Neurologic Morbidity Associated with High-Risk Coronary Bypass Surgery: A 400-Case Comparative Experience

Jeffrey P. Gold, MD,[1] John Wasnick, MD,[2] William Maldarelli, CCP,[3] Ilya Zhuraavlev, MD,[2] Kaila Enitt Torres, MD,[1] Douglas Condit, PAC[1]

Departments of [1]Cardiovascular and Thoracic Surgery, [2]Cardiac Perfusion, and [3]Cardiac Anesthesia, Albert Einstein College of Medicine, New York, New York, USA

ABSTRACT

The frequency of use of off-pump coronary artery bypass (CAB) surgery to surgically treat coronary artery disease has varied greatly from center to center and from surgeon to surgeon because of preference, training, and experience. We report an experience with 400 consecutive isolated CAB procedures selectively managed with on-pump or off-pump surgery, according to the perceived potential for aortic embolization or stroke as determined by clinical and imaging determinations. The off-pump CAB group (46 patients) was 7.1 years older ($P < .05$) and had an 11% lower ejection fraction ($P < .03$) than the on-pump group. There was no difference in gender, urgency of surgery, hemodynamic stability, angina class, or incidence of prior myocardial infarction. All 400 patients underwent intraoperative transesophageal echocardiography, and many underwent an epiaortic study to supplement image quality. Patients without palpable or imaged advanced aortic disease or deemed to be at clinically high risk for stroke (advanced age, prior strokes, or advanced cerebrovascular or peripheral vascular disease) underwent on-pump procedures requiring 55 minutes of aortic ischemia and 97 minutes of high-flow, high-pressure bypass on average. All others underwent off-pump procedures. The numbers of grafts per patient were similar (3.2 on-pump, 2.8 off-pump; = ns). There was no in-hospital or 30-day mortality in either group. Using the New York State risk-adjustment algorithm, we found the predicted mortality rate for the off-pump group was higher (2.24% on-pump versus 5.54% off-pump, $P = .008$). The postoperative length of stay was longer in the off-bypass group (3.67 days versus 4.31 days, $P = .003$). The frequencies of hospital readmission and perioperative complications (renal, pulmonary, infection, bleeding, cardiac, neurologic) were similar, and there were no postoperative strokes in either group. The selective use of off-pump surgery safely managed patients at higher risk for perioperative stroke and associated embolic multisystem organ failure and death. Individual surgeon and center-wide use of a selective approach is recommended as an alternative to a single-procedure nonselective approaches.

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Address correspondence and reprint requests to: Jeffrey P. Gold, MD, Department of Cardiovascular and Thoracic Surgery, Montefiore Medical Center, 111 E 210 St, Bronx, NY 10467, USA; 1-718-920-7000; fax: 1-718-231-7113 (e-mail: jgold@montefiore.org).

INTRODUCTION

The recent intense focus on off-pump coronary artery bypass (CAB) surgery has resulted in a varied clinical impact and much controversy [Kahn 2004, Mitka 2004, Peterson 2004, Puskas 2004, Widimsky 2004]. The application of this technology has ranged from complete adoption of off-pump CAB for virtually all patients referred for coronary revascularization to the opposite strategy of continued use of on-pump CAB for all such patients. To some extent, this choice has been center dependent, with a group of surgeons and/or cardiologists making a decision regarding the role of off-pump surgery. More commonly, the decisions regarding off-pump surgery seem to be practitioner dependent, relating to the practitioners' understanding of the literature, personal experience, and early results associated with off-pump techniques compared with their individual historical coronary surgery anecdotal controls.

The selective use of the two technologies as part of a spectrum of surgical care has been less commonly described. Most studies that have compared on-pump and off-pump surgery have either been reports of single-technique series, with or without the use of historical controls, benchmarked literature comparison, simultaneously performed nonrandomized cases, or randomized cases [van Dijk 2001, Angelini 2002, Magee 2003, Sharony 2003]. In many instances, these reports detail experiences in multiple centers and almost always report on multiple individual surgeons within any given single center who have variable experiences, skills, and relative indications for each procedure, particularly the off-pump procedures.

Each cardiac surgical program and, to a greater extent, each surgeon have developed an individualized approach to the care of patients who undergo coronary surgery. These care parameters extend from the preoperative assessment of risk factors and procedure selection through early post-bypass and postoperative care. We report on our early experience with off-pump coronary surgery, which we employed selectively for patients deemed to be at "high risk" for on-

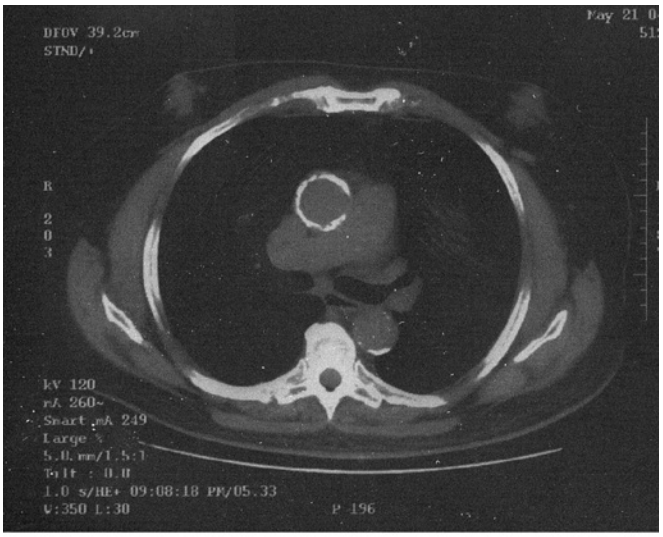
pump coronary surgery in 400 nonselected consecutive cases. This report details a sequential experience in a single center, with all cases having been supervised by a single surgeon. A predetermined clinical algorithm based on the perceived risk of cerebral and/or systemic atheroembolization, rather than a randomized or historical-control approach, was used to select the surgical procedure.

METHODS

The New York State (NYS) Department of Health (DOH) Cardiac Surgery Recording System (CSRS) was used as the primary data source for the analysis of 400 consecutive isolated first-time (nonreoperative) CAB procedures in a single institution that were performed by a single surgeon and cardiothoracic surgery residency staff in an academic teaching program. The NYS CSRS is an audited peer-reviewed data-collection system mandated by the NYS DOH for recording and analyzing data in a highly controlled fashion [Jones 1998, Block 1999]. The data are verified through review of unusual reporting frequencies, cross-matching the CSRS data with other DOH administrative and vital statistics databases, and the audited review of medical records. The surgical outcomes for all cardiac surgery performed in NYS since 1990 have been collected, analyzed, and published ([NYS DOH 2002] and E. L. Hannan, NYS DOH, personal communication). The data were collected prospectively and analyzed retrospectively from this secure, verified, and highly regarded registry. The contemporary NYS DOH data used for the creation of the multivariable risk factor equations predicting surgical outcome include all reported isolated CAB procedures.

Multiple preoperative demographic, comorbidity, and cardiac factors were retrospectively reviewed for 400 consecutive isolated CAB cases. Patients were identified from the database as having undergone an on-pump or off-pump procedure from the total cardiopulmonary bypass time (>0 minutes versus 0 minutes). From the multivariable predictive analysis performed by the NYS DOH, the individual and group predicted operative mortality rates were calculated for off-pump and on-pump CAB cases. All patients who underwent isolated valvular, congenital, thoracic vascular, combined valvular/coronary, or vascular/coronary surgery were excluded from this retrospective analysis. All patients who underwent any form of reoperation surgery (CAB or other type) were excluded as well; thus, the analysis was focused on a highly selected, reproducible, widely studied cohort of patients.

All patients with preoperative cerebrovascular disease known from history, symptoms, or the presence of a carotid artery bruit underwent carotid artery ultrasound examination [Rorick 1990]. In addition, all patients aged 80 years and older underwent carotid artery imaging, regardless of neurologic history and physical examination findings. If high-grade unilateral symptomatic disease or bilateral stenotic symptomatic or asymptomatic disease was identified, the patient underwent carotid thromboendarterectomy prior to or during the CAB surgery [Saimanen 2000]. The only exception to preoperative carotid thromboendarterectomy was when the symptomatic high-grade carotid artery disease was associated with symptomatic left main coronary artery disease or intra-aortic balloon pump–dependent class IV angina. In these cases, a combined surgical procedure was performed [Naylor 2003].



Mid thoracic computed tomography image of a patient with multiple-vessel coronary artery disease and a heavily calcified aorta who underwent a successful off-pump coronary bypass procedure.

All patients underwent coronary revascularization under moderate-dose balanced narcotic anesthesia and were followed with arterial, pulmonary artery, and transesophageal echocardiographic monitoring. All patients were surgically managed with a sternotomy incision, transsternal internal mammary artery graft harvesting, and minimally invasive upper-leg vein and/or radial artery harvesting.

Patients with evidence of extensive aortic calcification on a plain radiographic film of the chest or at the time of diagnostic left heart catheterization underwent noncontrast chest computed tomography scanning (Figure) or preoperative transesophageal ultrasound analysis. Intraoperatively, careful palpation of the ascending aorta and intraoperative transesophageal aortic imaging frequently suggested the need for epiaortic echocardiographic long- and short-access imaging [Marschall 1994, Konstadt 1995, Davila-Roman 1996, Hartman 1996, Nicolosi 1996, Murphy 1997, Trehan 1997]. These techniques were used to guide the procedure selection, as well as aortic cannulation and any additional aortic manipulation, including clamping, proximal anastomosis, and so on. In a number of instances, the combination of the clinical history, aortic palpation, transesophageal echocardiographic results, and epiaortic imaging results suggested the need for off-bypass "no touch" surgery employing pedicled revascularization, which was subsequently carried out [Hangler 2003, Lund 2003].

The off-bypass patients were managed by employing conventional stabilization techniques for off-bypass transsternal surgery. This group of off-bypass patients was highly selected on the basis of advanced age, advanced aortic calcification and/or atherosclerosis, or other factors and a coronary

Table 1. Preoperative Demographic Parameters*

	On-Pump (n = 354)	Off-Pump (n = 46)	*P*
Male sex	68%	74%	NS
Mean age, y	62.5	69.6	.003
Surgical priority (nonelective)	35.5%	38.2%	NS
Hemodynamic stability (unstable)	1.8%	2.1%	NS

*NS indicates not statistically significant.

Table 2. Perioperative Clinical and Technical Parameters*

	On-Pump	Off-Pump	*P*
Canadian angina class III and IV	30%	31%	NS
Prior myocardial infarction	58%	53%	NS
Preoperative ejection fraction	41.0%	30.1%	.018
No. of grafts/patient	3.21	2.82	NS
Total pump time, min	97.1	0	NR
Aortic cross-clamp time, min	55.7	0	NR

*NS indicates not statistically significant; NR, not relevant.

anatomy thought to be suitable for off-bypass surgery or to be at increased risk with conventional on-pump surgery.

Off-pump anticoagulation treatment was maintained following a loading dose of 100 U/kg heparin, and stabilization was facilitated with a suction-assisted device (Medtronic, Minneapolis, MN, USA). Normotensive conditions similar to the patients' preoperative levels were maintained with pharmacologic support as necessary. Heart rate was not adjusted pharmacologically or by pacing. Heparin treatment was reversed as necessary with protamine sulfate following the completion of the anastomoses. Body temperature was maintained as close to normothermia as possible during the entire procedure.

In those patients who underwent cardiopulmonary bypass, the arterial cannula was passed with echocardiographic guidance into the proximal intrathoracic descending aorta following anticoagulation treatment with 400 U/kg heparin to maintain an activated coagulation time of 480 seconds or more at all times. A combination of antegrade and retrograde cold (4°C) blood (8% hematocrit) cardioplegia was used at 15 mL/kg and was repeated via retrograde and conduit routes at 3 to 5 mL/kg following completion of all anastomoses but the final one (which was usually the left internal mammary artery).

High-flow and high-pressure cardiopulmonary bypass was maintained during the entire perfusion interval by targeting mean pressures of 75 to 85 mm Hg [Gold 1995, Plestis 2001, Kadoi 2003]. These pressures were maintained as necessary with moderate-dose phenylephrine hydrochloride (NeoSynephrine) administered as a continuous infusion by the perfusionists. All patients' core temperatures were continuously maintained at normothermia during the entire perfusion interval. The hematocrit on bypass was kept at greater than 22% whenever possible [McLean 1994, Murkin 1995].

Patients were maintained in a normotensive range postoperatively with a minimum heart rate of 65/min. Temporary epicardial pacing was employed as necessary. Multiple pharmacologic agents were used when required to adjust afterload and contractility so as to keep the systolic blood pressure in the range of 100 to 130 mm Hg and the cardiac index in the range of 2.5 to 3.0 L/min per m^2 at a minimum. Perioperative acetylsalicylic acid treatment was used in all patients and carried through hospital discharge and thereafter, and a number of patients were given either warfarin sodium (Coumadin) or glycoprotein IIb/IIIa drugs, depending on preoperative comorbidity. All OBCAB patients received IIb/IIIa drugs postoperatively.

Postoperative complications were tracked by attending surgeons, critical care physicians, cardiologists, and consultants, including neurologists, pulmonologists, infectious disease specialists, nephrologists, and others. In addition, all patients were closely managed by residents and physician assistants, who also recorded all perioperative complications. These complications were divided into cardiac, pulmonary, gastrointestinal, neurologic, hematologic, infectious, renal, and miscellaneous complications. The definitions for each of these complications were developed by the NYS Cardiac Advisory Committee and have been widely employed for more then 10 years. Seventy-seven specific types of complications were recorded. In addition, all instances of perioperative/in-hospital and 30-day mortality for any cause were recorded. The patient's condition on hospital discharge and the disposition of the discharge (home, home with professional care, rehabilitation service, acute-care hospital, and so on) were recorded for every patient. All hospital readmissions to our hospital system for any reason and to any other hospital of which we were made aware during the 30-day period following hospital discharge were also recorded, as were the cause(s) of the readmission.

All of these data were tracked and analyzed by the Cardiac and Thoracic On-Line Reporting (CATORpro) intranet data-reporting system (Cornell University) and reported to the NYS DOH CSRS on a quarterly basis for the entire duration of the study period. The data were verified for accuracy by Island Peer Review Organization (IPRO) consistent with the NYS DOH monitoring policy, which included independent chart-review audits performed at fixed intervals to verify the accuracy of submitted data compared with chart-based documentation.

RESULTS

Of the 400 consecutive patients, 46 (11.5%) underwent off-bypass surgery. The age, sex, surgical priority, and preoperative hemodynamic stability characteristics of the on-pump population are compared with the patients who underwent coronary surgery employing off-pump techniques during the same period (Table 1). The off-bypass patients were somewhat older and showed a nonsignificant trend toward more urgent and emergent surgical procedures.

The Canadian angina class, the prevalence of one or more transmural myocardial infarctions, the left ventricular ejection fraction, the number of coronary grafts, and the pump/cross-clamp times are found in Table 2. The somewhat fewer distal vessels grafted in the off-pump group (2.82 versus 3.21) trended toward but did not achieve statistical significance

Table 3. Operative Mortality*

	On-Pump	Off-Pump	*P*
Predicted mortality (NYS DOH)	2.24%	5.57%	.008
Observed hospital mortality	0.0%†	0.0%‡	NS
Observed 30-day mortality	0.0%†	0.0%‡	NS

*NYS DOH indicates New York State Department of Health; NS, not statistically significant.

†Observed mortality significantly different from expected; $P < .001$.

‡Observed mortality significantly different from expected; $P < .001$.

Table 4. Postoperative Data*

	On-Pump	Off-Pump	*P*
Total hospital length of stay, d	6.04	8.04	.049
Postoperative length of stay, d	3.67	4.31	.037
Cardiac complications (AFib/other), n	114/7	14/2	NS
Lung complications (slow wean/other), n	3/0	2/0	NS
Neurologic complications (CVA/other), n	0/6	0/3	NS
Infectious complications (sternal/other), n	0/10	0/2	NS
Gastrointestinal complications, n	0	0	NS
Hemorrhagic complications (ReOp/other), n	2/15	0/1	NS
Urinary complications (retention/other), n	4/1	2/0	NS
Total hospital readmissions (patients), n	25	3	NS

*AFib indicates atrial fibrillation; NS, not statistically significant; CVA, cerebrovascular accident; ReOp, reoperation.

($P = .086$). The 10% lower ejection fraction in the off-pump group of patients was significantly different. This finding was not explained by a difference in prior myocardial infarctions, the extent of grafted coronary artery disease, or clinical stability at the time of surgery.

The expected and measured mortality rates for these populations are shown in Table 3. There was 100% follow-up of both groups at the 30-day mark, as required for reporting purposes. Although the predicted operative mortality rates for the 2 groups were significantly different, with the on-pump group having less than half the predicted perioperative mortality of the off-pump group, there were no perioperative or 30-day deaths in either group. The measured mortality rates for the entire population of patients who underwent isolated CAB in NYS during the same interval was 2.20%, based on a nearly simultaneous cohort of 92,245 patients reported in the state-wide registry ([NYS DOH 2004] and E. L. Hannan, NYS DOH, personal communication). This comparison demonstrated that the on-pump population reported here is statistically comparable in predicted surgical risk (2.24%) with that of the larger population of all of the patients who underwent a CAB procedure at the same time; however, the reported series has a significantly lower mortality rate (0%). The off-pump group has a 2.5-times higher predicted mortality rate than the average patient who underwent CAB in the state. The off-pump group has a significantly lower observed mortality rate (0%).

Total length of hospital stay, postoperative length of stay, 30-day status, readmission rate, and readmission indications are found in Table 4. The off-pump patients have a total length of hospital stay that is 2 days longer (8.04 days versus 6.04 days) and a postoperative length of stay that is 0.64 days longer (4.31 days versus 3.67 days) than the corresponding stays in the on-pump group. Of the 28 patients who were readmitted within 30 days, 8 patients readmitted for pain (3 readmitted for ischemic symptoms) were all in the on-pump group. Ten other patients were readmitted for arrhythmias, and 2 were readmitted for a late neurological event. The incidences of postoperative atrial fibrillation/flutter, the most common complication, were similar in the 2 groups.

DISCUSSION

Each cardiac surgery program and, to a greater extent, each cardiac surgeon have developed an individualized approach to the role of off-pump coronary surgery in their practice. In many instances, the role is evolving, given the incremental increases in off-pump experience and improving technology. The extent of use of off-pump technology may be determined by the surgeon's degree of comfort with the currently available technology as well as by patient-related specifics, including demographic, comorbidity, and anatomical coronary/conduit–related factors. Although many surgeons (and authors) may argue for the exclusive use of either technique, a selective approach as both techniques continue to evolve may also be reasonable.

The selective use of off-pump surgery in older, sicker patients with more advanced left ventricular dysfunction produced no perioperative mortality in spite of a more than 2-fold higher predicted mortality. The difference in predicted mortality is multifactorial and is based on the NYS DOH incremental risks, including dialysis-dependent renal failure, depressed ejection fraction, and extensively calcified aortas noted in this off-pump CAB cohort. The incidence of postoperative stroke has also been extensively studied, and associated preoperative risk factors have been reported [Blauth 1988, Taylor 1994, Cernaianu 1995, Rao 1995, Roach 1996]. These factors typically include advanced age, depressed ejection fraction, prior stroke, significant extracranial carotid artery disease, diabetes mellitus, and peripheral vascular disease [Newman 1996, D'Ancona 2003]. Intraoperative risk factors, including prolonged bypass times, calcified aortas, and postoperative atrial fibrillation, have also been associated with perioperative strokes [van der Linden 2001, Charlesworth 2003, Likosky 2003].

Because there was no surgical mortality in either group, we cannot suggest that off-pump technology might have reduced the mortality rate in the on-pump group. Differences therefore would have to lie in the morbidity rates, which appeared comparable, although finer indices of long-term neurocognitive function and quality-of-life health indices were not measured in this cohort. The relatively small number of patients in the off-pump group and the small number of total postoperative complications weaken this analysis but do not suggest a more favorable outcome for either of the groups.

Length of postoperative hospital stay is frequently used as a surrogate for an amalgamated set of postoperative morbidi-

ties. There was a small but significant increment in postoperative length of stay (0.64 days) in the off-pump group. Thus, the widely touted argument that off-pump surgery shortens hospital postoperative length of stay was not applicable to the higher-risk group being studied. The on-pump and off-pump postoperative hospital lengths of stay compared favorably with those of other series and historical controls. It is indeed possible that a more widespread use of off-pump surgery in the on-pump group would have further shortened the on-pump patient postoperative length of stay, but such a conclusion would be speculative at best.

It is difficult to separate the judgmental, clinical management, and technical factors associated with the observed outcomes. However, the routine use of transesophageal and epiaortic echocardiographic imaging, the minimal handling of the aorta, the cannulation of the proximal descending aorta with the cannula tip distal to the left subclavian artery, and the pressure/flow management in the patients revascularized on cardiopulmonary bypass appear to be the important components of the on-pump CAB management strategy and possibly distinguish the management of this sequential cohort of patients from that of other reported on-pump CAB patient cohorts. The highly selective and protocol-driven use of off-pump surgery distinguishes this experience as well.

Most CAB procedure–related visceral organ and neurologic injuries are thought to be embolic and/or hypoperfusion based [Moody 1990, Clark 1995, Amarenco 1996, Barbut 1996, 1997]. Manipulation of the great vessels, either by clamp-and-cannula manual manipulation or by endoaortic "sand blast" perfusion-generated blood flow effect, has been associated with most of the embolic material and most of the strokes, visceral organ injuries, prolonged hospital stays, and the many perioperative deaths [Barbut 1994, Brækken 1997]. The turbulence generated by aortic cannula flow can be easily imaged in the aorta by echocardiographic techniques. Not subjecting the transverse aortic arch and the distal ascending aorta, two regions highly prone to advanced atherosclerosis with ulcerated or mobile components, to surgical manipulation or cannula-flow trauma is the logical approach and may have been beneficial in this series and in others [Clark 1995, Sylivris 1998]. Thus, selectively using off-pump surgery for patients considered to be at high risk for embolization or hypoperfusion may be reasonable [BhaskerRao 1998, Taggart 1999, Diegeler 2000, Watters 2000, Bowles 2001]. In the same fashion, maintaining stable intraoperative and postoperative systemic blood pressures that mirror the patients' known preoperative hemodynamics with either coronary revascularization technology has been previously reported as beneficial and may have been related to the excellent outcomes reported here.

This study is limited by the relatively small numbers of patients, particularly in the off-pump group, and the fact that the cases of the patients deemed to be at high risk and therefore candidates for off-pump surgery were not randomized. The study is strengthened by the nature of a consecutive series from a single institution in which the technical aspects of the procedures and perioperative management have been standardized. Additional studies focused on patients deemed to be at high risk for atheroembolization will shed further light on the role of off-pump CAB.

CONCLUSION

Neurologic injury, prolonged hospitalization, and perioperative death have all been reported to complicate CAB surgery. This series of 400 consecutive isolated CAB procedures performed in a single teaching institution demonstrates that a strategic selection of procedure (on-pump versus off-pump technique) and perioperative hemodynamic management can reduce the complications and deaths associated with these frequently performed procedures. The selective use of off-pump technology, guided by preoperative and intraoperative assessment, extends the safety of surgical revascularization to higher-risk surgical candidates. Given the durability, completeness, and safety associated with surgical coronary revascularization, it remains an excellent means of managing acquired atherosclerotic coronary artery disease for many subsets of our patients.

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