Coronary Artery Bypass Grafting With and Without Cardiopulmonary Bypass: A Comparison Analysis

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Abstract: Coronary artery bypass grafting (CABG) using stabilization devices in place of the heart–lung machine is being performed on a wide range of patients. This study retrospectively compared the performance of off-pump coronary artery grafting bypass (OPCAB) with conventional bypass patients over the same 6-month period at The Medical University of South Carolina. Data were collected and compared from the National Cardiac Database of the Society of Thoracic Surgeons (STS). Parameters studied included age, gender, left ventricular ejection fraction (LVEF), previous myocardial infarction (MI), disease severity, number of grafts, complications, blood usage, ventilation times, operating room (OR) time, and hospital length of stay (LOS).

There were no significant difference between the patient groups with regard to age, gender, LVEF, previous MI, predicted mortality, and LOS. Operative mortality was also similar in the two groups: conventional bypass 4/117 (3%) and OPCAB 2/86 (2%). The conventional bypass patients (CPB) had significantly (p < 0.05) more diseased vessels (2.9 vs. 2.6) and distal grafts (4.1 vs. 2.7), as compared to the OPCAB group. OPCAB procedures resulted in significantly (p < 0.05) lower mean OR time (365 min vs. 406 min) and reduced mean postoperative ventilation hours (3.4 vs. 8.3 hours), as compared to conventional bypass. There were significantly (p < 0.05) fewer blood transfusions in the OPCAB group (1.1 units vs. 2.4 units), and the percentage of patients transfused blood was significantly less (34.9% vs. 57.3%). Nine out of 95 (9.5%) of patients who presented for OPCAB were converted to conventional bypass. Although there may be potential benefits to OPCAB, further studies must be directed at determining those patients who would benefit most from CABG using the off-pump technique. Keywords: cardiopulmonary bypass, off-pump coronary artery bypass surgery, beating heart surgery. JECT. 2001;33:86–90

Open-heart surgery is regarded as one of the most significant medical advances in the 20th century (1). Today, this surgery is performed with relatively low risk from neonate to octogenarian at a rate of 2000 surgeries a day (1). The development and progress of cardiac surgery was made possible with the assistance of cardiopulmonary bypass (CPB).

The advantage of using the heart–lung machine during coronary artery bypass is the ability to operate on a still heart within a relatively bloodless field, while enabling exposure of all distal coronary circulation. Under these conditions, the surgeon can manipulate the heart and make accurate, secure grafts to bypass diseased coronaries and re-establish flow to the myocardium.

Despite its widespread use, CPB is a nonphysiological process. Deleterious side effects attributed to the use of CPB include coagulopathy, inflammatory response, edema, renal dysfunction, and neurological deficits (2). The use of the heart–lung machine is considered by some to be the main culprit. Kirklin et al. state “the most obvious mechanisms for damage during CPB are exposure of blood to an abnormal environment, and altered arterial blood flow patterns” (3), which may lead to and increased operative mortality and morbidity leading to increased length of stay and hospital charges.

Concern about these complications has led to the development of a method of coronary artery bypass grafting (CABG) that does not involve the use of the heart–lung machine. Off-pump coronary artery bypass surgery (OPCAB) employs the use of a stabilizing device that renders the area around the target vessel motionless; thus, facilitating vascular anastomosis. The heart is not arrested and continues to beat throughout the entire procedure, with the cardiac output maintained by the patient’s heart while the anastomosis is performed. Depending on the location of the diseased vessel, the surgical approach is either a median sternotomy or a thoracotomy. The concept of operating on a beating heart was described by
Favrolaro (4) in 1969. Favrolaro demonstrated that the right coronary artery (RCA) could be bypassed without the use of CPB (4). The 1980s brought renewed interest in CABG without CPB (5–8).

Proponents of the OPCAB technique cite a reported lower incidence of blood transfusion peri- and postoperatively (7–12), decreased ventilator time (7, 10), and decreased length of stay (LOS) (13).

Disadvantages of OPCAB include potentially incomplete revascularization of the circumflex artery and poor outcomes of patients within 48 h of acute myocardial infarctions (14). Concern also exists among certain surgeons in regard to complete revascularization, graft patency, and the need to “limit of ischemic time in regard to this technique” (14).

Patient selection of this OPCAB procedure is an area that varies widely. Some institutions employ this method only on their highest risk patients; that is, renal failure, previous cerebral damage, acute myocardial infarction (AMI), respiratory failure, > 70 years old, or low EF (13). Others prefer the OPCAB procedure only for patients with left anterior descending (LAD) and/or right coronary artery (RCA) lesions (13). In a recent study by Ascione et al. (15), exclusion criteria for OPCAB surgery included ejection fraction less than 30%, recent MI (within 30 days), distal circumflex disease, diabetes mellitus, serum creatinine > 130 \( \text{mol/L} \), concurrent diuretic therapy, previous cerebral damage, acute myocardial infarction (AMI), respiratory failure, > 70 years old, or low EF (13). The 1980s brought renewed interest in CABG surgery (Group I) with OPCAB surgery (Group II). The null hypothesis is that there are no differences in outcomes between these two groups.

MATERIALS AND METHODS

Patient Analysis

A retrospective review of the CABG patients \((n = 212)\) was conducted using the STS database. These included 117 on-pump patients and 86 OPCAB, analyzed from the 6-month period. Nine patients were converted to on bypass and were excluded from the initial analysis. Parameters analyzed at included age, gender, LVEF, previous MI, disease severity, number of grafts, complications, blood usage, ventilator times, OR times, and hospital LOS. All aspects of this research were done in compliance with the guidelines set forth by the Institution Review Board of the Medical University of SC. The operating surgeon determined selection of patients for CABG/OPCAB after review of the patient’s history and physical, angiogram and in discussion with the patient and his or her cardiologist.

Anticoagulation Management

Heparinization for CPB was 300–400 units/kg to achieve a desired ACT of 400 seconds or greater until termination of bypass. Protamine dosage was surgeon dependent and this was done to re-establish baseline ACT using either a heparin dose response calculation, 60% or 100% of total heparin.

In the OPCAB group, the heparin dose was 150 \( \mu \text{g/kg} \) before the start of the first anastomosis to achieve a target ACT greater than 250 seconds with additional heparin given as needed. Protamine was given to return ACT to preoperative values following completion of the procedure.

Anesthetic Technique

During OPCAB procedures, the selection of anesthetic agents was dependent upon the need to maintain hemodynamic stability and at the same time provide for early emergence and extubation. Following induction, the patient was maintained on a sufentanil infusion with isoflurane for amnesia. Paralysis was maintained with an intermediate acting nondepolarizer, such as vecuronium. Following the last distal anastomosis, the sufentanil drip was discontinued, and propofol was initiated until the conclusion of the case. Using this anesthetic technique, the patient was extubated within 2 to 4 hours following the procedure.

The anesthetic technique for CAB differed from the OPCAB technique. When CPB was chosen, an anesthetic technique was chosen which optimized hemodynamics, maintained analgesia and amnesia, and provided early extubation after CPB. The patient was loaded with sufentanyl 2–4 mg/kg and maintained on an infusion of 0.3 mg/kg/hour. Isoflurane was continued at 0.5–1.0 vol% throughout the case to ensure amnesia. Pancuronium was usually used for muscle relaxation.

Surgical Technique

In the on pump group, CPB was initiated using ascending aortic cannulation and two-stage venous cannulation of the right atrium. The circuit consisted of a roller pump (Terumo Sarns, Ann Arbor, MI) and a membrane oxygenator (Jostra-Bentley, Irvine, CA). The pump prime included either 1800 \( \text{cc} \) Plasmalyte A or 1300 \( \text{cc} \) Plasmalyte A and 500 \( \text{cc} \) Hespan, 20–30 meq \( \text{NaHCO}_3 \), and 1000 units Heparin. Systemic temperatures ranged from 32–34 \( ^\circ \text{C} \).
Patient pressures were maintained between 60 and 100 mmHg, with blood flow rates between 1.8 L/min/m² and 3.0 L/min/m². Myocardial protection was maintained with antegrade and retrograde cold blood cardioplegia.

In the OPCAB group, exposure and stabilization of the distal anastomosis was achieved with either the Genzyme (Genzyme, Boston, MA) or Medtronic Octopus (Medtronic, Anaheim, CA) retractor. The target vessel was exposed and snared using polypropylene suture or silicone retractor tapes. Ischemic preconditioning and or an intravascular shunt were selectively utilized, depending on surgeon preference. Adequate visualization was achieved using a CO₂ blower humidifier with warm 0.9% normal saline. Proximal anastomoses were performed using a partial occlusion clamp. Normothermia was maintained with a heater cooler blanket. The CPB circuit was setup dry and available for emergency bypass if needed.

**Statistical Analysis**

Data were obtained retrospectively from STS database and entered into a Microsoft Excel database (Microsoft Corp., Redmond, WA). The data were then analyzed by Student’s t-test using Sigma Stat statistical software. A p-value of < 0.05 was considered significant. Data were presented as mean ± SD unless otherwise stated.

**RESULTS**

Off-pump and on-pump demographic data for the patients included age, gender, LVEF, previous MI, predicted mortality, and LOS. These values were not significantly different, as shown in Table 1. Of the 212 patients, 132 (62%) were male, and 80 (38%) were female. Mean age was 64.9 years, with a range of 30 to 88 years old. Mean ejection fraction for both groups was 48%. Previous myocardial infarction accounted for 45% of the CPB patients and 38% of the OPCAB patients. Operative mortality was similar in the two groups: 4/117 (3%) in the CPB group and 38% of the OPCAB patients. Operative mortality was significantly lower in the OPCAB group (2.7 vs. 4.1) than in the CPB group, as shown in Table 2.

OPCAB procedures had significantly (p < 0.05) lower mean OR times (365.0 ± 68.7 min vs. 406.0 ± 85.7 min) than the on-pump group (Table 3). Median post-op ventilation hours, compared to conventional bypass, were significantly (p < 0.05) reduced (8.3 hours vs. 3.4 hours) (Table 3). There were significantly (p < 0.05) fewer red blood cell transfusions in the OPCAB group (1.1 ± 1.8 units vs. 2.4 ± 3.2 units) and the percentage of patients transfused was lower (34.9 vs. 57.3%) (Table 4).

Nine patients, originally in the CAB group (9/95) were converted to bypass attributable to poor distal targets (n = 4), hemodynamic instability (n = 4), or aortic dissection (n = 1).

**DISCUSSION**

This study compared a retrospective review of our OPCAB experience with a group of patients that had conventional bypass. The data showed that ventilator hours, length of stay, and red blood cell transfusion requirements were significantly lower in the OPCAB group. It also showed that the conventional bypass group had more diseased vessels and received more distal grafts than the OPCAB group.

Several studies have reported the cost containment advantages of coronary artery bypass surgery without the use of the heart lung machine. This technique may result in lower costs for the hospital and to the patients. Ascione et al. (15) reported a study of 200 patients and observed a significant cost saving, and lower transfusion requirements in patients who underwent coronary revascularization using the OPCAB technique. Puskas et al. (21) saw a cost reduction in hospital charges of 24%.

In our study, the number of grafts performed were significantly lower in the OPCAB group (2.7 vs. 4.1) than in the CPB group. Incomplete revascularization has been raised as a major concern in those patients who undergo

### Table 2. Intraoperative data.

<table>
<thead>
<tr>
<th>Operation</th>
<th>CPB n = 117</th>
<th>OPCAB n = 86</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diseased vessels</td>
<td>2.8 ± 0.4</td>
<td>2.5 ± 0.6</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Distal grafts</td>
<td>4.1 ± 2.0</td>
<td>2.6 ± 0.9</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>O.R. time (min)</td>
<td>363.6 ± 85.6</td>
<td>326.9 ± 68.6</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

### Table 3. Postoperative data.

<table>
<thead>
<tr>
<th>Operation</th>
<th>CPB n = 117</th>
<th>OPCAB n = 86</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilator (hours)</td>
<td>8.3*</td>
<td>3.4*</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>LOS (days)</td>
<td>6.99*</td>
<td>4.64*</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

*Median values.
The strategies to extubating OPCAB patient versus conventional bypass patients are different at our institution as outlined in the methods section. The OPCAB patients are placed on of a fast-track anesthesia protocol stopping the sufentanil drip with the last anastomosis and extubating within 4 hours postoperatively. This difference in anesthetic management may account for shorter ventilation times and ultimately to a lower length of stay (22). Ott et al. reported a rapid recovery protocol on 104 patients who underwent conventional cardiopulmonary bypass and revascularization. They decreased their bypass and extubation times, administered corticosteroids, and used aggressive diuresis. This resulted in a 3-day discharge rate of 29% of their patients with an average length of stay of 4.8 days. Based on studies such as this, other institutions may be able to decrease their length of stay and costs associated with conventional cardiopulmonary bypass, so that financial and length of stay differences between the two techniques may be negligible (23).

There was a significant difference in the incidence of red blood cell transfusion in the OPCAB group versus the CPB group (34.9% vs. 57.3%). In addition, the average number of units transfused were significantly lower (1.1 units vs. 2.4 units) in the OPCAB group. This has been observed in other investigations. (6, 7, 17). Rubens et al. (20) reported a significant difference in the hematological effects of COBE SMART circuit with improved platelet preservation, decreased fibrinolysis and thrombin generation. Advances and improvement in the cardiopulmonary bypass circuit have further reduced the need for red blood cell transfusion in patients undergoing conventional cardiopulmonary bypass techniques.

Results from the current study demonstrated that, at our institution, the OPCAB technique allows for shorter operative time, fewer red blood cell transfusions, and reduced length of stay. With gained surgical experience and patient selection, the indications for OPCABs have evolved at our institution. During the last 6 months (August 1999–February 2000) OPCABS comprised 35% (47/134) of our adult patients undergoing coronary revascularization. Two of these, or 4% (2/47), were converted to traditional cardiopulmonary bypass technique.

Table 4. Blood product usage.

<table>
<thead>
<tr>
<th></th>
<th>CPB</th>
<th>OPCAB</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBC (units)</td>
<td>2.4 ± 3.20</td>
<td>1.1 ± 1.80</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>FFP (units)</td>
<td>0.21 ± 0.90</td>
<td>0.3 ± 0.90</td>
<td>NS</td>
</tr>
<tr>
<td>Platelets (units)</td>
<td>0.1 ± 0.30</td>
<td>0.1 ± 0.3</td>
<td>NS</td>
</tr>
<tr>
<td>Cryo (units)</td>
<td>0.0 ± 0.0</td>
<td>0.0 ± 0.0</td>
<td>NS</td>
</tr>
</tbody>
</table>

RBC = Red blood cells.
FFP = Fresh frozen plasma units.
Cryo = Cryoprecipitate.

OPCAB. Benetti et al. (9) observed that approximately 12% of their 700 patients who underwent coronary revascularization using an OPCAB technique had incomplete revascularization. More recently, Puskas et al. (17) reported significantly higher grafts per patient in the on-pump group as compared to their off-pump group (3.6 vs. 2.0). This is similar to our results. These investigators considered complete revascularization to be the “gold standard” for coronary bypass surgery irrespective of the surgeon’s choice of incision or use of CPB. A further corollary to this would be that the goal for coronary revascularization would be long-term relief from angina, avoidance of re-intervention, and prevention of future myocardial infarctions, regardless of the technique used for coronary bypass. Hart et al. (18) stated that OPCAB must permit full revascularization of all regions without encouraging inadequate or incomplete operations; however, some groups are at a significantly higher risk for perioperative morbidity and mortality with CPB. These may include patients with renal failure, significant neurologic deficits, and pulmonary failure. In these groups of patients, it may be beneficial to utilize the OPCAB technique to provide revascularization to critical areas of myocardium and not subject these high-risk groups of patients to traditional CPB.

Long-term patency of bypass grafts performed using OPCAB techniques is unknown. Some investigators have demonstrated that coronary revascularization using OPCAB techniques have an angiographic patency of 97.7% before discharge (17). At 6 months, Jansen et al. demonstrated a patency rate of 95%. However, 5- and 10-year angiographic studies have not been performed. Operating room times were significantly lower in the OPCAB group as compared to the CPB group. Other investigators have observed this. Operating room costs at our institution range from $7.00 to $11.00 per minute. This lower operative time using OPCAB techniques suggest that significant savings may occur using this method of myocardial revascularization. One investigator, Bonatti (19), had significantly longer operative times for the OPCAB group. However, the authors suggest that this may have been attributable to a steep learning curve that can be associated with learning the OPCAB technique.
coronary revascularization will be based on patient outcomes. If graft patency and angina relief are the same long term for OPCAB patients when compared to CPB group, this may reduce the need for perfusionists involved in adult CABGs.

Perfusion education programs have a responsibility to look at the future of our profession and predict the outlook for employment opportunities. We also may need to look at tailoring our programs to reflect our changing profession to include an adjunctive program of study, such as physician assistant with a degree in perfusion.

As perfusionists, we need to anticipate this period of change and prepare accordingly. It should be exciting to us as professionals to witness the technological advances that are capable of contributing to improved outcomes to the patients we have all committed to serving during our professional lives.

REFERENCES