Off-Pump Coronary Artery Bypass Surgery
Fundamentals for the Clinical Cardiologist

Subodh Verma, MD, PhD; Paul W.M. Fedak, MD; Richard D. Weisel, MD; Paul E. Szmitko, BSc; Mitesh V. Badiwala, BSc; Daniel Bonneau, MD; David Latter, MD; Lee Errett, MD; Yves LeClerc, MD

Case Report: Mrs. G is a 65-year-old retired banker who has had Canadian Cardiovascular Society class III angina for the past 2 months and symptomatic intermittent claudication for the past year. Her past medical history is unremarkable except for the presence of multiple vascular risk factors (smoking, hypertension, dyslipidemia, and diabetes). Coronary angiography revealed triple vessel disease involving the left anterior descending, second obtuse marginal, and right coronary arteries, as well as the akinetic anterior and inferior walls, with an estimated ejection fraction of 30%. Carotid duplex revealed 40% stenosis of the right internal carotid artery and 60% stenosis of the left internal carotid artery. A chest x-ray showed a possible calcified ascending aorta. The patient was referred for consideration of coronary artery bypass graft (CABG) surgery. Is Mrs. G a candidate for off-pump CABG? What are the indications, precautions, and considerations that facilitate decision-making about off-pump CABG surgery?

Conventional CABG surgery uses cardiopulmonary bypass (CPB) to allow cardiac surgeons to operate on a motionless heart that has been arrested by means of cardioplegia. CABG with CPB (on-pump CABG) quickly became the gold standard surgical procedure for myocardial revascularization, as it allowed surgeons to bypass multiple coronary arteries with greater control and precision. However, recently there has been increasing interest in the development and use of technologies that allow surgeons to perform CABG surgery without CPB (known as off-pump CABG or OPCAB).

Rationale for the Development of OPCAB Surgery
CPB is not a benign intervention. It is associated with a number of adverse consequences that are primarily related to a systemic inflammatory response elicited by the activation of cellular and humoral mediators as circulating blood comes into contact with the extracorporeal circuit of the CPB machine. The biochemical, cellular, and molecular aspects of this pump-induced inflammatory response are believed to contribute to postoperative myocardial, renal, and neurological dysfunction, coagulopathies, respiratory failure, and multiple organ dysfunction.1,2 On-pump CABG is also associated with microembolization of gaseous and particulate matter from blood constituents and lipids as they are cycled through the CPB circuit,3 a process implicated in the development of postoperative neurological and cognitive dysfunction.

The development and application of OPCAB technology has largely been driven by the hope of decreasing the incidence and/or severity of these adverse outcomes by performing CABG surgery without CPB. Impetus for this technology has been driven by reports indicating a reduction in early mortality,4–7 early neurocognitive dysfunction,8–11 stroke,7,12–14 and renal failure15–17 when compared with outcomes in patients undergoing conventional CABG with CPB.

OPCAB Technology
Successful OPCAB surgery depends on the optimization of cardiac positioning to access target coronary vessels, cardiac stabilization to dampen
local cardiac wall motion around the distal anastomotic site, and techniques directed at minimizing myocardial injury from the interruption of coronary perfusion while adequately visualizing the distal anastomotic site.

**Cardiac Positioning**

Unlike on-pump CABG, hemodynamic compromise with OPCAB surgery is a concern during cardiac positioning. Lifting and rotating the heart during OPCAB may alter such hemodynamics as cardiac output, mean arterial pressure, stroke work, left ventricular end-diastolic pressure, and right atrial pressure. As expected, greater changes arise when the heart is positioned to expose the lateral wall compared with the anterior aspect of the heart.18-20 These hemodynamic effects are primarily related to the compression and geometrical distortion that occurs when the heart is displaced using either conventional deep pericardial retraction sutures or sutured stockinet.19 Fluid and inotropic use in addition to placing the patient in the Trendelenburg position may limit these effects18 and prevent intraoperative conversion to CPB.21

Heart positioning devices available for use during OPCAB are generally suction devices that pull the heart up either by apical or non-apical attachment (Figure 1 and Figure 2). Sepic et al19 reported that target vessel exposure using an apical suction device resulted in near-baseline hemodynamics when compared with exposure by means of deep pericardial retraction sutures.

**Cardiac Wall Motion Stabilization**

Local cardiac wall immobilization at the site of the coronary arteriotomy is essential to allow for optimal anastomotic suturing. A number of devices have been developed whereby surgeons can immobilize small areas of the heart either by local compression to the epicardial surface of the heart or by vacuum suction to pull up on the epicardium surrounding the target arteriotomy site. Some devices, such as the Coro-Vasc System (CoroNeo Inc), use silastic snares that are looped around the target coronary vessel and then fixed to a small immobile plate, thus directly immobilizing the target vessel.

**Preventing Intraoperative Myocardial Ischemia**

Displacement of the beating heart, combined with local wall motion fixation during OPCAB surgery, may interfere with coronary blood flow and contribute to myocardial ischemia.23,24 Furthermore, temporary occlusion of the target coronary vessel during OPCAB surgery is typically required to allow adequate visualization for creation of the distal anastomosis. This causes regional myocardial ischemia and may contribute to hemodynamic instability.

Intraluminal shunts can be placed within the anastomotic vessel, allowing distal perfusion during bypass grafting (Figure 2). Several studies have reported that these shunts are
safe, protecting the regional myocardium from ischemia and preventing left ventricular dysfunction.24–27 Because distal regional ischemia is generally localized, transient, and well tolerated, especially in cases of bypass to an occluded vessel, shunts are used only when necessary to minimize the risk of vessel damage via intraluminal coronary manipulation and subsequent graft failure.28

Other techniques, including passive and active distal coronary perfusion through the coronary artery being bypassed, have been developed and studied.29–33 Passive distal coronary perfusion involves shunting of blood typically from either the aorta or the femoral artery through to the distal coronary artery, whereas active perfusion uses an in-line pump to augment flow to the distal coronary artery. Studies examining the physiological effect of active versus passive distal coronary perfusion have shown that active distal coronary perfusion provides superior myocardial protection compared with passive perfusion.31,32

Patient Selection

Before the development of technology that gave surgeons safe access to the lateral and posterior coronary arteries, OPCAB surgery was reserved for patients who needed single or double coronary artery bypasses of the anterior vessels, for patients who tended to be younger, and for those who had intact left ventricular function. As multiple coronary bypasses covering all coronary territories became possible with the development of cardiac positioning and stabilization devices, OPCAB surgery was directed toward those patients who were at high risk of complication from CPB and thus would derive the most benefit from OPCAB. Such patients tended to be elderly and to have comorbid conditions, such as carotid disease, renal dysfunction, chronic pulmonary disease, peripheral vascular disease, and atherosclerotic ascending aortic disease.34 As technology has advanced and surgeons have become comfortable performing OPCAB surgery, a more diverse patient population has undergone CABG off-pump. Retrospective studies show that this procedure is safe and well tolerated by most patients. In fact, surgeons who routinely use this technology believe that up to 90% of patients referred for CABG can safely undergo OPCAB surgery.35 Furthermore, higher risk patients, including those undergoing reoperative CABG, diabetics, and the elderly may gain the most benefit from OPCAB surgery.36 Hemodynamic instability or poor targets (ie, intramyocardial and/or diffusely diseased vessels) are considered to be absolute contraindications to OPCAB surgery. Other precautions and relative contraindications are listed in Table 1.

Recent Evidence

With the growing interest in OPCAB surgery over the last decade, a number of studies have reported the safety and efficacy of OPCAB. Indeed, randomized trials demonstrate that OPCAB surgery yields results at least comparable to on-pump surgery in the early and mid-term postoperative periods, and that OPCAB surgery has advantages in a number of areas37–44 (Table 2).

What Does the Future Hold?

The last decade has witnessed a tremendous interest in OPCAB technology with promising preliminary results in diverse populations. Questions surrounding the adequacy of long-term revascularization with OPCAB remain; however, over the next few years, the results of late follow-up will be reported to determine whether OPCAB is associated with long-term graft patency, one of the most important considerations of this technique. In the interim, OPCAB technology seems to be safe and to offer equal, if not better, short-term results. As cardiac surgeons become more comfortable with the technique, it is expected that by the year 2005, up to 50% of CABG surgery will be performed off-

**TABLE 1. Contraindications to OPCAB**

<table>
<thead>
<tr>
<th>Absolute Contraindications</th>
<th>Relative Contraindications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemodynamic instability</td>
<td>Cardiomegaly/congestive heart failure</td>
</tr>
<tr>
<td>Poor quality target vessels including:</td>
<td>Critical left main disease</td>
</tr>
<tr>
<td>Intramyocardial vessels</td>
<td>Small distal targets</td>
</tr>
<tr>
<td>Diffusely diseased vessels</td>
<td>Recent or current acute MI</td>
</tr>
<tr>
<td>Calcified coronary vessels</td>
<td>Cardiogenic shock</td>
</tr>
<tr>
<td>MI indicates myocardial infarction; LVEF, left ventricular ejection fraction.</td>
<td>Poor left ventricular function (LVEF&lt;35%)</td>
</tr>
</tbody>
</table>
TABLE 2. Recent Evidence for Off-Pump CABG

<table>
<thead>
<tr>
<th>Study</th>
<th>Description</th>
<th>Findings</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHACAS 1 and 2</td>
<td>RCT with 401 patients undergoing elective CABG (201 patients on-pump, 200 off-pump)</td>
<td>Benefits of OPCAB in terms of decreased in-hospital morbidity (↓ incidence of chest infection, inotropic requirement, supraventricular arrhythmia, blood transfusion, ICU stay, total length of stay) No difference in terms of survival at 2 years, frequency of cardiac events (MI, PTCA, recurrent angina, arrhythmia, CHF, redo CABG), and medication usage</td>
<td>Mean follow-up was 25.0±9.1 months in BHACAS 1 and 13.7±5.5 months in BHACAS 2. Contrasts previous findings that suggested patients undergoing OPCAB surgery had a higher likelihood of undergoing repeat PTCA or CABG; disparity may be due to use of newer cardiac stabilization technologies in these trials</td>
</tr>
<tr>
<td>Octopus Study Group</td>
<td>One-month and 1-year results of a randomized comparison of OPCAB surgery with on-pump CABG surgery in 281 “low-risk” patients</td>
<td>Blood product transfusion, CK-MB release, and length of hospitalization were less in the on-pump group. Incidence of recurrent angina at 1 month and the proportion of patients free of death and/or CV events (stroke, MI, coronary re-intervention) at 1 month and 1 year were similar between the 2 groups. OPCAB surgery was more cost effective than on-pump surgery, which had 14.1% more direct costs per patient.</td>
<td>Poor LV function, recent Q-wave MI, and emergency and/or concomitant major surgery were exclusion criteria. Similar completeness of revascularization among patients yet significant difference in the mean No. of distal anastomoses (greater in on-pump group)</td>
</tr>
<tr>
<td>SMART study</td>
<td>Randomized trial comparing OPCAB with on-pump CABG amongst 200 patients</td>
<td>Decreased CK-MB and troponin I serum levels, lower transfusion requirements, and shorter postoperative stay (by 1 day) among OPCAB patients No. of grafts performed, completeness of revascularization, and combined hospital and 30-day mortality and stroke rates were similar.</td>
<td>Patients unselected for coronary anatomy, ventricular function, or other comorbidities with the exception of those in cardiogenic shock or those requiring preoperative IABP support</td>
</tr>
<tr>
<td>Drenth et al</td>
<td>Randomized trial comparing PCI to OPCAB surgery in patients with isolated LAD disease (102 patients)</td>
<td>Composite end point (including freedom from death, MI, CVA, and repeat target revascularization) was 23.5% in the PCI group and 9.8% in the OPCAB group (P=0.07). OPCAB patients had significantly lower angina class and required less antianginal medication.</td>
<td>These preliminary results suggest that OPCAB may be a superior intervention for patients with isolated LAD disease.</td>
</tr>
<tr>
<td>Sharony et al</td>
<td>Propensity case-match analysis of OPCAB in patients with atheromatous aortic disease</td>
<td>Hospital mortality and stroke incidence were significantly lower among OPCAB patients. OPCAB patients had greater freedom from postoperative complications.</td>
<td>458 patients with atherosclerotic aortic disease identified by routine intraoperative TEE while undergoing isolated CABG surgery (229 OPCAB and 229 on-pump)</td>
</tr>
<tr>
<td>Al Ruzzeh et al</td>
<td>Retrospective study examining efficacy of OPCAB in 1398 high-risk patients</td>
<td>In older patients with poor LV function and renal dysfunction, OPCAB surgery was associated with ↓ perioperative MI, ICU stay, and 30-day mortality.</td>
<td>Patients with preoperative EuroSCORES of ≥5. Results suggest OPCAB surgery may be associated with a greater short-term benefit than on-pump CABG in high-risk patients, but this requires prospective evaluation.</td>
</tr>
</tbody>
</table>

BHACAS indicates Beating Heart Against Cardioplegic Arrest Studies; SMART, Surgical Management of Arterial Revascularization Therapies; RCT, randomized clinical trial; ICU, intensive care unit; MI, myocardial infarction; PTCA, percutaneous transluminal coronary angioplasty; PCI, percutaneous coronary intervention; LAD, left anterior descending artery; CVA, cerebrovascular accident; TEE, transesophageal echocardiography; and EuroSCORES, European System for Cardiac Operative Risk Evaluation.

... OPCAB surgery remains technically more demanding and has a steeper and longer learning curve. As OPCAB becomes more frequent, cardiac surgical trainees will have the opportunity to routinely incorporate it into their residency training. Devices such as the sutureless coronary anastomotic connectors have the potential of transforming this technically challenging procedure into one that is more easily performed.
Mrs. G underwent OPCAB surgery with a left internal thoracic artery to the left anterior descending artery and left radial T graft (off the left internal thoracic artery) to the second obtuse marginal and posterior descending artery (Figure 3). Her perioperative course was unremarkable, and she was discharged from hospital at day 4 after surgery. By using the OPCAB technology and radial T grafting, complete revascularization was accomplished without manipulation or cannulation of the atherosclerotic aorta.

Note Added in Proof

During the review process, several clinical trials comparing OPCAB to on-pump CABG were published. In a single-center trial conducted on 300 patients requiring CABG surgery, Legare et al. were unable to demonstrate any advantage with OPCAB in terms of patient morbidity assessed in terms of mortality, transfusion, perioperative MI, stroke, new atrial fibrillation, sternal wound infection, or length of hospitalization. Similar conclusions were reached by Gerola et al.

References

21. Soltofski P, Salerno T, Levinsky L, et al. Conversion to cardiopulmonary bypass in...