

Off-Pump Coronary Artery Bypass Surgery

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Off-pump coronary artery bypass (OPCAB) surgery is gaining acceptance among surgeons as an option for the operative treatment of coronary artery disease. OPCAB surgery is performed *without* the use of cardiopulmonary bypass (CPB). CPB involves diverting the blood flowing into the heart directly to the aorta via a pump oxygenator.

The use of CPB and induced cardioplegia are the main features of standard coronary artery bypass surgery. With OPCAB surgery, however, the blood flow is left alone, and the patient's heart is allowed to continue beating. The surgeon operates on the beating heart, gaining a stable area on which to work through the aid of a specially designed epicardial-wall stabilizer. Because the OPCAB technique does not involve CPB, it is not associated with the many pump-related complications that have come to be associated with cardiac and aortic surgery. It represents a significant advancement in the surgical treatment of coronary artery disease.

BACKGROUND

Off-pump coronary revascularization was first performed in 1964 in the former Soviet Union by Kolesov,¹ who, through a left thoracotomy incision on a beating heart, successfully grafted the internal mammary artery to branches of the left coronary artery. Others in the United States and Canada^{2,3} reported on the technique, but it was largely abandoned as the use of CPB and induced cardioplegic arrest during surgery became more routine. Over the next 2 decades, off-pump procedures were rarely performed and only in certain programs and on select patients. Large series were reported by Benetti et al⁴ in Argentina and by Buffolo et al⁵ in Brazil, where revascularization was accomplished with relatively suboptimal heart stabilization.

With the relatively recent advent of epicardial-wall stabilizers, off-pump procedures have become more popular. They are often performed as *minimally invasive* procedures, a term that emphasizes their limited intrathoracic exposure. These surgeries, such as the minimally invasive direct coronary artery bypass (MIDCAB), are performed by using limited parasternal incisions, special

instrumentation, and usually a 1- or 2-vessel bypass on a beating heart without the use of CPB.^{6,7} The OPCAB procedure evolved as a natural extension of the MIDCAB technique. Unlike MIDCAB however, OPCAB incorporates a full median sternotomy, facilitating exposure so that a multivessel (ie, > 2) bypass procedure may be performed. OPCAB surgery is being performed worldwide, especially in Scandinavia, Germany, Canada, Japan, and the United States. It is gaining further acceptance in the surgical community as more advanced devices to stabilize the beating heart are developed.

GENERAL FEATURES

The general features of OPCAB surgery are full median sternotomy, absence of CPB, use of a specialized heart-wall retractor, temporary interruption of the coronary blood flow during the performance of the distal anastomoses, and lastly, a rapid patient recovery with extubation either in the operating room or shortly thereafter.³ As might be expected, OPCAB surgery requires specialized anesthetic management that focuses on short-acting medications, preservation of normothermia, aggressive hemodynamic support, early extubation, and postoperative analgesia.^{8,9} A comparison of OPCAB surgery and traditional coronary artery bypass surgery is provided in **Table 1**.

ADVANTAGES

Standard aortocoronary bypass surgery involves the use of CPB, which in turn involves the use of a pump oxygenator to divert the blood flowing into the heart directly to the aorta, avoiding the heart and lungs. This allows the heart to be stopped, creating a stable environment in which the surgeon can operate while maintaining oxygenated-blood circulation in the patient.

However, there is widespread acknowledgment that CPB is responsible for many of the complications

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Table 1. Comparison of Features of OPCAB and Standard Coronary Artery Bypass Surgery

OPCAB	Standard Bypass Procedure
Beating heart provides aerobic perfusion	Pump oxygenator provides aerobic perfusion
Epicardial-wall stabilizer used to minimize movement of operative field	Cardioplegia solution used to arrest the heart
No invasive cannulation required	Aortic and venous cannulation required
Partial cross-clamp for proximal anastomoses	Complete aortic cross-clamp for distal anastomoses
Lower heparin dose required	Systemic heparinization needed to allow CPB
Early extubation and faster recovery	Relatively delayed extubation and recovery
No pump-related complications	Systemic inflammatory response possibly causing CNS, cardiac, pulmonary, renal, and gastrointestinal complications

CNS = central nervous system; CPB = cardiopulmonary bypass; OPCAB = off-pump coronary artery bypass.

generally associated with cardiac and aortic surgery. Contact of the patient's blood with the artificial surfaces of the CPB circuit produces a systemic inflammatory response via complement activation, which affects the heart, lungs, central nervous system, kidney, and gastrointestinal tract.¹⁰ In addition, embolic phenomena—related to surgical manipulation of the aorta and to the pump itself—are responsible for major neurologic complications and cognitive decline.¹¹

Without doubt, the major overall advantage of OPCAB is that it gives the surgeon the ability to perform multivessel coronary artery bypass *without* the use of CPB. With OPCAB surgery, the surgeon operates on the patient's heart while it is still beating, gaining a stable area on which to work through the aid of a specially designed epicardial-wall stabilizer. Eliminating the need for CPB has been the main impetus towards the popularization of both MIDCAB and OPCAB surgeries.

Because the pump oxygenator is not used, OPCAB surgery is not complicated by CPB-associated myocardial edema and decreased contractility. Additionally, while the OPCAB procedure involves a period of localized intraoperative ischemia, it avoids the potential for global ischemia, which may result from inadequate myocardial protection during the bypass procedure. Consequently, with OPCAB, there may be fewer postoperative dysrhythmias (especially atrial fibrillation)^{12,13} and less need for postoperative inotropic support and temporary cardiac pacing.

The incidence of perioperative bleeding is also significantly reduced in OPCAB surgery. The use of a lower dose of heparin, the lack of CPB-associated hemodilution, and the absence of pump-related platelet dysfunction all contribute to a lower potential for perioperative blood loss and associated heterologous transfusion. Studies comparing off-pump and standard-technique

surgeries report that the incidence of perioperative transfusion may be reduced by approximately one third to one half.^{14–16} This is also observable in **Table 2**, which shows results obtained from a large database on mainly standard-technique procedures compared with some recent OPCAB study results.

OPCAB surgery also leads to an avoidance of what is sometimes referred to as “pump lung” syndrome—degradation of surfactant and activation of complement, resulting in increased capillary permeability, interstitial edema, and reduced compliance. Although patients having undergone OPCAB surgery may have some degree of atelectasis, most patients, and even patients with fairly severe chronic obstructive pulmonary disease, are able to be extubated shortly after the procedure.

As noted earlier, CPB is associated with neurologic complications—major complications such as stroke and coma, as well as more subtle neurologic and cognitive defects. Neurologic complications may occur in as many as 50% of patients who undergo CPB.^{17,18} Although not yet established in controlled studies, such complications should be less prevalent in patients who undergo OPCAB surgery. Unlike most patients who undergo a standard bypass procedure, nearly all OPCAB patients are awake shortly after the procedure, and most sit up, talk, and take fluids within a few hours postoperatively.

The OPCAB technique has benefits related to anesthesia, as well. Pharmacologic management is far more predictable with OPCAB surgery because there is no pump-related effect on plasma drug concentrations.¹⁹ There are also fewer serum electrolyte disturbances, especially in glucose, potassium, and calcium levels. Postoperative fluid management is simplified, as well, because of reduced third space sequestration.⁹

Although the advantages of the OPCAB technique over the standard procedure may seem apparent in

Table 2. Comparison of Results: Standard Coronary Artery Bypass Surgery versus OPCAB Surgery

	Standard Bypass	OPCAB			
	STS Data*	Spooner et al [†]	Iaco et al [‡]	Turner et al [§]	Kwon et al
OPCAB Patients (n)	— [¶]	456	472	100	300
Age (yr)	62.9	62.8	64.3	62.9	67
Male (%)	70	77	79.2	63	71
Left ventricular ejection fraction (%)	50.9	55.7	58.0	50.9	51
Vessels bypassed (n)	3.0	1.9	2.3	1.9	3.4
Incidence of reoperation for bleeding (%)	2.3	1.0	—	1.0	0.3
Incidence of transfusion (%)	37.1	20.6	15.7	15.0	—
Incidence of atrial fibrillation (%)	19.3	13.3	—	5.0	3.7
Incidence of perioperative myocardial infarction (%)	1.2	0.8	0.2	—	1.0
Incidence of completed stroke (%)	1.7	0.2	0.4	0	0.7
Incidence of renal failure (%)	3.3	0	—	0	—
Hospital stay (days)	6.6	5.3	4.0	4.4	—
Mortality rate (30 day)	2.8	0.2	1.9	3.0	2.3

OPCAB = off-pump coronary artery bypass; STS = Society of Thoracic Surgeons. Dashes denote data not recorded.

*Data analyses of the STS national cardiac surgery database. The eighth year, January 1999. Available at <http://www.ctsnet.org/doc/2986>. Accessed September 28, 2000.

[†]Data from Spooner TH, Hart JC, Pym J: A two-year, three-institution experience with the Medtronic Octopus: systematic off-pump surgery. *Ann Thorac Surg* 1999;68:1478–1481.

[‡]Data from Iacò AL, Contini M, Teodori G, et al: Off or on bypass: what is the safety threshold? *Ann Thorac Surg* 1999;68:1486–1489.

[§]Data from Turner WF: “Off-pump” coronary artery bypass grafting: the first one hundred cases of the Rose City experience. *Ann Thorac Surg* 1999;68:1482–1485.

^{||}Data from Kwon K, Jenkins D, Firpo R, et al: Complete myocardial revascularization on the beating heart. *Am J Surg* 1999;178:501–504.

[¶]STS data did not distinguish on-pump from off-pump cases. Total sample size of the United States 1997 coronary artery bypass-only patients was approximately 175,000 persons.

numerous studies, prospective randomized trials have not been performed. Nonstatistical analysis shows that fewer vessels are being bypassed and that postoperative neurologic complications, transfusion requirements, and recovery periods are all appreciably reduced (Table 2).^{20–24} Preliminary reports on long-term graft patency are encouraging,^{5,25} but accurate outcome data will require more experience with the procedure and follow-up of longer terms.

DISADVANTAGES

A major disadvantage of OPCAB surgery is that the technique is technically more difficult for both the surgeon and anesthesiologist, and there is a learning curve on the part of both physicians. In addition, the surgery requires a paradigm shift away from the idea of a more controlled period during the vessel anasto-

moses to one in which the operation becomes more uncertain and dynamic.

Performance of the distal anastomoses on a beating heart must be done quickly and efficiently because the blood supply to that part of the myocardium is being temporarily interrupted. The anesthesiologist must often give large doses of inotropic agents to support the patient during this period. Excellent communication among all the members of the surgical team is essential.

The perfusionist needs to be readily available, yet CPB is infrequently used. However, when CPB is needed, it is most often on an urgent basis, frequently when the patient is hemodynamically unstable.

Also, because the distal anastomoses are performed under increased time pressure, some investigators are concerned that the graft quality may be impaired.²⁶ Lastly, there is concern that the improved hemostasis

in OPCAB is associated with increased procoagulant activity, which may put the patient at increased risk for postoperative thrombotic graft occlusion and pulmonary embolism.²⁷

INDICATIONS

Indications for OPCAB surgery vary widely among various programs. Whereas low-risk patients might be selected in some programs, it is clear that the greatest benefit of OPCAB surgery may be in those of the highest risk and in elderly patients.⁸ Surgeons often choose standard (ie, on-pump) bypass for patients who are hemodynamically unstable or who require reoperation or extensive revascularization.

SURGICAL PROCEDURE

Before entering the operating room, the patient is sedated, and if necessary, actively warmed by using a forced-air warming blanket. Unlike in traditional coronary artery bypass surgery, maintenance of normothermia throughout the procedure is essential, because it allows for early extubation. Access to the central circulation is obtained. Placement of a pulmonary artery catheter is usually warranted. Even in patients with good ventricular function, intraoperative cardiac output measurements may be indispensable, especially during the performance of the distal anastomoses.

Induction and maintenance of anesthesia are performed with an emphasis on cardiovascular stability, flexibility, and rapid reversibility. While saphenous vein (or other vessel) is being harvested, the heart is approached by using a median sternotomy incision. The left internal mammary artery is taken down, and dissection is carried out to optimize exposure. Deep pericardial retraction sutures are placed so the heart may later be positioned for placement of the distal anastomoses. Heparin is administered to keep the activated clotting time greater than approximately twice the baseline time.

For traditional coronary artery bypass surgery, at this point the surgeon would be preparing the patient to go on CPB and cardioplegic arrest. With CPB, a large arterial cannula is placed into the ascending aorta, followed by venous cannulation, usually via the right atrium. The patient is placed on the bypass machine, which consists of roller pumps, an oxygenator, heat exchanger, and various perfusion and suction cannulae. The surgeon then applies the aortic cross-clamp, which allows delivery of potassium-rich cardioplegia solution, to induce cardiac standstill. Revascularization is performed on the arrested heart.

For OPCAB surgery, however, the heart remains beating, and at this point the surgeon selects the site for

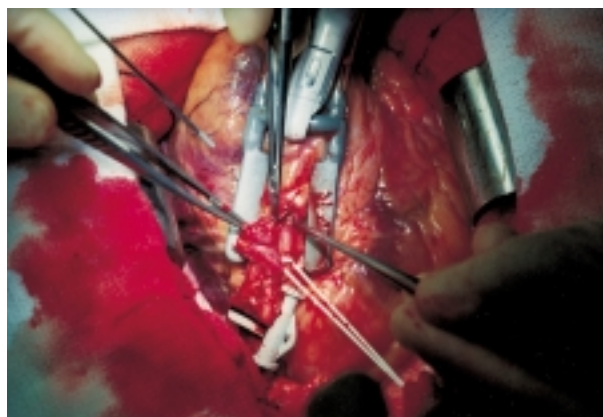


Figure 1. Anastomosis between the left internal mammary artery and the left anterior descending artery. Orientation is from the anesthesiologist's view. The siliconized rubber tape is occluding the artery proximal to the operative site. The epicardial-wall stabilizer is straddling the target vessel.

the first distal anastomosis. A siliconized rubber tape is placed around the vessel to produce atraumatic proximal coronary occlusion. If this is reasonably well tolerated, the surgeon then places the epicardial-wall stabilizing device, a key component of the OPCAB procedure. Although a number of devices have been developed over time, most systems in current use have either a rigid or malleable arm for positioning and a heart-stabilizing portion, or footplate, which is applied directly to the epicardium.²⁸ The footplate is placed straddling and parallel to the target vessel (**Figure 1**). This provides a small, relatively immobile area for the anastomosis, while also allowing the remainder of the heart to contract. With the stabilizing device well positioned, the surgeon incises the target vessel and performs the distal anastomosis under magnification by using 7-0 suture.

Once the coronary artery is occluded, the stabilizing device in place, and the target coronary artery opened, there is no "turning back." These manipulations may be relatively well tolerated, or alternatively, they may lead to progressively worsening ischemia, cardiac failure, and ultimately, cardiac arrest. This is clearly the most demanding part of the procedure for the anesthesiologist, who must aggressively maintain hemodynamic stability, often by using inotropic agents such as phenylephrine, norepinephrine, and epinephrine. Once the distal anastomosis is complete, the siliconized rubber tape is removed. After each distal anastomosis, coronary flow is restored, and the heart is allowed to recover.

In general, each of the distal anastomoses is completed before proceeding further. For most surgeons, the left anterior descending artery is bypassed first—

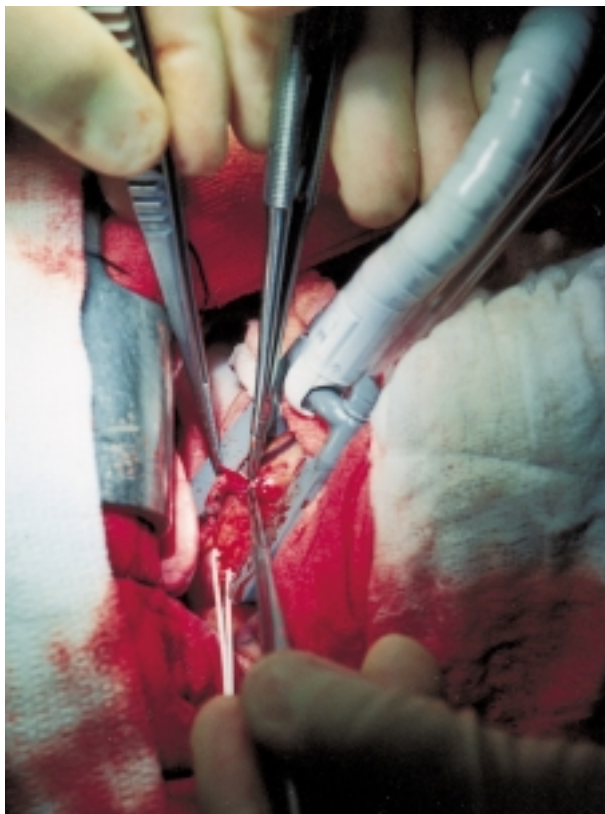


Figure 2. The heart is retracted out of the chest to perform the distal anastomosis to the obtuse marginal branch of the circumflex artery. A saphenous vein graft is used for this bypass. Most of the heart is covered by a moistened gauze at right.

often with the left internal mammary artery used as a pedicle graft—because of its location and importance. This allows immediate revascularization to the anterior wall, which theoretically should help the heart tolerate further manipulation. After completion of all distal anastomoses, a partially occluding clamp is applied to the ascending aorta, and the proximal anastomoses are created. All proximal anastomoses are created at one time to obviate the need for multiple aortic clampings, thus reducing the risk of embolic events.

For certain distal target sites (eg, posterior descending artery, obtuse marginal branches) deep pericardial retraction sutures or a sling are used to retract the heart into an optimal position for the surgical approach (**Figure 2**). As might be expected, retracting the heart out of the chest vastly alters hemodynamics and makes anesthetic management particularly challenging. During this period, the patient is placed in steep Trendelenburg's position, which has been shown to increase ventricular preload and to restore cardiac output to some extent, increasing both blood pressure and coronary blood



Figure 3. This patient was extubated in the operating room and is shown here about an hour after completion of off-pump coronary artery bypass surgery.

flow.²⁹ Nonetheless, if the manipulations to access these difficult distal sites are not tolerated, the surgical team must be ready to immediately convert to CPB.

After completion of all anastomoses, in traditional surgery, the patient would be “weaned” from CPB. Once the patient is stable, the surgeon would then remove the cannulae and repair the puncture sites. With either procedure, once the heart is reperfused with the bypass grafts, the heparin is reversed, hemostasis is assured, and the chest is closed.

To be eligible for extubation in the operating room or shortly thereafter, the OPCAB patient must be awake, relatively normothermic, nonacidotic, and adequately ventilating. In the immediate postoperative period, patients may be somewhat restless and have less than optimal oxygenation. This resolves over a short period of time (**Figure 3**).

A key to early extubation is adequate postoperative analgesia. Ketorolac (Toradol) is routinely given, and intravenous opioids are titrated to effect, often with the use of patient-controlled analgesia. Some clinicians routinely administer intrathecal opioids (eg, spinal morphine) or perform parasternal intercostal nerve blocks. Others combine a general anesthetic with thoracic epidural anesthesia and give epidural bupivacaine and morphine postoperatively.³⁰

Most OPCAB patients are ready to sit up and visit with family a few hours after the procedure. They are often able to transfer to a step-down unit within 12 hours and are ambulating within 1 or 2 days. Most patients are discharged on postoperative day 4 or 5.

SUMMARY

OPCAB surgery is a significant advance in the

operative treatment of coronary artery disease. CPB is avoided, multiple vessels may be bypassed, and most patients have a fairly rapid recovery. As both surgical and anesthetic experience with OPCAB surgery increases, further refinements will be made that will enhance the safety and efficacy of this new procedure. HP

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