Coronary Artery Bypass Graft Surgery Without Cardiopulmonary Bypass: A Review and Nursing Implications

Barbara T. Lorenz, MS, ARNP-CS, CCRN
Kathleen M. Coyte, RN, MSN, CCNS, CCRN

Majority of the literature credits Kolessov,1 from the former Soviet Union, with performing the initial off-bypass surgery in 1964, when he reported his experience in anastomosing the internal mammary artery to the left anterior descending artery on a beating heart. Later in the United States, Favaloro2 (in 1968) and Garrett et al3 (in 1973) presented their experiences with the use of saphenous vein grafts as additional conduits.

Despite these favorable initial results in the surgical treatment of coronary artery disease, the introduction and refinement of cardiopulmonary bypass (CPB, also referred to as the “heart-lung machine”) in the 1960s offered a more widely acceptable alternative to coronary revascularization. The CPB machine and cardioplegic arrest provided surgeons with a motionless target and a bloodless environment in which to accomplish a safe operation. Graft patency rates after this type of surgery are excellent. This preferred practice dominated cardiac surgery for more than 2 decades.

Initial reports described success with minimally invasive direct coronary artery bypass graft (CABG) surgery in which the left internal mammary artery was used to bypass the left anterior descending artery via a small anterior thoracotomy. Since then, rapid developments in surgical techniques enabled off-pump surgery to be performed through a median sternotomy for patients with multivessel coronary artery disease. The off-bypass technique has regained popularity as cardiac surgeons attempt to decrease the risks of surgical revascularization by eliminating the adverse effects of CPB. In this article, we provide an overview of the adverse effects of CPB, a review of the literature in which the outcomes of on- and off-bypass procedures are compared, and a discussion of nursing implications related to this emerging practice trend.
ADVERSE EFFECTS OF CPB

The wide attention given to performing myocardial revascularization without CPB can reasonably be attributed to the well-known and documented adverse effects of using the heart-lung machine. A variety of adverse effects contribute to postoperative morbidity and mortality (Table 1).

Coronary vessels can be diffusely damaged because CPB causes formation of emboli, which can be minimized but not completely controlled by filtration. The prevalence of stroke is 1% to 5%; most strokes are caused by emboli that occur during cannulation, surgical handling of the aorta, microemboli, or hypothermia.3,5 The risk of neurological impairment due to these causes is directly related to the duration of extracorporeal circulation.6 Other than stroke, manifestations of cerebral dysfunction include lessened ability to concentrate, disorientation, agitation, and confusion.7 Roach et al7 described adverse cerebral outcomes in 6.1% of patients undergoing CPB; these outcomes were defined as cerebral injury, nonfatal stroke, transient ischemic attack, stupor, or seizures. Predictors of neurological problems after CPB included age greater than 70 years, history of pulmonary disease, systemic hypertension, and perioperative hypotension or hypertension.7

Reports of research related to other blood-mediated problems emphasize bleeding complications and mediated responses. Substances altered during CPB include epinephrine, norepinephrine, renin, angiotensin II, vasopressin, aldosterone, bradykinin, glucagon, triiodothyronine, thyroxine, calcium, magnesium, and potassium.4 These circulating molecules can affect blood pressure, cardiac output, renal function, gastrointestinal tract function, pulmonary capillary permeability, and interstitial edema.4 Catecholamine release and vasoconstriction due to hypothermia can lead to a hypertensive period postoperatively.8

Bleeding complications related to CPB include destruction of platelets and red blood cells8 directly related to the continuous interface of blood with the circuitry of the CPB machine, as well as thrombocytopenia caused by platelet aggregation9 and remaining platelet dysfunction. Systemic heparinization and inadequate heparin reversal can also promote bleeding in the postoperative period.8 Air embolism is an adverse effect in 0.1% to 0.2% of patients.4

Complement activation, also caused by contact with pump surfaces, has been linked to activation of leukocytes, which cause capillary leakage and organ failure.9 Tonz et al9 studied 38 patients before, during, and after CPB and found activation of neutrophils and postoperative pulmonary impairment including decreased respiratory index, decreased alveolar-arterial oxygen gradient, and increased intrapulmonary shunt. In addition to neutrophil release, pulmonary dysfunction is linked to the inflammatory response through a decrease in release of surfactant and complement, which also leads to interstitial edema, increased capillary permeability, atelectasis, and impaired pulmonary compliance.10

Other adverse effects of CPB include the release of tumor-necrosis factor-α. Brasil et al10 found higher blood levels of this factor in patients undergoing CPB than in patients who did not undergo CPB. Those researchers10 suspected that tumor-necrosis factor-α was the cause of fever.

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**Table 1** Summary of selected adverse effects of cardiopulmonary bypass4-11

<table>
<thead>
<tr>
<th>Cause</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemodilution</td>
<td>Fluid retention, interstitial fluid</td>
</tr>
<tr>
<td>Neutrophil activation, decrease in surfactant</td>
<td>accumulation, Pulmonary dysfunction</td>
</tr>
<tr>
<td>Platelet destruction by cardiopulmonary bypass, platelet aggregation</td>
<td>Thrombocytopenia</td>
</tr>
<tr>
<td>Destruction by cardiopulmonary bypass circuits</td>
<td>Hemoglobinemia</td>
</tr>
<tr>
<td>Embolus formation, bypass &gt; 2 hours</td>
<td>Stroke, neurological dysfunction</td>
</tr>
<tr>
<td>Cannulation, bubble oxygenator</td>
<td>Air emboli</td>
</tr>
<tr>
<td>Cannulation of femoral artery</td>
<td>Aortic dissection</td>
</tr>
<tr>
<td>Release of catecholamines (epinephrine, norepinephrine) due to hypothermia</td>
<td>Hypertension</td>
</tr>
<tr>
<td>Release of tumor necrosis factor-α</td>
<td>Hypotension, tachycardia</td>
</tr>
<tr>
<td>Diuresis</td>
<td>Hypokalemia</td>
</tr>
<tr>
<td>Hypothermia</td>
<td>Myocardial depression</td>
</tr>
<tr>
<td>Glucagon release</td>
<td>Hyperglycemia</td>
</tr>
<tr>
<td>Systemic heparinization</td>
<td>Bleeding</td>
</tr>
<tr>
<td>Leukocyte release</td>
<td>Capillary leakage</td>
</tr>
<tr>
<td>Leukocyte release, microemboli</td>
<td>Organ failure</td>
</tr>
<tr>
<td>Renin-angiotensin activation, vasopressin release, hypothermia</td>
<td>Oliguria</td>
</tr>
</tbody>
</table>
tachycardia, hypotension, need for inotropic drugs, increased postoperative bleeding, and longer intubation time in patients who had undergone CPB. A postperfusion syndrome linked to contact of blood with the pump circuits causes this element and other elements of a systemic inflammatory response, which is manifested further by leukocytosis, increased vascular permeability, decreased systemic vascular resistance, metabolic acidosis, hemococoncentration, and signs and symptoms of circulatory shock. In this and other research, potential for complications increased when CPB time was more than 2 hours, and effects worsened if bypass was 3 to 4 hours in duration.11

COMPARISON OF OUTCOMES FOR ON-PUMP VERSUS OFF-PUMP CABG SURGERY

Large, prospective randomized trials comparing clinical outcomes of patients who underwent CABG surgery with and without CPB are not available in the literature because this technique has been used only recently in patients with coronary artery disease. However, various international surgical groups have reported their experience (Table 2).

The number of cases that each surgeon or group reported in the studies varied greatly depending on the researchers’ years of experience with the off-pump technique. Some researchers12-14,16,18 described only their off-pump experience, whereas others retrospectively compared off-pump results with on-pump results13,15,19,20 or with information in the Society of Thoracic Surgeons cardiac surgery database. In the studies that compared on-pump data with off-pump data, mortality figures generally did not differ significantly between the 2 groups. However, in several studies, researchers noted a decreased mortality in select populations of patients, such as patients with left ventricular dysfunction,14 advanced age (>70 years),12 and when groups were adjusted for risk.15 Arom et al10 (in 2000) retrospectively compared operative mortality, postoperative complications, and longitudinal outcomes between the 350 off-pump CABG surgeries and the 3171 on-pump CABG surgeries they had performed. The overall comparison of immediate outcomes between the groups and among individual risk groups (low, medium, and high) revealed similar patterns for operative variables and postoperative complications. However, in the high-risk group, operative mortality differed significantly (P=.008) between the on-pump cases (28.5%) and the off-pump cases (7.7%).

Commonly reported complications after CABG (eg, pulmonary or cardiac compromise, arrhythmias, and neurological events) occur at comparable rates or with decreased frequency when off-pump surgery is used rather than on-pump surgery.13,16 Calafiore et al16 and Boyd et al19 reported a statistically significant decrease in postoperative requirements for mechanical ventilation in the off-pump group. Buffolo et al13 also reported significantly lower overall frequency of pulmonary complications among patients who had off-pump surgery than among patients who had on-pump surgery.

The prevalence of stroke occurring after off-bypass surgery was similar to the prevalence after on-bypass surgery.5,13,19 A lower prevalence of stroke after off-pump surgery than after on-pump surgery occurred most often among high-risk patients.13,15 The more subtle neurological findings that affect cognitive function are more difficult, time-consuming, and costly to evaluate. However, our subjective experience suggests that off-bypass surgery patients are more alert than are on-bypass patients in the immediate postoperative recovery period, typically the first 48 hours, and then become similar in mentation to on-bypass patients several days further into recovery.

In many studies,13,17,19,20 the prevalence of atrial fibrillation was significantly lower in off-bypass patients than in on-bypass patients. Some researchers report no significant difference between groups in the prevalence of atrial dysrhythmias;5,18 however, when atrial dysrhythmias were present, both overall length of stay in the hospital and cost of surgery increased.5,13,19

Vasopressive and inotropic agents to maintain adequate hemodynamic parameters are not needed as often in the off-bypass surgeries as in the on-bypass surgeries, unless patients have other comorbid conditions such as severe left ventricular dysfunction.5,19 These findings may be partially due to the lack of nonpulsatile flow during surgery. However, intraoperative and postoperative hypothermia can occur with off-pump CABG (because blood cannot be warmed extracorporeally) and may negate these benefits. Support with an intra-
Aortic balloon pump was required less in the off-bypass groups than in the on-bypass groups; the greatest differences occurred in high-risk patients.5,15

A late unfavorable outcome for off-pump CABG noted in the literature is the early return of anginal symptoms (within 1 year of surgery). Moshkovitz et al14 reported a rate of 7.7% for return of anginal symptoms within 1 year, which was higher than the previously reported rate of 5%. Arom et al20 compared follow-up data between the on- and off-bypass groups for patients whose overall general states of health were similar. At 1 year after surgery, the off-bypass group reported significantly higher frequencies of angina, chest pain, and chest tightness than did the on-pump group (40% vs 21%, P<.001). Readmission rates for angina were also higher for the off-pump group than for the on-pump group (24% vs 9%, P<.001). These findings could be attributed to the different degrees of revascularization: more distal anastomoses occurred in the on-bypass group (3.2 grafts/patient) than in the off-bypass group (2.1 grafts/patient).

<table>
<thead>
<tr>
<th>Reference, year</th>
<th>N</th>
<th>Mortality, %</th>
<th>Morbidity</th>
<th>Mean No. of grafts per patient</th>
<th>Angiographic differences: on vs off pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benetti et al., 1991</td>
<td>700 off</td>
<td>1</td>
<td>4%</td>
<td>2.2</td>
<td>None at 1 month</td>
</tr>
<tr>
<td>Buffolo et al., 1996</td>
<td>1274 off</td>
<td>2.50</td>
<td>Decreased: arrhythmias, pulmonary, neurological complications</td>
<td>1.7</td>
<td>No difference</td>
</tr>
<tr>
<td>Moshkovitz et al., 1995</td>
<td>220 off</td>
<td>3.20</td>
<td>Myocardial infarction (2.7%), cerebrovascular accident (0.4%), infection (1.4%)</td>
<td>1.9 (22% to obtuse marginal branches)</td>
<td>NR</td>
</tr>
<tr>
<td>Bergsland et al., 1997</td>
<td>172 off, 1829 on</td>
<td>2.8, NS</td>
<td>On-pump: increased complications overall</td>
<td>3.39 on, 1.42 off</td>
<td>NR</td>
</tr>
<tr>
<td>Calafiore et al., 1998</td>
<td>280 off</td>
<td>2, NS</td>
<td>Decreased: pulmonary and bleeding complications</td>
<td>NR</td>
<td>None, including obtuse marginal grafts</td>
</tr>
<tr>
<td>Puskas et al., 1998</td>
<td>51 off, 245 on</td>
<td>0 off, 1.6 on</td>
<td>Decreased: need for balloon pump or inotropic support</td>
<td>On &gt; off</td>
<td>Off: 95.3% patency</td>
</tr>
<tr>
<td>Turner, 1999</td>
<td>100 off, 160 on</td>
<td>3, NS</td>
<td>NR</td>
<td>1.9 off, 3.0 on</td>
<td>NR</td>
</tr>
<tr>
<td>Cartier, 1999</td>
<td>275 off</td>
<td>1.10</td>
<td>Myocardial infarction (4%), atrial fibrillation (30%), stroke (0.7%), pulmonary complications (9.5%), infection (4.4%)</td>
<td>2.91</td>
<td>95% patency in 34 grafts studied</td>
</tr>
<tr>
<td>Boyd et al., 1999</td>
<td>30 off, 60 on</td>
<td>NS</td>
<td>Decreased: atrial fibrillation, low cardiac output syndrome</td>
<td>NR</td>
<td>100% patency in off-pump group</td>
</tr>
<tr>
<td>Arom et al., 2000</td>
<td>350 off, 3171 on</td>
<td>3.4, NS</td>
<td>Decreased: atrial fibrillation</td>
<td>2.1 off, 3.2 on</td>
<td>NR</td>
</tr>
</tbody>
</table>

NR indicates not reported; NS, not significant.
Most studies report fewer grafts per patient in the off-pump population, 1.42 to 2.91 grafts versus 3.0 to 3.39 grafts per patient in the on-pump group. These statistics have spawned much debate in the literature over the completeness of revascularization that can be achieved with off-pump CABG surgery. Technical difficulties have been reported in attempts to provide optimal visualization of the lateral aspect of the heart where the circumflex branches generally supply coronary blood flow. In earlier studies, Buffolo et al reported performing bypass grafts to circumflex branches with on-pump support. As experience was gained and off-pump techniques were perfected, later researchers such as Calafiore et al reported a global patency rate of 96% for 60 grafts to circumflex branches. Cartier, as well, cited the ability to provide complete revascularization in 93% of off-pump cases, with 73% of the cases including a bypass graft to circumflex branches.

One measure of the success of CABG surgery is graft patency rates. The patency of grafts at
various intervals after surgery has been compared in several studies, and no angiographic difference between the on- and off-pump groups has been reported.

Most of these angiograms were obtained before patients were discharged from the hospital as a measurement of early graft failure from technically difficult anastomosis. Long-term graft patency, however, cannot be determined until as many years of data are available for off-pump techniques as have been published for the on-pump technique. In addition, routine angiography after CABG surgery is difficult to support from an economic and logistical standpoint in any institution. Prospective randomized trials are needed to substantiate the long-term results for graft patency after off-pump surgery.

Economic advantages of off-pump surgery include overall decreased length of stay in the hospital and cost savings. The measured range of hospital days saved, as reported in these studies, was 1.4 to 4.4 days. Costs per case were estimated to be reduced by 30% in 2 studies and quantified at $3000 (US currency) by Buffolo and $1082 (Canadian currency) by Boyd. These cost reductions have been attributed to decreased costs associated with operating room supplies, beds in the intensive care unit, and length of stay in the hospital.

The most obvious short- and long-term benefit of the off-bypass technique is the decrease in hemolysis and platelet dysfunction induced by CPB. These findings are evidenced by several studies that show decreased operative blood loss and decreased need for postoperative transfusions of blood and blood products, thereby reducing patients’ risk for transfusion-related complications.

**IMPLICATIONS FOR NURSING PRACTICE**

The nursing care of patients after CABG surgery has responded to the evolution of cardiac surgery techniques as more patients have the surgery without the use of CPB. Nursing support is essential to complete the successful transition, in any institution, from on-pump to off-pump surgery. Because only a few cardiac surgery centers are performing off-pump surgery, the literature is incomplete in addressing the unique nursing perspective. Areas of concern for nurses include but are not exclusive to education of patients and staff, perioperative instrumentation, postoperative recovery, and discharge planning. The following discussion is experiential and anecdotal,
because these are not thoroughly addressed in the nursing literature.

Nurse educators, managers, and advanced practice nurses involved in the early stages of initiating an off-bypass program are best suited to anticipate potential changes in patients’ care. Staff education is the foundation of a successful overall transition to the off-bypass technique. The acceptance of this surgical approach will be the motivational force behind adaptation to the change in surgical philosophy. This adaptation can best be accomplished via small staff education programs and incorporation of off-bypass surgery concepts into training programs for critical care nurses.

Nurses play key roles in communication with and education of patients and patients’ families about this complex procedure, for example, providing preoperative counseling to patients and getting patients’ consent for the procedure. Before and while providing informed consent, patients need to understand and be able to differentiate their surgery from the various surgical techniques available. We have found that patients are increasingly becoming cognizant of off-pump and minimally invasive, direct CABG surgeries. More and more patients ask direct questions related to these techniques because they have gathered information from the Internet or through community networking.

Practitioners must have the knowledge to define each surgical technique and describe the benefits and risks. Patients in need of valve repair or replacement must understand that cardiopulmonary bypass is still required for this operation. Because of the different types of incisions used, patients must understand the intended technique and be aware, for example, that if vessels cannot be visualized when a thoracotomy approach is used, then a median sternotomy incision may be made. Additionally, even if a median sternotomy approach is used initially, some coronary branches may not be adequately visualized or stabilized. In such instances, conversion to CPB may ultimately be required to achieve a satisfactory distal anastomosis.

Materials for education of patients should include information about the different surgical techniques and what to expect during the immediate postoperative period in the surgical intensive care unit.
When off-bypass procedures are used, many changes are apparent in the operating room suite. In most studies, operative times were significantly decreased with off-bypass surgery; Arom et al\(^\text{20}\) cited a decrease of more than 1 hour in time spent in the operating room. Changes in instruments used during surgery, such as stabilizers, rings, and carbon dioxide blowers, will be continual until each surgeon has found the exact instruments that comfortably allow optimal visualization of all target vessels, especially the lateral territories of the left ventricle. Introduction of these new instruments has created opportunities for operating room nurses to have direct input and coordination into manufacturers’ designs of surgical products.

The steep initial learning curve for surgeons and other members of the operating team with transition to off-pump surgery may produce tense moments requiring patience and support from all members. The role of CPB technicians is de-emphasized in this environment; however, these technicians may be urgently relied upon to stabilize a situation when CPB is required unexpectedly. Published articles have listed reasons for conversion to CPB such as poor visualization of circumflex territories or hemodynamic instability, but no specific percentage of patients who met these criteria was noted. In a more recent study by Cartier\(^\text{18}\) in 1999, only 1 (0.4%) of 275 patients required conversion to CPB subsequent to the dissection of a preaneurysmal aorta. Hypothermia can be a problem when the blood cannot be warmed by extracorporeal methods. Redesigning external warming blankets can minimize this problem; applying blankets to the lower extremity when vein harvesting is completed and using head warmers throughout the procedure can be helpful. This warming process should continue during recovery in the surgical intensive care unit.

Discharge planning, as with any hospital procedure, should begin at admission or sooner in the outpatient setting, if possible. Knowledge of the population of patients, including the typical length of stay and postoperative routines, will aid nurses in counseling patients preoperatively on what to expect. Changes in surgical
technique, especially the midthoracotomy approach, may decrease hospital stays.22 For patients undergoing CABG surgery without the use of the CPB machine, the mean overall reduction in length of hospital stay was 2.5 days.5,13,16,19,20 Preparing patients for this eventuality in the preoperative period will ease the transition to home. Repetition of teaching that was started preoperatively will improve patients’ ability to recover successfully at home.23 Reinforcement of wound care, avoidance of respiratory complications, and activity progression and restrictions continue throughout the postoperative course. Discharge planning, by necessity, begins with the preoperative description of postoperative care with the patient and his or her family and caregivers. Reluctance among patients and their family members for early discharge may reflect inadequate preoperative and discharge instructions or unmet needs for social support. Provision of a cardiac rehabilitation specialist, dietician, pharmacist, and social worker available for specific home-care concerns or needs may lessen these anxieties.

CONCLUSION

Part of the surgical community continues to view off-bypass surgical techniques with cautious optimism. In an editorial, Ullyot24 describes the general reluctance to abandon current CPB technology. Many think that the use of the heart-lung machine is integral to the well-established reproducibility and beneficial long-term results of surgical revascularization. They are hesitant to abandon CPB for the sake of cost containment and yet-to-be-proven comparable long-term outcomes. As with any new surgical procedure, a certain degree of trepidation will be evident among nursing staff when the surgical team begins to use off-pump cardiac surgery with increasing frequency. In time, however, as off-bypass surgery becomes more common, trends will begin to emerge concerning the usual postoperative hemodynamics, blood use, and so on along with the related nursing care.

CPB, although by no means a therapy of the past, has risks that seem to be minimized by using off-pump CABG surgery. However,
the risks that are minimized are still overshadowed by concerns about off-bypass surgery, such as the completeness of surgical revascularization, graft patency, criteria for selection of patients, and the steep operative learning curve in the early stages of program development.

More recent studies report favorable outcomes for patients, but sample sizes were small; further investigation is needed to substantiate these findings. Generalizability of this technique will be proved by prospective randomized trials at multicenter sites. In the future, off-bypass surgery may remain a technique for cardiac surgeons to reduce morbidity and mortality and may develop into a more acceptable conventional trend.

References
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Crit Care Nurse 2002;22 51-60
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