Would You Like Some Cardiopulmonary Bypass With Your Coronary Revascularization?

John D. Puskas, MD; Mark Steele, CCP, CCT

In an effort to reduce morbidity and mortality attributable to cardiopulmonary bypass (CPB), US surgeons performed <20% of all coronary artery bypass (CAB) operations off-pump, without the use of CPB, in 2006. These surgeons were guided by several retrospective reviews of large databases that have shown off-pump CAB (OPCAB) is associated with lower risk-adjusted morbidity and mortality than coronary artery bypass grafting (CABG) on CPB (ONCAB). In 2004, the Society of Thoracic Surgeons, National Adult Cardiac Database added a data field to record intraoperative conversions, which permits the comparison of outcomes after OPCAB and ONCAB by intention-to-treat. In the first subsequent analysis of the Society of Thoracic Surgeons National Adult Cardiac Database, preoperative risk factors and postoperative outcomes were analyzed for 42,477 consecutive patients who underwent non-emergent, isolated, primary CAB surgery from January 1, 2004, through December 31, 2005. OPCAB was associated with a significantly reduced risk-adjusted incidence of death (odds ratio [OR], 0.83; \(P=0.03\)), stroke (OR, 0.65; \(P<0.001\)), myocardial infarction (OR, 0.67; \(P<0.001\)), major adverse cardiac events (OR, 0.71; \(P<0.001\)), renal failure (OR, 0.74; \(P<0.001\)), new dialysis (OR, 0.63; \(P<0.001\)), deep sternal wound infection (OR, 0.67; \(P=0.04\)), reoperation (OR, 0.86; \(P=0.004\)), atrial fibrillation (OR, 0.88; \(P<0.001\)), prolonged ventilation (OR, 0.75; \(P<0.001\)), and prolonged length of stay (OR, 0.70; \(P<0.001\)) compared with ONCAB. A recent retrospective review of risk factors and clinical outcomes for 11,413 consecutive patients who underwent isolated CABG between January 1, 1997, and May 31, 2005, at Emory University found that OPCAB particularly benefited female patients. Among women, OPCAB was associated with a significant reduction in death (OR, 0.39; \(P=0.001\)), stroke (OR, 0.43; \(P=0.002\)), and major adverse cardiac events (OR, 0.43; \(P<0.001\)) compared with ONCAB.

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Prospective, randomized trials and meta-analysis have also demonstrated improved early outcomes after OP-CAB compared with CPB on CPB. One of the benefits of the recent resurgence of interest in off-pump bypass has been renewed interest and investment in improvements to CPB technology after 25 years of relative technological stagnation. Mini-extracorporeal circulation (MECC) is a small-prime, heparin-bonded CPB circuit that incorporates a centrifugal pump and membrane oxygenator but does not include either an open venous reservoir or direct reinfusion of cardiomyocytic suction. Its design seeks to improve patient outcomes by minimizing the systemic inflammatory response to CPB and still provide the surgeon with an arrested heart on which to perform precise coronary anastomoses with relative ease. In this issue of Circulation, Dr Mazzei and his colleagues from Italy have contributed a prospective trial of 300 coronary surgery patients randomized to undergo isolated primary multivessel CABG performed either with CPB via the MECC mini-circuit or with complete avoidance of CPB via OPCAB techniques. The principal reported findings include serum levels of interleukin-6 (a marker of systemic inflammation) and creatine kinase, which were insignificantly lower in the OPCAB group compared with the MECC group. Peak serum levels of S-100 protein, thought to reflect cerebral injury, trended more strongly toward lower levels in the OPCAB group (\(P=0.058\)). In-hospital mortality, stroke, myocardial infarction, length of stay, and need for allogenic transfusion were similar between groups. During 1-year follow-up, overall survival and angina-free survival were similar between groups. Nuclear scanning showed perfusion defects in 9 OPCAB cases and 3 MECC cases (\(P=0.14\)). The authors concluded that MECC is associated with little pump-related systemic inflammation, and it may achieve the benefits of OPCAB and facilitate complete revascularization in cases where complex coronary anatomy may make OPCAB challenging.

Two interesting sets of questions are raised again by the analysis in the article by Mazzei et al. First, is OPCAB associated with a late price (ie, less complete or less durable revascularization) to pay for the early benefit of avoidance of morbidity and mortality associated with CPB? Second, is MECC such a significant improvement on conventional CPB technology that it meaningfully narrows the gap in early outcomes between conventional CABG on CPB and OPCAB?

As for the first question, the weight of randomized controlled trials and meta-analyses of randomized controlled trials have shown no difference in rates of recurrent angina or coronary re-intervention. A single-center randomized controlled trial that enrolled 200 unselected patients, randomly assigned to OPCAB versus ONCAB by an experienced surgeon, found significantly decreased cardiac enzyme...
release, transfusion requirement, and length of hospital stay in the OPCAB group. Completeness of revascularization was similar between groups (3.4±1.0 grafts/patient OPCAB versus 3.4±1.1 grafts/patient ONCAB; \( P=\text{ns} \)). At hospital discharge and at 1-year follow-up, graft patency rates determined by angiography were similar between groups for all conduits and coronary artery territories.

Nonetheless, this same question was raised by a recent report from the New York State Cardiac Surgery Reporting System. This propensity score analysis risk-matched patients who had OPCAB versus ONCAB in New York between 2001 and 2004. OPCAB patients had significantly lower inpatient/30-day mortality and suffered stroke and respiratory failure less frequently than ONCAB patients. OPCAB and ONCAB patients had similar 3-year survival, but OPCAB patients had higher rates of subsequent revascularization (hazard ratio [HR], 1.55; 95% confidence interval [CI], 1.33 to 1.80). The authors concluded that OPCAB is associated with lower in-hospital mortality and complication rates than ONCAB, but long-term outcomes are comparable, except for freedom from revascularization, which favors on-pump CABG. The authors were unable to determine the extent to which the higher repeat-revascularization rate was related to lower graft patency versus a higher incomplete-revascularization rate during the index procedure. They and others have recognized the importance of surgeon experience and expertise in comparison patient outcomes between alternative surgical procedures. All operations in the present study were performed by a single surgeon. The operating surgeon is described as having been “trained” in both off-pump bypass and the use of the MECC system. No information is given as to the level of experience or expertise of this surgeon with these techniques. It is well known that MECC is a relatively minor modification of the conventional CPB circuit from the point of view of the surgeon, and OPCAB is a radically different operation compared with conventional coronary bypass performed on the arrested heart. In a prior randomized study of off-pump versus conventional multivessel coronary bypass, a surgical team inexperienced in off-pump techniques reported a 10% absolute decrement in graft patency after off-pump compared with on-pump bypass. More experienced practitioners have accomplished equivalent patency rates between off-pump and on-pump surgery in other randomized trials.

Numerous authors have documented a long learning curve for off-pump bypass, which should ideally proceed in a logical fashion from simpler to more complex and demanding cases. With such a logical progression, the OPCAB learning curve may be negotiated with excellent patient safety. However, if the appropriate progression from simple to complex bypass cases is forcibly abbreviated by the demands of a randomization protocol, draft patency and patient outcomes may suffer. Dr Mazzei and his coauthors comment that OPCAB can be technically demanding particularly when marginal branches need to be revascularized. The authors comment that “complete revascularization may be not achievable off-pump in all individuals owing to the complex anatomy of coronary lesions and the possibility of hemodynamic instability while the beating heart is being manipulated.” This, in combination with the report that 6 patients required emergency conversion to CPB, may suggest that the operating surgeon was not entirely comfortable with beating heart techniques.

Nonetheless, the MECC system likely represents a meaningful step forward because it combines several previous innovations in perfusion technology, namely centrifugal pumping, heparin-bonded tubing, cardiotomy sequestration, and elimination of an open venous reservoir. Each of these has been compared favorably to its predecessor technologies. In particular, cardiotomy sequestration (ie, avoidance of direct reinfusion of shed blood from the pericardial space into the CPB circuit) has been shown to significantly limit thrombin generation, platelet activation, and systemic inflammation associated with CPB.

This effect is accomplished by suction of shed blood into a separate centrifugal cell washing system before reinfusion, a technique limited to relatively small volumes of shed blood because only packed red cells are returned to the patient and all other blood components are lost. Another purported benefit of MECC is smaller priming volumes, which result in a lesser degree of hemodilution. However, the recent incorporation of reverse autologous prime techniques and/or vacuum-assisted venous drainage can address this issue for many cases and minimize hemodilution even with conventional bypass circuits.

The avoidance of a blood–air interface in the open venous reservoir system, which is integral to traditional CPB circuits, may further reduce the inflammatory response of CPB, but only incrementally so. The trade-off here, of course, is an increased risk of air embolism with a closed venous system. If large amounts of air are accidentally entrained into the venous line (as with an inadvertent tear or puncture of the right atrium during CPB), the arterial filter may be overwhelmed and air may be directly pumped into the systemic arterial system. The authors acknowledge the risk of air in their statement that “particular care must be taken to avoid air intake into the circuit, especially at the site of the right atrial pursestring suture and during connection of the venous cannula to the venous line.” It is doubtful to us that avoidance of a blood–air interface in the venous reservoir system diminishes the systemic inflammatory response associated with CPB circuits enough to warrant the theoretical and practical risk of air embolism in a no-reservoir system. Instead, a reverse autologous prime with a conventional open venous reservoir system and sequestration of cardiotomy suction may be an optimal CPB strategy to both minimize systemic inflammatory response and maximize patient safety. This has been our perfusion strategy in coronary bypass cases that are performed on CPB at Emory University.

Off-pump bypass seeks to improve patient outcomes after CAB surgery by elimination of the morbidity associated with CPB, global myocardial ischemia, aortic cannulation, and cardioplegic arrest. It is logical to believe that if complete revascularization can be precisely accomplished without the use of CPB, then this surgical approach should optimize patient outcomes. It is also logical to believe that any technology that reduces the morbidity of CPB itself will improve outcomes with the conventional arrested-heart operation. However, even a “perfect” CPB circuit will require aortic cannulation and cross-clamping to achieve global

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myocardial arrest. By comparison, off-pump bypass offers the opportunity to accomplish complete revascularization in many cases with a no-aortic-touch technique. This technique has been shown to be particularly beneficial to elderly patients and those with atherosclerosis of the ascending aorta.

Thus, it is unlikely that improvements in CPB will ever match outcomes achievable by complete avoidance of CPB. However, off-pump bypass can only deliver optimal results to patients if complete and precise revascularization can be achieved. The learning curve for this new operation is longer than for the conventional arrested-heart procedure and requires a modified set of skills and techniques. Numerous surgical groups around the world are reaching the conclusion that complete revascularization with multiple arterial grafts can be reliably achieved without CPB and often without aortic manipulation. Whenever feasible, this surgical strategy is most likely to yield excellent short- and long-term results for CAB patients.

**Disclosures**

Dr Puskas has received research grants and honoraria from Boston Scientific and Medtronic, and has served on the speakers’ bureau and as a consultant/advisory board member for Boston Scientific and Medtronic. Dr Steele reports no conflicts.

**References**


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