Review

Coronary artery bypass grafting on the beating heart: surgical revascularization for the next decade?

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This review considers whether coronary artery bypass grafting (CABG) performed on the beating heart (off-pump or OPCAB) will supersede conventional CABG utilizing cardiopulmonary bypass (CPB) and cardioplegic arrest as the accepted gold standard. Randomized controlled trials, case-matched reports and observational studies have demonstrated lower morbidity in off-pump compared to conventional on-pump CABG with equivalent mid-term outcome at a significantly lower cost. Patients referred for surgical revascularization are increasingly elderly with more co-morbid medical conditions and elimination of CPB-related morbidity in these groups is associated with the most pronounced improvements in outcome, at least in observational studies. Long-term outcome, and in particular, long-term graft patency following OPCAB has not yet been reported. A barrier to the more widespread acceptance of OPCAB is the poor provision for training in off-pump techniques although structured cardiothoracic training that includes OPCAB surgery has been shown to be both possible and safe for patients. The evidence available to date therefore strongly supports the assertion that OPCAB may become the new gold standard in surgical revascularization. Whether it will ultimately replace conventional CABG, however, is dependent on the results of long-term patency studies and the wider development of adequate training programmes.

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KEYWORDS
Cardiopulmonary bypass; Beating heart surgery; Coronary artery bypass grafting.

Introduction

Conventional coronary artery bypass grafting (CABG) utilizing cardiopulmonary bypass (CPB) and cardioplegic arrest has for many years represented the gold standard in coronary revascularization; however, this situation is now being challenged. Patients referred for CABG are older, have a higher incidence of co-morbid illnesses, greater severity of coronary artery disease, worse ventricular function, and more frequently require urgent or emergency procedures than compared with 10–20 years ago.1,2 Conventional CABG utilizing CPB in these high-risk groups is associated with high complication rates, substantially increased mortality and significantly increased costs.3 Coronary artery bypass grafts performed on the beating heart, without the use of CPB (off-pump or OPCAB) can achieve equivalent multi-vessel revascularization compared to conventional on-pump surgery, with a 25% reduction in cost and significantly better short-term outcome, particularly in high risk groups.4-7 Reduced morbidity and peri-operative costs, in turn, increase the
Inflammatory response

The chief advantage of OPCAB is the avoidance of the morbidity associated with CPB and cardioplegic arrest. 'Post-pump' or systemic inflammatory response syndrome (SIRS) results from a cascade of events generated by the contact of plasma proteases and blood cells with the gaseous interface and bioincompatible surfaces of the CPB machine. Activation of plasma proteases generates pro-inflammatory mediators that activate leukocytes, vascular endothelial cells, and platelets. The resulting platelet degranulation, neutrophil and monocyte activation result in a cytokine release syndrome and, in extreme cases, the generation of a systemic inflammatory response.\textsuperscript{9,10}

Activation of protease cascades

CPB associated complement activation occurs primarily via the alternative pathway\textsuperscript{11} with elevated levels of C5a detectable within 5 min of the commencement of CPB.\textsuperscript{12} In randomized trials of on- versus off-pump CABG,\textsuperscript{13,14} C3a and C5a levels are significantly elevated in on-pump patients and remain elevated for up to 4 h post-operatively.\textsuperscript{13,14} In addition to complement activation there is excessive activation of the haemostatic system. Direct activation of the contact system of proteins (kallikrein, kininogen) by the CPB circuit results in the generation of Factor Xla and activation of the intrinsic clotting cascade. This results in the uncontrolled generation of thrombin. Thrombin and activated contact proteases also promote fibrinolysis via the activation of tissue plasminogen activator. High levels of thrombin formation and fibrinolysis ultimately result in factor depletion and deranged haemostasis. This is further impaired by haemodilution with circuit prime, platelet dysfunction, and depletion.\textsuperscript{15} CPB directly activates circulating platelets as do thrombin and contact proteases, which then adhere to the circuit or activated endothelium and leukocytes. Platelet numbers are further depleted by mechanical disruption and adherence within the CPB circuit. In randomized trials of off- versus on-pump CABG, CPB is associated with a significant prolongation of both the pro-thrombin time (extrinsic and common pathway) and the activated partial thromboplastin time (intrinsic pathway) with lower serum fibrinogen levels and thromboelastogram index, compared to off-pump.\textsuperscript{6,16} Similarly in a prospective non-randomized cohort study, Casati et al.\textsuperscript{17} demonstrated significantly higher antithrombin and plasminogen concentrations and reduced D-dimer formation (fibrinolysis) in patients undergoing off- compared to on-pump CABG. Deranged haemostasis results in micro-haemorrhage and excessive post-operative bleeding.\textsuperscript{15} Randomized trials, matched cohort and retrospective studies\textsuperscript{4–6,14,16,18,19} consistently demonstrate reduced blood loss, re-operation for bleeding and requirements for allogenic blood products, in OPCAB than in on-pump patients.

Cellular response

The neutrophil is believed to be the main effector of the inflammatory response to CPB.\textsuperscript{10} Neutrophils migrate to sites of inflammation, transmigrate to the interstitium (via interaction between P-selectin on neutrophils and E-selectin on endothelial cells), and degranulate, releasing a variety of cytotoxic molecules such as elastase, myeloperoxidase, and free radicals.\textsuperscript{10} Significantly lower levels of circulating neutrophils, serum neutrophil elastase, E-selectin levels, endomyocardial and serum levels of P-selectin and ICAM-1 and measures of oxidative cellular injury (lipid hydroperoxides and protein carbonyls), are detected in off- than in on-pump surgery.\textsuperscript{13,14,20}

Cytokine release

Activated monocytes, tissue macrophages, platelets and endothelium produce numerous pro-inflammatory and anti-inflammatory cytokines with plasma concentrations peaking several hours after CPB.\textsuperscript{21} Serum IL-8 and TNFa levels correlate with acidosis, haemodynamic instability, and organ dysfunction following cardiac surgery.\textsuperscript{22–24} These cytokines mediate neutrophil chemotaxis and adhesion molecule expression, facilitating neutrophil and monocyte translocation and endothelial activation. IL-8 levels are significantly lower in patients undergoing OPCAB\textsuperscript{12–14,22} as are levels of TNFa\textsuperscript{20,25} and its receptors, p55 and p75.\textsuperscript{12,25} Greater pro-inflammatory cytokine responses following bypass are observed in the elderly,\textsuperscript{26} patients with poor left ventricular function,\textsuperscript{27} and those with high responder polymorphisms for the promoter regions of pro-inflammatory genes.\textsuperscript{28} These patients seem to derive the greatest benefit from OPCAB surgery.

Emboli

In addition to the systemic inflammatory response, coagulation pathways, destruction of blood cells, the wound and the CPB machine produce numerous emboli of fibrin, fat, platelet and platelet leukocyte aggregates, red cell debris, gas, foreign material and spalled particles. Although emboli larger than 40 \textmu m are removed by the arterial filter, the patients' body is showered by many emboli smaller than 40 \textmu m. As capillaries are only about 8–10 \textmu m in diameter, these emboli obstruct small, diffusely distributed vascular beds that supply small numbers of cells producing a widespread low level of cell necrosis.\textsuperscript{9,10} Together, the systemic inflammatory response and cell death result in capillary permeability, tissue oedema and organ dysfunction.\textsuperscript{29} The organs affected include the heart, kidneys, and brain.
Organ dysfunction

Myocardial injury

There is a general consensus from randomized trials and prospective non-randomized cohort studies and aortic cross clamping, which, despite even optimal myocardial protection, results in some form of ischaemia and reperfusion injury. Randomized studies demonstrate greater myocardial ischaemia, as measured by myocardial lactate and acidaemia, and tissue inflammation, as measured by increased myocardial lipid peroxidation, in on-pump versus off-pump CABG. On-pump surgery was associated with higher inotope requirements and post-operative arrhythmias compared to OPCAB. Regression analysis of the BHACAS-1 trial also identified CPB plus cardioplegic arrest as the only independent predictor of post-operative atrial fibrillation. In contrast, two similar randomized trials detected no difference in either atrial fibrillation or ionotropic requirements. However, the patients in these trials were younger, were less likely to have unstable angina, require urgent revascularization or have poor left ventricular function compared to the BHACAS studies.

Renal injury

The BHACAS-1 study, as well as a non-randomized prospective study, demonstrated a significant reduction in glomerular (creatinine clearance) and tubular function (fractional excretion of sodium and free water clearance) in on- compared to off-pump surgery. On-pump surgery was also associated with increased secretion of markers of renal ischaemic injury (urinary hypoxanthine, xanthine and malondialdehyde levels). This subclinical evidence of renal injury was not associated with clinical sequelae in any of these studies. The aetiology of renal dysfunction after cardiac surgery is multi-factorial and in patients with co-morbid conditions that are associated with post-operative renal dysfunction (elderly, diabetics, renal impairment), CPB is associated with an increased risk of dialysis dependent renal failure.

Neurological injury

CPB may potentially contribute to neurological injury by loss of autoregulation at low temperatures or low perfusion pressures, micro and macro-emboli and alteration of the blood brain barrier by the systemic inflammatory response, resulting in brain oedema. Randomized trials of on- versus off-pump multivessel CABG clearly demonstrate significantly greater biochemical (S100), and radiological evidence of brain injury as well as a greater number of detectable cerebral emboli in on-pump patients. This is not associated with an increased incidence of stroke or measurable persistent neurocognitive deficits in randomized trials. Several large retrospective risk factor analyses have identified CPB as a risk factor for stroke in conventional CABG patients however. There was no overall difference in neurocognitive assessment at three or 12 months post surgery. There was a difference in the standardized neurocognitive change score, with greater improvement in neurocognitive function in the off-pump group at 3 months, however this was no longer evident at 12 months. In a smaller randomized trial of 60 patients at our institution there was also no difference in neurocognitive outcomes 3 months post-operatively although Zamvar et al. demonstrated a higher incidence of neurocognitive impairment in on-pump at 1 and 10 weeks post-operatively in a similar sized study. These three randomized studies considered relatively young patients with mean age ranging from 59 to 63 years and none reported the body mass index of patients. Elderly and obese patients are at particularly high risk for neurological complications following on-pump cardiac surgery, and observational studies have demonstrated a neuroprotective effect of off-pump surgery in these groups. Although Zamvar et al. considered relatively young patients with mean age ranging from 59 to 63 years and none reported the body mass index of patients.

Clinical outcomes

Three randomized clinical trials, as well as analyses of several large registries, have demonstrated that OPCAB

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achieves equivalent multi-vessel revascularization compared to conventional on-pump surgery with better short-term and equivalent mid-term outcomes.\textsuperscript{4–6,63–69} In a meta-analysis of the BHACAS-1 and -2 studies chest infection, inotropic requirement, incidence of arrhythmias, post-operative blood loss and consequent transfusion requirement, intubation time, intensive care unit stay and hospital length of stay were significantly lower in the off-pump group.\textsuperscript{4} Furthermore, mid-term follow-up of these patients demonstrated equivalent cardiac and all-cause mortality, major adverse cardiac event (MACE) rates, and quality of life, in on- and off-pump groups.\textsuperscript{63} In two other randomized studies, Van Dijk and associates in the Octopus Study Group random\-ized 281 patients, and Puskas and colleagues at Emory University\textsuperscript{6} randomized 200 patients, to either on- or off-pump multivessel CABG. In both trials, those undergoing off-pump surgery had a shorter ventilation time, were discharged from hospital earlier, bled less and required fewer blood transfusions.

Randomized trials are not directly applicable to the entire population undergoing CABG and the interpretation of their findings is limited by their entry and exclusion criteria as well as by the power of the study to detect specific endpoints. The latter two randomized studies in particular\textsuperscript{5,6} considered predominantly low risk patients. Analysis from several large registries, where all patients undergoing CABG are considered, have also demonstrated significant reductions in morbidity associated with off-pump compared to conventional CABG however. In the largest contemporary multi-centre comparison of outcomes in multi-vessel CABG patients \(n = 204,602\) patients from the STS database), avoidance of CPB (17,969 OPCAB patients) was associated with a significant survival benefit \(OR [95\% CI] 0.83 [0.72, 0.96]\) in propensity-matched pairs.\textsuperscript{64} In addition, on multivariate analysis, OPCAB was associated with decreased morbidity including stroke and renal failure.\textsuperscript{64} The benefits were even more pronounced in those at higher risk of CPB-associated morbidity (notably the elderly) those with poor left ventricular function, renal impairment, obesity or diabetes.\textsuperscript{64} Subgroup analysis of propensity-matched groups identified off-pump survival benefits in patients with previous CABG \(OR 0.53\), diabetics \(OR 0.66\), LVEF between 30% and 50% \(OR 0.75\), females \(OR 0.79\), and age 66–75 years \(OR 0.80\).\textsuperscript{64} Other registries have also demonstrated that the short-term benefits accrued from off-pump surgery are more marked in those at higher risk of post-operative morbidity. We recently investigated the incidence of early mortality and morbidity in a retrospective analysis of 1570 consecutive high-risk CABG-only patients. Using multivariate logistic regression analysis, off-pump surgery was shown to result in reduced blood loss, transfusion requirement, ITU, and hospital stay.\textsuperscript{65} Al-Ruzzeh et al.\textsuperscript{66} demonstrated reduced ITU stay, frequency of peri-operative MI and mortality in a study of high risk patients undergoing off- versus on-pump CABG, defined as those with a EuroSCORE >5. In a multivariate analysis of 990 elderly patients (over 70 years) from the Bristol registry, off-pump surgery was found to be associated with reduced need for inotropes, intra-operative arrhythmias, blood loss and transfusion requirement when compared to on-pump.\textsuperscript{67} We also compared OPCAB versus conventional CABG in overweight and obese patients and demonstrated that after adjustment for confounding factors, OPCAB was associated with significant reductions in early mortality, transfusion requirement, intensive care unit and hospital stay and neurological complications including stroke.\textsuperscript{60}

Registry data has also demonstrated equivalent mid-term outcome in on- and off-pump CABG. A review of the Cleveland Clinic Registry demonstrated no difference in mid-term outcome at 4 years; survival was 87.3% versus 91.2%, \(P = 0.2\), and freedom from major adverse cardiac events (MACE) was 75.2% and 82.9% \((P = 0.14)\) in off-pump versus on-pump groups, respectively.\textsuperscript{68} Similarly, Calafiore and colleagues reported no difference in cardiac and all-cause mortality, cardiac events or repeat revascularization procedures between on- versus off-pump CABG (1806 patients, 906 OPCAB) at a mean of 42 months (range 23–65 months) post-operatively.\textsuperscript{69}

**Unanswered questions**

In spite of the large body of evidence supporting better short-term outcomes with off-pump, several important concerns remain. Operating on the beating heart, with difficult access and exposure, especially when grafting vessels on the lateral or inferior wall of the beating heart, might potentially compromise the quality of the distal anastomoses and result in inferior graft patency. The avoidance of CPB-related morbidity might therefore be at the expense of long-term benefits. Angiographic follow-up of two of the randomized trials of off- versus on-pump CABG previously cited\textsuperscript{5,6} have clearly demonstrated that technical quality of the distal anastomoses is not an issue however, at least in the short term. One-year angiographic patency in 153 patients in the Emory randomized trial, demonstrated 95.8% and 93.6% for on- versus off-pump, respectively (absolute difference −2.2%; 95%CI −6.1 to 1.7, \(P = 0.27\)).\textsuperscript{70} Similarly, one-year angiographic patency of a randomized subgroup of patients from the multi-centre Octopus Study Group trial, was 93% and 91% for on- versus off-pump (absolute difference 2%; 95%CI −6.5 to 10.4).\textsuperscript{71} Observational studies also report excellent early angiographic patency following OPCAB, although these are more prone to reporting bias. Early post-operative angiography in 257 patients undergoing total arterial grafting, off-pump, revealed 97.8% (264/270) patency of internal thoracic artery and 97.9% (512/523) patency of radial artery grafts.\textsuperscript{72} In contrast to these findings, a recent prospective randomized study of 104 CABG patients with incomplete angiographic follow-up demonstrated 98% and 88% early graft patency in on- versus off-pump groups, respectively.\textsuperscript{73} This reduction in graft patency in off-pump patients was highly statistically significant \((P < 0.002)\). This study was insufficiently powered to detect differences in graft patency however, and can also be criticized for the nature of the statistical analysis, which appears post hoc and parsimonious. Another important
limitation is the observation that the two surgeons in this trial only occasionally performed off-pump surgery in their normal practise (13% of all CABG cases in the preceding two years). It is difficult to see how this cannot have introduced a bias into the result. Analysis of 16 988 consecutive patients operated on in 72 centres in the US demonstrated that OPCAB performed in low, as opposed to high, volume units was associated with a highly significant increase in cardiac specific, as well as overall, mortality.64

In the mid- to long-term, lower graft patency ultimately results in a higher mortality and frequency of adverse cardiac events, an earlier return of symptoms, lower quality of life, and an increased requirement for repeat revascularization procedures. Mid-term follow-up of the BHACAS-1 and -2 patients demonstrated no difference in mortality or cardiac events at a mean follow-up of 25 months for BHACAS-1 and 14 months for BHACAS-2.6 Thirty-three (17%) of 200 patients in the off-pump group died or had a cardiac-related event, compared with 42 (21%) of 201 in the on-pump group (Odds ratio 0.78, 95% confidence interval (CI) 0.49–1.22). One year follow-up from the Octopus trial65 reported no difference in the rate of freedom from death, stroke, myocardial infarction, and coronary re-intervention (91% on-pump versus 88% off-pump, absolute difference, 2.6%; 95%CI –4.6 to 9.8). This study also demonstrated no difference in quality of life between the two groups; EuroQol summary scores increased in both groups from 0.65 at baseline to 0.84 three months after surgery. Analysis of disease-specific and generic quality of life in BHACAS-1 and -2 patients at a median of three years follow-up also reported no difference between on- or off-pump groups.63

Another concern that arises from off-pump surgery is a tendency to not graft smaller vessels, particularly the marginal branches of the circumflex. Randomized trials have demonstrated that it is possible to perform the same number of grafts and achieve equivalent completeness of revascularization with on- or off-pump,4–6 however several registries report significantly fewer grafts in off-pump compared to on-pump. Sabik et al.,75 in a report from the Cleveland Clinic used propensity-scoring analysis to match 406 on-pump and 406 off-pump patients from their registry. The mean number of bypass grafts was 2.8 ± 1.0 in off-pump patients and 3.5 ± 1.1 in on-pump patients (P < 0.001). Fewer grafts were performed to the circumflex (P < 0.001) and right coronary (P = 0.006) artery systems in the off-pump patients. In an analysis of 1401 patients from the Bristol registry, 191 (15.8%) had incomplete revascularization (M Caputo, GD Angelini, unpublished observations). This was attributed, in 70% of cases, to small or diffusely diseased vessels and resulted in increased mortality and cardiac-related events in incompletely revascularized patients. In a retrospective study, Lund et al.76 demonstrated that grafting circumflex branches <1 mm off-pump, was an independent risk factor for post-operative mortality and myocardial infarction. It is paradoxical that small and diseased vessels are more common in patients that benefit most from off-pump surgery in terms of short-term outcome. Incomplete revascularization detected in registry data undoubtedly reflects a tendency not to graft small diseased vessels. In the same manner that distal marginal grafts on the beating heart were once considered off limits, however, it is likely that improvements in stabilization technology and intraoperative anaesthetic management will permit grafting of smaller vessels by the majority of surgeons.

The future

The clinical evidence demonstrates lower morbidity in off-pump compared to conventional on-pump CABG with equivalent mid-term outcome. Long-term outcome and, in particular, the gold standard of surgical revascularization long-term graft patency following OPCAB remain unknown. The benefits appear most marked in high-risk patients, but these have not been considered specifically in randomized clinical trials. At present, no consensus exists as to the precise indications for off-pump, as opposed to conventional on-pump, surgery and the choice of surgical technique rests largely with the operating surgeon. As these questions are answered, it may become apparent that on-pump CABG is detrimental to many patients. Furthermore, increasing demands on healthcare resources worldwide demand the use of cost-effective therapies in the management of coronary disease. The BHACAS-1,7 Octopus71 and Emory70 trials demonstrated that OPCAB reduced peri-operative costs by as much as 15–30%. In the BHACAS-1 study, this was attributed to the reduced cost of operating materials, bed occupancy, and transfusion requirements (total mean cost per patient: on-pump, $3731.6 ± 1169.7 versus off-pump, $2615.13 ± 953.6; P < 0.001).7 In addition to direct hospitalisation and peri-operative costs, Nathoe and colleagues71 calculated follow-up costs associated with repeat admissions for stroke, myocardial infarction or repeat revascularization procedures. At one-year, the total direct costs of on-pump surgery were 14.1% ($1839) higher per patient than those of off-pump surgery (mean cost per patient: on-pump, $14908 versus off-pump, $13069; P < 0.01). In the Emory study, mean total hospitalisation cost per patient at hospital discharge was $2272 (95% CI, $755–$3732) less for OPCAB (P = 0.002) and $1955 (95% CI, $766 to $4727) less at 1 year (P = 0.08).70

The widespread acceptance of a new surgical technique depends on its reproducibility and on the feasibility of teaching the technique to the next generation of surgeons. Despite the apparent benefits of OPCAB surgery there is a lack of structured training programmes for OPCAB in the UK and elsewhere. A recent survey77 from several cardiothoracic training centres in the United States demonstrated that only 22% of residents had performed 20 or more OPCAB procedures during their training, and only 12% had performed 20 or more complete myocardial revascularizations using OPCAB. Of these, only 4% had performed OPCAB circumflex coronary artery revascularization. Similar results were obtained in a survey of cardiothoracic trainees in the UK where only
51% of UK trainees surveyed have experience of OPCAB in their training programme (GD Angelini, unpublished observations). In Bristol, training in OPCAB starts in the second year of a six-year residency programme and progresses in parallel with training in on-pump techniques. Over the last five years we have successfully trained four of our residents in off-pump surgery, all of whom are now consultants. This has not been associated with any increase in patient morbidity or mortality. More recently, continuous performance monitoring (e.g., CUSUM) has been introduced to complement our training programme by monitoring changes in performance over time and alerting trainers to suboptimal performance. This has shown that cumulative performance by trainees becomes equal to, or better than, that of a consultant after approximately 100 OPCAB cases. In addition, performance for all trainees in off-pump cases was equivalent to or better than their performance with conventional on-pump CABG. This evidence clearly demonstrates that, where senior surgeons are proficient in OPCAB techniques, a structured cardiothoracic training programme that includes OPCAB surgery is both possible and safe for patients. The Emory University group has also demonstrated that it is possible to introduce OPCAB into an established surgeon’s practice without any increase in patient morbidity. This was attributed to careful case selection such that high-risk patients with poor left ventricular function, left main stem or complex three-vessel disease were excluded from OPCAB until sufficient operator experience (over 200 cases) had been obtained.

The success of beating heart surgical programmes has prompted other developments in surgical revascularization. In particular, OPCAB, in conjunction with a thoracic epidural, represents a further step towards reduced morbidity. The peri-operative use of high thoracic epidural anaesthesia (TEA) and analgesia in patients undergoing cardiac surgery leads to stress-response attenuation, intense peri-operative analgesia, cardiac sympatholysis and thus improved vascular graft blood flow, post-operative mobilization, pulmonary and gastrointestinal function, and reduced morbidity. Randomized trials of epidural anaesthesia in on-pump CABG report shorter ventilation times, fewer arrhythmias, frequency of sternal dehiscence, renal failure, strokes, and chest infections. Although this combination has yet to be evaluated in randomized trials, in OPCAB preliminary studies suggest that it results in even shorter recovery times and earlier extubation in off-pump patients. A recent extension of this technique has been OPCAB utilizing thoracic epidural in the awake patient. Avoiding tracheal intubation entirely may maximize the benefits of effective regional anaesthesia.

These developments represented a natural evolution towards minimally invasive surgical revascularization and will ultimately result in a blurring of the boundaries between interventional cardiology and cardiac surgery, resulting in the creation of cardiovascular specialists. This is already evident in the renewed enthusiasm for hybrid or integrated revascularization procedures. The combination of minimally invasive coronary artery bypass grafting of the left anterior descending artery, on the beating heart, via a mini thoracotomy, (MIDCAB or LAST procedure) plus percutaneous treatment of other diseased vessels (PCI) has been promoted as advantageous in patients at high risk for conventional coronary artery bypass. This resurgence of interest in hybrid procedures has been fueled in part by the apparent success of drug-eluting stents at reducing reintervention rates compared to PCI using non-drug-eluting stents, coupled with the desire of interventional cardiologists to broaden the scope of PCI. Currently, multi-vessel OPCAB permits equivalent, and probably even superior levels of revascularization with lower MACE and fewer target lesion revascularization rates (TLR) than hybrid revascularization however. This is chiefly attributed to restenosis following PCI in hybrid procedures. PCI using bare metal stents, although associated with restenosis rates in the early period by 25–30% is still inferior to surgical revascularization. Recent randomized studies have shown lower re-intervention rates following multi-vessel CABG when compared to multi-vessel PCI with stents, as has a large meta-analysis of randomized trials comparing PCI versus CABG, even when subgroups comparing stented patients were considered separately. Furthermore, drug-eluting stents, although very impressive in selected patients, have not yet been shown to have proven efficacy or cost benefits in the majority of patients currently considered as candidates for surgical revascularization, i.e., complex multi-vessel disease, diabetics, and chronic occlusions.

OPCAB, by reducing procedural morbidity in high-risk groups, may also offer a superior alternative to many patients that currently undergo multi-vessel PCI. Serruys et al. in a randomized trial of conventional CABG with CPB versus non-drug eluting stents reported similar frequencies for mortality (OR 0.89 [95%CI 0.45–1.77]) and major morbidity, plus a reduced cost ($10665 versus $13638, P < 0.001) despite a higher re-intervention rate for stenting (OR 5.52 [95%CI 3.59–8.49]). Several other similar trials have drawn the same conclusions. It is not unreasonable to suggest that OPCAB surgery, associated as it is with lower morbidity, equivalent graft patency, midterm outcome and a significant reduction in cost compared to conventional CABG may therefore offer a superior alternative to many patients that currently undergo multi-vessel PCI. This benefit appears most obvious in patients with diabetics, chronic total arterial occlusions, long or ostial stenoses and bifurcation lesions where restenosis rates are higher. It is less likely.

Potential advantages in other high-risk groups, such as the elderly or those with renal or respiratory impairment, require further evaluation in clinical studies.

Conclusion

There is now a large body of experimental and clinical evidence that supports the wider application of off-pump surgical revascularization. The chief advantage over conventional CABG is the avoidance of the morbidity associ-
ated with CPB. As the patients referred for surgical revascularization get older with more co-morbid medical conditions, OPCAB presents a surgical technique with superior short-term outcome, equivalent graft patency, mid-term outcome, and reduced cost. Evaluation of long-term outcome and graft patency and the future provision of training in OPCAB techniques will determine, ultimately, whether it shall replace conventional on-pump revascularization in the future.

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