A glance at the history of the development of Coronary Artery Bypass Surgery (CABG) throws up the interesting finding that the first milestones were without cardiopulmonary bypass (CPB) support. Off-pump CABG (OPCAB), having predated On-pump surgery, has had a roller coaster ride for want of a clean, still and bloodless field, culminating in the introduction of CABG on CPB (On-pump) by Favaloro in 1967. This development profoundly "democratised" the CABG procedure in that now a broad number of surgeons could achieve better and reproducible results with considerably more optimum operating conditions. The initial enthusiasm for On-pump CABG gradually gave way to concerns regarding its safety, especially with regard to complications arising from CPB, and not CABG per se. Foremost of these relate to microembolic showering during manipulation of the aorta and neurocognitive dysfunction. In addition, CPB triggers a whole-body inflammatory response caused by contact activation of the complement cascade. This leads to multiple organ dysfunction affecting the kidneys, liver, lungs, brain and heart itself. Studies published over a decade and a half ago questioned the safety of On-pump CABG. The proportion of patients recovering without any complication was found to be only 64.3%. In addition, health insurance data and data from clinical studies showed that 10.2% did not leave the hospital within 14 days after the operation and 3.6% of the patients were discharged to a non-acute care facility. These and other observations, pari passu with the development of mechanical and pharmacological organ stabilizers and intracoronary shunts, resurrected OPCAB in the early 1990s.

As regards surgical technique, the actual suture anastomosis of the vessels follows the same technique both in On- and Off-pump surgery. The difference is that unlike On-pump surgery, where the heart is arrested by means of cardioplegia, in Off-pump surgery the area of interest is kept immobile with the help of organ stabilizers while the anastomosis is being performed. Pharmacologic agents like short-acting beta-blockers (e.g. Esmolol) or Adenosine are used in conjunction with these mechanical stabilizers to achieve the goal of a relatively motionless field. Exposure of the heart is aided by retraction devices like the "Starfish", which lift up the apex from the pericardial cavity (Table 1). Retraction can also be achieved by means of folded sponges placed in the pericardial sac to lift the heart, or by pericardial hitching sutures. Distal coronary perfusion is maintained by means of flexible intracoronary shunts introduced into the coronary vessel prior to commencement of the anastomosis (Fig. 1). Although these devices are designed for one-time use, they may be reused after ETO sterilization. This assumes importance as far as cost-containment in a country like India is concerned, giving a further fillip to Off-pump surgery.

Numerous large observational studies and small randomized controlled trials (RCT) have been published in the past 18 years suggesting benefits from OPCAB. Among these are, a reduction in stroke, duration of post-operative ventilation, need for reoperation, bleeding, wound infection, renal failure, post-operative length of stay and decreased atrial fibrillation and inotrope requirement. A major study published in 2001 (the Octopus trial), showing no major differences in cardiac, neurological and neuropsychological outcomes in patients operated On- and Off-pump was also a shot in the arm for Off-pump surgery. However, as with any new technique, initial enthusiasm was somewhat dampened by reports of incomplete revascularization using OPCAB. This and other reports led to the first RCT comparing the two procedures, the Randomized On/Off bypass study (ROOBY) in 2009. At 1-year of follow-up, Off-pump patients had worse composite outcomes.
of death, myocardial infarction (MI), graft patency and repeat revascularization. The conversion rate from Off- to On-pump procedures was 12.4%, a figure 5 times that reported in the National Database of Thoracic Surgeons! This was bandied as glaring evidence of the participant practitioners’ inexperience. The authors had addressed the prickly issue of surgeon experience by doing a sensitivity analysis based on high volume (>50 pre-study cases) versus low volume operators, and had found no significant difference in outcomes. Nonetheless, many have questioned the figure of 50 cases as being insufficient to indicate surgeon experience, whilst disregarding anesthesiologist experience.

As if this was not enough, another nail in the coffin of OPCAB was driven by a recent Cochrane review meta-analysis from Copenhagen considering 10 low-bias trials (n = 4950) of a total of 86 RCTs comparing Off-pump with On-pump surgery, which found 30% higher risk of all-cause mortality with Off- vs. On-pump CABG. Other adverse events like MI, stroke, renal insufficiency or repeat revascularization were similar despite a slightly lower number of distal anastomoses Off-pump versus On-pump. In fact the authors, Moller et al hazard to state, “findings suggest that funding sources matter, with the device industry-funded trials less apt to show harm from Off-pump CABG,” thereby suggesting that vested interests may be at play. But a major issue with the Cochrane review is that it included just one additional study to the meta-analysis by Afilalo et al (vide infra) which incidentally had showed clear superiority of Off-pump CABG. This additional study, ironically of Moller himself, had a staggering 25% mortality Off-pump, which obviously seriously skewed the results of the review to suggest harm with OPCAB.

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**Table 1 – Commonly used stabilizer/retraction devices.**

<table>
<thead>
<tr>
<th>Name of stabilization device</th>
<th>Stabilization mechanism</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medtronic-Utrecht Octopus® tissue stabilization system</td>
<td>Suction</td>
<td>Good stabilization for LAD</td>
<td>Difficulty in LCx territory, cumbersome (discontinued)</td>
</tr>
<tr>
<td>Octopus 1</td>
<td>Suction</td>
<td>Good stabilization for LAD</td>
<td>Bulky, cumbersome, difficulty in LCx, long arm causes less stability; (discontinued)</td>
</tr>
<tr>
<td>Octopus 2</td>
<td>Suction</td>
<td>Better stabilization, lesser pod height</td>
<td>Stiff pods may cause heart injury (discontinued)</td>
</tr>
<tr>
<td>Octopus 3</td>
<td>Suction</td>
<td>Malleable suction pods, better adaptation to heart contour</td>
<td>Increased horizontal motion; (in use)</td>
</tr>
<tr>
<td>Octopus 4</td>
<td>Suction</td>
<td>360° arm movement</td>
<td>Damage to coronary endothelium, possibility of catching back wall during anastomosis; (not widely used)</td>
</tr>
<tr>
<td>Genzyme Elite stabilizer</td>
<td>Compression of coronary between tapes</td>
<td>No need for shunt</td>
<td></td>
</tr>
<tr>
<td>Guidant system</td>
<td>Suction</td>
<td>High flexibility of arm</td>
<td>Usable only on custom-made retractor (in use)</td>
</tr>
<tr>
<td>Starfish positioning system</td>
<td>Suction</td>
<td>Allows for posterior vessel access</td>
<td>May cause apical ischemia, injury (in use)</td>
</tr>
</tbody>
</table>

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Angelini et al analyzed 2 RCTs comparing Off-pump and On-pump patients 6–8 years following surgery to assess graft patency, major adverse cardiac-related events (MACE), and health-related quality of life. The patient cohort followed up was from the Beating Heart Against Cardioplegic Arrest Studies (BHACAS) 1 and 2 trials. Overall, 10.8% of grafts were occluded across both groups. Further, logistic regression analysis showed no evidence that grafts were more likely to be occluded in OPCAB than in On-pump patients. The differences in MACE-free survival and quality of Life indicators did not approach statistical significance. Although these findings greatly bolstered the case of the proponents of OPCAB surgery, some shortcomings pointed out were that the modality of assessment of graft patency was non-invasive (MDCTA) as against the gold standard of coronary angiography; also, the study was a single center study by a single surgical team, and hence could not necessarily be extrapolated to other surgeons and centers. Another concern with OPCAB is the lesser number of grafts put. But this has long been disproved by a review of 22 RCTs which showed only 0.2 fewer grafts being put in this group compared with On-pump.

A meta-analysis published by Afilalo et al included all published and unpublished RCTs of Off-pump versus On-pump CABG from the MEDLINE, EMBASE and Cochrane databases. It took into consideration a total of 59 trials, encompassing 8961 patients. There was a significant 30% reduction in post-operative strokes with Off-pump surgery [risk ratio (RR) 0.70, 95% CI: 0.49–0.99]. There was no significant difference in mortality (RR: 0.90, 95% CI: 0.63–1.30) or MI (pooled RR: 0.89, 95% CI: 0.69–1.13). In the meta-regression analysis, the effect of OPCAB on all of the clinical outcomes was similar regardless of mean age, proportion of females in the analysis, the effect of OPCAB on all of the clinical outcomes (pooled RR: 0.89, 95% CI: 0.69–0.98).

The most recent comparison study of the two techniques is the CABG Off or On pump revascularization study (CORONARY Study) published in March this year. The trial randomized 4752 patients undergoing CABG to Off-pump or On-pump groups. There was no significant difference seen in the primary end-points of death, MI, stroke, or new renal failure requiring dialysis at 30 days (Table 2).

There were, however, some differences in secondary outcomes (Table 3), with the Off-pump group showing advantages of less bleeding, respiratory infections, and acute kidney injury, but this group also had fewer grafts performed and had more repeat revascularizations thereby mandating longer term follow-ups before a final verdict.

<table>
<thead>
<tr>
<th>Table 2 – CORONARY: primary outcomes.</th>
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<tbody>
<tr>
<td>Endpoint</td>
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<tr>
<td>Primary composite end point</td>
</tr>
<tr>
<td>Death</td>
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<tr>
<td>MI</td>
</tr>
<tr>
<td>Stroke</td>
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<tr>
<td>New renal failure</td>
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</table>

The investigators thus struck a middle path by recommending either of the two techniques based on patient factors, provided the surgeon was competent in both. For example, if a patient had renal dysfunction or a heavily calcified aorta, OPCAB would be preferred.

Much like the proverbial see-saw, a 1-year follow-up angiographic study of the ROOBY cohort was reported this year by Hattler at the AHA Congress in Orlando. He revealed that Off-pump patients had a lower saphenous vein patency than On-pump, but a similar arterial graft patency rate, leading to less effective revascularization. Grover in an editorial tried to reconcile the difference between the ROOBY and CORONARY trial findings. The latter involved only surgeons experienced in Off-pump surgery, whereas the ROOBY trial also had trainees as operating surgeons. On a conservative note however, he cautioned that any firm conclusions would have to await long term follow-up results.

Training of surgeons in OPCAB techniques has been an issue as it requires a great deal of focus and enthusiasm, apart from safety concerns. However, even this issue has been laid to rest by a recent study from the Bristol Heart Institute that Off-pump surgery is not only safe and reproducible, but the technique can be taught effectively and safely to trainees with clinical outcomes unrelated to either the level of supervision or the seniority of the trainees.

The final frontier for the Off-pump coronary surgeon remains the patient with left main disease as well as those with severely depressed LV function. Here too, lower mortality and complication rates have been demonstrated. OPCAB has been validated with results quite similar to the CORONARY trial in left main stem disease also. Murzi et al showed that OPCAB was associated with lower in-hospital mortality (0.5% vs. 2.9%; p = 0.001) and morbidity in terms of stroke, renal dysfunction and pulmonary complications/infections. But the biggest bugbear of OPCAB, viz. fewer grafts (2.7 ± 0.7 vs. 3 ± 0.7; p = 0.001) and lower rate of complete revascularization (88.3% vs. 92%; p = 0.04) continue to remain. On multivariate analysis, CPB was confirmed to be an independent predictor of in-hospital mortality (OR 5.74; p = 0.001). The countervailing pros and cons negating each other lead to similar survivals at 1.5 and 10 years, a fact validated by Cheng et al. OPCAB has also been shown to give superior results in patients with chronic kidney disease.

The International Society for Minimally Invasive Cardiothoracic Surgery (ISMICS) recommendations state that the use of Off-pump bypass reduces perioperative morbidity, neurocognitive dysfunction and hospital length of stay and should be considered especially in high-risk patients, for example,
those with severe ascending aortic calcification, liver disease, renal insufficiency or other systemic processes that may be exacerbated by CPB, in order to reduce morbidity and mortality. Based on available data, the guidelines contend, both approaches are reasonable, with certain factors tilting the balance one way or the other. For example, the oft-quoted instance of a patient with a heavily diseased aorta being more amenable to Off-pump surgery. The European Guidelines (2010) on the other hand make no mention of Off-pump surgery, stating instead that over 70% of bypass surgeries worldwide are conducted On-pump (perhaps a diplomatic way of making an undiplomatic point).

As for our experience at the National Heart Institute in Delhi of over 5000 cases done Off-pump with a conversion rate of less than 1% and mortality of 1.6%, we can safely state that this is an effective technique, provided it is adopted and practiced in spirit as well as letter. The surgeon, and perfuse the team, should be well conversant with the nuances of Off-pump techniques, besides being motivated, focused and inclined, and not be a proponent just to join the bandwagon and be counted, whilst jeopardizing the patient’s interest. In the end, a doctor’s reputation lives through his/her patients, and this is no truer than for a cardiac surgeon. The best technique is that which works best for that particular patient, in the context of his clinical setting and his treating surgeon’s repertoire lending credence to our strong belief that it is the surgeon and not the technique, which is at the heart of the problem.

**References**