Anaortic, off-pump coronary artery surgery: should it be the standard-of-care?

Recent trials have shown that coronary artery bypass grafting remains the standard-of-care for multivessel coronary artery disease. However, the main criticism of surgery in these trials has been the higher rate of stroke. Off-pump coronary artery bypass grafting (OPCAB) has been suggested as a technique to reduce the rate of stroke. However, large randomized trials comparing coronary artery bypass grafting with OPCAB have failed to show any neurological benefit, most probably because surgeons in these trials fail to avoid manipulation of the ascending aorta. Herein, the authors review a technique of OPCAB surgery where manipulation of the ascending aorta is completely avoided – ‘anaortic OPCAB’ – facilitated by the use of composite and in situ grafts using bilateral internal mammary arteries.

Keywords: coronary artery bypass grafting  coronary artery disease  off-pump coronary artery bypass grafting  stroke

The recently published ASCERT [1], SYNTAX [2] and FREEDOM [3] trials have demonstrated a clear benefit for coronary artery bypass grafting (CABG) over percutaneous coronary intervention (PCI) in the treatment of multivessel coronary disease that increases over time [4]. The main criticism of CABG in the SYNTAX trial was the higher 30-day stroke rate when compared with PCI (2.2 vs 0.6%). However, the stroke rate converges over time [2]. Macro- and micro-embolisation (e.g., atheroma, platelet, air, fat and calcium, among others) are the cause of most brain and distal organ injuries after cardiac surgery [5], along with hypoperfusion and a systemic inflammatory response. Avoiding cardiopulmonary bypass (CPB) with ‘off-pump’ CABG (OPCAB) has been put forward as a solution to this problem. The term ‘OPCAB’ describes a heterogeneous group of techniques, the common factor of which is the avoidance of CPB.

The confusion surrounding OPCAB and on-pump CABG surgery, and the evidence for and against each technique, has not been helped by the large randomized trials comparing CABG with OPCAB (i.e., the ROOBY and CORONARY trials) [6,7]. These trials failed to show a neurological benefit for OPCAB over CABG. Surgeons performing OPCAB in the ROOBY and CORONARY trials did not avoid manipulation of the ascending aorta; most often, a partial occlusion clamp or a ‘heart-string’ device was used to place vein grafts on the aorta [6,7]. The ROOBY and CORONARY trials suggest that simply avoiding CPB alone is not enough to reduce the rate of stroke. The results contrast with the very low stroke rate observed in other studies, where aortic manipulation is completely avoided during OPCAB [8]. The ROOBY trial also demonstrated that surgeons must be experienced in the OPCAB technique to obtain good results [9–11].

Increasingly, there are surgeons around the world pursuing an ‘aortic no-touch’ or ‘anaortic’ OPCAB technique, often using all-arterial grafts. Anaortic CABG refers to OPCAB without any manipulation of the ascending aorta whatsoever. Elimination of aortic manipulation by not cannulating the aorta for CPB, not cross-clamping for cardioplegic arrest and not placing a partial occlusion or side-biting clamp for fashioning aorto–coronary grafts can virtually eliminate emboli from the equation. This is even more important in the subgroup of high-risk patients who are elderly, or have peripheral vascular disease, diabetes, renal impairment or chronic airway disease [12].

The aim of this article is not to provide a review comparing OPCAB with CABG; the vast majority of OPCAB series and randomized trials are comparisons of CABG with CPB and aortic cross-clamping versus OPCAB with an aortic side-biting clamp. The aim of this article is to discuss the concept of anaortic OPCAB and the significant reduction in morbidity it can provide.

Stroke & cardiac surgery

Stroke is the most devastating nonlethal complication after cardiac surgery for patients, their families and the surgeon. The cause of
stroke during and immediately after cardiac surgery includes emboli (e.g., atheroma, platelet aggregates, air, calcium and plastics from the CPB circuit, among other causes), hypoperfusion, small-vessel cerebrovascular disease and intracranial hemorrhage. Sometimes the cause of stroke is multifactorial; however, embolic stroke remains to be the most common cause after cardiac surgery [13].

Eliminating emboli from coronary artery surgery has the potential to prevent up to two-thirds of strokes after CABG. The authors’ group has published several systematic reviews of anaortic OPCAB versus other revascularization techniques [8,14,15]. Figure 1 is a Forest plot of studies comparing anaortic OPCAB first with OPCAB with a side-biting clamp, and second with conventional CABG, clearly demonstrating the stroke-reduction benefit of anaortic OPCAB. The stroke rate for traditional on-pump CABG in most series and databases is between 1 and 3%, whereas the stroke rate for anaortic OPCAB in most series and in the systematic review evidence is between 0.2 and 0.4% [8]. While the authors are unable to definitely prove that the three- to five-fold reduction in stroke after anaortic OPCAB is due to the elimination of emboli, the fact that two-thirds of stroke cases after cardiac surgery are embolic makes this fact more than coincidental. The risk of stroke

<table>
<thead>
<tr>
<th>Study (year)</th>
<th>Anaortic (n) Events</th>
<th>Total</th>
<th>Side clamp (n) Events</th>
<th>Total</th>
<th>Weight (%)</th>
<th>Risk ratio, M–H (random, 95% CI)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calafiore et al. (2002)</td>
<td>3 1533</td>
<td>5</td>
<td>460</td>
<td>16.2</td>
<td>0.18 (0.04–0.75)</td>
<td>[21]</td>
<td></td>
</tr>
<tr>
<td>Emmert et al. (2011)</td>
<td>2 271</td>
<td>13</td>
<td>567</td>
<td>15.2</td>
<td>0.32 (0.07–1.42)</td>
<td>[19]</td>
<td></td>
</tr>
<tr>
<td>Kapetanakis et al. (2004)</td>
<td>4 476</td>
<td>40</td>
<td>2527</td>
<td>27.5</td>
<td>0.53 (0.19–1.48)</td>
<td>[22]</td>
<td></td>
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<tr>
<td>Kim et al. (2002)</td>
<td>0 222</td>
<td>1</td>
<td>123</td>
<td>3.7</td>
<td>0.19 (0.01–4.52)</td>
<td>[23]</td>
<td></td>
</tr>
<tr>
<td>Leacche et al. (2003)</td>
<td>0 84</td>
<td>5</td>
<td>556</td>
<td>4.5</td>
<td>0.60 (0.03–10.68)</td>
<td>[70]</td>
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<tr>
<td>Lev-Ran et al. (2005)</td>
<td>1 429</td>
<td>6</td>
<td>271</td>
<td>8.1</td>
<td>0.11 (0.01–0.87)</td>
<td>[71]</td>
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<tr>
<td>Osawa et al. (2011)</td>
<td>2 451</td>
<td>1</td>
<td>9</td>
<td>6.8</td>
<td>0.04 (0.00–0.40)</td>
<td>[72]</td>
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</tr>
<tr>
<td>Patel et al. (2002)</td>
<td>3 597</td>
<td>2</td>
<td>520</td>
<td>11.0</td>
<td>1.31 (0.22–7.79)</td>
<td>[69]</td>
<td></td>
</tr>
<tr>
<td>Vallely et al. (2002)</td>
<td>1 1201</td>
<td>3</td>
<td>557</td>
<td>7.1</td>
<td>0.15 (0.02–1.48)</td>
<td>[24]</td>
<td></td>
</tr>
<tr>
<td>Total (95% CI)</td>
<td>5264</td>
<td></td>
<td>5590</td>
<td>100</td>
<td>0.30 (0.16–0.55)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total events: 16 76
Heterogeneity: $\chi^2 = 8.94$, df = 8 ($p = 0.35$); I² = 11%
Test for overall effect: $Z = 3.81$ ($p = 0.0001$)

<table>
<thead>
<tr>
<th>Study (year)</th>
<th>Anaortic (n) Events</th>
<th>Total</th>
<th>CABG (n) Events</th>
<th>Total</th>
<th>Risk ratio, M–H (random, 95% CI)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calafiore et al. (2002)</td>
<td>3 1533</td>
<td>41</td>
<td>2830</td>
<td>0.14</td>
<td>0.04–0.44)</td>
<td>[21]</td>
</tr>
<tr>
<td>Emmert et al. (2011)</td>
<td>2 271</td>
<td>51</td>
<td>2111</td>
<td>0.31</td>
<td>0.07–1.25)</td>
<td>[19]</td>
</tr>
<tr>
<td>Izumoto et al. (2009)</td>
<td>1 59</td>
<td>2</td>
<td>132</td>
<td>1.12</td>
<td>0.10–12.10)</td>
<td>[68]</td>
</tr>
<tr>
<td>Kapetanakis et al. (2004)</td>
<td>4 476</td>
<td>94</td>
<td>4269</td>
<td>0.38</td>
<td>0.14–1.03)</td>
<td>[22]</td>
</tr>
<tr>
<td>Kim et al. (2002)</td>
<td>0 222</td>
<td>3</td>
<td>76</td>
<td>0.05</td>
<td>0.00–0.94)</td>
<td>[23]</td>
</tr>
<tr>
<td>Patel et al. (2002)</td>
<td>3 597</td>
<td>19</td>
<td>1210</td>
<td>0.32</td>
<td>0.10–1.08)</td>
<td>[69]</td>
</tr>
<tr>
<td>Total (95% CI)</td>
<td>3158</td>
<td></td>
<td>10,628</td>
<td>0.28</td>
<td>0.16–0.48)</td>
<td></td>
</tr>
</tbody>
</table>

Total events: 13 210
Heterogeneity: $\chi^2 = 4.60$, df = 5 ($p = 0.47$); I² = 0%
Test for overall effect: $Z = 4.52$ ($p < 0.0001$)

Figure 1. The influence of aortic manipulation on the rate of stroke. (A) OPCAB with side clamp versus anaortic OPCAB; (B) anaortic OPCAB versus conventional CABG.
CABG: Coronary artery bypass grafting; df: Degrees of freedom; M–H: Mantel–Haenszel; OPCAB: Off-pump coronary artery bypass grafting.
Reproduced with permission from [8,15].
increases with age and comorbidities. There are several papers that demonstrate a benefit of anaortic OPCAB in the reduction of stroke in elderly and high-risk patients [12,16,17].

While the authors prefer to completely avoid aortic manipulation, the use of clampless anastomotic devices, such as the HEARTSTRING (Maquet, Rastatt, Germany) is preferable to a side clamp if an aortocoronary anastomosis is required [18]. These are associated with a lower rate of stroke than the use of a side clamp [19].

Where is the evidence for anaortic OPCAB?
The authors have previously described how they perform anaortic total arterial OPCAB [20]. Briefly, all graft in-flow is based on one or both internal mammary arteries (IMAs; or the gastroepiploic artery) using composite ‘T’ or ‘Y’ grafts (or a combination; Figure 2). The second limb to the graft may be the right IMA, radial artery or indeed the long saphenous vein graft (although the authors’ group avoids this approach). Pericardial release incisions allow for excellent exposure of the target arteries and intracoronary shunts are used routinely to allow for distal perfusion, a bloodless surgical field and to reduce technical errors, such as catching the back wall of the artery with a suture. The technique is reproducible and is used as the routine revascularisation technique by two out of the five surgeons in the authors’ unit.

All of these techniques have been validated with large, early, single-center studies [21–24], which are summarized in Table 1. The vast majority of this work has been published in the cardiothoracic surgery literature and has not formed part of any randomized controlled trials. This has meant that evidence for the true benefit of anaortic OPCAB and its ability to eliminate aortic manipulation and the risk of cerebral and systemic emboli may not have reached the wider medical community.

The desire to have randomized controlled trial evidence to demonstrate the benefits of one technique over another is admirable. However, the large randomized trials comparing CABG and OPCAB published to date have failed to include high-risk patients (known to benefit most from OPCAB), have not been performed using the anaortic technique, or have been performed by surgeons without adequate OPCAB expertise. Such trials, thus, underestimate the potential of anaortic OPCAB and are biased towards CABG. Puskas and colleagues’ excellent single-surgeon randomized controlled trial of 200 patients comparing OPCAB with CAGB demonstrated equivalent, excellent immediate and 1-year graft patency rates and outcomes between the two techniques [25]. There are several large series of anaortic OPCAB demonstrating excellent morbidity and mortality results that should be considered when weighing up the evidence for each of the techniques [26].

A later retrospective study from Puskas’ group of over 14,000 patients clearly demonstrated the benefits of OPCAB over CAGB in high-risk patients [16]. The results are demonstrated graphically in Figure 3. This can then be contrasted with the randomized controlled ROOBY trial that demonstrated disappointing results in both the on-pump CAGB and OPCAB group, with the OPCAB group having a high conversion to on-pump CAGB and poorer graft patency rates [27]. Clearly the expertise and experience of Puskas et al. accounts for the excellent results and the clear benefit for OPCAB over CAGB [16].

There is no doubt that anaortic OPCAB is a technically more challenging procedure, associated with a learning curve. This has been seen as a barrier to the uptake of the technique in some centers. Training can be undertaken in centers with dedicated OPCAB surgeons: this is especially useful in order to develop the techniques required for cardiac positioning to revascularize the inferior and lateral walls. An
Table 1. Trials demonstrating safety and efficacy of composite grafts.

<table>
<thead>
<tr>
<th>Study (year)</th>
<th>Design</th>
<th>Follow-up (standard deviation)</th>
<th>n</th>
<th>Patency (%)</th>
<th>p-value</th>
<th>Survival (%)</th>
<th>p-value</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barner et al. (2012)</td>
<td>Retrospective; CABG; radial T graft vs radial free graft; nonprotocol angiography</td>
<td>7.4 (3.8) years</td>
<td>269</td>
<td>Composite: 1 year: 99.6</td>
<td>10 years: 62.9</td>
<td>Conventional: 1 year: 97.1</td>
<td>10 years: 75.4</td>
<td>0.146</td>
</tr>
<tr>
<td>Nasso et al. (2009)</td>
<td>RCT; CABG; LIMA/RIMA T graft vs LIMA/RIMA in situ</td>
<td>2 years</td>
<td>204</td>
<td>1 year: 96.5</td>
<td>2 years: 75.4</td>
<td>0.62</td>
<td>[49]</td>
<td></td>
</tr>
<tr>
<td>Lemma et al. (2004)</td>
<td>Retrospective; CABG; LIMA/radial composite vs free; symptomatic angiography</td>
<td>14.9 months</td>
<td>176</td>
<td>Composite: 80 (in 4.6% patients with angina and/or positive EST)</td>
<td>74 (in 6.6% patients with angina and/or positive EST)</td>
<td>0.59</td>
<td>98.8</td>
<td>97.7</td>
</tr>
<tr>
<td>Muneretto et al. (2003)</td>
<td>Prospective RCT; CABG in patients &gt;70 years; total arterial grafting (LIMA + RIMA/RA composite) vs CABG (LIMA/SVG); protocol angiography</td>
<td>15 (4) years</td>
<td>100</td>
<td>Composite: RIMA: 100</td>
<td>RA: 96.7</td>
<td>Conventional: SVG: 84</td>
<td>0.009</td>
<td>95</td>
</tr>
<tr>
<td>Lev-Ran et al. (2002)</td>
<td>Retrospective; CABG; in situ BIMA vs LIMA/RIMA T graft</td>
<td>4 years</td>
<td>649</td>
<td>Composite: –</td>
<td>Conventional: 89.8</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

BIMA: Bilateral internal mammary artery; CABG: Coronary artery bypass grafting; Cx: Circumflex artery; EST: Exercise stress test; LAD: Left anterior descending artery; LIMA: Left internal mammary artery; NS: Not significant; RA: Radial artery; RCA: Right coronary artery; RCT: Randomized controlled trial; RIMA: Right internal mammary artery; SVG: Saphenous vein graft.
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on-pump beating heart technique can be used to help traverse the learning curve. Exposure of OPCAB techniques to trainees is important and there is evidence that in the correct environment, with adequate supervision, the results of trainees can be equivalent to those of trained surgeons [28,29].

Anaortic OPCAB versus PCI

PCI is often put forward as a lower risk alternative to CABG, particularly in the elderly. Benefits of PCI over surgery include significantly lower 30-day morbidity and a more rapid return to usual activities. However, PCI involves several potential issues, particularly in the elderly. Elderly patients often have multivessel disease with calcified vessels that are not particularly suitable for PCI and, therefore, the patient may be incompletely revascularized. PCI involves passing a wire across the aortic arch into the ascending aorta and there is a risk of embolic stroke [30,31]. Bare-metal stents have a risk of in-stent restenosis and drug-eluting stents have a risk of sudden thrombosis mandating at least 12 months of treatment with dual antiplatelet therapy [32]. A total of 5% of patients require subsequent noncardiac surgical procedures within the first 12 months of a PCI, risk of death/myocardial infarction/stent thrombosis is up to 35% when surgery is performed within the first month and is <10% after 6–12 months [33]. This exposes patients to the risk of bleeding if the antiplatelet therapy is continued and to stent thrombosis if it is discontinued, a classic ‘catch 22’. If patients are offered anaortic OPCAB then the antiplatelet therapy can be interrupted when performing subsequent surgical procedures, reducing bleeding and not exposing the patients to the risk of acute stent thrombosis.

A recent paper by Halbersma et al. compared 400 patients undergoing total arterial anaortic OPCAB with outcomes from the SYNTAX trial [34]. The 30-day mortality was 0.2%, the 30-day stroke rate was 0.2% and the 30-day symptomatic graft occlusion was 0.2%, impressive by any standards. The authors compared the 12-month outcomes with the SYNTAX trial 12-month outcomes (Table 2). The outcomes for anaortic OPCAB versus CABG and PCI in the SYNTAX trial are striking. Anaortic OPCAB with total arterial grafts provides a significant reduction in stroke, major adverse cardiac and cerebrovascular events, and reintervention when compared with CABG and PCI as conducted within the SYNTAX trial.

Bilateral mammary arteries

There are several compelling arguments for the use of skeletonized bilateral IMAs (BIMA) in CABG. These include a clear survival benefit [35–38], obtaining two conduits from a single sternotomy (reducing morbidity from other harvest sites) and providing two in-flows to the heart without having to perform a proximal anastomosis during OPCAB surgery. However, there is a disappointingly low usage of BIMA in most countries performing CABG [39]. Surgeons often quote a ‘lack of evidence’ for their use, increased sternal morbidity, increased operative time and that elderly patients should receive vein grafts as they will not obtain the survival benefit conferred in younger patients.

Data from the Cleveland Clinic (OH, USA) have established the superiority of both single and later double IMA grafts over saphenous vein grafts [36]. An excellent meta-analysis by Taggart et al. clearly demonstrates the survival benefits of using bilateral, rather than single, mammary artery grafts [35,40]. Since this paper, there have been numerous institutional series [37,38] demonstrating the survival benefit of a second mammary artery, and the authors are

![Figure 3. High-risk patients benefit disproportionately from off-pump coronary artery bypass grafting.](image-url)
awaiting the medium- and long-term data from the ART trial [41].

Sternal morbidity is reduced if the arteries are harvested in a skeletonized fashion and if care is taken not to injure the veins and muscle behind the sternum [42–44]. Certainly female, obese, diabetic patients who have BIMA harvested with a muscle and vein pedicle are at significant risk of devastating sternal wound complications [44,45]; and Hba1c is a predictor of sternal wound infection [46]. There are several clinical and basic science studies demonstrating the superior sternal perfusion offered by skeletonized IMA harvesting [47,48].

The procedural time is increased when BIMAs are harvested. However, as surgeons become more proficient, this time decreases. The authors’ philosophy is that in the short term, you may save the patient an extra incision for alternative conduit harvest and that the increased survival benefit makes the extra time and effort worth it.

Being elderly should not preclude a patient from the benefits of arterial grafts; patients >75 years have better cardiac event-free survival when two arterial grafts (compared with one) are used [49]. The use of BIMA grafts in the elderly means that, more often than not, the entire procedure can be conducted via a sternotomy, sparing the legs and arms to facilitate more rapid mobilization and return to normal function. The use of vein grafts requires aortic in-flow that must be obtained with the use of bypass and aortic cross-clamping or the use of a partial occlusion side-biting clamp with the inherent risk of atheroemboli and iatrogenic type A dissection. Elderly patients often have varicose or calcified veins that are suboptimal conduit and prone to early occlusion. The IMAs, by contrast, are often large with slightly thickened walls, facilitating easy harvesting and manipulation during CABG (Figure 2).

### Table 2. A series of anaortic off-pump coronary artery bypass grafting with total arterial grafts compared with the SYNTAX trial results.

<table>
<thead>
<tr>
<th>12-month follow-up</th>
<th>Anaortic OPCAB (%)</th>
<th>CABG SYNTAX (%)</th>
<th>TAXUS™ SYNTAX (%)</th>
<th>p-value (anaortic OPCAB vs CABG)</th>
<th>p-value (anaortic OPCAB vs TAXUS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-cause death</td>
<td>1.8</td>
<td>3.5</td>
<td>4.4</td>
<td>NS</td>
<td>0.02</td>
</tr>
<tr>
<td>Myocardial infarction</td>
<td>2.0</td>
<td>3.3</td>
<td>4.8</td>
<td>NS</td>
<td>0.02</td>
</tr>
<tr>
<td>Stroke</td>
<td>0.8</td>
<td>2.2</td>
<td>0.6</td>
<td>0.07</td>
<td>NS</td>
</tr>
<tr>
<td>Repeat revascularization</td>
<td>1.3</td>
<td>5.9</td>
<td>13.5</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Symptomatic graft occlusion</td>
<td>0.8</td>
<td>3.4</td>
<td>3.3</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>MACCE</td>
<td>5.3</td>
<td>12.4</td>
<td>17.8</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

CABG: Coronary artery bypass grafting; MACCE: Major adverse cardiac and cerebrovascular event; NS: Not significant; OPCAB: Off-pump coronary artery bypass grafting. Adapted with permission from [54].

### Radial artery grafts, composite grafts & competitive flow

There is an increasing body of literature demonstrating the superiority of the radial artery over saphenous vein grafts, especially in studies reporting long-term follow-up [50]. Harvest of the radial artery is less likely to result in wound complications compared with the saphenous vein [51,52]. While early patency rates of vein grafts are excellent, in the mid-term they develop aggressive atherosclerosis [53] that is hard to treat with PCI and is potentially dangerous if manipulated during redo coronary surgery [55]. The method of arterial graft failure is more often a ‘string sign’; it is unclear whether this represents an occluded state or a physiological response to flow. Of radial arterial grafts displaying the string sign in the randomized RAPS trial, 50% had a thrombolysis in myocardial infarction (TIMI) flow of >2 and were asymptomatic [56]. A recent publication from Hayward et al. demonstrated a 90% radial artery patency at 5 years [57]. Even more importantly, the radial arteries that were patent were completely free of disease. This contrasts strongly with vein grafts at 10 years, which often have significant endoluminal disease [58].

Much of the radial artery patency data are based on aortocoronary grafts, rather than on the use of composite extension grafts or T grafts. The diameter of the ascending aorta is 30 mm in most people, while the radial artery is a fourth order artery with a diameter of 3–4 mm. Anastomosis of a radial graft to the aorta exposes it to high wall shear stress, potentially causing endothelial injury, radial artery spasm and subsequent graft failure. On the other hand, anastomosing the radial artery to the IMA (either as an extension or a T graft) is technically easy and there is an excellent caliber match, eliminating turbulent flow and maintaining usual pulse wave forms. The
more physiological state is probably protective for the radial artery, and the proximal IMA’s ability to dilate according to need means that a single in-flow is sufficient for revascularization.

The single biggest criticism for the radial artery graft is the patency where the target artery stenosis is less than 80% [59]. This creates a competitive flow situation causing vasoconstriction of the muscular radial artery in order to maintain its wall shear stress, resulting in occlusion. Our argument is that it is not the fault of the radial artery and that the vessel probably did not require a graft in the first instance. Angiographic assessment of the severity and significance of coronary disease is often a subjective one. Objective evidence can be obtained by assessing the fractional flow reserve; the FAME 1 [60] and FAME 2 [61] studies have clearly demonstrated that physiological assessment with the fractional flow reserve and appropriate targeted PCI achieves a better outcome.

This raises the issue as to whether coronary angiography should be the only assessment prior to surgery? The argument that a lesion is only moderately diseased and should, therefore, have a vein graft is somewhat flawed. Equivocal lesions (maybe even all target-vessel lesions) should be assessed with the fractional flow reserve and those that are significant should have revascularization with arterial grafts, and those that are not significant should be left alone. This obviously requires more time and effort at diagnostic angiography, but in line with the FAME studies and PCI, the outcomes for surgical revascularization can only be improved.

The fear of some surgeons when using T grafts is the potential implications of losing the left IMA (LIMA) to the left anterior descending artery (LAD) component of the graft, and then removing the huge benefit that a patent LIMA to LAD affords a patient [62]. Early graft failure is often related to technical mishaps when constructing the T graft and care must be taken when performing this anastomosis. Later failure is often related to competitive flow, either in the LAD or from the other target arteries. This reinforces the need to objectively assess lesions prior to making decisions on grafting strategies. The long-term patency and patient survival data after composite grafting have been reported in several single-center studies. The results of these are summarized in Table 1.

Another concern expressed by some surgeons is that a single IMA in-flow is insufficient for total cardiac revascularization. However, the IMA is usually significantly larger than the left main coronary artery and this supplies the vast majority of the heart. The LIMA also has the capacity to dilate according to demand and this happens immediately and over time [63,64]. The use of two IMAs for anaortic OPCAB is obviously ideal, but the authors often use a LIMA/left radial T graft for elderly or morbidly obese patients requiring three-vessel revascularization, thus reducing operative times and potential morbidity.

**Conclusion**

Complete coronary revascularization using total-arterial grafts without touching the aorta and without using CPB is possible in the vast majority of patients. It requires greater training and considerable care and attention. This is the same as in other cardiac surgical procedures, such as mitral repair or aortic surgery. For the standard of CABG to improve (much like the standard of PCI has improved), then surgeons and units must be willing to invest the time and effort into pursuing more advanced techniques. There must also be a willingness of surgeons to refer patients who would benefit from anaortic OPCAB to a subspecialist surgeon if they do not feel comfortable with the technique.

CABG with a LIMA to the LAD and vein grafts to other territories was a good operation in the 1980s. However, since the 1980s there have been improvements, such as multiple IMA grafting, the revival of the radial artery as a graft [65], and the use of OPCAB and minimally invasive techniques. As with all human endeavours, surgeons must be willing to change and improve their techniques to get the best outcomes for their patients.

Kolessov, a pioneering Russian surgeon, presented the first LIMA to LAD anaortic OPCAB series in the late 1960s [66]. His work was initially received with almost universal skepticism, both in Europe and the USA. It was not until Favaloro’s landmark saphenous vein aortocoronary bypass series was published in 1970 that CABG was accepted in the mainstream [67]. The LIMA to LAD forms the backbone of coronary revascularization and the irony of Kolessov’s reception is not lost on the authors of this article.

Anaortic OPCAB provides the opportunity for surgeons to completely revascularize the heart with all-arterial grafts, without using CPB and...
without manipulating the aorta. This may lead to the virtual elimination of stroke from CABG and a significant reduction in morbidity. It takes more effort to learn the technique and the operation time is extended by the routine use of BIMA, but surely the outcomes justify the effort?

Future perspective

Some groups are developing the techniques of minimally invasively anastomotic OPCAB, performed using endoscopic and robotic technology. Complete revascularization using anastomotic OPCAB is possible using this technology and the goal is to perform this surgery with less pain, shorter time in hospital and faster recovery time.

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### Executive summary

- Coronary artery bypass grafting is the standard of care for patients with multivessel coronary artery disease, but the higher rate of stroke compared with percutaneous coronary intervention remains a concern.
- The rate of stroke in coronary artery bypass grafting is most likely related to the degree of manipulation of the ascending aorta.
- Anastomotic, off-pump coronary artery bypass grafting is a technique that allows complete revascularization of the heart, using all arterial grafts, without any manipulation of the ascending aorta.
- The rate of stroke associated with anastomotic off-pump coronary artery bypass grafting is <0.5%.
- Anastomotic off-pump coronary artery bypass grafting allows patients the advantages of surgical revascularization (lower rates of mid- to long-term mortality, myocardial infarction and need for repeat revascularization) compared with percutaneous coronary intervention.

### References

Papers of special note have been highlighted as:
- of interest
- of considerable interest

2 Large registry study (n = 189,793) demonstrating the survival benefit 4 years after coronary artery bypass grafting compared with percutaneous coronary intervention.
4 Most relevant randomized comparison of coronary artery bypass grafting versus percutaneous coronary intervention in the era of drug-eluting stents.
6 FREEDOM trial demonstrates that diabetic patients with multivessel disease benefit from surgery compared with percutaneous coronary intervention.


» Description of the authors’ technique of anaortic off-pump coronary artery bypass grafting.


37. First large registry study to highlight the survival benefit of using both internal mammary arteries.


Meta-analysis that demonstrates the benefit of radial artery versus saphenous grafts.


