

# Recent advances in adult cardiac surgery

**Cardiac surgery remains the definitive therapy for severe heart disease despite being the most invasive and expensive of the available therapeutic options. This article describes the most important of many recent advances in the field.**

Cardiac surgery remains the definitive therapy for severe heart disease despite being the most invasive and expensive of the available therapeutic options. Recent advances, the majority of which address these problems, include developments in percutaneous and surgical treatments for coronary artery disease and cardiac dysrhythmias, minimally invasive cardiac and thoracic aortic surgery; as well as adjuncts to surgery including cardiac imaging, blood conservation, and national publication of surgeon specific activity and outcome data.

## Methods

The authors selected topics after consultation with surgeons in their department. A literature search was performed using Medline (1997–2005), focusing on the best available evidence for each topic. International guidelines published by scientific societies and national review committees were also consulted.

## Coronary surgery vs percutaneous coronary intervention

Percutaneous coronary intervention (PCI) was initially reserved for single vessel disease, based on randomized controlled trials and registries of PCI and coronary artery bypass grafting (CABG). These studies provided a foundation for early practice but are now of largely historical interest because patients were highly selected, and standard modern adjuncts including antiplatelet agents, statins, modern surgical strategies, and coronary stenting were not widely used. The 1990s saw rapid improvements in both coronary stent technology and experience with the technique, and the indications for PCI expanded. Babapulle et al (2004) show how potentially the most important technological development was progression from bare metal to drug-eluting stents: the latter are associated with significantly lower restenosis rates.

Coronary stenting offers a far less invasive alternative to revascularization than bypass surgery. Stents are used because of lower rates of restenosis when compared with balloon angioplasty alone, and they also have an impor-

tant role in the management of complications from angioplasty (Babapulle et al, 2004). The drawbacks to stents are that the blood supply to septal branch arteries is compromised, and that long-term patency rates are unknown. This contrasts unfavourably with surgical anastomosis which does not compromise branch arteries, and achieves patency rates of over 95% at 15 years when the left internal thoracic artery is anastomosed to the left anterior descending artery (Barner and Barnett, 1994).

Six randomized controlled trials comparing surgery with coronary stents have been published to date (Goy et al, 2000; Morrison et al, 2001; Rodriguez et al, 2001; Serruys et al, 2001; Abizaid et al, 2002; Deigler et al, 2002). All of these trials were conducted predominantly with bare metal stents. Of these trials, four compared stenting with CABG in multi-vessel disease (Goy et al, 2000; Morrison et al, 2001; Serruys et al, 2001; Abizaid et al, 2002). One study showed a difference in mortality at 1 year between the two interventions, favouring stenting (Goy et al, 2000). In the three largest studies no difference was detected at 1 year between the combined rates of death, stroke and myocardial infarction; but the rate of repeat revascularization for patients undergoing stenting was several times higher than in patients undergoing CABG (Morrison et al, 2001; Serruys et al, 2001; Abizaid et al, 2002). Two large trials have compared stenting and CABG in single vessel disease (Morrison et al, 2001; Deigler et al, 2002). Although neither trial demonstrated a significant difference in the rate of death or Q-wave myocardial infarction at 1 year, there was a difference in the primary endpoint of death, myocardial infarction and repeat revascularization combined, favouring the CABG group in both studies.

The ARTS II study results were published last year (Serruys et al, 2005). Sirolimus-eluting stents were used in this study, which showed lower rates of myocardial infarction, stroke, death and re-intervention than bare metal stents at 6 months and 1 year. There was no significant difference in the combined adverse event rate between the drug-eluting stents and historical surgical controls from the ARTS I trial, although the death rate in the surgical group was 2.7% compared to 1% in the stent group at 1 year.

In summary best available evidence comparing drug-eluting stents with surgery shows equivalence in 1 year combined adverse cardiac events. Repeat revascularization rates, however, are significantly higher after stenting than after surgery, even where drug-eluting stents are used. Overall cost-effectiveness appears to favour the

stent group (Serruys et al, 2001; Abizaid et al, 2002), although limited evidence (Yock et al, 2003) suggests that the higher re-intervention rates for stents may reverse this cost-benefit in the midterm. Trial data comparing stents and surgery are limited by the absence of long-term follow up, unrepresentative samples, and rapid development of techniques and technology on both sides of the divide. Long-term clinical studies are needed that focus on significant outcomes such as mortality, and the effects of revascularization procedures, especially repeat revascularization, on quality of life.

## Off-pump vs on-pump surgery

Coronary artery bypass surgery can be carried out with the use of cardiopulmonary bypass (on-pump), or without (off-pump). Most surgeons operate on-pump: until recently the advantages of a still, clear operating field, myocardial protection and haemodynamic and respiratory control, appeared to outweigh the disadvantages of bypass (Table 1). Improvements in technology and technique have led some institutions to favour off-pump surgery, anticipating that patients should benefit from reduced operative mortality, stroke and other morbidity.

Over 50 randomized controlled trials of off-pump vs on-pump surgery, and several meta-analyses have been published. The four largest trials conclude that off-pump surgery offers better outcomes, leading to reductions in postoperative atrial fibrillation, transfusion and inotrope requirements, ventilation times, length of hospital stay, and cost, compared to on-pump surgery (Angelini et al, 2002; Nathoe et al, 2003; Puskas et al, 2003; Straka et al, 2004). But no randomized trial has detected the hoped for difference in death or stroke. A meta-analysis that assessed 95 randomized controlled trials of off-pump vs on-pump CABG, of which 37 trials containing 3369 patients were suitable for inclusion, found no significant differences in 30-day mortality, stroke, myocardial infarction, graft patency or reintervention (Cheng et al, 2005).

One reason for the failure to show a difference in outcome may be that off-pump surgery is technically challenging: it has a long, steep learning curve which may result in poorer outcomes in less experienced cen-

tres (Novick et al, 2001). This is reflected by studies where patients in the off-pump groups received fewer grafts (Czerny et al, 2001), and off-pump anastomotic patency was lower (Khan et al, 2004). In the 'no touch' off-pump technique the proximal ends of saphenous vein grafts are anastomosed to other saphenous vein grafts, or to the internal mammary arteries instead of the aorta, meaning that the aorta is not handled at all during surgery. Stroke rates as low as 0.2% have been demonstrated using this technique (compared to over 2% with the conventional off-pump technique) (Lev-Ran et al, 2005), suggesting that this approach might show significantly better outcomes when compared with on-pump surgery.

Several large retrospective analyses have, however, demonstrated a significant difference in postoperative mortality and stroke. The largest such study looked at over 11 000 off-pump and 106 000 on-pump operations (Cleveland et al, 2001). The off-pump group had lower risk-adjusted mortality and major morbidity, fewer strokes, and less renal failure.

## Minimally invasive and robotic techniques

There is no universally accepted definition of minimally invasive cardiac surgery: the term embraces techniques that avoid cardiopulmonary bypass, use smaller incisions, or endoscopic aids. There are several ways of performing minimally invasive coronary surgery (Table 2), and bypass conduits can also be harvested through limited incisions (Figure 1). Robotic surgery has been used to perform coronary (Figure 2) and mitral valve surgery; pacemaker placement, and to treat pericardial and mediastinal disease. The first twenty four totally endoscopic coronary bypasses in the UK were performed at St Mary's Hospital.

**Table 2. Minimally invasive techniques in coronary artery bypass grafting**

Off-pump coronary artery bypass (OPCAB)	Any coronary artery bypass surgery carried out without cardiopulmonary bypass
Minimally invasive direct coronary artery bypass (MIDCAB)	Surgery performed off-pump through a small thoracotomy under direct vision
Endoscopically assisted atraumatic coronary artery bypass (Endo-ACAB)	Internal mammary artery harvested endoscopically, coronary anastomosis performed off-pump through a mini-thoracotomy under direct vision
Totally endoscopic coronary artery bypass (TECAB)	Surgery performed off-pump entirely endoscopically with robotic assistance
Hybrid	MIDCAB, Endo-ACAB or TECAB with elective percutaneous coronary stenting of additional stenoses

**Table 1. Problems associated with cardiopulmonary bypass**

Systemic inflammatory response
Embolic events causing stroke, mesenteric and renal ischaemia
Volume loading
Decreased ventricular function, arrhythmias
Atelectasis, acute lung injury
Acute renal failure
Coagulopathy, bleeding

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**Figure 1.** Scars from endoscopic harvesting of radial artery and saphenous vein in the same patient.



**Figure 2.** a. Scars from totally endoscopic coronary artery bypass grafting. b. Postoperative coronary angiogram showing patent coronary anastomosis (arrowed).

Current experience with minimal access surgery is largely retrospective and non-controlled although prospective trials are in progress. Meta-analyses comparing minimally invasive with conventional saphenous vein harvest have shown significant reductions in wound complications and length of hospital stay, and increased patient satisfaction with endoscopic approaches (Athanasίου et al, 2004). These are the goals that have driven the technology, but the increased unit cost and operation time, risk of emergency conversion to a conventional approach, and the significant learning curve have limited wider uptake of these techniques.

### Surgery for atrial fibrillation

The incidence of postoperative atrial fibrillation is approximately 33% in patients undergoing mitral valve surgery, 10% in those undergoing aortic valve surgery and 2% in patients undergoing CABG. It is associated with increased morbidity including stroke in the immediate postoperative period. Conventional medical treatments leave most postoperative patients in atrial fibrillation. The Maze III operation is currently the gold standard treatment for atrial fibrillation in patients undergoing mitral surgery: transmural lesions are created using radiofrequency ablation throughout both atria, isolating arrhythmogenic areas and pathways. The classic

Maze procedure cures atrial fibrillation in over 95% of patients (Cox et al, 2000), but relatively few surgeons perform the Maze III because of its complexity. Pulmonary vein isolation reflects the finding that paroxysmal atrial fibrillation originates from ectopic beats in the pulmonary veins in over 90% of cases (Haissaguerre et al, 1998). Pulmonary vein isolation is a simpler operation and it is curative in approximately 80% of patients with paroxysmal atrial fibrillation preoperatively (Oral et al, 2002).

Although new ablation technologies including radiofrequency, microwave and cryotherapy have facilitated thoracoscopic and minimally invasive approaches, the indications for surgical treatment of atrial fibrillation will probably remain limited to patients with concomitant cardiac surgical pathology requiring surgery. Percutaneous catheter ablation has similar cure rates in experienced hands, it is low risk, less invasive than even minimally invasive surgical approaches, and currently more cost-effective (Benussi, 2004).

### Blood conservation

Cardiac surgery consumed over 10% of the 2.2 million units of blood issued by the National Blood Service of England in 2004. Several blood conservation strategies have addressed the morbidity associated with postoperative bleeding and transfusion, and reduced availability of blood products.

Tranexamic acid and aprotinin are antifibrinolytics each associated with a significant reduction in blood transfusion, and reoperation for bleeding compared with placebo following cardiac surgery (Henry et al, 2003). Neither drug was found in this meta-analysis to be associated with significant increases in adverse events. Cell salvage systems suction blood from the operative field or postoperative drains, heparinize and wash it to produce concentrated erythrocytes which can be returned to the patient. Washed cell salvage has been calculated to reduce the odds of requiring a blood transfusion by almost a fifth (Carless et al, 2003).

A significant source of heterogeneity in the studies included in both meta-analyses was variation in thresholds for transfusion. Both these meta-analyses conclude that there is no further need for placebo controlled trials of either strategy in cardiac surgery. Rigorously designed studies designed to establish the haematocrit that optimizes coronary anastomotic patency and myocardial oxygen delivery; and studies that define the risk-benefits of allogeneic blood transfusion in cardiac surgery are now needed.

### Cardiac imaging for cardiac surgery

Standard two-dimensional echocardiography relies on geometrical assumptions: three-dimensional (3D) reconstructions provide more accurate information. 3D echocardiography is gaining acceptance as a clinical tool thanks to improvements in data acquisition and analysis

allowing real-time 3D images. 3D echocardiography offers superior assessment of mitral valve anatomy and functional morphology: a vital part of successful mitral valve repair (Macnab et al, 2004).

Magnetic resonance angiography (MRA) imaging yields high resolution, animated 3D reconstructions. MRA is routinely used in planning elective aortic aneurysm surgery. The contrast agent gadolinium accumulates in myocardial scar and fibrotic tissue: gadolinium scans are occasionally used by surgeons to plan revascularization when standard imaging gives equivocal results.

Multi-slice computed tomography (CT) coronary angiography has moved beyond detecting early markers of coronary atherosclerosis. 64 row multi-detector CT, which images the heart in seconds (Figure 3) offers superior spatial resolution to magnetic resonance imaging. Compared with conventional coronary angiography the sensitivity and specificity of multi-slice CT for detecting significant lesions (defined as >50% stenosis) were 95% and 98% respectively (Hoffmann et al, 2005).

Single positron emission computed tomography (SPECT) is an established tool for evaluating the relative importance of coronary stenoses in multi-vessel disease by imaging uptake of radioactive tracers at rest and during exercise. Image gating now allows simultaneous assessment of perfusion and wall motion, quantifying ventricular function and reversibility of ischaemia, and guiding surgical revascularization. SPECT has been used to risk-stratify patients undergoing revascularization (Sabharwal and Lahiri, 2003).

**Figure 3.** Multi-slice computed tomography coronary angiography showing stenosis in the mid left anterior descending artery (arrowed).



### Endovascular repair of the descending aorta

Thoracoabdominal aortic aneurysm repair is associated with a mortality of 10–20%, and a risk of paraplegia of approximately 10% despite refinements in surgical technique and spinal cord protection. Endovascular techniques appear to have a primary success rate of over 95%, with a 5.5% operative mortality, and rate of neurological complications of less than 2% (Sayed and Thompson, 2005).

Combined endovascular and surgical repair of thoracoabdominal aortic aneurysms, where the abdominal aneurysm is repaired surgically allowing reimplantation of visceral vessels, providing access for endoluminal stenting, and avoiding the large thoracoabdominal incision is a relatively new strategy that is gaining in acceptance. There is, however, no randomized or large cohort study data on endovascular repair of thoracoabdominal aortic pathology, and randomized trials of endovascular approaches to pathology limited to the abdominal aorta have not shown a sustained benefit in morbidity or mortality (EVAR Trial Participants, 2005). Large randomized studies comparing endovascular with conventional approaches for thoracoabdominal aortic pathology with long-term follow up are now needed.

### Surgery for heart failure

CABG has been shown to offer superior results to cardiac transplantation in highly selected patients with ejection fractions below 20%, sufficient reserves of hibernating myocardium and suitable coronary anatomy. Right ventricular dysfunction and elevated pulmonary artery pressures are relative contraindications to CABG. Careful patient selection, and temporary mechanical support mean that operative mortality has been reduced to 7% in this high-risk group, with 5-year survival of almost 80% (Hausmann et al, 1997).

Mitral regurgitation often occurs in heart failure. High operative mortality in the 1980s led to the assumption that postoperative deterioration in left ventricular function was the inevitable byproduct of removing the low resistance regurgitant pathway. Understanding the need to preserve the subvalvular apparatus, and to correct and prevent annular dilatation, as well as improved experience in mitral valve repair techniques has improved results, with hospital mortality as low as 2% in one series (Bach and Bolling, 1995).

In 2003 the United States Food and Drug Administration approved the Thoratec HeartMate left ventricular assist device for long-term support of patients with end-stage heart failure. Approval was based on data which demonstrated that left ventricular assist device insertion decreased 1-year mortality by a third compared to medical management (Rose et al, 2001). Early bleeding and late infection remain problematic in these patients.

### Publishing surgeon-specific data

The Kennedy report on the enquiry into paediatric cardiac surgical deaths at Bristol Royal Infirmary in the UK stated that: 'patients must be able to obtain information as to the relative performance of the trust...and consultant units within the trust'. The Society of Cardiothoracic Surgeons of Great Britain and Ireland (SCTS) has collected activity and mortality data since the 1980s, seeing steadily improving mortality despite increasing emergency referrals, patient age and comorbidity. The Society's own National Cardiac Surgery Register, which in 2003 contained data from over 210 000 individual patient records, with 100% data capture for NHS centres, is substantially more accurate than the Department of Health's Hospital Episode Statistics figures, on which Dr Foster based the first surgeon-specific figures published in 2003.

Last year individual surgeon data for all adult cardiac surgeons in the UK was published by the SCTS in the form of limits: surgeons lying within 99.99% confidence limits (4 standard deviations) over an aggregated 3-year period were said to have met SCTS standards (Keogh and Kinsman, 2004). While this meets the aim of demonstrating safety of individual surgeons, it does not facilitate patient choice as surgeons are not ranked. When surgeon-specific rankings were first published in the USA subsequent improvements in results were driven in part by a new reluctance to operate on high-risk candidates (Schneider and Epstein, 1996). It is hoped that accurate risk-stratified data will help to avoid that scenario happening in the UK (Bridgewater, 2005).

### Conclusions

Cardiac surgery has been at the forefront of development in surgical techniques since its inception. The development of endovascular and percutaneous techniques suggest a further period of rapid evolution is upon us. Areas are likely to see important developments

in the near future include stem-cell based therapy and biotechnology, particularly with reference to surgery for heart failure. **BJHM**

*Conflict of interest: none.*

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### KEY POINTS

- Coronary artery bypass grafting offers superior freedom from repeat revascularization compared to stenting in multi-vessel disease, and equivalent risk of stroke and death.
- Off-pump surgery offers reduced postoperative morbidity, length of stay and cost compared to on-pump surgery, but no randomized controlled trial has yet demonstrated the expected reduction in perioperative stroke and mortality.
- Minimally invasive approaches to valve and coronary artery surgery are being adopted more widely, but there are no reliable data comparing the results with conventional approaches. Learning curve is a significant issue and retraining of surgeons is required to overpass the learning curve.
- The Maze III offers 90% freedom from atrial fibrillation at 1 year when performed in conjunction with mitral valve surgery, more limited surgical ablation may become a standard part of cardiac surgery in patients at risk of atrial fibrillation.
- Antifibrinolytics and cell salvage have been used successfully to reduce blood transfusion requirements.
- Surgeon-specific mortality data was published for the first time in 2003 by the Society of Cardiothoracic Surgeons of Great Britain and Ireland: the task is now to provide robust, risk-adjusted data.

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### Additional educational resources

#### For doctors

<http://www.scts.org/>

The website of the Society of Cardiothoracic Surgeons of Great Britain and Ireland contains links to national cardiac surgery activity and outcome data, as well as discussion documents on surgical league tables

<http://www.ctsnet.org/sections/innovation/index.html>

A free multi-media resource in the form of lectures, videos, full-text books, provided by the Cardiothoracic Surgery Network

<http://www.hsforum.com>

Free multi-media resource in the form of lectures, videos and online discussions, provided by The Heart Surgery Forum, a cardiothoracic multi-media journal with a special interest in innovation in cardiac surgery

#### For patients

<http://www.ctsnet.org/doc/6393>

A free full-text online book for patients and relatives describing all aspects of heart surgery, with short sections on minimally invasive options

<http://www.scts.org/index.cfm?patientinfo=yes>

An online resource provided by the Society of Cardiothoracic Surgeons of Great Britain and Ireland, including facts about heart surgery; and activity and death rates in cardiac surgery for all UK units