

# Anaesthesia for Off-Pump Coronary Artery Bypass Grafting

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## Summary

Off-pump coronary artery bypass graft (OPCAB) surgery has regained popularity because it may avoid some of the complications associated with cardiopulmonary bypass (CPB). There are also potential cost savings to the patient and these factors have led surgeons to re-examine the procedure to counteract the rapidly developing competition of cardiological revascularisation by angioplasty and stenting. The technique of anaesthesia for OPCAB surgery has evolved to meet the surgical advances that have taken place. The major challenge faced by anaesthesiologists is in the prevention, early diagnosis and treatment of arrhythmias associated with manipulation of the heart that is integral to this type of surgery.

## Historical perspective

Off-Pump coronary artery bypass graft surgery (OPCAB) falls into that common medical category of The Reinvented Procedure. In fact the very first coronary bypass surgery was done off-pump, because cardiopulmonary bypass was not available. In 1946, Arthur Vineberg described the technique of tunnelling the pedicle of the internal mammary artery (IMA) into the myocardium in the hope that anastomoses would form between its branches and the coronary arteries. The operation was more successful than one would think and when coronary angiography was developed in the 1960s, long term patency of these grafts was demonstrated in 70-80% of cases.

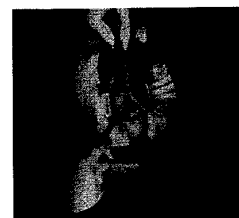
The first truly successful and broadly accepted operation for coronary artery disease (CAD) was coronary artery bypass graft (CABG) using a segment of saphenous vein interposed between the ascending aorta and the coronary artery distal to the obstructing lesion. This was performed by David Sabiston of Duke University in 1962. With the use of the recently developed technique of cardio-pulmonary bypass (CPB), CABG became a widely used treatment for CAD. It was felt that CPB with aortic cross clamping and cardiac arrest, facilitated performing delicate anastomoses on the relatively small coronary arteries. Nonetheless, surgeons have been performing CABG surgery without bypass since the inception of the operation. In 1967, Kolessov reported his experience in anastomosing the IMA to the left anterior descending coronary artery (LAD) on the beating heart in 6 patients. Subsequently, the procedure continued to be performed but it was always felt that the quality and long-term patency of the grafts was not as good as those done on a non-beating heart under CPB.

The development of angioplasty and stenting in the 1980s and 1990s provided the cardiologists with an alternative treatment to CABG for CAD that would avoid the high cost of the surgical procedure,

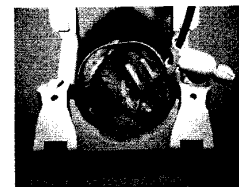
both monetary and in terms of morbidity and mortality cost to the patient. It has been shown in many studies that although the two modalities had similar short-term results for angina relief, CABG had a higher initial cost but produced longer lasting relief, whereas angioplasty had a lower initial cost but required more frequent interventions in the ensuing years. Surgeons were therefore interested in developing a procedure that could provide patients with the most durable revascularisation, that of the LIMA to LAD CABG, at re-

### Jack Shanewise, Associate Professor at Emory University, views the development of CABG without CPB as occurring in three stages

**Figure 1:** The early stage: Grafts were limited to easily accessible vessels on the anterior and inferior aspects of the heart. Some stabilisation of the anastomotic site was provided with retraction sutures (Figure 1), but surgeons relied on pharmacological stabilisation to facilitate surgery. Beta antagonists were given to slow the heart rate and decrease the force of contraction and adenosine was given to induce brief periods of asystole, during which time the surgeon could apply a few difficult sutures.



**Figure 2:** The stabilisation stage: Development of effective stabilisers during the late 1990s made pharmacological stabilisation unnecessary (Figure 2). Instruments used today combine a sternal retractor and a stabilisation device, which either presses down or pulls up (via suction) via tines on either side of the coronary artery to be grafted.



**Figure 3:** The retractor stage: Retraction techniques involve suturing a stockinette sling in the pericardial well to allow displacement of the apex of the heart out of the chest (Figure 3) [Reference 1]. This technique provided access to all of the coronary arteries without CPB.



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duced cost and length of stay which could compete with coronary angioplasty (Figures 1,2,3).

This interest led to the development of techniques such as minimally invasive direct coronary artery surgery (MIDCAB), surgery via a small anterior thoracotomy for treatment of single LAD disease with a LIMA to LAD graft, and OPCAB, where multiple vessels may be grafted via a full sternotomy on a beating heart. Various tech-

niques have been developed to stabilise the beating heart so that the results of grafting will approximate those done on arrested hearts on CPB.

Anaesthesia for OPCAB has evolved as a result of the surgical advances that have taken place.

Anaesthesiologists have had to adapt their techniques, not only to ensure that the patient's passage through the operation is safe but

**Table 1 : Anaesthesia Sequence**

Preoperative Assessment	Assessment of the patient should include review of the angiogram and discussion of the order of grafting with the surgeon.
Premedication	Diazepam 0.1 mg/kg PO Cyclimorph 0.1mg/kg IMI on call to theatre
Theatre preparation	CPB machine ready for quick set up and perfusionist in attendance. Dry set up may be employed in some cases and full set up used if regular CABG with CPB is to follow OPCAB. Current cost of the oxygenator is R16,000.00
Patient preparation	1. External defibrillator pads – may save time in the event of ventricular fibrillation. Internal paddles should also be available and connected to the defibrillator. 2. IV 14 G peripheral line. Ringers Lactate 1000 ml via fluid warmer and high capacity extension. 3. 18 g radial artery cannula 4. 4 lumen central line via right internal jugular vein 5. 8,5 F sheath via right internal jugular vein. To be used for Continuous Cardiac Output (CCO) Pulmonary Artery Catheter. All lines are put up under full sterile precautions and the infusion of the prophylactic antibiotic is started as soon as the first IV line is secure.
Induction and maintenance of anaesthesia	Induction and maintenance of anaesthesia should be tailored to suit the extubation protocols followed by individual institutions. Our regimen is as follows : 1. Midazolam (0.1 mg/kg) or Hypnomidate induction 2. Rocuronium muscle relaxant to preserve slow heart rate 3. Remifentanyl infusion with fentanyl ( 6 –10 mcg/kg ) or sufentanyl ( 2 – 3 mcg/kg) added. Remifentanyl is commenced at 1 mcg/kg/min until intubation has been achieved and then reduced to 0.1 – 0.5 mcg/kg/min (depending on how much extra opiate has been added) 4. Isoflurane (0.75 – 1.2 %) 5. Normal Saline /5% Dextrose with 4g Magnesium Sulphate per litre commenced at 100 ml/hour With this technique, the only drug that has to be added if CPB has to be utilised, is Midazolam (0.2 – 1.0 mg/kg)
Monitoring	Standard minimal monitoring and 5 lead ECG with ST segment analysis
Pulmonary artery catheter	1.CCO pulmonary artery catheter is placed via 8,5 f sheath once the patient is asleep 2. Mixed venous saturation (SVO2) oximeter is calibrated 3. Serum potassium is checked and corrected to approximate a value of 4.8 mmol/l
Baseline TEE Exam	Comprehensive baseline TEE exam performed. This includes assessment of regional wall motion abnormalities with particular attention paid to the areas supplied by the vessels to be grafted.
Temperature monitoring and conservation	1. Core temperature monitored via urinary catheter tip probe 2. Forced air warming device attached via a sterile lower body blanket once vein harvesting from lower legs is complete 3. IV fluids given via a hot-line fluid warmer (41 Celsius) 4. Head covered with drapes 5. HME and low flow anaesthesia
Skin incision and sternotomy	Bolus of remifentanyl if necessary
Preparation for coronary grafting	All patients receive 1 mg/kg Heparin prior to grafting. The ACT should be doubled from 120 to more than 250 seconds. The potassium level is rechecked and hypokalaemia treated appropriately. There is often a period of haemodynamic instability while the surgeon manipulates the heart initially. If this does not improve when the heart is returned to the pericardium, it may signal future problems that may occur during grafting.
Treatment of arrhythmias	All arrhythmias must be diagnosed and treated immediately (Table 2). Any arrhythmia may occur and all will cause some degree of haemodynamic instability. Even a nodal rhythm will cause hypotension because of the loss of the atrial filling component of left ventricular preload is as much as 40 -50% in the presence of myocardial ischaemia and the resultant loss of myocardial compliance.
Distal coronary anastomoses	Prevent a drop in cardiac output of more than 20% by: Ensuring adequate preload during heart manipulation: 1.Tilt the patient 20 degrees head down to improve blood return to the right side of the heart 2. Infuse colloid if necessary Ensure adequate contractility by infusion of inotropes. Low dose adrenalin and phenylephrine infusion is usually sufficient to maintain CO.
Proximal coronary anastomoses	The systolic blood pressure should be reduced to 95-100 mmHg prior to side clamping of the aorta.
Post grafting	The heparin is partially or fully reversed with protamine sulphate. An ACT of 150 s is usually necessary to prevent bleeding, but one should bear in mind that the graft anastomoses are not protected by the relative haemostatic disruption that normally follows CPB and that a moderately prolonged ACT may protect the anastomoses until endothelialisation has taken place ( 4-6 hours).
Blood conservation	All spilled blood is sucked up into a cell-saver reservoir and if there is sufficient collected at the end of the procedure (approximately 350 ml or more, a centrifuge bowl is added and the red cell fraction is spun off and returned to the patient.
Post op TEE exam	All patients have a routine post anastomosis TEE exam to check regional wall motion.

also to meet the changing emphasis on the financial aspects of the treatment of CAD. There has been a flood of recent publications relating to the anaesthesia for OPCAB and the only consistent factor has been that each technique differs from the next.<sup>5</sup> There are many instances where the South African requirements differ from the international experience and it may be useful to discuss local techniques.

The technique of MIDCAB has largely been abandoned because of the difficulty in dealing with complications in a timeous manner because of the limited access. For example, ventricular fibrillation becomes a potentially fatal problem as access to the heart for defibrillation is difficult and conversion to CPB would take too long if a resistant VF were to occur. In addition, bleeding may be difficult to control, particularly from the proximal end of the mammary bed. Another reason for avoiding the MIDCAB approach is that cardiologists are performing angioplasty and stenting when a single LAD lesion is present and refer only the more difficult lesions and multiple vessel disease for surgery. These factors make OPCAB a safer option.

### Anaesthesia for OPCAB

The anaesthetic technique for OPCAB will be described with emphasis on the common problems faced by the anaesthesiologist and the methods available for their prevention and treatment. The analgesic technique used should be determined by the postoperative ventilatory requirements. In our institution, all patients are ventilated for four hours postoperatively. At that stage a decision is made on whether to begin the weaning process or to ventilate the patient overnight and extubate the next morning. The technique used for anaesthesia and analgesia allows for the flexibility to make this decision. Whatever technique is used, it may be useful to consider the approach of Glenn Gravlee as discussed in his presentation "New Approaches to Cardiac Surgery", delivered at the 2001 ASA Refresher Course.<sup>10</sup>

"Remifentanyl infusions offer the potential haemodynamic stability and stress response suppression of old-fashioned high dose opioid anaesthesia without incurring the liability of prolonged post-operative respiratory depression and ventilator support. My opinion is that this technique is best applied over an opioid "foundation" using a longer acting agent such as fentanyl or morphine, because the rapid resolution of remifentanyl's clinical action can lead to a profoundly rapid onset of pain and a sudden stress response somewhat analogous to reversing fentanyl or morphine with a 0.4mg bolus of naloxone." Another technique would be the use of a thoracic epidural (see SAJAA Volume 7, Number 3, September 2001).

Our anaesthetic technique is described in Table 1, but some aspects require further discussion.

### Ischaemia during grafting

The most important factor that defines anaesthesia for OPCAB is that myocardial ischaemia occurs as a direct result of the surgery and will continue until the graft is opened and flow to the coronary artery is reconstituted. The involved coronary artery is occluded completely during anastomosis to prevent bleeding into the operative field. This results in complete ischaemia to the myocardium supplied by the vessel. Cardiac arrhythmias occur as a consequence of the ischaemia and unless diagnosed early and treated aggressively, may prove fatal. It is worth having studied the pre-operative angiogram as the degree of stenosis of a particular vessel may determine the outcome of this occlusion. For example, a severely stenosed vessel (>90%) may lead to less severe myocardial ischaemia when occluded than a vessel with only 60-70% stenosis. The reason for this is that a collateral circulation is more likely to have developed with the more severe

stenosis and may prevent ischaemia during the occlusion.<sup>2</sup>

### Ischaemic preconditioning (IPC)

IPC was the first reproducible form of cardioprotection to be described. It is the most powerful cardioprotective intervention available, more so than any pharmacological agent tested so far. Two phases of IPC are known to exist:

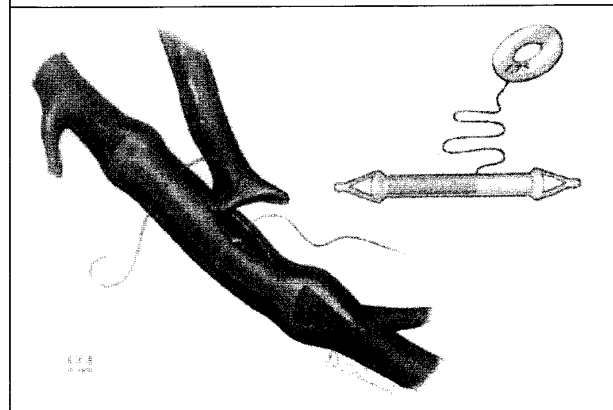
1. An early phase, which develops within minutes of the ischaemic stimulus and lasts 1 to 2 hours.
2. A late phase, which develops more slowly, 12 to 24 hours after the ischaemic stimulus and lasts 72 hours.

Several signalling intermediaries and mediators have been identified, including adenosine, nitric oxide, protein kinase C and potassium adenosine triphosphate (K ATP) channels. The mechanism appears to involve slowing ATP depletion in the myocardium. Several studies have shown its usefulness in clinical practice, including cardiac surgery. Indeed, the early phase of IPC is used in OPCAB to protect the myocardium from ischaemia during grafting of the distal anastomosis. Either the aorta is cross-clamped or an occlusive suture is placed around the coronary artery to be grafted. The occlusion lasts for 2 to 3 minutes and this is followed by a period of reperfusion for 3 minutes, after which the occlusion may be reapplied for another 2 to 3 minutes. This IPC protects the myocardium by preserving ATP during the occlusion of the coronary artery while grafting takes place.<sup>3</sup>

### Intra Coronary Shunts

Intra coronary shunts were developed to allow for a relatively bloodless field and yet maintain distal blood flow during grafting. Even with the intra-coronary shunts, ventricular fibrillation remains a dreaded complication. The reason for this is that cardiac output is usually reduced during the grafting period and as a consequence, coronary blood flow falls and myocardial ischaemia ensues (Figure 4).

Figure 4 : Intra-coronary shunt used to maintain distal blood flow during grafting



### Cardiac output during heart manipulation

There are many factors conspiring to reduce the cardiac output:

1. The pre-load falls as a result of obstruction to venous return because of the manipulation of the heart. To counter this, the anaesthetist has to ensure adequate intravascular volume by judicious volume loading and use of the Trendelenberg position. The surgeon may also incise the right side of the pericardium to allow displacement of the right atrium into the right thorax to prevent obstruction of venous return.

2. Myocardial contractility is reduced by several factors including ischaemia and pharmacological agents such as beta antagonists and antiarrhythmic agents.

**Continuous cardiac output monitoring**

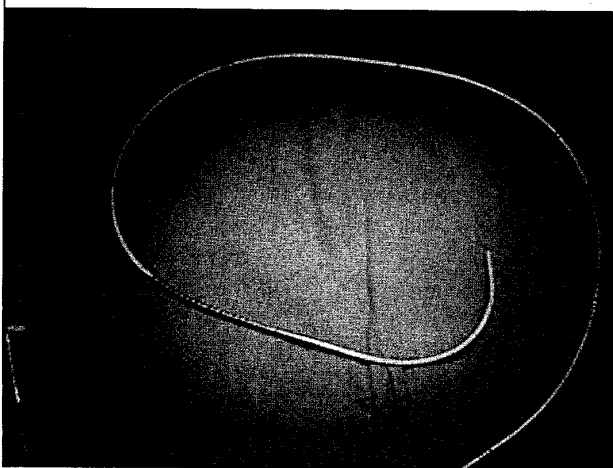
Because the cardiac output is so important during grafting it is logical to measure this parameter during the procedure. A continuous cardiac output (CCO) thermodilution pulmonary artery catheter with oximetric mixed venous saturation (SVO<sub>2</sub>) measurement is a reliable and accurate way to measure CO, if the facility is available. The catheter uses a built in thermal filament to heat the blood every 30-60 seconds and measures change in temperature at the tip of the catheter via a thermistor (Figure 5). A wash-out curve is generated and the CCO calculated from the area under the curve. The CCO is updated every 30-60 seconds. This updated value reflects an average of the last 3-6 minutes of cardiac output data that has been collected. This "time averaging" technique means that a change in CCO will be reflected in 3-6 minutes. The results are displayed graphically as CO or cardiac index (CI). In addition, the SVO<sub>2</sub> is measured continuously and if all other factors are stable, changes in CO are registered instantaneously by changes in the SVO<sub>2</sub>.

The manipulation of the heart is accompanied by a predictable fall in the CI of 20% from the baseline and only returns to the baseline level once the heart is returned to its proper place in the pericardium. This is preceded by a fall in the SVO<sub>2</sub>.

Despite the commonly held view that surgery to the lateral and posterior parts of the heart is associated with more haemodynamic instability than surgery on the anterior aspect, reports have shown the contrary. One study showed that the CI fell equally, by 17%, during surgery on the Left Anterior Descending artery (LAD), the Circumflex (Cx) and Right Coronary Artery (RCA) systems.<sup>6</sup>

The CI should be managed with inotropic support and volume loading, at least to prevent a continued fall and at best to improve it. If the CI continues to fall, progressive myocardial ischaemia will occur and increase the chances of ventricular ectopy and fibrillation (Figure 5).

Figure 5: Continuous cardiac output thermodilution catheter showing built in thermal filament.

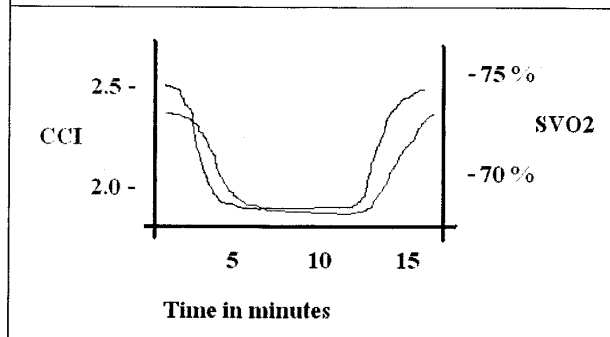


**SVO<sub>2</sub> monitoring**

Critics of CCO monitoring point out that changes in the CO are registered too slowly to be useful in the rapidly changing environment of OPCAB surgery.

SVO<sub>2</sub> monitoring is used to complement CCO monitoring be-

Graph showing predictable drop in CCI and SVO<sub>2</sub> during manipulation of the heart.



Graph showing pattern of CCI and SVO<sub>2</sub> during double vessel grafting, with return to the baseline when the heart is returned to its normal position in the pericardium

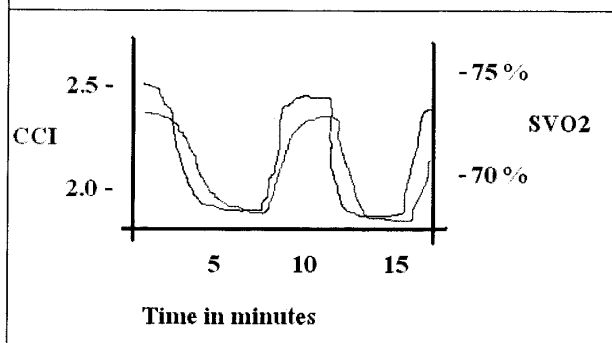
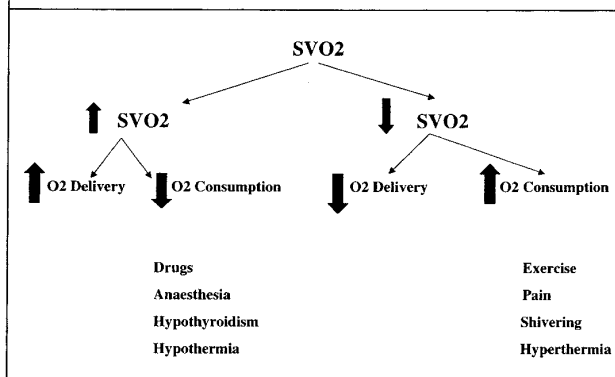


Diagram 1: Showing causes of change in SVO<sub>2</sub>



cause acute changes in CO are registered more rapidly by changes in the SVO<sub>2</sub>.

A decrease in SVO<sub>2</sub> is caused by a decrease in oxygen delivery or an increase in oxygen consumption (Diagram 1).

A decrease in oxygen delivery is caused by a decrease in arterial oxygenation and a decrease in CO. Therefore, under constant anaesthetic conditions during manipulation of the heart, a sudden drop in SVO<sub>2</sub> is caused by a drop in the CO (Diagram 2). These changes typically precede the changes in CCO by a few minutes. The SVO<sub>2</sub> therefore is used to monitor acute changes in CO and the CCO to confirm the changes and provide a trend of CO. The combination of CCO and SVO<sub>2</sub> monitoring provides a very useful monitor of CO during this period.

Diagram 2: Showing relationship between drop in SVO<sub>2</sub> and Cardiac Output

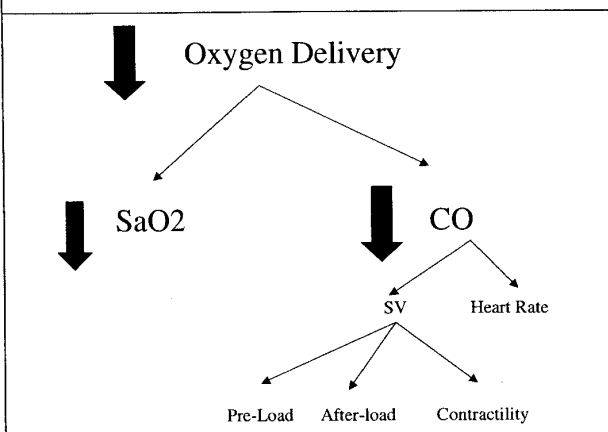
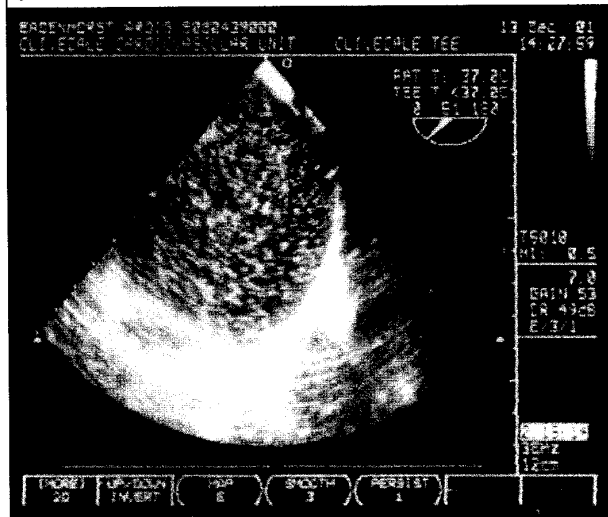


Figure 6: Transoesophageal echo showing artefact caused by saline filled glove used to stabilise the heart during grafting



**Transoesophageal Echocardiography**

An alternative to CCO and SVO<sub>2</sub> monitoring is intraoperative transoesophageal echocardiography (TEE). This provides a useful continuous monitor of myocardial blood supply via assessment of regional wall motion. Unfortunately, clear visualisation of the left ventricle, via the typical transgastric short axis views, is not always possible when the heart is being manipulated (Figure 6). Use of the omniplane TEE probe has been shown to improve visualisation via mid-oesophageal long axis views of the left ventricle.

In our unit, surgical exposure is aided by a saline filled glove, which is placed behind the heart during grafting and makes proper TEE visualisation almost impossible. We therefore rely exclusively on CCO as a monitor of CO during grafting.

**Treatment of arrhythmias**

All arrhythmias have the potential for causing haemodynamic catastrophe during OPCAB surgery. The anaesthesiologist has to adopt a “beat to beat” monitoring attitude and no arrhythmia must be allowed to go undetected and untreated. Careful attention must be paid to electrolyte and acid base disturbance as well as myocardial ischaemia and CO. Magnesium sulphate infusion has been shown to be useful to prevent and treat both atrial and ventricular arrhythmias during OPCAB surgery.<sup>8,9,12</sup> The most important factor is constant communication with the surgeon. See Table II for a more detailed discussion of arrhythmias and their treatment.

**Postoperative extubation**

There have been many recent publications proving the safety and cost savings of fast track and ultra fast track anaesthesia for OPCAB surgery.<sup>11,13,14</sup> Fast track anaesthesia results in extubation 1 to 6 hours post operatively. With ultra fast track techniques, the patient is extubated in the operating theatre. Very few of these publications describe the level of active management necessary to avoid the major haemodynamic events that are very common during this period. The only way to ensure that these events do not take place, is for the anaesthetist to be in attendance up to the time of extubation. In addition, the staffing ratios of the intensive care units are generally seven

Table II: Arrhythmias and their treatment<sup>7,8,9,12</sup>

Arrhythmia	Consequences	Treatment
Atrial fibrillation (AF) Contributing factors: 1. elevated circulating catecholamine and electrolyte disturbances 2. systemic inflammatory mediator release 3. direct irritation and inflammation of the atria after incision of the pericardium.	1. Atrial contraction may contribute up to 50% of LV stroke volume during OPCAB surgery. Loss of this contribution in AF will result in decreased CO. 2. Rapid ventricular response and exacerbation of ischaemia	1. Recheck potassium levels and infuse K to achieve levels of approximately 4.8 mmol/l. 2. Magnesium sulphate – infusion of up to 10g per day 3. Amiodarone 300mg IV infusion over 30 minutes as a loading dose, followed by 1200mg over 24 hours. Effective prophylaxis in CABG surgery. Increases rate of conversion to sinus rhythm. Proarrhythmia and pulmonary toxicity rare but acute pulmonary toxicity has a mortality rate >50%. 4. Beta antagonist prophylaxis such as Sotalol (should be given incrementally in 1-5 mg boluses to avoid hypotension) Magnesium and beta antagonists may have an additive effect. 5. DC shock
AV conduction block and nodal rhythm.	Loss of atrial contribution and decreased CO.	Dual chamber Pacemaker
Ventricular ectopy.	May be benign, but may herald onset of ventricular fibrillation.	1. Recheck potassium levels 2. Magnesium sulphate : less required to prevent ventricular arrhythmias than atrial (2 – 3g) Hypomagnesaemia is caused by perioperative diuretics, sympathetic stimulation and exogenous catecholamines. 3. Lignocaine 4. Amiodarone 5. Sotalol
Ventricular fibrillation		DC shock. Conversion to CPB may be necessary if VF is resistant to treatment.

Post operative course	The patient is transferred to the CT ICU fully anaesthetised and is placed on a ventilator for a period of four hours. At that time a decision is made on whether to start the weaning process or to electively ventilate until the next morning. Propofol and morphine (0.1 mg/kg/four hours) infusions are routinely used up to the time of extubation. Remifentanyl is continued at 0.1 mcg/kg/min until the syringe is complete or until the time of weaning from the ventilator, when it is weaned prior to extubation.
Temperature	Patients after OPCAB do not usually have the same temperature rise postoperatively as those following CPB (37.5°C in OPCAB cf 38.5°C following CPB). However they will shiver if they are woken up prematurely and their core temp has not yet reached 37.5°C. All patients should have a forced-air warming device used until this temperature has been achieved. In one study on patients who had non-cardiac, major surgery it was shown that there is a higher incidence of myocardial ischaemia postoperatively at mean core temperatures of 35.4 Celcius compared to 36.7°C.
Pain control	Should be optimised using a multimodal approach, before the weaning process begins <sup>13</sup> Thoracic epidural analgesia has been used successfully to facilitate fast and ultra fast track anaesthesia. Insertion of an epidural catheter is generally regarded as safe, provided that platelet count and function are normal and coagulation study results are within normal limits, even if subsequent anticoagulation is planned. Currently accepted practice is to place the catheter one hour prior to heparinisation and to delay surgery for 24 hours if a bloody tap occurs. <sup>11</sup>
Haemodynamic parameters	1. Inotropes and vasoconstrictors should be in the process of being weaned to low dose or off. 2. Balloon pump should be in the process of being weaned
Bleeding	Should be less than 100 ml/hr during first four hours
Extubation criteria	The patient should be awake, pain free and haemodynamically stable and meet conventional mechanical and biochemical criteria for extubation.

nurses per bed – levels that are not possible in our environment (our unit has a ratio of 1.5 per bed). We have chosen the (paradoxically,) relatively safer route of keeping the patient anaesthetised for 4 hours postoperatively and then deciding on whether to extubate or ventilate over night and extubate the following morning.

Whichever track is adopted, there is growing use in North America of the Integrated Post Cardiac Surgical Unit, where there is a flexible nursing ratio for different acuity levels in the same physical area (nurse to patient ratio of 1:1 for ventilated patients and 1:2 for extubated patients). We make use of this concept and charge the patients accordingly, so that once they are extubated they are charged high care rates without being moved from the ICU (Table III).

### Conclusion

OPCAB surgery presents the anaesthesiologist with a unique opportunity to be closely involved with the decision making and management of patients with coronary artery disease. This is particularly important at the time of grafting of the distal coronary anastomoses when the potential for ventricular fibrillation is a constant possibility. Electrolytes and CO must be scrupulously monitored to prevent arrhythmias and their prompt diagnosis and treatment is essential to avoid the sequelae of ventricular fibrillation.

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