Anaesthesia for off-pump coronary artery bypass grafting

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Abstract

Achieving surgical revascularization of the heart, while avoiding the insult of cardiopulmonary bypass, is particularly desirable in specific high-risk patient groups. The relatively recent advances in surgical technique allowing high-quality grafting without mechanical arrest have led to an increase in popularity of off-pump coronary artery bypass surgery. Nonetheless, operating on the beating heart, manipulating it and purposely inducing ischaemia, invariably has significant haemodynamic consequences which must be carefully yet aggressively managed. To compound the situation, the intraoperative monitoring typically employed to evaluate cardiac function, such as electrocardiography and echocardiography, are of limited efficacy at crucial moments in the procedure. It is therefore essential that the anaesthetist is able to assimilate information from a multitude of sources in order to safely navigate the patient through a period of continually changing cardiovascular stress.

Keywords Cardiopulmonary bypass; coronary artery bypass; ischaemic preconditioning; myocardial reperfusion; myocardial revascularization; off-pump coronary artery bypass

Royal College of Anaesthetists CPD Matrix: 3G00, 2G01

Learning objectives

After reading this article, you should be able to:
- identify the respective benefits of on- and off-pump coronary artery bypass surgery
- understand the causes and management of haemodynamic instability in off-pump surgery
- appreciate a suitable technique for delivering anaesthesia in off-pump surgery
- recognize the paramount importance of communication between surgeon and anaesthetist

In 1946, the Canadian Arthur Vineburg grafted the internal mammary artery into the beating heart in an effort to promote spontaneous anastomoses with the coronary arteries. Two decades later cardiopulmonary bypass (CPB) was invented, and with a motionless, bloodless field, surgeons were able to delicately graft donor site vessels to the myocardium and perform formal anastomoses with the coronary vasculature. Despite the success of CPB, the inherent problems with cardioplegia and with exposing blood to an artificial circulation have driven advancement in off-pump coronary artery bypass (OPCAB) techniques. In recent years, new surgical devices have been introduced which stabilize and immobilize regional motion while the heart continues to operate as an effective pump. Such devices have improved graft integrity and allowed OPCAB to become a viable interventional option, should the requisite surgical expertise be available.

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The advantages of an OPCAB technique include no requirement for arterial and venous cannulation, no exposure of blood to artificial membranes and no use of cardioplegia solutions to stop the heart. Subsequently, this results in a reduction in coagulopathy and inflammatory mediator activation, along with greater preservation of homeostatic norms such as serum electrolyte and acid-base balance. Simultaneously, however, OPCAB might be regarded as a distinctly challenging and unattractive option as time-pressured microvascular surgery on a moving target is clearly a suboptimal environment for producing grafts of quality and durability.

Numerous meta-analyses have been conducted to resolve the on-pump versus off-pump debate. Both can be considered safe surgery with mortality rates less than 2%.[1] OPCAB shows a trend to earlier extubation, shorter ICU and hospital length of stay, and reduced bleeding.[1] There also appears to be a lower incidence of both stroke and renal dysfunction. However, graft viability, as expected, is superior in on-pump surgery.[1] Aside from these points, differences in the majority of complications, including all-cause mortality, do not meet statistical significance in either group (Table 1). Consequently, the most consistent recommendation from the many meta-analyses is that the decision between techniques should be tailored to the individual patient. For example, OPCAB could be preferential in the elderly.[2] While in contrast, an on-pump CABG might benefit a younger patient. This is because the latter population is physiologically better equipped to overcome the insult of CPB, and will benefit more from longer-term graft durability.

Ultimately, however, surgical skill is the most important consideration, and without a definitive outcome benefit to support OPCAB, many centres provide an exclusively on-pump service.

Surgery

For grafting of multiple vessels, a full median sternotomy is performed. Typically, the heart is enucleated, re-orientated and suspended anteriorly in a cradling device. The target wall is then immobilized and stabilized, allowing grafting and anastomoses, while the cardiac cycle continues uninterrupted.

The left internal mammary artery (LIMA) is most commonly grafted to the left anterior descending artery (LAD). Grafting of the radial artery or saphenous vein requires proximal anastomosis to the ascending aorta, which necessitates application of an aortic side clamp. All distal anastomoses require clamping of

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Data from meta-analysis by Deppe et al., 2016. Comparison of outcomes in off-pump vs. on-pump CABG

Adverse event	Odds ratio (95% CI)	*p*-value
All-cause mortality	0.86 (0.69–1.06)	0.1606
Cardiac related mortality	0.94 (0.66–1.32)	0.7795
Repeat revascularization	**1.87 (1.13–3.11)**	**0.0176**
Re-thoracotomy	0.82 (0.64–1.04)	0.1099
Cerebrovascular accident	**0.74 (0.58–0.95)**	**0.0186**
Renal dysfunction	**0.79 (0.71–0.89)**	**0.0003**
Renal replacement	0.78 (0.58–1.04)	0.0945
Infection	**0.72 (0.60–0.85)**	**<0.0001**
Blood transfusion requirement	**0.60 (0.47 to 0.75)**	**<0.0001**

OR $<$ 1 favours off-pump and OR $>$ 1 favours on-pump. Outcomes which reached statistical significance are highlighted

Table 1

the respective coronary artery and thus interruption of myocardial blood supply.

Minimally invasive cardiac bypass

Minimally invasive direct-access coronary artery bypass grafting (MIDCAB) is a single vessel anastomosis of the LIMA to the LAD. Access is gained by a small thoracotomy and necessitates collapse of the left lung (and thus a double-lumen endotracheal tube). The graft requires relatively little manipulation of the heart and is therefore attractive in terms of maintaining physiological normality. That aside, the complexity of the procedure which produces only a single graft means it is rarely considered, especially given the now widespread availability of percutaneous coronary intervention.

Physiological consequences of surgery

Diastolic dysfunction

Surgical access during LAD grafting requires minimal manipulation of the heart and so cardiac output is largely unchecked. However, for grafting to the right coronary artery (RCA) and circumflex (CFX), the posterior and lateral walls must be respectively exposed. To achieve this, the heart is lifted and then angled up vertically with the atria at the base. Blood must flow *uphill* and thus a significant increase in atrial pressures is observed, with inevitable impairment of ventricular filling.

Systolic dysfunction

Once the heart has been repositioned, the target wall is immobilized to improve surgical conditions for anastomosis. This enforced regional wall motion abnormality (RWMA), imposes limits upon ventricular contraction and thus stroke volume. The degree of clinical affect is related to the area of myocardium immobilized. Lateral and anterior walls are responsible for the majority of ventricular contraction, thus immobilization for grafting to the CFX or LAD, have the most adverse consequences for cardiac output.

Valvular incompetence

Both the use of a stabilization device and reorientation of the heart into the vertical position can lead to significant valvular dysfunction, particularly of the mitral and tricuspid valves. This will be more pronounced in valves with pre-existing pathology.

Ischaemia

In order to produce a bloodless field for anastomosis, coronary artery cross-clamping is required. This has the inevitable consequence of myocardial ischaemia. The magnitude of this effect is inversely related to the adequacy of the pre-existing supply. This is to say, that clamping of a heavily stenosed vessel will induce less local ischaemia due to both adaption of the tissue and improved collateral supply.

The consequence of ischaemia is dependent on the territory involved. Artificial occlusion of the LAD or CFX may lead to RWMA. However, this may not be as detrimental to cardiac output as a dysrhythmia propagating from pacemaker cell ischaemia secondary to RCA occlusion.

There are several approaches used to reduce myocardial ischaemia during coronary cross-clamping:

Optimizing oxygen delivery/consumption to the myocardium: perfusion of the remaining coronary vessels should be maximized by aggressively defending diastolic blood pressure. This can be achieved through infusion of a vasopressor such as metaraminol, phenylephrine or noradrenaline. Such an infusion will inevitably increase afterload and thus myocardial work and oxygen consumption. Subsequently, a balance must be struck, with a MAP of 70 mmHg usually considered an appropriate target.

Additionally, beta-blockers are commonly administered perioperatively. Through direct reduction in myocardial workload, they increase myocardial tolerance of ischaemia. Furthermore, the slower heart rate will improve the surgical field. Metoprolol or, alternatively esmolol, are both highly effective choices.

Myocardial perfusion might also be increased through dilation of the coronary vessels. Unfortunately, drugs which achieve this, such as glyceryl trinitrate, invariably cause a degree of systemic vasodilation and preload reduction. Adequate preload is essential to maintaining forward flow when the heart is repositioned, and therefore such drugs are best avoided.

Preconditioning:

- **Ischaemic preconditioning**: Intentional surgical occlusion of the target coronary vessel for 2 minutes, followed by a 3-minute reperfusion time, invokes a signalling change in chemical intermediaries within the myocardium. The result is a decrease in the rate of ATP consumption and subsequently increased tolerance to periods of ischaemia. This protection is immediate but dissipates after 1–2 hours. There is then a delayed effect at around 24 hours. It is less powerful but may last up to 72 hours.
- **Pharmacological preconditioning**: Halogenated ethers, such as isoflurane and sevoflurane, confer a cardioprotective effect, seemingly through a preconditioning mechanism similar to the above. Subsequently, a vapour-based approach to maintenance of anaesthesia, seems preferable to total intravenous anaesthesia, although this is not supported by robust clinical evidence. Opioids also demonstrate a propensity to precondition the myocardium.

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