Cardiopulmonary bypass

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Abstract

The primary function of the cardiopulmonary bypass (CPB) machine is maintaining systemic perfusion while the heart is under manipulation, its chambers are open or it suffers severe dysfunction. The CPB circuit consists of a reservoir, blood pump, oxygenator, heat exchanger, arterial filter, cardioplegia delivery device and cannulae, interconnected by various sized tubing.

Venous cannula re-direct venous blood away from the pulmonary circulation towards the venous reservoirs. A blood (roller or centrifugal) pump impulses blood volume forward through a membrane oxygenator and it allows rapid transfusion of oxygenated blood into the systemic circulation. The CPB flow needs to be enough to maintain an adequate cardiac output, which is normally achieved maintaining a flow of 2.2 litres/minute/m^2 and a mean arterial pressure over 65 mmHg. The mortality and neurological complications after cardiac surgery are similar using either normothermic or hypothermic CPB. However, slow rewarming after hypothermia has been shown to reduce neurocognitive dysfunction. Before separation from CPB, good team communication is essential. A safety checklist that includes optimal temperature, heart rhythm, de-airing, acid-base status, ventilation, electrolytes and patient position should be applied. If heparin was used to maintain anticoagulation, it can be reverted with protamine after the patient is stable off-CPB. Some patients require inotropic or mechanical support to be 'weaned' from CPB.

Keywords Anticoagulation; blood pump; cardiac surgery; cardiopulmonary bypass; oxygenator; reservoir; separation from CPB

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Learning objectives

After reading this article, you should be able to:

- define the function of the cardiopulmonary bypass (CPB) machine and describe its components
- identify the main physiological goals that need to be achieved while patient is connected to CPB, as well as the conditions that need to be present before a safe attempt to separate from CPB
- summarize the main therapeutic strategies to consider when weaning from CPB is difficult

Cardiopulmonary bypass circuit

The primary function of the cardiopulmonary bypass (CPB) machine is to maintain systemic perfusion while the heart is under manipulation, its chambers are open or it suffers severe dysfunction. The heart-lung machine diverts the blood from the native heart (left and right chambers) and the lungs and returns it to the arterial circulation.

The CPB circuit consists of a reservoir, oxygenator, heat exchanger, arterial filter, cardioplegia delivery device and cannulae, interconnected by various sized tubing. The circuit is completed with a blood pump that generates flow. The Society of Clinical Perfusionists of Great Britain and Ireland (SOCPGBI) Standards of Practice *March 2011*,[1] stated that by virtue of the standard of their clinical and technical knowledge and experience, ultimately, the choice of equipment used during perfusion procedures should be made by the most senior clinical perfusion scientist, following appropriate consultation and assessment with other colleagues.

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Venous reservoirs

Venous reservoirs allow the heart to be drained and decompressed during surgery and in some instances, reduce the systemic circulating volumes. Both the open (hard shell — Figure 1) and closed (soft or collapsible) systems rely on gravitational force to drain the venous blood from the patient into the CPB circuit. A height differential between the patient's right atrium and the reservoir is paramount for good venous drainage.

The hard shell has two main benefits. Firstly its passive removal of entrained venous air, and secondly the option of applying vacuum to assist drainage. The open system integrates a cardiotomy and defoaming compartment to process suction blood from the operating field contaminated by lipids and bone fragments along with pleural collections. The benefit of the closed system is reduced inflammatory activation due to blood contact with smaller surface area of artificial surfaces, which may lead to reduce postoperative transfusion of blood products.[2] Therefore, the soft-shell requires a separate cardiotomy for processing suction blood. Modern venous/cardiotomy reservoirs have the ability to selectively separate these collections from the circulating volume and process them via a cell saver.

When an open system is used, a safe level of blood volume in the reservoir is maintained throughout any procedure to avoid air entry into the arterial circuit. The arterial pump must stop functioning when the level in the reservoir is sub-optimal.

Pipes and cannulation strategies

The goal for CPB cannulation is to re-direct venous blood away from the pulmonary circulation towards the CPB circuit and allow for rapid transfusion of oxygenated blood into the systemic circulation. The ascending aorta is the preferred choice for arterial cannulation as it is clearly visible and accessible. The innominate or femoral arteries offer an alternative site for cannulation for complex or repeated surgery procedures. A swing on the perfusion line pressure gauge identical to that of the monitored invasive arterial trace and the transfusion of volume

Figure 1 Open reservoir — combined venous and cardiotomy.

without a raised line pressure demonstrates a good cannulation. The arterial cannulation is normally performed under direct vision (surgical cut down), although thin walled percutaneous arterial cannulae have been developed to be inserted using a Seldinger approach.

Any reduction in the internal diameter increases both resistance to flow and pressure drop at the cannula tip. Thin walled cannulae are wire reinforced to reduce risk of obstruction to flow caused by kinking. The straight single end-holed design has been improved by the addition of curved multiple side-holed tips (Figure 2a and b). These reduce the risk of endothelial damage to the intima when high flows are generated.

For venous cannulation during closed heart operations, a two-staged venous cannula is used (Figure 3). The cannula comprises of a distal fenestrated portion sitting in the inferior vena cava (IVC) draining blood from the lower half of the body, and a larger holed section positioned in the right atrium draining venous blood returning via the superior vena cava (SVC). For surgical

Figure 2 Aortic cannulation. (**a**) Single end-hole design arterial cannula. (**b**) Curved soft flow side hole tip arterial cannula.

procedures that require the chambers of the heart to be opened such as mitral valve surgery or myxoma removal, a single-staged cannula is inserted into both the inferior and superior vena cava and joined by a Y piece. The cavae are snugged and secured around the cannula so that all the venous blood returns to the CPB machine. As venous drainage occurs using gravity, both the internal diameter of the cannula and the height differential between the patients right atrium and the venous reservoir, will have an impact on the drainage performance.

The growth in minimal access open-heart surgery that often may require femoral vein cannulation has encouraged the development of the wire framed Smartcanula® (Smartcanula LLC, Switzerland), whose collapsible wire frame allows easy insertion and its sprung framework reduces blood flow resistance.

Figure 3 Venous cannulation. Observe two-staged venous cannula with side holes above tapered (top) and single-stage venous cannula for bi-caval cannulation (bottom).