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 cannulae in the right atrium or cavae redirect venous blood away from the pulmonary circulation. A blood pump propels the blood volume forward through a membrane oxygenator and allows rapid transfusion of oxygenated blood back 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. 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. Heparin is used to maintain anticoagulation, and should be reversed with protamine after the patient is stable off CPB. Some patients require inotropic or mechanical support to facilitate 'weaning' from CPB.

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

The Royal College of Anaesthetists CPD Matrix: 3G00

Cardiopulmonary bypass circuit

The primary function of the cardiopulmonary bypass (CPB) machine is to provide systemic circulatory and respiratory support whilst allowing surgical intervention to the heart and great vessels. The process of cardiopulmonary bypass diverts the blood away from the heart and the lungs and returns it to the arterial circulation.

The CPB circuit consists of one or two drainage cannulae, a reservoir, oxygenator, heat exchanger, arterial filter, cardioplegia delivery device and return cannulae (Figures 1 and 2). The blood pump integrated into the circuit generates the necessary forward flow to maintain perfusion.

The safe use of CPB requires an expert team consisting of cardiothoracic anaesthetists, surgeons and perfusionists. Perfusionists are clinical scientists who are specially trained to operate the CPB machine, as well as providing support to the anaesthetic and surgical teams with other devices such as cell-savers, intra-aortic balloon pumps, and other advanced forms of mechanical support.

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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
- summarise the main therapeutic strategies to consider when weaning from CPB is difficult

To the uninitiated, the CPB machine can appear to be a mass of tangled tubes and complex machinery. In this review we aim to explain the circuit in a systematic fashion, as well as providing an overview of the practical conduct of CPB, and the safe separation from the heart—lung machine at the conclusion of an operation.

Pipes and cannulation strategies

The goal for CPB cannulation is to redirect venous blood away from the heart and pulmonary circulation towards the CPB circuit and to allow for rapid transfusion of oxygenated blood back into the systemic circulation.

Various types of venous cannulae are available (Figure 3), and the choice largely depends on whether the heart chambers will be opened (e.g. mitral or aortic valve surgery), or closed (e.g. coronary artery bypass grafting (CABG)). For closed heart operations, a two-staged venous cannula is used. The cannula is inserted into the right atrium, with the distal tip placed into the inferior vena cava (IVC) draining blood from the lower half of the body, and a larger fenestrated section positioned in the right atrium draining venous blood returning via the superior vena cava (SVC) and coronary sinus. For surgical procedures that require the chambers of the heart to be opened, two separate cannulae are inserted into the IVC and SVC and these cannulae are then joined by a Y piece. The cavae are secured around the cannula so that all the venous blood returns to the CPB machine. It is important to understand that venous drainage to the CPB machine largely occurs using gravity, so both the internal diameter of the cannula and the height differential between the right atrium and the venous reservoir will have an impact on drainage performance.

An alternative strategy is femoral cannulation, which is often used for newer minimal-access surgical techniques. Specialized cannulae, often incorporating a collapsible wire frame to allow for easier insertion are available.

For return of oxygenated blood from the CPB machine back into the systemic circulation, the preferred choice is the ascending aorta as it is easily accessible. Alternative sites for complex or repeated surgical procedures include the innominate, axillary or femoral arteries.

Arterial cannulation is normally performed under direct vision or via cut-down by the surgeon, although thin-walled percutaneous arterial cannulae have been developed to be inserted using a Seldinger technique.

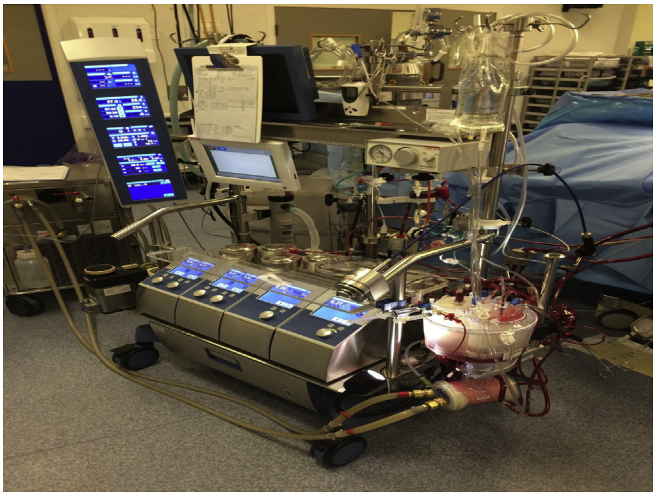

Figure 1 Cardiopulmonary bypass machine.

Figure 3 Observe arterial cannula (top) and two-stage venous cannula (bottom). The diameter of the venous pipe is larger than the arterial cannula.

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. Curved multiple side-holed tips are widely used as these reduce the risk of damage to the intima when high flows are generated.

Venous reservoirs

Venous reservoirs allow the heart to be drained and decompressed during surgery (Figure 4).

There are broadly two types of venous reservoirs — the open ('hard shell') system and the closed ('soft shell') system. The open system is the more commonly used, and has two main benefits: firstly it allows passive removal of entrained venous air, as the venous return drains into an open reservoir. Secondly, it allows the option of applying vacuum to assist drainage. The open system integrates a separate cardiotomy and defoaming circuit to process suction blood acquired from the operating field which may be contaminated by lipids, bone fragments or pleural collections. 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 if the blood volume in the reservoir reaches a critical level.

The closed system has a limited volume capacity, but offers a smaller surface area of blood contact with artificial surfaces or air. This produces less inflammatory activation which may lead to a reduction in postoperative complications and transfusion of blood products.[1] Closed systems however require a separate circuit for processing suction blood.

Blood pumps

The blood pumps in the CPB circuit can be divided into those involved in the generation of systemic flow (driving blood from the venous reservoir through the oxygenator and returning it to the systemic circulation), and those involved in operative suction and cardioplegia delivery.

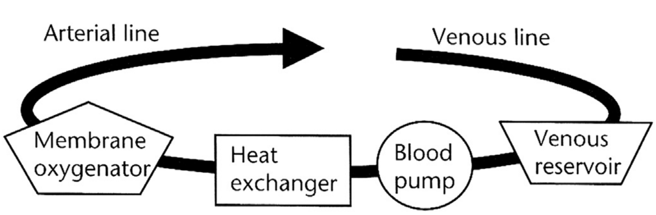

Figure 2 Cardiopulmonary bypass circuit. The venous blood flows into the reservoir, from there the pump propels it through the heater/cooler, then through the oxygenator and finally it goes back to the patient through the arterial cannula. (From MacKay & Arrowsmith, Core Topics in Cardiac Anesthesia 2nd ed., reproduced with kind permission).

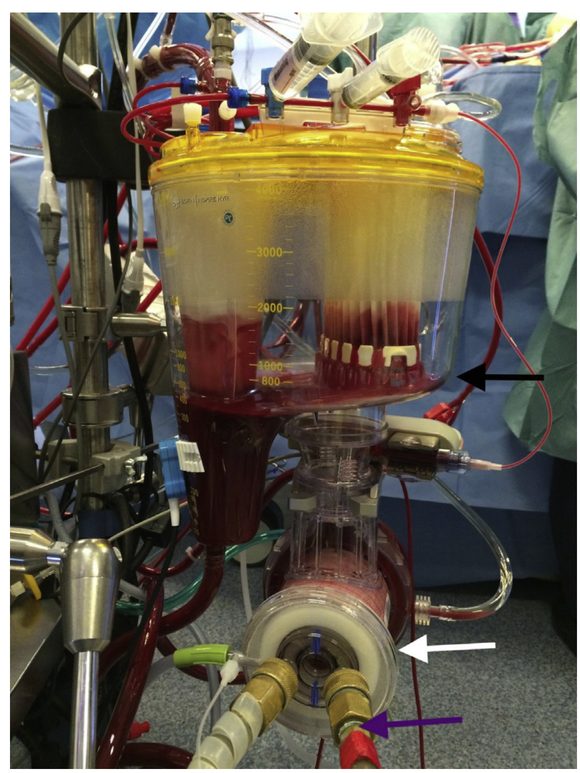

Figure 4 Hard shell venous reservoir with oxygenator and heater/cooler. In the lower part of the reservoir (black arrow) is placed the oxygenator (white arrow) with two water pipes which provides water for the heater exchanger (purple arrow).