Cardiopulmonary bypass

Hannah Kiziltug

Guillermo Martinez

Abstract

The primary function of the cardiopulmonary bypass (CPB) machine is to provide oxygenated blood flow to the systemic circulation while providing the surgeon with a motionless, bloodless surgical field. The CPB circuit consists of a reservoir, blood pump, oxygenator, heat exchanger, arterial filter, cardioplegia delivery device and cannulae, interconnected by various sized tubing. The venous cannula directs blood away from the heart and lungs via the CBP circuit and the arterial cannula returns the oxygenated blood to the systemic 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, therefore a flow of 1.8–2.2 litres/minute/m^2 is recommended when at normothermia, although these flows can be reduced if the temperature is less than 28°C. The mortality and neurological complications after cardiac surgery are similar using either normothermic or hypothermic CPB. Maintenance of anaesthesia on CPB is often achieved with a propofol infusion (sometimes with the addition of remifentanil), but the use of volatile anaesthetic is also possible through the CPB machine. A vaporizer can be attached to the CPB circuit and volatile anaesthetic delivered into the sweep gas passing through the oxygenator. A safety checklist before separation from bypass is essential, and it may include: optimal temperature, heart rhythm, de-airing, acid-base status, ventilation, electrolytes and patient position. If heparin was used to maintain anticoagulation, it 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 anaesthesia; cardiac surgery; cardioplegia; cardiopulmonary bypass; oxygenator; separation from CPB

Royal College of Anaesthetists CPD Matrix: 3G00

Learning objectives

After reading this article, you should be able to:

- describe the function of the cardiopulmonary bypass machine and its components
- understand the main physiological goals and consequences while a patient is connected to CPB, as well as the conditions that need to be present to ensure a safe separation 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 provide oxygenated blood flow to the systemic circulation whilst providing the surgeon with a motionless, bloodless surgical field. The cardiopulmonary bypass system consists of arterial and venous cannulae, a venous reservoir, blood oxygenator, heat exchanger, pumps to propel forward flow, an arterial filter and cardioplegia delivery system as illustrated in Figures 1 and 2.

Although the CPB machine may initially appear complex, familiarization with its different components provides greater understanding and respect for what is in fact a very elegant and efficient system. In this review we will describe the function of the different components of the bypass system along with a practical overview of the conduct of cardiopulmonary bypass and safe separation from the bypass circuit.

Arterial and venous cannula

The venous cannula direct blood away from the heart and lungs via the CBP circuit and the arterial cannula return the oxygenated blood to the systemic circulation.

The type of venous cannula used depends on the nature of the surgery to be performed. For surgery that does not require the heart chambers to be opened (such as coronary artery bypass grafting), two-stage venous cannula is often used. This is inserted through the right atrium with the distal tip lying within the inferior venae cava (IVC). Drainage holes at the distal end drain blood from the IVC while a larger set of holes a few centimetres from the tip sit within the right atrium, draining blood from the superior venae cava (SVC) and coronary sinus. For surgical procedures that require the chambers of the heart to be opened, such as valve surgery, bicaval cannulation is utilized. Two separate single-staged cannulas are placed into the SVC and IVC and connected to a Y-piece. The cavae are secured around both cannulas allowing all the venous blood to be directed into the CBP circuit and providing a heart completely empty of blood. Flow through the cannula is governed by the Hagen–Poiseuille equation with the pressure gradient largely provided by gravity, although vacuum-assisted drainage is gaining prominence as a mechanism to maximize the venous return. The internal diameter of the cannula and the height differential between the right atrium and the venous reservoir will impact on performance.

Femoral venous cannulation is sometimes utilized for more complex surgery. A specialized elongated single stage cannula is passed through the femoral vein and into the IVC to allow venous drainage. The femoral cannula is reinforced with a wire frame to allow for easier insertion.

The arterial cannula returns oxygenated blood from the bypass system to the patient’s systemic circulation. The most common site of arterial cannulation is the ascending aorta as it is

***Hannah Kiziltug** MBChB FRCA is a Senior Clinical Fellow in Cardiothoracic Anaesthesia at Papworth Hospital NHS Foundation Trust, Cambridge, UK. Conflicts of interest: none declared.*

***Guillermo Martinez** MD is a Consultant Anaesthetist at Royal Papworth Hospital NHS Foundation Trust, Cambridge, UK. Conflicts of interest: none declared.*

Please cite this article in press as: Kiziltug H, Martinez G, Cardiopulmonary bypass, Anaesthesia and intensive care medicine (2018), https://doi.org/10.1016/j.mpaic.2018.04.008

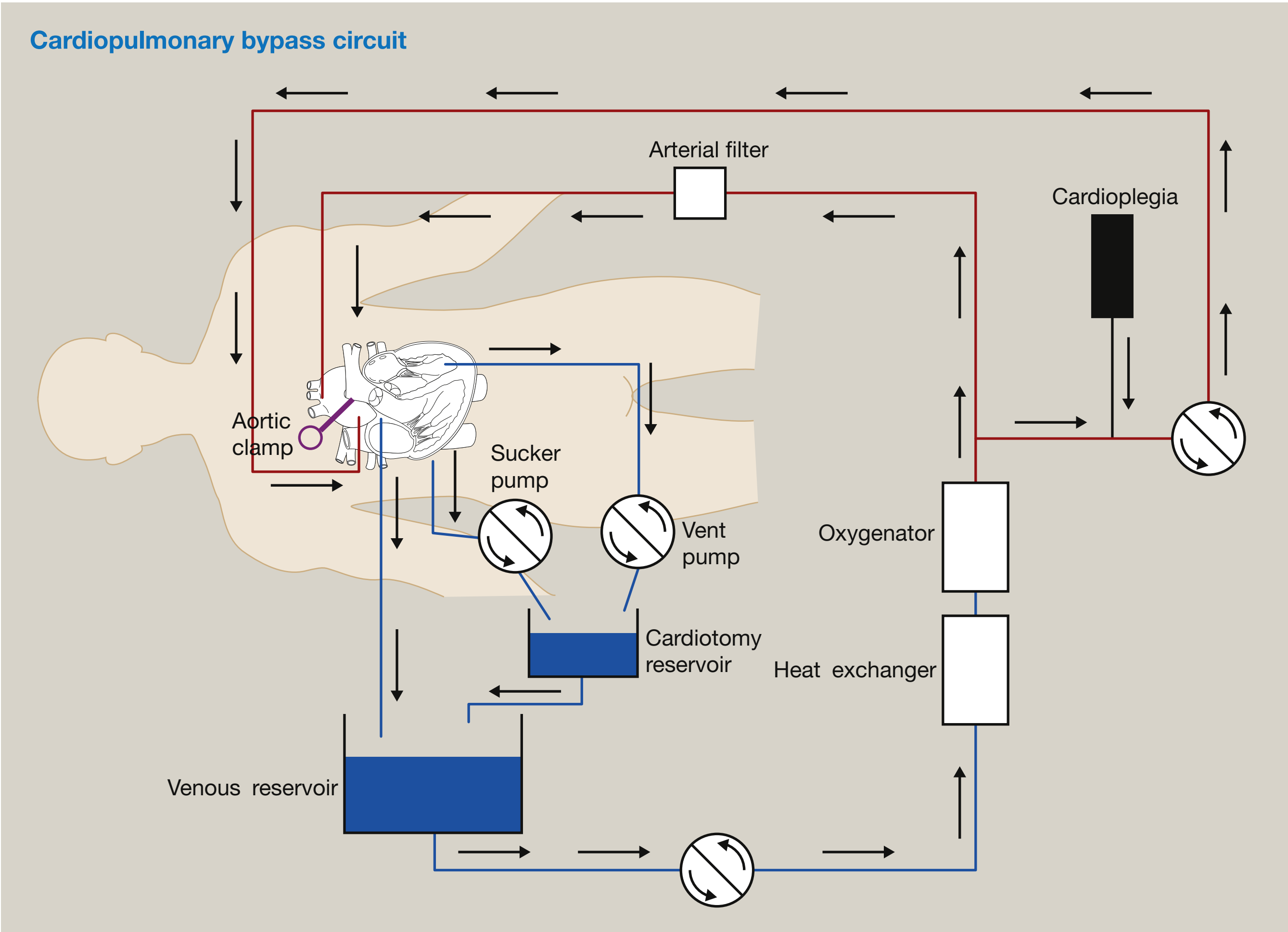

Figure 1

easily accessible and has the lowest incidence of aortic dissection; however, the innominate, axillary of femoral arteries can be cannulated for more complex surgery.

Arterial cannulas are normally inserted by direct vision (aorta) or via surgical cut down (i.e. femoral), although cannulas have been developed that allow a Seldinger approach for both accesses. It is important to control the patient's blood pressure during aortic cannulation to help reduce the risk of aortic dissection.

The arterial cannulas are thin walled as this presents a lower resistance to flow due to their increased internal diameter. Wire reinforcement reduced the risk of cannula kinking and obstruction to flow. Cannulas often incorporate a curved tip with multiple side holes as this reduces damage to the intima when high return flows are generated.

Venous reservoir

Blood drained from the venous cannula first enters the venous reservoir, this acts as a chamber for the venous blood to drain into before being pumped to the oxygenator and allows the addition of fluids or drugs. Reservoirs can be either open (hard shell as illustrated in Figure 3) or closed (soft or collapsible); both systems mostly rely on gravity to drain venous blood from the patient to the bypass system. The open system is more frequently used, it has two main benefits it allows for the passive removal of entrained air as it drains into an open reservoir, it also allows for the addition of negative pressure to assist with venous drainage. The open system combines blood scavenged by suction from the operative field with blood drained from the venous system. The suctioned blood may contain debris such as lipids or bone fragments and so must first pass through a filter and defoaming circuit to remove foreign particles. When an open system is used a level of fluid must be maintained within the reservoir throughout the procedure to prevent inadvertent air entry into the arterial system. The arterial return must stop functioning if the volume of fluid in the venous reservoir falls below a critical level.

Closed or soft shell reservoirs have a lower volume capacity which reduces amount of contact the blood has with artificial surfaces, in addition the nature of the closed system reduced the blood air interface. This reduced the inflammatory activation which leads to a reduction in post-operative complication and transfusion requirements.[1] When a closed system is used a separate circuit is required for processing suctioned blood.

Oxygenator

The oxygenator re-oxygenates desaturated haemoglobin and simultaneously removes carbon dioxide from the venous

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