Cardiopulmonary bypass

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Abstract

Cardiopulmonary bypass is an essential component of many cardiac surgical procedures, temporarily taking over the function of the heart and lungs during surgery. Components of the bypass circuit are described and the preparation for and management of bypass outlined. Cross clamping the ascending aorta risks causing myocardial ischaemia, which is prevented by use of a cardioplegic solution to stop the heart from beating or an 'intermittent cross clamp fibrillation' technique. Blood conversation is provided by suckers, vents and red blood cell salvage. Safety, side effects and associated therapies are discussed.

Keywords Cardioplegia; cardiopulmonary bypass; myocardial protection; oxygenator; perfusion

Introduction

Many cardiac surgical procedures, from correction of congenital defects through replacement of diseased valves to transplants, are made possible through cardiopulmonary bypass (CPB) replicating the function of both heart and lungs extracorporeally during surgery. Blood from the systemic venous system is continuously diverted from the body into the CPB circuit, where a pump drives the blood through a gas exchange device ('oxygenator'), and back in to the patient through an arterial cannula. The blood then flows around the systemic arterial circulation, and though the capillaries and veins before flowing back to the CPB circuit. The heart and lungs are 'bypassed', and surgery can be performed safely on a still and bloodless heart, typically for 1 or 2 hours, with CPB components recommended by the manufacturers for up to 6 hours of use.

Preparation

Prior to CPB, the circuit is primed air free with intravenous fluid such as Hartmann's solution with added heparin (typically 5000 to 10,000 IU). For the anaemic patient red blood cells can be used to substitute some of the crystalloid fluid to prevent excessive haemodilution. It is essential the patient is adequately anticoagulated in preparation of CPB. This requires full heparinization (often 300 IU/kg) to prevent activating the clotting system on contact with the foreign surfaces that constitute the circuit with potentially catastrophic consequence. Anticoagulation status can be checked by point-of-care activated clotting time (ACT) test, with a target value dependent on institution and ACT device used, but typically maintained >400 s throughout the period of CPB. A target value for flow is calculated based on the patient body surface area, commonly equivalent to a cardiac index of 2.4 L/min/m^2. This can be adjusted during CPB according to patient need based on monitoring of vital parameters.

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Circuit components

Control of CPB is via a heart–lung machine consisting of control panel, pumps and safety devices supplemented with a gas blender, patient monitoring systems and ideally a digital data collection system. The CPB circuit (Figure 1) consists of the following disposable components.

Venous cannula

The venous cannula drains venous blood from patient by gravity siphon by one of the following pathways:

- Single-stage cannula in right atrium.
- A two-stage cannula, with tip draining from inside inferior vena cava (IVC) and ports in the body of the cannula positioned in the right atrium draining blood arriving from the superior vena cava (SVC), can provide better drainage.
- Separate cannulation of IVC and SCV, joined by a 'Y' piece, can further optimize drainage in some procedures (e.g. mitral valve operations) and is also used to avoid air entrainment if surgery involves accessing the right side of heart or in the presence of a septal defect.
- Sometimes it is necessary to use long cannula to access the right atrium via the femoral vein.

Venous reservoir

Polycarbonate hardshell or less commonly a softshell housing receives blood drained from venous cannulae, which incorporates a defoaming agent to prevent froth. De-airing of any bubbles entering the reservoir is achieved through buoyancy and a blood pathway through a screen filter.

Blood pump

Replaces heart function by pumping blood onward from the reservoir. Typically this is a continuous flow though a pulsatile modality is possible. Two common types of pump are used:

- Roller pump – positive displacement device with two rollers on a rotating arm that compress tubing, usually silicone, against a backplate.
- Centrifugal pump –a radial rotary pump with a central inlet. Vanes on a bearing column magnetically coupled to electric motor rotate rapidly creating a constrained blood vortex with a blood outlet on the perimeter of the polycarbonate housing. The flow out is perpendicular to the fluid entering.

Heat exchanger

Allows control of patient temperature by warming or cooling blood as it passes through the device. A stand-alone heater–cooler unit pumps water of the desired temperature through the heat exchanger, where a non-permeable stainless steel or polyurethane barrier allows heat transfer between the water and the blood. The heat exchanger is often integrated with, or adjacent to, the oxygenator within the same polycarbonate housing.

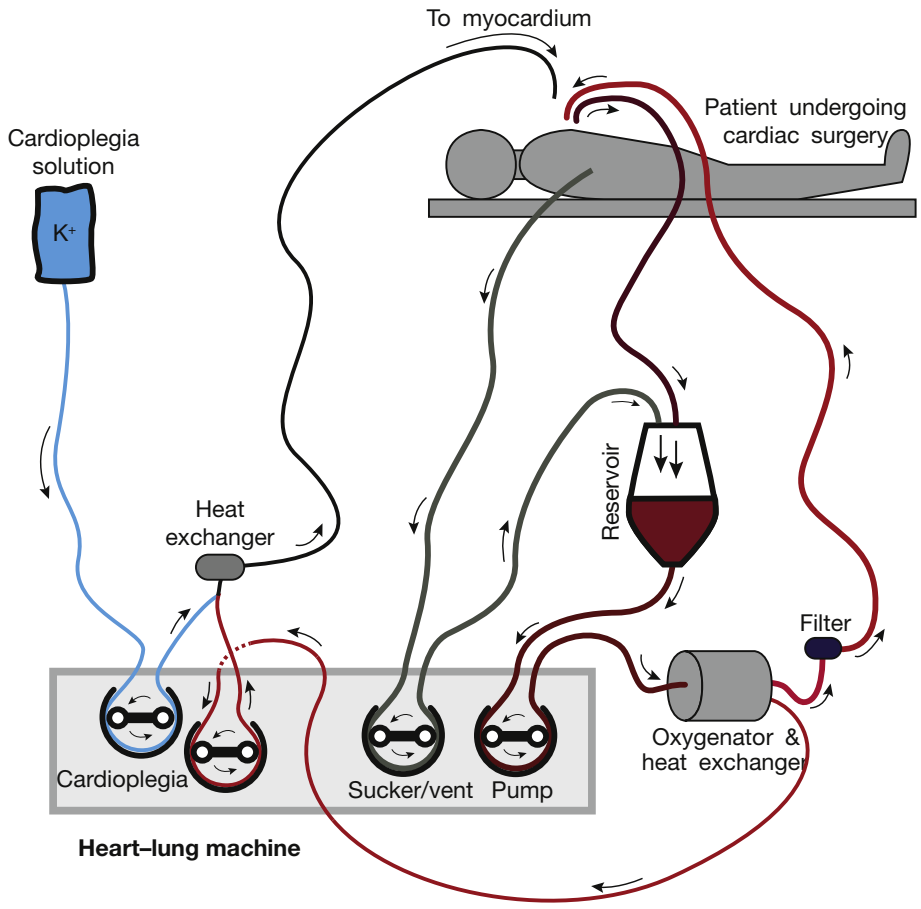

Figure 1 Blood pathway through cardiopulmonary bypass circuit. (Illustration courtesy of Ben Middleton.)

Patients are often cooled during CPB to reduce metabolic requirements, typically to between 32°C and 35°C.

Oxygenator

The oxygenator (Figure 2) replaces lung function by enabling gas exchange via a membrane consisting of many microporous polypropylene hollow fibres. Gas flows inside the fibres with blood flowing around them, with oxygen passing from gas to blood and carbon dioxide passing from blood to gas. Gas exchange occurs through the micropores via a protein film, which develops as blood comes into contact with the oxygenator at the initial phase of CPB. A gas blender allows control of pO_2 by altering FiO_2 (typically 0.4–0.8) and control of pCO_2 by altering gas flow (typically 2–4 L/min) through the oxygenator. Ultimately, fluid leakage through pores limits the potential life of devices, but 'true membranes' without pores can be used for longer applications, but are less efficient as gas transfers via the membrane material.

Arterial filter

Filters blood prior to its return to the body to ensure no particulate debris or gaseous emboli enter the circulation. Recent designs have integrated the arterial filter function into the oxygenator block design and housing.

Arterial cannula

Returns blood to patient circulation through the following pathways:

- Bevelled or angled cannula placed in the ascending aorta.
- Sometimes the axillary or femoral artery is cannulated, for example, for some aortic procedures, re-do operations or minimal access approaches.

Tubing

Polyvinyl chloride tubing throughout the circuit bridges the components together.

Suckers and vents

Additional roller pumps (commonly referred to as 'pump suckers') on the heart–lung machine allow any blood lost into the open chest, while the patient is heparinized, to be sucked back and returned to the circulation via the venous reservoir. On entering the reservoir salvaged blood passes through a depth filter, either within a separate cardiotomy reservoir or through a separate pathway within the venous reservoir, to ensure no particulates enter the circulation.

During CPB, some blood can still return directly to the heart for, example via the physiological bronchial shunt which returns some deoxygenated blood to the left side of the heart via the pulmonary veins. To maintain an empty heart and clear surgical field, suckers (or 'vents') can be positioned inside the heart, for example in the left ventricle or pulmonary artery.

Cell salvage systems are used in a number of surgical specialities to suck blood from the surgical wound for reinfusion. The

