Cardiopulmonary bypass

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Abstract

The success of cardiac surgery is the result of revolutionary thinking by those who were unafraid to take risks in the 1950s, when cardiopulmonary bypass was in its infancy. The development of the heart–lung machine has moved a long way from the cumbersome screen oxygenator to today's modern disposable hollow-fibre units. Perfusionists are one part of a team of highly skilled professionals dedicated to delivering the best quality care. Perfusion science is going through a number of changes, many of which are focused on receiving recognition from the Health Professions Council. Hospitals can enact local policies enabling perfusionists under the supervision of consultants to administer drugs on bypass. Regulation of parameters on cardiopulmonary bypass remains controversial. Best practice is still evolving with regard to perfusion pressure, pump flow, temperature management and central nervous system monitoring. Most coronary artery bypass surgery is now performed at normothermia or mild hypothermia, making the argument for α-stat or pH-stat blood gas management less critical. Indeed, if the patient has intact cerebral autoregulation (not routinely tested preoperatively), neither pump flow nor pressure influences cerebral blood flow over that autoregulatory range.

Keywords α-stat; central nervous system monitoring; drug administration; flow; normothermic; oxygenator; perfusionist; pH-stat; pressure; systemic vasculature resistance

History

The time line for the development of cardiac surgery is shown in Table 1. The history from the concept of extracorporeal circulation in 1813 by Le Gallois to the current trend of so-called mini-bypass is charted. This claims to reduce the deleterious effects of cardiopulmonary bypass (CPB) by minimizing the blood–air interface.

Blood pumps

CPB diverts blood away from the heart (and lungs) and returns it to the systemic arterial system. Therefore, CPB must replace the function of the lungs (gas exchange) and heart (circulation). Advances in efficient atraumatic blood-pumping devices have been slow compared with those in oxygenator technology. Roller and centrifugal pumps are the most commonly used devices.

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Learning objectives

After reading this article, you should:

- understand the historical development of cardiopulmonary bypass and the key components in the bypass circuit
- know the primary considerations in the way cardiopulmonary bypass is conducted
- understand the importance of, and the controversy surrounding, the parameters used to control bypass.

Roller pumps

These are the most widely used type of pump. These pumps consist of rollers (usually two, 180° apart) positioned on the end of a rotating arm. Forward flow is induced by the rollers compressing tubing mounted in a U-shaped raceway. The flow rate is dependent on the diameter of the tubing, the diameter of the raceway and the rotation rate of the rollers. Roller pumps have the advantage of being simple to set up and prime; however, they are traumatic to blood.

Centrifugal pumps

Two types predominate: the first uses a nest of smooth plastic cones contained within plastic housing; the second makes use of a vaned impeller. The cones or impellers are magnetically coupled to an electric motor and, when rotated rapidly, impart kinetic energy to the blood, inducing forward flow. These devices are completely non-occlusive, and are dependent on preload and afterload. An electromagnetic flow probe must be attached to the arterial line to determine pump flow. These pumps are more complex, yet less traumatic to the blood elements (reduced haemolysis). Massive air embolism is less likely.

The bubble oxygenator

Lillehei, in collaboration with Dewall, developed the first bubble oxygenator (Figure 1a). These oxygenators are highly efficient, inexpensive and disposable. Venous blood is passed upwards in a vertical column through which oxygen is simultaneously bubbled. Eddies and vortexes are created whereby oxygen enters the blood and carbon dioxide is released. The column consists of either multiple vertical tubes or a fine mesh that acts as a spoiler to promote mixing of the gas and blood. At the top of the column, the gases and blood form a foam. Defoaming agents cause coalescence of the bubbles. On exiting the column, the arterialized blood passes through a filter and bubble trap (Figure 1b).

The membrane oxygenator

Membrane oxygenators are more physiological and extensively used. They mimic the pulmonary capillary by interposing a thin membrane between the blood and the gas. There are different types of membrane, including a flat sheet usually arranged as a 'fan-fold' and hollow fibres. These fibres have an internal diameter of 100–200 μm. The total number of fibres ultimately determines the efficiency of the gas exchange. Gas flows on the inside of the fibre and blood flows to the outside, thus maximizing the surface area available for gas exchange. Membrane oxygenators have several advantages: they separate the blood

Key developments in extracorporeal support

Date	Activity
1813	Le Gallois first proposed the principle of extracorporeal circulation
1916	McLean discovered heparin
1934	De Bakey developed the roller pump
1937	Gibbon performed the world's first cardiopulmonary bypass – on a cat
1953	Gibbon used a film oxygenator with his heart–lung machine to perform the first clinical cardiopulmonary bypass on a patient with an atrioseptal defect
1955	Lillehei successfully utilized cross-circulation
1956	Dewall developed the bubble oxygenator
1965	Bodell developed the membrane oxygenator
2003	Concept of the mini-bypass

Table 1

and gas phases, create far fewer bubbles, give greater accuracy in blood gas control and make massive gas embolism almost impossible. On the downside, they are more expensive and technically more difficult to set up.

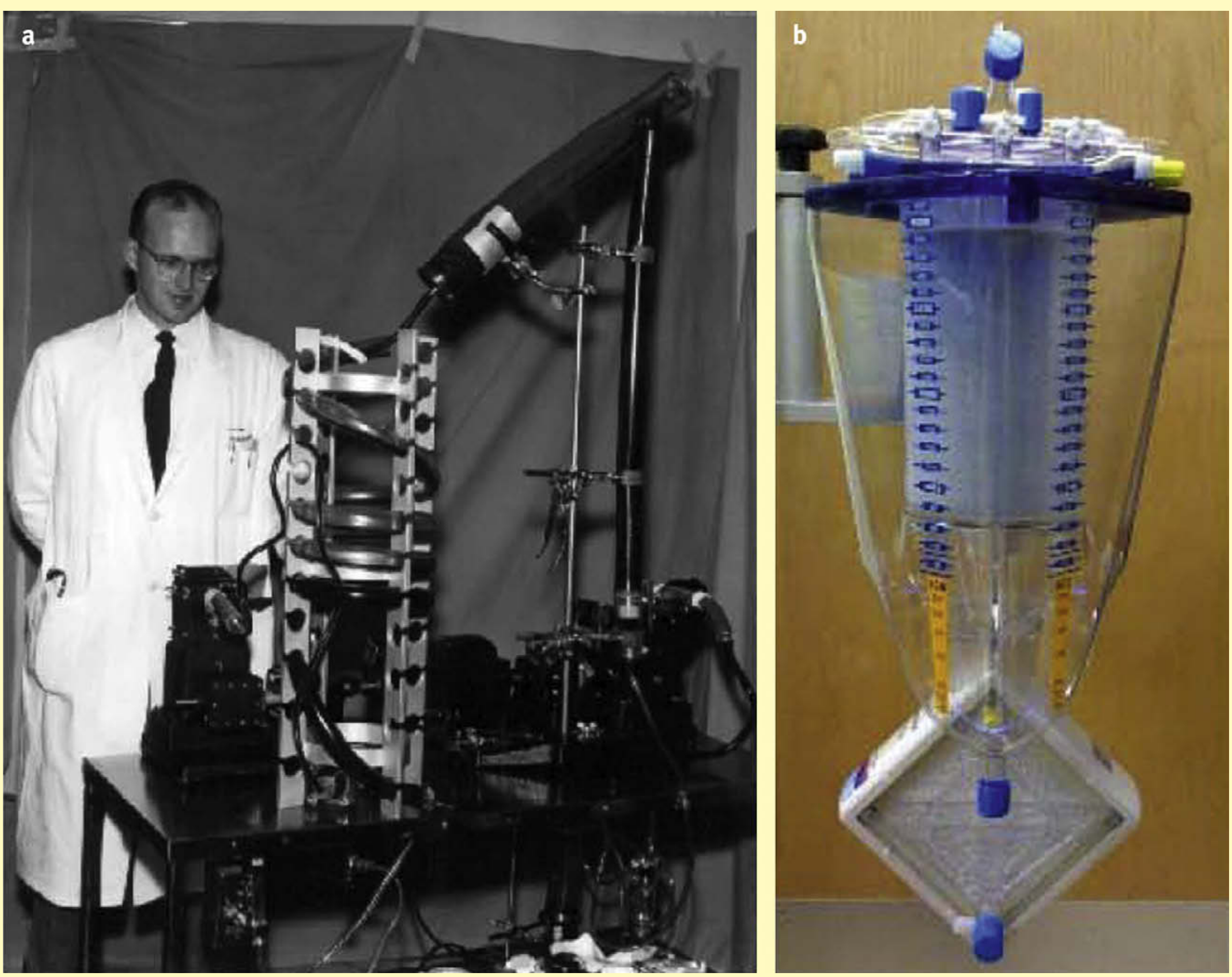
Key considerations on the conduct of cardiopulmonary bypass

Anticoagulation

Adequate systemic anticoagulation is an absolute requirement for CPB. Unfractionated heparin at a dose of 300 iu/kg is used. Activated clotting time (ACT), measured using a portable device, determines the adequacy of heparinization. An ACT >400 seconds is required before going onto bypass.

Cannulation strategy

The ascending aorta (occasionally femoral artery) is cannulated first. At this stage, avoidance of hypertension (mean arterial pressure (MAP) <60 mmHg) reduces the risk of arterial dissection. Venous cannulation (right atrium or cavae) then follows.



a DeWall with the original bubble oxygenator. **b** A modern hollow-fibre membrane counterpart.
Courtesy of University Archives, University of Minnesota, Minneapolis.

Figure 1

