CARDIOPULMONARY BYPASS FOR CARDIAC SURGERY

PUMP OXYGENATOR APPARATUS

The precise apparatus available for cardiopulmonary bypass (CPB) changes frequently, but the basic components remain constant.

A ***venous reservoir*** *is* usually present and is positioned to provide adequate siphonage of blood by gravity. This provides *storage of excess volume* and *allows escape of any air bubbles* returning with venous blood.

The ***oxygenator*** provides oxygen to the blood and allows elimination of carbon dioxide. Currently, ❋**bubble** oxygenators, ❋**membrane** oxygenators, and ❋**microporous hollow-fiber** oxygenators are available for clinical use.

An efficient ***heat exchanger*** *is* necessary for control of the perfusate temperature to achieve systemic cooling and rewarming during CPB. Most heat-exchanging devices are included as an integral part of the pump oxygenator.

The ***arterial pump*** *is* usually a ❋**roller pump**, which should be adjusted before each perfusion to be slightly nonocclusive. The ***pump tubing*** is either **Silastic** or **latex**, which, unlike the Tygon tubing, does not become stiff at low temperatures. ❋**nonocclusive vortex pumps** are also available, their use is generally restricted to extracorporeal membrane oxygenator (ECMO) or ventricular assist device (VAD) circuits.

PHYSIOLOGIC RESPONSE TO CARDIOPULMONARY BYPASS

Many complex physiologic changes occur when a patient is temporarily supported by means of an oxygenator system. The term ***total CPB*** indicates that nearly all of the systemic venous blood is returned to the oxygenator. ***Partial CPB*** implies that some of the systemic venous blood returns to the heart and is ejected into the aorta.

Two main types of physiologic variables exist during CPB: ***externally controlled variables***, which are controlled by the surgeon and perfusionist, and ***patient variables***, which are less easily regulated.

Externally Controlled Variables

① ***perfusion flow rate*** *is* controlled by the perfusionist but should be actively established by the surgeon. normothermic perfusion flow rates of 1.7 liters per minute per sq. m. or greater are usually acceptable, but flow rates of 2.0 to 2.5 liters per minute per sq. m. provide a more secure margin of safety for organ perfusion.

② ***Temperature of the perfusate***, and secondarily of the patient, is controlled by the perfusionist by means of the heat exchanger. This is one of the most important decisions to be made about each patient during CPB. Particularly in small infants, moderate and profound hypothermic perfusion allows the safe, temporary reduction in flow that is advantageous for the accurate intracardiac repair of many malformations

③ ***Pulmonary venous pressure*** (left atrial pressure) should also be maintained near 0 mm. Hg during total CPB. High pulmonary venous pressure during CPB may result from ❶ excessive pulmonary collateral blood flow, an ❷ unrecognized extracardiac left-to-right shunt (e.g., patent ductus arteriosus), or ❸ incomplete venous drainage leading to increased pulmonary blood flow. Marked and prolonged elevation in pulmonary venous pressure during CPB promotes accumulation of extravascular lung water and probably contributes to postoperative pulmonary dysfunction.

④ ***Hematocrit*** of the patient-oxygenator system is determined by the ☛body size and ☛hematocrit of the patient, the ☛composition and amount of the initial priming volume of the pump oxygenator, the ☛amount of blood lost, and the ☛composition and volume of solutions infused during CPB.

The initial priming volume is determined by the ♠volume required for the oxygenator and its reservoir, the ♠pump lines, the ♠bubble trap, and the ♠cardioplegia apparatus.
At normothermia, a hematocrit of 30% to 40% appears optimal for oxygen transport and preserves the appropriate blood rheologic properties. Higher hematocrits result in increased oxygen content at the expense of increased viscosity and decreased blood flow.
⑤ ***Glucose concentration*** is increased in the priming solution (about 350 mg. per 100 ml.) to provide an energy source as well as to promote an osmotic diuresis during and soon after CPB.
⑥ ***Arterial oxygen levels*** are usually maintained between 100 and 250 mm. Hg with current bubble and membrane oxygenators.
⑦ ***The arterial carbon dioxide pressure ($Paco_2$)*** is determined by the ratio of gas flow to blood flow in the oxygenator, with higher ratios resulting in a lower $Paco_2$. A $Paco_2$ of 30 to 40 mm. Hg (measured at 37° C.) is considered optimal during CPB.

Patient Variables

The body's physiologic response to CPB is extremely complex and only partially understood.
① ***Systemic vascular resistance*** falls abruptly with the onset of CPB. Thereafter, it gradually increases throughout the period of bypass, although there is considerable variation among patients.
② ***Total body Oxygen consumption (Vo_2) and Pvo_z*** levels are both partially controlled by the perfusion flow rate and the patient's temperature.
③ ***Metabolic acidosis*** is almost always present during bypass, but lactate levels should not exceed 5 mEq. per liter if adequate perfusion flow rates are maintained.
④ ***Changes in body composition*** During and after CPB, extracellular fluid is increased. The major shift of fluid is from the intravascular space to the interstitial space, resulting in increased interstitial fluid pressure and decreased plasma volume.

DAMAGING EFFECTS OF CPB

***Safe* CPB is characterized by** the absence of structural or functional damage after the perfusion. The vast majority of patients suffer no clinically apparent ill effects from CPB; however, an occasional patient develops severe multiorgan dysfunction despite an otherwise accurate and complete intracardiac repair.

In its most severe form, the ***postperfusion syndrome*** is characterized by a diffuse whole-body inflammatory reaction, with elements of increased capillary permeability, extravascular extravasation of plasma, increased interstitial fluid, leukocytosis, fever, peripheral vasoconstriction, breakdown of red blood cells, and a diffuse bleeding diathesis.

Some incremental risk factors for an adverse clinical response to CPB

- *duration of bypass*. (extends beyond approximately 3 hours,
- *age*. (neonates and very elderly appear less tolerant of the damaging effects of CPB)
- pre-existing renal dysfunction.
- type of oxygenator
- composition of the perfusate,
- perfusion flow rate
- presence or absence of pulsatile flow
- patient's temperature.
- Certain cardiac malformations, particularly cyanotic congenital heart disease

The mechanisms for damage after CPB are most likely ♦ ***altered arterial blood flow patterns and*** ♦ ***exposure of blood to abnormal events***, with the exposure of blood to abnormal events being the more powerful determinant (show in figure below).

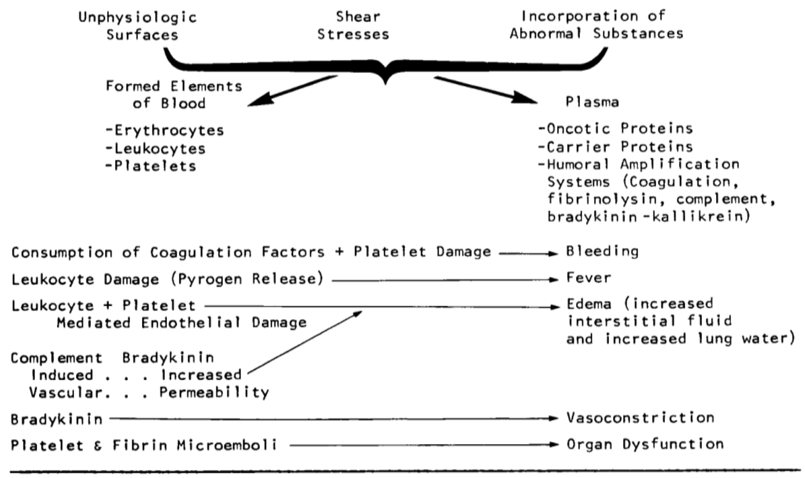

Figure 54–225. Schematic representation of a current concept of the damaging effects of cardiopulmonary bypass related to the exposure of blood to abnormal events. (From Kirklin, J. K., Kirklin, J. W., and Pacifico, A. D.: Cardiopulmonary bypass. *In* Arciniegas, E. [Ed.]: Pediatric Cardiac Surgery. Chicago, Year Book Medical Publishers, 1985.)

Blood Conservation

❋***Autotransfusion of shed mediastinal blood after cardiac operations*** has been shown to be a safe and effective method for minimizing postoperative transfusion requirements, although large-volume autotransfusion is probably deleterious.

❋***Red blood cells aspirated from the operative* field** can be separated by centrifugation and washing before reinfusion.

❋***Intraoperative ultrafiltration of blood*** using hollow-fiber hemofilters may also be used to conserve blood.Hemofiltration or cell separation techniques can be used to conserve the blood that remains in the oxygenator after the termination of CPB.

❋**Autologous blood donated before cardiac operations** has been shown to reduce the need for homologous transfusion, whereas the harvesting of platelet-rich plasma remains unproven as a means to improve post-CPB hemostasis.

Clinical Methodology in CPB

After performing a median sternotomy and opening and tacking up the pericardium, the external cardiac anatomy is carefully assessed. Any dissection before CPB is usually accomplished before heparin is administered. Pursestring sutures are placed for arterial and venous cannulation and placement of the cardioplegic needle. The initial heparin dose is 3000 units per kg., and adequate anticoagulation is verified by an activated clotting time greater than 8 minutes.

Arterial Cannulation

The ascending aorta is generally used for arterial cannulation. The femoral artery is used under special circumstances, such as in patients undergoing resection of aneurysms or dissection of the ascending aorta.

Venous Cannulation

❋ In **infants and children**, **two angled**, metal-tipped venous cannulas, which are inserted directly into each vena cava, are used for most operations, **particularly if working through the right atrium or right ventricle**.

❋ A **single venous cannula** is often used if working through the **left atrium**, **left ventricle**, or **ascending aorta** and **occasionally through the high right ventricle** (e.g., changing a valved external conduit).

❋ A **single venous cannula** is also employed in those **neonates** in whom the entire repair is performed under **total circulatory arrest**.

❋In **adults**, a **single** large cavoatrial **(two-stage)** venous cannula with additional holes that come to lie in the right atrium while the tip is in the inferior vena cava, may be used for **coronary bypass grafting**, **aortic valve operations**, **mitral valve operations**, and **combinations of these**.

❋When working **in the right atrium, two venous cannulas** are employed.

Conduct of Cardiopulmonary Bypass

After the patient is heparinized, cannulation is effected and CPB is established. The initial perfusate temperature is 30° C. to 34° C., which usually allows for effective cardiac action if CPB needs to be discontinued abruptly because of an oxygenator system malfunction. The perfusion flow is gradually increased to about 2.2 liters per minute per sq. m., after which perfusion cooling is begun

Approximately 5 minutes before removing the aortic crossclamp, rewarming is initiated by increasing the flow rate to 2.0 to 2.5 liters per minute per sq. m. and raising the temperature of the water in the heat exchanger to 42° C..

When the cardiac action is vigorous, the venous line is partially occluded to elevate the left atrial pressure to 10 to 14 mm. Hg to promote effective cardiac ejection for debubbling the heart. With strong suction on the aortic needle vent, the heart is gently massaged, and the left atrial appendage is gently inverted as the anesthesiologist inflates the lungs to force any residual air out of the pulmonary veins. CPB is then gradually discontinued when the cardiac action is vigorous and the nasopharyngeal temperature reaches 37° C.