Introduction

Congenital heart disease (CHD) is the most common congenital disorder in newborns **(Tennant et al., 2010).** The reported prevalence of CHD at birth ranges from 6 to 13 per 1000 live births **(Ishikawa et al., 2011).** CHD is one of the leading causes of perinatal and infant death from congenital malformations **(Wren et al., 2012).**

The pathophysiology involved seems to be multi-factorial. It is unlikely that a single intervention could achieve the ideal goal. To date, the concept of organ protection should be no longer limited to the individual organ. Instead, investigations must be extended to focus on a systemic level. Both pharmacological strategies and modifications of mechanical devices may have important clinical implications **(Song and Yim, 2001).**

In the last two decades, technological development and intensive clinical research on CPB helped to establish basic guidelines to enhance the outcome for neonatal and infant patients **(Eggum et al., 2008).**

Continuous product improvement has resulted in a miniaturized CPB circuit, tailored to the size of the patient. Manufacturers of circuit elements (oxygenators, arterial filters, ultrafiltration devices) downsized the new models without

compromising on the safety and performance quality. Additionally, new pediatric dedicated heart-lung machines with pole-mounted pump-heads gave the opportunity to redesign the customary circuits to reduce the volumes and contact surface area and therefore diminished hemodilution and inflammatory response **(Ando et al., 2004).**

Another technological innovation that has been successfully introduced as a routine treatment into pediatric CPB is the use of coating materials on the circuit surface, the results from clinical studies showed a significant decrease of cytokine and interleukin level in plasma when CPB circuit was coated **(Miyaji et al., 2008).**

Furthermore, conventional ultrafiltration and modified ultrafiltration during and post-bypass gained lately on popularity as a powerful anti-inflammatory and anti-hemodilutional strategy. This was possible due to the availability of a wide range of small pediatric hemconcentration devices **(Allen et al., 2009).**

Improved outcome of surgery for CHD depends on early identifying of lesion, modifying the preoperative and intraoperative risk factor, and effective interventions for organ preservation during surgery for CHD **(Brown et al., 2003).**

Hopefully, within the next few years, further advances in perfusion technology will help to minimize the prime volume of

oxygenators, filters, centrifugal pumps, and tubing. This will reduce hemodilution, the inflammatory response and blood exposure **(Hickey et al., 2006).**

Objectives

- Review of the effects of cardiopulmonary bypass on the vital organs' normal physiology and normal functions.
- Discussion of the techniques and strategies involved in organ preservation during surgery for congenital heart disease.
- Presentation of future trends and developments in pediatric cardiopulmonary bypass techniques.

Physiology and Techniques of Extracorporeal circulation in the Pediatric Patient

Modern cardiac surgery with cardiopulmonary bypass (CPB) is characterized by decreasing complication rates in combination with increased patient risk profile and surgical complexity **(Baillot et al., 2009).**

The aim of the CPB circuit is to isolate the cardiopulmonary system so that optimal surgical exposure can be obtained for operations on the heart and great vessels. At a minimum, the circuit must be capable of adding oxygen and removing carbon dioxide from blood and providing adequate perfusion of all organs with this blood. The circuit must fulfil these requirements without permanently damaging the cardiopulmonary system, the blood, or any of the patient's end organs. Substantial differences between adult and pediatric CPB are summarized in (Table 1) and components of a typical CPB circuit are illustrated in (Figure 1) **(Greeley et al., 2011).**

Table (1): Differences between Adult and Pediatric Cardiopulmonary Bypass **(Greeley et al., 2011).**

Parameter	Adult	Pediatric
Hypothermic temperature	Rarely below 25-30°C	Commonly 15-20°
Use of total circulatory arrest	Rare	Common
Pump prime Dilution effects on blood volume Additional additives	25-33%	150-300% Blood, albumin
Perfusion pressures	50-80 mmHg	20-50 mmHg
Influence of pH management	Minimal at moderate hypothermia	Marked at deep hypothermia
Measured $Paco_2$ differences	30-45 mm Hg	20-80 mm Hg
Hypoglycemia	Rare, requires significant hepatic injury	Common, reduced hepatic glycogen stores
Hyperglycemia	Frequent, generally easily controlled with insulin	Less common, rebound hypoglycemia may occur

Table (1): Differences between Adult and Pediatric Cardiopulmonary Bypass **(Greeley et al., 2011).**

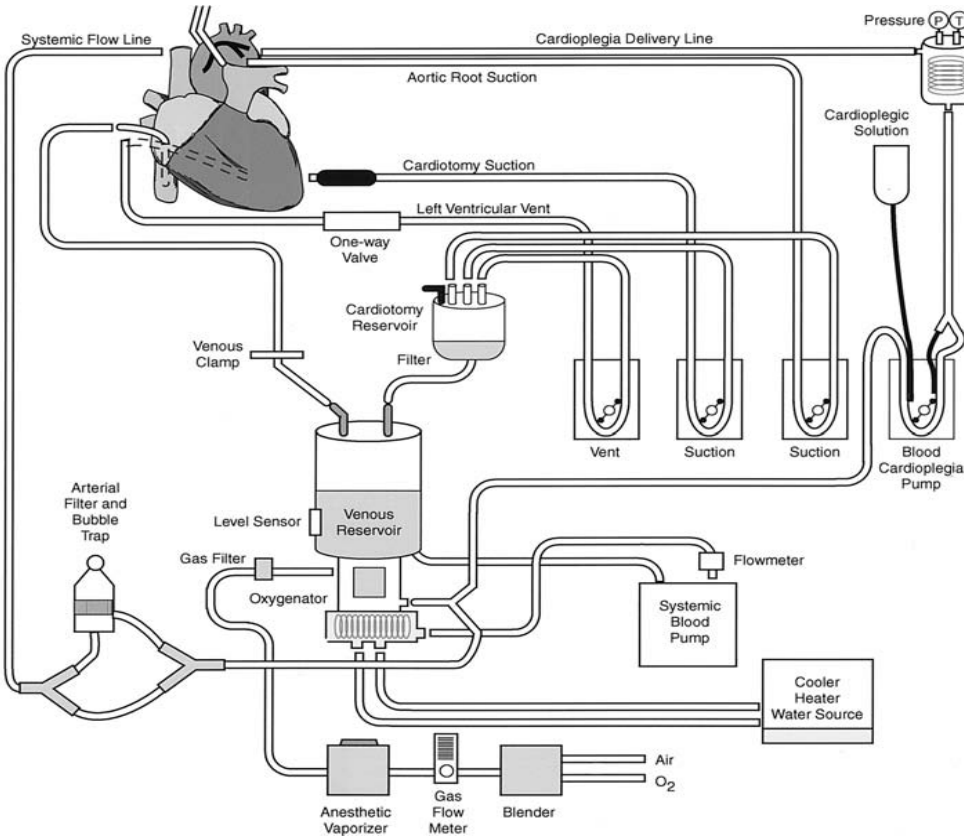

Figure (1): Diagram of a typical cardiopulmonary bypass circuit with vent,field suction, aortic root suction, and cardioplegic system. Blood is drained from a single “two-stage”catheter into the venous reservoir, which is part of the membrane oxygenator/heat exchanger unit. Venous blood exits the unit and is pumped through the heat exchanger and then the oxygenator. Arterialized blood exits the oxygenator and passes through a filter/bubble trap to the aortic cannula, which is usually placed in the ascending aorta. Blood aspirated from vents and suction systems enters a separate cardiotomy reservoir, which contains a microfilter, before entering the venous reservoir.The cardioplegic systemis fed by a spur from the arterial line to which the cardioplegic solution is added and is pumped through a separate heat exchanger into the antegrade or

retrograde catheters. Oxygenator gases and water for the heat exchanger are supplied by independent sources.

Venous Drainage

For the cardiopulmonary system to be isolated, all venous return to the heart must be available to the CPB circuit. Blood is collected from the venous circulation and drained by a siphon into a reservoir that lies on or near the floor wall below the patient. Total (also complete or full) CPB exists when all of the systemic venous drainage to the heart is captured and returned to the CPB circuit. Partial CPB exists when only a portion of the systemic venous drainage to the heart is captured and returned to the CPB circuit. Venous reservoirs are either of the soft-shell collapsible type or the hard-shell no collapsible type. Hard shell reservoirs are constructed of rigid plastic vented to atmosphere, with the venous and cardiotomy reservoirs integrated in one unit. These reservoirs allow better visualization of reservoir volume and easier removal of venous cannula air than soft-shell reservoirs **(Walther et al., 2002).**

The problems of venous obstruction are magnified during CPB in the neonate because the cannula in the inferior vena cava (IVC) may obstruct venous return from the splanchnic bed, resulting in ascites from increased hydrostatic pressure and/or directly reduced perfusion pressure across the mesenteric, renal, and hepatic vascular beds. Significant renal, hepatic, and gastrointestinal dysfunction may ensue and should be anticipated in the young infant with unexplained ascites.

Similar cannulation problems may result in superior vena cava (SVC) obstruction. This condition may be more ominous during bypass. Under these circumstances, three problems may ensue: (i) cerebral edema; (ii) a reduction in regional or global cerebral blood flow (CBF); and (iii) a reduced proportion of pump flow reaching the cerebral circulation causing inefficient brain cooling. In the operating room it is advisable either to monitor SVC pressures via an internal jugular catheter or by looking at the patient's head for signs of puffiness or venous distension after initiating bypass. Neurological monitoring, such as near-infrared cerebral oximetry or transcanial Doppler ultrasound, can rapidly detect decreases in CBF due to SVC obstruction. Patients with anomalies of the large systemic veins (persistent left SVC or azygous continuation of an interrupted IVC) are at particular risk for problems with venous cannulation and drainage **(Sakamoto et al., 2002).**

Arterial Inflows

Normally, arterial inflow is obtained via a cannula placed in the lesser curve of the ascending aorta proximal to the innominate artery. This arrangement allows perfusion of all vessels of the arch and distal aorta and of the coronary ostia. Pediatric cannulae range from 2.0 to 5.0 mm in outer diameter. In older children undergoing reoperative procedures, arterial inflow via a femoral artery may be necessary when the heart or great vessels are adherent to the underside of the sternum. Problems with aortic cannula placement also occur. The aortic

cannula may slip beyond the take-off of the innominate artery and, therefore, selectively flow to the right side of the cerebral circulation. Also, the position of the tip of the cannula may promote preferential flow down the aorta or induce a Venturi effect to steal flow from the cerebral circulation. This problem has been confirmed during CBF monitoring by the appearance of large discrepancies in flow between the right and left hemisphere after initiating CPB **(Cecere et al., 2002).**

Other clues to cannula misplacement include better cooling in the lower body than in the upper body. The presence of large aortic to pulmonary collaterals, such as a large patent ductus arteriosus (PDA), may also divert blood to the pulmonary circulation from the systemic circulation thereby reducing CBF and the efficiency of brain cooling during CPB. The surgeon should gain control of the ductus either prior to or immediately after instituting CPB to eliminate this problem and, if possible, large aortopulmonary collaterals should be embolized in the cardiac catheterization laboratory prior to the operative procedure. Neonates with significant aortic arch abnormalities (e.g. aortic atresia, interrupted aortic arch) may require radical modifications of cannulation techniques **(Andropoulos et al., 2003).**

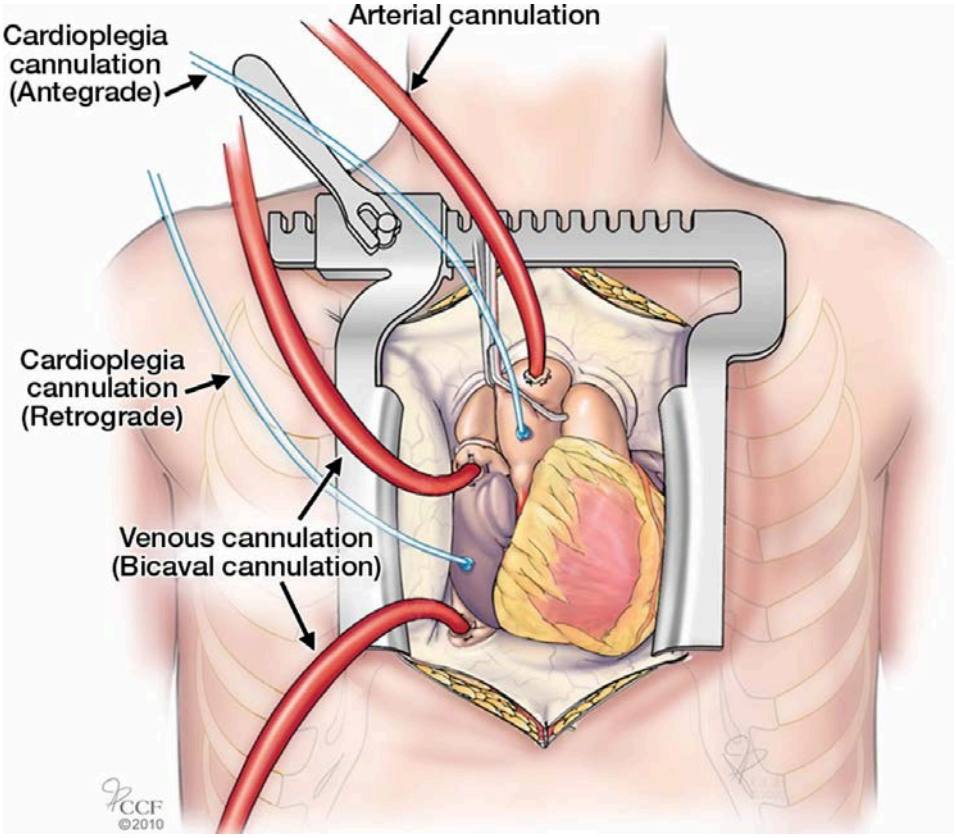

Figure (2): Arterial Canulation and Venous Canulation **(El-Sherief .,2013).**

Pump

A critical component of the CPB system is the arterial blood pump. At present, clinical use is divided quite evenly between nonocclusive centrifugal and occlusive roller pumps. Several studies have reported less hemolysis with the centrifugal pump compared to the roller pump in vitro.

A number of relatively small clinical trials have compared the two pump types in relation to emboli generation, blood trauma and clinical trauma with no clear consensus to promote one or the other **(Murphy et al., 2009).**

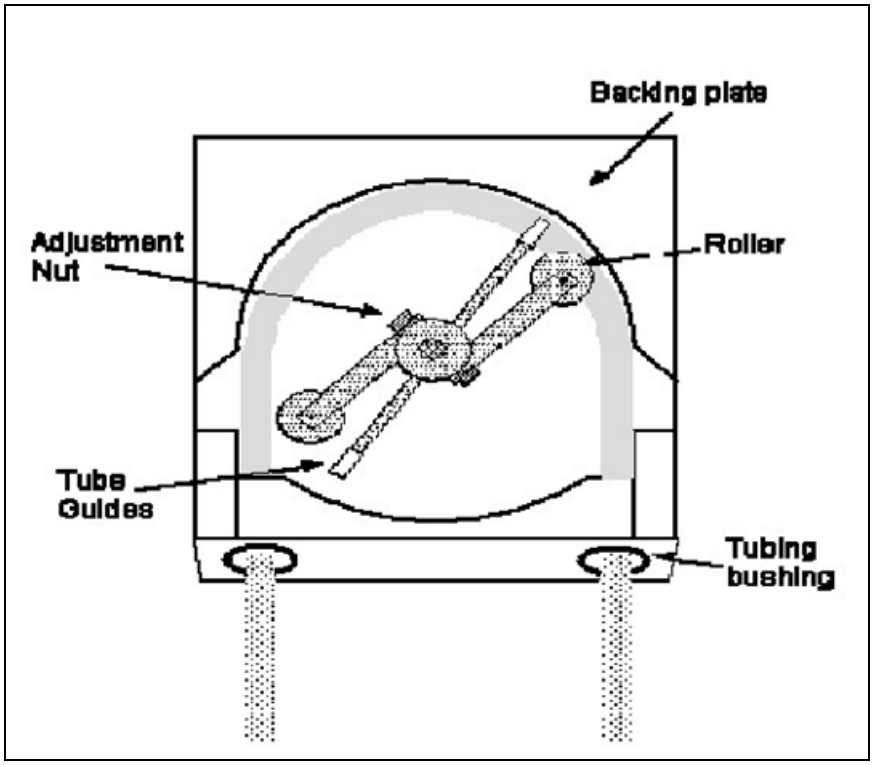

Figure (3): Typical double-Headed nonocclusive roller pump**.**

Oxygenators

Oxygenators aim to perform the gas exchange functions of the lung in the CPB circuit. Even though oxygenators are incorporated into a system in which blood is pumped under pressure, all gas exchange occurs at atmospheric pressure because the oxygenators are vented to the atmosphere. Two

types of oxygenators are available: bubble oxygenators and membrane oxygenators. Only membrane oxygenators are currently used for care of pediatric cardiac surgical patients **(Cecere et al., 2002).**

In addition to gaseous exchange, membrane oxygenators also remove gaseous microemboli from the circuit **(Jones et al., 2002).**

Evaluation of the hollow-fiber oxygenator in the laboratory demonstrated improved hemodynamics with decreased pressure drop across the hollow-fiber membrane, indicating lower resistance to flow **(Talor et al., 2010).** The reduction in pressure should result in lower hemolysis and less inflammatory activation. In addition, the hollow-fiber membrane has a smaller priming volume, reduced surface area, and permits adequate gas exchange. Gas transfer occurs across a protein layer that covers the micropores. As a result of this direct contact coupled with long-term use, this oxygenator demonstrates significant plasma leakage resulting in decreased gas exchange over time, thereby necessitating the need for device change-out **(Kotani et al., 2013).**

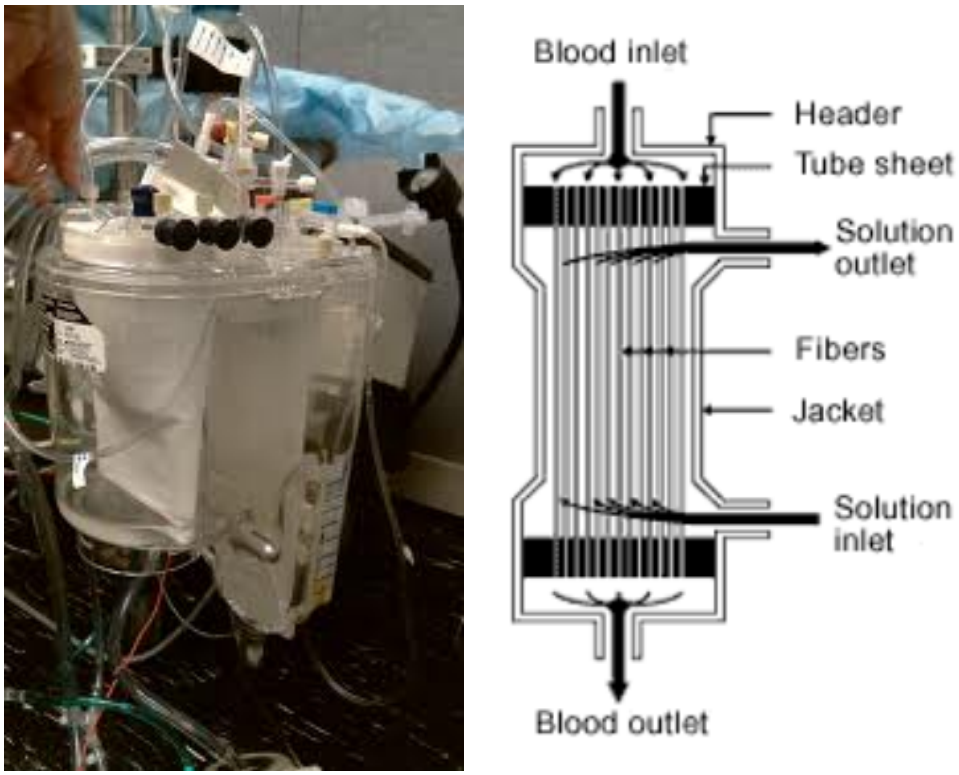

Figure (4): Hollow-fiber micro porous membrane oxygenator.

Heat Exchangers

A heat exchanger is also used in conjunction with the oxygenator. This device is typically placed just before the oxygenator because it helps to prevent bubbles from forming in the blood. The heat exchanger may be used to either warm or cool the blood, but generally the blood is cooled to minimize oxygen consumption. Monitoring the temperature of the blood during the operation as well as observing the speed and temperature of rewarming afterward is important. Rewarming

too quickly or to too great a temperature may cause significant problems **(Hessel et al., 2003)**.

Cradiotomy Suction

Cardiotomy or pump suction is incorporated into most CPB circuits, serving as an important source of blood conservation. Often, the cardiotomy suction is used before initiation of CPB during cannula placement. Adequate anticoagulation must be achieved before cardiotomy suction is used so that clot is not introduced into the cardiotomy or venous reservoir. Blood from the pericardium, collected by cardiotomy suction and returned to the venous reservoir, activates the extrinsic coagulation pathway during CPB. Aspirated pericardial blood returned to the venous reservoir is the most important activator of the coagulation system during CPB. Pericardial aspirate is rich in tissue factor and procoagulant cellular (primarily platelet derived micro particles). Cardiotomy suction is the major source of blood trauma and hemolysis during CPB due to the simultaneous aspiration of air and blood **(Dc Somer et al., 2002).**

Micropore Filters

Arterial filters have been demonstrated to reduce embolic load also when incorporated in CPB circuits including the most modern hollow-fibre membrane oxygenators (Figure 5). **(Guan et al., 2009).**