SNS COLLEGE OF ALLIED HEALTH SCIENCES

SNS Kalvi Nagar, Coimbatore - 35

Affiliated to Dr MGR Medical University, Chennai

DEPARTMENT OF CARDIO PULMONARY PERFUSION CARE TECHNOLOGY

COURSE NAME : PRINCIPLES OF PERFUSION TECHNOLOGY I

2nd YEAR

TOPIC : COMPONENTS OF HEART LUNG MACHINE

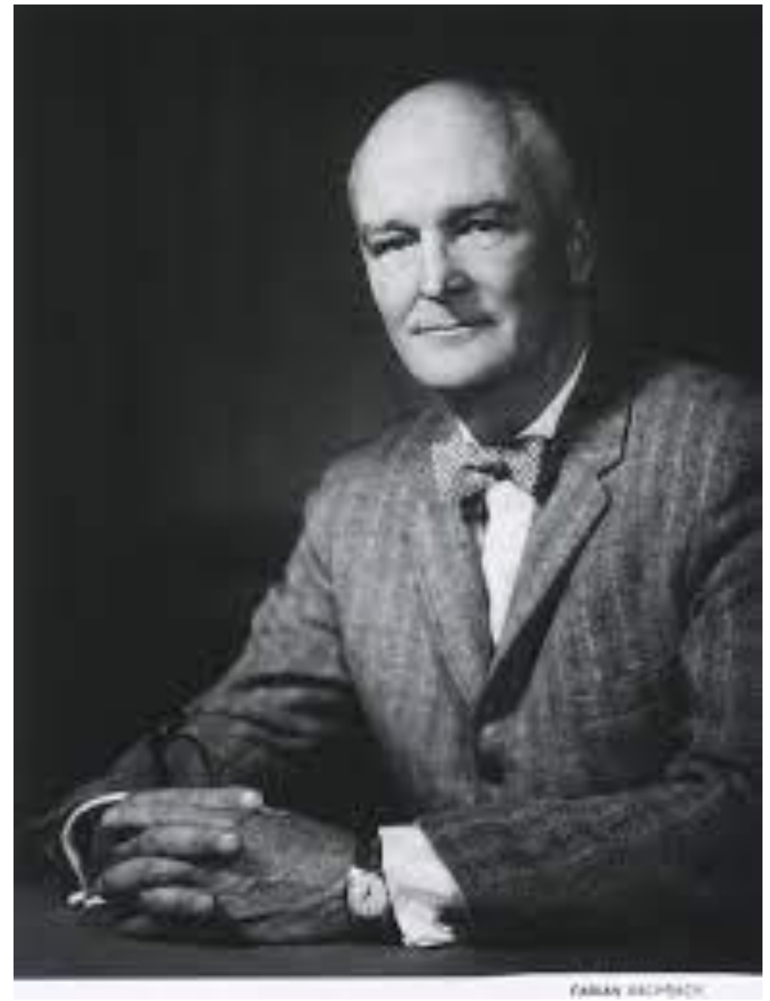
HEART LUNG MACHINE

DEFINITION

- Also called as cardiopulmonary bypass machine(CBM) that temporarily takes over the functions of the heart and lungs, especially during heart surgery.
- The machine consists of a pump, which functions as the heart, and an oxygenator, which replaces the function of the lungs.
- Cardiopulmonary bypass (CPB) provides a bloodless field for cardiac surgery.
- It incorporates an extracorporeal circuit to provide physiological support in which venous blood is drained to a reservoir, oxygenated and sent back to the body using a pump.

HISTORY

- On May 6, 1953, Dr. Gibbon used his heart-lung machine to successfully repair an atrial septal defect in an 18 year-old girl,
- Marking the first successful clinical use of a Heart-Lung Machine

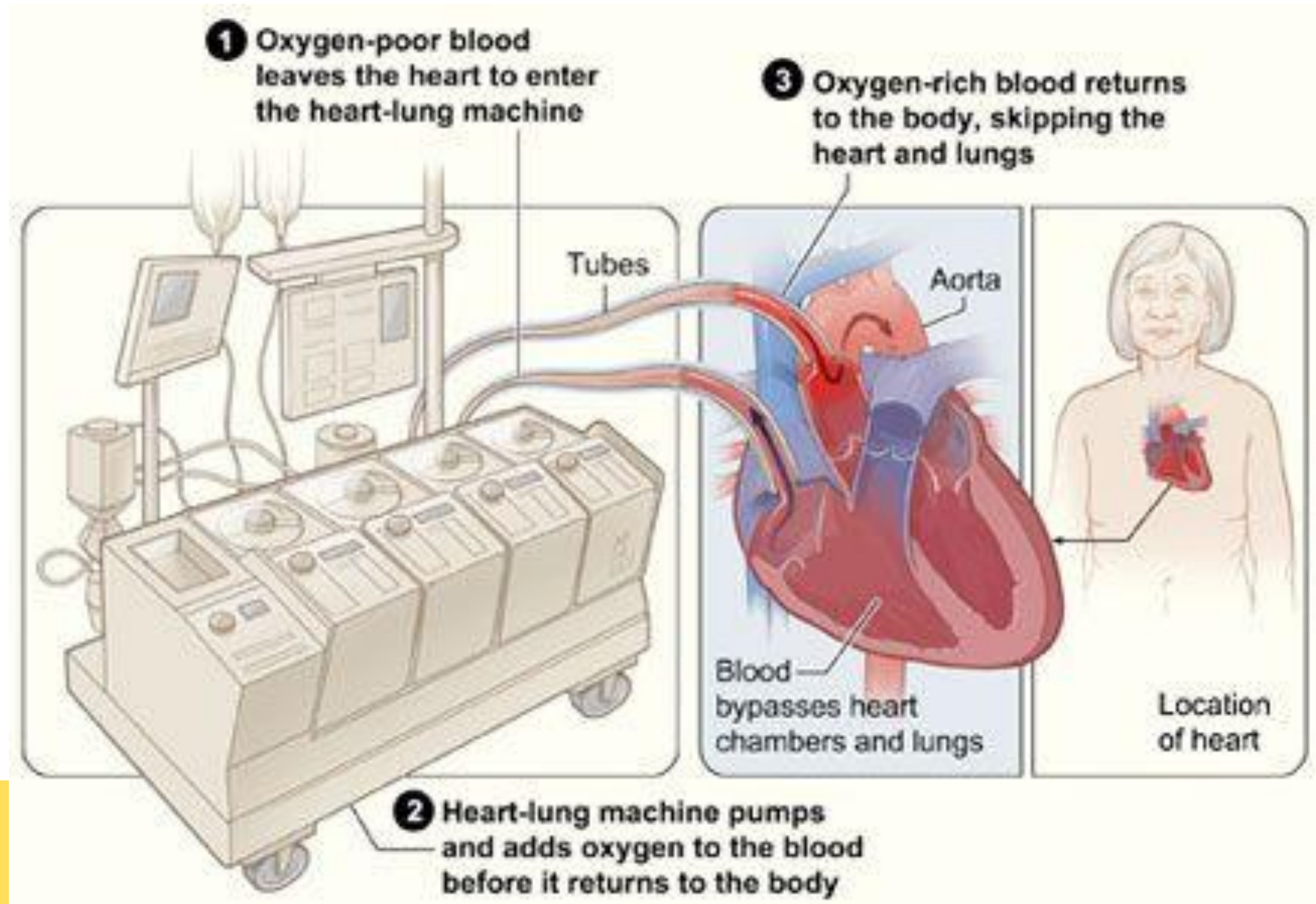


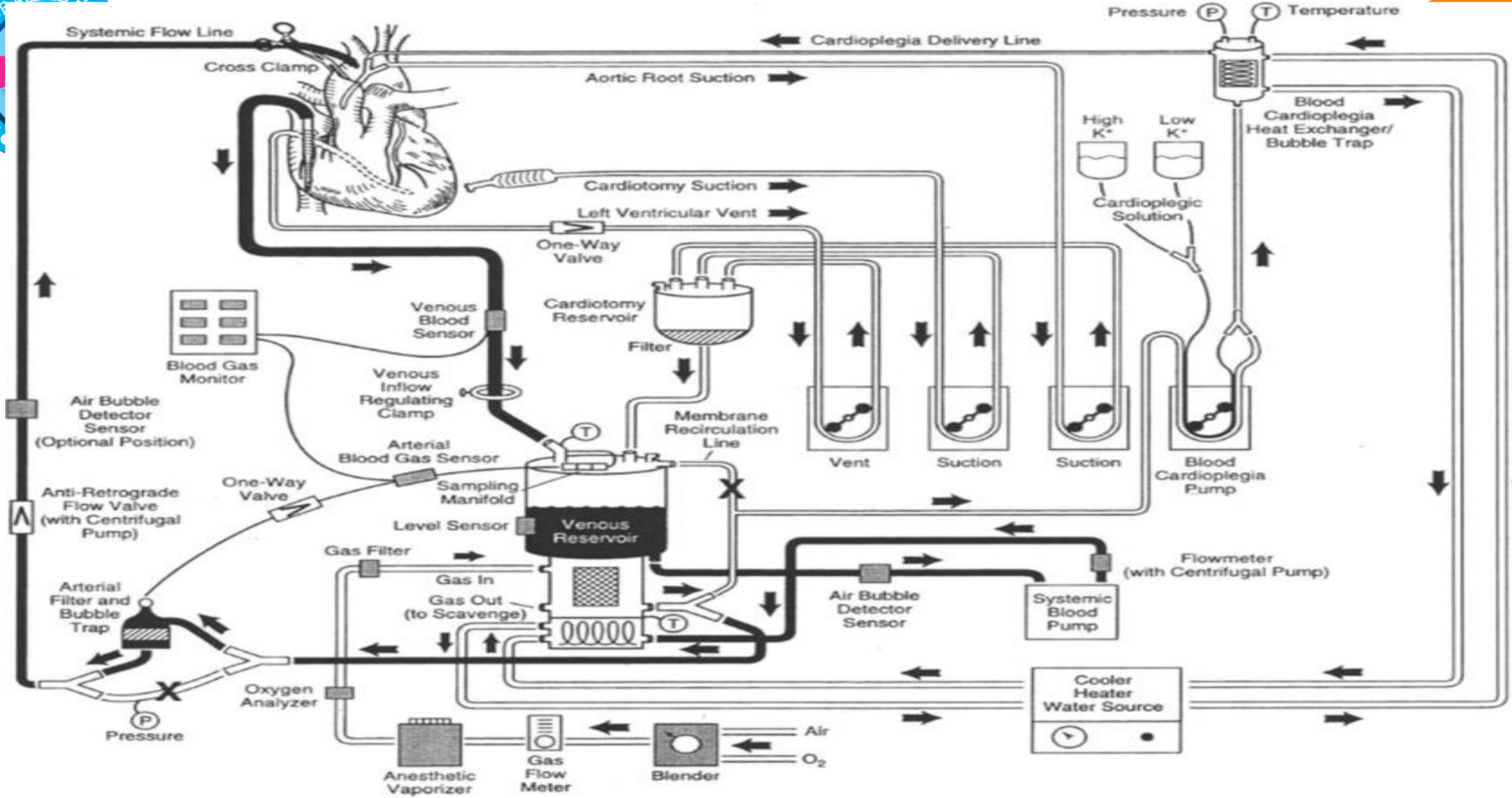
COMPONENTS OF HLM

- Venous cannula
- Arterial cannula
- Oxygenator
- Venous Reservoir
- Pumps
- Tubing
- Heat exchanger
- Cardiotomy suckers
- Cardiac Vents and
- Adjuncts such as the level detector, arterial line pressure transducer, arterial line bubble trap and filter, cardioplegia line pressure meter, gas line filter, gas flow meter, and one-way valves on cardiac vents.

1. The circuit starts at the right heart side, where all/part of the venous return is drawn into the reservoir via a venous cannula. This happens passively by gravity, relying on the difference in height between the patient and the reservoir.
2. The blood is then driven via a systemic blood pump or the main pump into the oxygenator, which oxygenates the blood and transforms it into usable blood.
3. The next step is returning this blood to the patient, but not all of it will return to the same place. The blood instead is split into two. The normal (oxygenated) blood goes back to the patient via the aortic cannula, which is penetrated by the surgeon in the distal ascending aorta.
4. Heat exchange system used in extracorporeal circulation to warm or cool the blood or perfusion fluid flowing through the device.

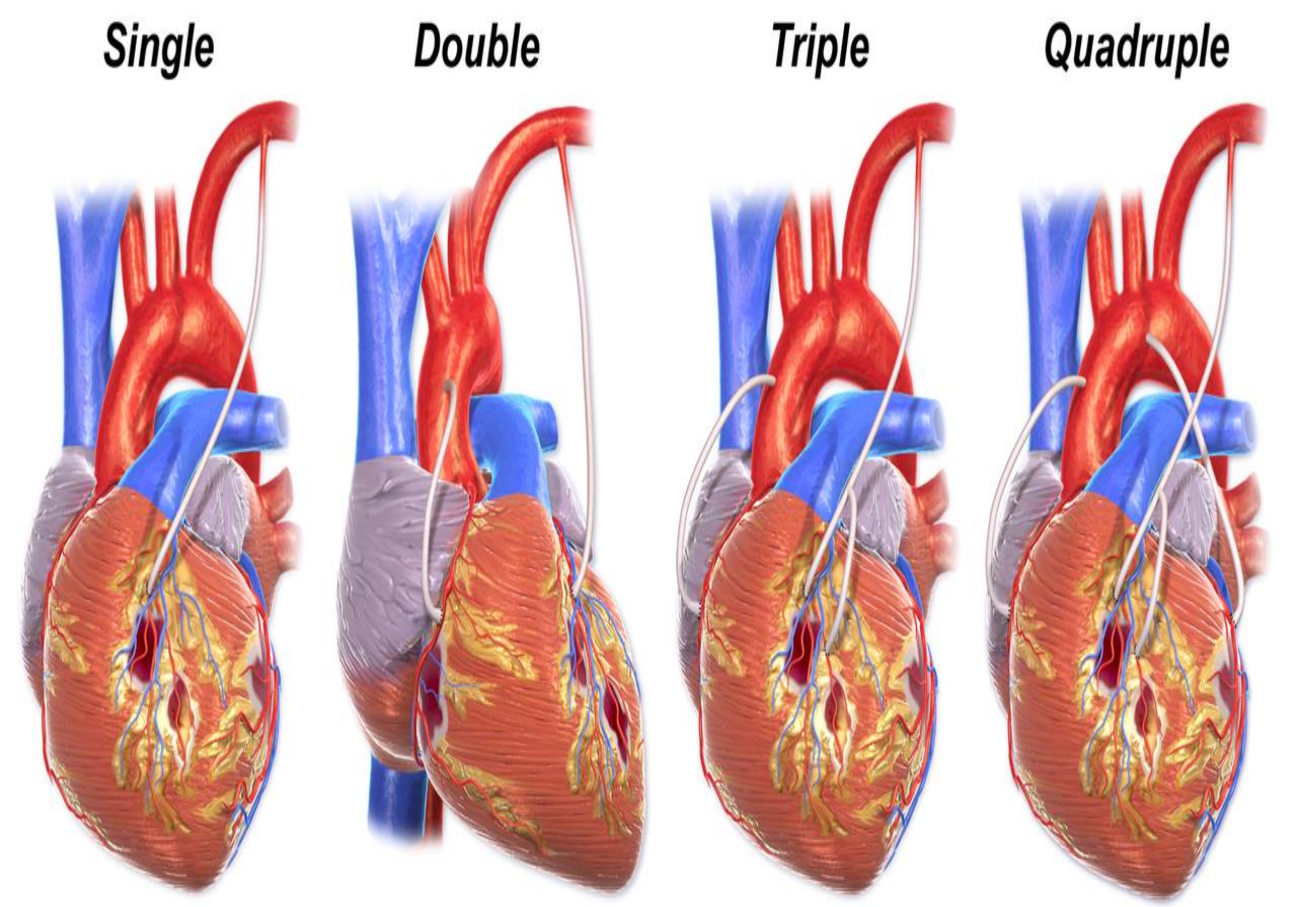
- **Suckers -** Cardiotomy suckers all receive blood from the patient and return it to the reservoir to support the circuit
- **Vents -** Left ventricular vents (aortic root, RSVP [right superior pulmonary vein], apical, pulmonary) follow the same pattern as suckers
- **One-way vent valves** to prevent adverse pumping of air into the heart




Systemic Flow Line
Cross Clamp
Pressure
Temperature
Cardioplegia Delivery Line
Aortic Root Suction
Blood Cardioplegia Heat Exchanger/ Bubble Trap
High K+
Low K+
Cardiotomy Suction
Left Ventricular Vent
Cardioplegic Solution
One-Way Valve
Cardiotomy Reservoir
Filter
Venous Blood Sensor
Blood Gas Monitor
Venous Inflow Regulating Clamp
Air Bubble Detector Sensor (Optional Position)
Arterial Blood Gas Sensor
Membrane Recirculation Line
Vent
Suction
Suction
Blood Cardioplegia Pump
Anti-Retrograde Flow Valve (with Centrifugal Pump)
One-Way Valve
Sampling Manifold
Level Sensor
Venous Reservoir
Gas Filter
Gas In
Gas Out (to Scavenge)
Flowmeter (with Centrifugal Pump)
Air Bubble Detector Sensor
Systemic Blood Pump
Arterial Filter and Bubble Trap
Oxygen Analyzer
Pressure
Cooler Heater Water Source
Air
O2
Anesthetic Vaporizer
Gas Flow Meter
Blender

SURGICAL PROCEDURES

- Coronary artery bypasses surgery.
- Cardiac valve repair and/or replacement (aortic valve, mitral valve, tricuspid valve, pulmonic valve)
- Repair of large septum defects (atrial septum defect, ventricular septum defect, atrioventricular septum defect)
- Transplantation (heart transplantation, lung transplantation, heart-lung transplantation)
- Implantation of heart.



Coronary Artery Bypass Graft (CABG)

INDICATIONS

- The role of CPB could thus be summarized as follows:

1. Empty the heart. Drain all the blood out (achieved via venous cannulas).
2. Oxygenate the blood. Thus stop the lungs via oxygenators.
3. Adjust its chemical and electrolyte contents via a reservoir container.
4. Adjust its temperature via the heat exchanger machine.
5. Return it to the patient via arterial cannulas.

- Also, provide means to ensure the following:

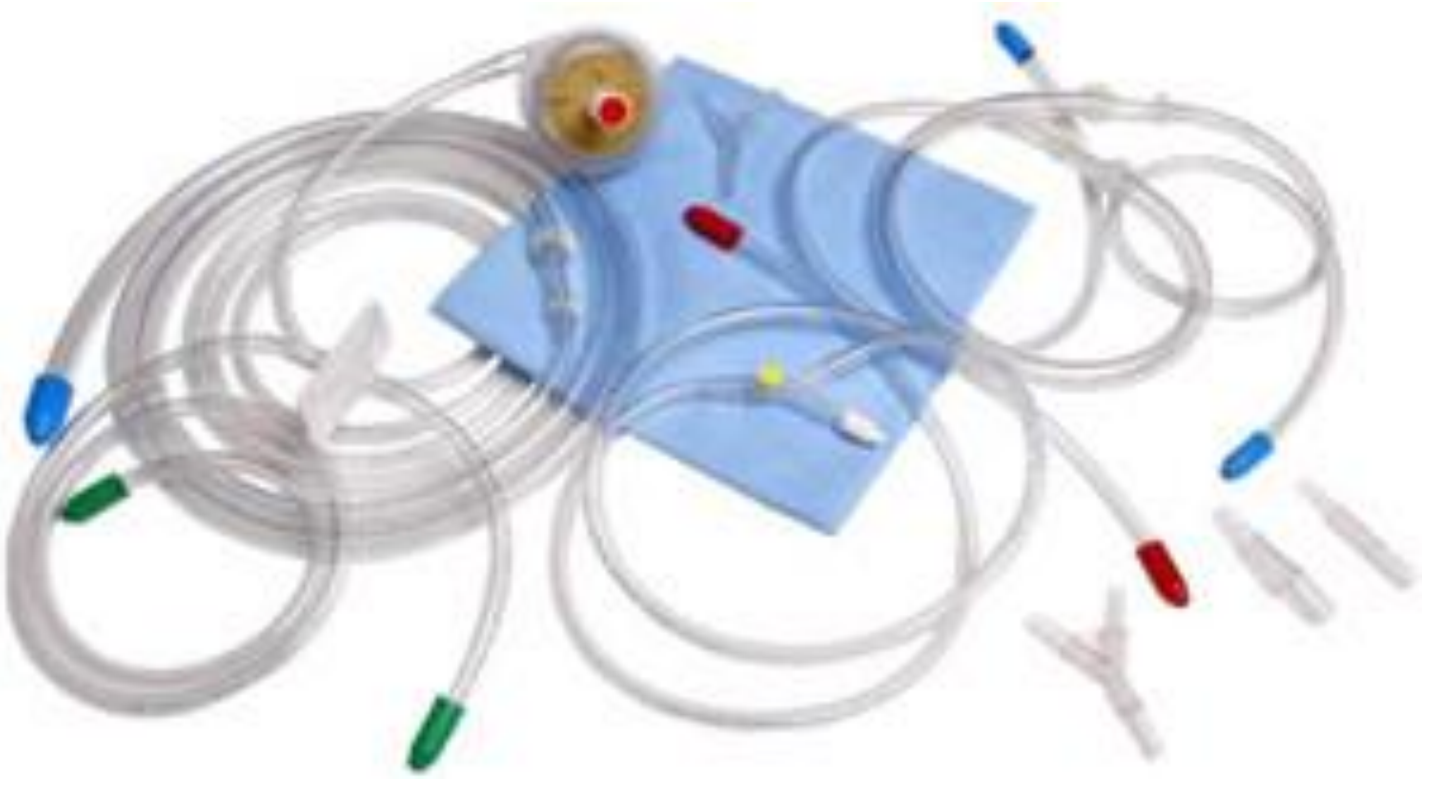
1. Save blood lost during surgery and return it to the patient via cardiotomy suckers.
2. Prevent distention of the heart during surgery via cardiac vents.
3. Deliver cardioplegia and provide myocardial protection.
4. Provide safety nets and standby pathways (safety adjuncts). This is all achieved via a closed circuit driven by pumps and connected by tubes.

Components of the CPB machine and the extracorporeal circuit

Equipment	Function
Oxygenator system, venous reservoir, oxygenator, heat exchanger	Oxygenate, remove carbon dioxide and cool/rewarm blood
Gas line and FiO_2 blender	Delivers fresh gas to the oxygenator in a controlled mixture
Arterial pump	Pumps blood at a set flow rate to the patient
Cardiotomy suckers and vents	Scavenges blood from the operative field and vents the heart
Arterial line filter	Removes microaggregates and particulate matter >40μm
Cardioplegia systems	Deliver high-dose potassium solutions to arrest the heart and preserve the myocardium
Cannula	Connect the patient to the extracorporeal circuit

TUBINGS

- The blood is drained from the right side of the heart and returned to the systemic circulation through the aorta
- The tubing in the CPB circuit interconnects all of the main components of the circuit.
- Materials may be used for the manufacture of the tubing; include polyvinyl chloride (PVC), silicone (reserved for the arterial pump boot) and latex rubber.
- The size of tubing used at different points in the circuit is determined by the pressure and rate of blood flow that will be required through that region of the circuit, or through a particular component of the circuit

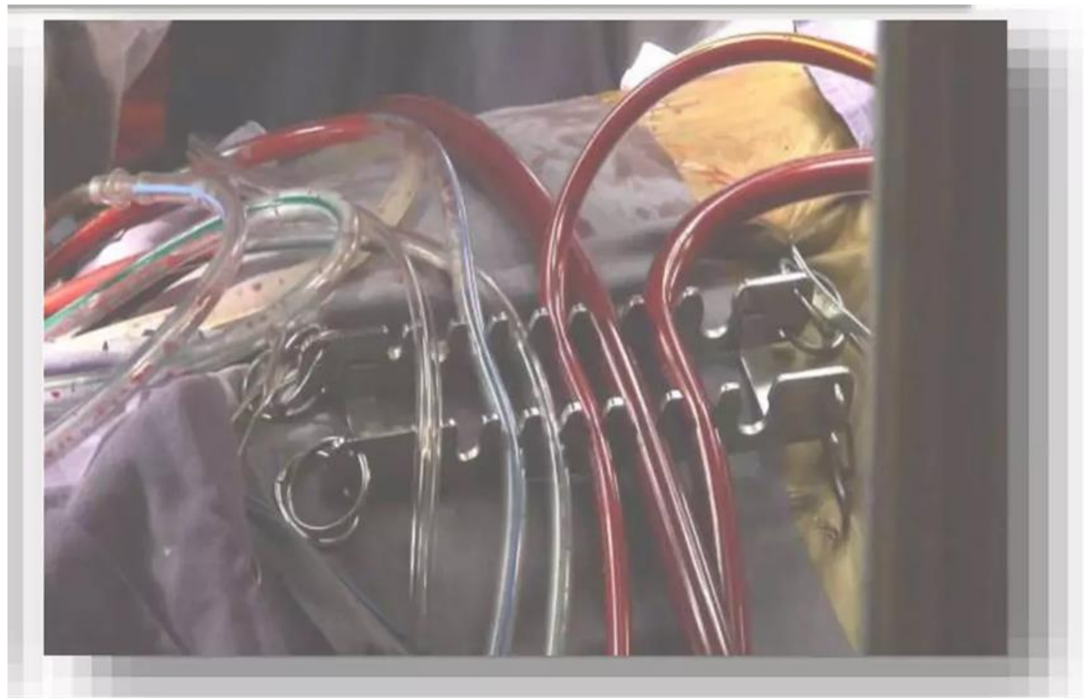


TUBING SIZES

Tubing size	Function
3/16″ (4.5 mm)	Cardioplegia section of the blood cardioplegia delivery system
1/4″ (6.0 mm)	Suction tubing, blood section of the blood cardioplegia delivery system
3/8″ (9.0 mm)	Arterial pump line for flow rates <6.7l/minute, majority of the arterial tubing in the extracorporeal circuit
1/2″ (12.0 mm)	Venous line, larger tubing is required to gravity drain blood from the patient

TUBING MATERIALS

- PVC a fairly strong material.
- versatility.
- PVC is a fairly rigid plastic, but plasticizers can be added to make it highly flexible.



DISADVANTAGE

PVC tubing stiffens during hypothermic CPB and tends to induce spallation; that is, the release of plastic microparticles from the inner wall of tubing as a result of pump compressions.

- Latex rubber generates more hemolysis than PVC, whereas silicone rubber is known to produce less hemolysis when the pump is completely occluded, but can release more particles than PVC.
- As a result of this, and because of PVC’s durability and accepted hemolysis rates, PVC is the most widely used tubing material.

Arterial cannulae

- The arterial cannula is used to connect the "arterial limb" of the CPB circuit to the patient and so deliver oxygenated blood from the heart-lung machine directly into the patient's arterial system
- The required size is determined by the size of the vessel that is being cannulated, as well as the blood flow required
- The ascending aorta is the most common site of arterial cannulation for routine cardiovascular surgery.
- This is because the ascending aorta is readily accessible for cannulation when a median sternotomy approach is used and has the lowest associated incidence of aortic dissection.

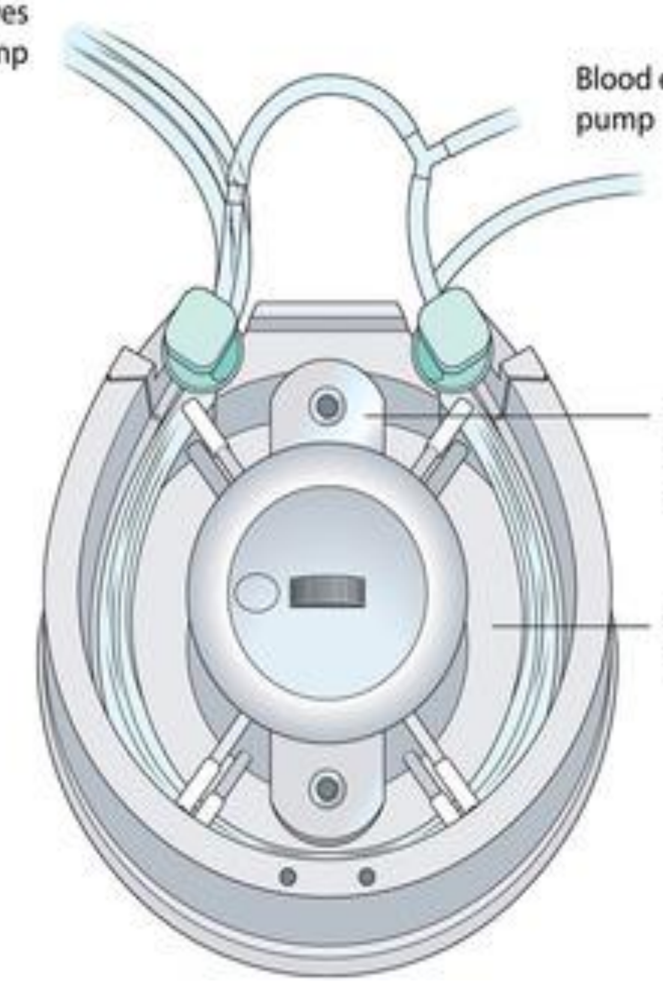
Venous cannulae

- Venous cannulation for CPB allows deoxygenated blood to be drained from the patient into the extracorporeal circuit.
- The type of venous cannulation used is dependent upon the operation being undertaken.

Pump heads

There are two types of pumps used in extracorporeal circuits:

1. Those that produce a flow – roller pumps.
2. Those that produce a pressure – centrifugal pumps.

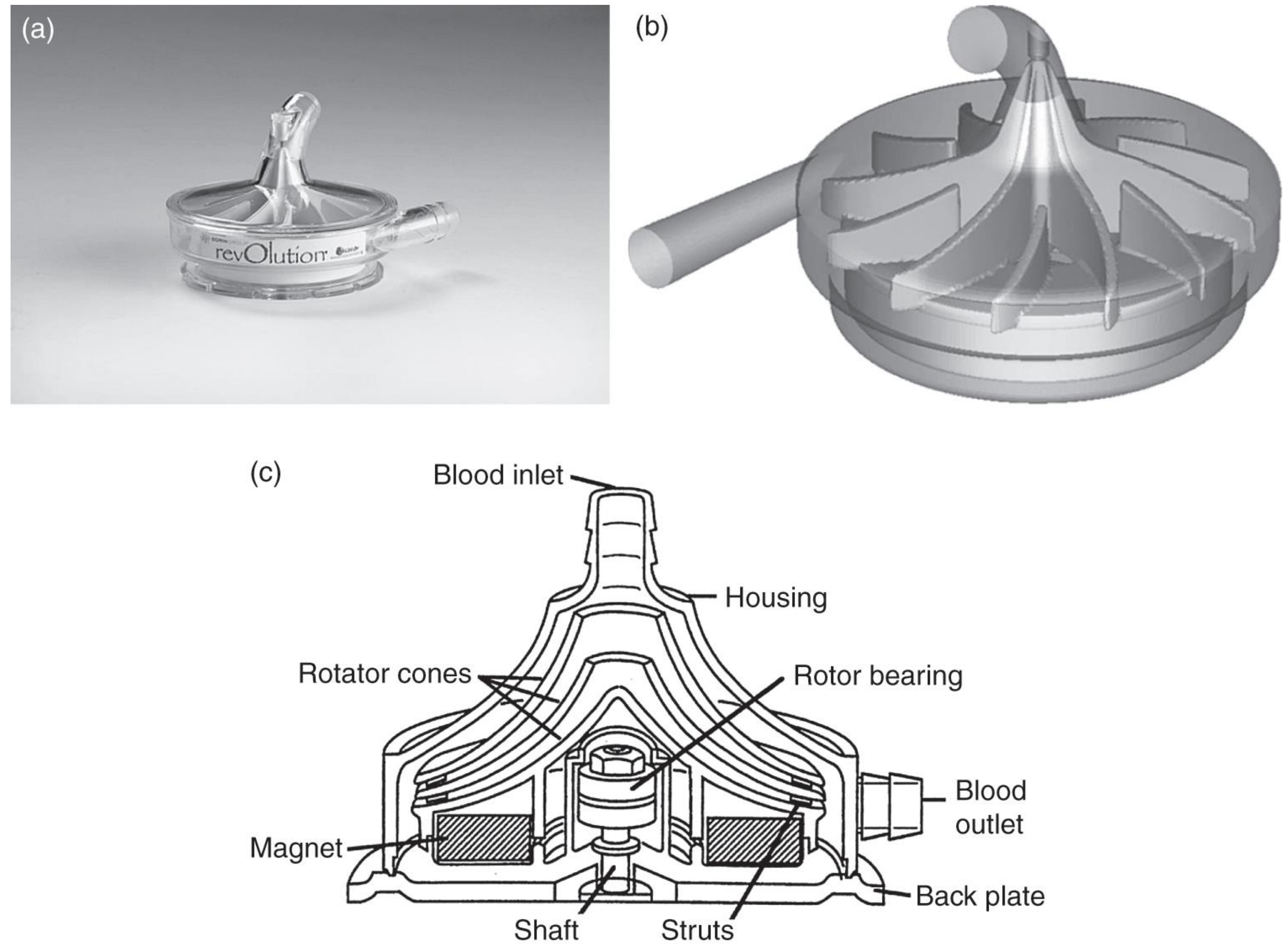


ROLLER PUMPS

- Roller pumps positively displace blood through the tubing using a peristaltic motion.
- Two rollers, opposite each other, "roll" the blood through the tubing.
- Roller pumps are relatively independent of circuit resistance and hydrostatic pressure; output depends on the number of rotations of the pump head and the internal diameter of the tubing used

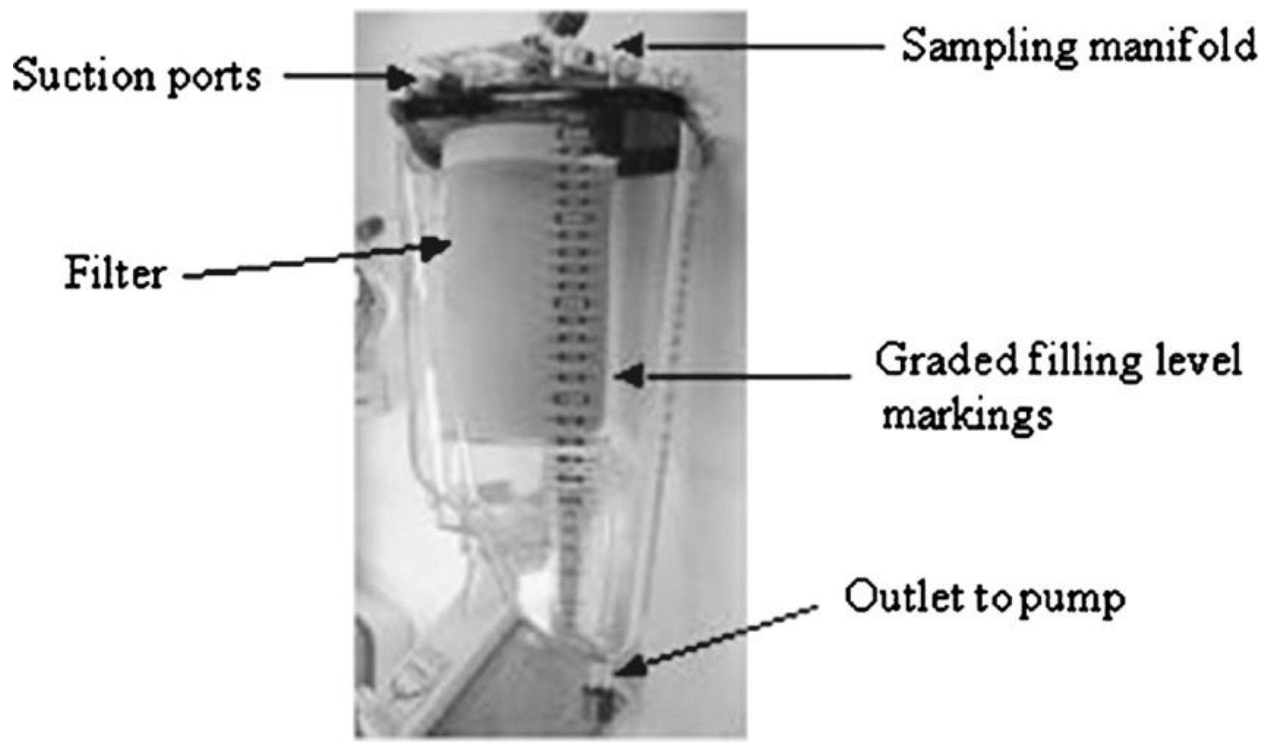
Centrifugal pumps

- The Biomedicus head contains a cone with a metal bearing encased in an outer housing, forming a sealed unit through which blood can flow
- The cone spins as a result of the magnetic force that is generated when the pump is activated.
- The spinning cone creates a negative pressure that sucks blood into the inlet, creating a vortex
- Centrifugal force imparts kinetic energy on the blood as the pump spins at 2000–4000 rpm (this speed is set by the user).
- The energy created in the cone creates pressure and blood is then forced out of the outlet.
- The resulting blood flow will depend on the pressure gradient and the resistance at the outlet of the pump



Reservoirs

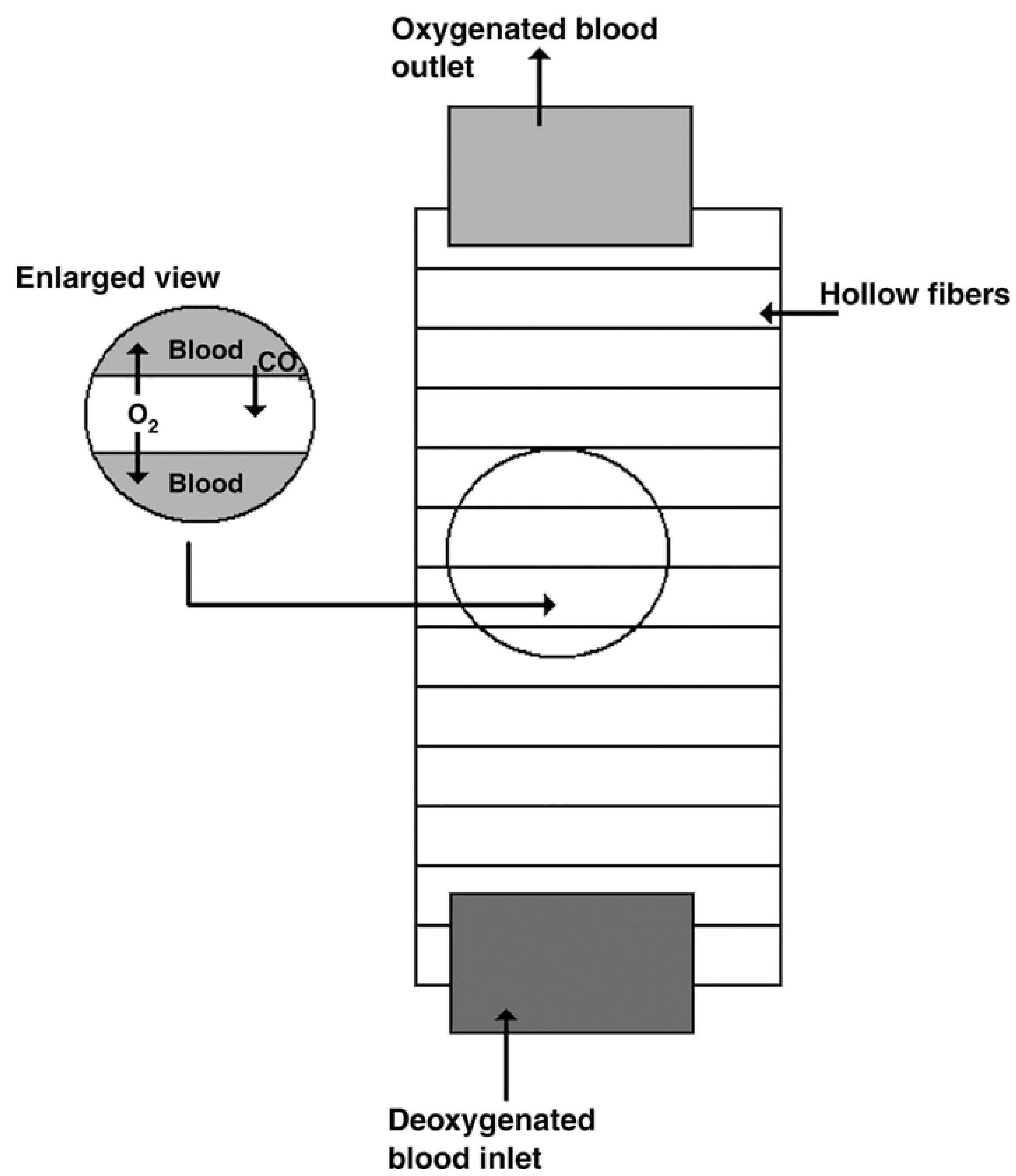
- Cardiotomy reservoirs may be hardshell or collapsible. Hardshell reservoirs are most commonly used in adult cardiac surgery.
- Hardshell reservoirs usually comprise of a polycarbonate housing, a polyester depth filter and a polyurethane de-foamer.
- The reservoir component of the CPB circuit therefore provides high-efficiency filtration, de-foaming and the removal of foreign particles
- The reservoir acts as a chamber for the venous blood to drain into before it is pumped into the oxygenator and permits ready access for the addition of fluids and drugs.
- A level of fluid is maintained in the reservoir for the duration of CPB.



Oxygenators

- The oxygenator include efficient oxygenation of desaturated hemoglobin and simultaneous removal of carbon dioxide from the blood.
- The oxygenator therefore acts as an artificial alveolarpulmonary capillary system.
- Gas exchange is based on Fick's Law of Diffusion:

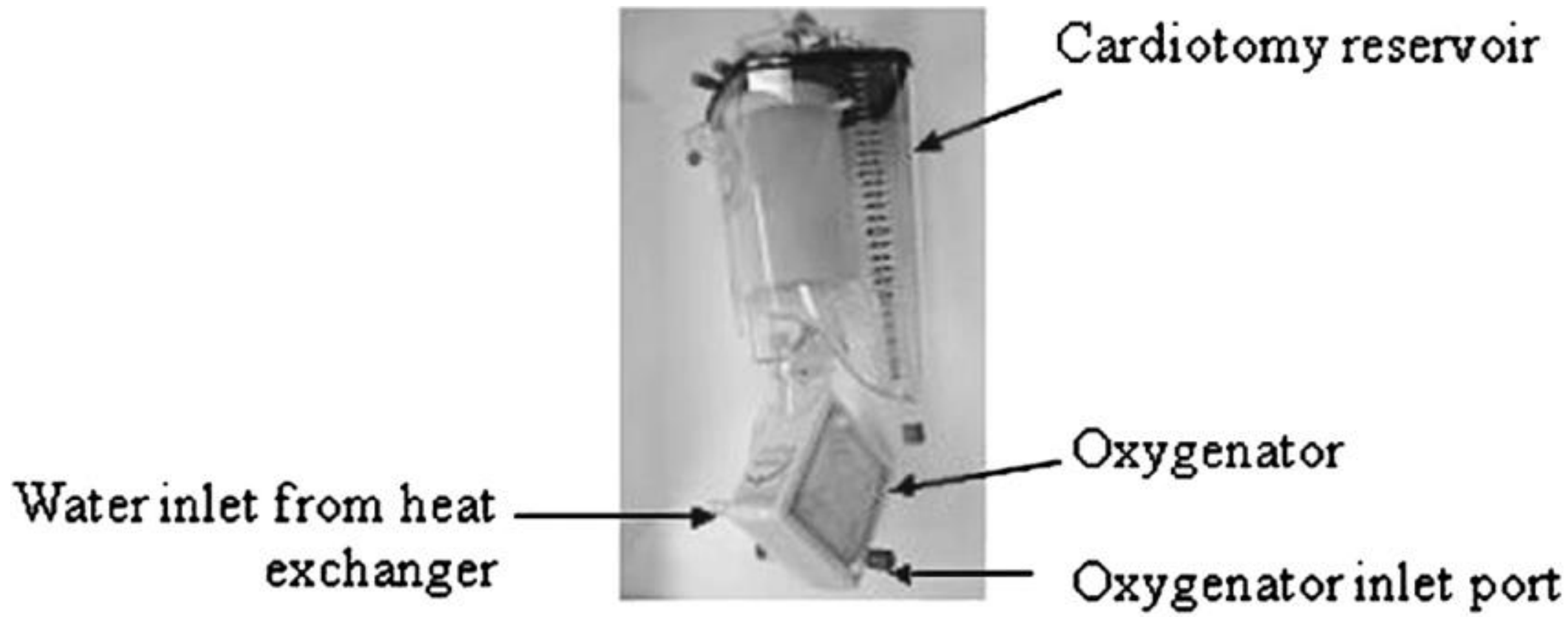
$$\textbf{Volume of gas diffused} = \frac{\text{Diffusion coefficient * Partial pressure difference}}{\text{Distance to travel}}$$



Fick's laws of diffusion states that the rate at which a molecule moves through a material is proportional to the concentration gradient (the difference in concentrations) between the two ends of the material; and inversely proportional to the thickness of the membrane.

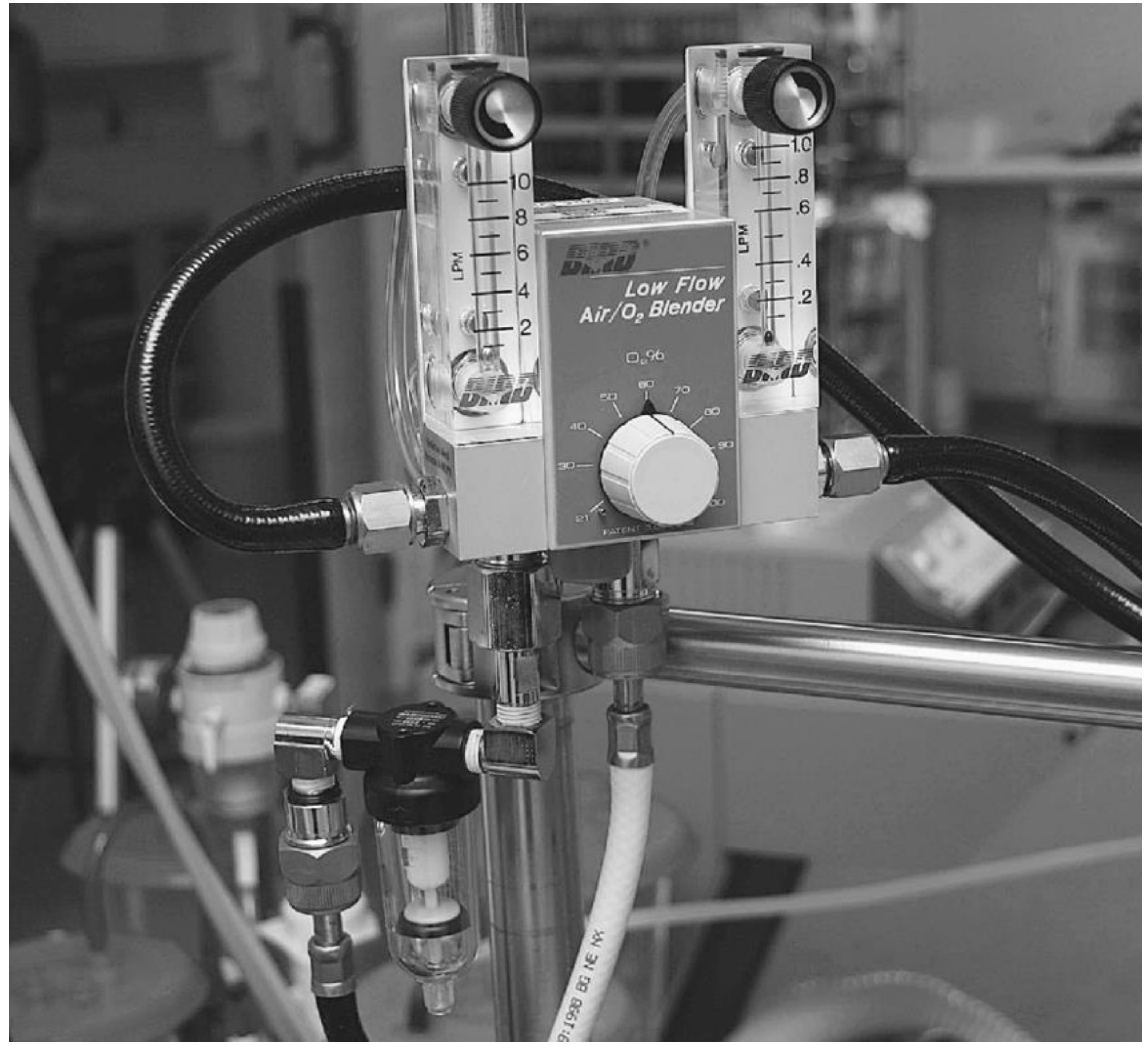
Heat exchanger

- The majority of oxygenators consist of a module for gas exchange with an integrated heat exchanger
- The external heater–cooler has digital regulating modules to allow precise control of temperature through thermostat-controlled heating and cooling elements within the console.
- Controlled cooling and re-warming of the patient are crucial to ensure an even distribution of temperature throughout the body and to prevent damage to blood components, proteins and tissues.



Gas supply system

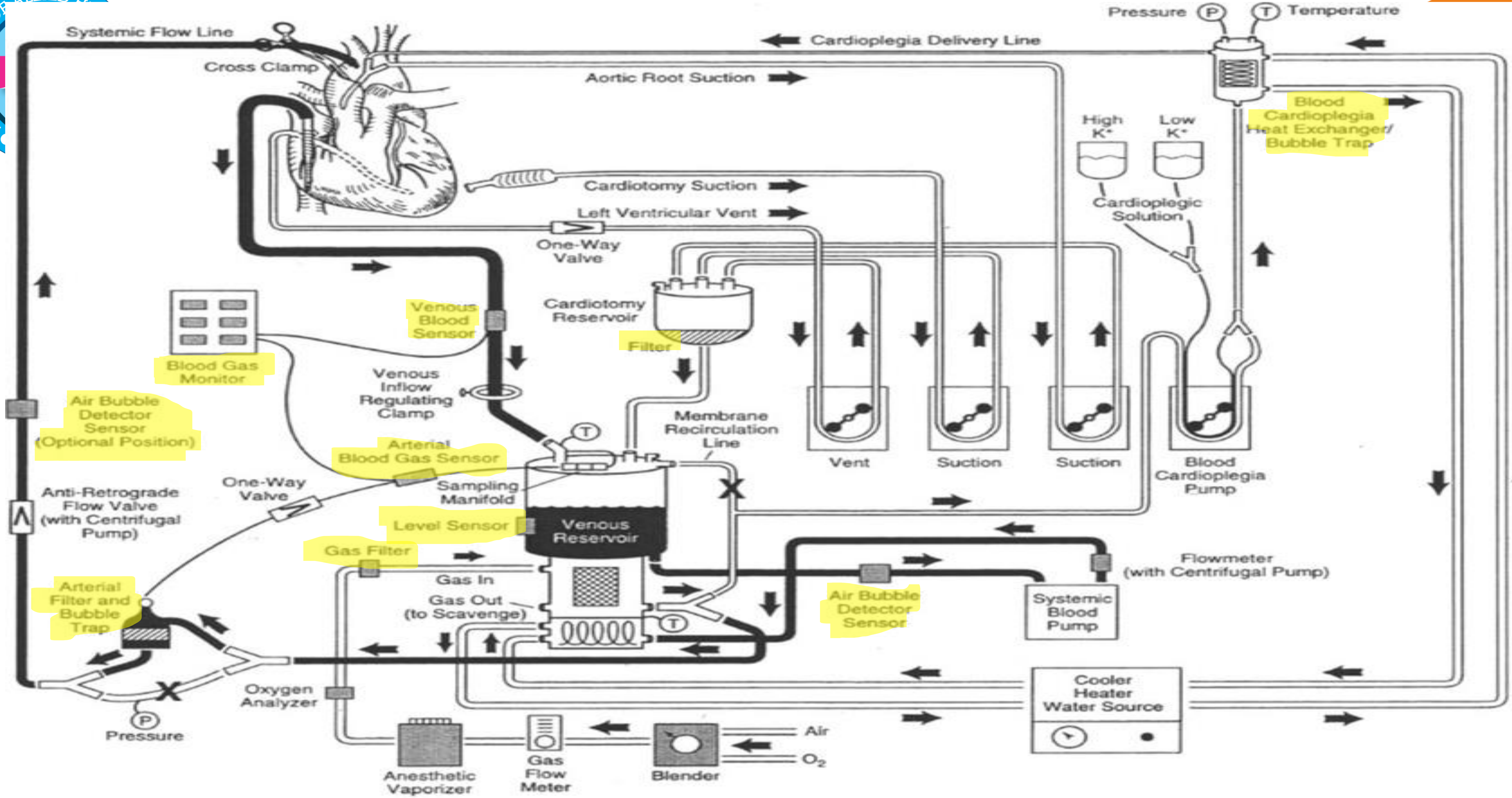
- The gas supply system provides a source of oxygen, air and carbon dioxide to the oxygenator.
- A blender mixes piped oxygen and air to the concentration set by the user, and the gas is delivered at a rate set on a flow meter.



Filters and bubble traps

There are numerous filters that can be used within the extracorporeal circuit. These range from 0.2µm gas line filters to 40µm arterial line filters

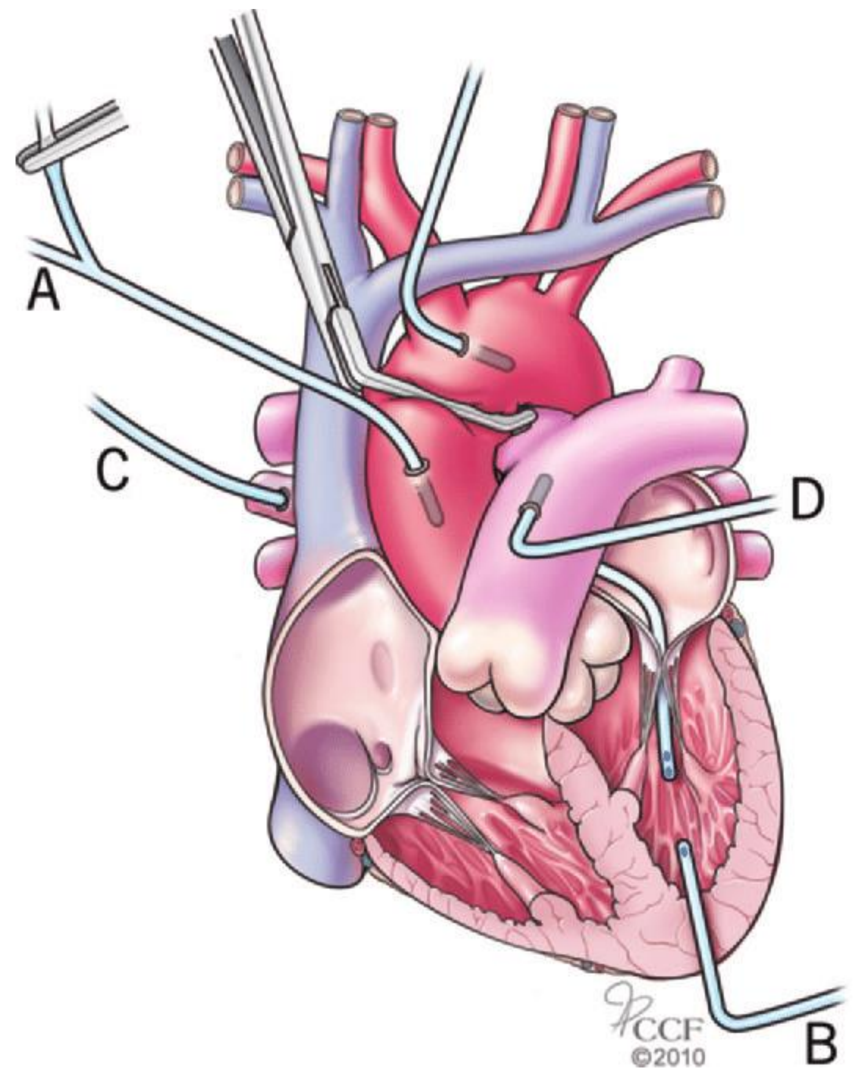
Filter type	Application and specification
Gas line	Removes 99.999% of bacteria found in the gas stream minimizing cross-contamination between the patient and the equipment
Pre-CPB	0.2µm filter is used during the priming and re-circulation phase. It is designed for the removal of inadvertent particulate debris and microbial contaminants and their associated endotoxins
Arterial line	Designed to remove microemboli >40µm in size from the perfusate during extracorporeal circulation. This includes gas emboli, fat emboli and aggregates composed of platelets, red blood cells and other debris
Leukodepletion	Reduces the levels of leukocytes, either from the arterial line or cardioplegia system, and excludes microemboli >40µm
Cardioplegia	Blood cardioplegia: >40 µm filter. Crystalloid cardioplegia: >0.2 µm filter. Low priming volume filter for cell-free solutions.
Blood transfusion	Designed to reduce the levels of leukocytes and microaggregates from 1 unit of packed red blood cells or whole blood
Cell salvage	Designed for the filtration of salvaged blood to remove potentially harmful microaggregates, leukocytes and lipid particles



Systemic Flow Line
Cross Clamp
Pressure
Temperature
Cardioplegia Delivery Line
Aortic Root Suction
Blood Cardioplegia Heat Exchanger/ Bubble Trap
High K+
Low K+
Cardiotomy Suction
Left Ventricular Vent
One-Way Valve
Cardioplegic Solution
Cardiotomy Reservoir
Venous Blood Sensor
Blood Gas Monitor
Filter
Venous Inflow Regulating Clamp
Air Bubble Detector Sensor (Optional Position)
Arterial Blood Gas Sensor
Membrane Recirculation Line
Vent
Suction
Suction
Blood Cardioplegia Pump
Anti-Retrograde Flow Valve (with Centrifugal Pump)
One-Way Valve
Sampling Manifold
Level Sensor
Venous Reservoir
Gas Filter
Gas In
Gas Out (to Scavenge)
Flowmeter (with Centrifugal Pump)
Arterial Filter and Bubble Trap
Air Bubble Detector Sensor
Systemic Blood Pump
Cooler Heater Water Source
Oxygen Analyzer
Pressure
Anesthetic Vaporizer
Gas Flow Meter
Blender
Air
O_2

Suckers and vents

- The suckers attached to the CPB circuit allow blood to be salvaged from the operative field to be returned to the circuit via the reservoir.
- “Vent” suckers are specifically used to drain blood that has not been directly removed from the heart by the venous pipes.
- Sites for placing vents:
  - the aortic root;
  - the left ventricle;
  - the right superior pulmonary vein;
  - the left ventricular apex; and
  - the left atrium or pulmonary artery.



Cardioplegia delivery systems

- The purpose of cardioplegia is to cause rapid diastolic cardiac arrest.
- This produces a still, flaccid heart, which facilitates surgery and also is the state in which myocardial metabolism is almost at its lowest levels.
- Reduction in the metabolic state of the heart is achieved by cooling using cold cardioplegia and also by core cooling of the body.
- The common constituent of all cardioplegia solutions is a high concentration of potassium, as this produces diastolic cardiac arrest.

Hemofilters

- Also known as ultrafilters or hemoconcentrators, these contain semipermeable membranes (hollow fibers) that permit passage of water and electrolytes out of blood.
- They are normally connected to the CPB circuit at a high pressure port or line, such as the systemic flow line, to provide a driving force for blood through the device.
- Blood to be filtered before being returned to the patient.
- Fluid removal is usually 30 to 50 ml/minute, and depending on the membrane used
- Hemofiltration may be used during or after CPB, mainly to manage hyperkalemia or acidosis

Alarms

- All alarm systems are linked into the computer system of the CPB circuit and directly regulate or stop the pump flow when appropriate.
- The alarm systems used within the circuit aid the perfusionist in running a safe pump and are all vital components of the circuit.
- The alarms are engaged prior to initiating CPB and are not turned off, or over-ridden, until the patient has been weaned from CPB.
- Some of the alarms are
  - Low level alarm on venous reservoir
  - High-pressure alarm on arterial line
  - Bubble alarm - (arterial line and blood cardioplegia) Alarms when bubbles are sensed
  - Oxygen sensor - Alarms when oxygen supply to the oxygenator fails

References

- Cardio Pulmonary Bypass Sunit Ghosh Florian Falter Albert C. Perrino
- Manual of Clinical Perfusion Bryan V. Lach Second Edition
- https://youtu.be/RmwMzw_YTNU

THANK YOU