Cardiopulmonary Bypass Machine: Overview

- CPB: Technique that diverts venous blood away from the heart, adds O2, removes CO2, and returns the blood to a large artery (usually the aorta)
- Basically providing artificial ventilation and perfusion.
- Disadvantage: Nonphysiologic – arterial pressure is typically below normal and blood flow is nonpulsatile.
- CPB machine has 5 basic components:
  - A venous reservoir
  - An oxygenator
  - A heat exchanger
  - A main pump
  - An arterial filter
  - A vaporizer for delivering anesthetic gases
- Modern machines use a single disposable unit with a reservoir, oxygenator, and heat exchanger built in.
- Most machines also have separate accessory pumps that can be used for blood salvage (cardiomyotomy suction), venting (draining) the LV, and cardioplegia.
- Priming the circuit: the circuit must be primed with fluid (400 cc for babies, 800 for kids, 1200-1800 cc for adults).
  - A balance salt solution is used (i.e. lactated) with the addition of other components: Colloid (albumin, hetastarch), manitol (for renal protection), heparin, bicarbonate and THAM.
- At BIDMC, the cardioplegia solution is composed of
  - high K⁺ solution:
    - KCl 60 mEq
    - Magnesium sulfate 8 mEq
    - Dextrose 2.5 g
    - Tromethamine (THAM) 10 mEq
    - In Normal Saline 500 ml
  - “low K⁺ solution:
    - KCL 30 mEq
    - Magnesium sulfate 15 mEq
    - Dextrose 5 g
    - Tromethamine (THAM) 20 mEq
    - In Normal Saline 1000 mL
At the onset of bypass, hemodilution usually decreases the Hct to about 22-25%. The Hct depends on the starting Hct and the patient’s blood volume. For babies and severely anemic adult patient – blood may be added to the priming solution.

**Reservoir**
- Receives blood from the pt via one or two venous cannulas in the RA or SVC+IVC.
- Blood flows to the reservoir by gravity drainage.
- Since venous pressure is usually low, the driving force is directly proportional to the difference in height between the pt and the reservoir.
- Priming the machine creates a siphon effect and entrainment of air can produce an air lock that may prevent blood flow.
- The fluid level in the reservoir is critical: If the reservoir is allowed to empty, air can enter the main pump and cause fatal air embolism.

**Oxygenator**
- Blood is drained by gravity from the bottom of the venous reservoir into the oxygenator, which contains a blood gas interface that allows blood to equilibrate with the gas mixture (air +O₂). This is where a volatile anesthetic is added (at the oxygenator gas inlet).
- In the modern machine the membrane-type oxygenator is a very thin, gas-permeable silicone membrane (this is because arterial O₂ is inversely related to the thickness of the blood film in contact with the membrane.
- CO₂ tension is dependent on total gas flow.
- Bubble-type oxygenator: tiny bubbles (foam) are formed as the O₂ passes through small holes at the base of a blood column. The tiny bubbles provide a large surface area for blood to equilibrate with the inflow gases. The bubbles are then removed by passing the blood across a defoaming agent (a charged silicone polymer). Disadvantage: trauma to the formed elements in blood, which becomes more significant for procedures requiring more than 2 hours of CPB.

**Heat Exchanger**
- From the oxygenator the blood enters the heat exchanger, where it is either cooled or warmed, depending on the temperature of the water flowing through the exchanger (4-42 °C).
- Heat transfer occurs by conduction.
- Since gas solubility decreases as blood temperature rises, a filter is built into the unit to catch any bubbles that may form during rewarming.

**Main Pump**
1. **Roller Pumps:**
   - Flow is produced by compressing large-bore tubing in the main pumping chamber as the heads turn.
   - Flow is directly proportional to the number of revolutions per minute.
   - Excessive red cell trauma is prevented by subtotal occlusion.
• The constant speed of the rollers pumps blood regardless of the resistance encountered.
• As a safety feature, all roller pumps have a hand crank to allow manual pumping.
• Pulsatile blood flow is possible with some roller pumps

2. Centrifugal Pumps:
• Consist of a series of cones in a plastic housing. As the cones spin, the centrifugal forces created propel the blood from the centrally located inlet to the periphery.
• In contrast to roller pumps, blood flow is pressure-sensitive and must be monitored by an electromagnetic flowmeter (increased in distal pressure will decrease flow and must be compensated by increasing the pump speed.)
• These pumps are less traumatic to blood than roller pumps since they are non-occlusive.
• Although not commonly used, centrifugal pumps can deliver pulsatile flow.

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Disadvantage</th>
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<tbody>
<tr>
<td>Roller</td>
<td></td>
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<tr>
<td>1. Predictable pump flow based on pump speed</td>
<td>1. Can pump large quantities of air</td>
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<td>2. Capable of pulsatile flow</td>
<td>2. Can overpressurize lines, causing them to burst</td>
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<tr>
<td>Centrifugal</td>
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<tr>
<td>1. Cannot pump large quantities of air</td>
<td>Output not necessarily indicated by pump speed</td>
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Arterial Filter
• Particulate matter (eg, thrombi, fat globules, calcium, tissue debris) enter the CPB circuit with alarming regularity.
• In addition to filters used at other locations, a final, in line, arterial filter (24-40 µm) is mandatory to prevent systemic embolism.
• Once filtered, the propelled blood returns to the patient, via a cannula in the ascending aorta or other artery.
• The filter is always constructed with a (normally clamped) bypass limb in case it becomes clogged or develops high resistance. For the same reason, arterial inflow pressure is measured before the filter. The filter is also designed to trap air, which can be blend out through a built-in stopcock.

Accessory Pumps and Devices
1. Cardiotomy Suction:
• The cardiotomy suction pump aspirates blood from the surgical field during CPB and returns it to the main pump reservoir.
• It can be used ONLY after heparinization of the patient (usually after ACT > 200).
• A cell-saver suction may also be used, but that blood is returned to a separate reservoir. At the end of the procedure, the cell-saver blood can be centrifuged, washed, and given back to the patient.
• Excessive suction pressure contributes to red cell trauma.
• Excessive use of cell-saver suction (instead of cardiotomy suction) during bypass depletes CPB circuit volume.

2. Left Ventricular Vent:
• Even after institution of total bypass, with time blood accumulates in the left ventricle as a result of residual pulmonary flow from the bronchial arteries (which arise directly from the aorta or the intercostals arteries) or thebesian vessels, or as a result of aortic regurgitation.
• Distention of the left ventricle compromises myocardial preservation and requires decompression (venting).
• Most of the time this is accomplished by a catheter inserted into the left ventricle via the right superior pulmonary vein and left atrium.
• Less commonly, venting is accomplished through a catheter in the left ventricular apex or through the aortic valve.
• The blood aspirated by the vent pump normally passes through a filter and is returned to the venous reservoir.

3. Cardioplegia Pump:
• Cardioplegia is most often administered via an accessory pump on the CPB machine. This technique allows optimal control over the infusion pressure, rate, and temperature.
• A separate heat exchanger ensures control of the cardioplegia solution’s temperature.

4. Ultrafiltration
• Ultrafiltration can be used during CPB to increase the patient’s hematocrit without transfusion.
• It consist of hollow capillary fibers that can function as membranes, allowing separation of the aqueous phase of blood from its cellular and proteinaceous elements.
• Hydrostatic pressure forces water and electrolytes across the fiber membrane. Effluents of up to 40 mL/min may be removed.