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

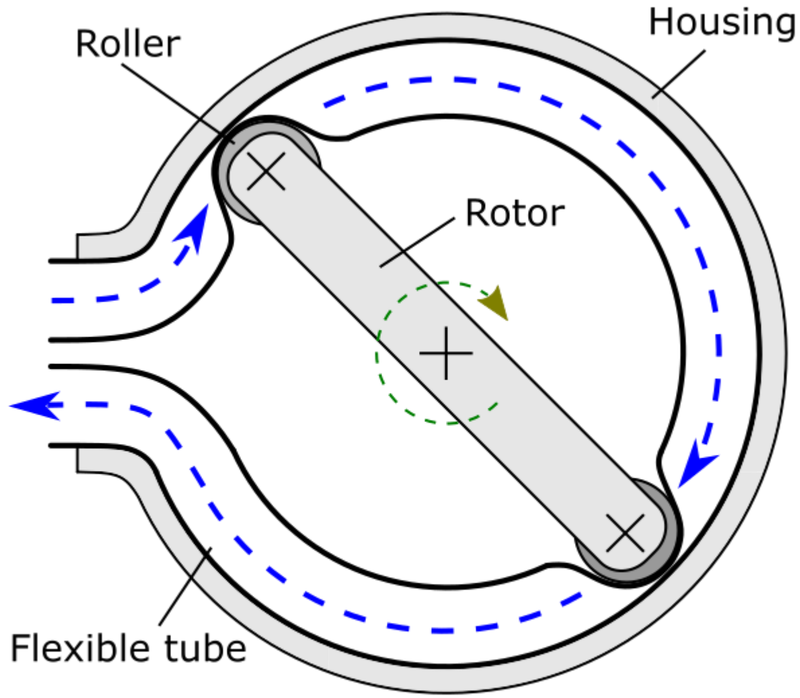
COURSE NAME : PRINCIPLES OF PERFUSION TECHNOLOGY I

2ND YEAR

TOPIC : BLOOD PUMP

CHARACTERISTICS OF AN IDEAL BLOOD PUMP

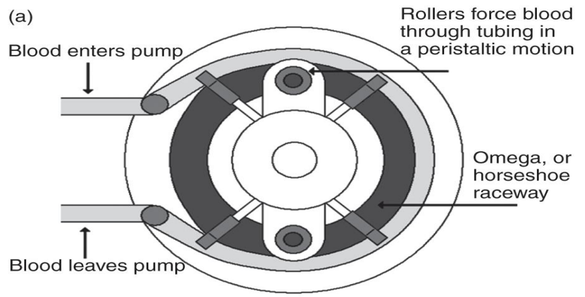
- Controllable stroke volume and pulse rate
- Capable of producing a wide range of outputs which are linearly proportional to the pulse rate and independent of afterload
- Minimal transfer of kinetic energy to the blood
- Parts in contact with blood are disposable, have smooth surface, and are of simple design



Conventional roller pump with complete tube occlusion in the areas of the rollers

CHARACTERISTICS OF AN IDEAL BLOOD PUMP (CONT)

- Devoid of areas conducive to blood stagnation, turbulence, or cavitation
- Calibration easy and reproducible
- Automatically controlled and operated for routine use with manual and/or battery operation potential in the event of power failure
- Includes a monitor of actual versus predicted pump speed that halts pump flow when the pump speed exceeds the set pump speed by more than a fixed percent



Types of blood pumps

Pumps can be classified into two main categories

Displacement pumps

Rotary pumps

- Displacement pumps
  - Roller pump
- Rotary pumps
  - Radial (centrifugal) pumps
  - Diagonal pump
  - Axial pump

NON PULSATILE & PULSATILE PERFUSION

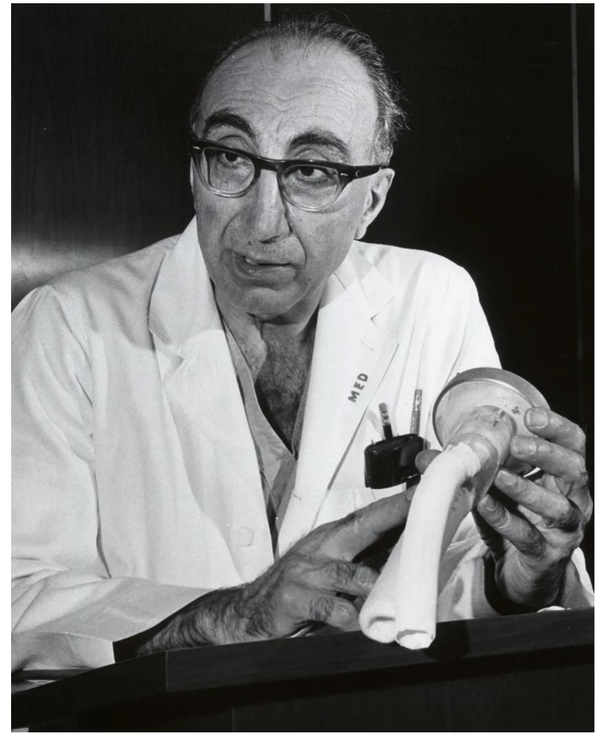
- Non-pulsatile perfusion is known to have a detrimental effect on cell metabolism and organ function.
- The pulsatile perfusion more closely resembles the pattern of blood flow generated by the cardiac cycle and should therefore more closely emulate the flow characteristics of the physiological circulation, particularly enhancing flow through smaller capillary networks in comparison to non-pulsatile perfusion.

DISPLACEMENT PUMPS

ROLLER PUMPS

History

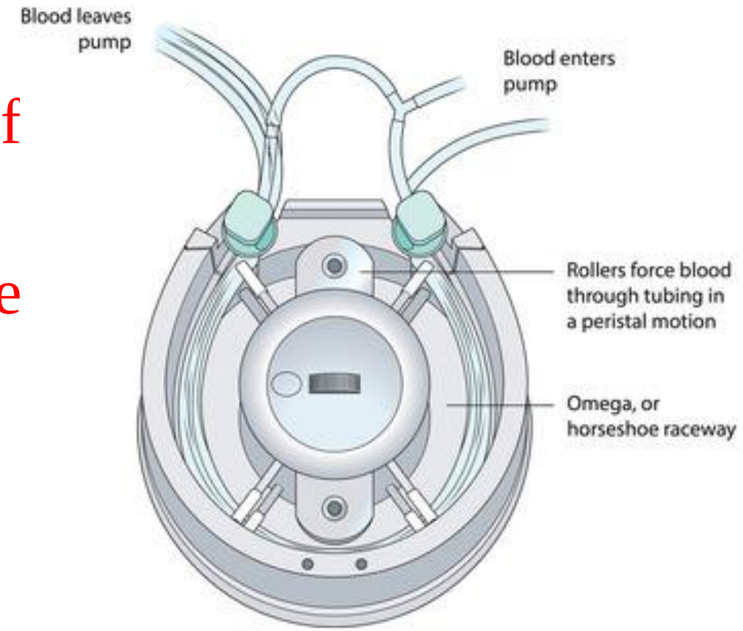
- They are one type of positive displacement pump
- The basic design of the roller pump was patented in 1855 by Porter and Bradley.
- In 1887, Allen patented a pump designed for blood transfusion
- In 1934, DeBakey et al. made a modification to the Porter-Bradley infusion pump to prevent creepage of the latex rubber tubing during blood transfusion
- 1959, Melrose proposed a more advanced design, in which the roller ran along the tubing held in place by a grooved backplate



Michael E. DeBakey

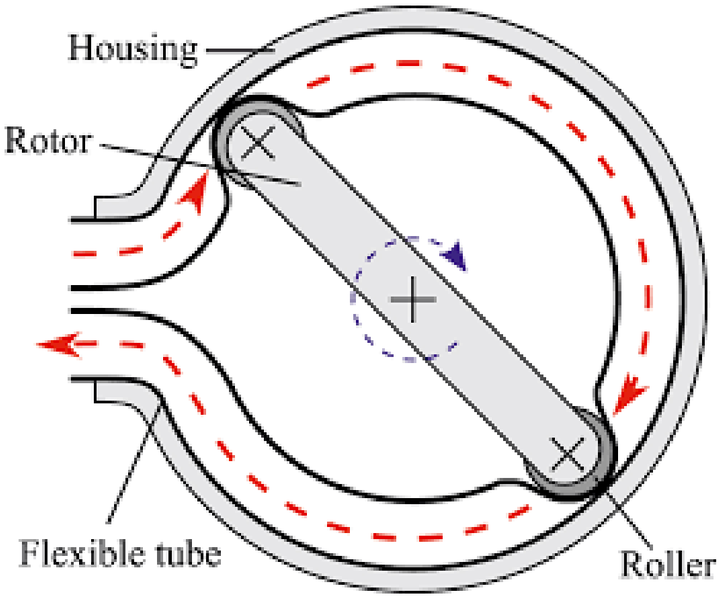
Working Principle

- The principle of operation of this pump is that two rollers, placed opposite to each other, ‘‘roll’’ the blood through a piece of tubing
- The rollers completely occlude the tubing, the pump is capable of generating both positive and negative pressures
- A roller pump is relatively independent of factors such as resistance and hydrostatic pressure head
- An occlusive roller pump depends on two main variables;
  - the number of rotations of the pump head with a known diameter
  - the internal diameter of the tubing held in the pump head



STRUCTURE

- They consist of a length of tubing located inside a curved raceway at the perimeter of the travel of rollers mounted on the ends of rotating arms (usually two, 180 degrees apart).
- They are arranged in such a way that one roller compresses the tubing at all times.
- Flow of blood is induced by compressing the tubing, thereby pushing the blood ahead of the moving roller.
- Flow rate depends on the size of the tubing, length of the raceway, and the rpm (revolutions per minute) of the rollers
- Depending upon the number of rollers, roller pumps are classified as:
  - Single
  - Double
  - Multiple roller pumps



Single-Roller Pump

- Only one roller
- The roller rotate 360º to eject out the blood
- Used in 1950s & 1960s
- More pulsatile flow will be achieved
- The tubings are placed as 360º

DOUBLE ROLLER PUMP

- 2 rollers
- 180º rotation
- Back plate - 210º, semi circular backplate
- The occlusion is done alternatively by the two rollers
- This is a non-pulsatile flow [continues flow]

Multiple-Roller Pump

- Using three or more rollers
- The curvature of the backing plate can be reduced to 120° or less.
- Not used nowadays, because this cause more hemolysis

TUBINGS

- Silicon rubber
- Poly vinyl chloride [commonly used]
- Latex rubber

PVC is most because of its durability and acceptable hemolysis

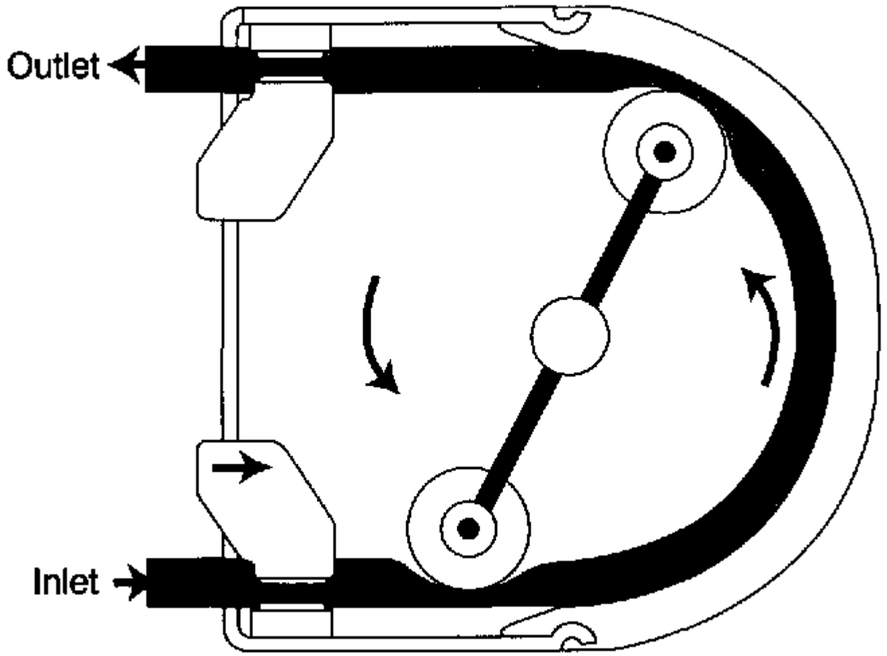
Latex rubber –disadvantage-more hemolysis, also can cause reaction

Most pump loops are made of silicone or PVC and, to a lesser extent, of latex rubber

SPALLATION - the release of plastic microparticles from the inner wall of tubing as a result of pump compressions.

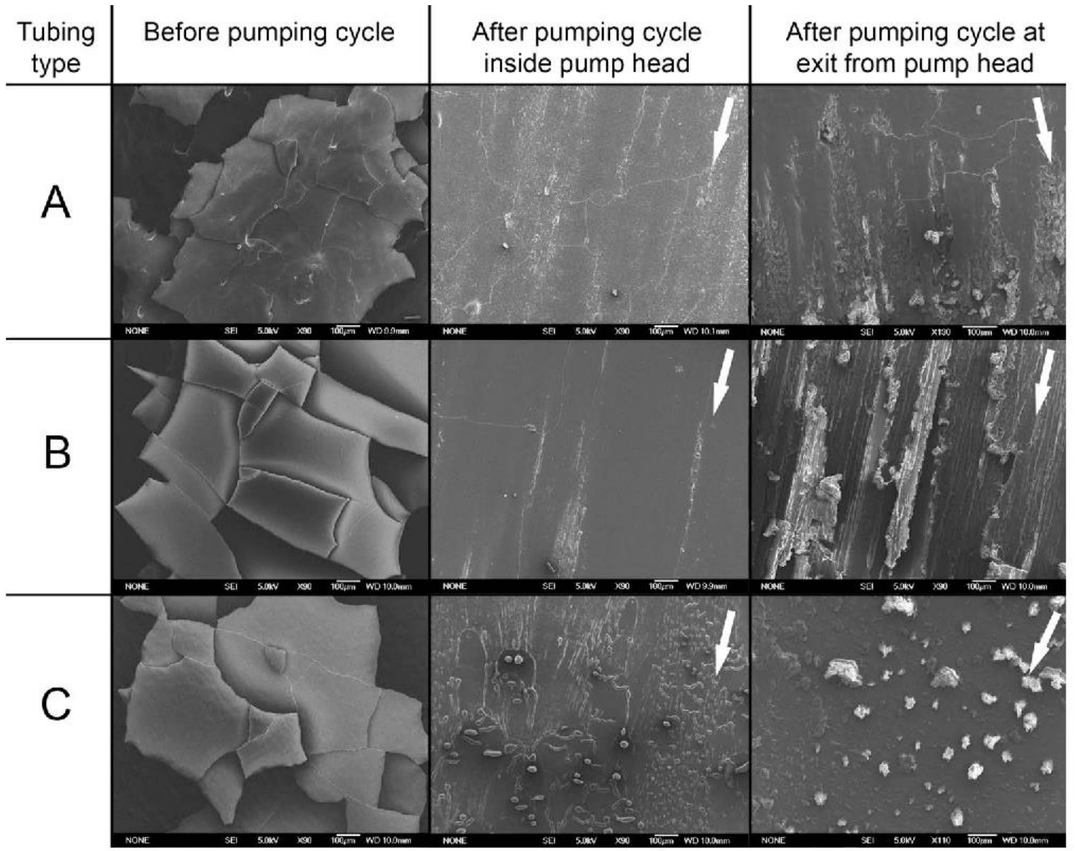
ADVANTAGES OF ROLLER PUMP

- Reusable with inexpensive disposable part
- Easy to sterilize
- Simple flow rate determination
- Variable stroke volume for different sized particle
- The occlusion caused lowest hemolysis than non-occlusive pump



DISADVANTAGES

- Blood trauma
- Tubing spallation
- Possibility of circuit disruption and termination from excessive line pressure
- Particulate micro emboli from tubing spallation
- Possibility of massive air emboli
- Contra indicated for long term use because of tubing wear and blood trauma [in case of ECMO]



COMPLICATIONS

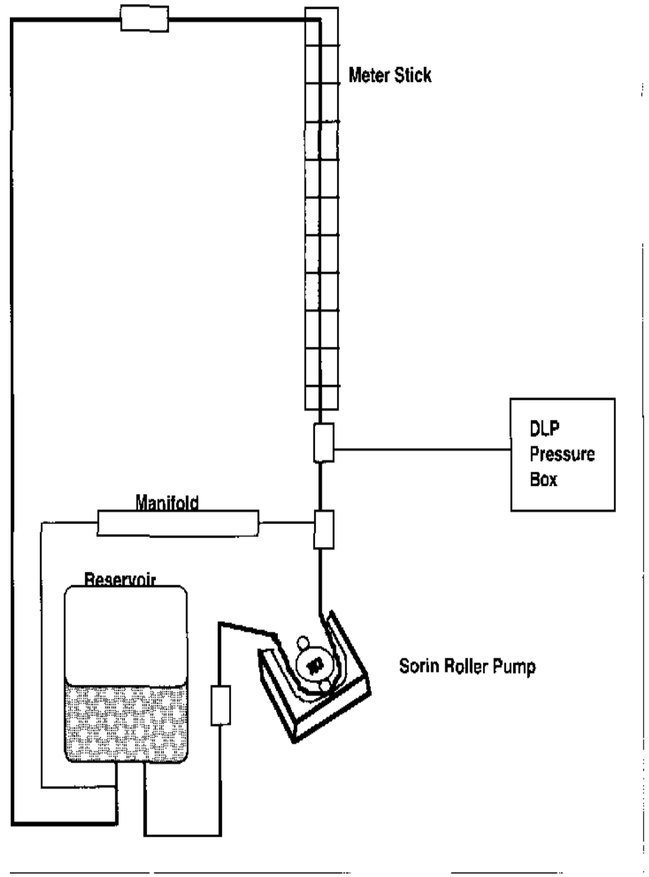
- Mal occlusion
- Miscalibration or miscalculation,
- Fracture of pump tubing
- Run away of pumping
- Loss of power or pump failure
- Spallation and pumping of large amounts of air
- Accident due to high pressure
- Cavitation –[stable air bubble formed in tube from a death space in that area]

Occlusion

- Refers to the occlusion as the roller presses the tubing against the raceway
- Occlusion is set by holding the tubing line vertically so the top of the fluid is about 30 cm above the pump and then gradually decreasing occlusiveness until the fluid level falls at a rate less than 1 cm/minute
- Occlusion should be set each roller separately.
- This compression appears to be more critical ,
  - Excessive compression – hemolysis and tubing wear
  - Very little compression –forward output impaired , rarely hemolysis

Occlusion setup

1. Load the unprimed tubing in the roller pump raceway.
2. Introduce appropriate amount of priming solution in the oxygenator
3. Close the sampling ports and recirculating lines
4. Hold the distal arterial line vertically
5. Advance a column of priming approximately 30cm above the level of the pump
6. Deocclusion of the rollers by moving the rollers away from the backing plate to ensure there are no excessive occlusion.
7. Adjusting roller occlusion against the backing plate to allow slight drop of fluid at a rate less than 1cm/min.
8. The occlusion should be set to each roller separately (one by one),if one of the rollers in the pump head does not yield the same rate of fluid drop(under occlusion),the occlusion should be set to the roller that is tightest

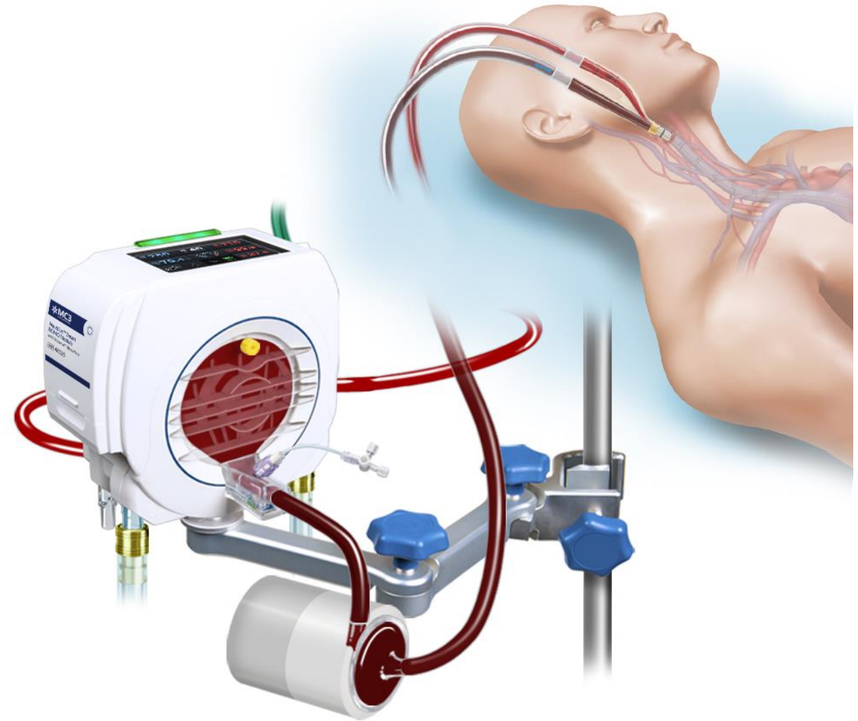


Assessment - 1

- Characteristics of an ideal blood pump
- What are the types of blood pumps?
- What are the types of roller pumps?
- Why PVC is mostly used in tubings?
- Occlusion setting

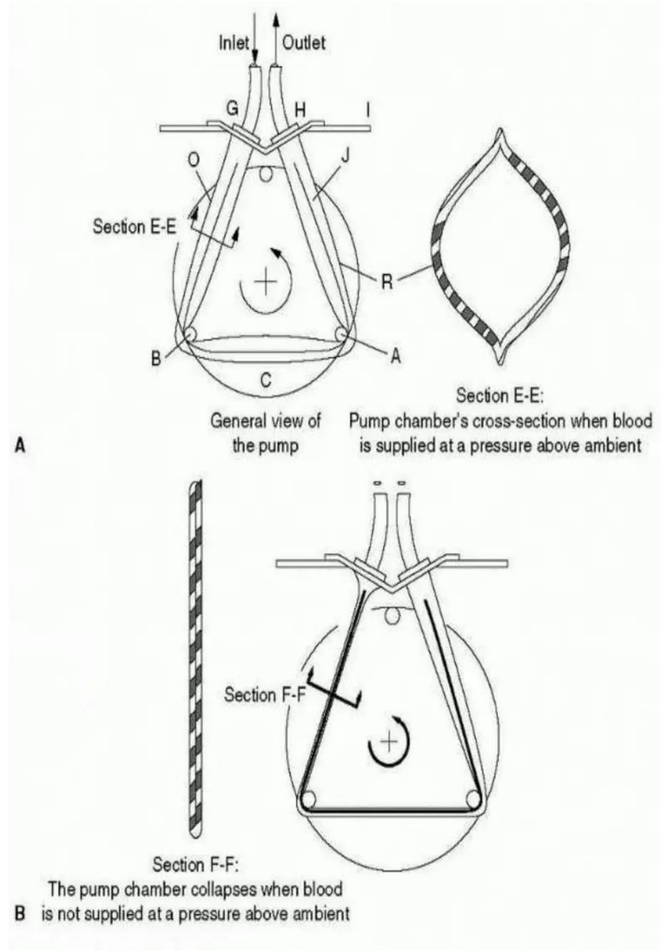
Non occlusive pump

- Rhone-Poulenc in France originally designed a nonocclusive roller pump for use in routine CPB procedures.
- This pump became known worldwide after its successful use in neonatal respiratory support



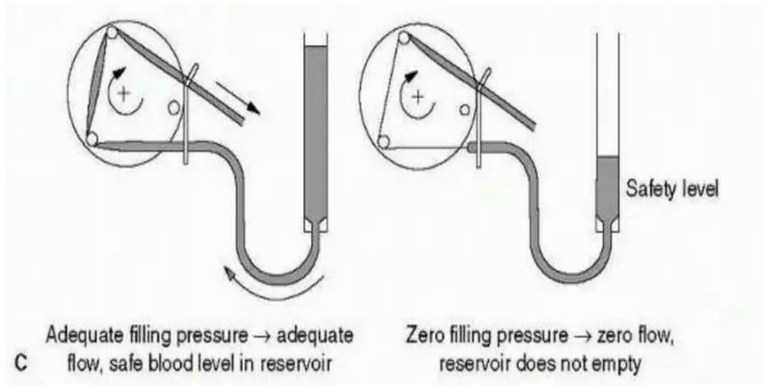
WORKING PRINCIPLE

- The MC3 pump is a passive filling, peristaltic pump that combines many advantages of both the centrifugal and the roller pump.
- This pump is nonocclusive and should be used as for all nonocclusive pumps, in combination with a flow meter .
- It consists of a completely flat pump chamber that is wrapped under tension around rollers.
- The rollers are mounted on a rotor.



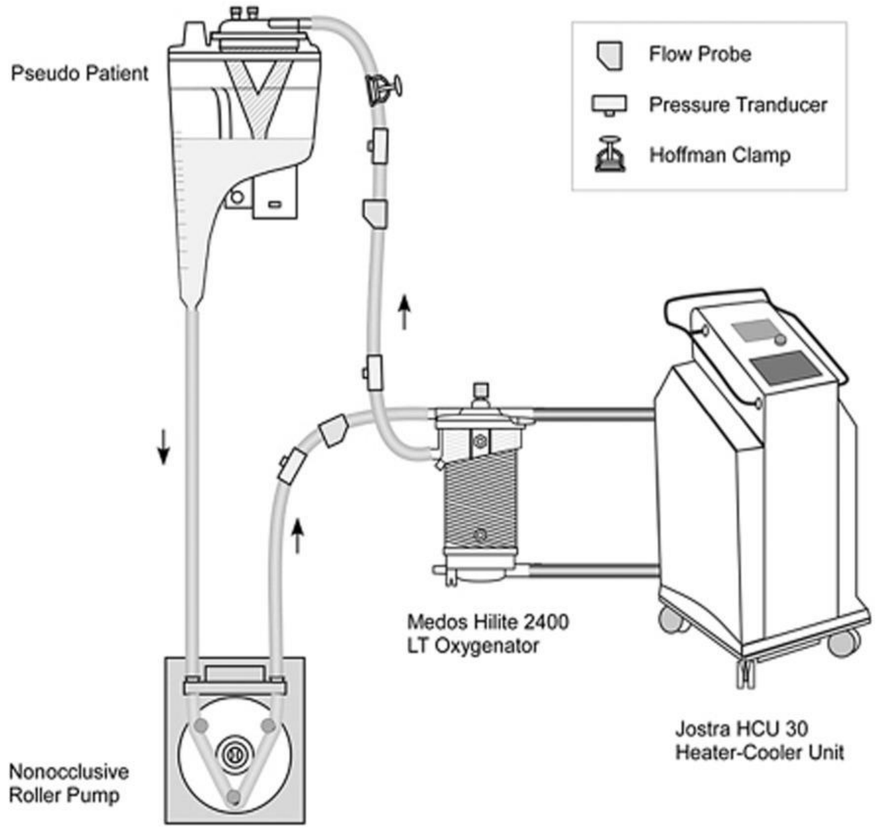
WORKING PRINCIPLE (CONT)

- Rotations of the rotor imparts a peristaltic motion to the blood within the pumping chamber
- When the inlet of the chamber is supplied with blood at a pressure above ambient, blood is moved toward the outlet .
- Because of its design, the pump chamber can only get filled when there is a positive hydrostatic pressure at the inlet .
- When there is no fluid in the chamber or when the pressure is below or equal to the ambient pressure, the pump chamber will be completely flat in the portion engaged by the rollers.



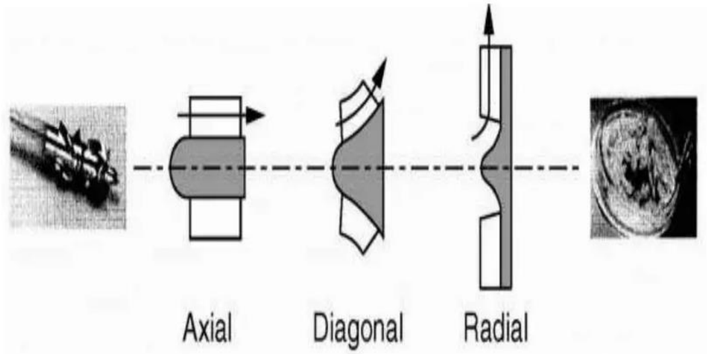
ADVANTAGES

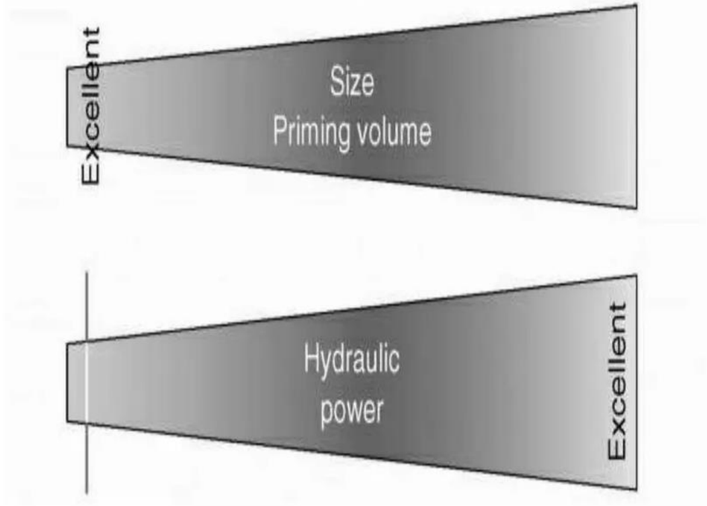
- The pump can no longer pump blood because no blood is available in the pump chamber
- No negative pressure will be generated because the flat design of the pump chamber will not expand
- Air cannot be pumped because the pump needs a preload, which is only present with fluid in the reservoir
- The natural flat shape of the pump chamber allows for a total collapse, thereby preventing retrograde flow when the pump is stopped.
- Attenuate blood damage and reduce microbubble generation.
- Prevent failure of tubing connections
- Hemocompatible as a centrifugal pump
- A lesser activation of neutrophils and platelets as well as a lower hemolysis level than in a centrifugal pump



ROTARY PUMPS

- Rotary pumps have three basic designs: axial, diagonal, and radial
- From a hydraulic power standpoint, radial pumps have the better design, whereas axial pumps have the lowest priming volume.
- From a cost perspective standpoint, axial pumps are more expensive than diagonal and radial pumps because of the built-in electronic motor, which currently excludes them for routine CPB
- Efficient pumping capability and small size, axial pumps are increasingly utilized in ventricular assist devices
- In diagonal and radial pumps, a disposable housing is coupled magnetically with an electric motor, making these designs more suitable for routine CPB.



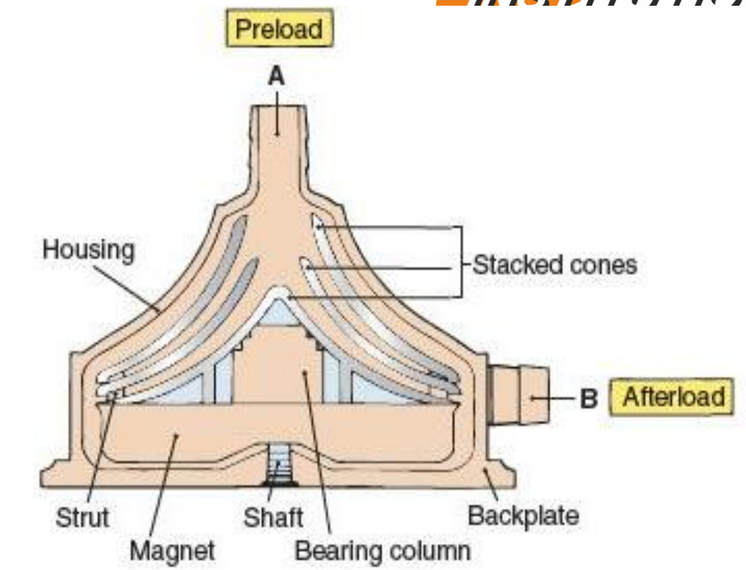


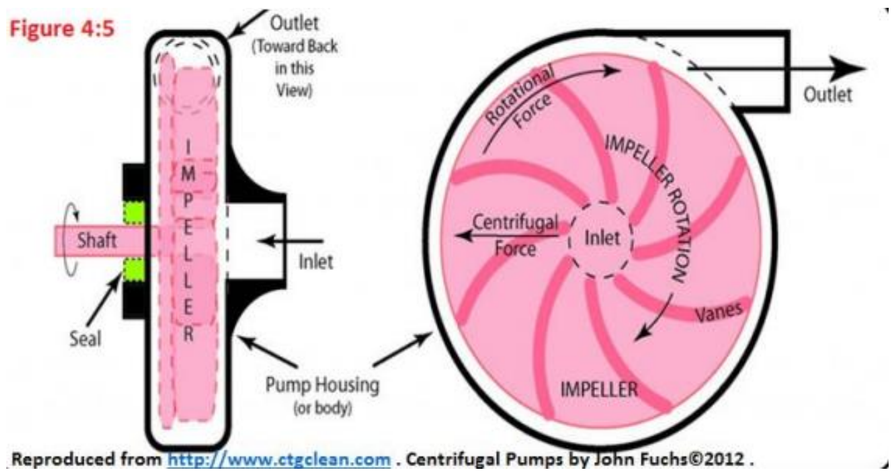
RADIAL (CENTRIFUGAL) PUMPS

- **<u>CENTRIFUGAL PUMP</u>**
- In the early 1970s, research related to the development of an artificial heart was the basis of the development of centrifugal pumps for CPB.
- The biomedicus 600 became available in 1973.
- **Working Principle**
- Centrifugal pumps operate on the principle of moving fluid by creating a pressure gradient between the inlet and the outlet of the pump

CHARACTERISTICS OF CENTRIFUGAL PUMP

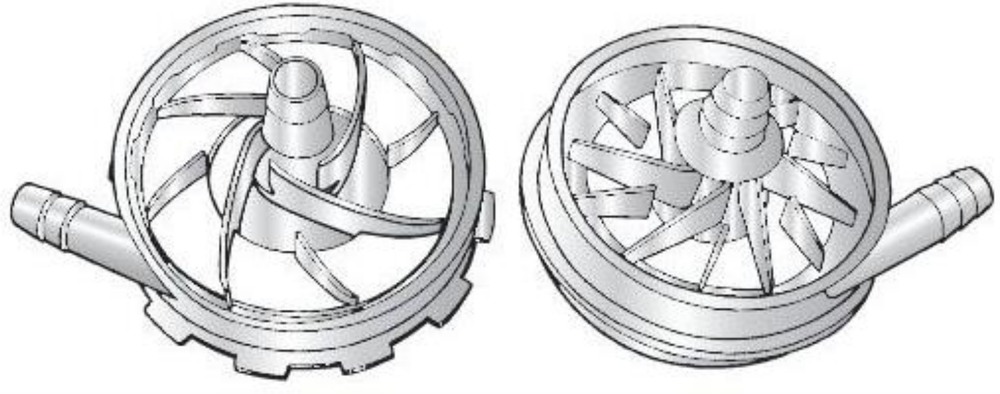
- The basic design of centrifugal pump consist of an impeller arranged with either varies of smooth plastic cones inside a plastic housing .
- Blood enters at a point at the center of the nested corners and exist in another point.
- The spinning cones create a negative pressure that pulls blood into the pump.
- Once the blood is inside the pump head, energy is imparted to blood by spinning cones, forming a vortex.
- The vortex is then constrained by the outside plastic housing, generating pressure to pump the blood at outlet

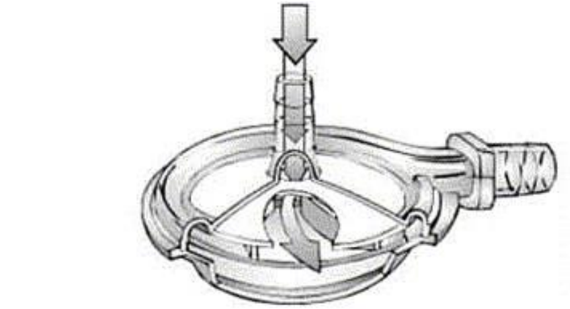


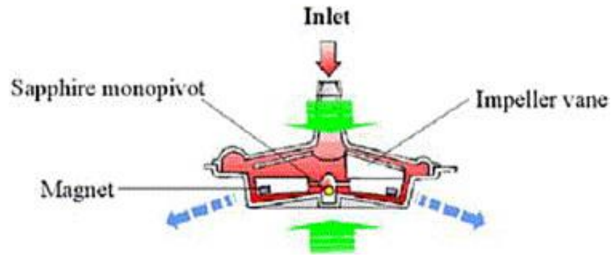


CHARACTERISTICS OF CENTRIFUGAL PUMP (cont)

- The cone spin by means of an indirect magnetic connection to a drive shaft on the centrifugal pump console.
- Between inlet and outlet there is no occlusive device in the pump.
- If the corner were not spinning fluid could flow through the head in either direction
- During bypass flow is affected by preload and afterload
- PRELOAD- Pressure at the inlet point
- AFTERLOAD- Pressure at the outlet point
- The disposable pump head is placed in a permanent console







CHARACTERISTICS OF CENTRIFUGAL PUMP (cont)

- The resistance at the outlet is a function of two components:
  - one is the CPB circuit (oxygenator, filter, tubing, arterial cannula)
  - the second is the systemic vascular resistance (SVR) of the patient.
- The flow produced by a centrifugal pump directly depends on the pressure that the centrifugal pump generates, a centrifugal pump is called a pressure pump.
- A centrifugal pump is afterload dependent
- The flow will be influenced by changes in resistance in both the circuit and the patient
- The main advantages and disadvantages of centrifugal pumps have their origin in some basic concepts of their working principle: the centrifugal force and the generation of heat

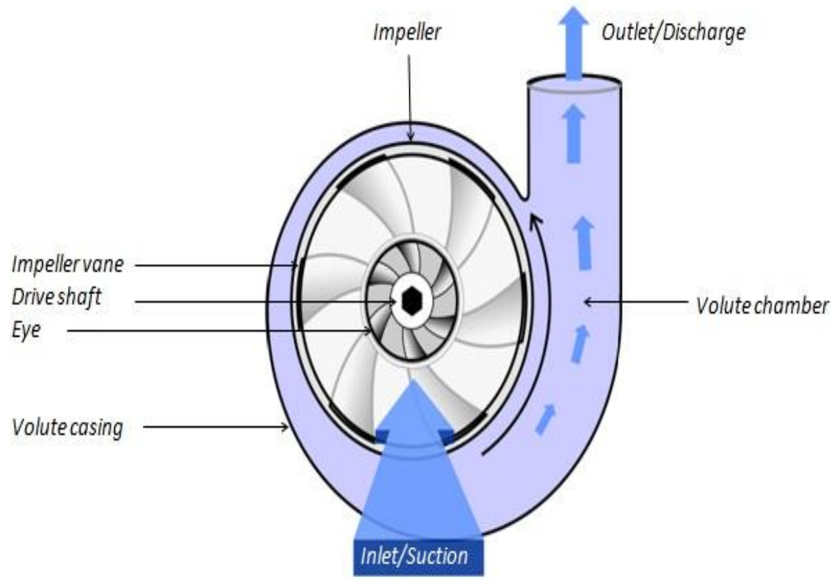


Figure 2. Volute case design

ADVANTAGES

- Because of centrifugal pumps are sensitive to afterload pressure there is no possibility of excessive line pressure build up in arterial line of the pump, because flow decrease when pressure increases.
- Have tendency not to pump air that may be introduced into the circuit. Because of high pressure at periphery and low pressure at the center of the pump head
- Decreased blood trauma
- Less cavitation
- Elimination of tubing wear or spallation

DISADVANTAGES

- Different operation technique for initiation
- Flow meter is necessary
- Retrograde flow when pump slows or stops
- More expensive and non-reusable pump
- It is estimated that approximately 50% of all CBP procedure now use a disposable centrifugal pump head in the arterial position

SPECIFIC CLINICALLY AVAILABLE CENTRIFUGAL PUMP

- Biomedicus pump
- Delpin pump
- Life stream pump
- Capiox pump
- Nikkiso pump

COMPARISON B/W ROLLER PUMP & CENTRIFUGAL PUMP

ROLLER PUMP	CENTRIFUGAL PUMP
Positive displacement pump	Kinetic energy
Reusable pump with inexpensive disposable parts	More expensive and non - reusable pump
Ease of sterilization	No possibility of disruption from excessive line pressure buildup
Simple flow rate determination	Decreased blood trauma
Variable stroke volume for differed sized patients	Less cavitation
Preload and afterload independent	Preload and afterload dependent
No chance of hypoperfusion	Cause hypoperfusion
Spallation and blood trauma	No spallation occur
High negative pressure hence risk of air embolism is high	Flow meter is necessary
Flow rate is determine by rpm× sv [stroke volume]	It will not generate high negative pressure and decreased risk of micro embolism

COMPARISON B/W ROLLER PUMP & CENTRIFUGAL PUMP

ROLLER PUMP	CENTRIFUGAL PUMP
Contraindicated for long term use because of tubing wear and blood trauma	It depends on the resistance of vascular system
Protein & platelet denaturation occurrence induces more compliment activation	It is indicated for long term procedure
It is susceptible to emptying the reservoir and pumping air to patient	It will not generate excessive pressure about 700-900mmHg
They are occlusive in nature	Non –occlusive
It does not cause retrograde flow	Causes retrograde flow

Diagonal Pump

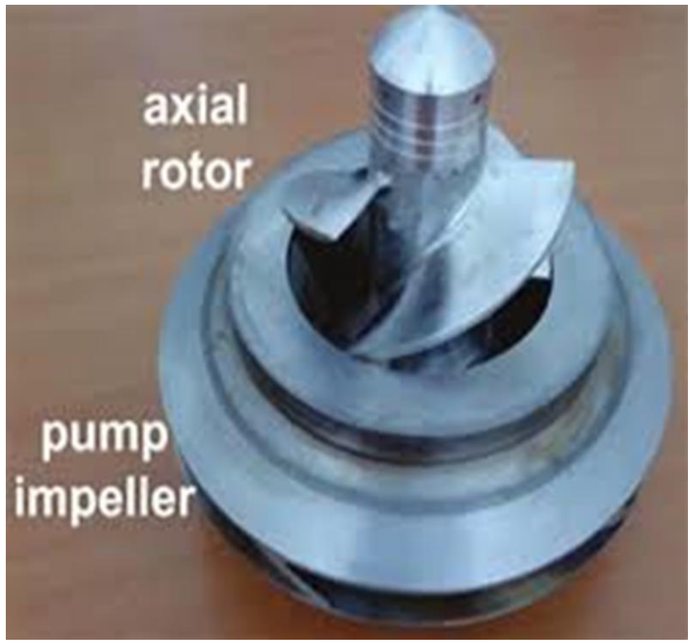
- There is currently only one diagonal pump available, the DeltaStream
- This pump was developed by the Helmholtz Institute in Aachen to provide a highly integrated blood pump for use not only in CPB procedures but also for longer-duration support, such as ECMO and ventricular assist
- Two systems were developed,
  - one with a built-in electric motor for ventricular assist and ECMO procedures
  - the other with a disposable pump head and an external motor for short-term procedures
- Major advantages of this pump are
  - its capability of generating pulsatile flow
  - small size
  - simple design

WORKING PRINCIPLE

- The basic design has a hydraulic efficiency and a priming volume between that of an axial pump and a centrifugal pump
- The pump consists of a cylindrical electric motor integrated into the pump and an annular blood flow path that surrounds the motor for cooling purposes
- The impeller is positioned between the pump inlet and the motor.
- The motor cylinder and the impeller have a diameter of approximately 25 mm.
- The RPM necessary to achieve a certain flow against a given resistance will be higher than that in impeller centrifugal pumps.

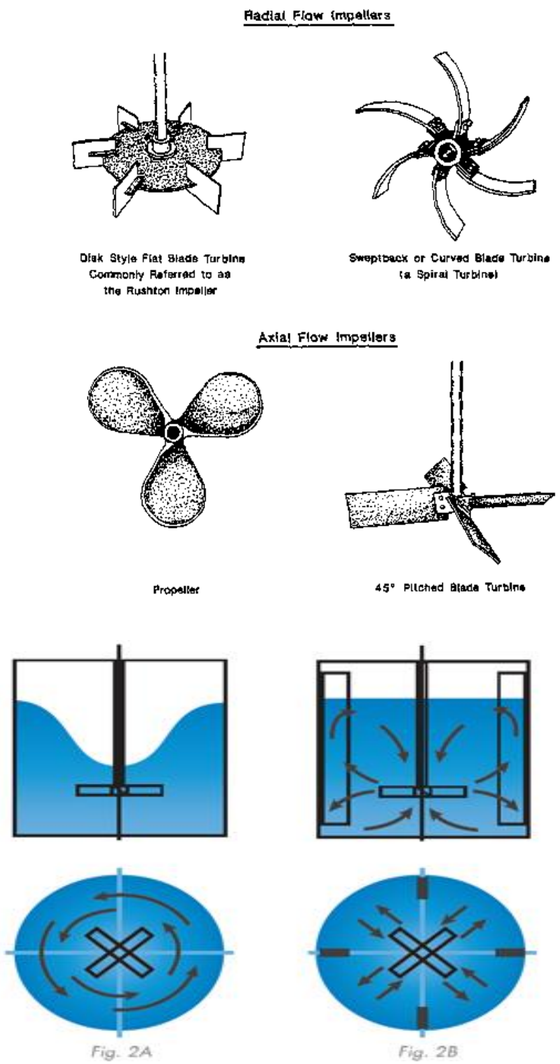
AXIAL PUMP

- The axial blood pump is a new generation of rotary pump
- It consists of axial or diagonal impeller driven by an electric motor to generates an axial flow by rotating the blood internal impeller.
- Impeller is an important component in axial pump, and its structure mostly determines the heart pump performance, thus a marked improvements in impeller design ensures a high flow rate and little blood damage.
- Axial pump motivated by electric motor to provide high speed rotation.



AXIAL PUMP

- When comparing between centrifugal and axial pump design theory, centrifugal pumps are capable of producing higher pressures at lower flows, where as axial pumps typically generate higher flows at lower pressure rises.
- The priming volume of axial pumps is smaller than that of centrifugal pumps, so it usually utilized in pediatrics ECMO and ventricular assist device.
- In addition axial flow pumps have a lower energy consumption, which allows lighter power supply components and eventually implantable batteries

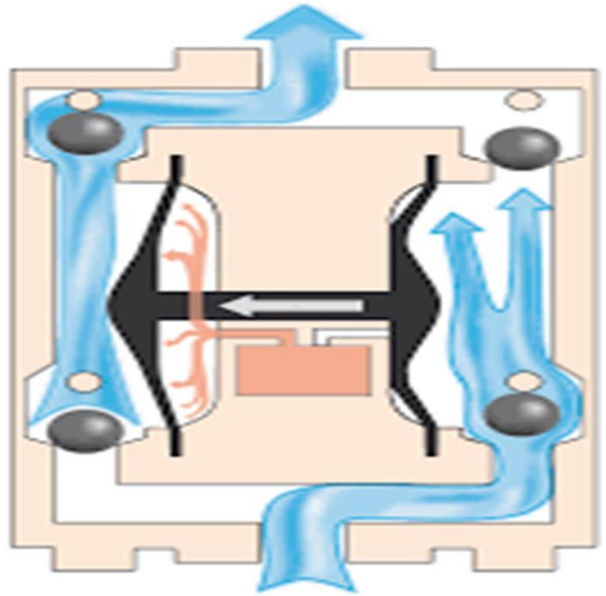


Reciprocating Pumps

- A reciprocating pump is a device that converts mechanical energy into hydraulic energy by sucking the liquid into a cylinder.
- In this pump, a piston reciprocates, which uses thrust on the liquid and increases its hydraulic energy.
- The reciprocating pump is a second type of positive displacement pump in which a fluid chamber is alternately filled and emptied, creating pulsatile flow
- Two advanced types of reciprocating pumps are
  - **diaphragm and ventricle pumps.**

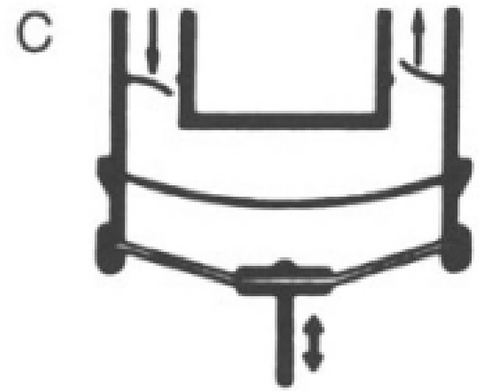
DIAPHRAGM PUMPS

- Diaphragm pumps, commonly used for long-term ventricular assistance, propel blood from the holding chamber when acted upon by a hydraulic, pneumatic, or mechanical force.
- It is also known as membrane pump.
- It is a positive displacement pump that uses a combination of the reciprocating action of a rubber, thermoplastic or Teflon diaphragm and suitable valves on either side of the diaphragm to pump a fluid



CHARACTERISTICS

- Have good suction lift
- Suitable for discharge pressure upto 1200 bar
- Have good dry running characteristics
- Can be upto 97% efficient
- Have good self priming capability



Advantages and Disadvantages

Advantages

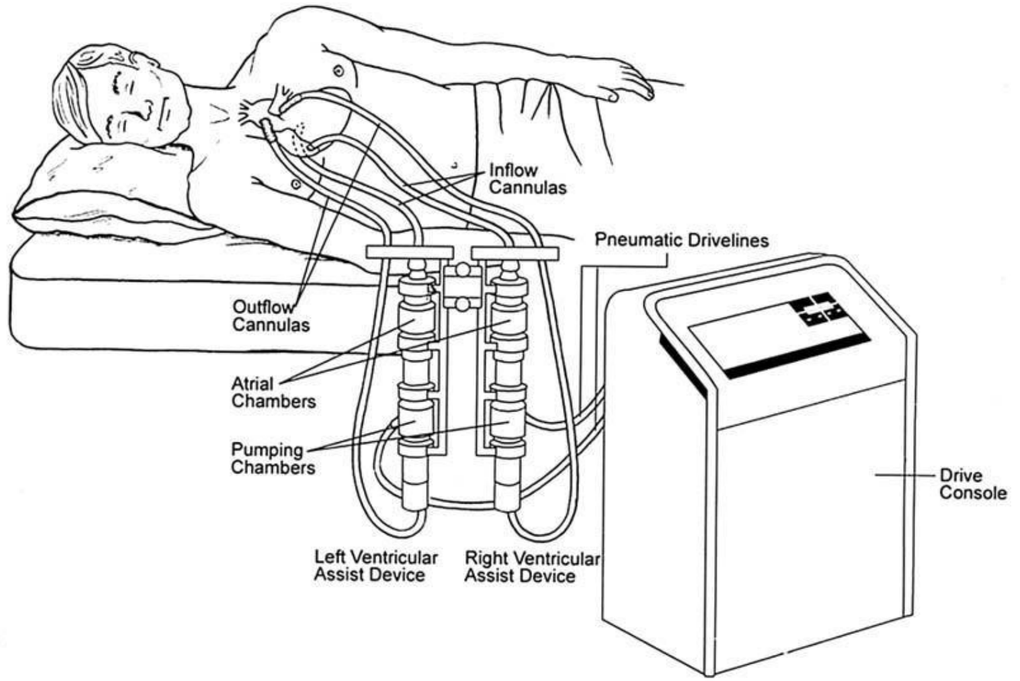
- Seal less and oil free
- Almost steady flow
- Handless most media types-Particularly corrosive or abrasive chemicals

Disadvantages

- Low maximum speed

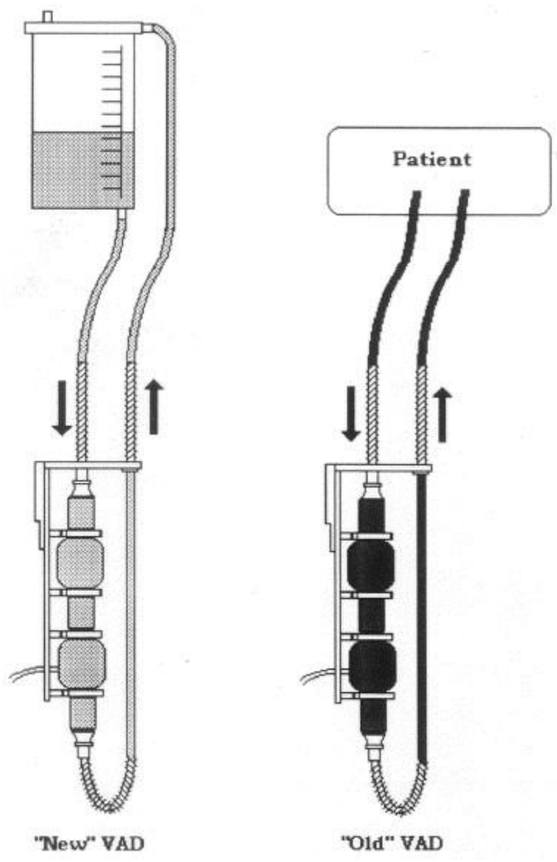
VENTRICLE PUMP

- Ventricle pumps have a flexible ventricular chamber encased in a rigid housing.
- The chamber is compressed by infusion of fluid or air into the housing, causing the ejection of blood.
- Unidirectional blood flow is achieved with valves at both the inlet and the outlet ports.
- This design has been used recently to create a successful ventricular assist device, the BVS System 5000 (Abiomed, Danvers, MA)



VENTRICLE PUMP (cont)

- This external blood pump is the first device to be approved by the Food and Drug Administration for ventricular assistance for postcardiotomy cardiogenic shock.
- The BVS System 5000 consists of two flexible sacks.
- The upper chamber collects atrial blood by gravity drainage while the lower chamber is emptied by pneumatic pressure.
- Two tri-leaflet polyurethane valves provide unidirectional blood flow.



Bellow Pump

- Pneumatic dual reciprocating bellows pump has been widely used in chemical transportation due to its good sealing and anticorrosion performances
- The large outlet pulsation limits its performances on precise transportation and control of the fluid.
- Although the design of employing flexible linkage between the bellows has been proposed as an effective solution for this shortcoming, the design, manufacture, and control of the pump also become much more complicated.

REFERENCES

- Cardio Pulmonary Bypass Sunit Ghosh Florian Falter Albert C. Perrino
- Cardiopulmonary Bypass Principles and practice Glenn P. Gravlee
- Cardio Pulmonary Bypass Christina T. Mora

THANK YOU