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BUCUREŞTI

AD-COR Program inovativ de formare in domeniul cardiologiei pediatrice
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MODUL TEORETIC

Anatomy and Pathology of the Cardiovascular System and Extracorporeal Circulation

Imputernicit: Prof. Dr. Tammam Youssef

Activitate prestata de I.R.C.C.S. POLICLINICO SAN DONATO – MILANO, ITALIA in baza contractului nr. 18/22144/29.07.2015

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Acest material a fost documentat/ validat/ prezentat la sesiunile de formare în cadrul proiectului *„AD-COR Program inovativ de formare în domeniul cardiologiei pediatrice”* - POSDRU/179/3.2/S/152012, proiect cofinanțat din Fondul Social Operațional Sectorial Dezvoltarea Resurselor Umane 2007-2013.

Beneficiar: Universitatea de Medicină și Farmacie „Carol Davila” București

Anatomy and Pathology of the Cardiovascular System and Extracorporeal Circulation

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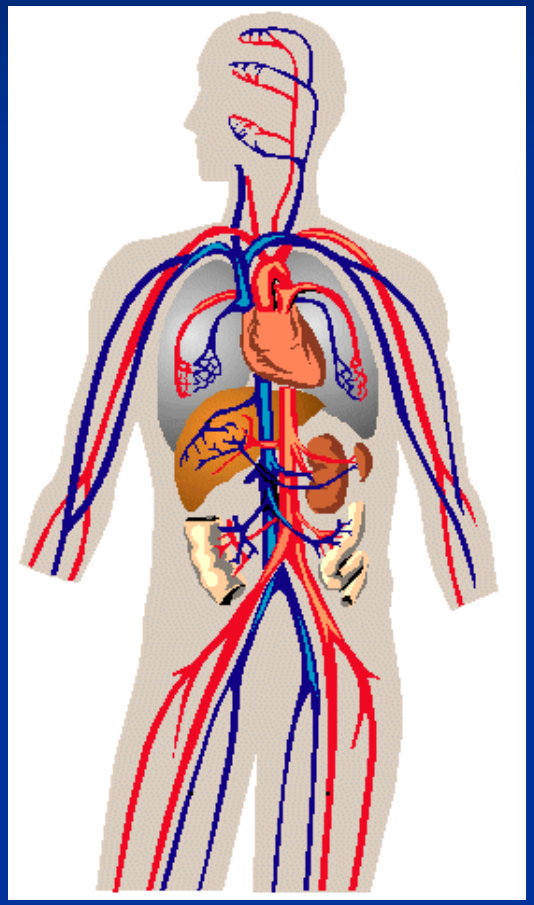
IRCCS Policlinico S. Donato

Cardiovascular System - Physiology and Pathology

1. Cardiovascular system physiology
2. Blood Physiology
3. Cardio- vascular pathologies
4. Extracorporeal circulation
5. Elements in the ECC:
    1. Disposables
    2. HLM
6. CPB Phases
7. ECMO

Cardiovascular System - Physiology and Pathology

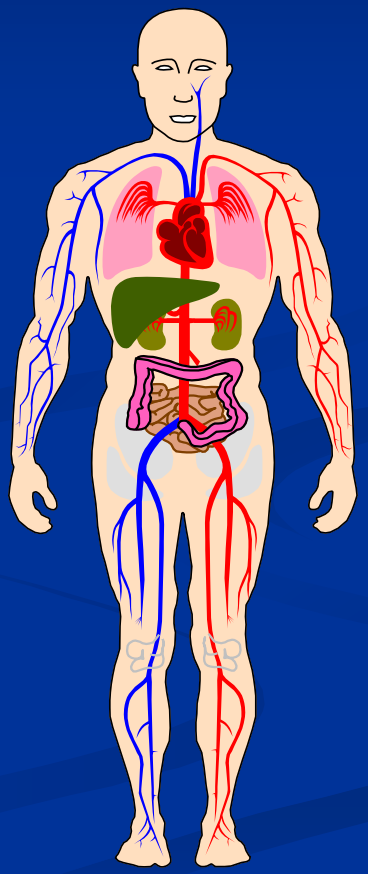


Human body can be compared to a complex and extremely efficient machine, composed of tissues and organs fed by the blood trough the

Cardiovascular system

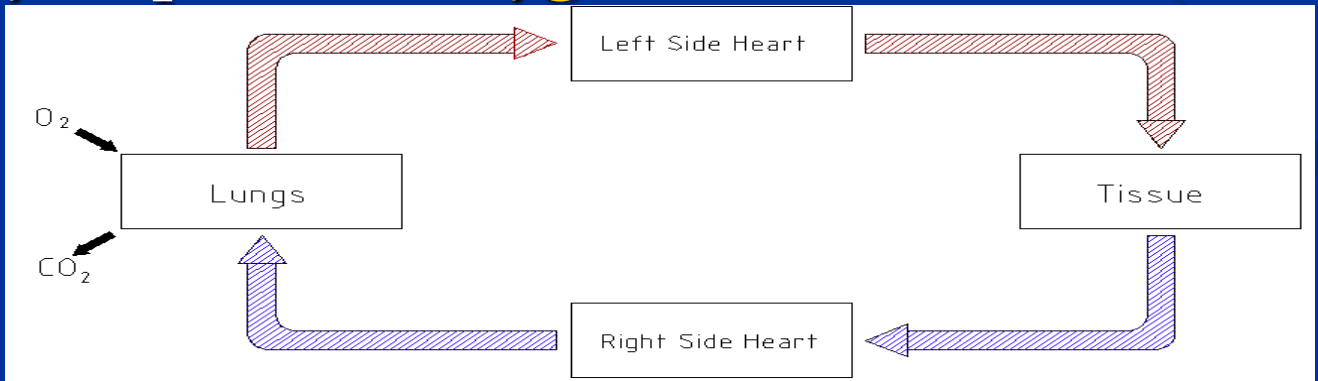
Components of the Cardiovascular System

- Heart
  - provides blood flow
  - generates blood pressure
- Vascular system
  - provides pathway to and from the cells
  - controls distribution of blood to organs and cells
    - Systemic circulation
    - Pulmonary circulation



Cardiovascular System - Physiology and Pathology

- The main components of the human cardiovascular system are the heart and the blood vessels. It includes: the pulmonary circulation, a "loop" through the lungs where blood is oxygenated; and the systemic circulation, a "loop" through the rest of the body to provide oxygenated blood.

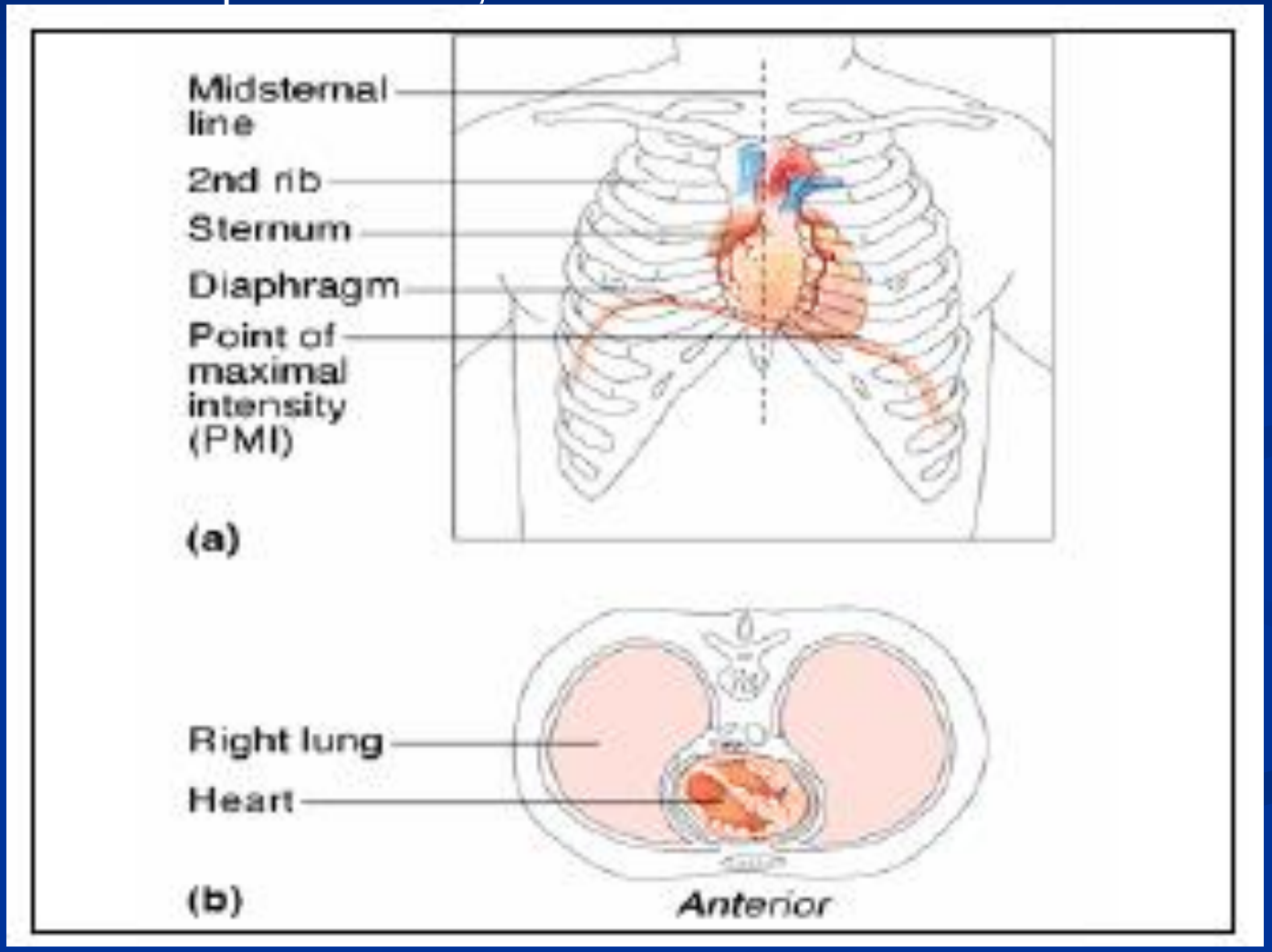


Cardiovascular System - Physiology and Pathology

- Body cells need oxygen in order to burn energy and maintain the body alive
- Co2, water and other waste components are released by the cells as waste products of metabolism
- The main player of transportation of those substances is blood
- Blood flows inside the cardiovascular system and transport nutrients and waste products from the tissues

Cardiovascular System - Physiology and Pathology

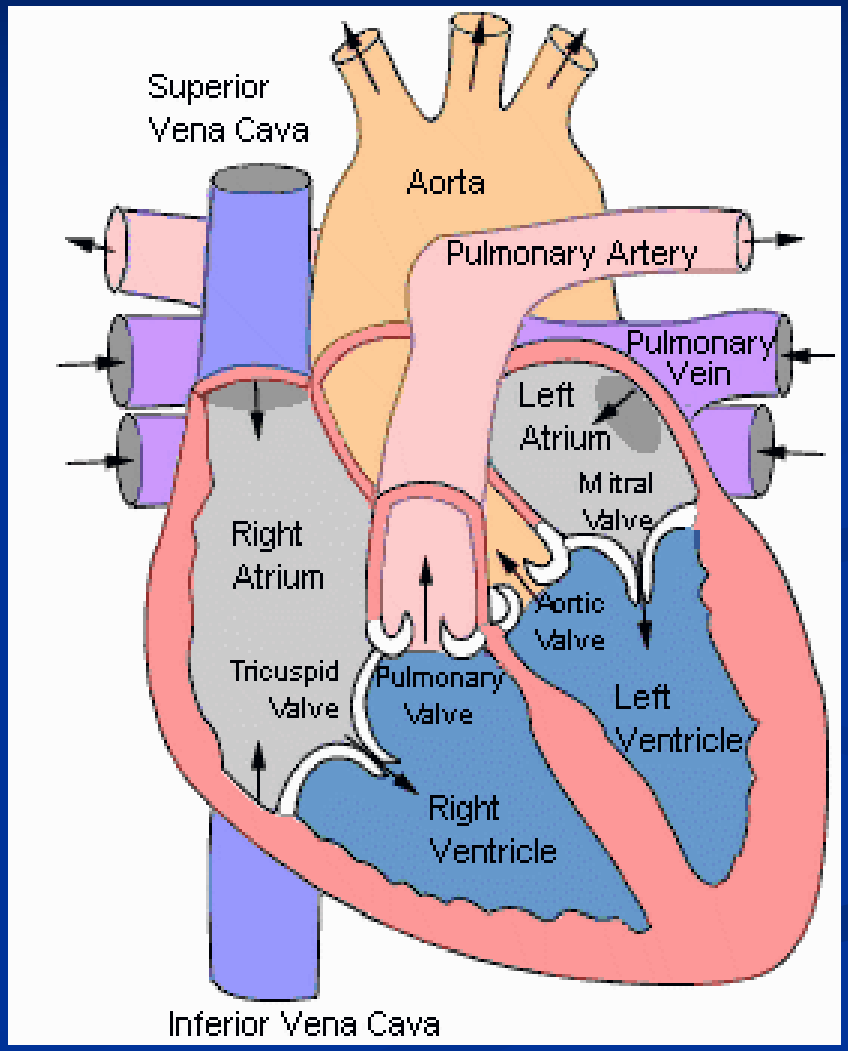
Location of the heart: Mediastin
between the lungs in the middle of the chest. A double-layered membrane called pericardium, surrounds the heart like a sac.



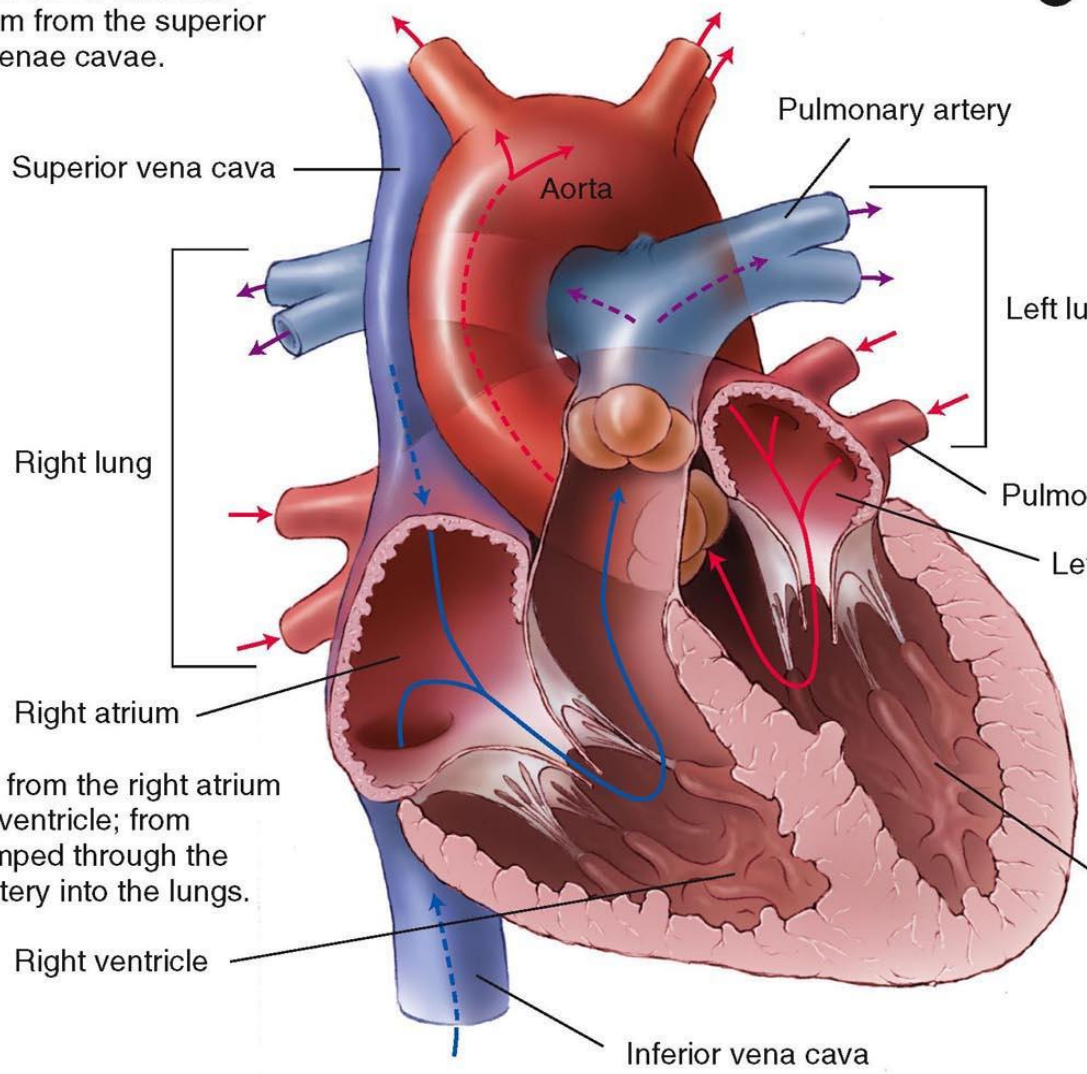
Cardiovascular System - Physiology and Pathology

The Heart is a pump made up of muscle tissue. It consists of four chambers:

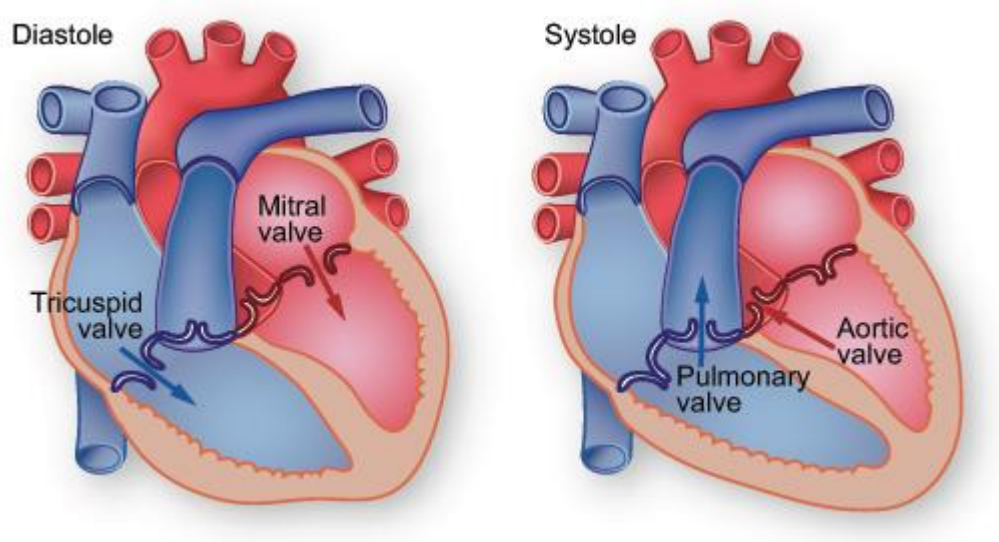
1. Left and Right Atria
2. Left and Right Ventricles



Cardiovascular System - Physiology and Pathology

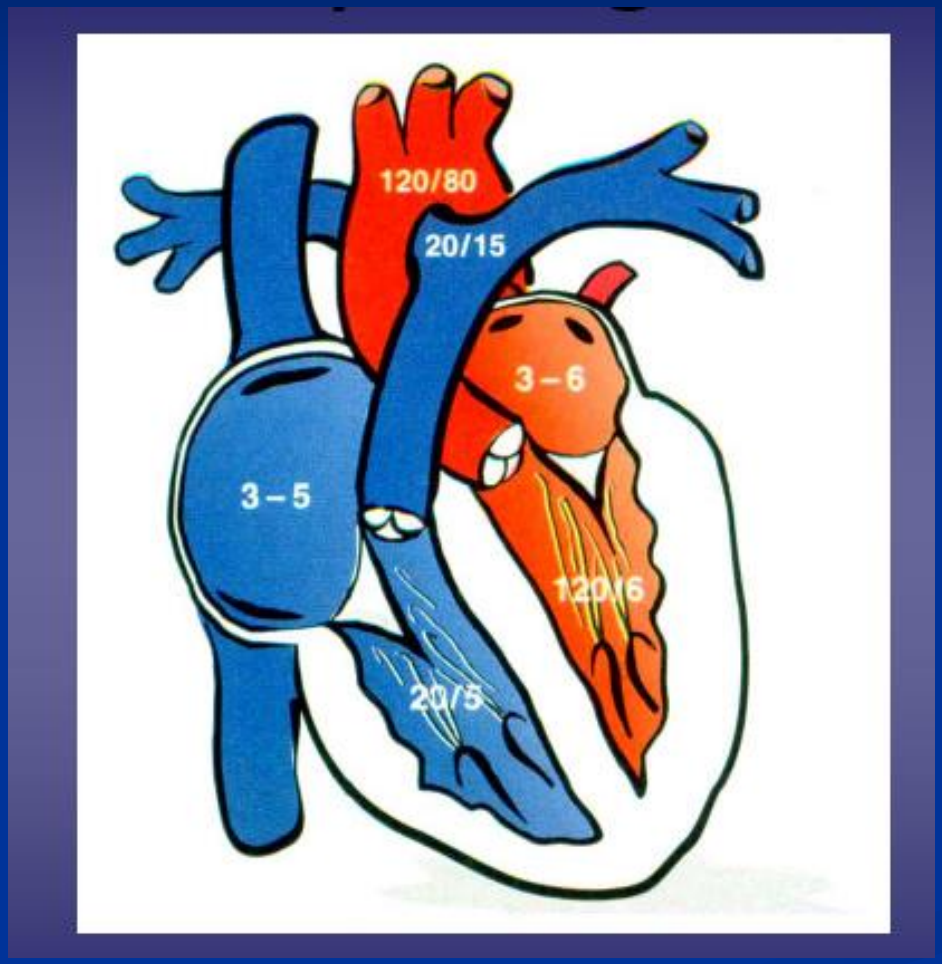


Cardiovascular System - Physiology and Pathology



1. **Diastole:** Blood collects in the upper chambers (the right and left atria), the heart's natural pacemaker (the SA node) sends out an electrical signal that causes the atria to contract. This contraction pushes blood through the tricuspid and mitral valves into the resting lower chambers (the right and left ventricles).
2. **Systole:** the second part of the heart, the ventricles, are full of blood. As the tricuspid and mitral valves shut tight to prevent a back flow of blood, the pulmonary and aortic valves are pushed open. While blood is pushed from the right ventricle into the lungs to pick up oxygen, oxygen-rich blood flows from the left ventricle to the heart and other parts of the body.

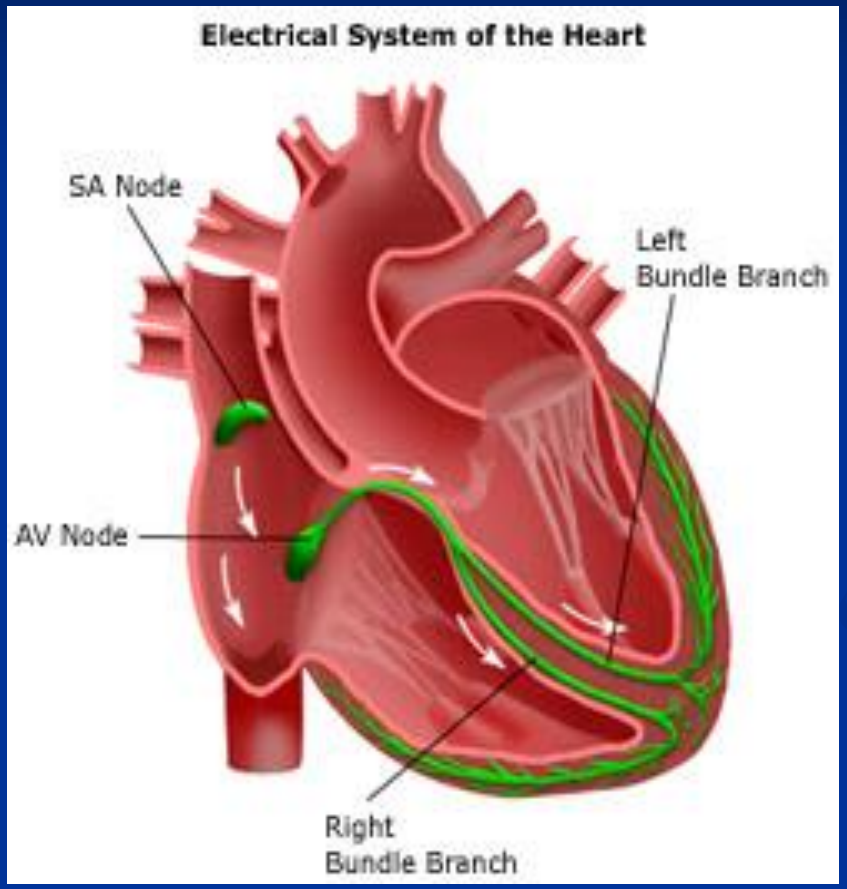
Cardiovascular System - Physiology and Pathology



Systolic Phase : Left Ventricle contraction with ejection of 70-80 cm^3 of blood and artery dilatation.
Systolic pressure~120mmHg

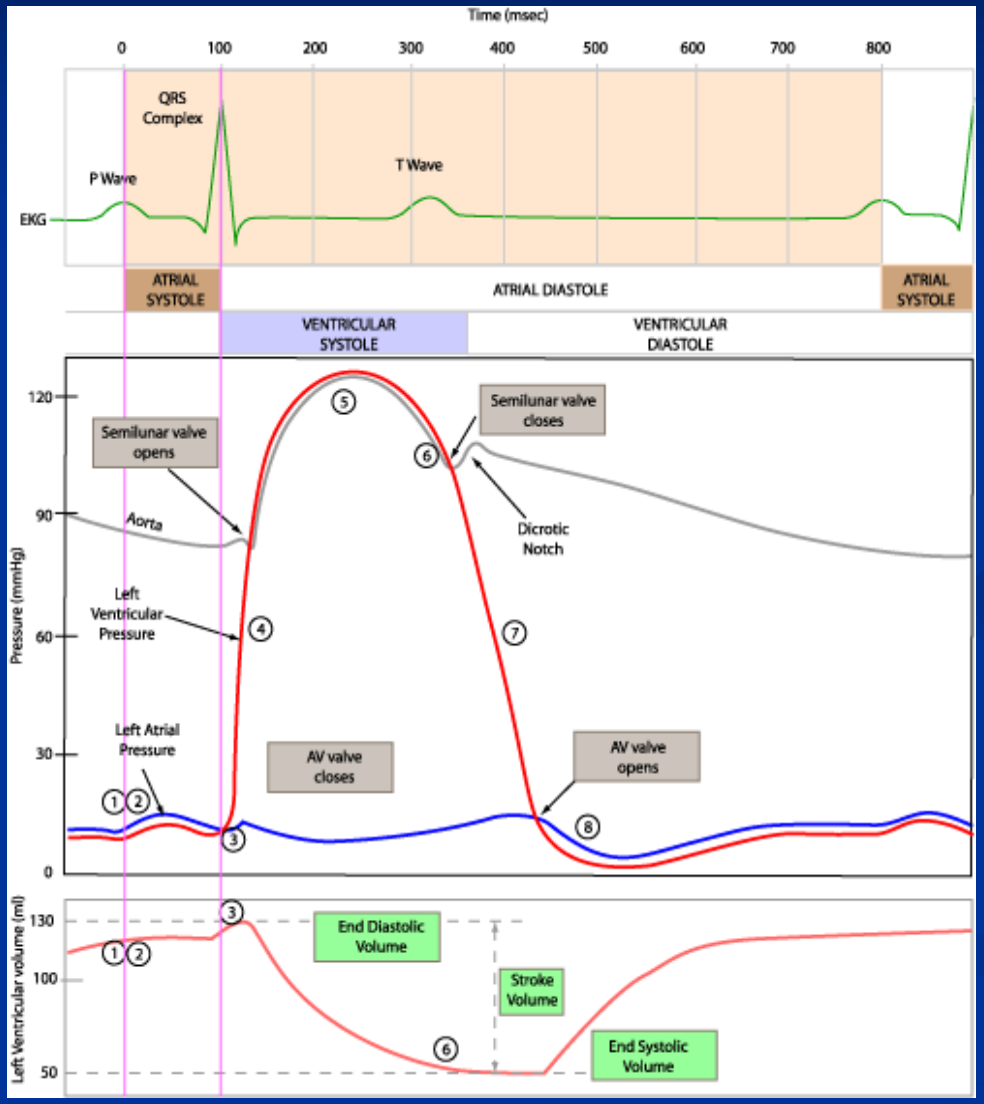
Diastolic Phase: release and consequent filling of the left ventricle and retraction of the artery.
Diastolic Pressure ~80mmHg

Cardiovascular System - Physiology and Pathology



Contraction of the heart is due to an electrical signal transmission trough the electrical tissues

Cardiovascular System - Physiology and Pathology



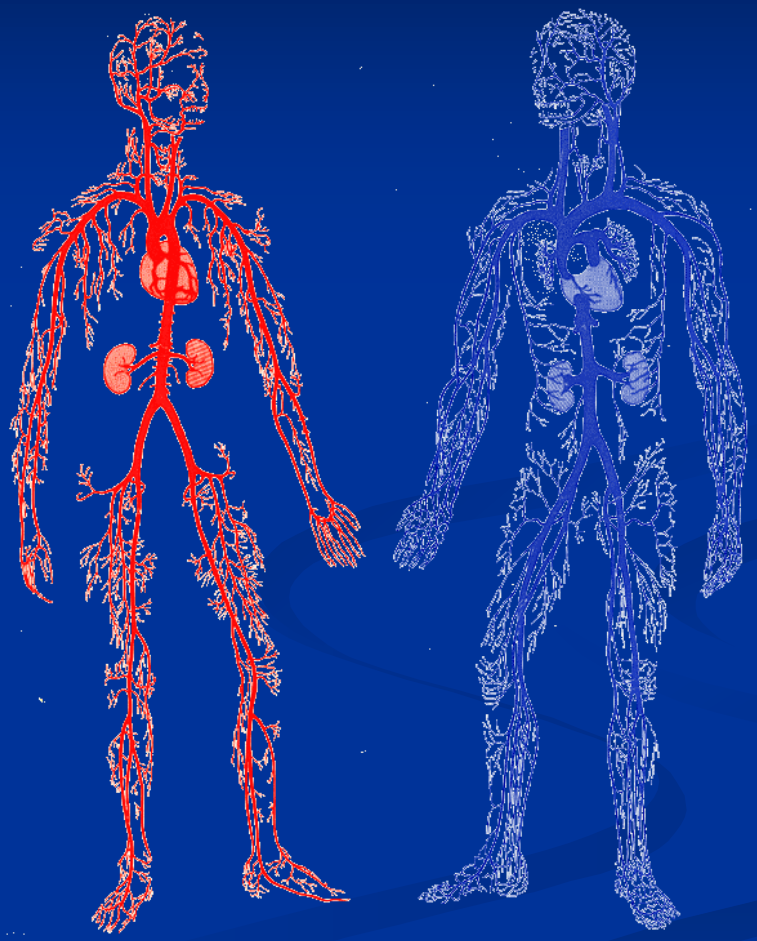
The Cardiac Cycle ECG

P Wave: Atrium Contraction
QRS Wave: Ventricles Contraction
T Wave: ventricle Depolarization

Cardiovascular System - Physiology and Pathology

- The vascular system resembles to very long and skinny tunnels that are all through the body

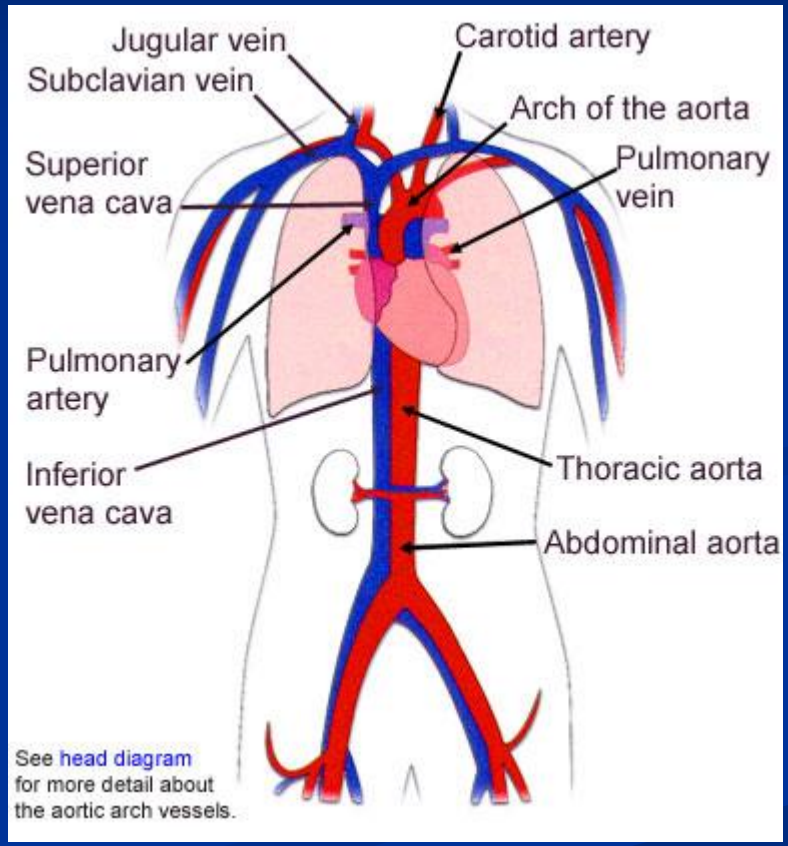
- VEINS
- ARTERIES
- CAPILLARIES



Cardiovascular System - Physiology and Pathology

Blood Flow in the Systemic Circulation

- Oxygen rich blood leaves the heart and travels through arteries to the tissues
- In the capillaries, oxygen and food are given to the cells
- Blood finally travels back through the veins to the heart to pick up oxygen

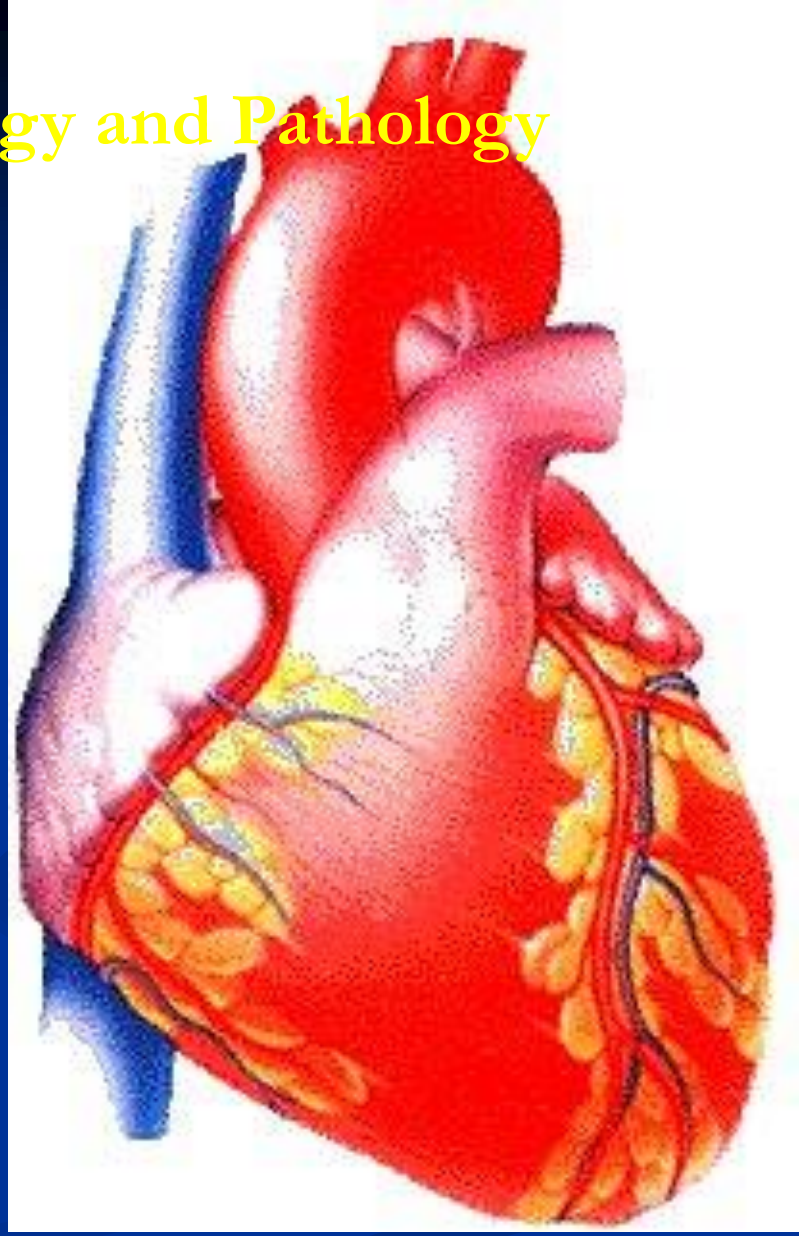


Cardiovascular System - Physiology and Pathology

Coronary Arteries

The Coronary Arteries continuosly supply oxygenated blood to the heart muscle. The Coronary Arteries start from the Aortic root

There are two main arteries: the Left and the Right Coronary Arteries. The Left Coronary Artery lies down the front of the heart as we look at it. The Right Coronary Artery comes down the rear part of the heart

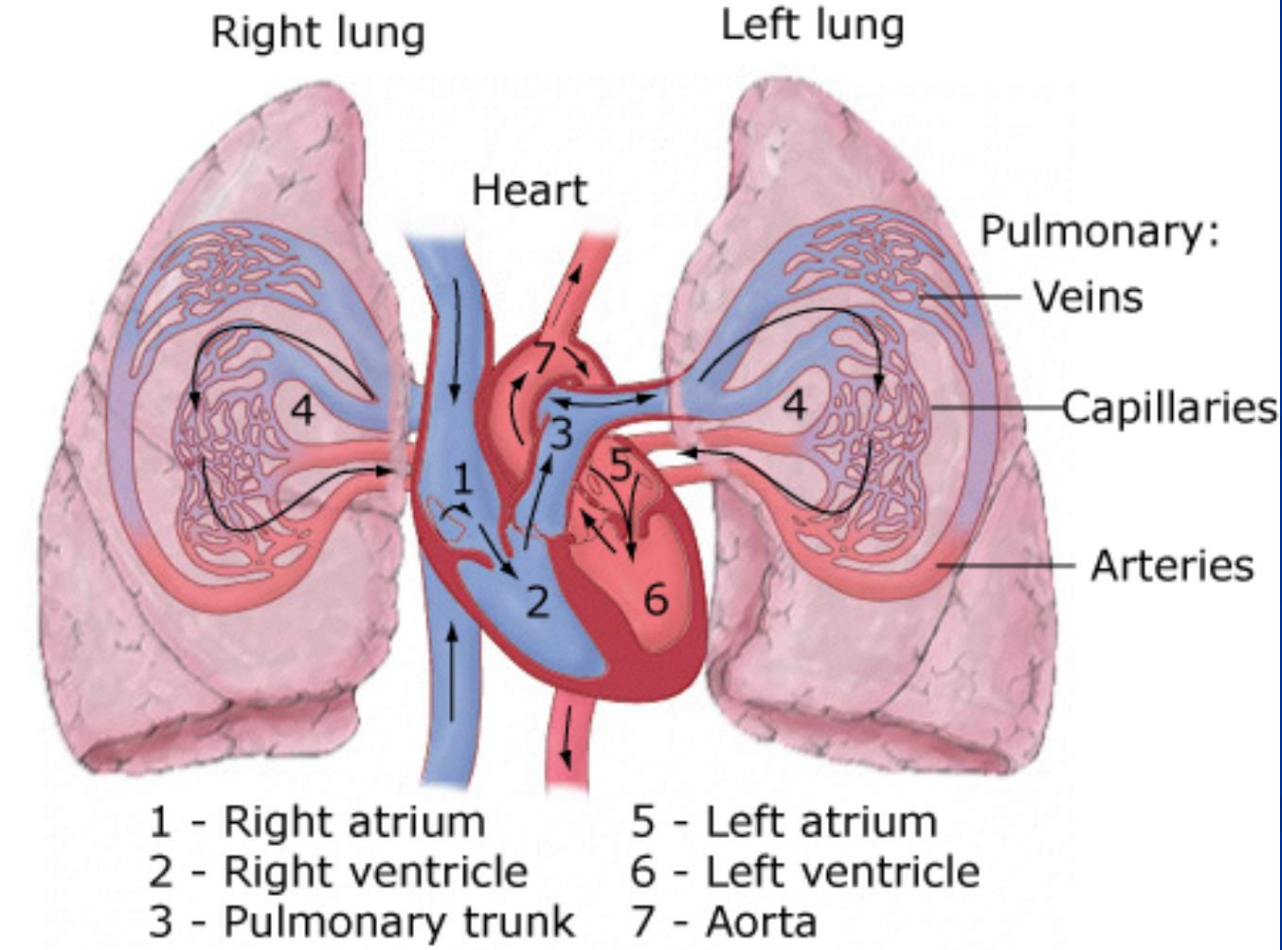


Right
Coronary Artery

Left
Coronary Artery

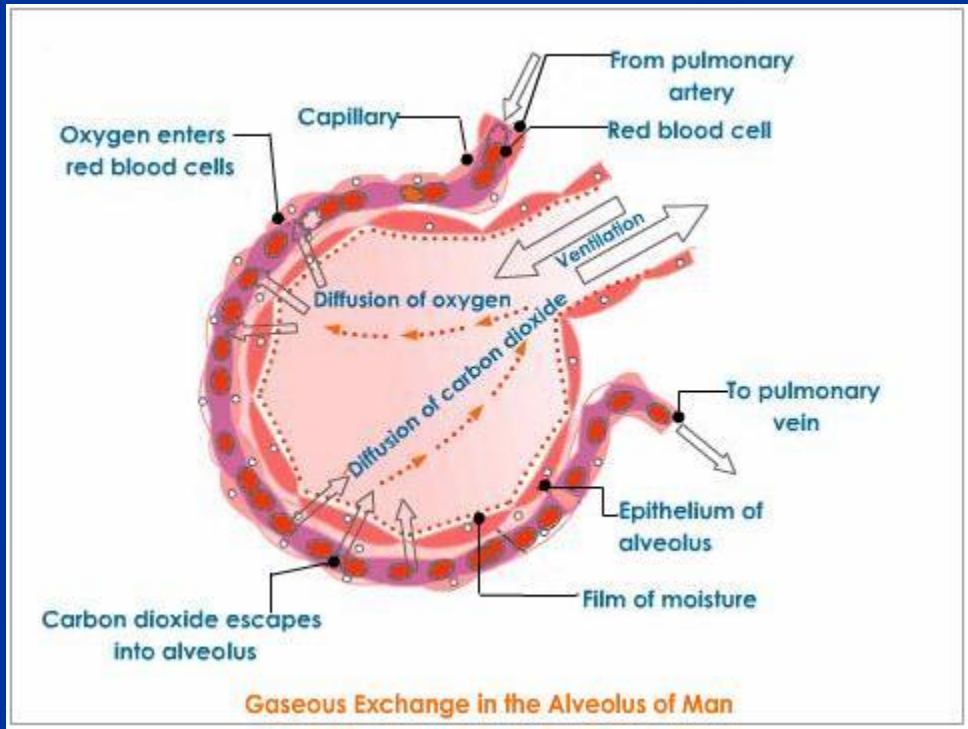
Cardiovascular System - Physiology and Pathology

Lungs are an extremely efficient GAS exchanger composed of a group of alveolus that creates a huge surface of GAS exchange (100-140 m^2).



Cardiovascular System - Physiology and Pathology
Lungs

- Oxygen taking and carbon dioxide (CO2) elimination from the lungs is known as external respiration.
- The oxygen introduced in the lungs, with the inspiration have to be delivered to the organism
- The oxygen exchange in the lungs at the alveolar level takes place under the diffusion principle

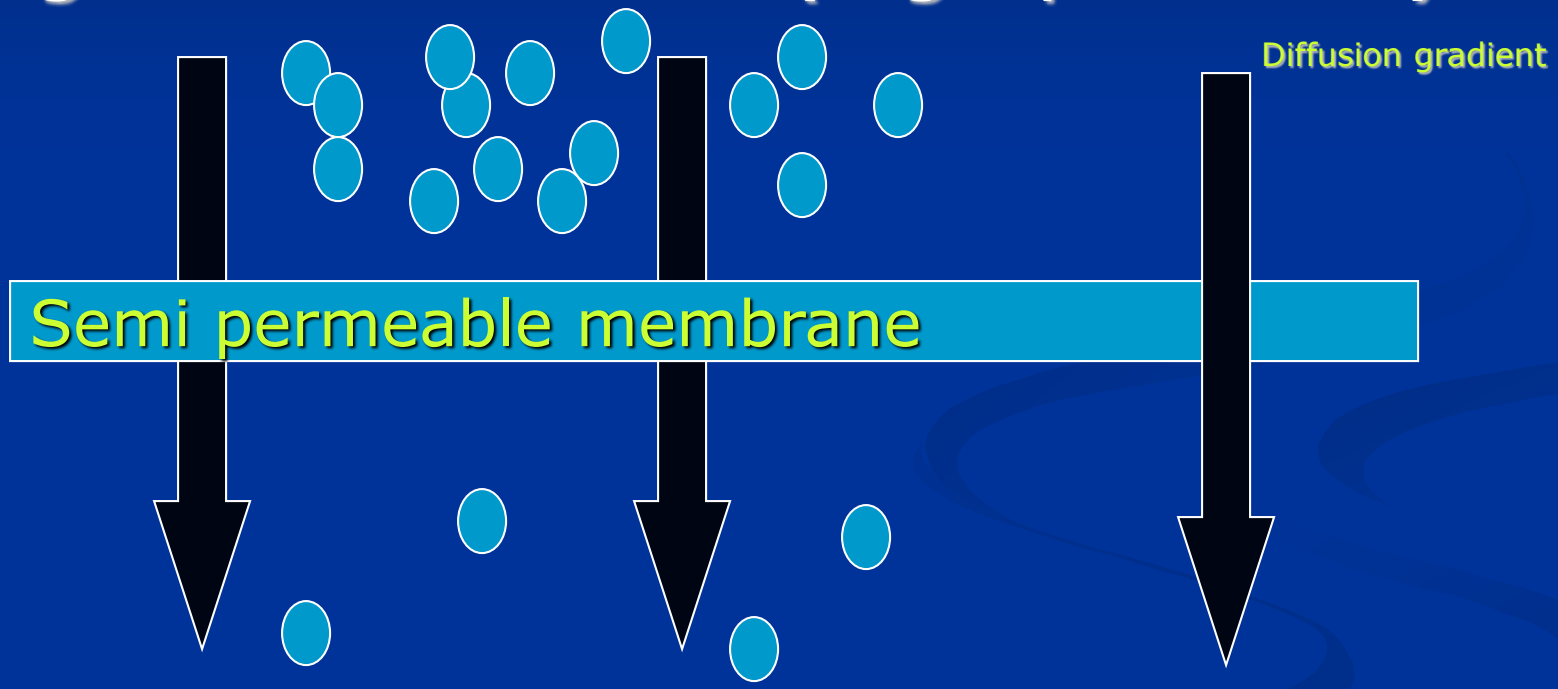


Cardiovascular System - Physiology and Pathology

Gas Exchange Principle

DIFFUSION PRINCIPLE

High concentration (high pressure)



Low concentration (low pressure)

Cardiovascular System - Physiology and Pathology

Gas Exchange Principle

Gas Partial pressure =
gas concentration x Tot gas mix. pressure

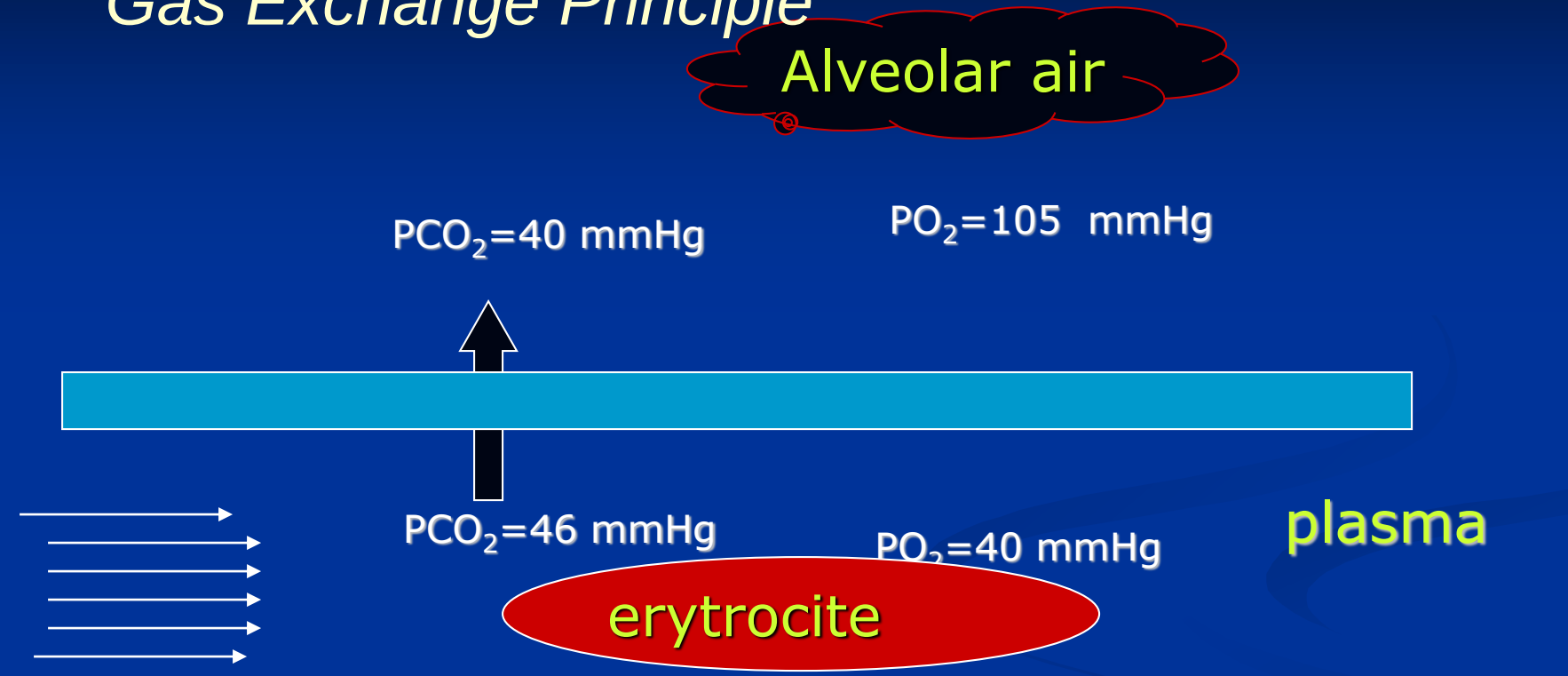
Atmospheric Pressure= 760 mmHg

Alveolar Air:

N_2	=	74,9%	=	596 mmHg
O_2	=	13,6%	=	104 mmHg
CO_2	=	5,3%	=	40 mmHg
H_2O	=	6,2%	=	47 mmHg
Total		100 %	=	760 mmHg

Cardiovascular System - Physiology and Pathology

Gas Exchange Principle



Cardiovascular System - Physiology and Pathology

Gas Exchange Principle

Exchanging Force:

delta pO_2 = 100-40 = 60 mmHg

Exchanging surface 100-140 m^2.

The max pO2 in the blood is 100mmHg, but due to a not 100% exchange system the final pO2 in the blood is 95 mmHg

Cardiovascular System - Physiology and Pathology

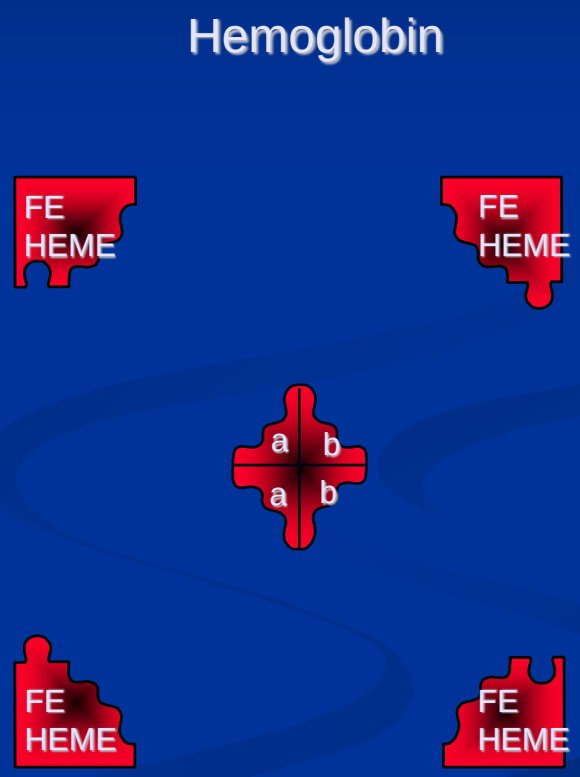
In the ECC the exchanging surface of the extracorporeal device is much more lower. We can play acting on the delta pO2 in order to improve the exchanging efficiency Theoretically we can supply the artificial lung with O2(pO2 = 760 mmHg) obtaining a ΔpO_2 =720 mmHg.

Gas Exchange Principle

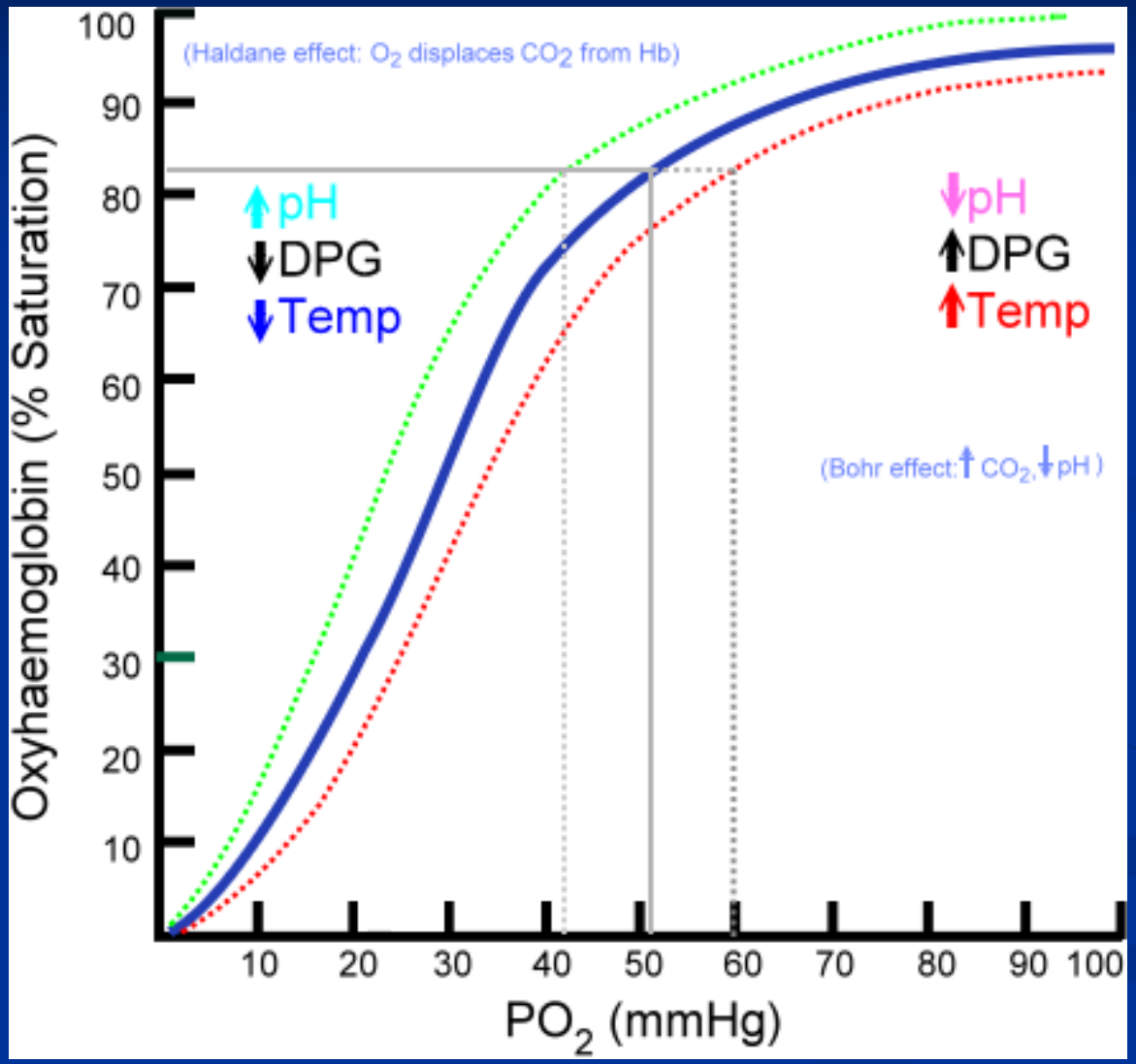
1 hemoglobin molecule is linked with
4 O_2 molecules

1 gr of hemoglobin can transport
1.34 gr of oxygen

O_2 SATURATION % = 100%



Cardiovascular System - Physiology and Pathology



DPG 2,3-diphosphoglycerate **: A highly anionic organic phosphate which is present in human red blood cells that controls the ability of oxy to move from the red cells**

Cardiovascular System- Physiology and Pathology

OXYGEN CAPACITY

Total volume of oxygen bound to a fully saturated hemoglobin

$$O_2\ capacity_{(ml O_2/100ml blood)} = 1.34_{(ml O_2/gm)} \times Hb_{(gm/100ml blood)}$$

OXYGEN CONTENT

Amount of oxygen the blood is actually carrying

$$O_2\ content_{(ml O_2/100ml blood)} = O_2 capacity \times O_2 saturation\ \%$$

OXYGEN SATURATION

$$O_2\ saturation\ \% = O_2 content \div O_2 capacity$$

PRINCIPLES OF GAS EXCHANGE

PHYSIOLOGICAL VALUES

	ARTERIAL	VENOUS	
pO_2	95-100	40	mmHg
pCO_2	40	46	mmHg
O_2 capacity	20.6	20.6	(mlO_2/100mlblood)
O_2 content	20.3	15.5	(mlO_2/100mlblood)
O_2 saturation	97	65	%
O_2 consumption	100 - 200		ml/min

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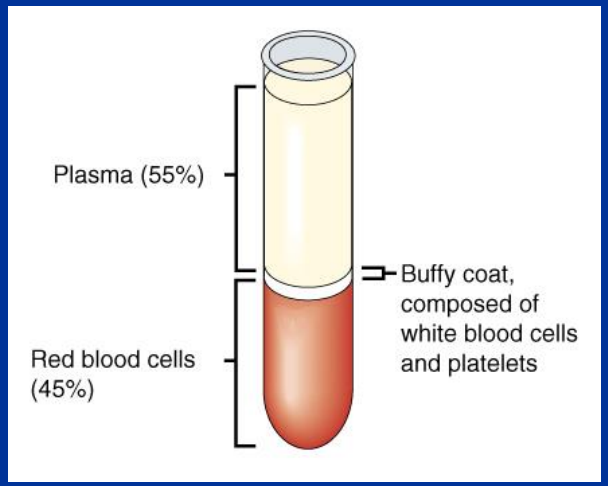
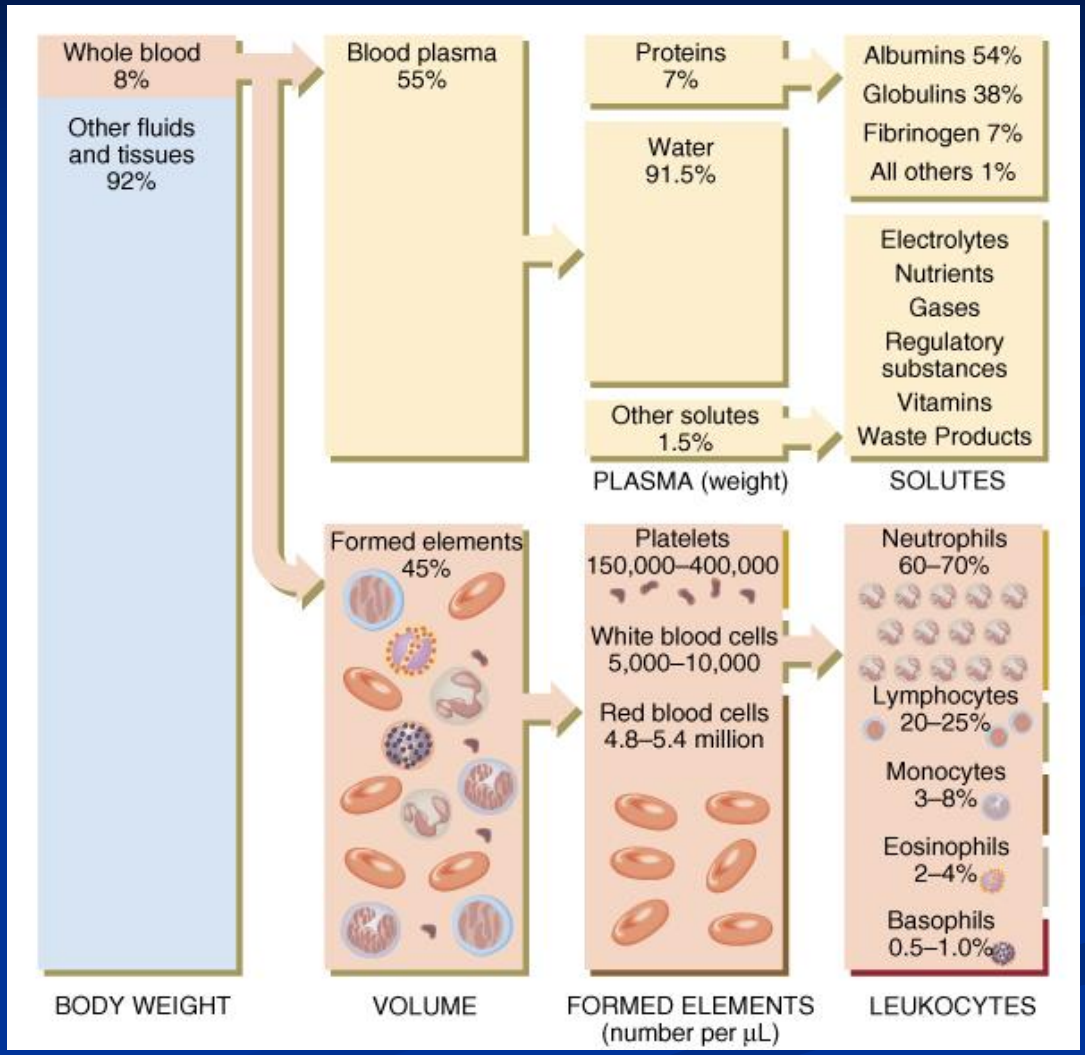
Components of Blood

- **Hematocrit**
  - 55% plasma
  - 45% cells
    - 99% RBCs
    - < 1% WBCs and platelets





Cardiovascular System - Physiology and Pathology
Blood

- The transport functions include:
  - Carrying oxygen and nutrients to the cells
  - Transporting carbon dioxide and nitrogenous wastes from the tissues to the lungs and kidneys where these wastes can be removed from the body
  - Carrying hormones from the endocrine glands to the target tissues
- The regulation functions include:
  - Helping regulate body temperature by removing heat from active areas, such as skeletal muscles, and transporting it to other regions or to the skin where it can be dissipated
  - Playing a significant role in fluid and electrolyte balance because the salts and plasma proteins contribute to the osmotic pressure
  - Functioning in pH regulation through the action of buffers in the blood
- The protection functions include:
  - Preventing fluid loss through hemorrhage when blood vessels are damaged due to its clotting mechanisms
  - Helping (phagocytic white-blood cells) to protect the body against microorganisms that cause disease by engulfing and destroying the agent
  - Protecting antibodies in the plasma against disease by their reactions with offending agents

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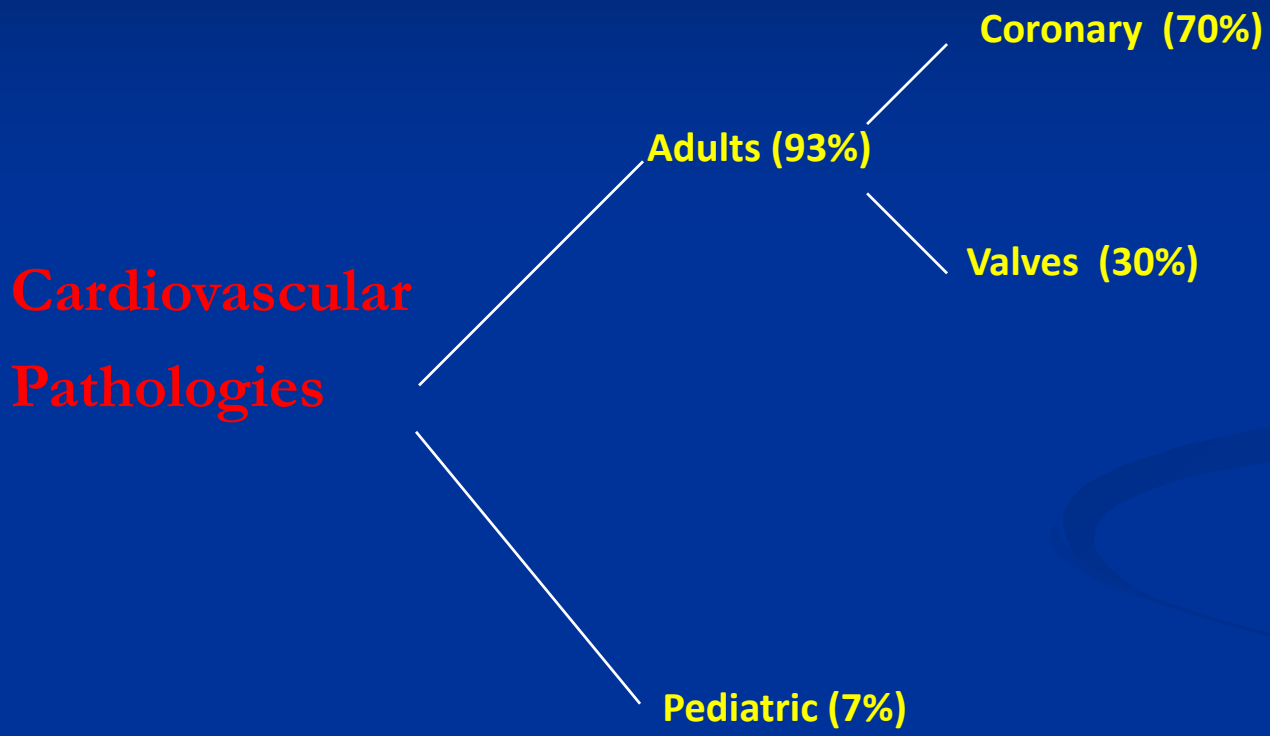
Cardiovascular System - Physiology and Pathology

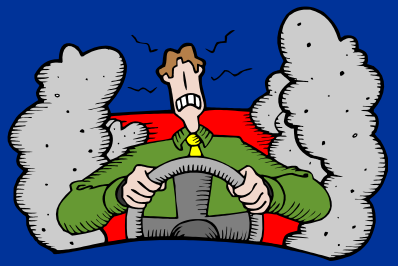


Cardiovascular System - Physiology and Pathology

PATHOLOGIES

Paediatric cardiopathies
(Congenital defects)

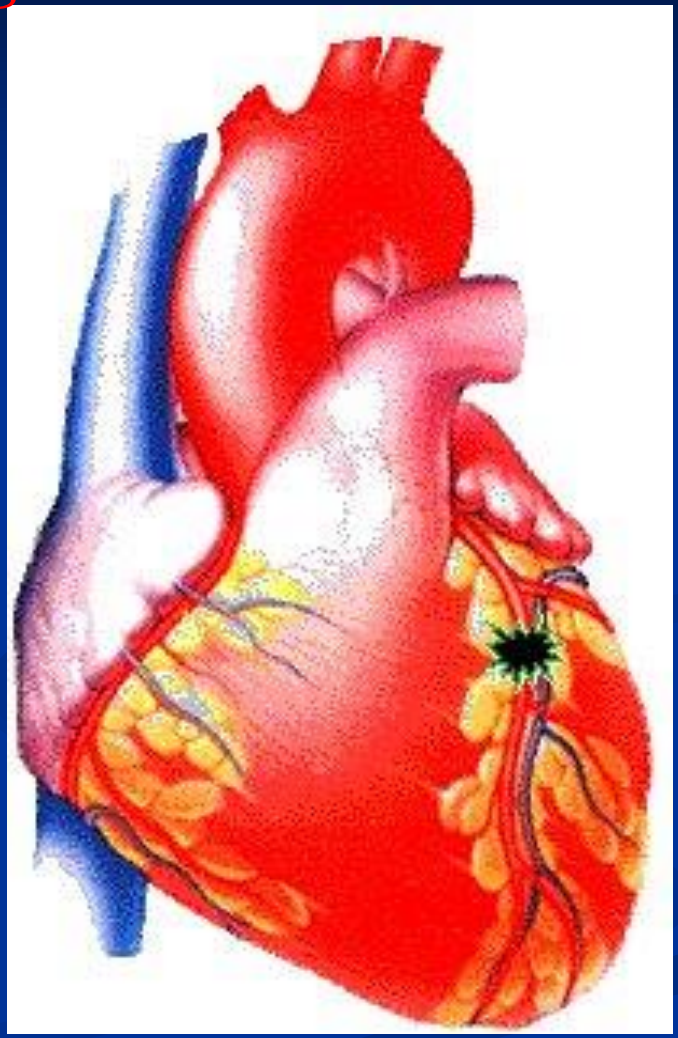
- Atrial and ventricular septal defects
- Pulmonary valve stenosis
- Patent Ductus Arteriosus
- Various vassels defect



Adult cardiopathies

- Coronary stenosis
- Valvular pathologies
- Aneurism /Main vassels stenosis

Cardiovascular System - Physiology and Pathology - Adult pathologies



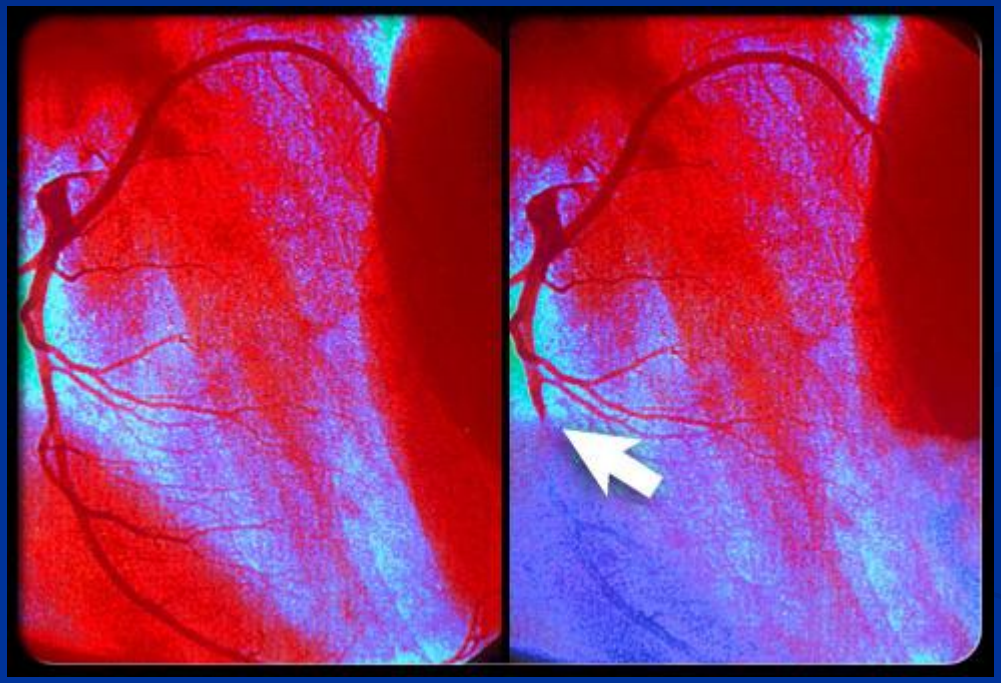
Coronary Stenosis

The coronary arteries could occlude. This leads to a lack of oxygen to the heart muscle (ischemia) and brings to Angina Pectoris or finally to the death of tissues after the occlusion (heart attack).

It is necessary to create a by-pass between aorta and the obstructed vessel in order to reperfuse the area after the stenosis

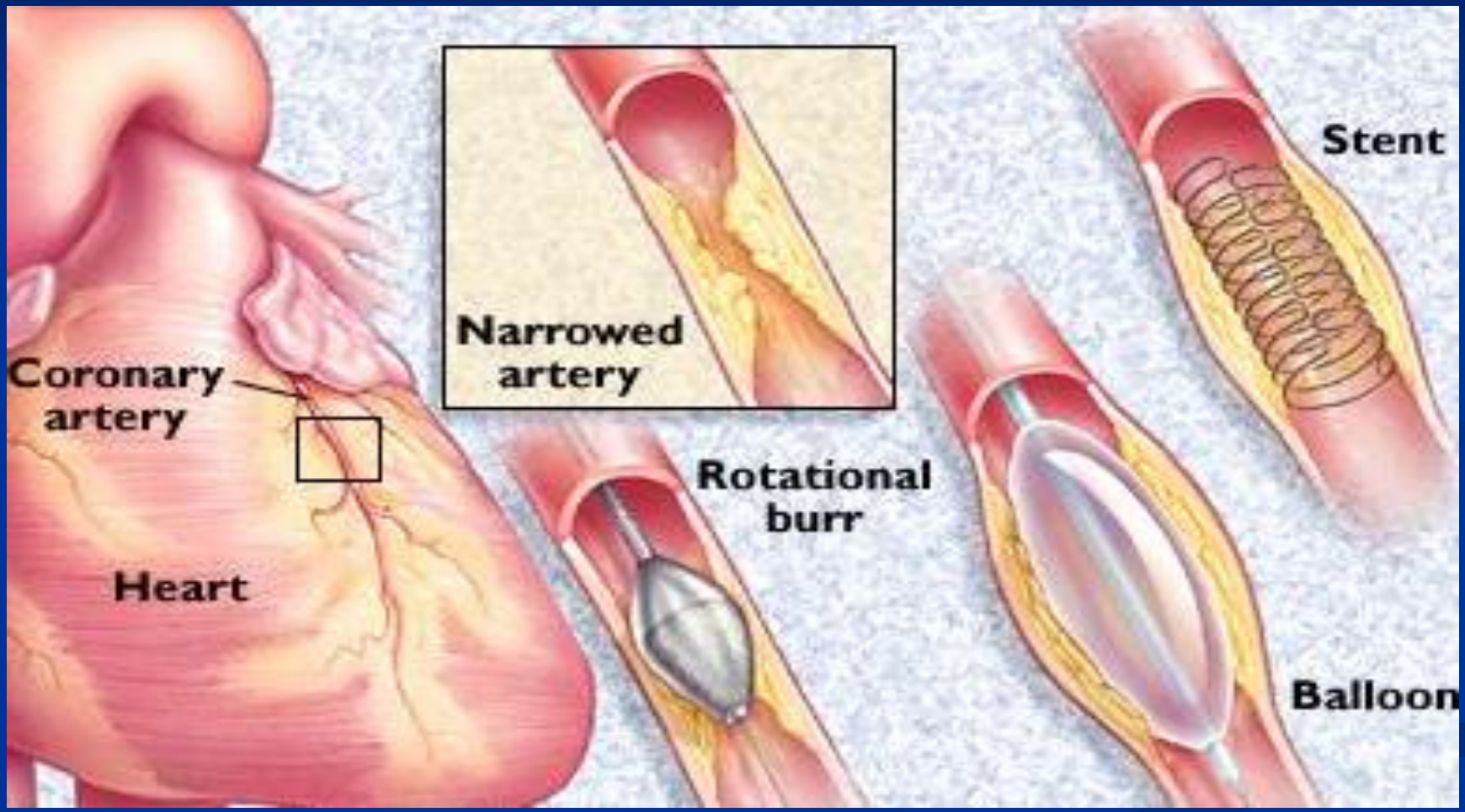
Cardiovascular System - Physiology and Pathology

Adult pathologies



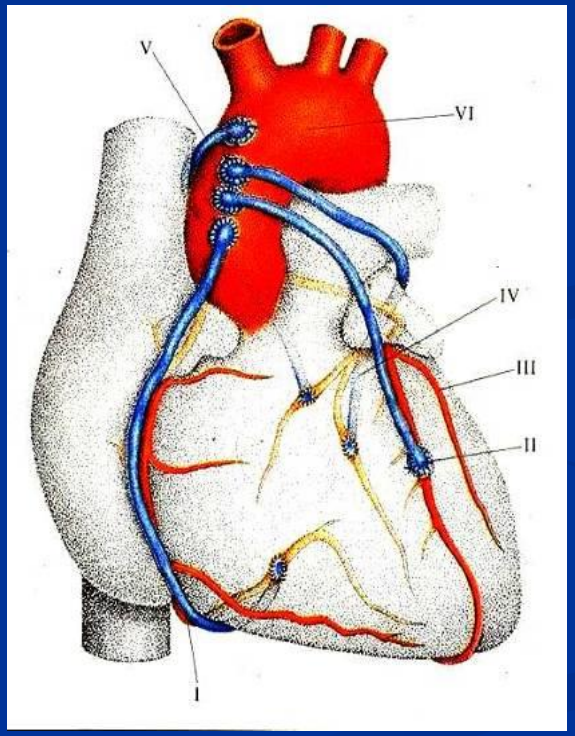
Cardiovascular System - Physiology and Pathology

Adult pathologies



Cardiovascular System - Physiology and Pathology

Coronary Artery Bypass Graft



Cardiovascular System - Physiology and Pathology

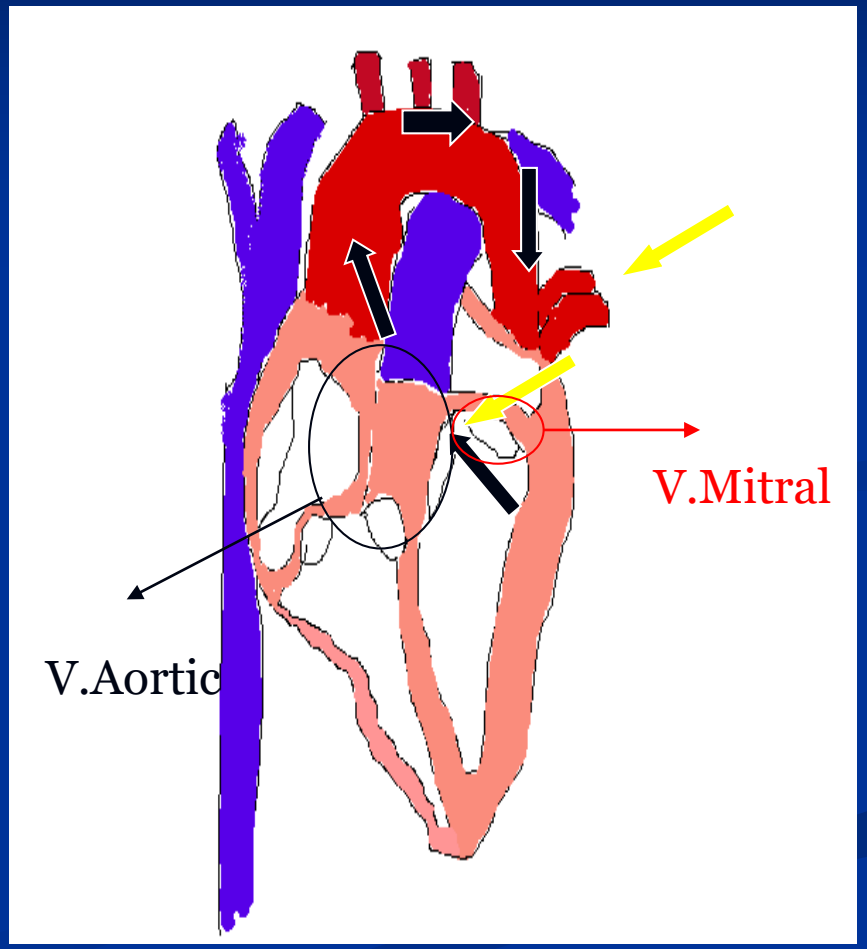
Adult Pathologies

Valve pathology affects mainly the left part of the heart where pressure is very high.
The reduced functionality of the valves can be divided into two main causes:

1.Valvular Stenosis: The valve does not open correctly (i. e. calcification)

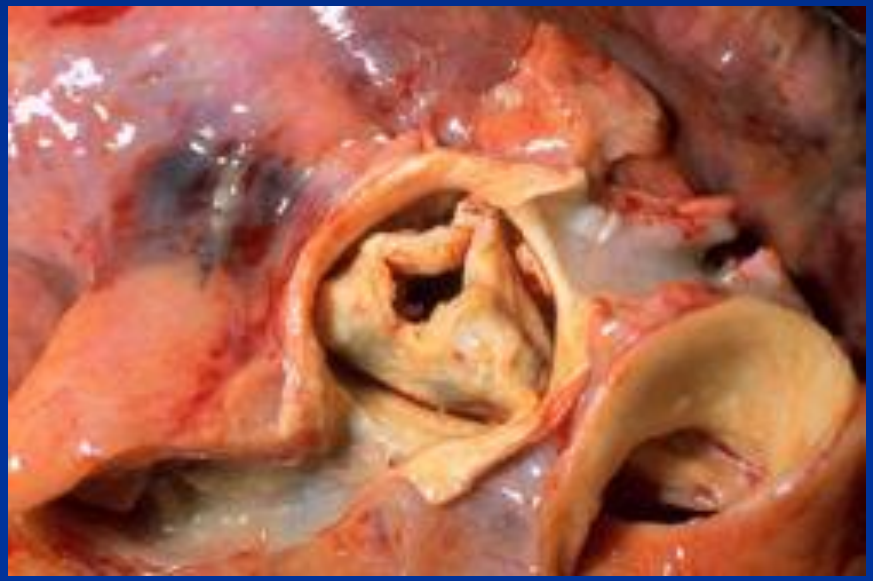
2.Valvular insufficiency (regurgitation), or "leaky valve", this occurs when a valve does not close tightly. In this case some blood will leak backwards across the valve. The valve operation can be:

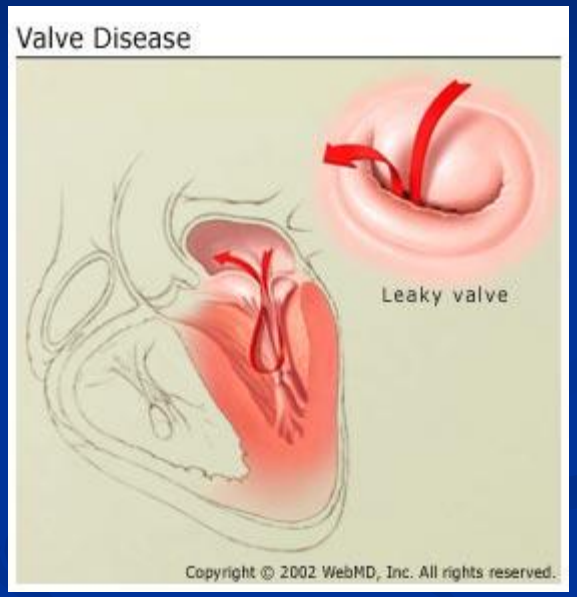
- Valve replacement
- Valve reconstruction



Cardiovascular System - Physiology and Pathology

Aortic Stenosis

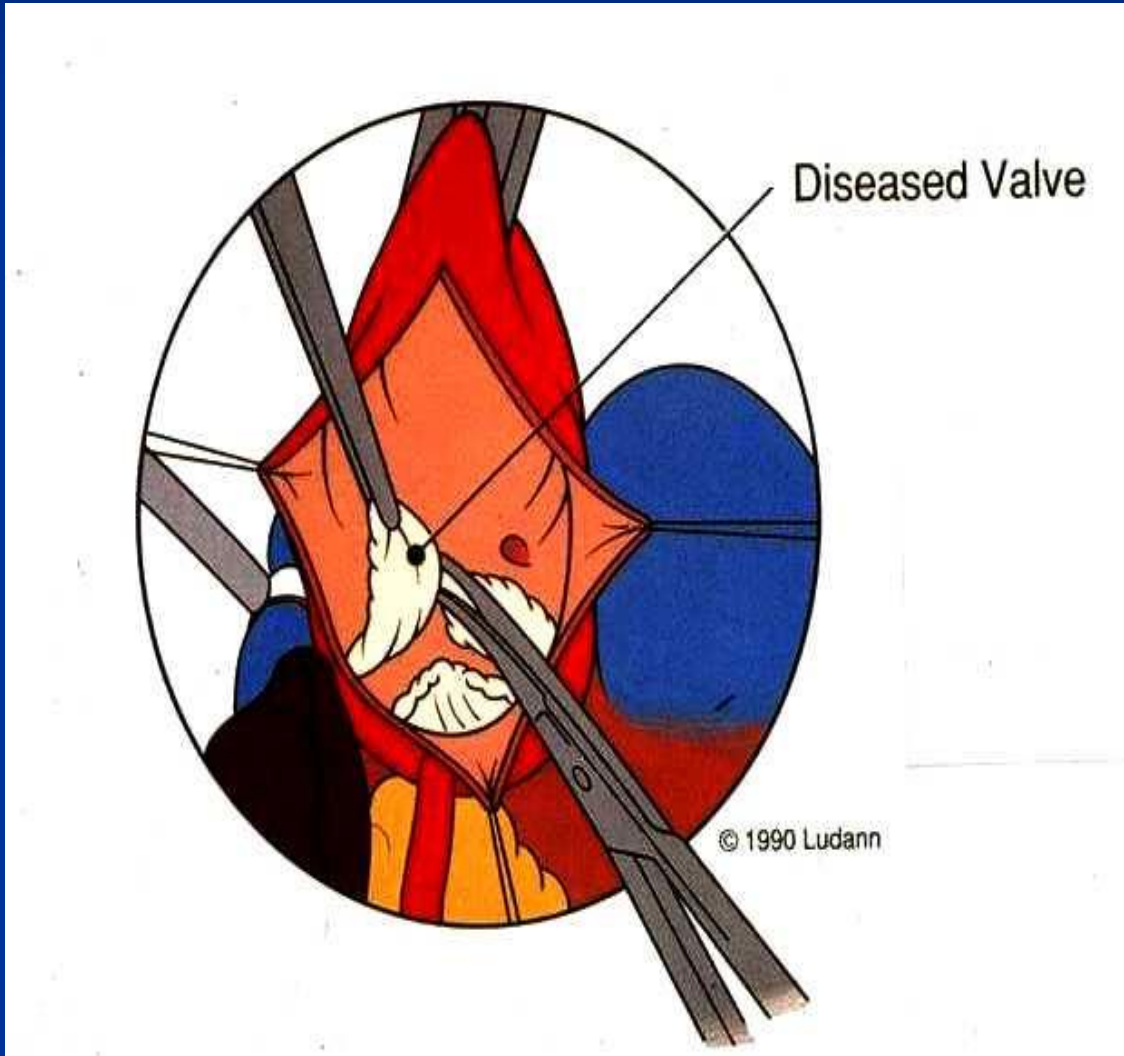




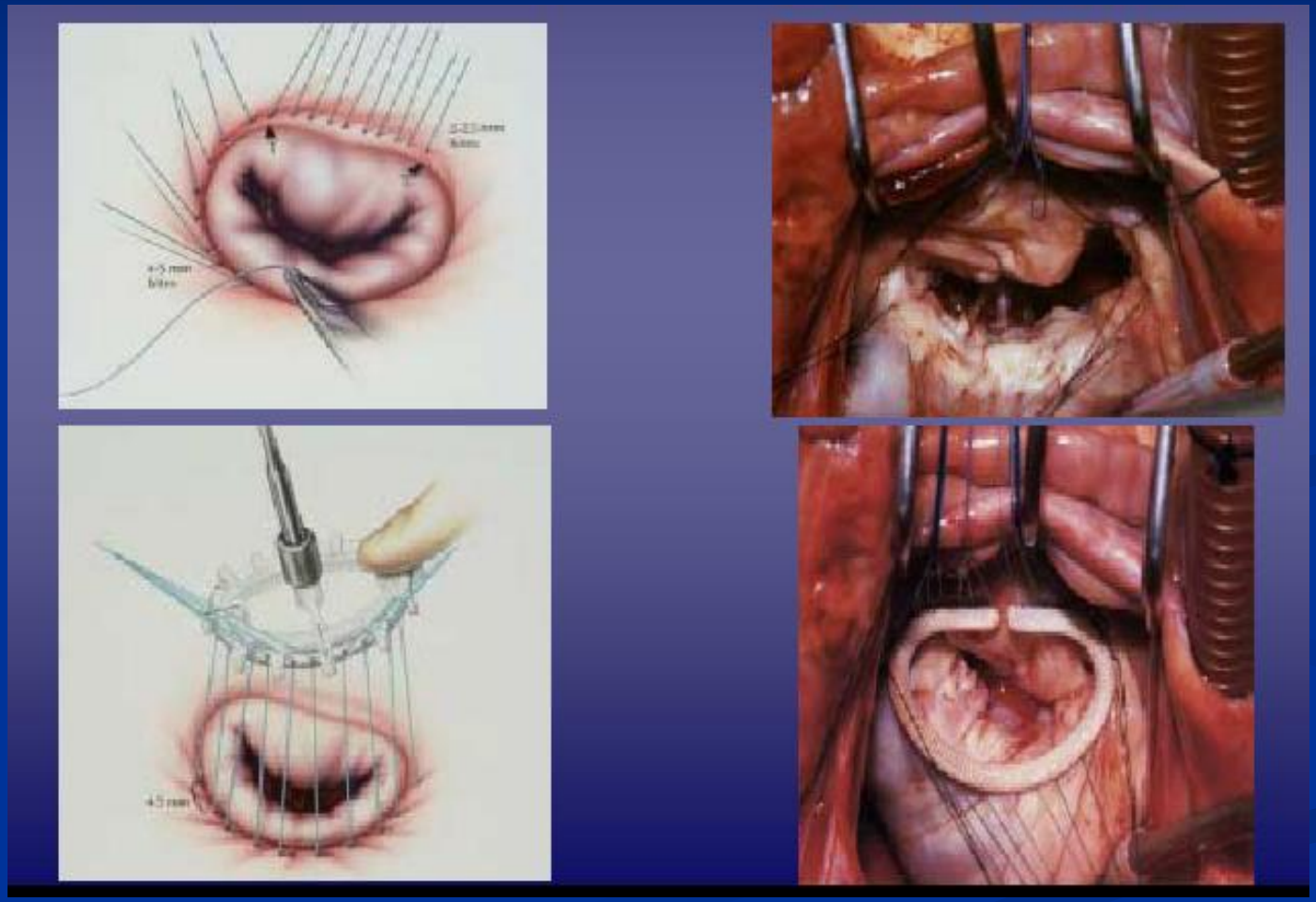
Mitral Insufficiency

Cardiovascular System - Physiology and Pathology

Valve Reconstruction

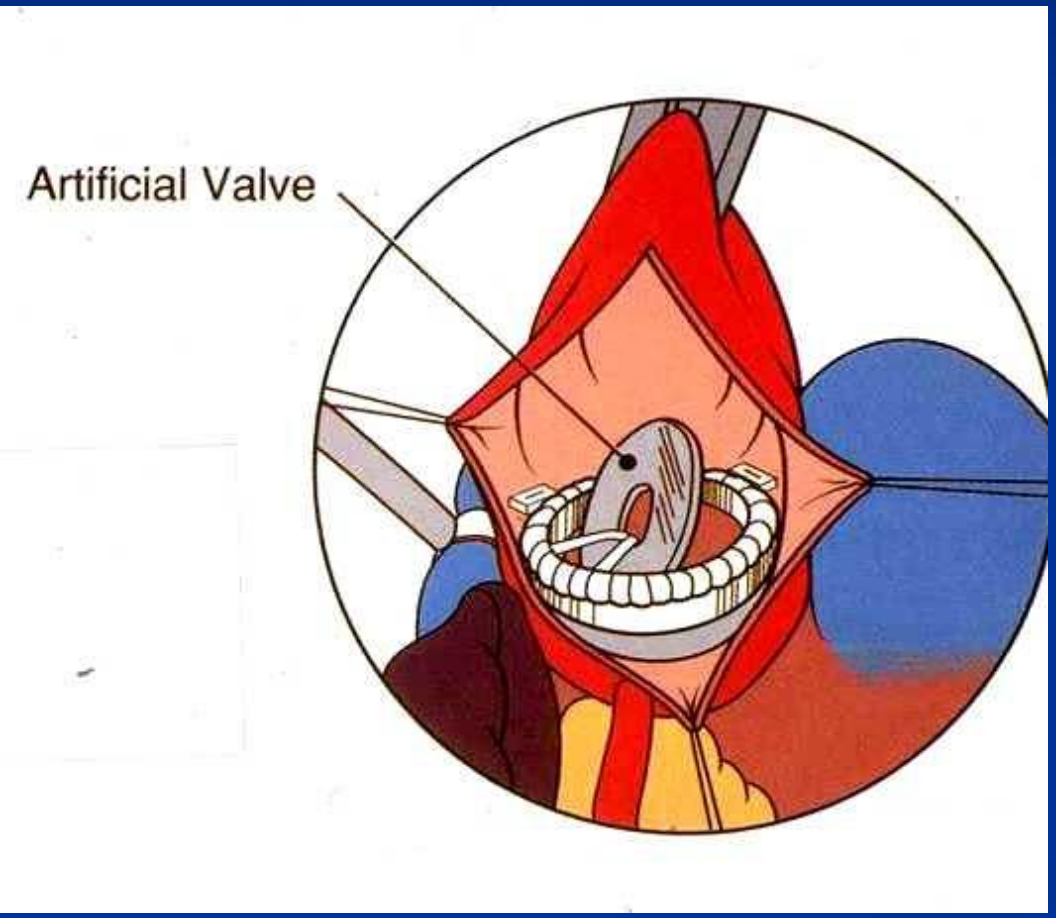


Ring for the valve reconstruction



Cardiovascular System - Physiology and Pathology

Valve Substitution



Mechanical Valve

Biological Valve

Cardiovascular System - Physiology and Pathology

Aneurysm

- Aneurysm is a general definition for any vessel dilatation, usually representing an underlying weakness in the wall of the vessel. While the stretched vessel may occasionally cause discomfort, a greater may leads to a rupture, with severe pain, massive internal hemorrhage and, without prompt treatment, to a quick death.

Cardiovascular System - Physiology and Pathology

Congenital Defects

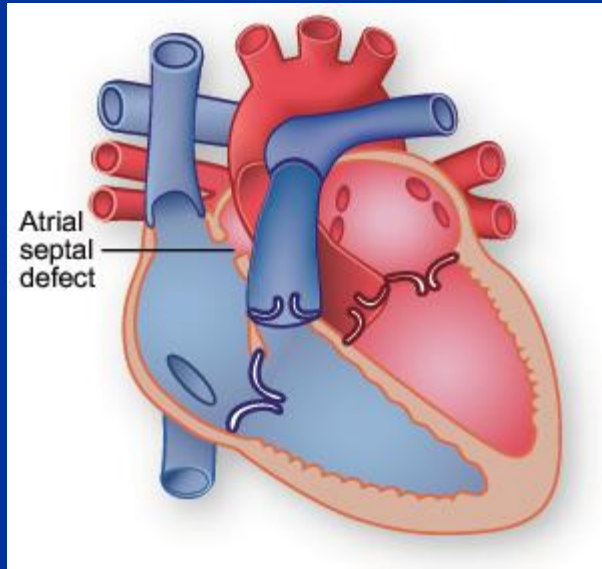
There are many different types of congenital heart defects. More than one defect may be present at the same time.

- Atrial septal defect (ASD)
- Atrioventricular canal defect
- Coarctation of the aorta
- Coronary artery anomalies
- Double outlet right ventricle (DORV)
- Ebstein's anomaly
- Hypoplastic left heart syndrome
- Patent ductus arteriosus
- Patent foramen ovale (PFO)
- Pulmonary atresia
- Pulmonary stenosis
- Tetralogy of Fallot
- Total anomalous pulmonary venous connection
- Transposition of the great arteries

Cardiovascular System - Physiology and Pathology

Congenital Defects

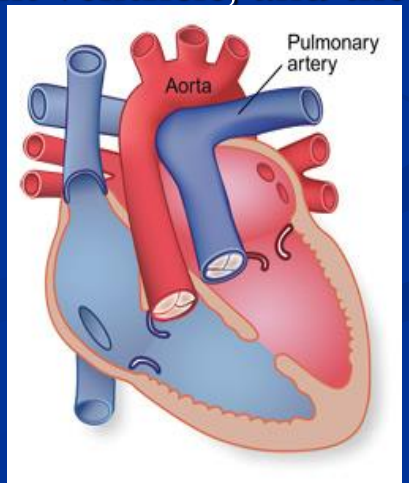
- ASD
- Atrial Septal Defect (ASD) is a hole in the septum, the wall separating the right atrium of the heart from the left atrium of the heart.
  - Surgery usually involves covering the hole with a patch



Cardiovascular System - Physiology and Pathology

Congenital Defects

- Transposition of great arteries
- The "great arteries" are the pulmonary artery and the aorta. In transposition of the great arteries, the normal position of the arteries is reversed. The aorta comes out of the right ventricle (instead of the left ventricle), and the pulmonary artery comes out of the left ventricle (instead of the right ventricle).
- The most common surgery for transposition of the great arteries can be performed within the first month of life. It is called an arterial switch. As the name suggests, the surgery reverses the positions of the arteries, so that the pulmonary artery is connected to the right ventricle, and the aorta is connected to the left ventricle



Cardiovascular System - Physiology and Pathology

Congenital Defects

- Tetralogy of Fallot is made up of 4 heart defects:
  - A hole in the wall between the lower chambers (the ventricles), which lets oxygen-poor blood mix with oxygen-rich blood. This is called a ventricular septal defect (VSD).
  - A narrowed outlet to the pulmonary artery, usually combined with an abnormal pulmonary valve. This can block blood flow from the lower-right chamber (the right ventricle) into the lungs.
  - An aorta that straddles the wall (septum) between the lower chambers (the ventricles). This lets oxygen-poor blood flow into the aorta.
  - Thickened and enlarged heart muscle tissue in the lower-right chamber (the right ventricle).
- Open heart surgery to correct the defects is usually performed.

Cardiovascular System - Physiology and Pathology

1. Cardiovascular system physiology
2. Blood Physiology
3. Cardio- vascular pathologies
4. Extracorporeal circulation
5. Elements in the ECC:
    1. Disposables
    2. HLM
6. CPB Phases
7. ECMO

Extracorporeal Circulation

Extracorporeal Circulation (Cardiopulmonary Bypass) is a procedure to circulate and oxygenate the blood while surgery is performed on the heart. It involves the diversion of blood from the heart and lungs through a heart- lung machine and the return of oxygenated blood to the aorta.

HOW ?

- Collecting blood from the systemic veins before it enters the heart;
- Returning blood to the systemic arteries after the heart;
- Replacing function of the lungs
  - adds oxygen to the blood
  - removes carbon dioxide from the blood.
- Replacing function of the heart
  - generates blood flow
  - generates blood pressure

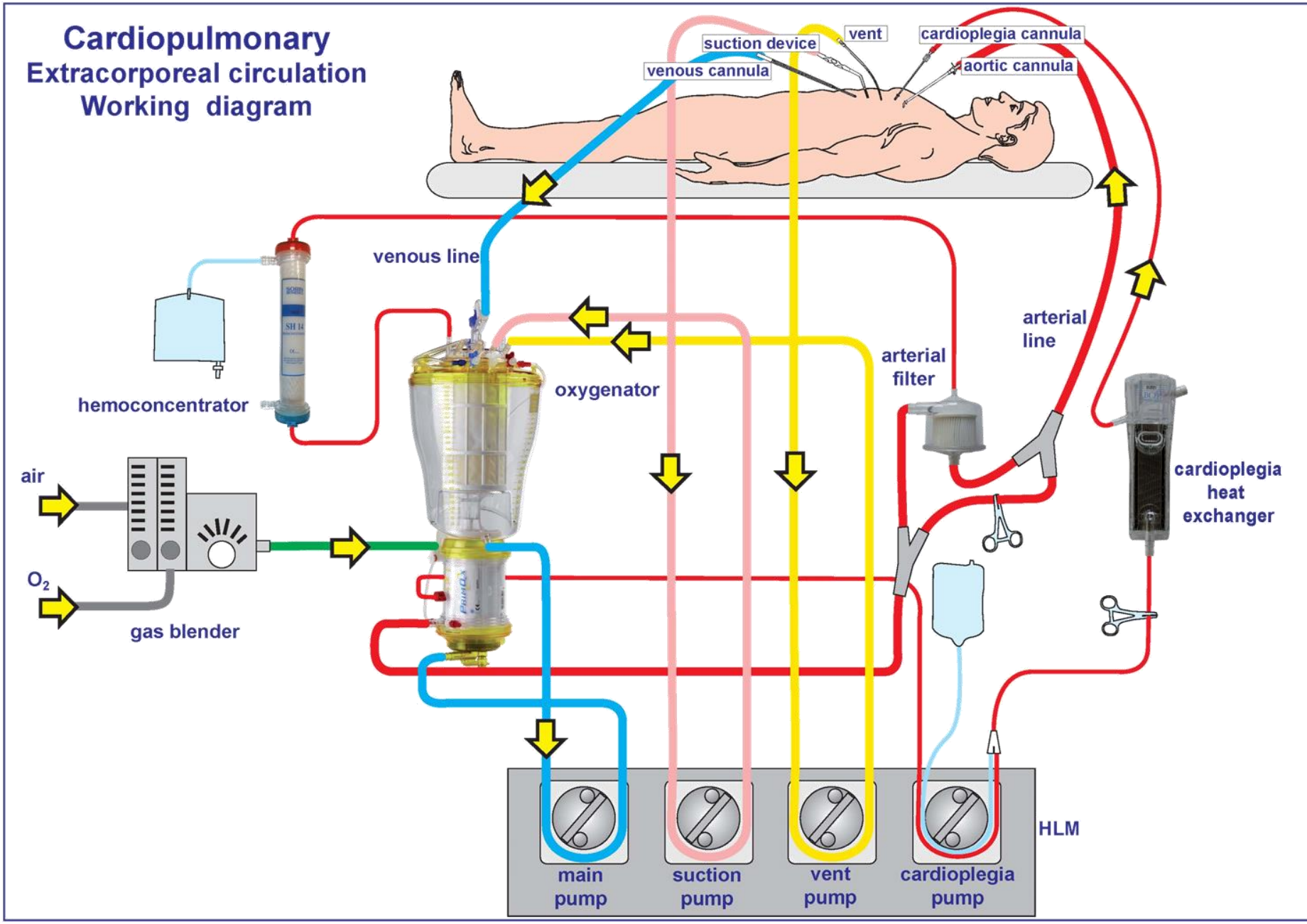
Indication for ECC

- Coronary by pass (CABG)
- Valvular Pathologies
- Vascolar Pathologies
- Heart Transplantation
- ECMO
- Congenital cardiopathologies

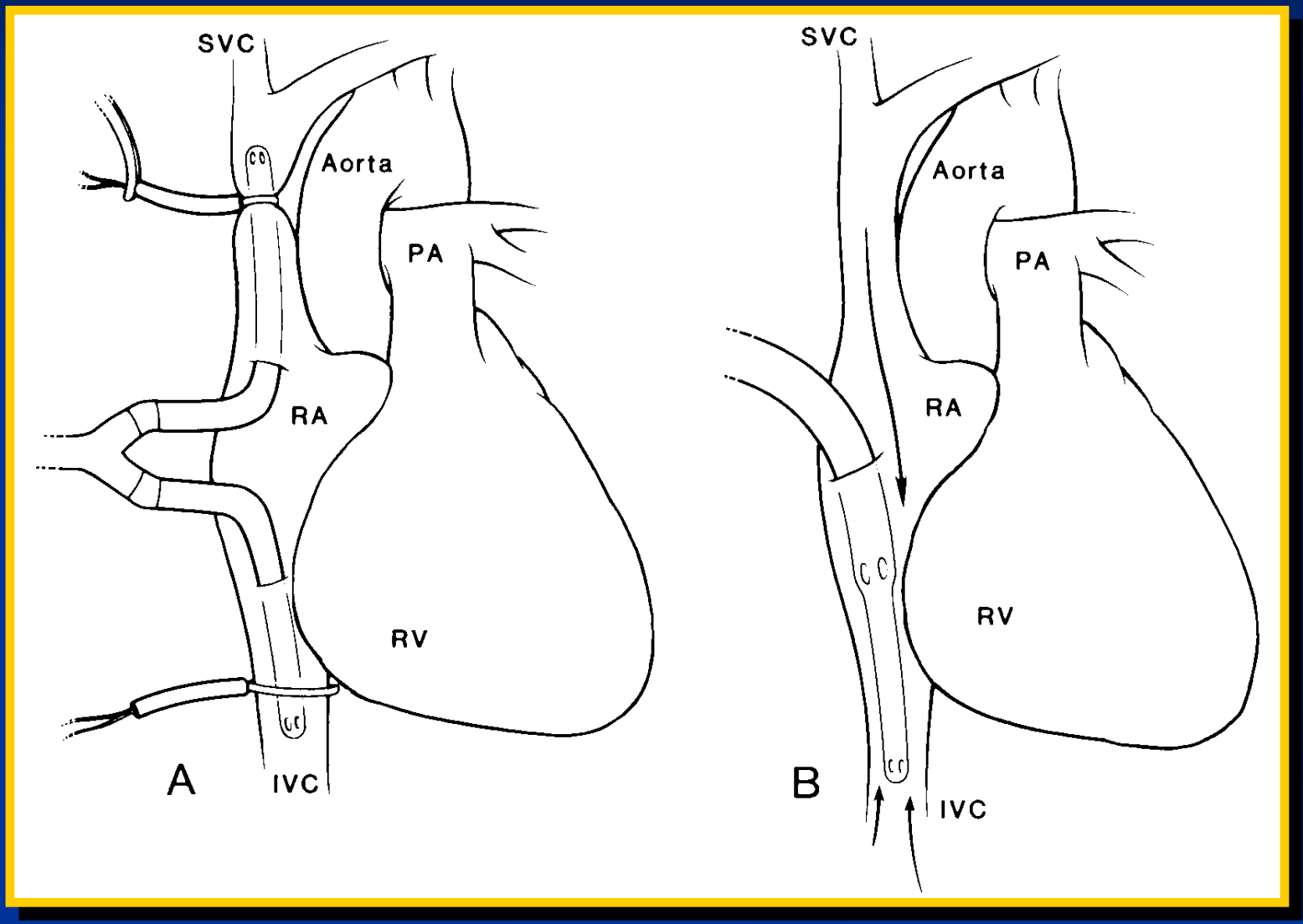
Components of the ECC

- Cannulae
- Pumps
- Oxygenators
- Reservoirs
- Filters
- Cardioplegia
- Hemoconcentration
- Biocompatibility
- Safety Devices
- Miscellaneous

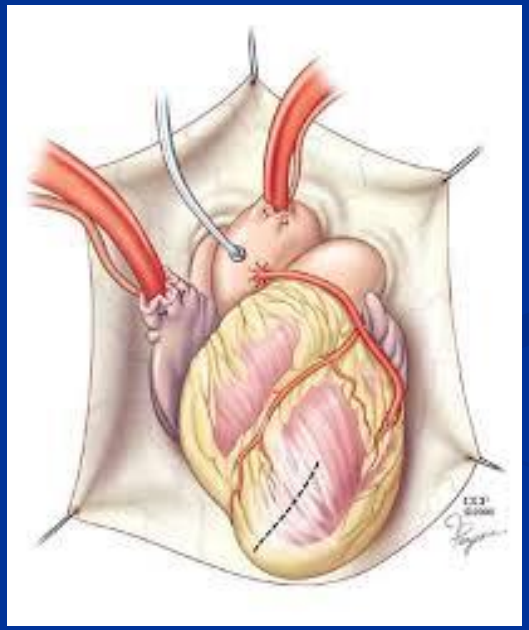
Cardiopulmonary
Extracorporeal circulation
Working diagram



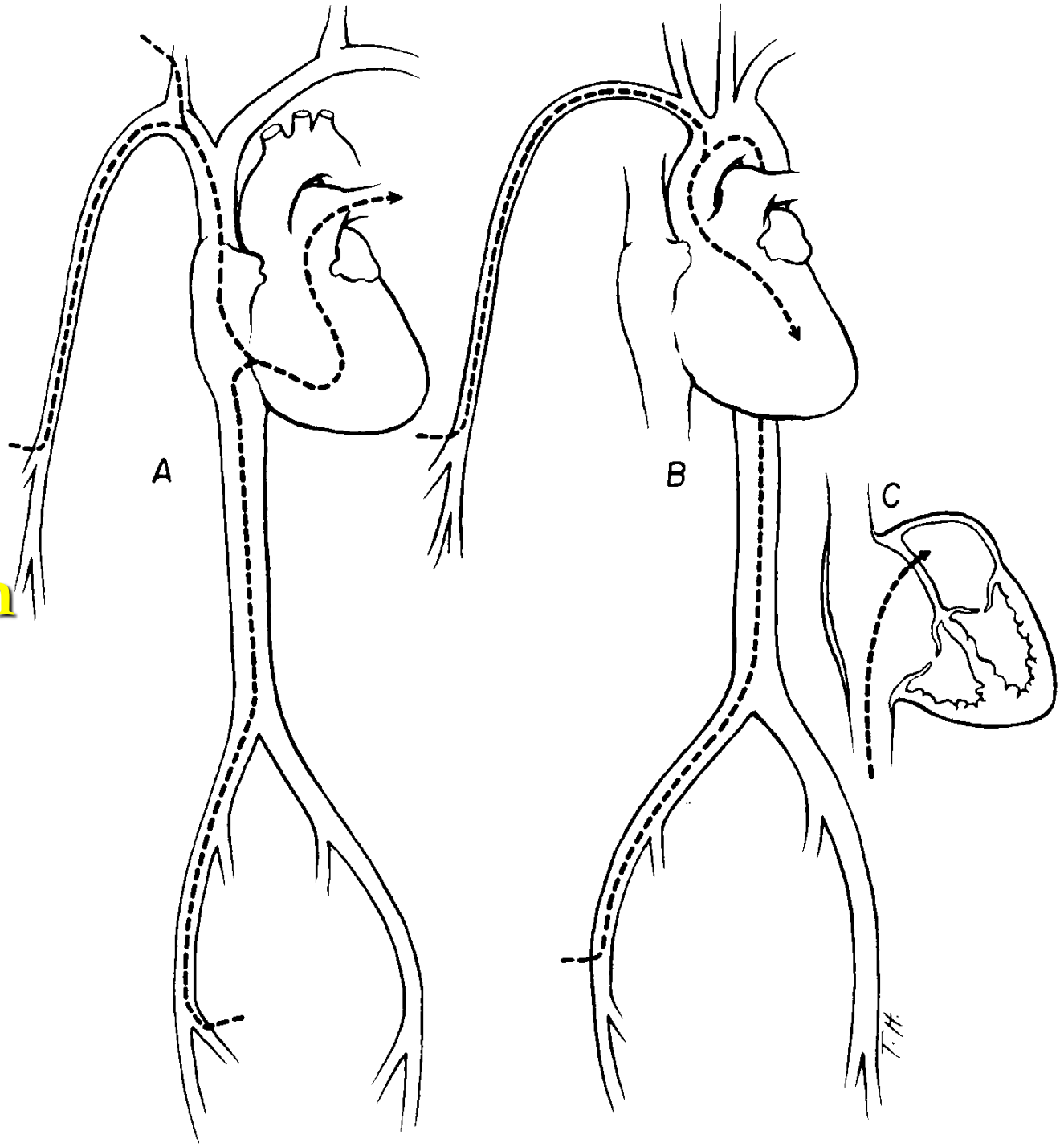
Venous Cannulation



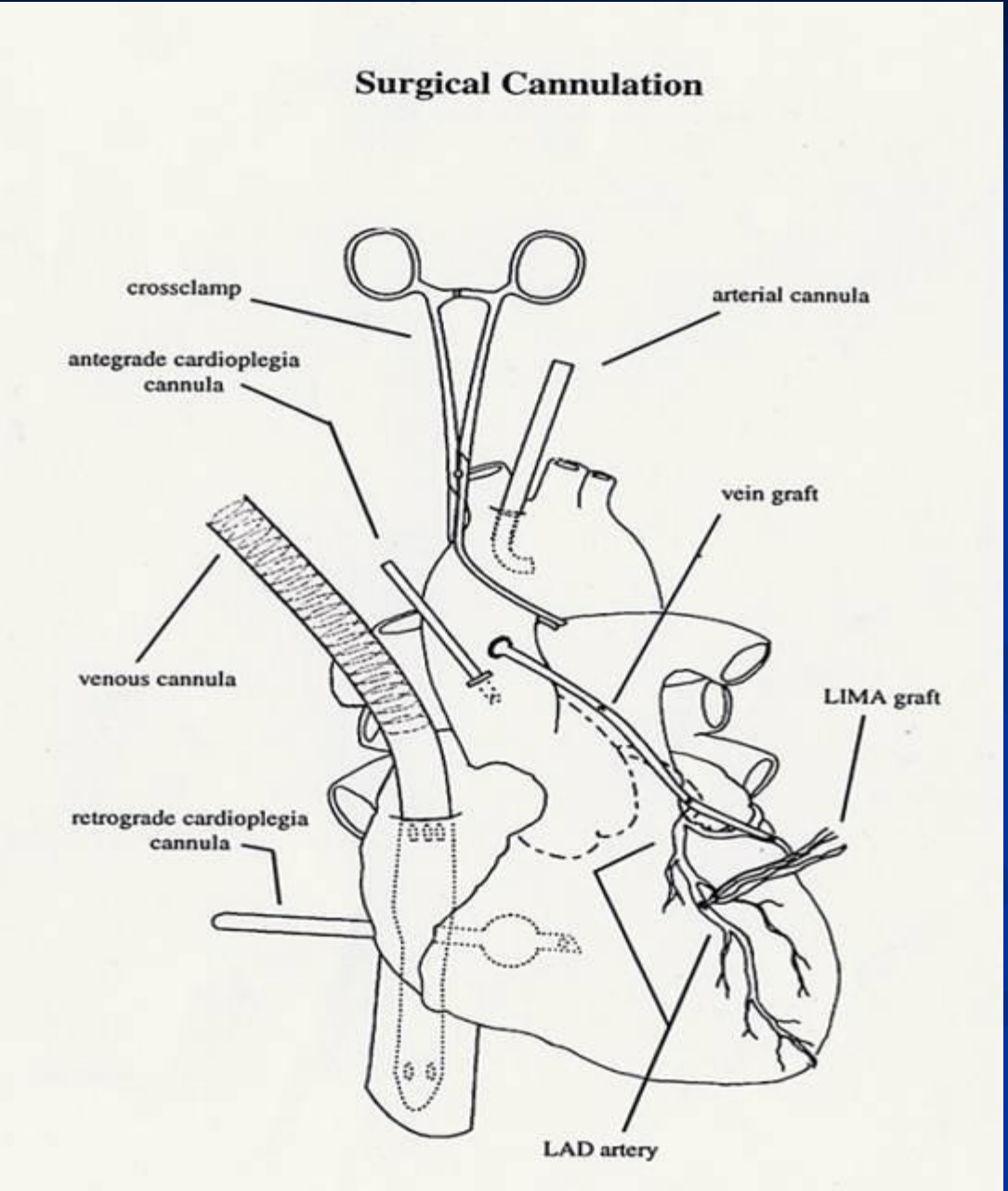
ARTERIAL CANNULATION



Femoral Cannulation



Cardiovascular System - Physiology and Pathology



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Cardiovascular System - Physiology and Pathology

During bypass surgery, patient life depends by the so called HLM (Heart Lung Machine)

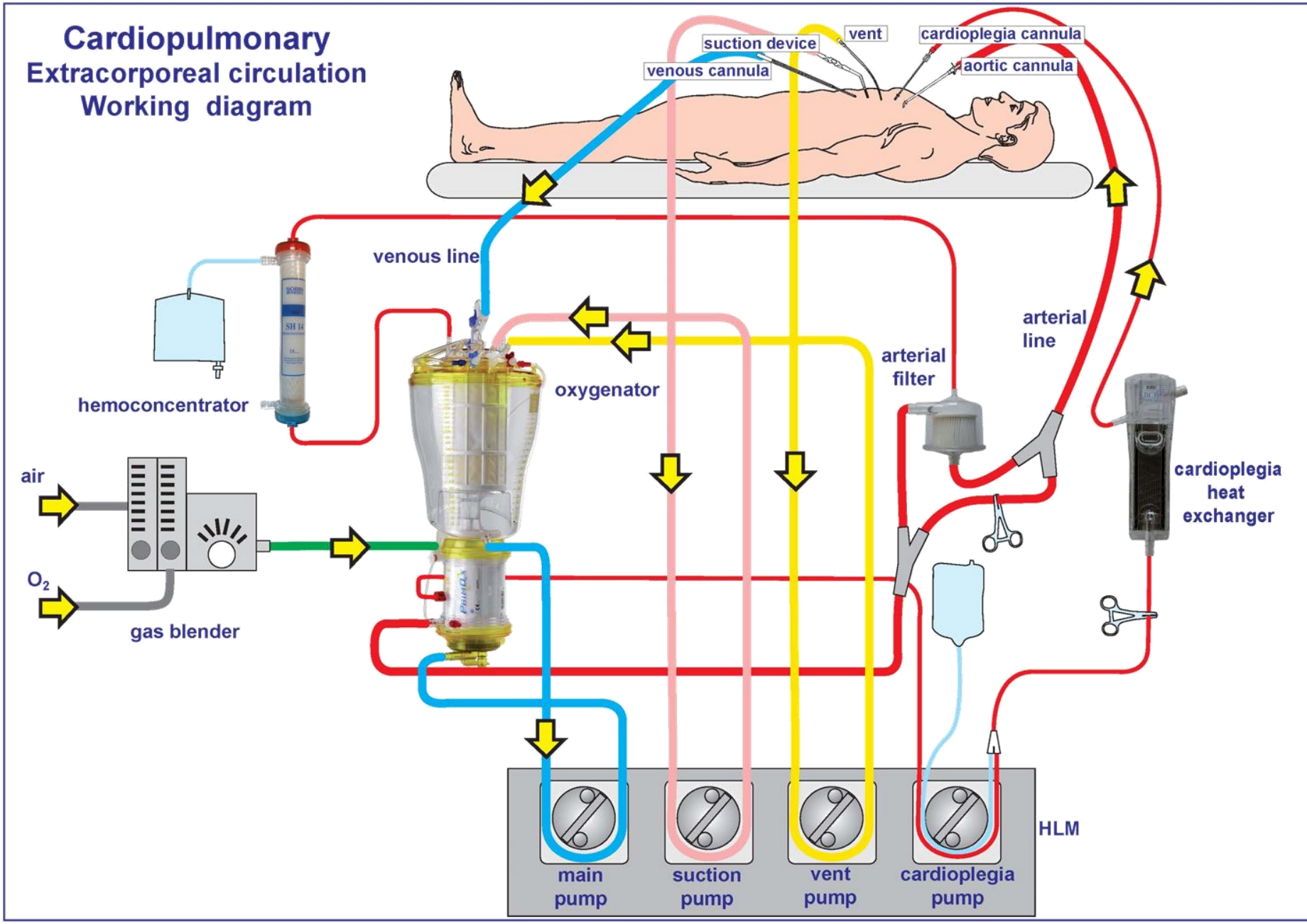
Heart → Roller or Centrifugal Pump → HLM

Lung → Oxygenator

Vessels → ~~Extra~~corporeal Circuit
(Vein- Arteries)

} Disposable PTS

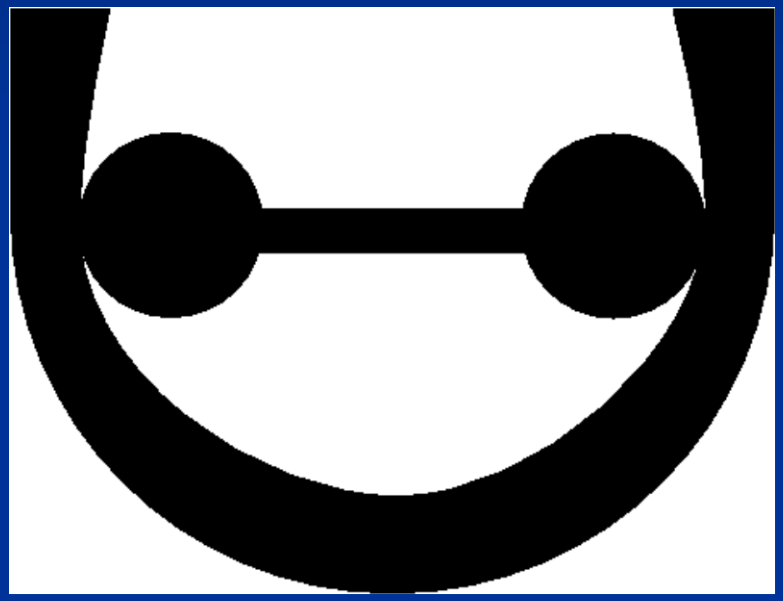
Cardiopulmonary
Extracorporeal circulation
Working diagram



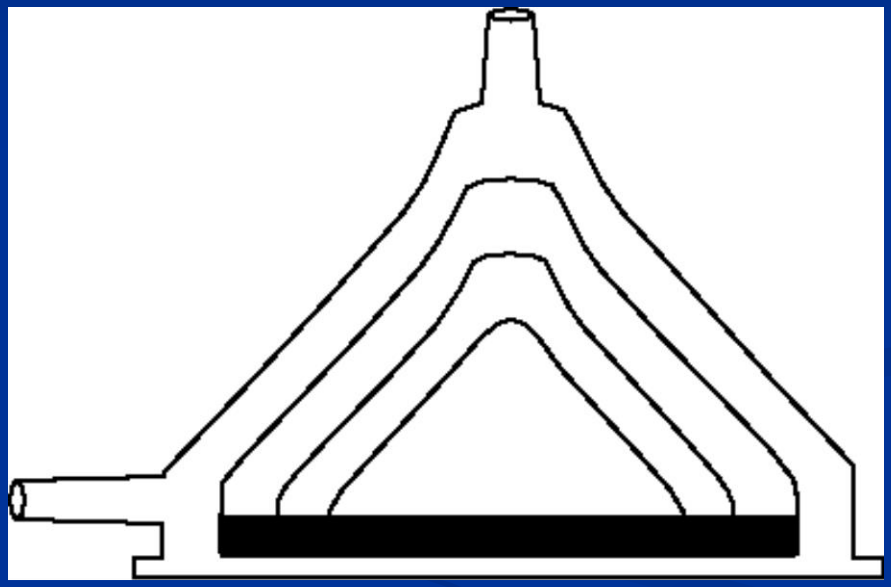
Pumps

- **Move blood and fluid through and out the ECC**
  - arterial pump takes over function of heart
  - suction of blood from the surgical site
  - decompression of heart
  - delivery of cardioplegia solution

Roller and Centrifugal Pumps



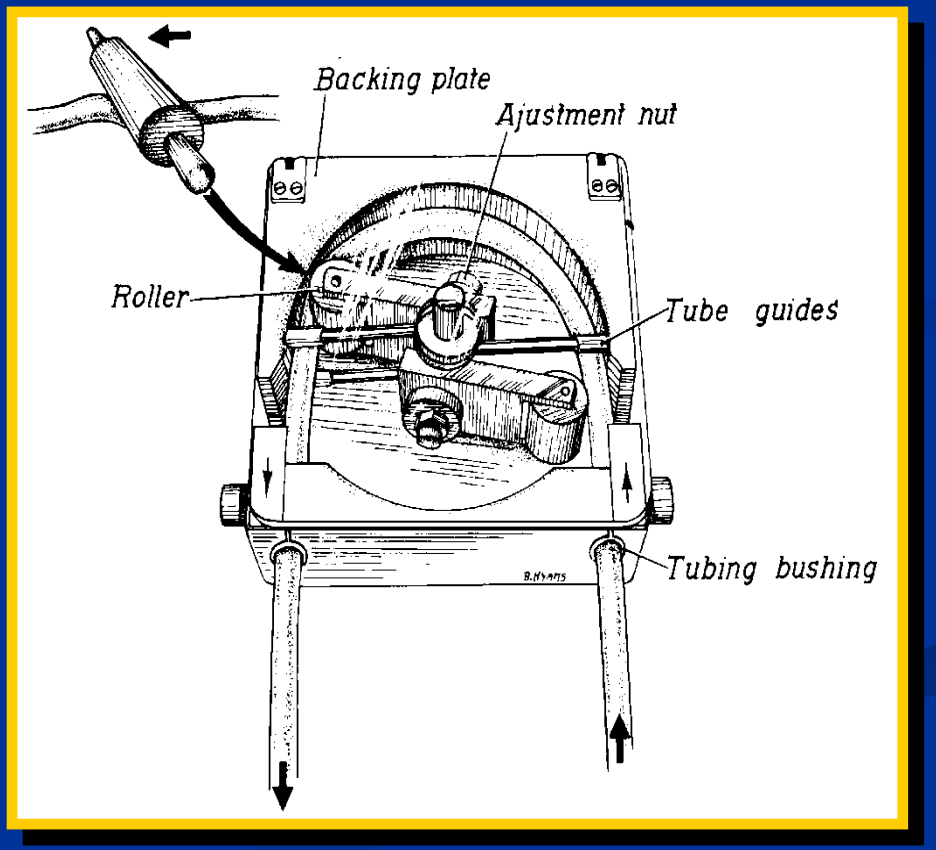
Roller Pump Head



Centrifugal Pump Head

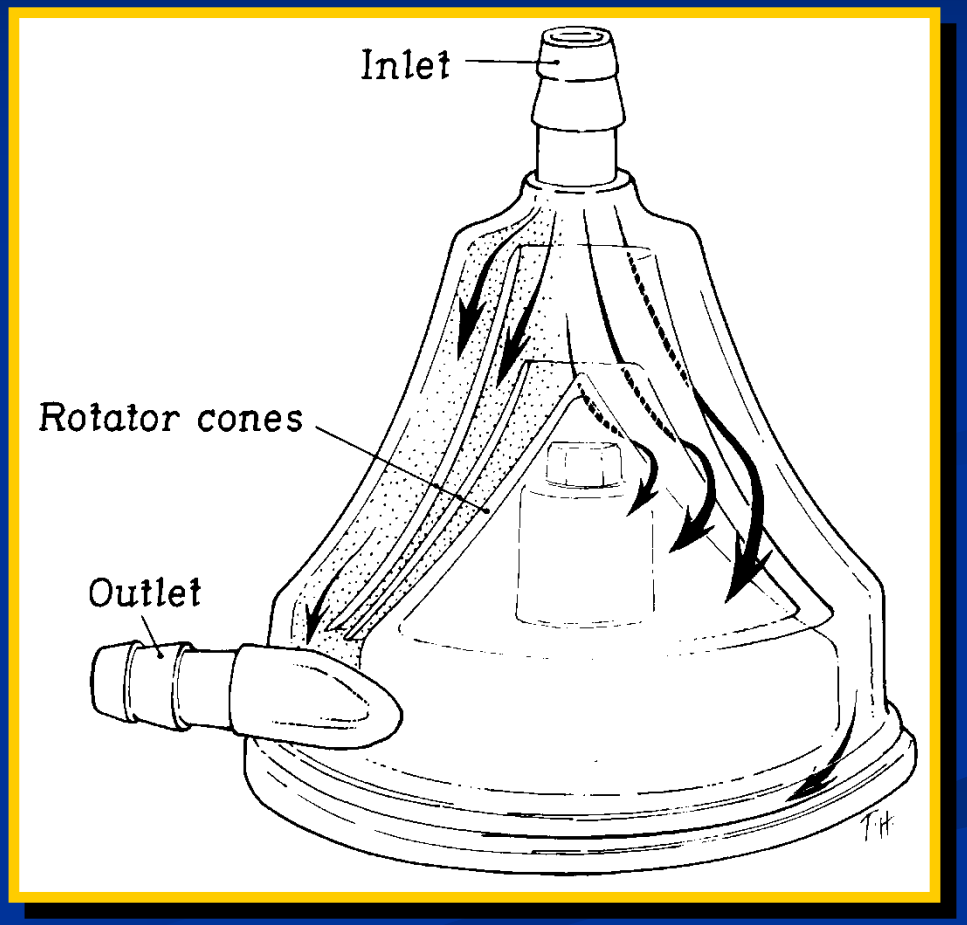
Roller Pump

- Flow induced by compression of tubing against raceway
- Flow depends on size of tubing, length of raceway, and RPM
- Pump occlusion mandatory
  - fluid height 60 to 75 cm (24 to 30 inches)
  - backflow of 1 cm/min



Centrifugal Pump

- Forward flow produced by centrifugal force created by spinning cones or impellers
- Totally nonocclusive and afterload dependent
  - flow meter required to determine actual flow
  - significant backflow can occur through the pump
- Used only as arterial pump head

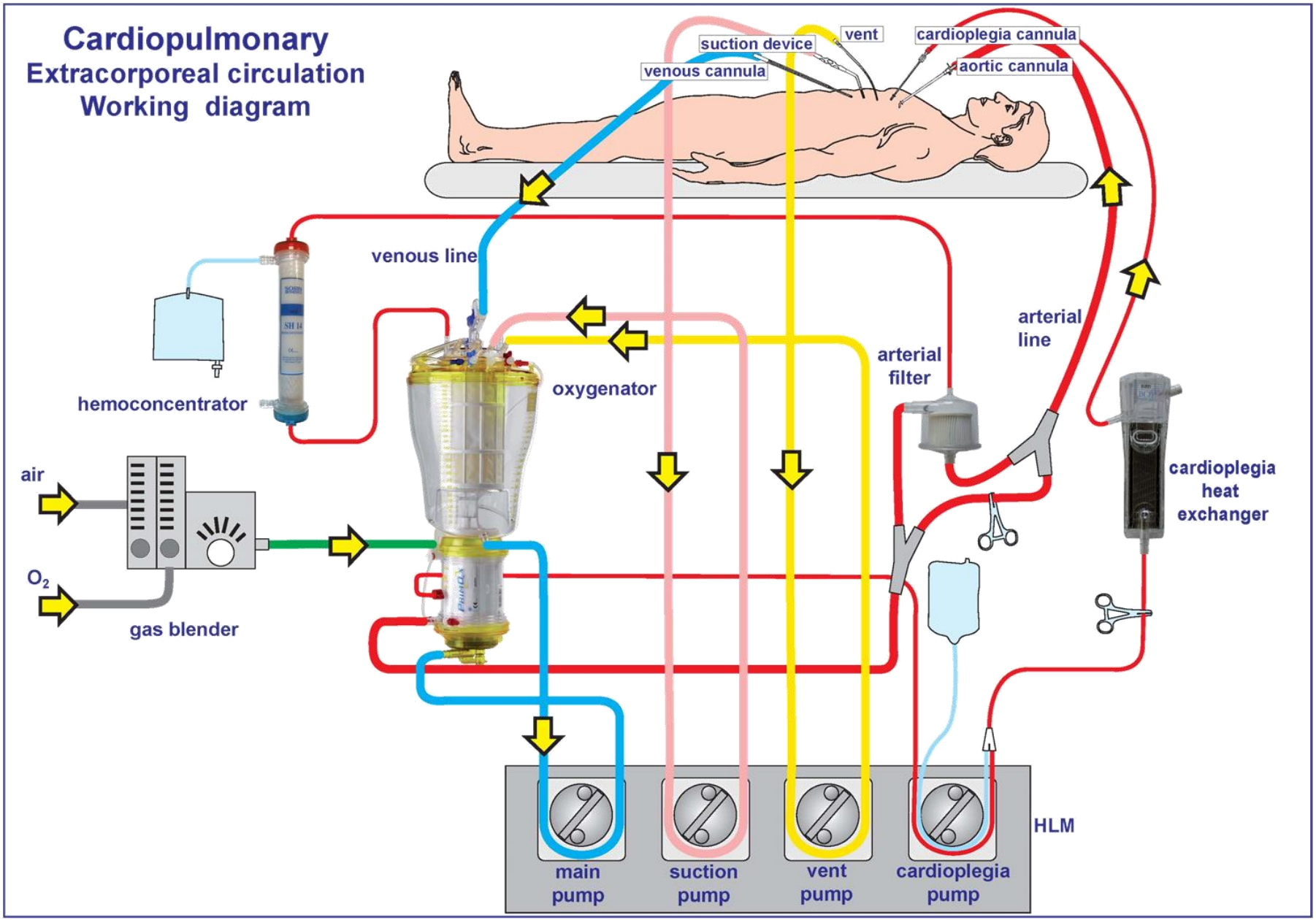


Cardiovascular System - Physiology and Pathology
Pumps

ROLLER Occluding system

Centrifugal Pump via centrifugal force

Cardiopulmonary
Extracorporeal circulation
Working diagram



Oxygenators

- Provide gas exchange
  - oxygen
  - carbon dioxide
- Control arterial and venous levels of oxygen and carbon dioxide
  - take over function of lungs
- Control blood temperature and patient temperature

Reservoirs

- Collection point for blood and fluid
- Defoams blood
- Filters shed blood
- Store blood and fluid

Filters

- Remove unwanted material from blood, fluids, and gases
- Arterial line filters remove:
  - gross air
  - gaseous microemboli
  - particulate microemboli
- Gas line filters remove:
  - water
  - bacteria
- Pre-bypass filters remove:
  - particulate microemboli

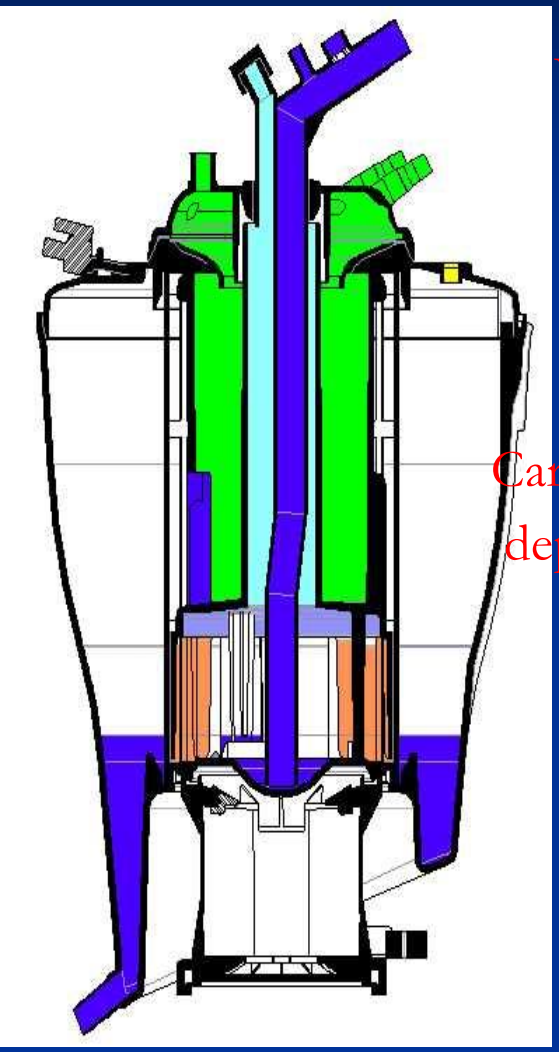
Cardiovascular System - Physiology and Pathology

Oxygenator

Disposable device for the lung replacement

Pediatric Oxygenators

CARDIOTOMY/ VENOUS RESERVOIR



Venous Inlet

Cardiotomy Inlets

Cardiotomy Filter
depth filter ~ 40μ

Venous Filter ~ 120μ

Venous drainage can be accomplished by

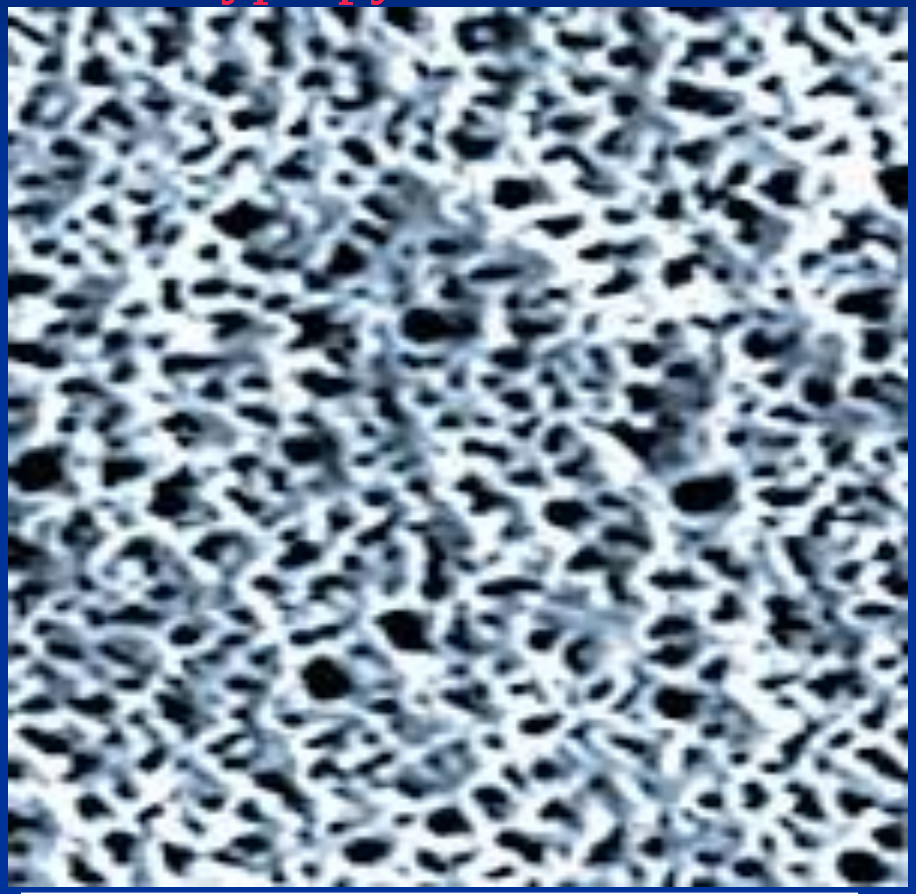
1. Gravity Drainage
2. Kinetic Assisted Venous Return (KAVR)
3. Vacuum Assisted Venous Return (VAVR)

Cardiovascular System - Physiology and Pathology

Oxygenator

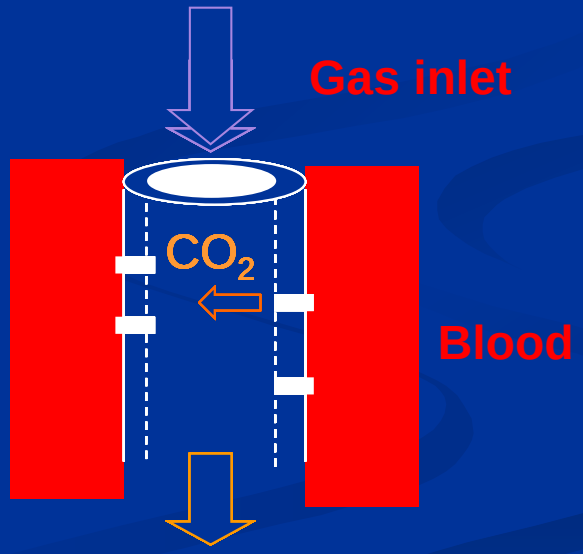
Microporous Membranes

Polypropylene Membrane



FIBER WALL:	30μm
INTERNAL DIAMETER:	150 – 240μm
AVERAGE MICROPORE SIZE	0.3 μm

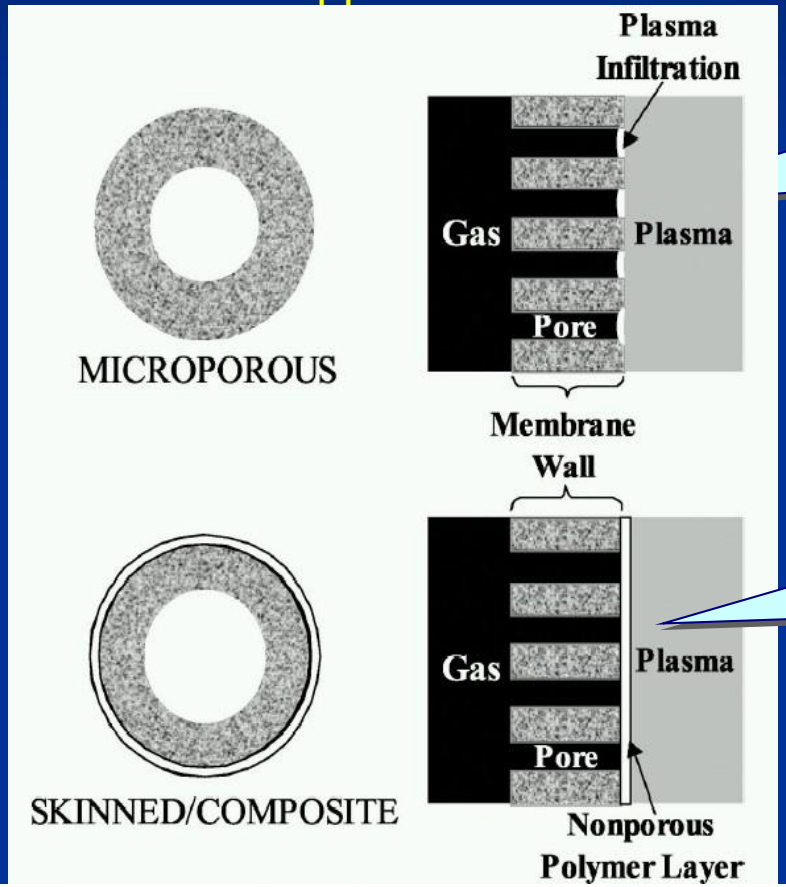
Function: mimetic alveoli surface



Hollow Fiber basic structure
Polypropylene and Polymethylpentene HF

OUTER SURFACE

Short term application



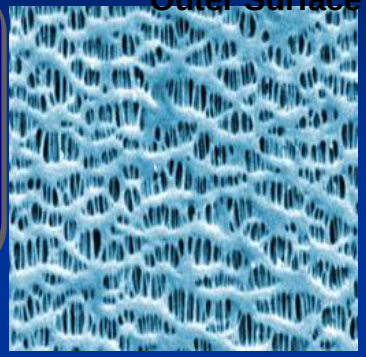
Polypropylene fibres:

Gas is in contact with blood through microporous hollow fibres.

Gas transfer is obtained by **direct contact** .

SEM images

Outer Surface

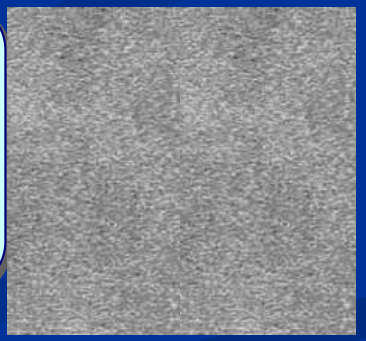


POLYPROPYLENE
"standard" fibre

Polymethylpentene fibres:

Hollow fibres are protected by a thin outer layer.

Gas transfer is obtained by gas **diffusion** through this thin layer

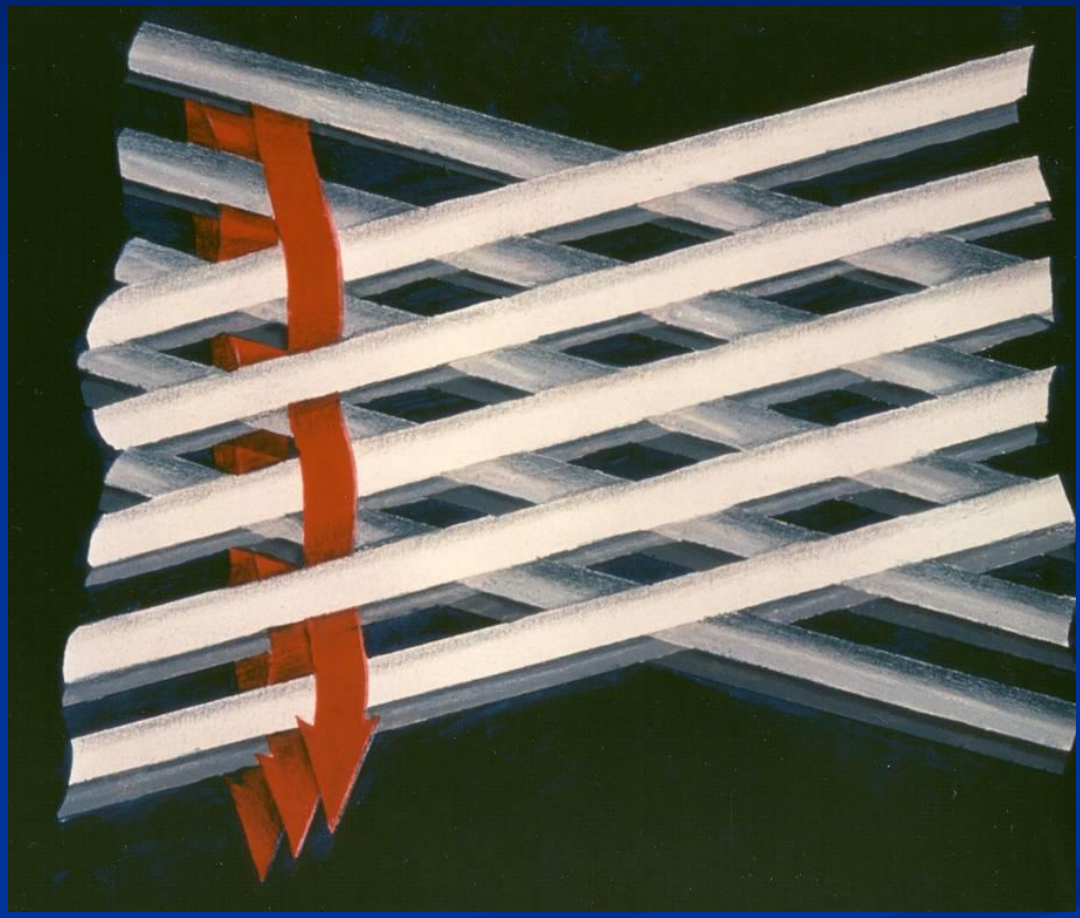


POLYMETHYLPENTENE
"plasma-tight" fibre

Long term application

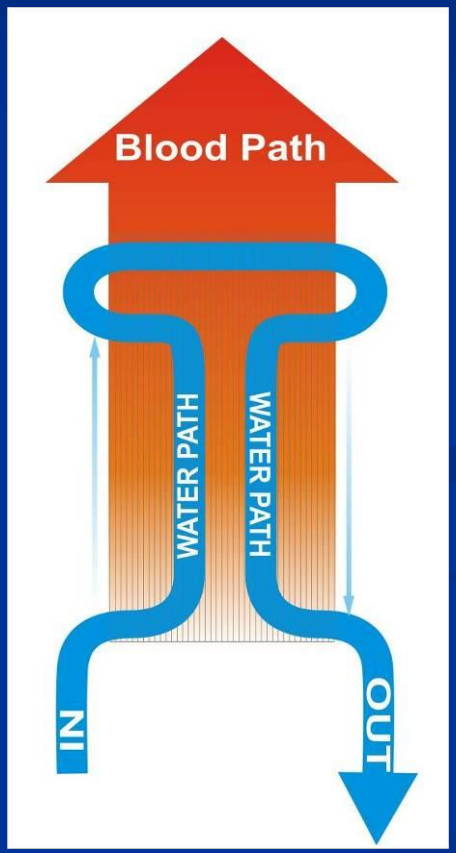
The criss-cross HF mat structure

- **Hollow Fibers** are arranged in woven mats in a precise geometrical configuration.
- Mats are then superposed alternatively at an angle, in order to maximize gas transfer and to reduce excessive obstruction to blood flow.



Blood flows outside the fibers

Cardiovascular System - Physiology and Pathology
Heat Exchange



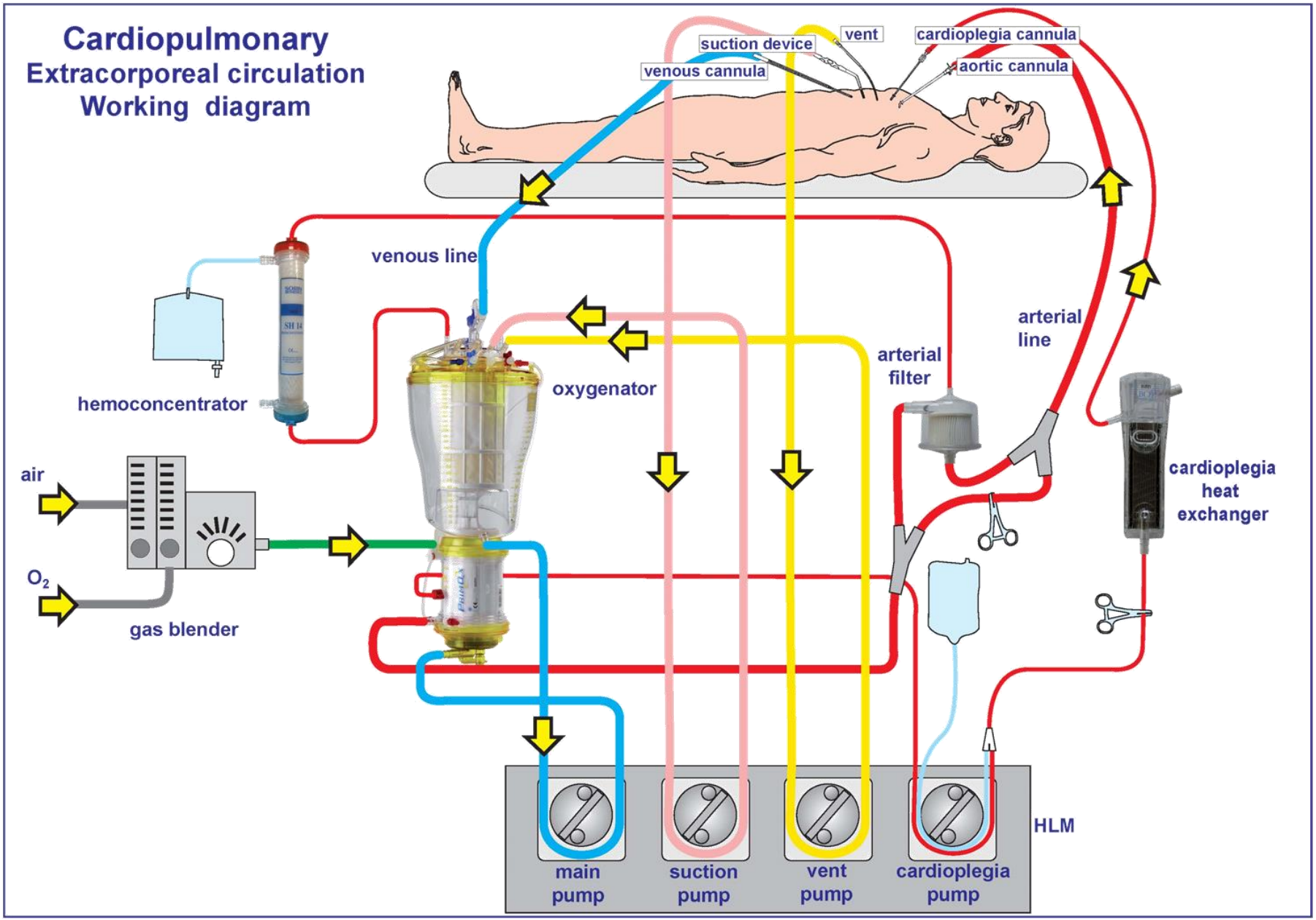
HEAT TRANSFER COEFFICIENT η (Eta) @ VARIOUS BLOOD FLOWS AND SPONTANEOUS WATER FLOW*

$$\eta = \frac{Tbo - Tbi}{Twi - Tbi}$$

Tbo = Blood Inlet Temp.
Twi = Water Inlet Temp.

- 50% COUNTERCURRENT WATER PATH
- REVERSIBLE WATER IN-OUT

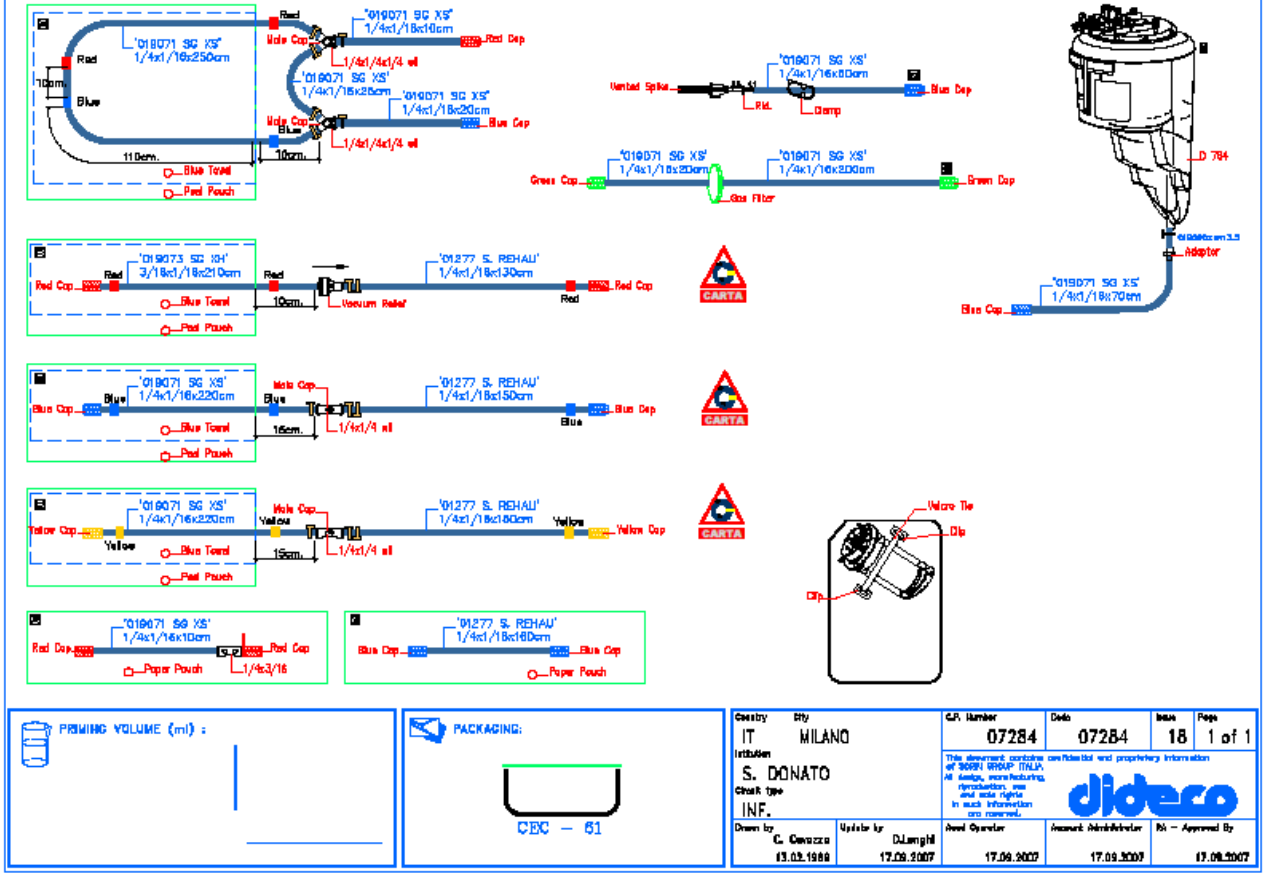
Cardiopulmonary
Extracorporeal circulation
Working diagram



Cardiovascular System - Physiology and Pathology

Circuits

Circuit Drawing



Set up and Priming

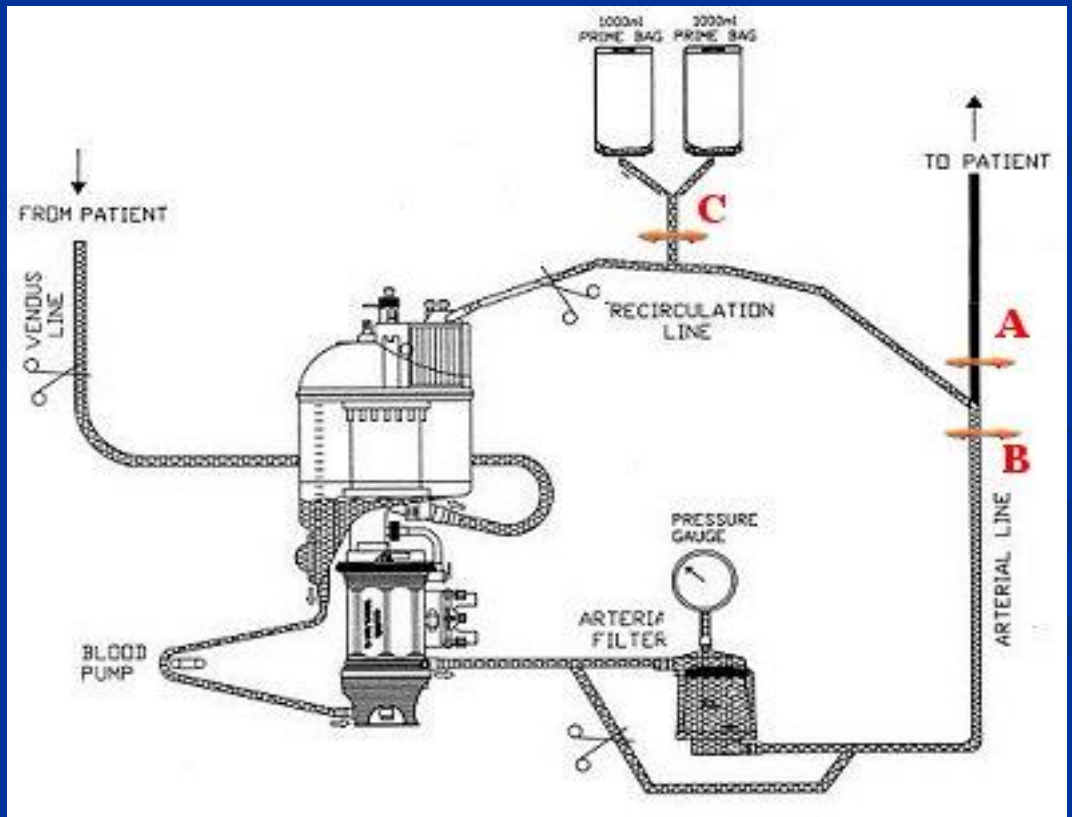
- After the set up of the Oxygenator and the perfusion tubing system it is necessary to Prime the circuit
- The Priming is necessary to remove air bubble inside the circuit
- PRIME is a mixture composed by: Ringer, Normosol, Albumin, Blood… the solution must be ISOTONIC and ISOSMOTIC it must contain the same quantity of ions of salts as blood.

It is important to keep the prime volume as much lower as possible in order not to induce high hemodilution in the patient that could cause several physiological problems.

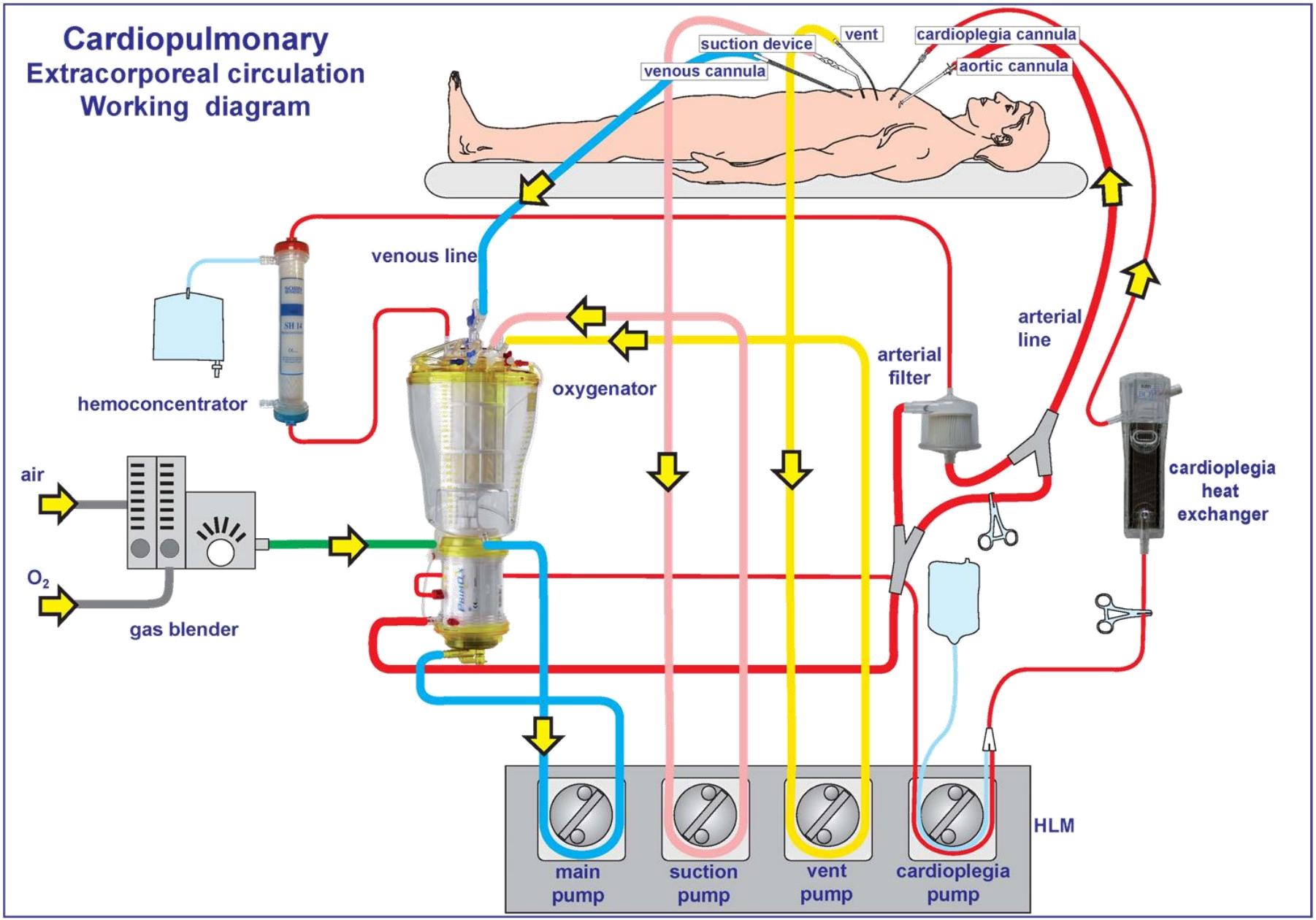
Cardiovascular System - Physiology and Pathology

RAP – Retrograde Autologous Priming

Reducing the degree of hemodilution and priming volumes have been demonstrated to be of great importance in the armamentarium of several surgical teams, in order to decrease bleeding and transfusion requirements. Autotransfusion, under several modalities have contributed to avoid the use of allogeneic blood and minimize hemodilution. A technique known as retrograde autologous priming is a variant of autotransfusion.



Cardiopulmonary
Extracorporeal circulation
Working diagram



What does Cardioplegia mean?

- *Kardia*: Heart
- *Plege*: Stroke

- Definition:
  - Paralysis of the heart, as may be done electively in stopping the heart during cardiac surgery.
  - Cardioplegia may be done using chemicals, cold (cryocardioplegia) or normothermic.

By the technicall point of view?

Technically this means arresting or stopping the heart so that surgical procedures can be done in a still and bloodless field. The heart is isolated from the rest of the blood circulation by means of an occlusive cross-clamp placed on the ascending aorta. Cardioplegia lowers the metabolic rate of the heart muscle thereby preventing cell death during the ischemic period.

Main goals of hypotermic cardioplegia

- Immediate and sustained electromechanical quiescence.
- Rapid and sustained homogenous myocardial cooling.
- Maintenance of therapeutic additives in effective concentrations.
- Periodic washout of metabolic inhibitors.

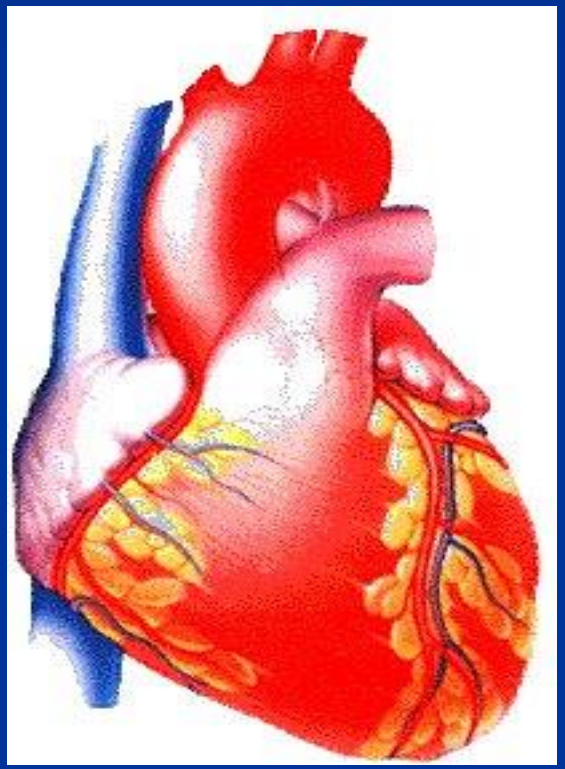
What makes up Cardioplegia?

- Calcium (Ca++) ion in low concentration is included in the solution to maintain integrity of cell membrane to ensure that there is no likelihood of calcium paradox during reperfusion.
- Magnesium (Mg++) ion may help stabilize the myocardial membrane by inhibiting a myosin phosphorylase, which protects adenosine triphosphate (ATP) reserves for post-ischemic activity. The protective effects of magnesium and potassium have been shown to be additive.
- Potassium (K+) ion concentration is responsible for prompt cessation of mechanical myocardial contractile activity. The immediacy of the arrest thus preserves energy supplies for post-ischemic contractile activity in diastole.
- The chloride (Cl-) and sodium (Na+) ions have no specific role in the production of cardiac arrest. Sodium is essential to maintain ionic integrity of myocardial tissue. The chloride ions are present to maintain the electroneutrality of the solution.
- Added bicarbonate (HCO3-) anion is included as a buffer to provide the solution slightly alkaline and compensate for the metabolic acidosis that accompanies ischemia.

Cardiovascular System - Physiology and Pathology

Cardioplegia

1. HYPOTHERMIA-NORMOTHERMIA
2. CHEMICAL ARREST
3. MYOCARDIAL PROTECTION



- **Mechanical arrest (K – induced, 80% reduction in O2 consumption)**
- **Hypotermia (10-15% further reduction in O2 consumption)**
- **When solution is introduced into the aortic root this is called antegrade cardioplegia. When introduced into the coronary sinus it is called retrograde cardioplegia.**
- **Maintain hypotermic arrest with re-administration every 15-20 min**
- **LV RV protection**

Cardiovascular System - Physiology and Pathology

Cardioplegia

CRISTALLOID CARDIOPLEGIA

Blood Cardioplegia

COOLING COIL

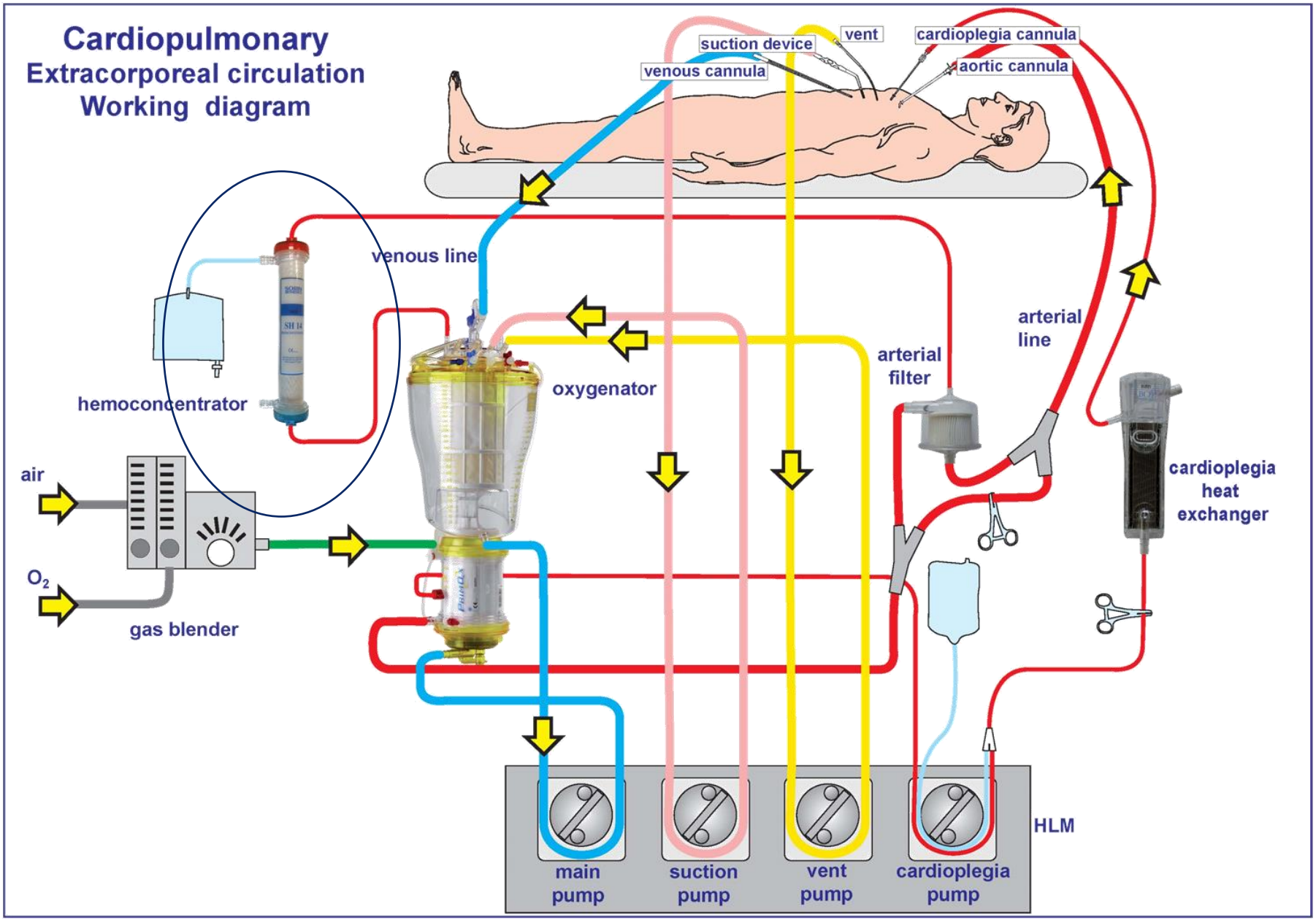
ONLY LINES / NO DEVICES

CSC 14

VANGUARD

In order to cool the cardioplegia mixture a heat exchanger is used.
Most heat exchangers work by passing the cardioplegia mixture close to cooled water or ice.

Cardiopulmonary
Extracorporeal circulation
Working diagram



Cardiovascular System - Physiology and Pathology
Hemoconcentration

Extra fluids in the circuit, may lead to a reduction of the HCT during bypass and a consequent increase of malfunction/morbidity related to organs (like kidney)

During and at the end of bypass the fluid in excess will be removed by stimulating natural diuresis and with the usage of the hemoconcentrator.

The hemoconcentrator is a dialysis filter with high capacity to remove fluids

Blood is flowing inside the fibers, fluid removal is due to the positive pressure inside the fibers.

The filter is able to remove small medium size molecules and to keep all blood proteins.

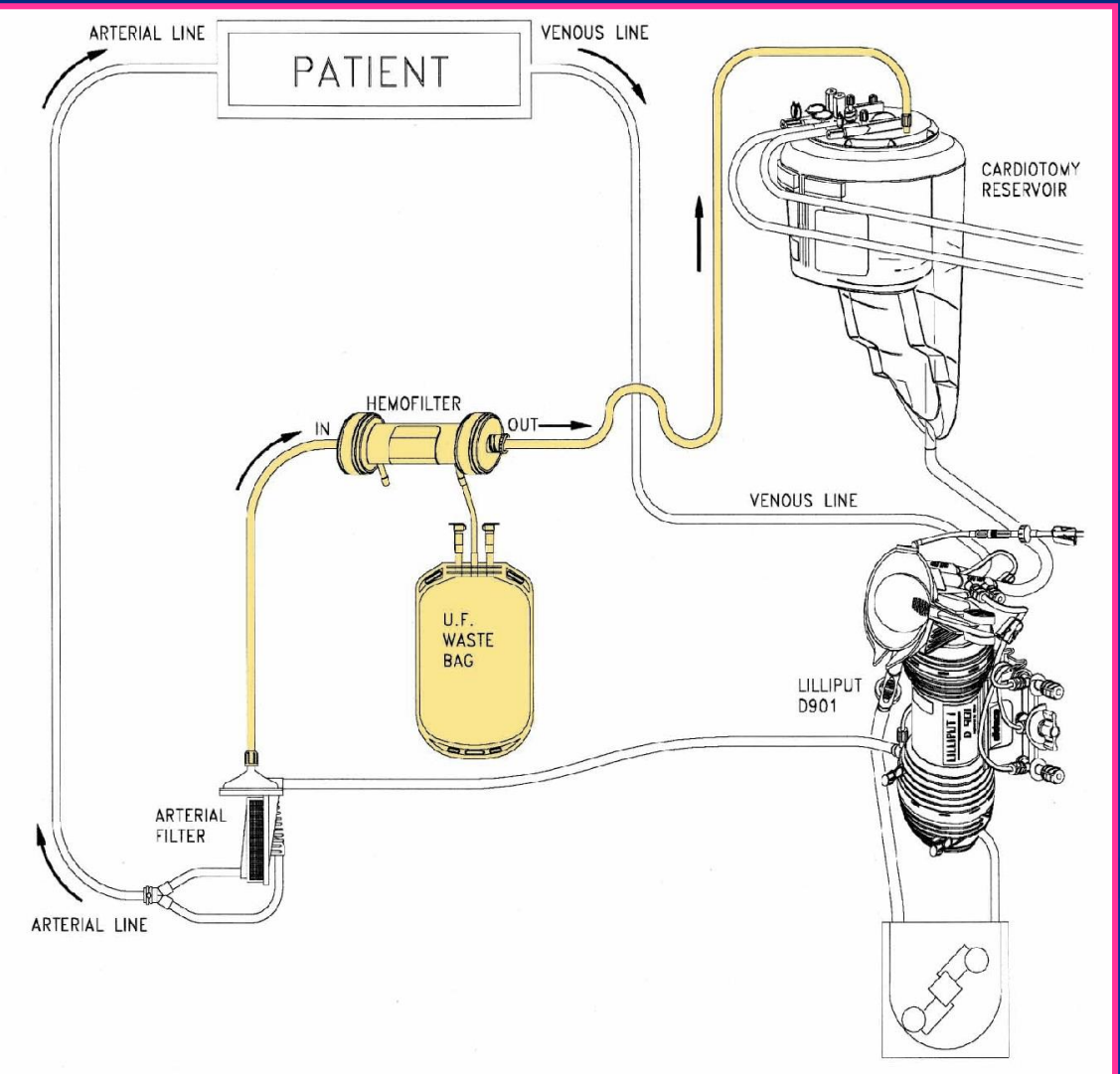
Hemofiltration is an extracorporeal therapy in which waste solutes or excess fluid are removed from blood by convection.

Cardiovascular System - Physiology and Pathology

Hemoconcentration

- The hemoconcentrator is part of the bypass circuit:
  - disposable device (single-use only)
  - used during and/or after the procedure to correct hematocrit
- Excess fluid from saline prime, cardioplegia solutions and drug administration causes hemodilution:
  - low hematocrit = low ratio of RBC to whole blood
  - need enough RBC concentration to keep oxygen levels high

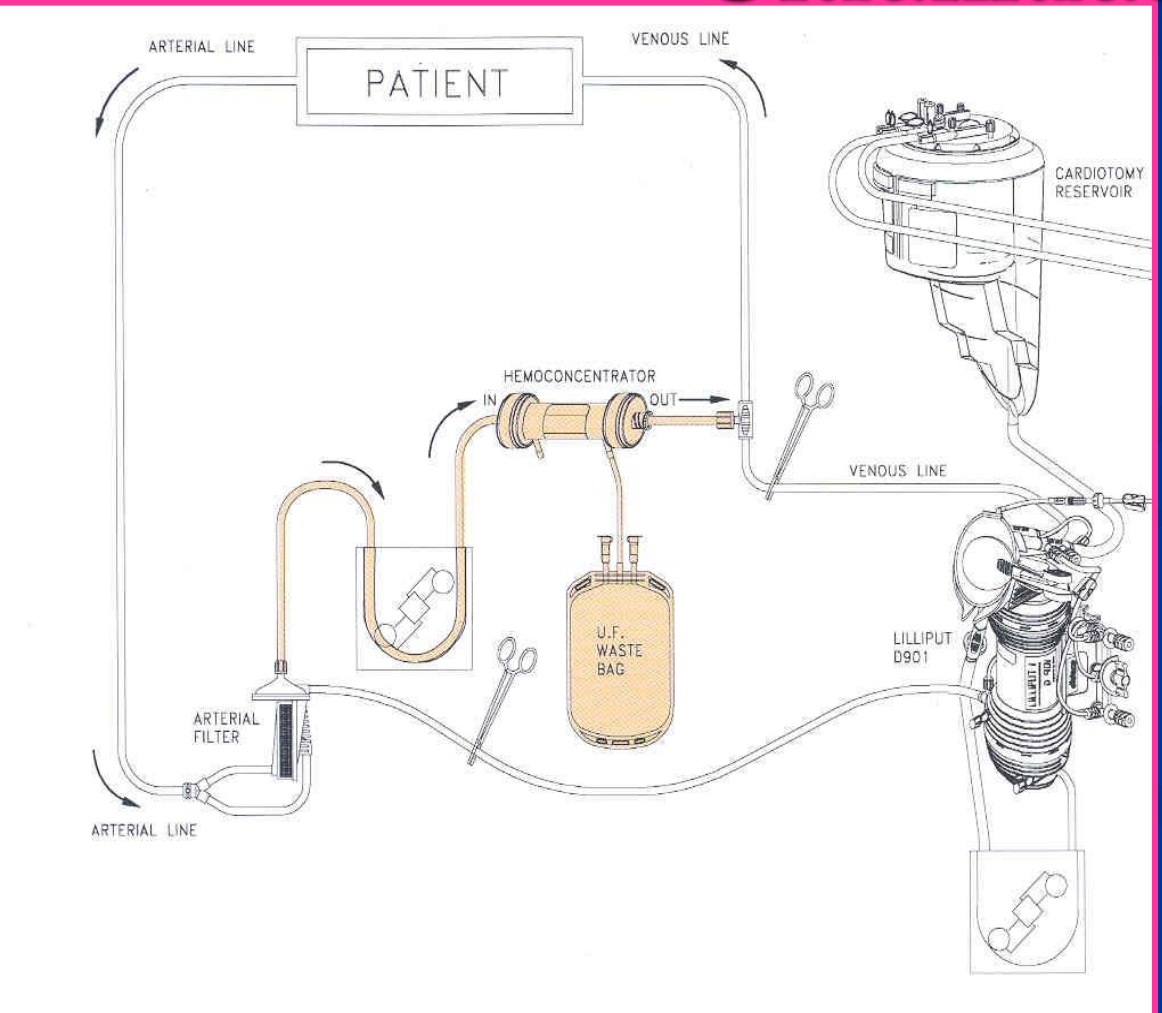
Hemoconcentration - Conventional Ultrafiltration



Conventional placement of the H. in the extracorporeal circulation circuit during cardiopulmonary by-pass and ultrafiltration . The Hemoconcentrator is placed with its inlet connected to the arterial line and outlet to the cardiotomy or to the venous reservoir.

Cardiovascular System - Physiology and Pathology

Hemoconcentration - Modified Ultrafiltration



The hemoconcentrator is placed with its inlet connected to the arterial line and outlet to the venous line. The pump tubing enclosed in the circuit allows the use of a roller pump to increase the blood flow through the hemoconcentrator

Cardiovascular System - Physiology and Pathology

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    3. Perfusion Tubing System
6. CPB Phases
7. ECMO

Cardiovascular System - Physiology and Pathology

CPB Phases

- Preparation of the Patient and Anaesthesia
- Opening the chest
- Cannulation
- Initiating CPB with HLM support
- Different Phases (cooling, circulatory arrest, rewarming)
- Coming off Bypass
- Closing

Cardiovascular System - Physiology and Pathology

CPB Phases

- Opening of the skin with a scalpel
- Opening of the sub skin
- Opening of the chest

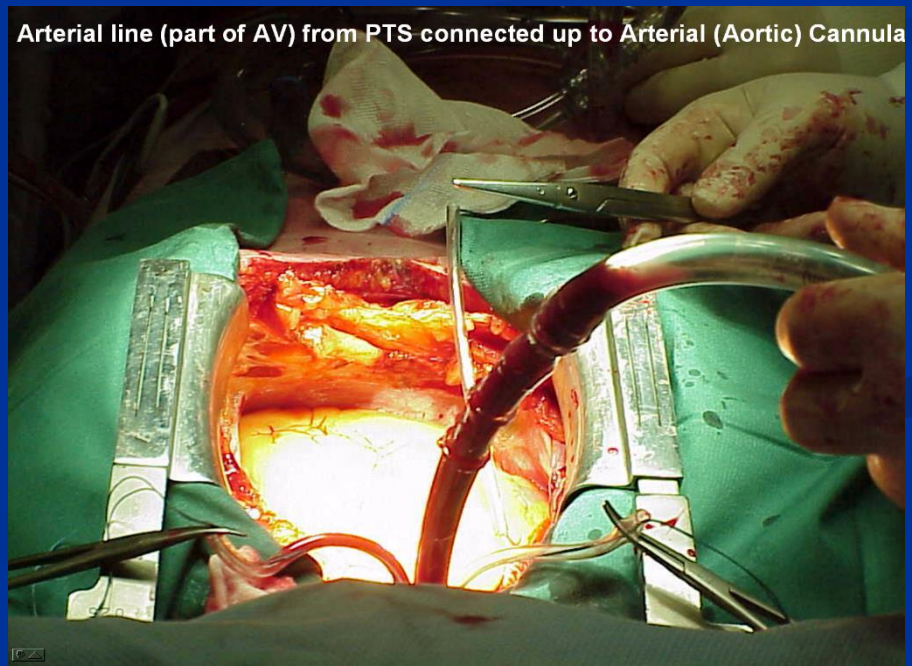
CPB Phases

- Start suction of the blood : once the chest is opened and heparin given a sucker cannula is used for removing the blood from the chest to keep it clean from blood

Cardiovascular System - Physiology and Pathology

CPB Phases

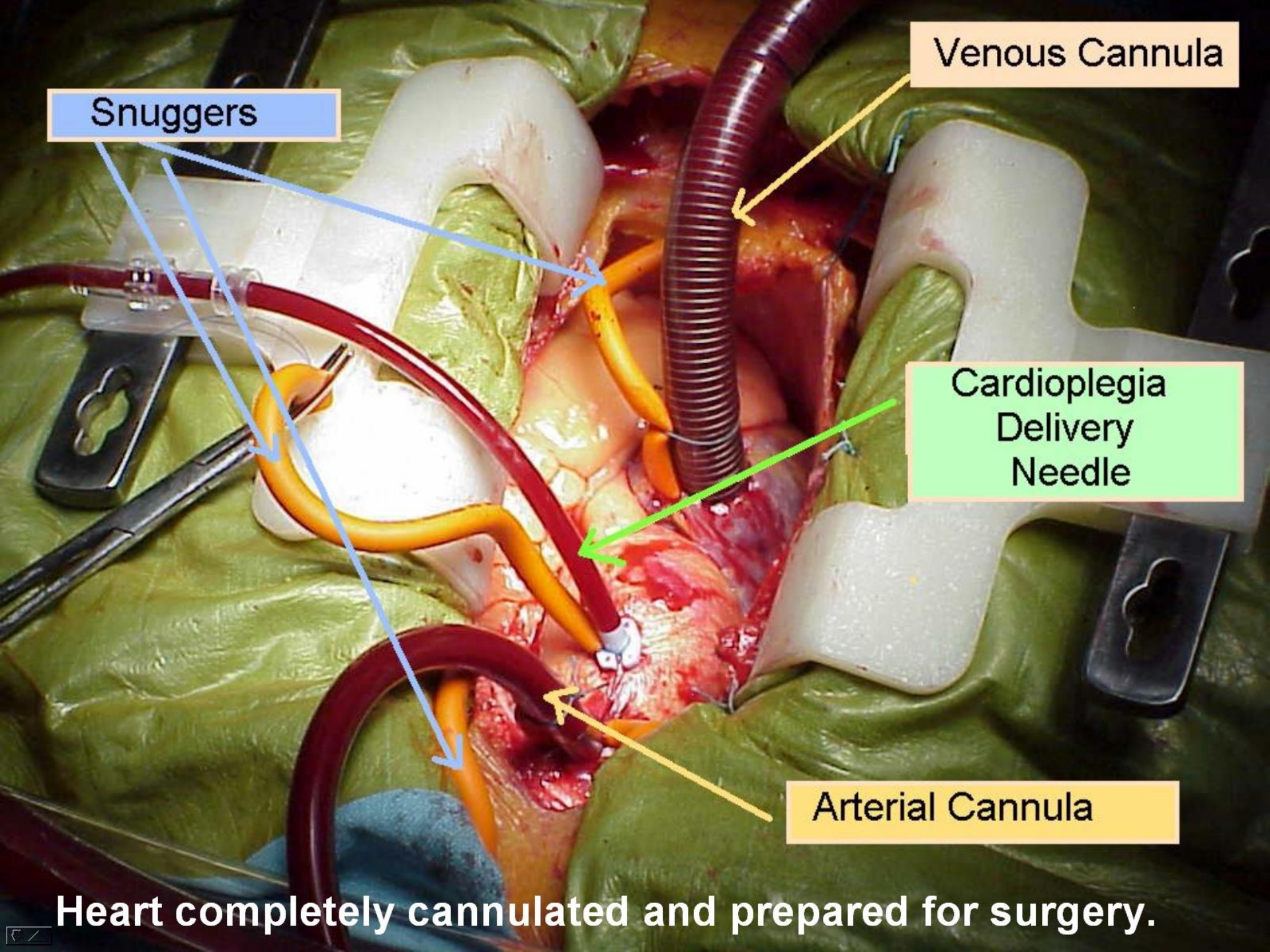
- Handover of the circuit : the perfusionist prepared the set of the HLM and send the table pack to the sterile field
- Cannulation phase: cannulation of the heart: the arterial and venous cannulation



CPB Phases

- Cardioplegia Cannula Insertion: the cardioplegia cannula is inserted in the aortic root if anterograde cardioplegia is done, in the coronary sinus if retrograde is performed

X-clamp and Cardioplegia Delivery: clamping of the aorta is the starting of the external circulation, the heart is isolated from the systemic circuit and cardioplegia is delivered in order to stop the heart beating



Heart completely cannulated and prepared for surgery.

Cardiovascular System - Physiology and Pathology

CPB Phases

- Vessel Harvesting: Wound in arm and leg from where vein is harvested for graft.
- Intervention is performed
- De- cannulation and closing of the chest.

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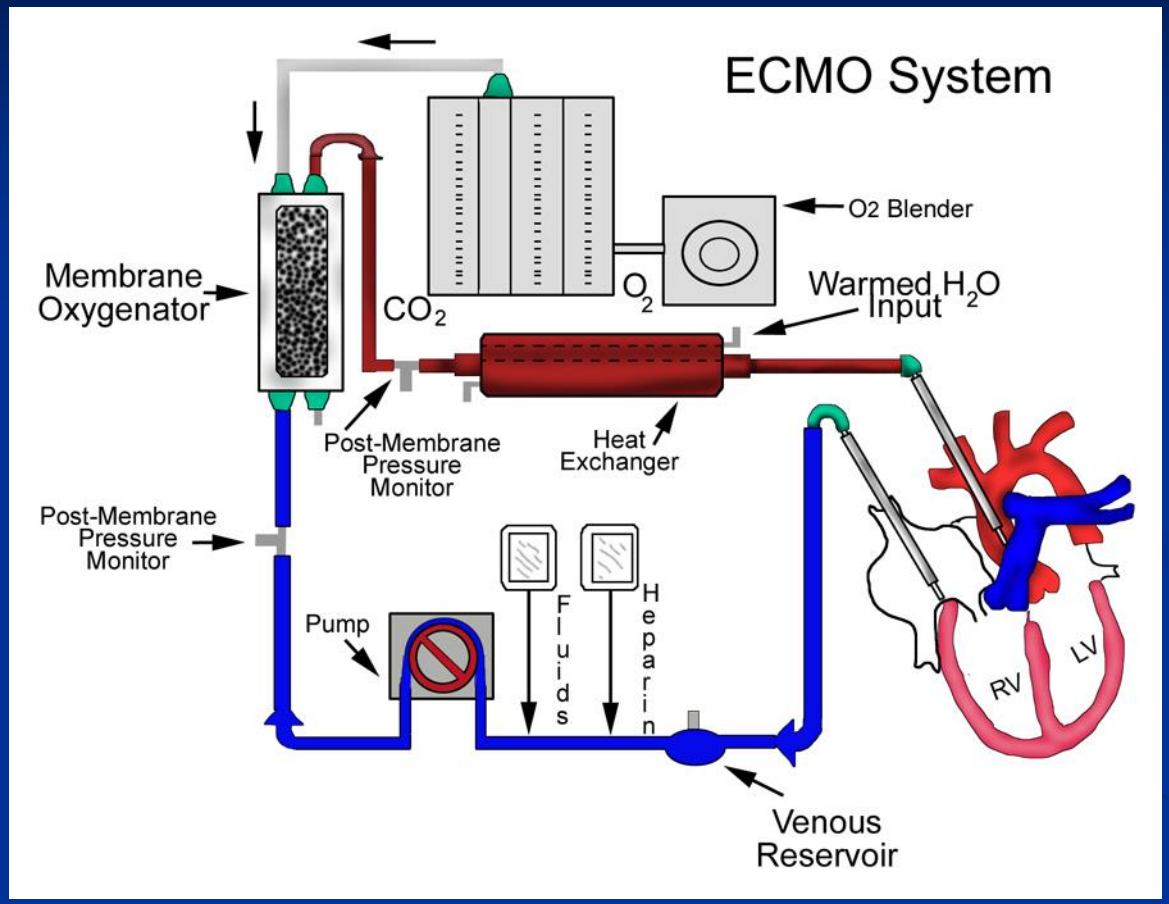
Cardiovascular System - Physiology and Pathology

ECMO (Extra Corporeal Membrane Oxygenation)

ECMO is a technique used to provide support to patients with severe but potentially reversible pulmonary and/or cardiac failure by using a modified heart lung machine, to take over the function of the heart and/or the cardiopulmonary system for a period up to 21 days

Cardiovascular System - Physiology and Pathology

ECMO ExtraCorporealMembraneOxygenation



Venous - Venous cannulation: no cardiac support
Venous - Arterial cannulation: cardiac support

Cardiovascular System - Physiology and Pathology

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