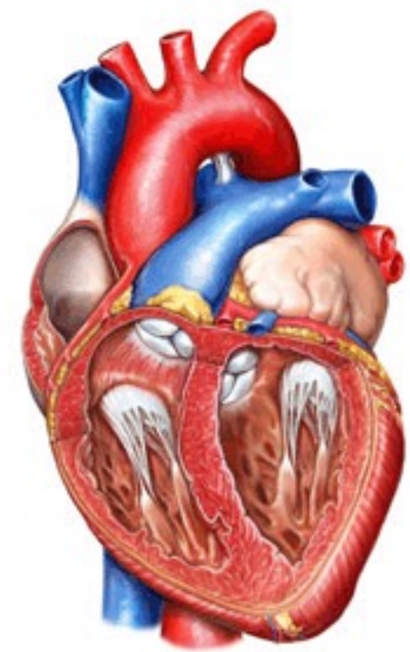
UiO : Department of Physics
University of Oslo

FYS 4250

Lecture 11



Case 11

- 45 years old female, farmer, single. Living alone, isolated farm with sheeps, cattle and some grain-growing activities. She has a history of two isolated incidents of epileptic seizures, had a tonsillectomy as a child but no other known medical incidents

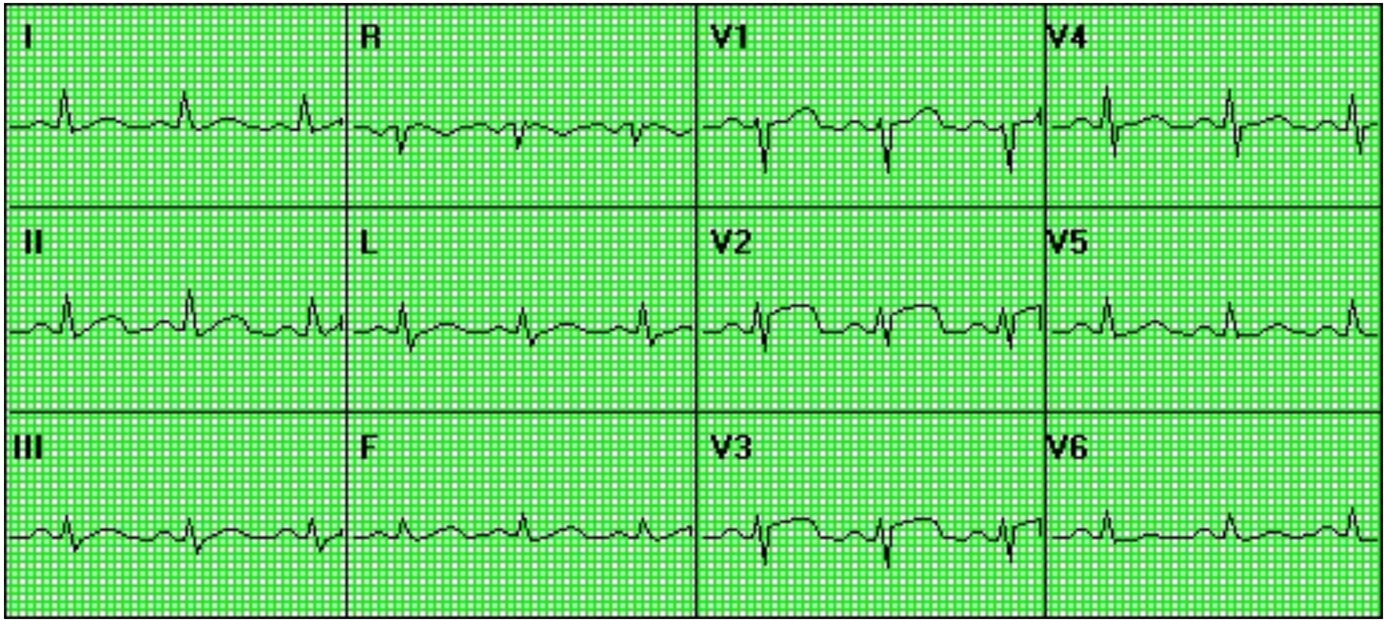
Case 11

- The patient complains about sickness, vomiting and a general feeling of discomfort. Her family doctor notes the consultation to be her first visit since 1998. The doctor prescribes pain killers, rest and admission of fluids for the next days to come.
- However, the patient returns the next day due to increased pain and dehydration. She is then admitted to hospital. At admission the patient has a healthy weight with a normal BMI = 21.5, she denies any signs of chest pain or shortness of breath, she is feverish and pale. Blood pressure is 135/80 mmHg (right arm) and 137/79 mmHg (left arm), this is not changing with position, heart rate = 84 bpm, no murmurs or pathological heart sounds, lungs and abdomen examinations are normal.

- What is the most likely diagnosis?

Case 11

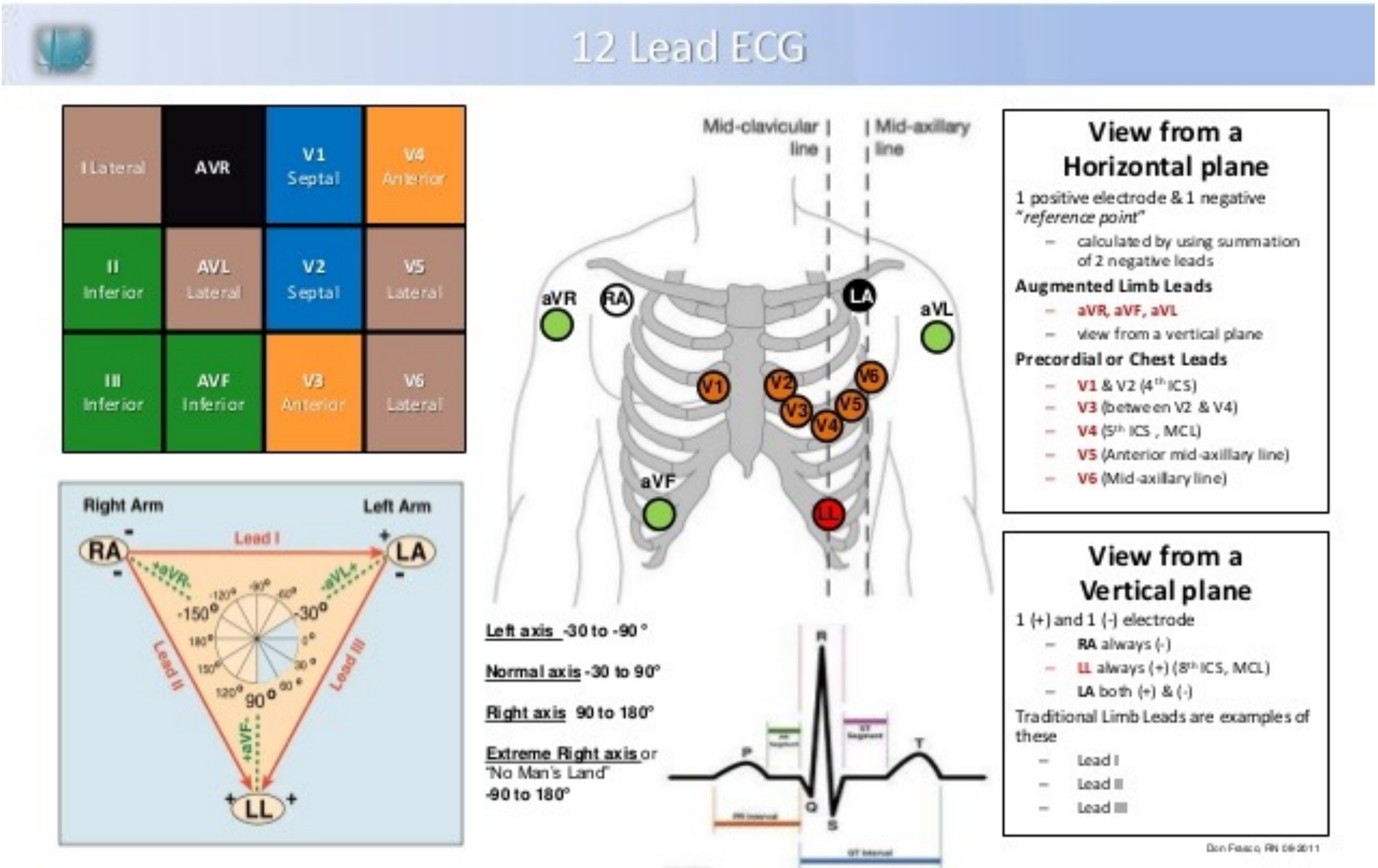
- After admission to hospital and maintained pain and vomiting, the doctors decides to take an ECG. After a 12-lead ECG, this looks like the chart below



http://www.madsci.com/manu/ekg_pics/mi_ant.gif

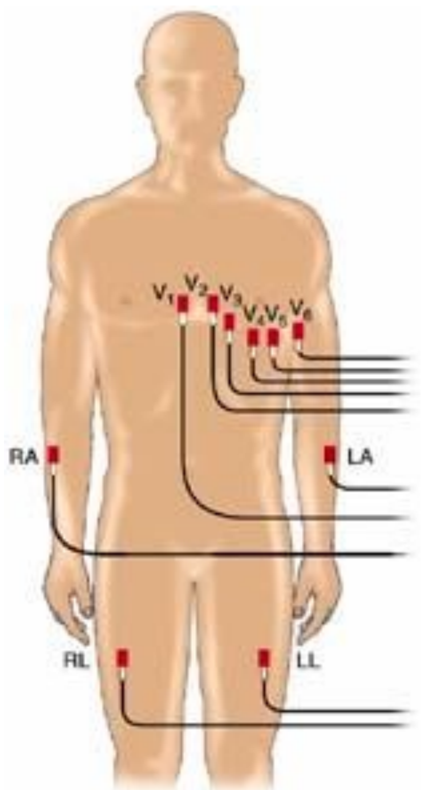
- What is now the most likely diagnosis?

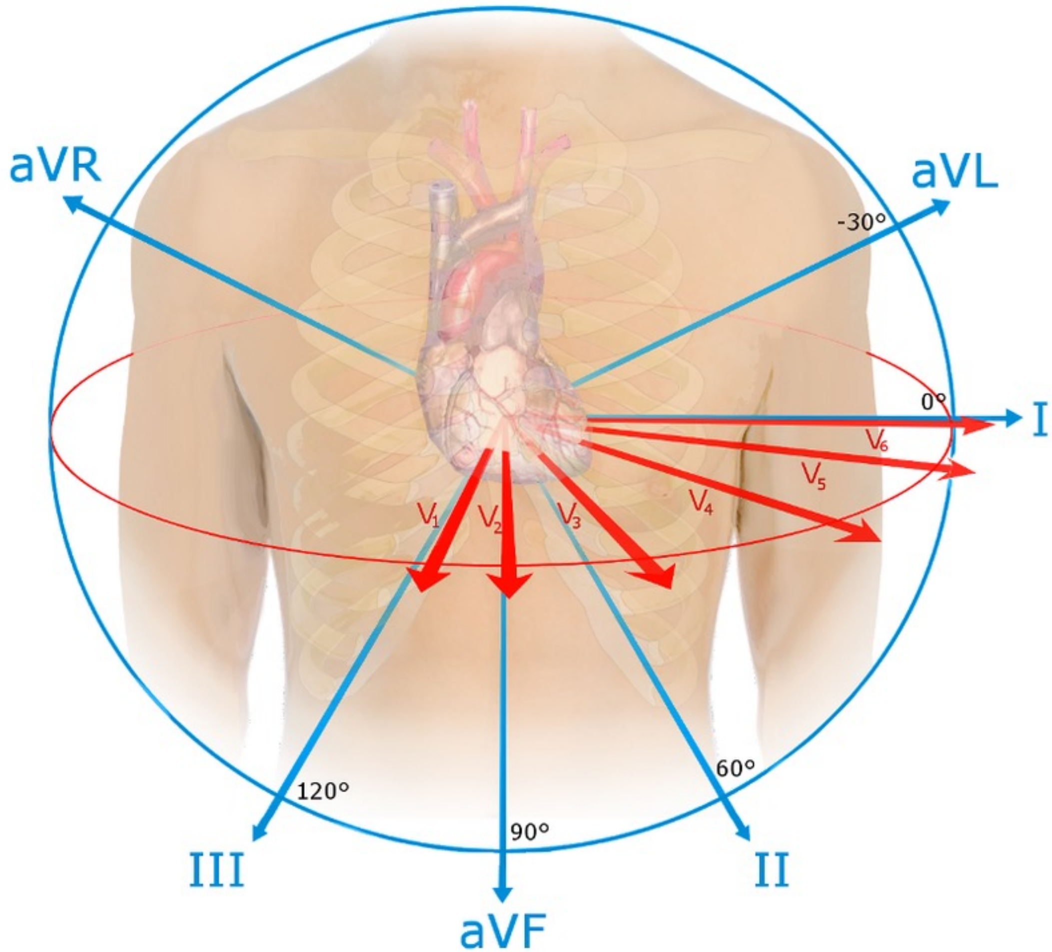
12-lead ECG



http://image.slidesharecdn.com/12-lead-ecg-hss-student-handout-ed-08-2011-2-121121182917-phpapp01/95/12-lead-handout-1-638.jpg?cb=1353522589

12-lead ECG

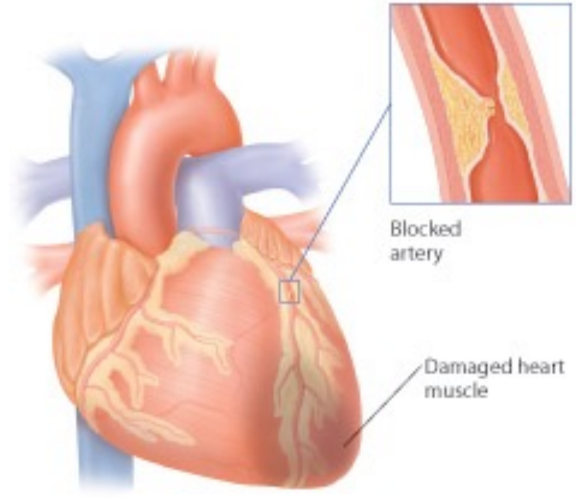




https://en.wikipedia.org/wiki/Electrocardiography#/media/File:Directions_of_EKG_leads.png

Heart infarction

- Myocardial infarction = blockage of the arteries supporting the heart with blood (Most people wait more than two hours after the onset of symptoms before they seek medical help. This delay might be fatal in worst cases, or may cause permanent damage to the heart)



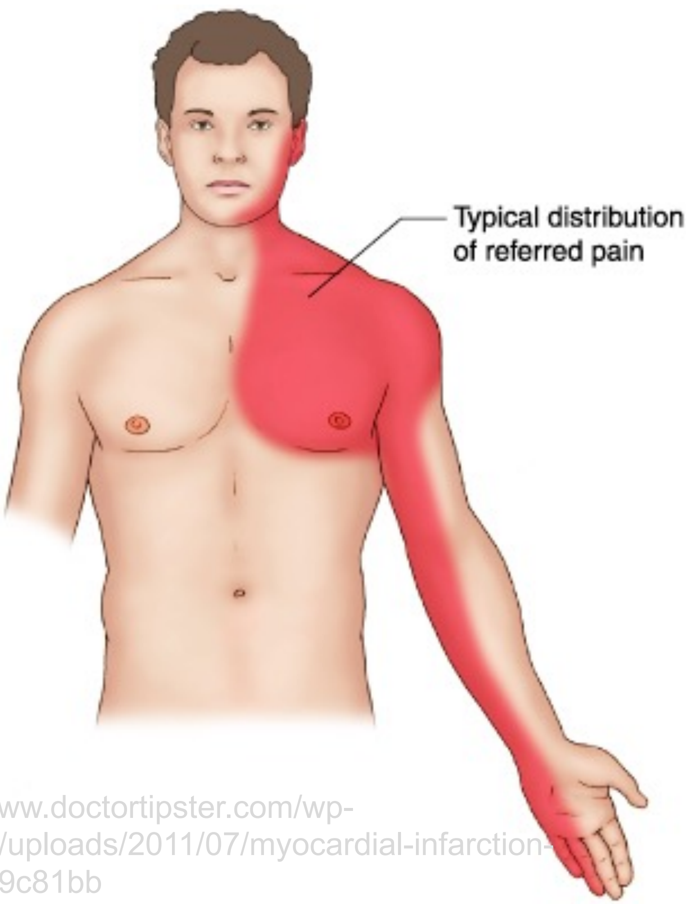
http://www.stonybrookheartcenter.org/images/uploaded/stonybrook/myocardial_infarction.jpg

Heart infarction

Main symptoms:

1. Pain in the jaw or shoulder
2. Sweating
3. Nausea
4. Shortness of breath
5. Indigestion or heartburn
6. Weakness or unusual fatigue

http://www.stonybrookheartcenter.org/Acute-Myocardial-Infarction.html



http://www.doctortipster.com/wp-content/uploads/2011/07/myocardial-infarction-31.jpg?9c81bb

- What to do now?

PCI

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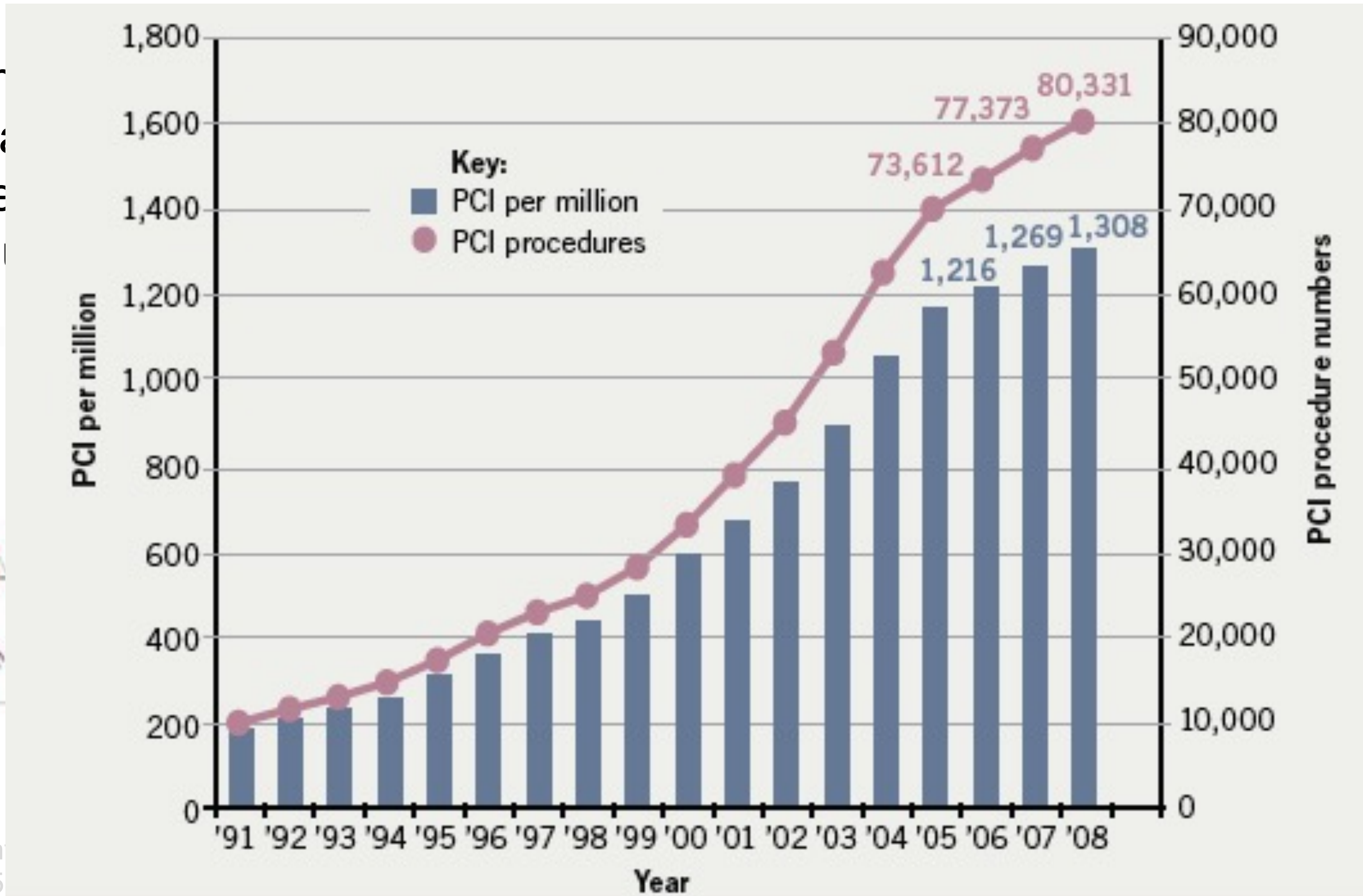

Data are audit returns data from BCIS[1] and are reproduced by kind permission of Dr Peter Ludman
Key: PCI=percutaneous coronary intervention

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5

/angiography

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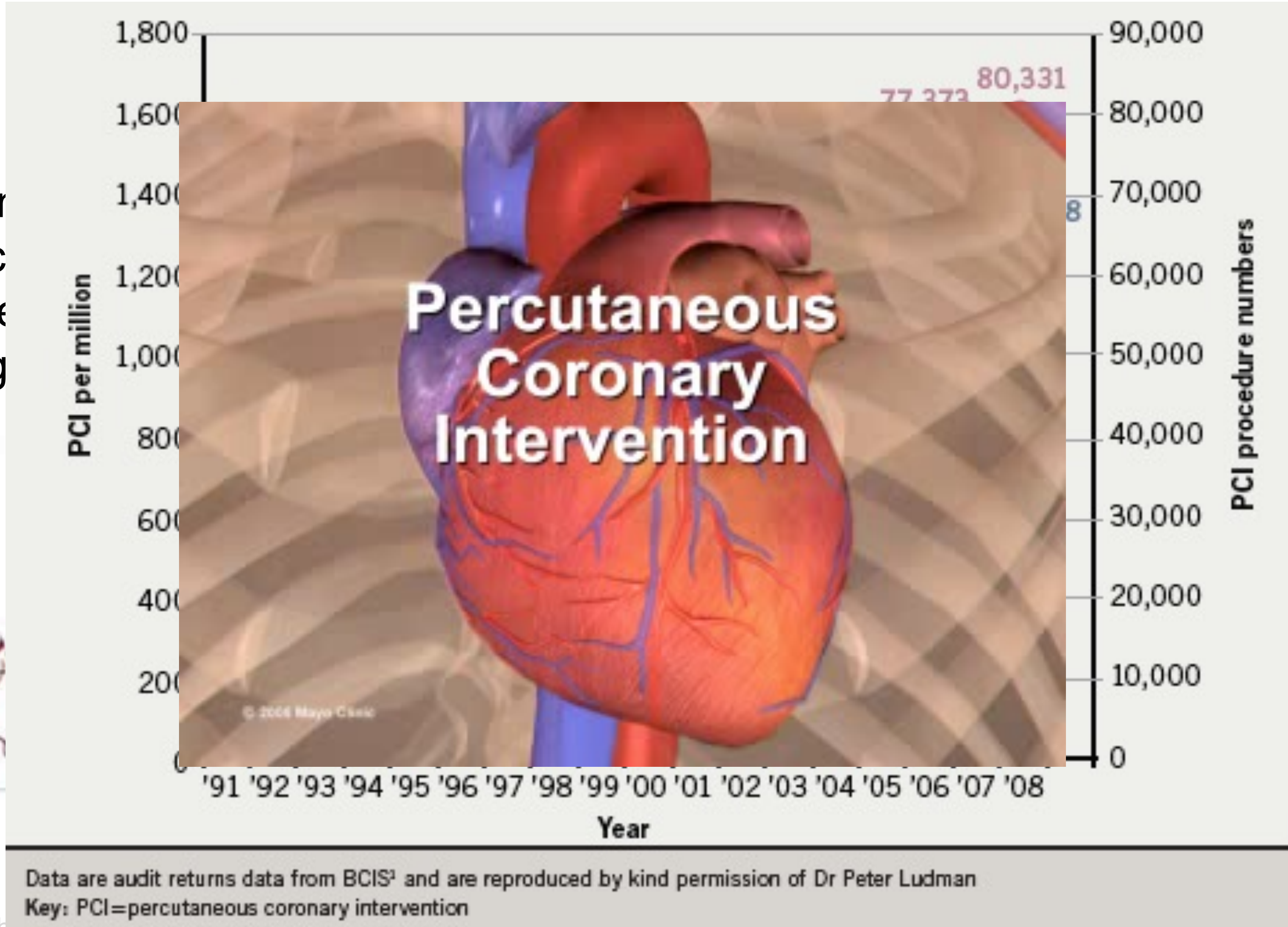


55551520_ma.jpg

http://www.yoursurgery.com/procedures/angiography
/images/FemAngioStent.jpg

Case 11

- The patient is now quickly recovering and is discharged on day four. Beta-blockers is prescribed in order to give the heart a soft recovery and protect it from a second heart attack. Everything seems under control until day 7 when the patient falls to the ground in the local supermarket. Cardiopulmonary resuscitation (CPR) is immediately initiated and defibrillator is connected to the patients chest with electrodes. However, the semi-automatic defibrillator shows a relatively regular ECG-complex, even if there is signs of flutter and vigorous contractions of the left ventricle. No electroshock can be discharged from the defibrillator due to the detected heart activity.

- What is your diagnosis now?

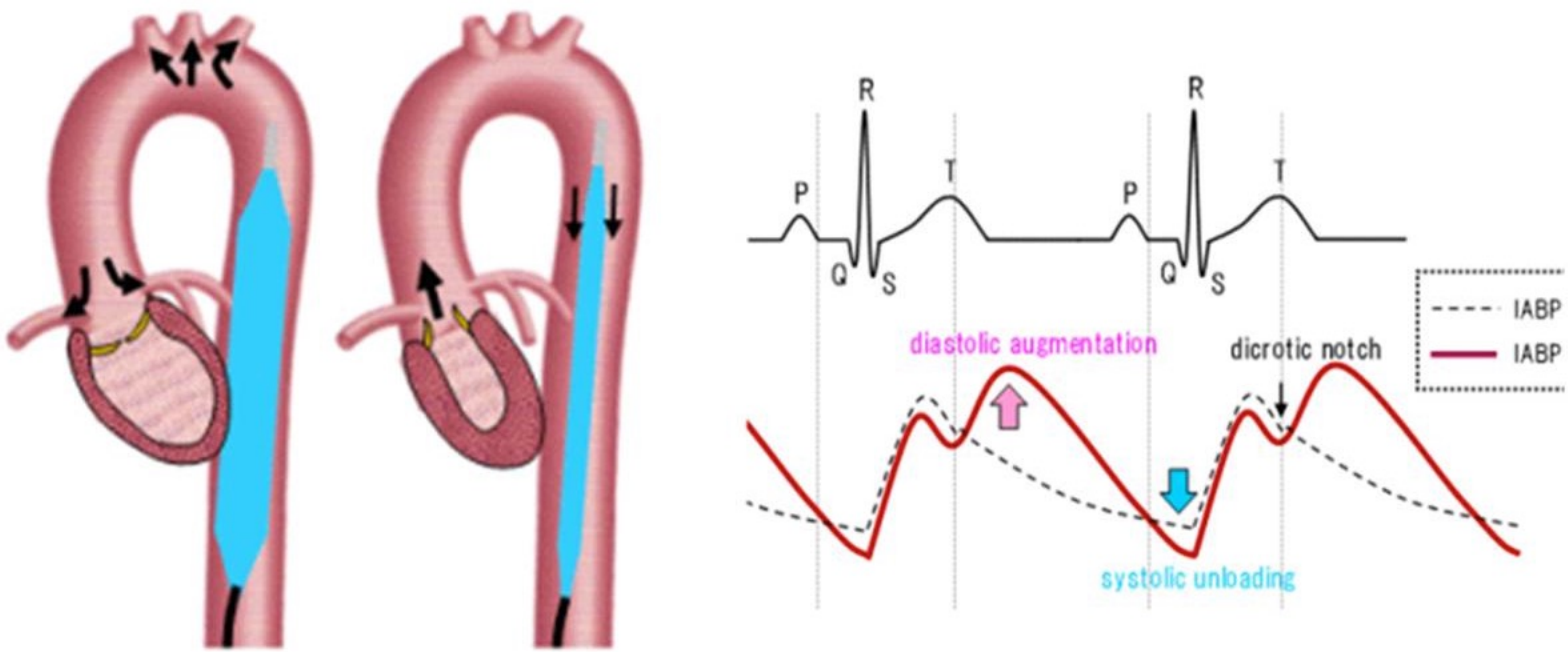
Case 11

- In the ambulance, a circulatory failure is diagnosed. Mechanical ventilation is initiated. The patient is then re-admitted to hospital, at the department of thoracic surgery. An ultrasound flow measuring device (to be discussed later) shows that the Mitral-valve is defective, and the patient is scheduled for open-heart surgery. Meanwhile, the patient is equipped with an intra-arterial balloon pump.

http://i.huffpost.com/gen/3979420/thumbs/o-AMBULANCE-570.jpg?7

IABP

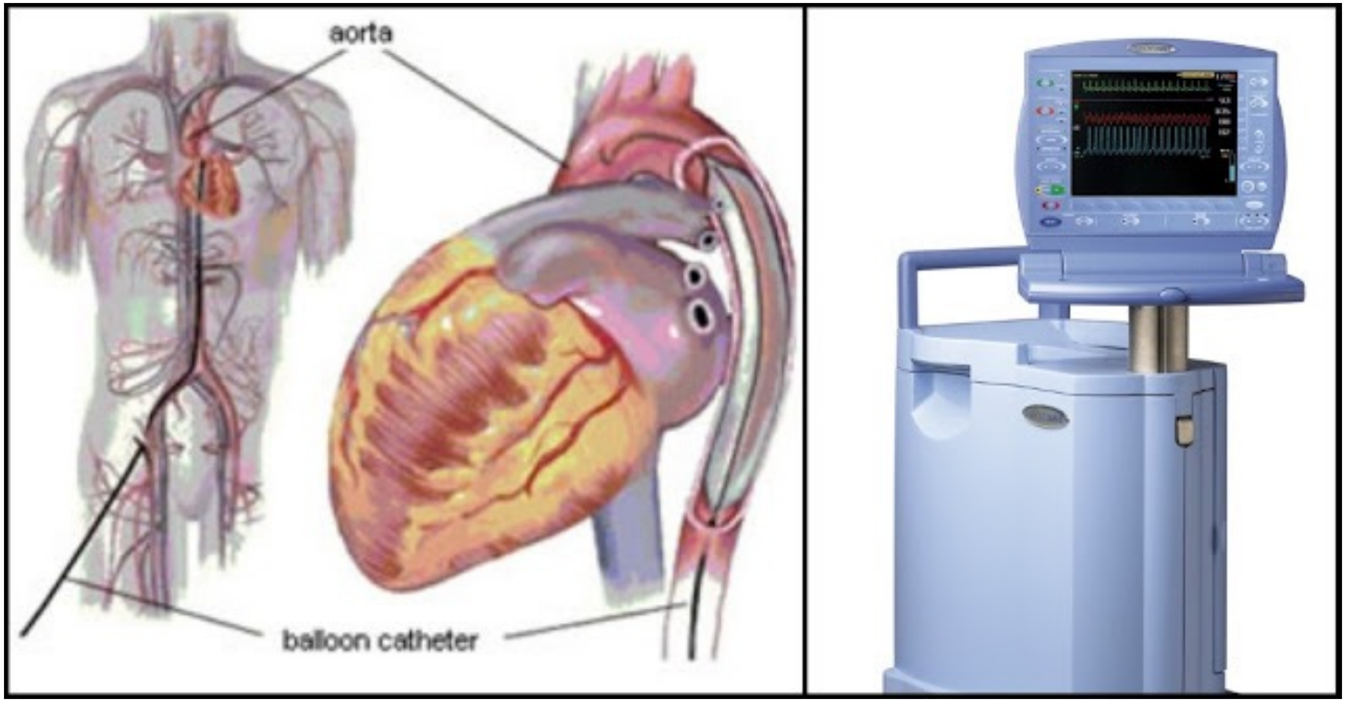
- IABP, intra arterial balloon pump.



Picture courtesey : http://www.eonet.ne.jp/~hidarite/ce/sinpai06.html

IABP

- The main purposes of the IABP:
  - To increase cardiac output
  - To increase myocardial perfusion



http://3.bp.blogspot.com/-Kdkdk9AV2S8/TaMVi0DPsBI/AAAAAAAAAtk/Wde4h-s9mFo/s640/Picnik+collage+iabp.jpg

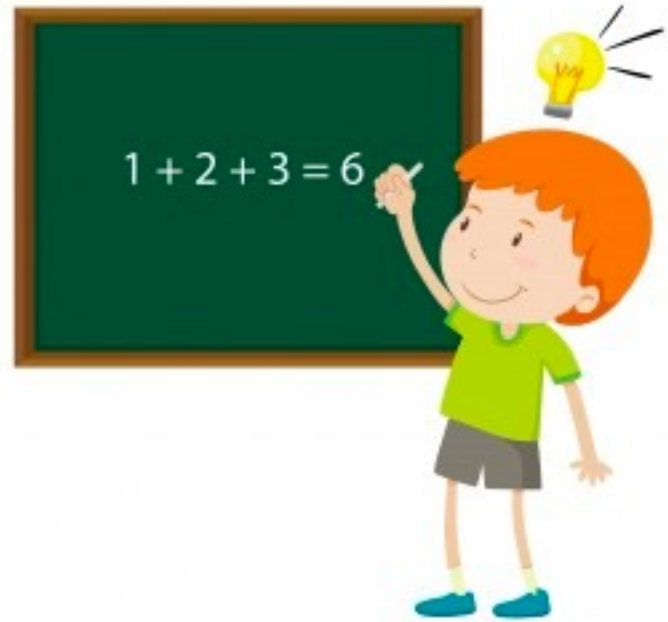
Exercise

Form groups of 2 or 3 students, and discuss:

a. What are the main risk factors with the IABP-technology?

http://integrativeosteopathy.com.au/wp-content/uploads/2015/08/Exercise.jpg

Answers



a. Asynchronous inflation
- Balloon puncture
- Balloon size
- Catheterization risks; infections, bleeding, ++
- Wrong position of the balloon
- Thrombosis, clotting
- ++

What if we need to replace the heart for a short period of time? (= Cardiopulmonary bypass)

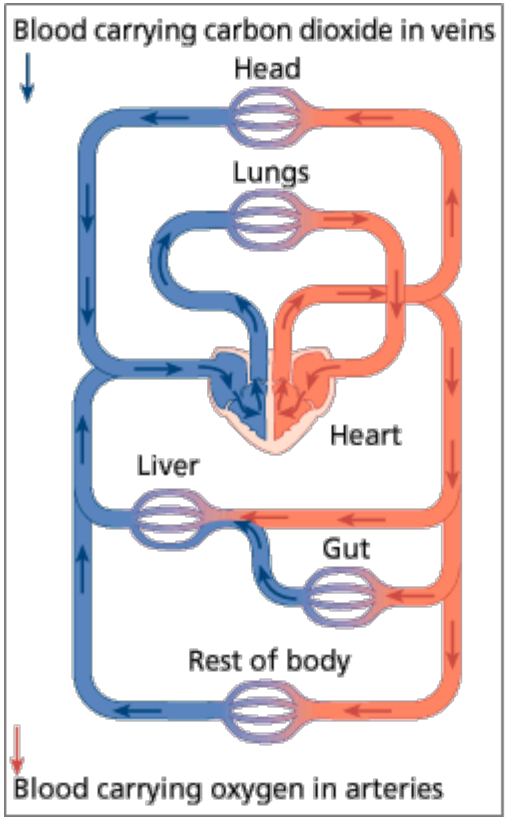
Cardiopulmonary bypass

What is necessary for a successful Cardiopulmonary Bypass? (CPB):

1. We need a basic understanding of the physiology of the circulation
2. A method to prevent blood from clotting
3. A blood pump for circulation
4. A way to exchange oxygen and carbon dioxide

http://3.bp.blogspot.com/-Kdkdk9AV2S8/TaMVi0DPsBI/AAAAAAAAAtk/Wde4h-s9mFo/s640/Picnik+collage+iabp.jpg

1. Basic physiology of circulation



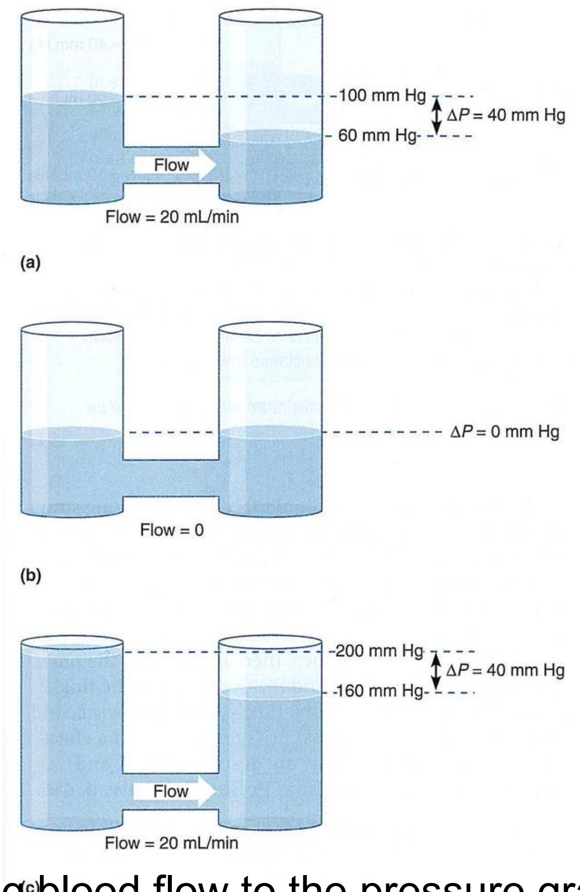
http://scienceblogs.com/clock/2006/06/bio101_lecture_7_physiology_co_1.php

Very simplified:

Arterial system: High pressure, carrying oxygen

Venous system: Low pressure, carrying carbon dioxide

1. Basic physiology of circulation



Germann WJ, Stanfield CL. Principles of Human Physiology, second edition.

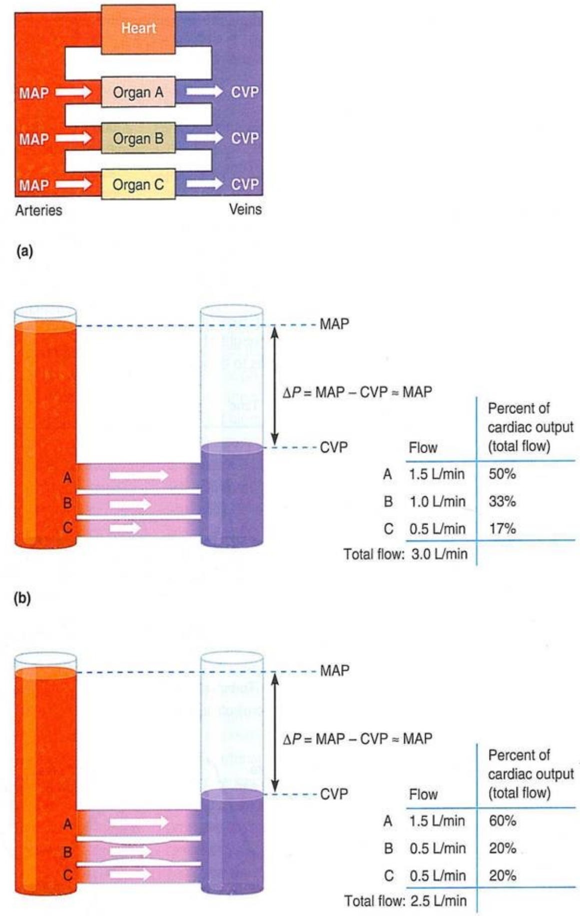
A model relating blood flow to the pressure gradient.

A single blood vessel is represented by a tube connecting two reservoirs. This shows that the pressure gradient, not the absolute pressure, determines the flow

1. Basic physiology of circulation

Poiseuille's law:

$$R = \frac{8L\eta}{\pi r^4}$$

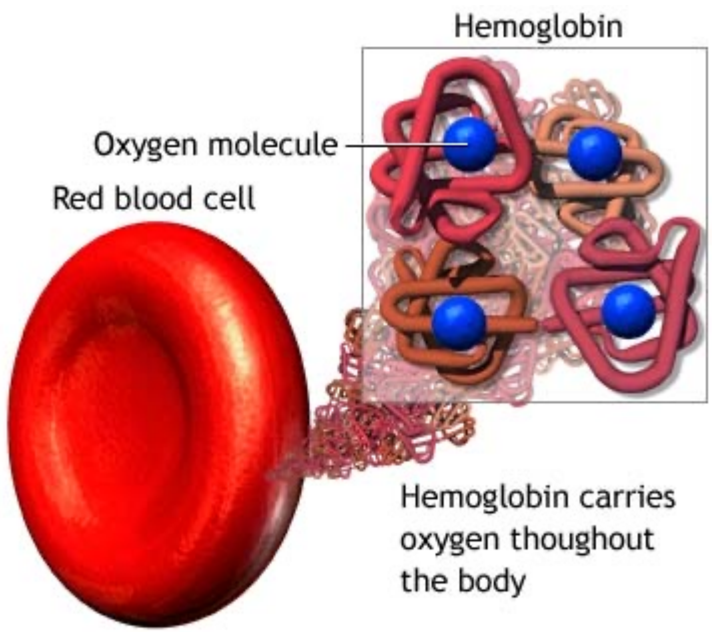


Germann WJ, Stanfield CL. Principles of Human Physiology, second edition.

The effects of pressure gradients and resistance on blood flow.

Given a constant Mean Arterial Pressure (MAP) and Central Venous Pressure (CVP) an increase in resistance in one organ results in a reduction of total flow and a change in distribution of blood flow

1. Basic physiology of circulation

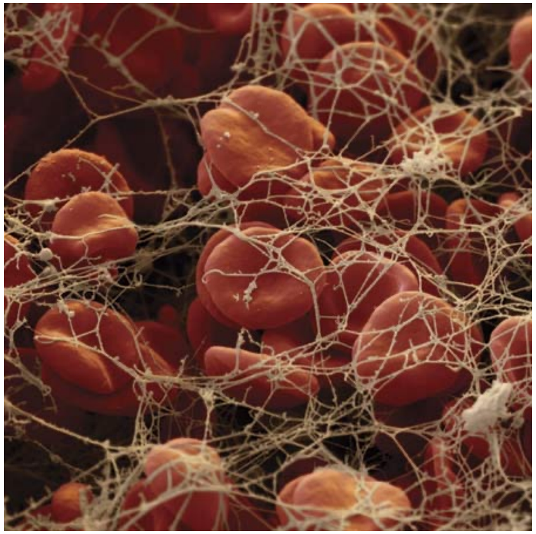


Germann J, Stanfild CL. Principles of Human Physiology, second edition.

http://www.dhmc.org/shared/adam/graphics/images/en/19443.jpg

Transport-system with several purposes: Transport of oxygen and carbon dioxide, delivery of blood sugar and removal of waste, temperature regulation, providing mechanisms for stoppage of bleeding and being an active part of the immune system

1. Basic physiology of circulation



Clotting

http://updatecenter.britannica.com/art?assemblyId=100538&type=A

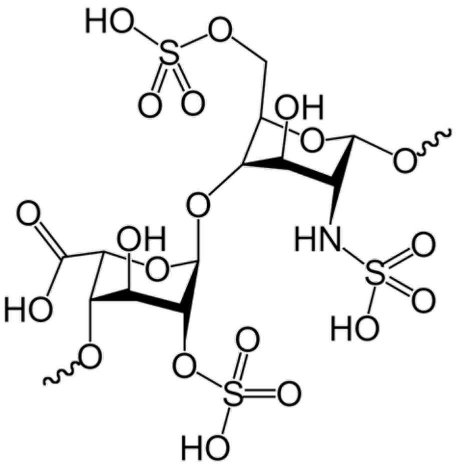
Hemolysis is a result of the breakdown of red blood cells, releasing free hemoglobin in the blood. This may result in a number of clinical incidents like kidney failure and liver complications.

Clotting is a process by which the blood forms solid clots as a result of coagulation of blood. This may lead to migration of the clot to other parts of the body where the clot may cause occlusion of blood vessels and tissue necrosis.

2. Prevent blood from clotting

Jay McLean, the discoverer of Heparin

http://www.oralchelation.net/heartdisease/ChapterEight/



Heparin

When whole blood is exposed to nonendothelialized surfaces, blood clotting will occur. Some kind of anticoagulant was needed to avoid clotting in a heart-assisting device.

1916 – Jay McLean discovered a powerful anticoagulant, Heparin.

Anti-coagulation

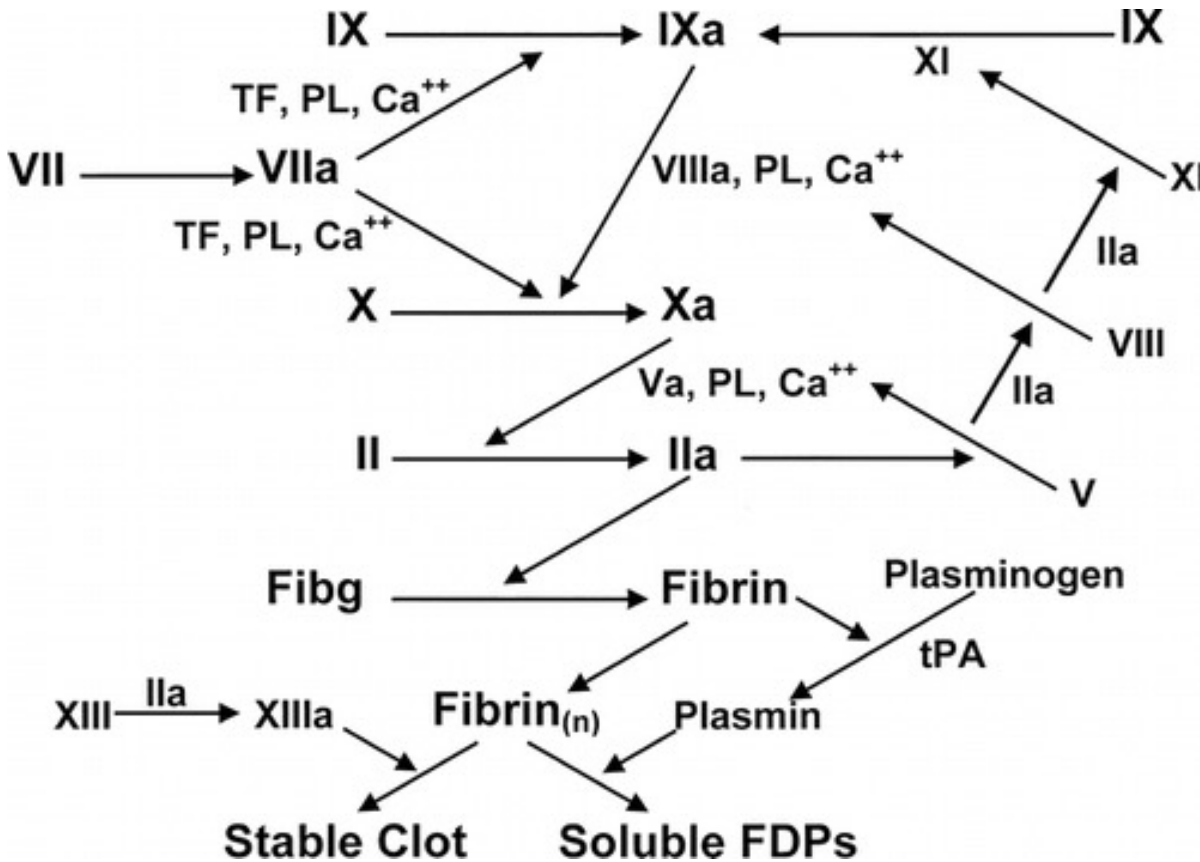
Heparin balancing

Bleeding Clotting

http://www.philgalfond.com/wp-content/uploads/ethics-scale-300x203.jpg

The plasma cascade system

Simplified version



http://www.archivesofpathology.org/na101/home/literatum/publisher/pinnacle/journals/content/arpa/2002/15432165-126.11/0003-9985%282002%29126%3C1376%3Apattpa%3E2.0.co%3B2/production/images/medium/i1543-2165-126-11-1376-f01.gif

Activated clotting time (ACT)

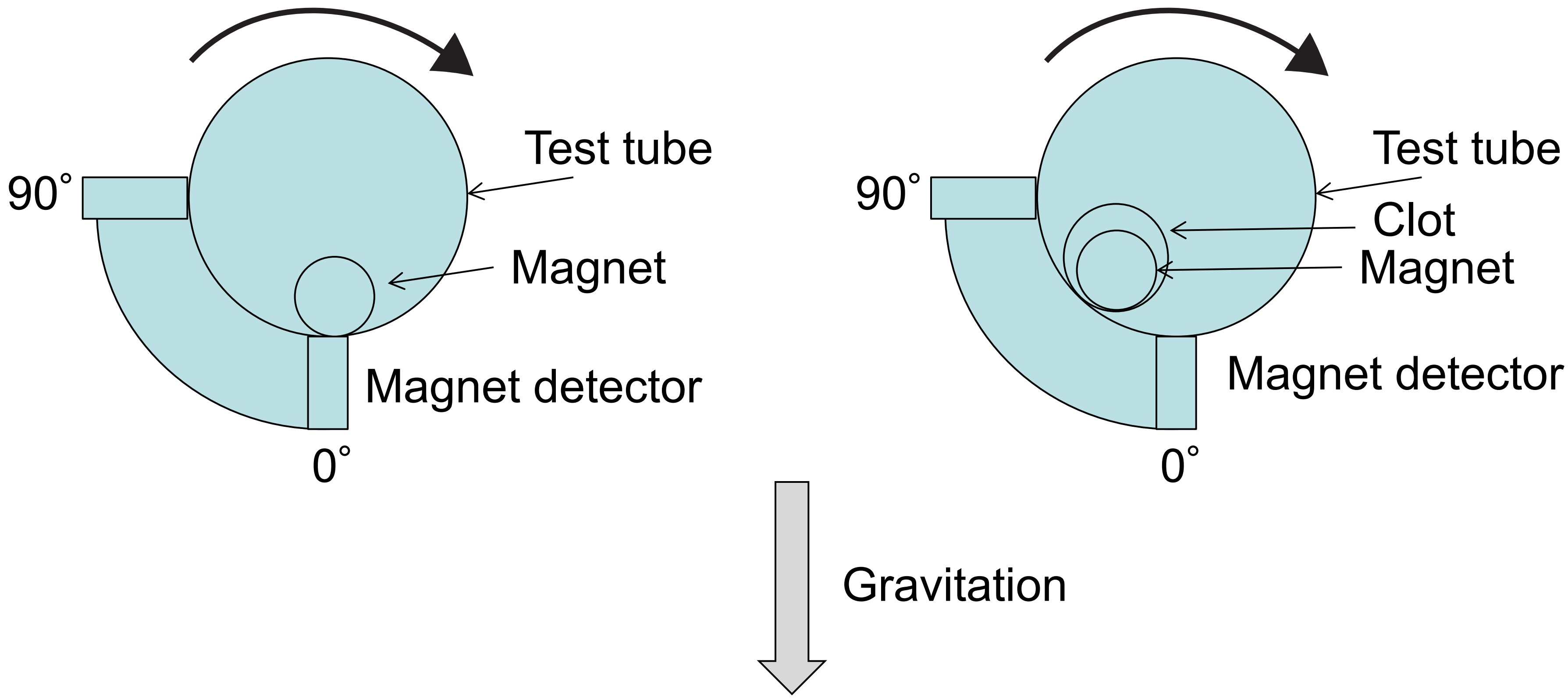
ACT monitoring principle

- Add a solution that will trigger clotting
- Monitor the time until a certain amount of the blood is clotted
- Optical or mechanical readings of clotting

How can we design a system for monitoring this clotting?

Labcompare.com

ACT monitoring principle, simple



http://facs.med.cuhk.edu.hk/site/ANA/ref/img/s/image090.jpg

Viscosimetric ACT

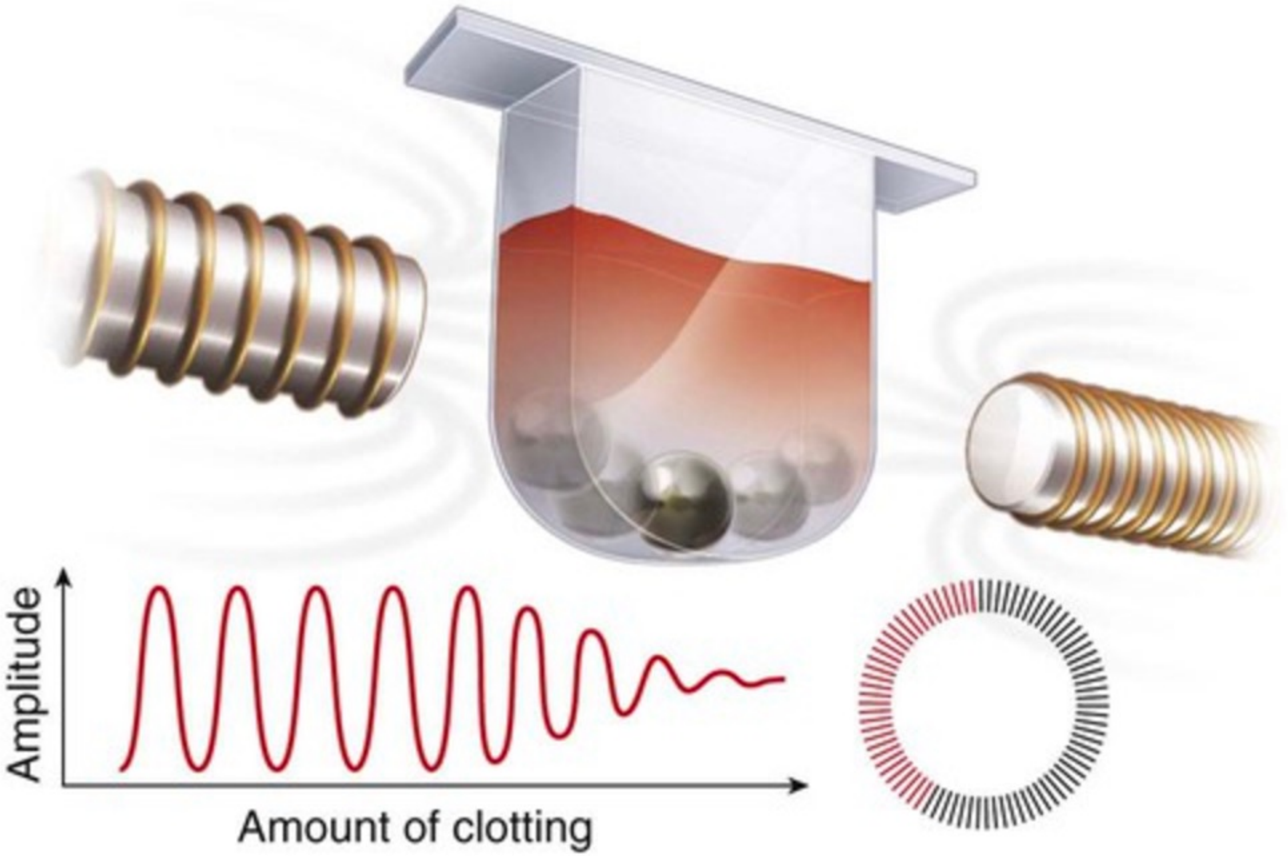


FIGURE 47-1 Viscosimetric (electromechanical) clot detection in a Diagnostica Stago analyzer. A steel ball oscillates in an arc from one side of the cuvette to the other. Movement is monitored continuously within a magnetic field. As the sample clots, viscosity rises and movement of the steel ball is impeded. Variation in amplitude stops the timer, and the interval is the clotting time.

https://clinicalgate.com/coagulation-instrumentation/

Photo-optical ACT

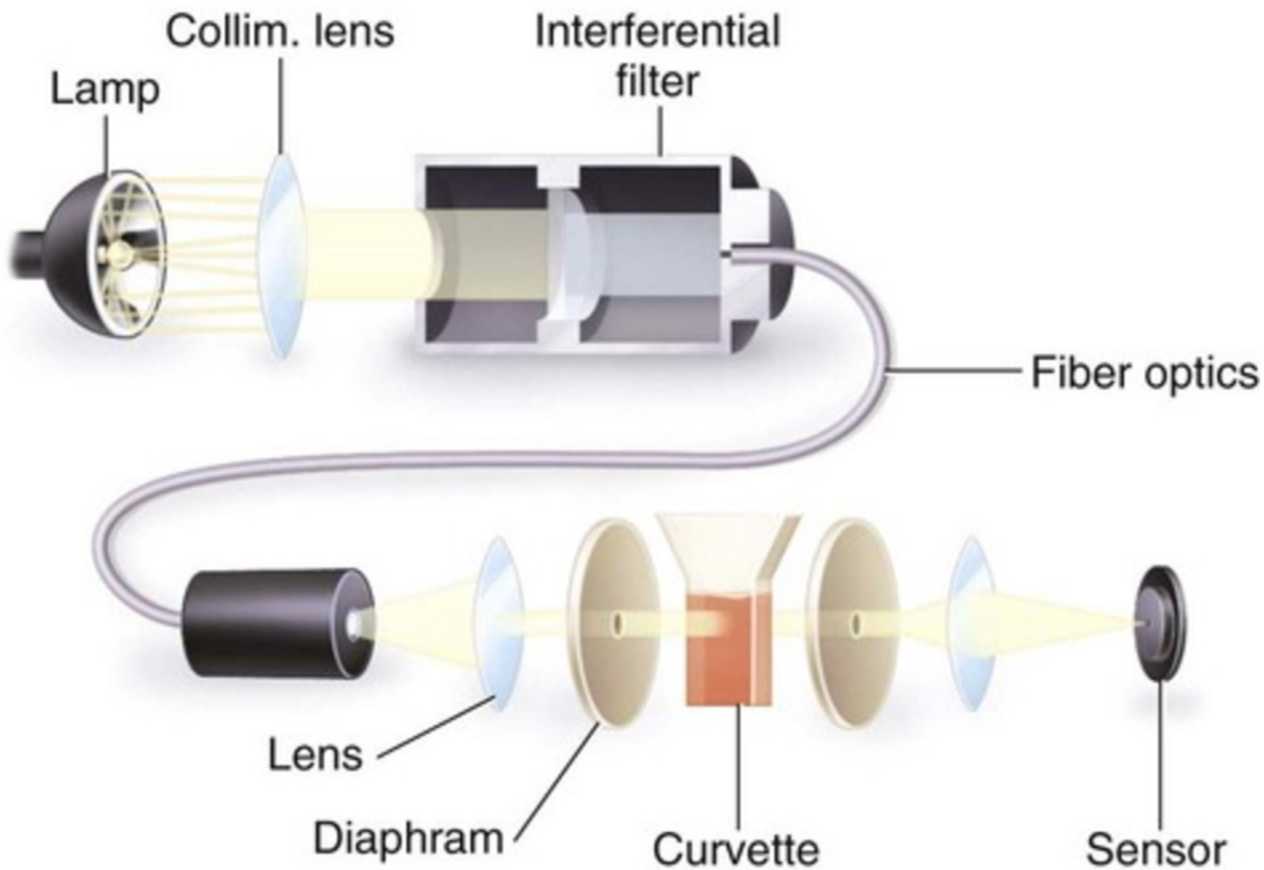


FIGURE 47-2 Photo-optical (turbidometric) clot detection. Polychromatic light is focused by a collimator and filtered to transmit a selected wavelength. Monochromatic light is transmitted by fiber optics and focused on the reaction cuvette. As fibrin forms, opacity increases and the intensity of light reaching the sensor decreases. *Collim.*, Collimator.

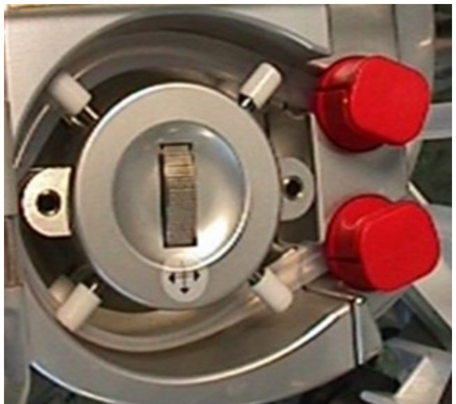
https://clinicalgate.com/coagulation-instrumentation/

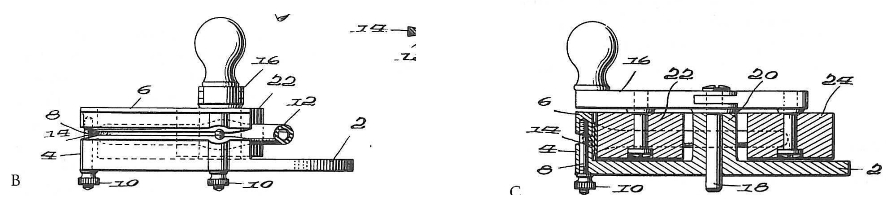
ACT

Sources of error?

1. Rotational speed
2. Blood viscosity
3. Magnet detector resolution
4. Tube properties (friction)
5. Other blood properties
6. ++

3. A blood pump





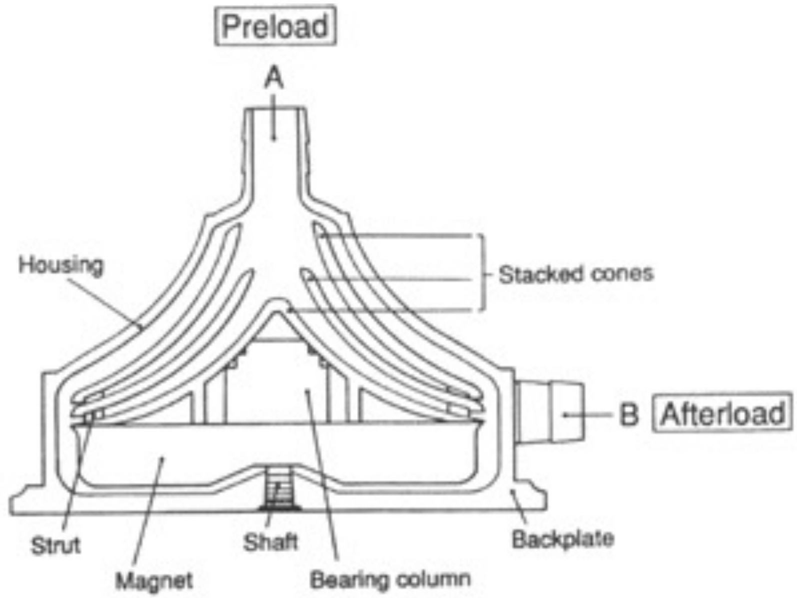
Original DeBakey roller pump. New Orleans Med Surg J 1934;87:387

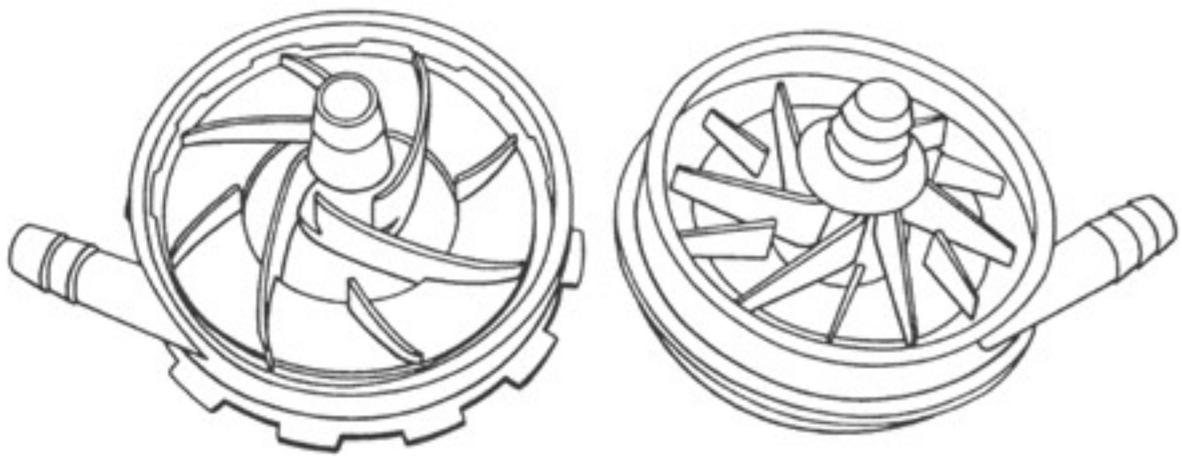
1934 - DeBakey made a modification to the Porter-Bradley pump to prevent creepage of the latex rubber tubing (patent 2 018 998)

This is essentially the same roller pump that is used today.

Case 3

Centrifugal





http://www.anesthesia-analgesia.org/content/108/5/1394/F6.large.jpg

Blood flow rate

Hagen-Poiseuille equation:

$$\text{Blood flow rate} = \frac{(\text{Pressure gradient}) \times (\text{Tube radius})^4 \times \pi}{(\text{Fluid viscosity}) \times (\text{Tube length}) \times 8}$$

To write it simple:

$$\text{Blood flow rate} = \frac{\text{Pressure}}{\text{Resistance}}$$

Should have low priming volume, low index of hemolysis (destruction of red blood cells) and be easy to control

http://www.anesthesia-analgesia.org/content/108/5/1394/F6.large.jpg

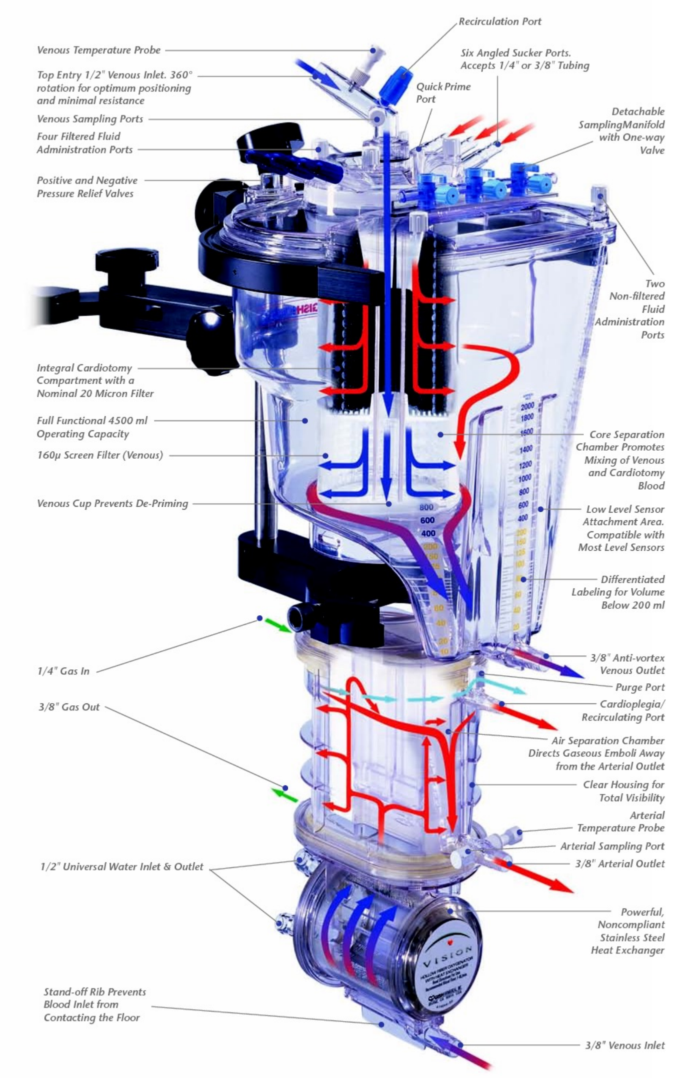
Centrifugal pump vs Roller pump

	Roller pump	Centrifugal pump
Advantages	Inexpensive, reusable	No disruption from excessive line pressure buildup
	Easy to sterilize	Decreased blood trauma
	Simple flow rate det.	No tubing wear
Disadvantages	Blood trauma	Needs flowmeter
	Circuit disruption	Retrograde flow possible when pump stops
	Occlusion variability affects flow rate	More expensive
	Tubing wear	

http://tele.med.ru/book/cardiac_anesthesia/text/gr/gr003.htm

4. A way to exchange oxygen and carbon dioxide

VISION
Hollow Fiber Oxygenator System



http://www.docstoc.com/docs/109449392/Hollow-Fiber-Oxygenator-System

4. A way to exchange oxygen and carbon dioxide

Hollow fibre oxygenators

- Hydrophobic surface that allow diffusion of gases across the membrane. Due to concentration gradients, oxygen diffuses into the blood while carbon dioxide diffuses out of the blood
- Small polymer tubes, 20 to 50 um thick, with an outer diameter of approximately 200 to 400 um.
- Blood flows outside the fibres while air (sweep gas), flows inside
- Carbon dioxide is exited through the exhaust-port of the oxygenator

4. A way to exchange oxygen and carbon dioxide

Gas exchange obeys Fick's law:

$$V_{\text{gas}} \alpha \frac{AD\delta P}{T} \qquad D \alpha \frac{\text{Sol}}{\sqrt{\text{MW}}}$$

Vgas = amount of transferred gas
A = Area
D = Diffusion constant
dP = Partial pressure difference

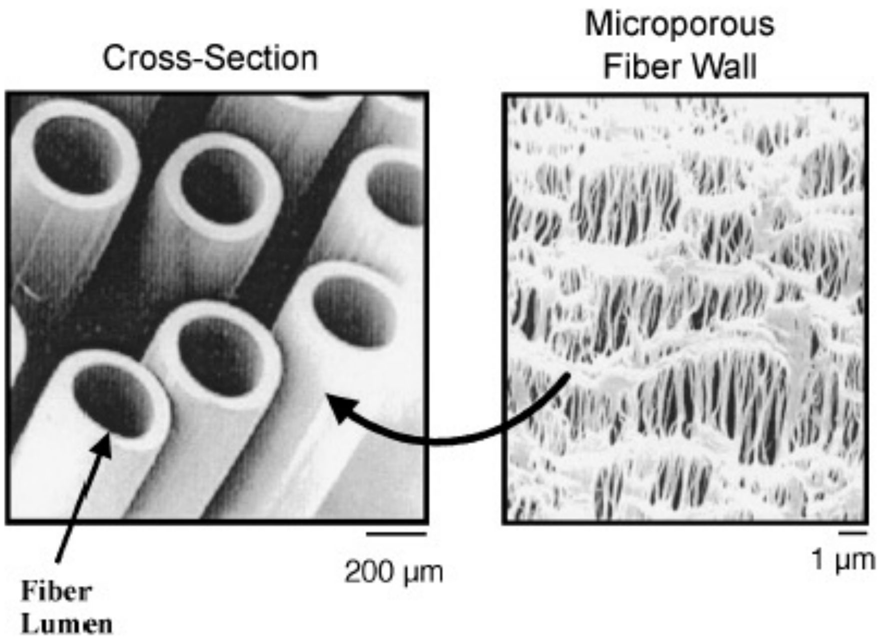
Sol = solubility
MW = Moleculear weight

Higher partial oxygen pressure (and to some extent carbon dioxide) is required to compensate for increased diffusional distance and reduced surface area compared to a human.

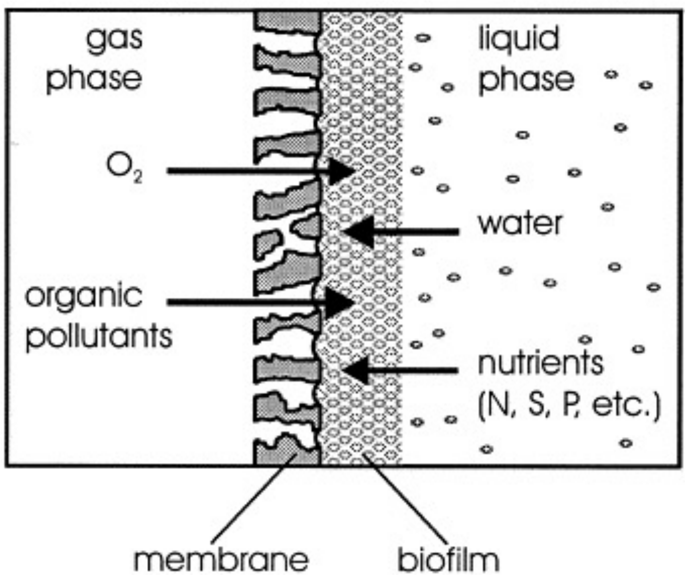
More gas permeable to CO2 than O2, ratio of 5:1

4. A way to exchange oxygen and carbon dioxide

Hollow fiber oxygenators



portal.unimap.edu.my



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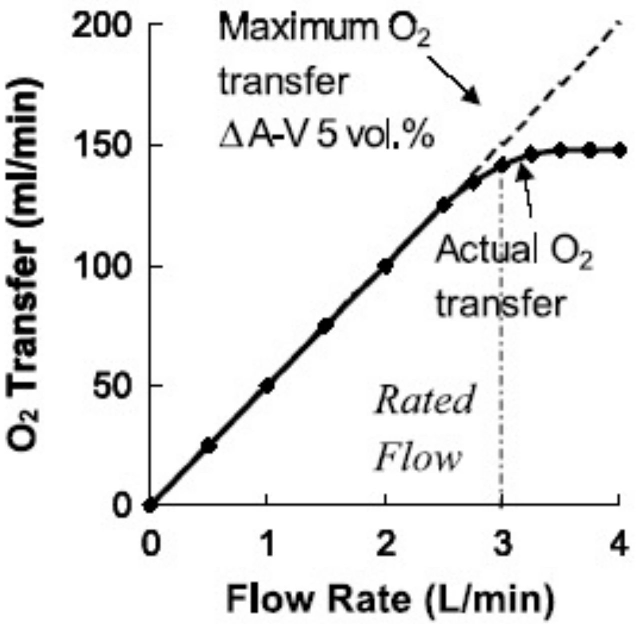
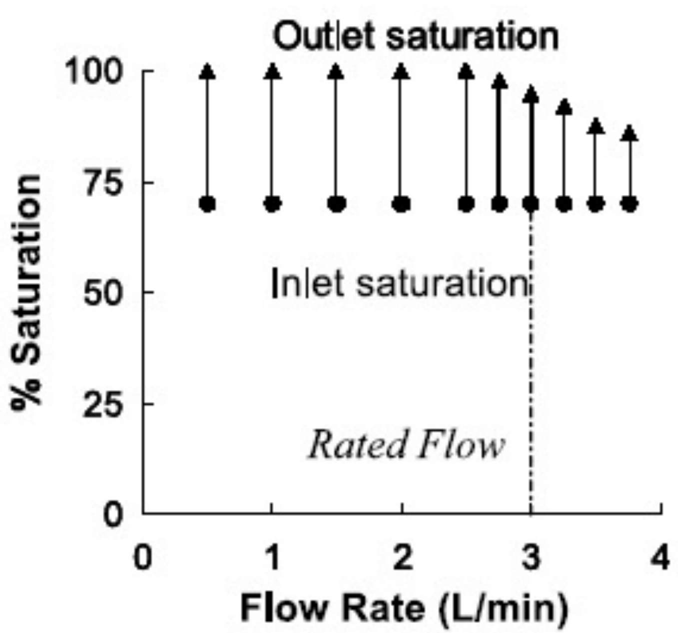
4. A way to exchange oxygen and carbon dioxide

Hollow fiber oxygenators





portal.unimap.edu.my

4. A way to exchange oxygen and carbon dioxide

Comparison of a natural lung vs the oxygenator:

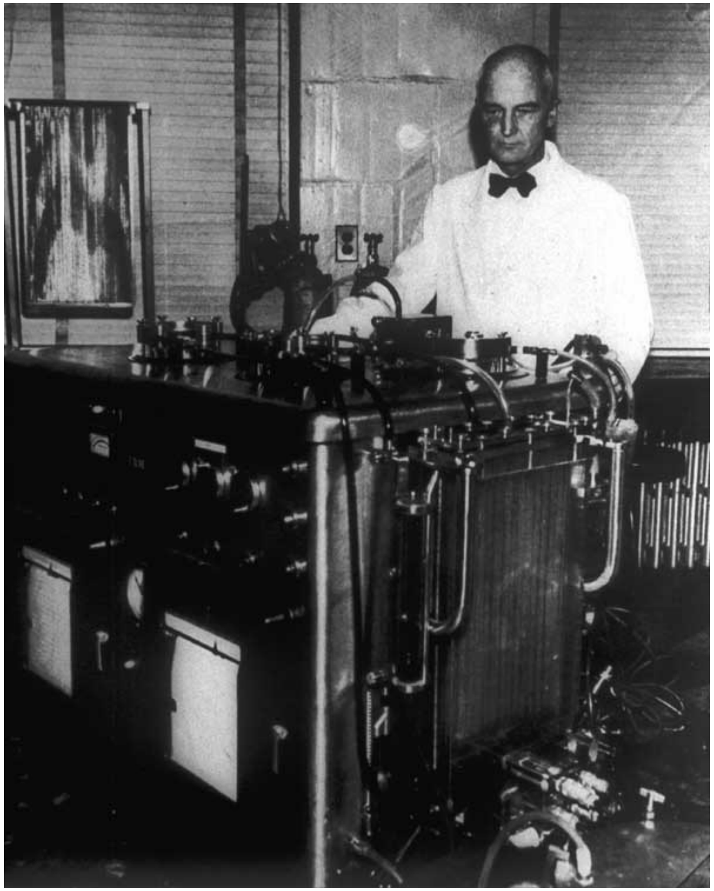
Natural lungs
-Total area: 100 – 150 m^2
-Surface to blood volume ratio: 300 cm^{-1}
-Diffusion distance: 1-2 um
-Gas exchange rate: 200-250 ml/min at rest, but up to 5000 ml/min under exercise

Oxygenator
-Total area: 1 – 4 m^2
-Surface to blood volume ratio: 30 cm^{-1}
-Diffusion distance: 10-30 um
-Gas exchange rate: 200-400 ml/min

Source: portal.unimap.edu.my

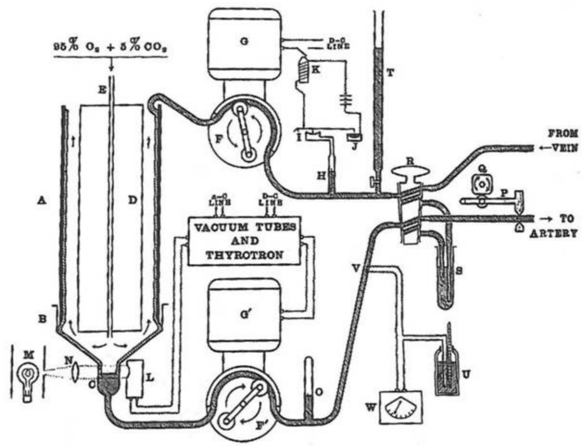
All put together = Heart Lung Machine

John H. Gibbon Jr.

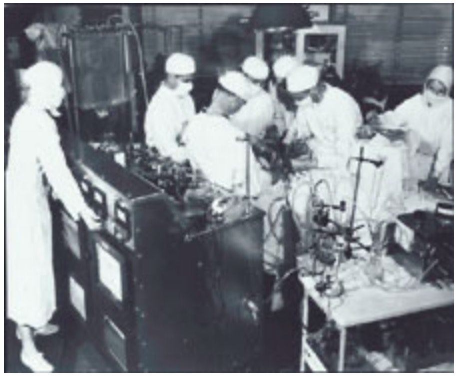


http://www.nature.com/nm/journal/v9/n10/images/nm937-F1.jpg

All put together = Heart Lung Machine



Gravlee, Davis, Kurusz, Utley. Cardiopulmonary bypass. Lippincott Williams & Wilkins second edition



http://jeffline.jefferson.edu/SML/archives/exhibits/notable_alumni/john_gibbon_jr.html

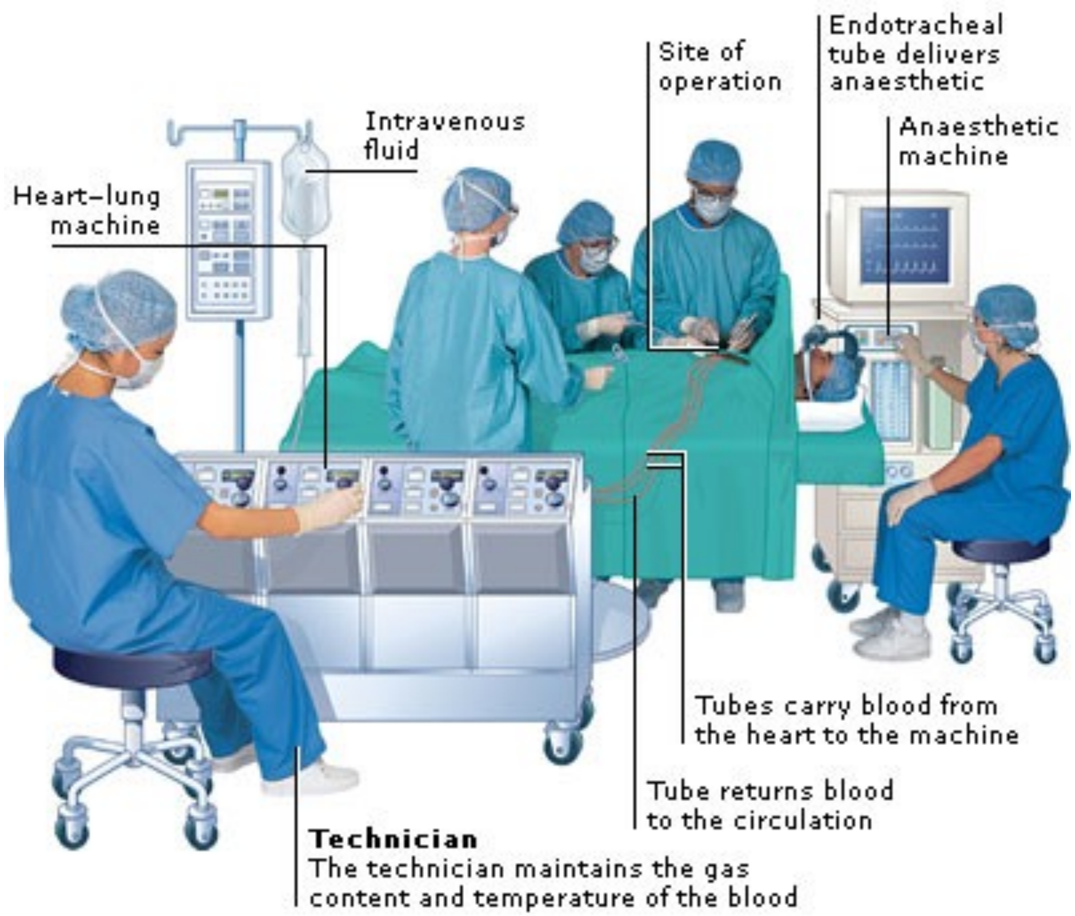
1937 - Gibbon reports the first successful total cardiopulmonary bypass on an animal with the use of Heparin, a Dale-Schuster pump and a vertical rotating cylinder oxygenator.

1951 - Dennis performed the first total cardiopulmonary bypass (CPB) in a 6 years old patient using a rotating screen oxygenator. Unfortunately, the patient could not be separated from the machine and died on the table

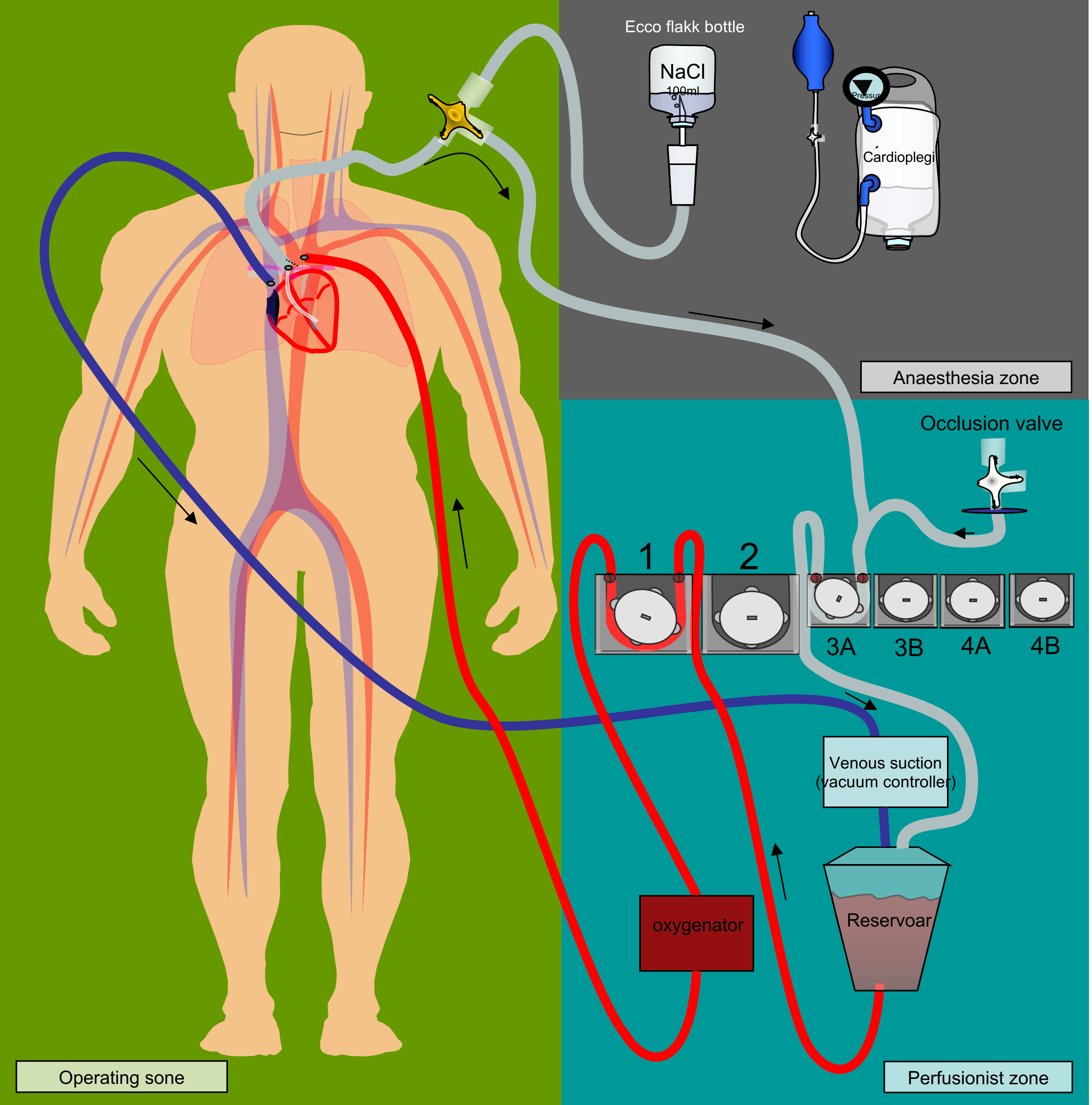
1953 - On May 6, 1953 the Gibbon Heart-Lung Machine was used for the first successful CPB in history when 18-year-old Cecilia Bavolek was undergoing surgery for an atrial septal defect.

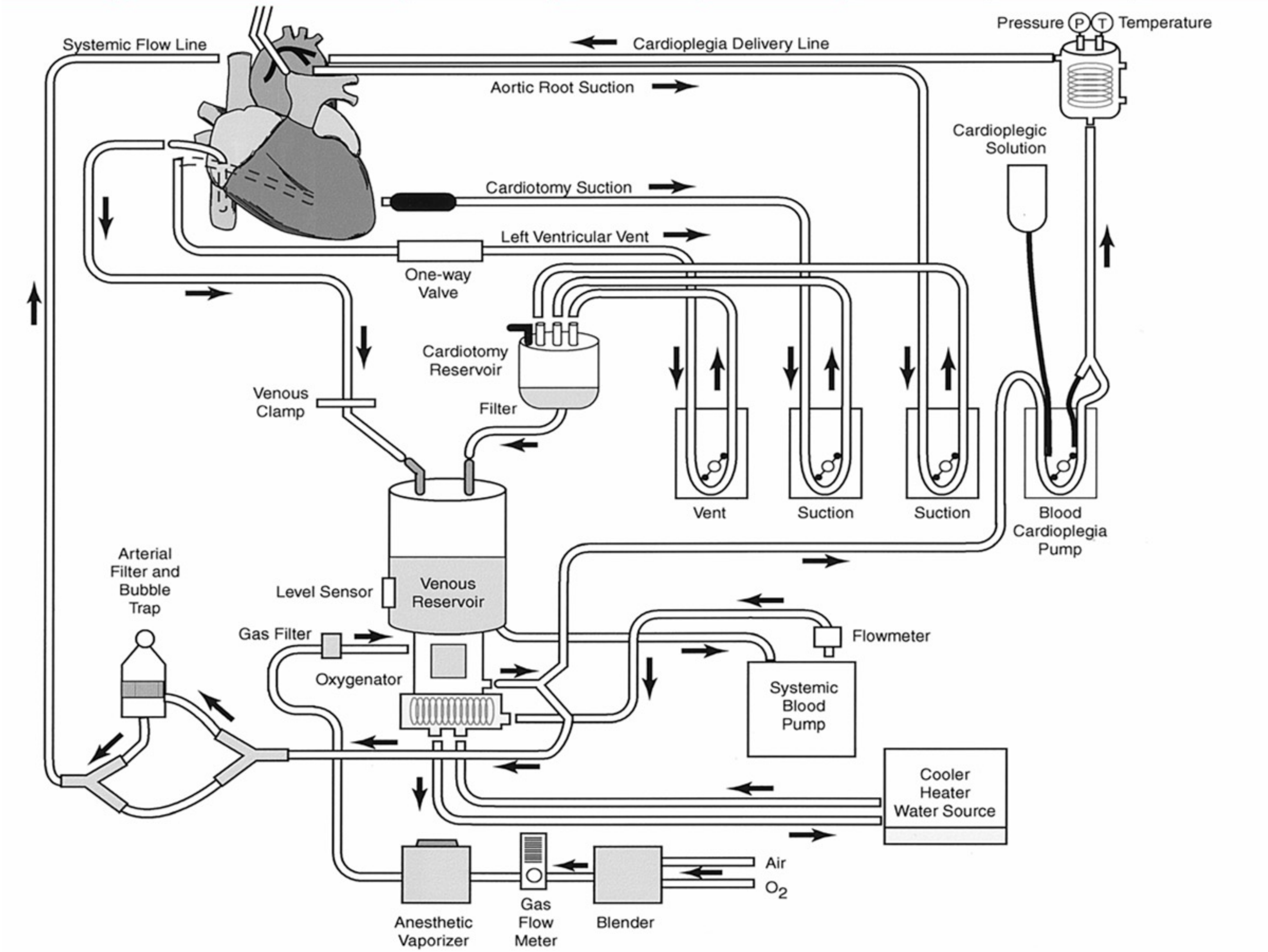
UiO : Department of Physics
University of Oslo

All put together = Heart Lung Machine



http://www.aviva.co.uk/library/images/med_encyclopedia/cfhg903surusi_001.jpg


Ecco flakk bottle
NaCl
100ml
Cardioplegi
Anaesthesia zone
Occlusion valve
1
2
3A
3B
4A
4B
Venous suction
(vacuum controller)
oxygenator
Reservoar
Operating sone
Perfusionist zone


Systemic Flow Line
Cardioplegia Delivery Line
Pressure
P
T
Temperature
Aortic Root Suction
Cardioplegic Solution
Cardiotomy Suction
Left Ventricular Vent
One-way Valve
Cardiotomy Reservoir
Venous Clamp
Filter
Vent
Suction
Suction
Blood Cardioplegia Pump
Arterial Filter and Bubble Trap
Level Sensor
Venous Reservoir
Gas Filter
Flowmeter
Oxygenator
Systemic Blood Pump
Cooler Heater Water Source
Air
O_2
Anesthetic Vaporizer
Gas Flow Meter
Blender

Cannulation

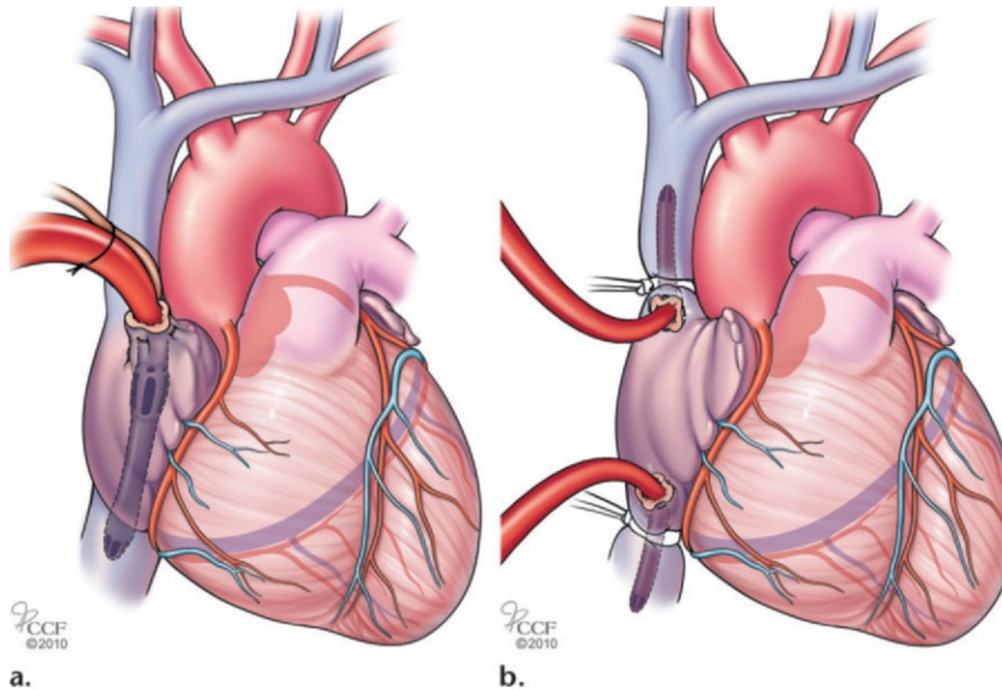


Figure 1. Two basic approaches for central venous cannulation. **(a)** Drawing shows cavoatrial (two-stage) cannulation: cannulation of the right atrial appendage. **(b)** Drawing shows bicaval cannulation: cannulation of the superior vena cava and the inferior vena cava. (Reprinted, with permission, from the Cleveland Clinic Center for Medical Art and Photography.)

El-Sherief: Basics of Cardiopulmonary Bypass: Normal and Abnormal Postoperative CT Appearances1

Cannulation

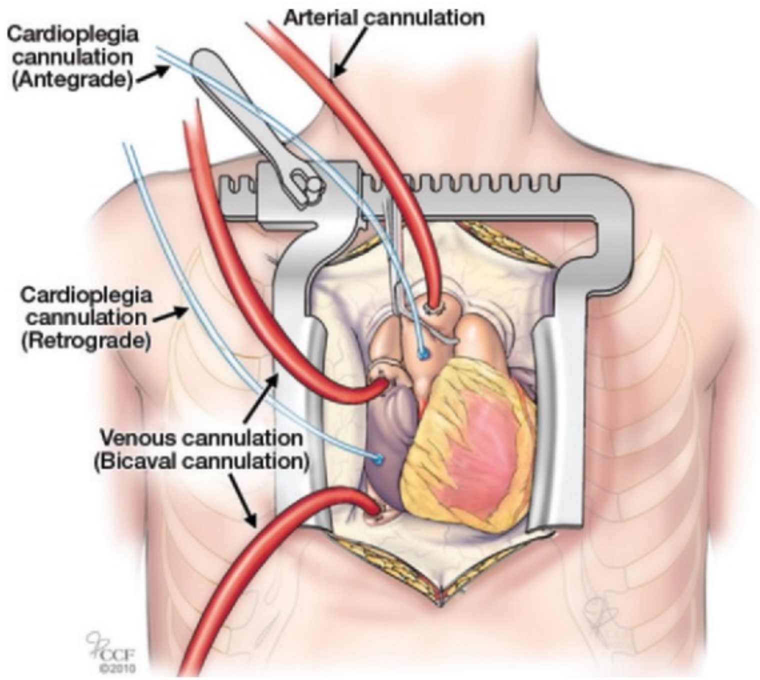


Figure 2. Drawing shows several routes of cannulation: arterial cannulation of the distal portion of the ascending aorta, antegrade cardioplegia cannulation, retrograde cardioplegia cannulation, and bicaval venous cannulation. *IVC* = cannula into inferior vena cava, *SVC* = cannula into superior vena cava. (Reprinted, with permission, from the Cleveland Clinic Center for Medical Art and Photography.)

El-Sherief: Basics of Cardiopulmonary Bypass: Normal and Abnormal Postoperative CT Appearances1

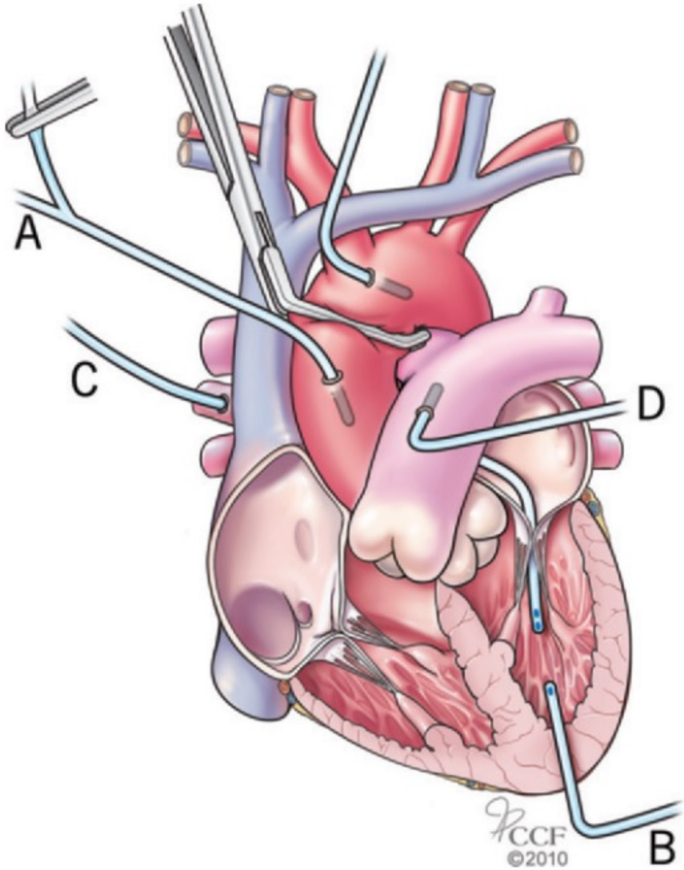


Figure 3. Drawing shows various left ventricular venting routes, with cannulation of the aortic root or the midportion of the ascending aorta *(A)*, cannulation of the left ventricular apex *(B)*, cannulation of the left atrium or the left ventricle via the right superior pulmonary vein *(C)*, and cannulation of the pulmonary artery *(D)*. (Reprinted, with permission, from the Cleveland Clinic Center for Medical Art and Photography.)

Venting and De-airing

When the heart is arrested or is fibrillating, distention of the ventricles may occur as a result of returning blood, an occurrence that is detrimental to subsequent contractility. The right ventricle is protected from distention by venous cannulation, whereas the left ventricle is not. The left ventricle can become distended from blood leaking across an insufficient aortic valve, which becomes especially problematic in a patient whose aorta cannot be clamped (eg, an emergency requiring hypothermic circulatory arrest)

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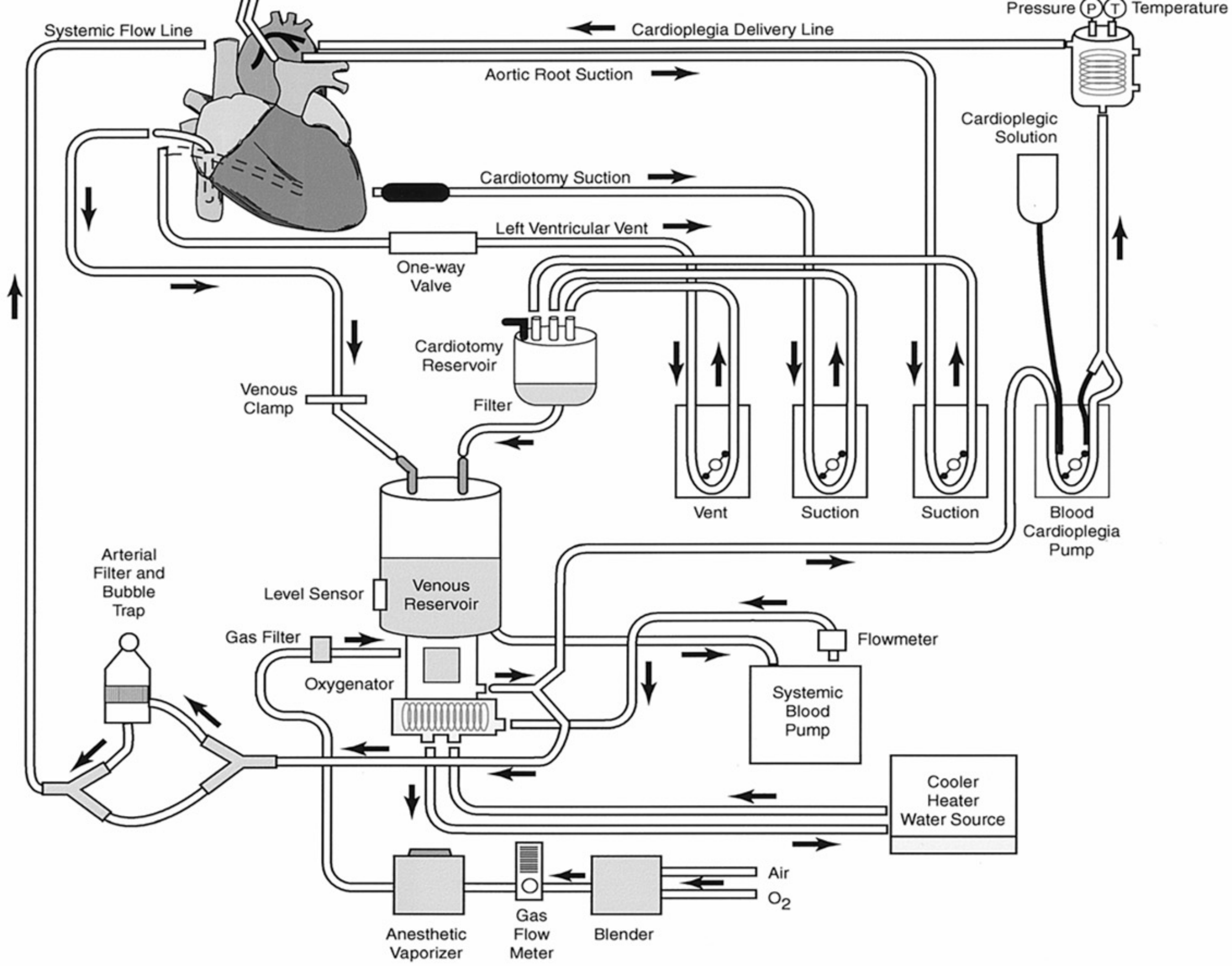
University of Oslo

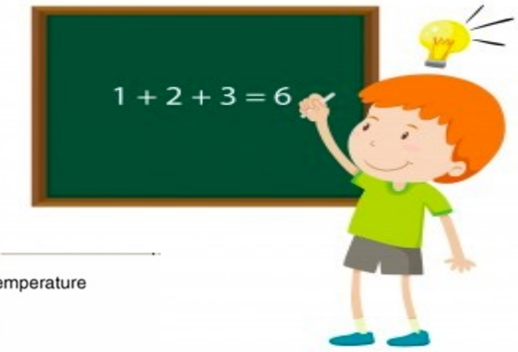
Exercise

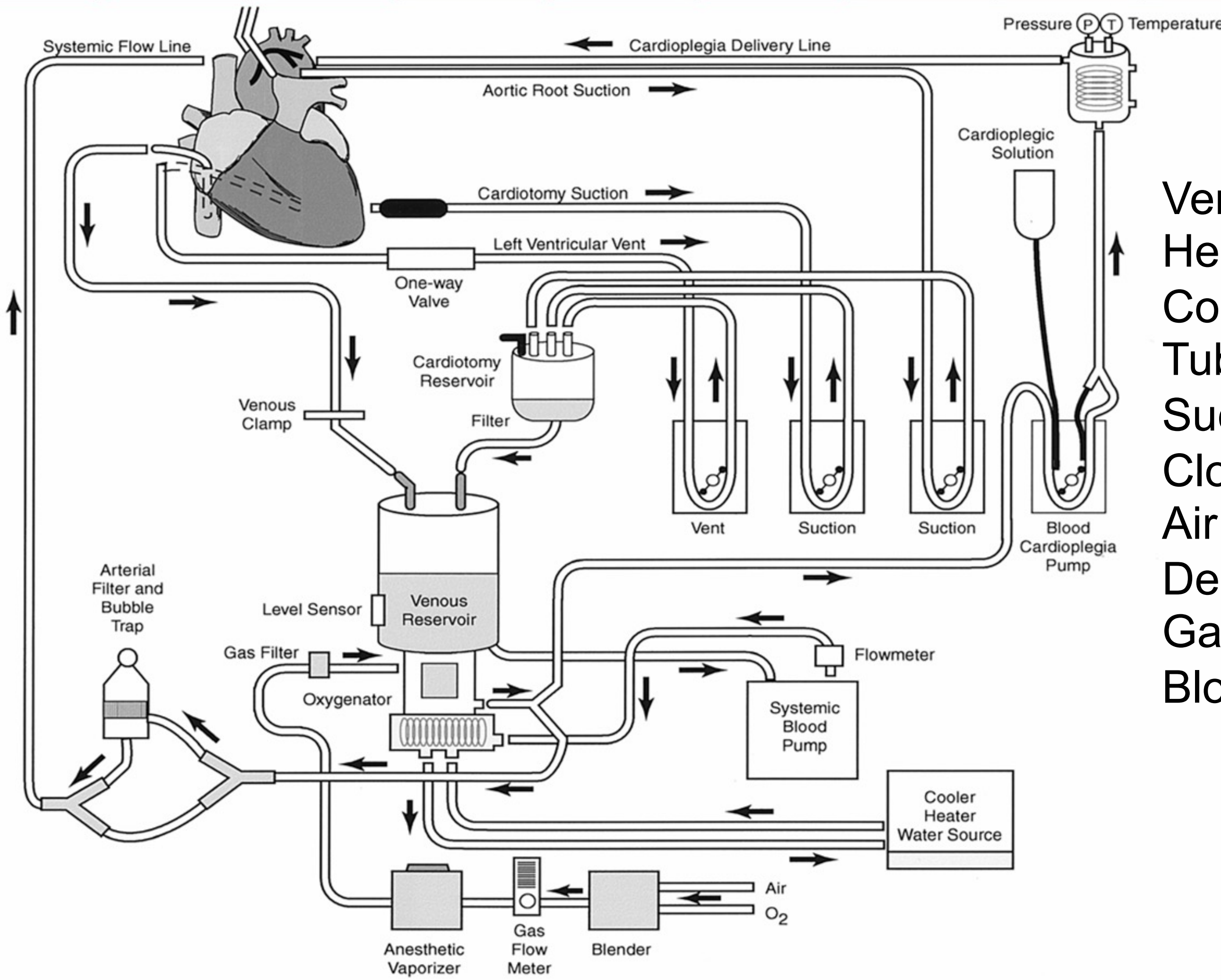
Form groups of 2 or 3 students, and discuss:

a. Explain the main parts of the HLM
b. Where are the main risk factors in CPB?



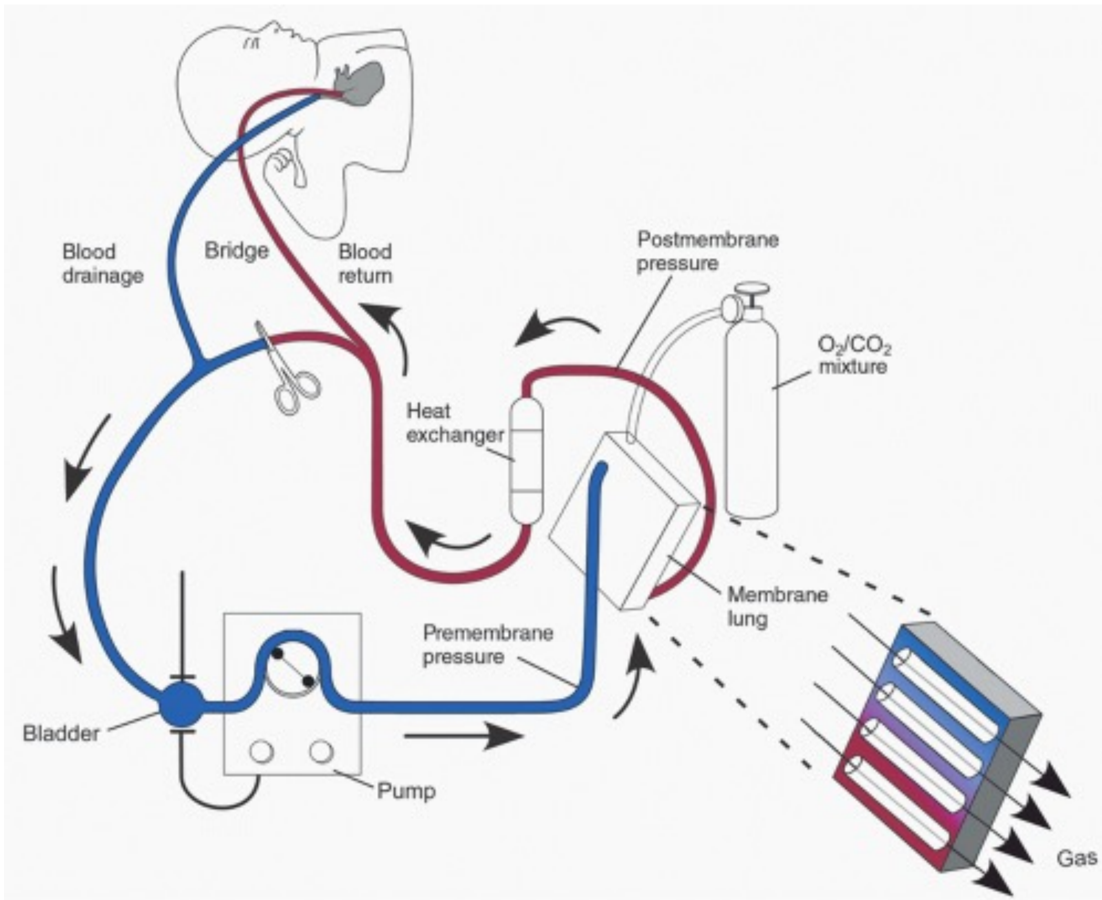
Answers





Venous return
Hemolysis
Connecting tubes
Tubing wear
Suction injuries
Clotting
Air bubbles
Decontamination
Gas mixer
Blood distribution in the body

ECMO (Extra corporal membrane oxygenation)

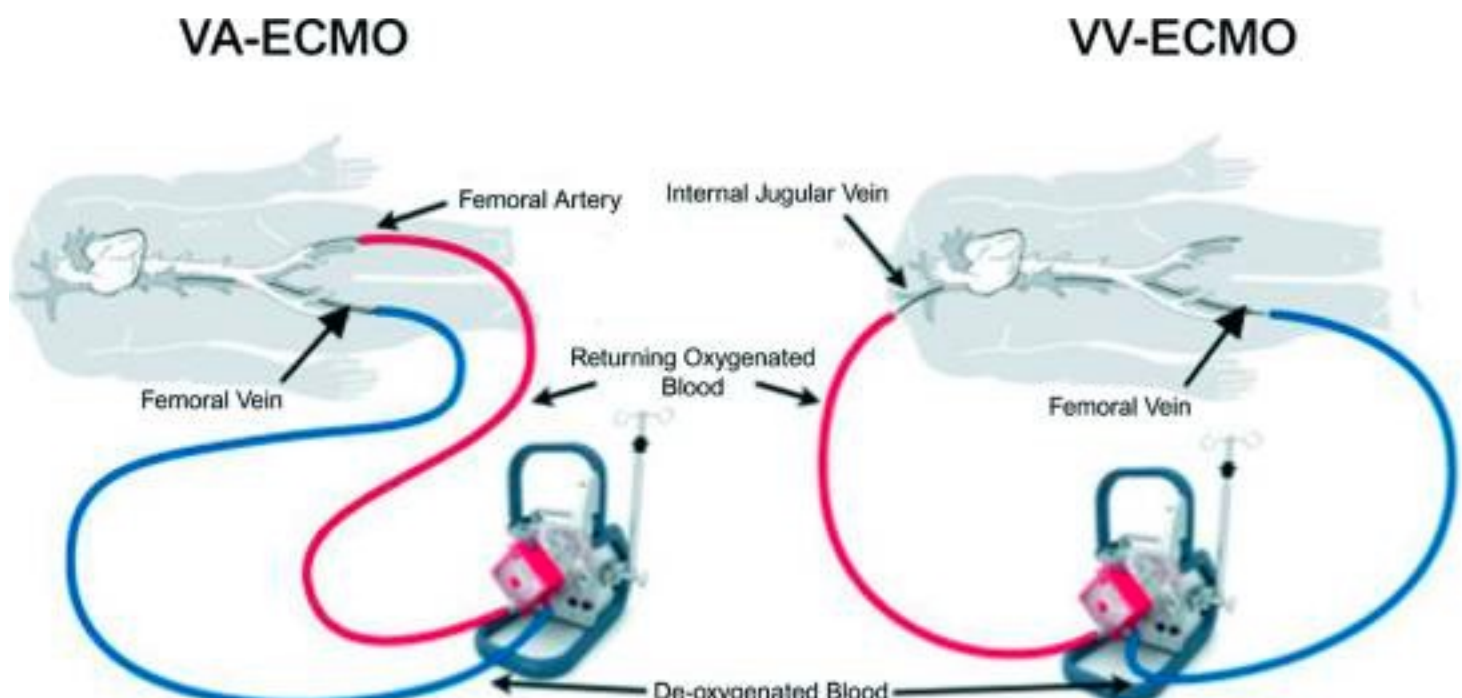


https://thoracickey.com/wp-content/uploads/2016/06/C31-FF1.gif

ECMO

Differences between ECMO and CPB

a. Cannulation. ECMO is typically cannulated through the neck (cervical) under local anesthesia, CPB is connected to the aorta under full anesthesia
b. CPB is short-time, ECMO is typically 3-10 days
c. ECMO is meant for intrinsic recovery of heart and lungs, CPB is for bypass
d. ECMO can be veno-venous or veno-arterial
e. Centrifugal pump, less priming volume, blood trauma, platelet activation and inflammatory response.



https://www.ncbi.nlm.nih.gov/corecgi/tileshop/tileshop.fcgi?p=PMC3&id=1113600&s=42&r=1&c=1

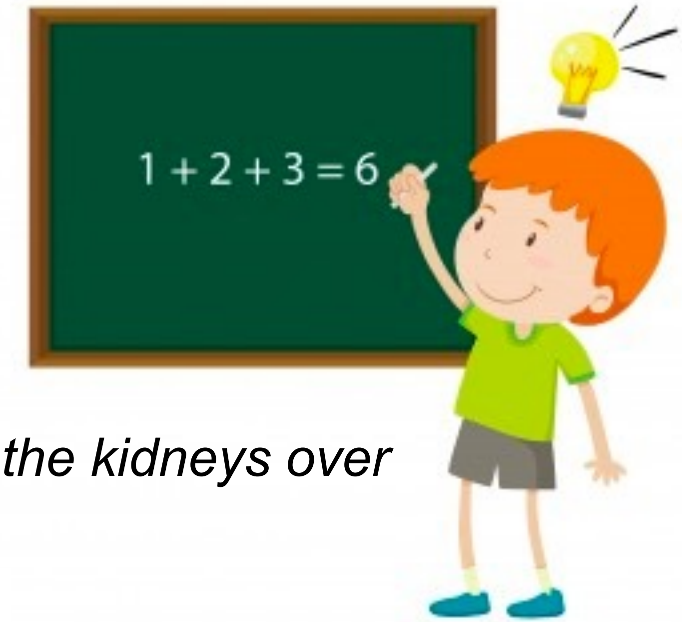
Exercise

Form groups of 2 or 3 students, and discuss:

a. What risks exists for ECMO but not for HLM?
b. How should the patient be monitored?

http://integrativeosteopathy.com.au/wp-content/uploads/2015/08/Exercise.jpg

Answers



a. *Kidney failure due to lack of blood to the kidneys over time*

Leg failure because the cannula in the groin may impede the blood flow to the leg which may lead to tissue necrosis

b. *Patient monitors (ECG, BP, SpO2) + frequent blood gases*

New methods replace the old, eg TAVI

https://www.youtube.com/watch?v=X1Uk9Jvbut0

Medical suction

Medical suction:

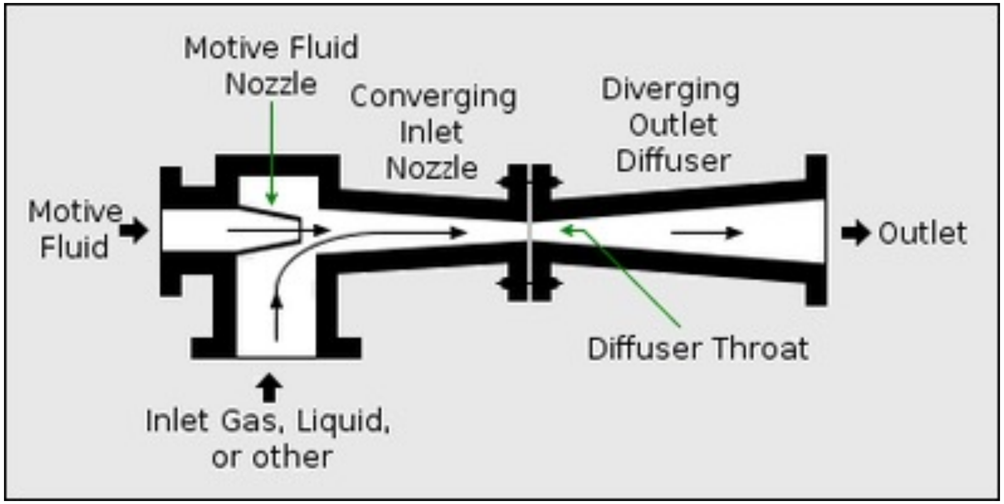
- In the operating room there is typically three different gas sockets:
    - Oxygen
    - Medical air
    - Instrument air

All gases sockets are equipped with excessive pressure, how is it then possible to design an underpressure suction?

- What physical principle can we use?

Medical suction

Bernoulli-principle



http://upload.wikimedia.org/wikipedia/commons/thumb/b/b4/Ejector_or_Injector.png/396px-Ejector_or_Injector.png

Incompressibble flow equation:

$$\frac{v^2}{2} + gz + \frac{p}{\rho} = \text{constant}$$

where:

v is the fluid flow speed at a point on a streamline,

g is the acceleration due to gravity,

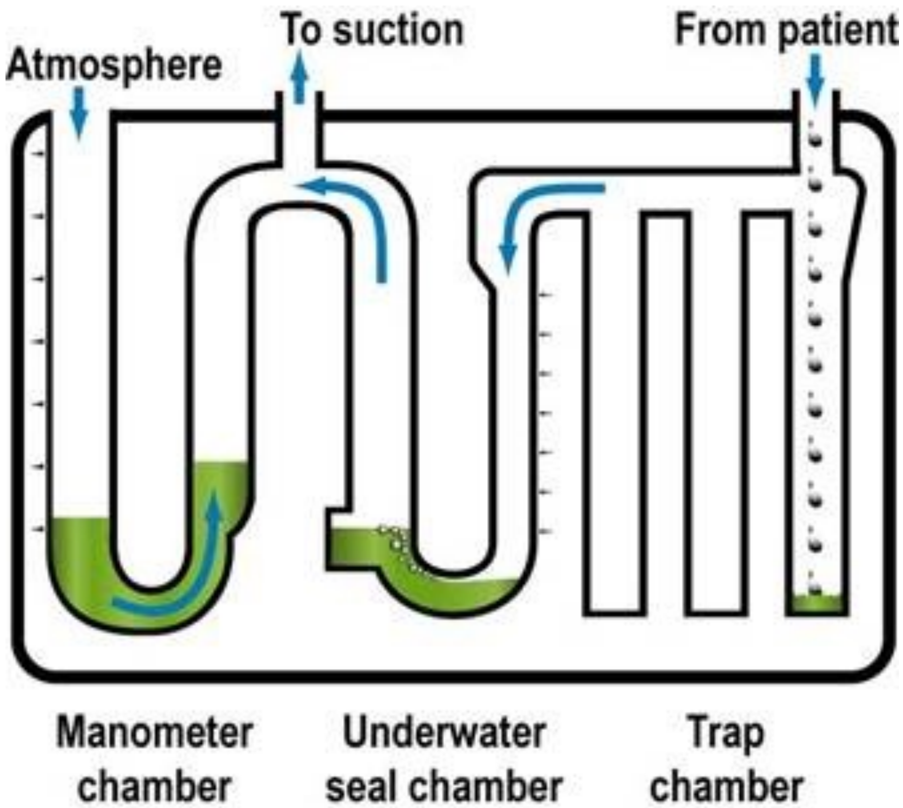
z is the elevation of the point above a reference plane, with the positive z-direction pointing upward – so in the direction opposite to the gravitational acceleration,

p is the pressure at the chosen point, and

ρ is the density of the fluid at all points in the fluid.

Source:https://en.wikipedia.org/wiki/Bernoulli%27s_principle

Medical suction



http://www.medicine-on-line.com/html/skills/s0001en.files/image010.jpg

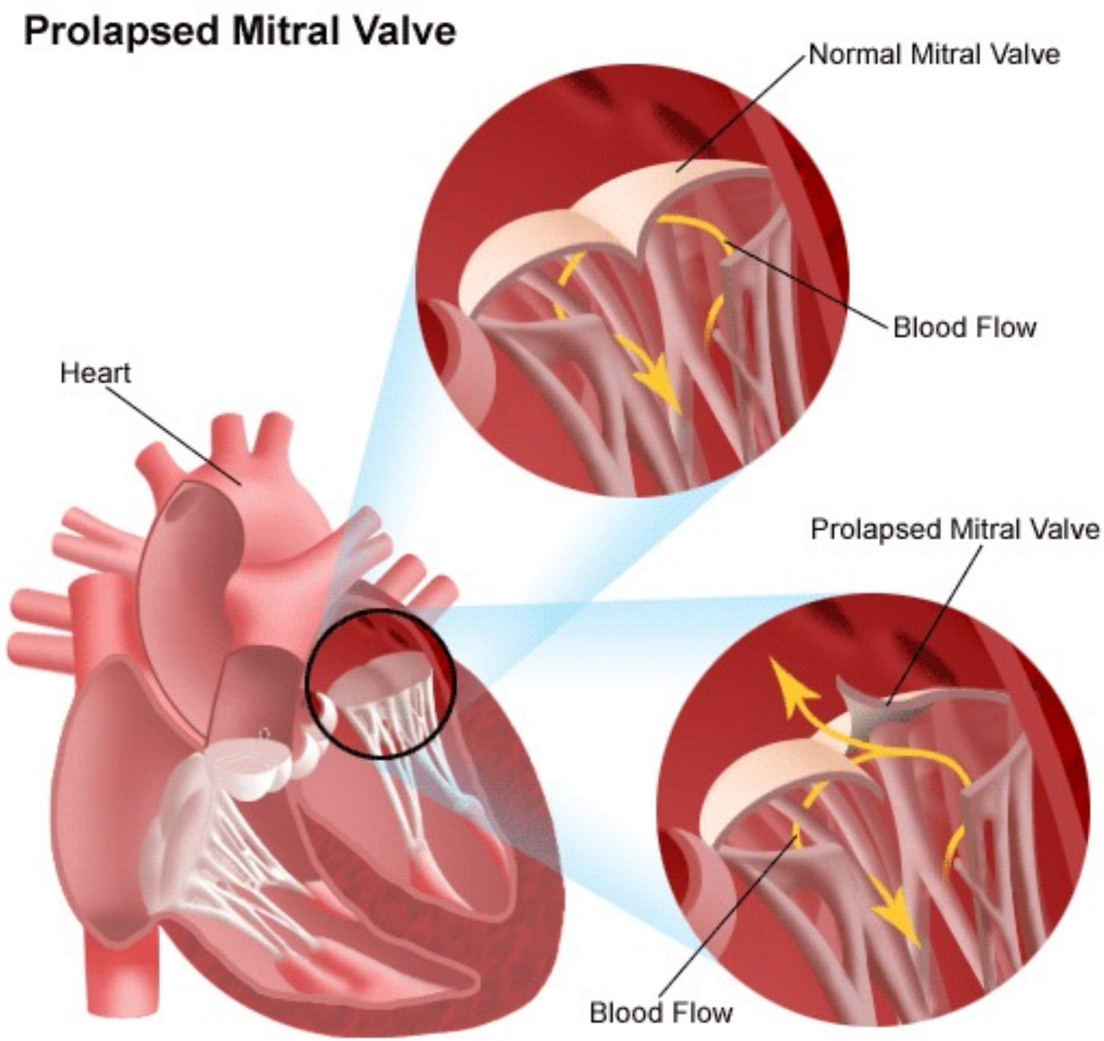
Case 11

The patient was successfully treated for her myocardial infarction and was apparently recovering properly. Then something goes terribly wrong several days after the treatment of the infarction started. Open-heart surgery was unsuccessful as the condition did not improve, and there were no pathological findings.

The main problem was obviously the Mitral valve which was no longer effective and thus a source of reflux to the left atrium, which became evident a week after the diagnosis of the infarction.

- What was the diagnosis?

Case 11



http://www.brighamandwomens.org/departments_and_services/womenshealth/hearthealth/assets/images/lowlevel_imgs/mitral-valve-prolapse/img.gif

Case 11

Answer: The post-mortem autopsy showed a number of big cerebral air-embolies which was supposed to be the direct cause of death. The initial problem with the Mitral valve was due to a papillary muscle rupture, which was a sequela of the initial infarct. The ECG exposed a myocardial infarction, but not the location of this. Unfortunately the focus area was in the papillary area, which led to the death of the papillary muscle tissue and then the valve disorder. This is a rare but feared complication of myocardial infarction.