Medical Devices
Cardiovascular System
(Week 09)

Dr Mohammad Sanami
Lecturer in Mechanical Biomedical Engineering

Address: Room B1-07b, School of Engineering | Tel: 01204903109 | Email: M.Sanami@Bolton.ac.uk

Introduction

- Nearly half of all deaths (49%) are attributed to cardiovascular disease (55% of women, 43% of men)
- The main causes of cardiovascular disease are coronary heart disease, also known as ischaemic diseases, and stroke.
- The cardiovascular system is an organ system that moves nutrients, gases and wastes to and from cells, and helps stabilise body temperature and PH to maintain homeostasis.
- All vertebrates have what is called a closed circularly system. This means that the blood never leaves the systems of blood vessels consisting of arteries, veins etc.

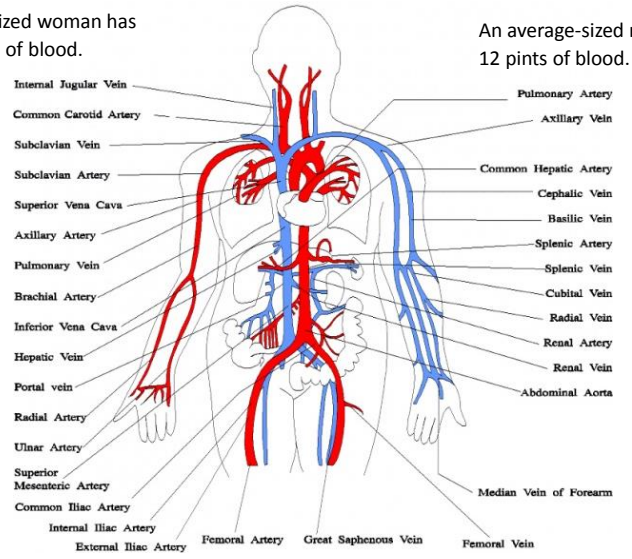
Blood Circulation (Principle Veins and Arteries)

An average-sized woman has about 9 pints of blood.

An average-sized man has about 12 pints of blood.

Normal **Blood** pressure is 120/80mmHg

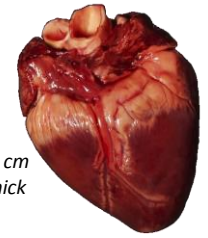
Approximately 7% of the body weight is **Blood**



Introduction

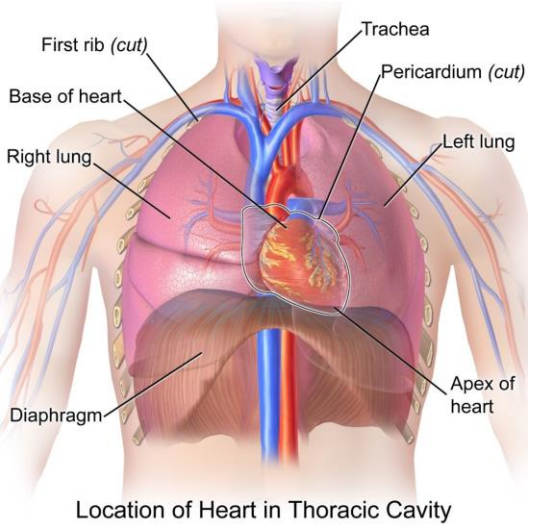
- Open systems which are present in creatures such as molluscs and insects have fluid in a cavity in which organs are directly bathed, and there is no distinction between blood and interstitial fluid.
- Some creatures, such as flatworms have no circulatory system. An extensively branched digestive system facilitates direct diffusion of nutrients to all cells.
- Oxygen can also diffuse from the surrounding water into the cells, and carbon dioxide can diffuse out.
- Closed systems of fish for example have a single circularly system. The heart acts only as one pump, and pumps the blood through the capillaries of the dills and then on to the capillaries of the body tissues.

Location of Heart



250–350 grams
12 cm × 8 cm × 6 cm
length wide thick

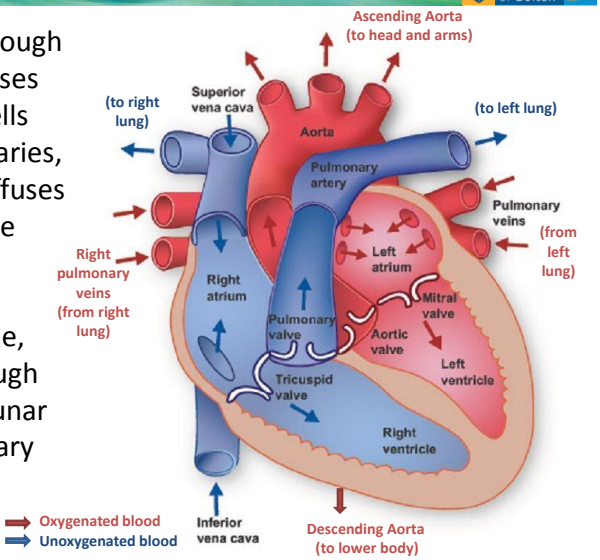
- The **heart** is a muscular organ in most animals, which pumps blood through the blood vessels of the circulatory system.
- Blood provides the body with oxygen and nutrients, as well as assists in the removal of metabolic wastes.
- In humans, the heart is located between the lungs, in the middle compartment of the chest.



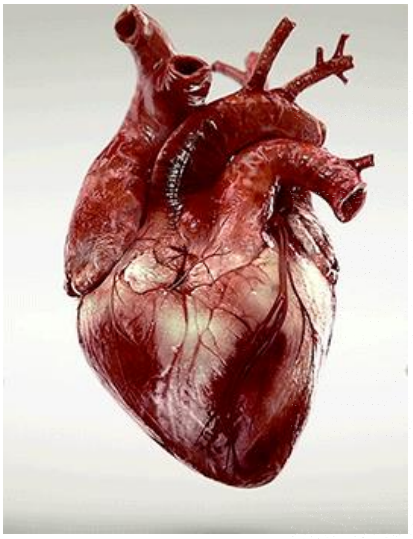
Location of Heart in Thoracic Cavity

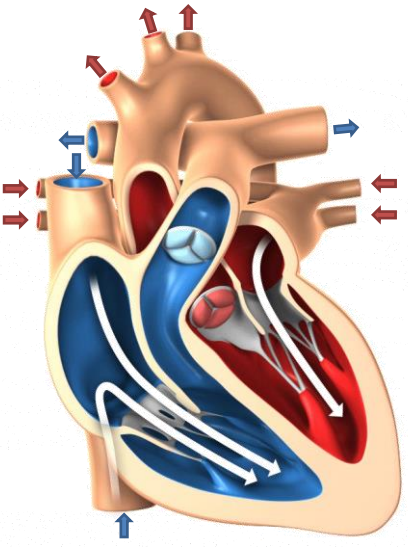
Blood Circuit

- As blood circulates through the body, oxygen diffuses from the blood into cells surrounding the capillaries, and carbon dioxide diffuses into the blood from the capillary cells.
- From the right ventricle, blood is pumped through the pulmonary semi-lunar valve into the pulmonary artery

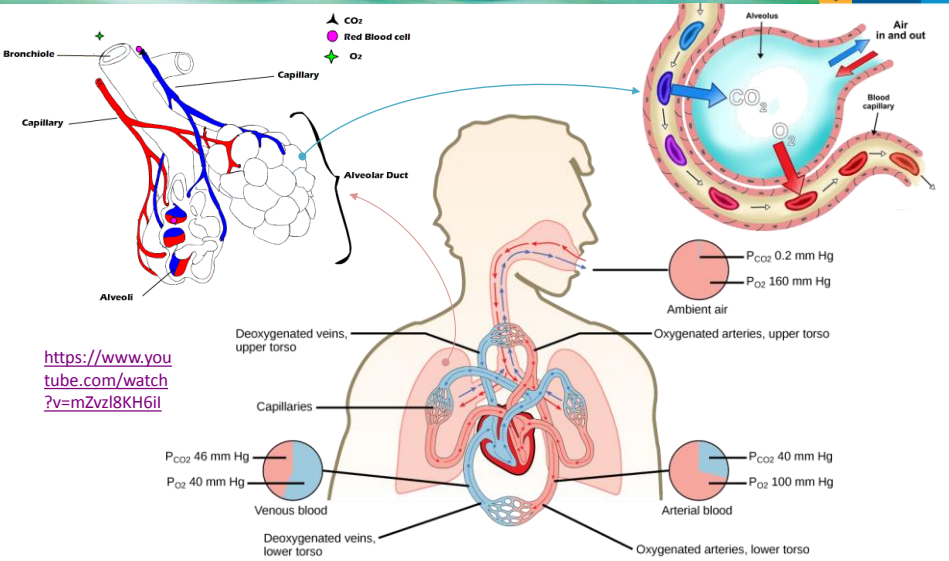


Pulmonary Circuit





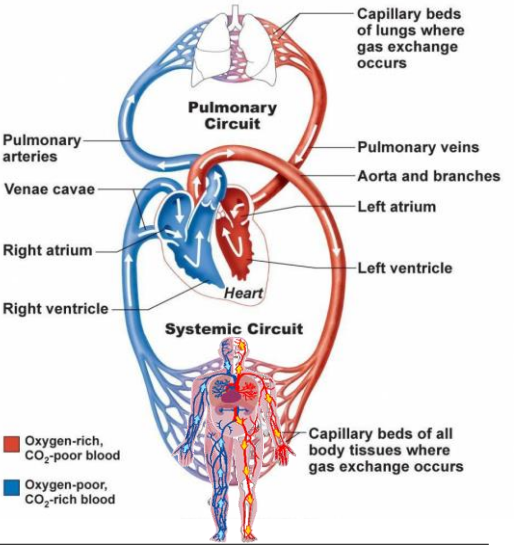
Pulmonary Circuit



https://www.youtube.com/watch?v=mZvzl8KH6iI

Pulmonary Circuit

- This blood enters the two pulmonary arteries and travels through the lungs, where it is oxygenated and then flows into the pulmonary veins.
- This oxygenated blood then enters the left atrium, which pumps it through the bicuspid valve, also called the mitral or left atrioventricular valve, into the left ventricle.



Pulmonary Circuit

- From the left ventricle, blood is pumped through the artic semi-lunar valve into the aorta, the largest artery in the body.
- The aorta arches and gives off major arteries to the upper body before travelling down the body just in front of the spine.
- Once the blood inters the peripheral tissues oxygen and nutrients are extracted from it and carbon dioxide and wastes added, and it will again be collected in the veins and the process will be repeated.
- Peripheral tissue do not fully deoxygenate the blood, so venous blood does have oxygen, but in a lower concentration than in arterial blood.

Pulmonary Circuit

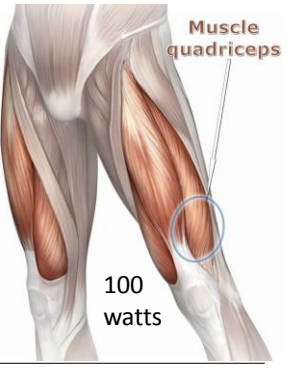
- Amount of blood ejected from one ventricle during ventricular systole = stroke volume.
- The amount of blood ejected from one ventricle during one minute is called the Cardiac output ~ 5.6 litres

Cardiac output = Hearth rate ✕ Stroke volume

5600 ml = 70beats/min × 80 ml

- At rest the heart beats ~ 70/80 beats/min. during exercise may approach 200 beats/min and pump 20 litres of blood.
- Estimates of the power output of the human heart range from 1 to 5 watts as it beats.

https://hypertextbook.com/facts/2003/IradaMuslumova.shtml

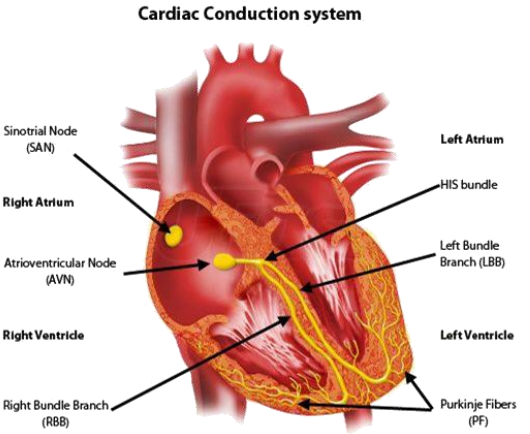


Pulmonary Circuit

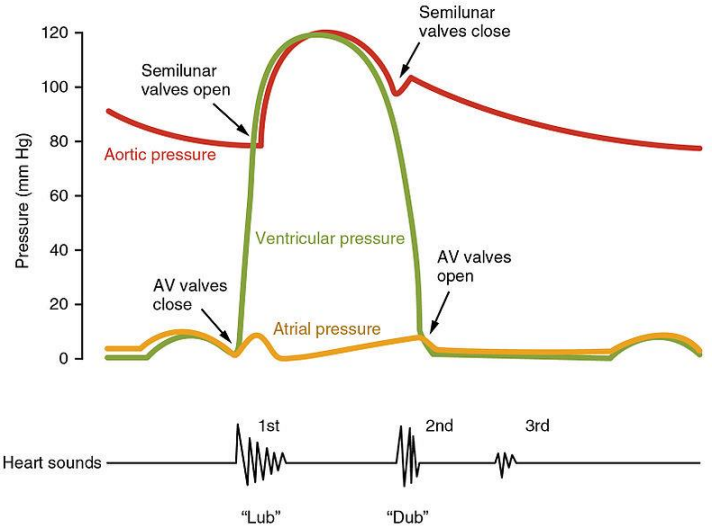
- Cardiac muscle must have a source of extracellular calcium ions and extracellular potassium ions. Without these the cardiac cells can not create action potential and therefore can contract.
- The sarcoplasmic reticulum is a special membrane that surrounds the muscle that can store and release calcium ions throughout muscle contraction and muscle relaxation.
- The heart pumps the blood by repeated contractions of its muscles. These cardiac contractions are produced due to an *electrical phenomenon called depolarisation*, that takes place in the heart muscles' cells (myocardial cells). The myocardial cells have a negative electric resting potential. Through the depolarisation, this potential goes temporarily to a positive value that stimulates them to contract.

Cardiac Conduction system

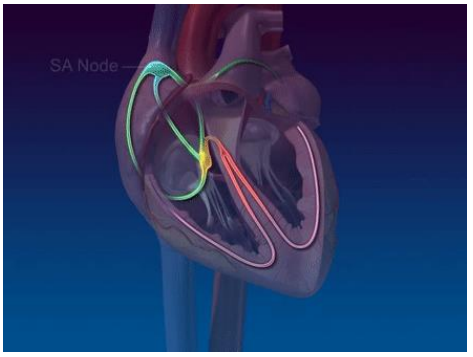
- **Sinoatrial (SA)** node is the hearts natural pacemaker
- Depolarisation is initiated in the SA node (electrical impulse started)
- Depolarisation spreads through adjacent atrial cells
- Signal reaches **Atrioventricular** (AV) nod. There is a slight pause (0.1s) to allow arteria to fully contract, then signal is passed on through the bundle of his (fast conduction pathways)
- **Purkinje fibres** distribute signal about ventricle to cause ventricular contraction.

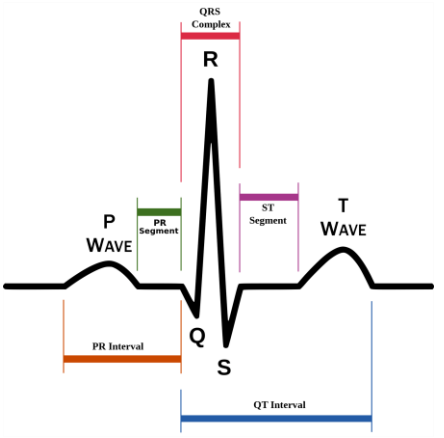


Blood Pressure



Electrocardiogram (ECG/EKG)

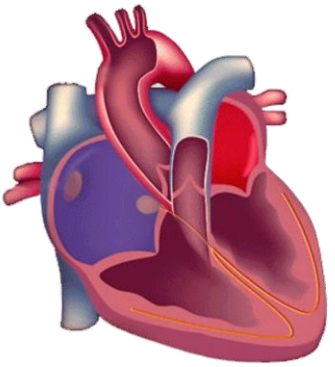


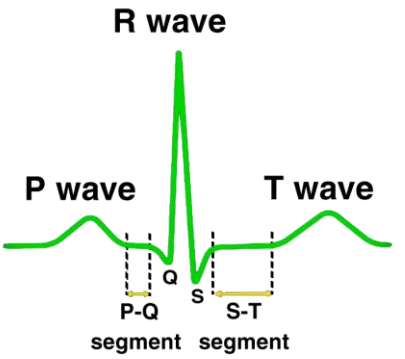


Electrocardiogram (ECG/EKG)

P Wave		Depolarisation of atrial muscle as negativity spreads from the SA node towards to ventricles
P-R Interval	For the start of the P wave to the start of the QRS complex	Time it takes for the impulse to travel from the SA node to the ventricles
P-R Segment	From the end of the P wave to the start of QRS complex	Interval between atrial and ventricular depolarisation
QRS Complex		Spread of excitation through the ventricular myocardium. This results in depolarisation of the ventricular muscle. Atrial repolarisation is also occurring but is masked by the larger QRS complex
S-T Segment	Interval between the end of the S wave and the start of the T wave	Period during which ventricles are more or less uniformly excited
T wave		Beginning of ventricular repolarisation (relaxation of ventricles)
Q-T Interval	Start of the QRS complex to the end of T Wave	Electrical systole (when ventricular beat is generated)

Electrocardiogram (ECG/EKG)

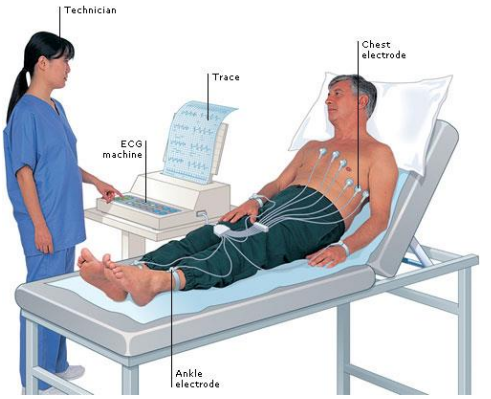




https://www.youtube.com/watch?v=RYZ4daFwMa8

Electrocardiogram (ECG/EKG)

- ECG is an important non-invasive source of diagnostic information. Although a constant cardiac membrane potential produces no measurable electrical effect at the surface of the body, the spread of excitation through the heart generates small resultant voltages which can be detected by electrodes attached to the skin.
- Each heartbeat is stimulated by electrical signals that travel through special nerve pathways in the heart muscle. These signals can be measured by electrocardiogram sometimes called ECG or EKG.



Heart Rhythm

Normal heart Rhythm – Sinus relates to the impulse starting from the SA node

Sinus Rhythm

Slow heart rate (below 60 beats/min)

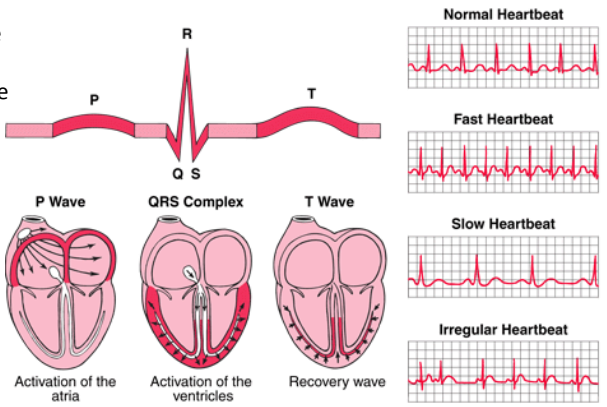
Sinus Bradycardia

Results of SA dysfunction, either by inhibited SA node impulse or slowed/ blocked conduction through the heart. Occurs in 30-40% of patients following acute myocardial infarction (MI).

Abnormal Heart Rhythm

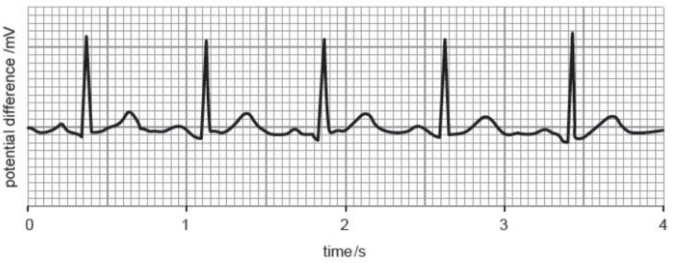
- Often results from increased sympathetic stimulate stimulation, such as pain, fever, increased oxygen demand and/or hypovolemia (decreased blood volume).
- Arrhythmias may be caused by many different factors, including:
  - Coronary artery disease
  - Electrolyte imbalances
  - Changes in heart muscle
  - Injury from the heart attack
  - Healing process after heart surgery

https://www.msdmanuals.com/home/heart-and-blood-vessel-disorders/abnormal-heart-rhythms/overview-of-abnormal-heart-rhythms



Question 1

The chart below shows an electrocardiograph (ECG) for a patient's heart beat at rest.



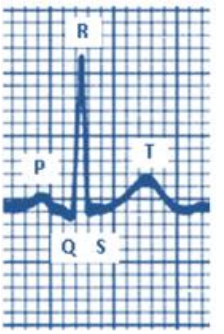
a) Calculate the average resting rate for this person in beats per minute.
b) Describe how the ECG would change if the person was carrying out physical exercise?
c) The trace of each heart beat shown on the electrocardiograph corresponds to three main waves of electrical activity in the heart P, QRS and T. label one heartbeat on the ECG with the letters P, Q, R, S and T to indicate these waves of electricity.
d) Describe what is happening in the heart during each of these waves of electrical activity, P, QRS, T.

Question 1 answer

a) 5 beats in 4 seconds × (60/4) = 75 beats per minute.
(if an alternative method is shown e.g., time between two R peaks = about 0.8/0.75 s, then accept a heartbeat between 75 and 80)

b) Trace for each heartbeat (would stay same size but) more frequent/filling time reduced/time between T and next P shorter;

c) P, Q, R, S, T, clearly labelled on a single heart beat.



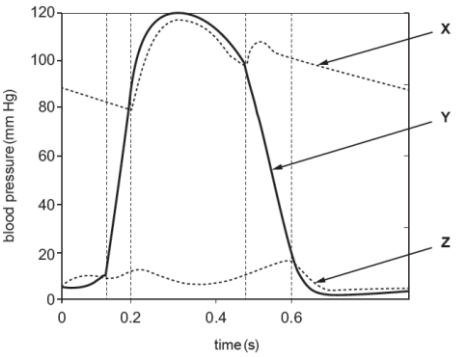
d) ***P*** atria contracting/ atrial systole
QRS impulse passing to base of ventricles / just before ventricles contract/ ventricular systole
T ventricles relaxing / ventricular diastole; reject heart

Question 2

The graph below shows the pressure changes in the left atrium and ventricle and the aorta during a single heartbeat.

a) Which of the letters **X** , **Y** and **Z** from the diagram show the pressure changes in the:
Left Atrium .....
Left ventricle .....

b) Pressure changes during the cardiac cycle cause the heart valves to open and close. At 0.2s state if the atrio-ventricular and aortic valves would be open or closed.
Atrio-ventricular valve .....
Aortic valve .....



c) Explain how ventricular systole causes these valves to open or close at this point in the cardiac cycle.

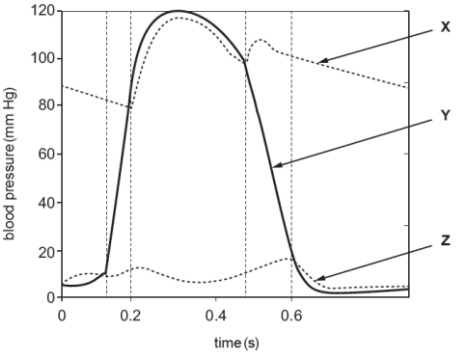
Question 2 answer

The graph below shows the pressure changes in the left atrium and ventricle and the aorta during a single heartbeat.

a) Left Atrium ..... ***Z*** .....
Left ventricle ..... ***Y*** .....

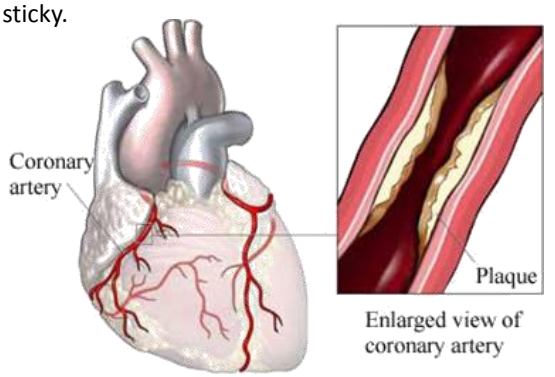
b) Atrio-ventricular Closed
Aortic valves Open

c) Ventricle contracts from base up;
Blood pressure in ventricle higher than atrium + AV valve closed:
Blood pressure in ventricle higher than in aorta + aortic valve forced open;



Coronary Artery Disease

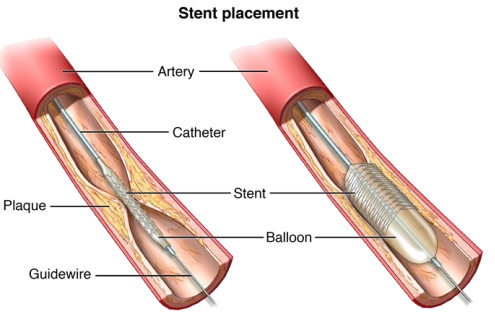
- Coronary arteries are hollow tubes which supply the heart with blood. Inside, they are smooth and elastic, allowing blood to flow freely.
- Overtime fat starts to deposit/ build-up in the blood vessel walls. This causes injury to the blood vessel walls and in an attempt to heal itself chemicals are released that make the walls sticky.
- Other substances such as inflammatory cells, proteins and calcium that travel in your bloodstream start sticking to the vessel walls. The fat combined with these other substances form a plaque that narrows the artery (atherosclerosis).



Coronary Artery Disease

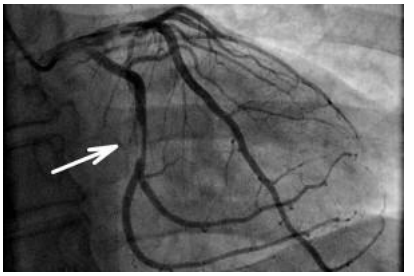
<u>Treatment</u>

- Reducing risk factors: lifestyle change, stop smoking, reduce cholesterol intake, low fat, low sodium, reduce weight if needed and reduce stress.
- Medications: help the heart work more efficiently and receive more oxygen-rich blood.
- Surgery and other procedures:
  - Balloon angioplasty (PTCA)
  - Stent placement
  - Rotoblation
  - Atherectomy
  - Coronary artery bypass surgery



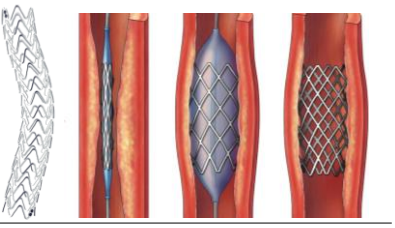
Balloon angioplasty

- First, a cardiac catheterisation is performed. The patient receives medication for relaxation. The doctor then numbs the area where the procedure will be performed.
- A sheath (thin, plastic tube) is inserted into an artery in the groin or sometimes the arm. Along, slender tube called a catheter is inserted through the sheath and guided thorough the blood vessel to the arteries surrounding the heart.
- A diagnostic procedure called coronary is performed next. A small amount of contrast material is injected through the catheter and is x-rayed as it moves.
- Narrowing of the coronary arteries can be detected along with the performance of the heart valves.



Heart Stent

- Then, a specially designed catheter with a small balloon tip is guided to the point of narrowing artery and inflated to compress the fatty matter into the artery wall and stretch the artery open to increase blood flow.
- A stent is a small stainless steel mesh tube that acts as a scaffold to provide support inside your coronary artery.
- A balloon catheter, placed over a guide wire, is used to insert the stent into the narrowed coronary artery. Once in place, the balloon tip is inflated, and the stent expands to the size of the artery and hold it open.
- The balloon is deflated and removed, and the stent stays in place permanently. Over a several week period, the artery heals around the stent.



Roroblation & Atherectomy

Rotoblation

https://www.youtube.com/watch?v=7Kl0sEP8VBA

- Acron-shaped diamond coated tip
- Spins around at high speed
- Grinds away the plaque on artery wall
- The microscopic particles are washed away in blood steam and filtered by liver

Atherectomy

Non calcified plaques

https://www.youtube.com/watch?v=WGFTKP04jtY

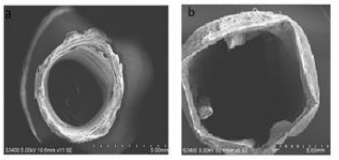
- The catheter has a hollow cylinder on the tip with an open window on one side and a balloon on the other side.
- The balloon is inflated pushing the window against the fatty matter
- A blade (cutter) within the cylinder rotates and shaves off any fat that protrudes into the window

Coronary Artery bypass surgery

- A blood vessel is removed (grafted) or redirected from one area of the body and placed around the area of narrowing to "bypass" it and restore blood fellow to the heart muscle.
- This substitute blood vessels can come from the chest, arms, or legs. They're safe to use because there are other pathways that take blood to and from those tissues.
  - There is an acute clinical need for small-diameter vascular grafts as a treatment option for cardiovascular disease.
  - We used an intelligent design system to recreate the natural structure and hemodynamics of small arteries.

https://www.youtube.com/watch?v=WX04rLHSTP4

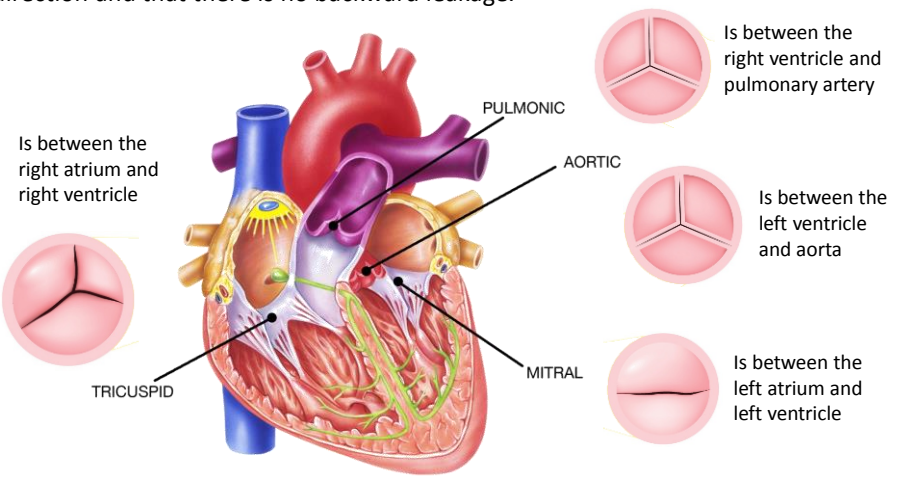
Conventional Helical



https://www.sciencedirect.com/science/article/pii/S1549963418305094#f0005

Heart Valve Disease

The four heart valves make sure that the blood always flows freely in a forward direction and that there is no backward leakage.



Heart Valve Disease

- ***Valvular stenosis:*** this occurs when a valve opening is smaller than normal due to stiff or fused leaflets. (hardened, restricting blood flow)
- ***Valvular insufficiency:*** also called leaky valve, this occurs when a valve does not close tightly (heart has to work harder, less blood may flow)
- ***Mitral valve prolapse:*** this occurs when the mitral valve leaflets are abnormally stretchy so that as the heart beats, the mitral valve bows or flops back into the left atrium.

Valve disease can develop before birth ***congenital*** or can be ***acquired*** sometime during one's lifetime.

- Coronary artery disease
- Heart attack
- Cardiomyopathy (heart muscle disease)
- Syphilis (a sexually transmitted disease)
- Hypertension
- Aneurysms
- Connective tissue diseases
- Tumours
- Some type of drugs and radiation

Replacement Heart Valve

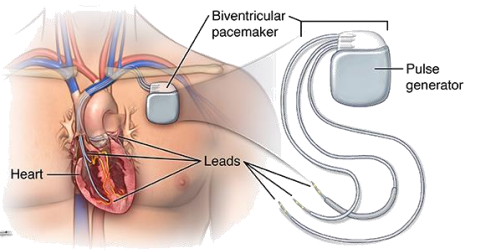
The old valve is removed and a new valve is sewn to the annulus of your old valve. The new valve can be a:

- ***Mechanical valve,*** It is made totally of mechanical parts that are tolerated well by the body. The bi-leaflet valve is used most often. It consists of two carbon leaflets in a ring covered with polyester knit fabric.
- ***Biological valve,*** also called a tissue or bio prosthetic valve, it is made of tissue taken from pigs or cows. It may also have some artificial parts to help give the valve support and sew it in place.
- ***Homograft valve,*** this type of valve may be used to replace a diseased aortic or pulmonic valve. A homograft is an aortic or pulmonic valve that has been removed from a donated human heart, preserved and frozen under sterile conditions.

Pacemakers

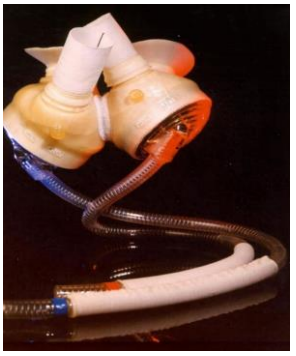
- A pacemaker is a device that sends small electrical impulses to the heart muscle to maintain a suitable heart rate. Pacemakers primarily prevent the heart from beating too slowly.
- The pacemaker has a pulse generator (which houses the battery and tiny computer) and leads (wires) that send impulses from the pulse generator to the heart muscle. Newer pacemakers have many sophisticated features that are designed to help manage arrhythmias and optimise heart-rate-related function as much as possible.
- Pacemaker designs began in the early 1950s. Wilson Greatbatch is created with newer pacemakers in the early 1960s.

Biventricular pacemaker



Total Artificial Heart

One of the old artificial heart



Total Artificial Heart

AB5000 Ventricle:

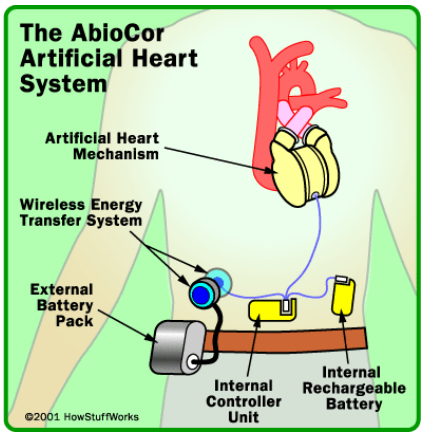
- The AB5000 Circulatory Support System provides temporary support for one or both sides of the natural heart in circumstances where the heart has failed, giving the patient's heart the opportunity to rest and potentially recover.
- The AB5000 Ventricle is vacuum assisted technology with clear housing to allow clinicians a view into the device. It use the same cannula as the BVS 5000 Blood Pumps, allowing for seamless transition of devices without requiring an additional surgical procedure

https://www.amazon.com/Abiomed-Circulatory-Support-Cardiac-Warranty/dp/B017WG7JSA

AbioCor Heart:

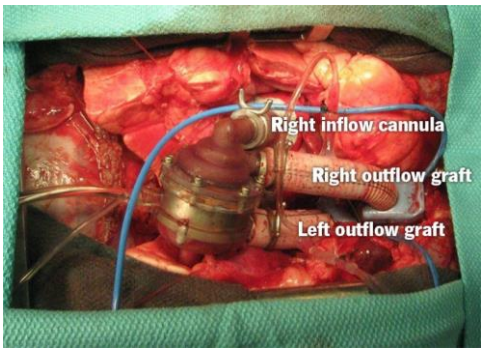
There are two type of total artificial heart , the *Cardio West* and the *AbioCor*.
The main difference between them is that Cardio West is connected to an outside power source and the AbioCor is not.

Diagram and X-ray of the AbioCor device implanted



Biocompatible Material for the total artificial heart

- Polyurethane , Pyrolytic carbon and the titanium-aluminium are the main material used to make the total artificial heart
- The titanium-aluminium-vanadium as well as the Pyrolytic carbon are the main biocompatible material for the total artificial heart
- Pyrolytic carbon material doesn't create any bad effect when implanted into human bodies, pyrolytic is Thrombosis resists blood clotting, it has durability property with a good strength

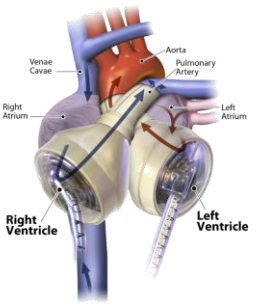


Manufacturing processes

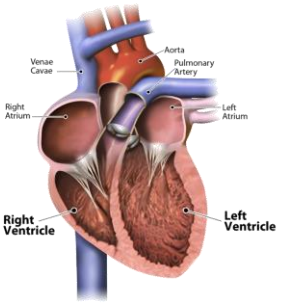
- There are several manufacturing process occurred during the fabrication of the total artificial heart, :
- ***The casting process :*** the process consists of casting the titanium material
- ***Machining:*** during the process of titanium material is machined to a specific finish referring to the design.
- ***Coating process :*** the process consists of coating the titanium microspheres
- ***The forming process*** it consists of a liquid which is poured on a ceramics layer, then it heated and dried
- ***Assembly process:*** this process is performed in a clean room to avoid contamination;
- ***Sterilisation:*** after the total artificial heart is tested and passes, it is sent to an outside service for sterilisation.

Critical issue during the design of the artificial heart

- There are several critical issues when designing a total artificial heart, the most critical issues are:
- The understanding of the blood flow fluid dynamics so that enough blood will be pumped and no blood clots will be created.
- Materials must be chosen that are biocompatible (Pyrolytic carbon) otherwise the pump could fail.
- The design size of the final product, most the total artificial heart is big can't fit into a child chest.



Total Artificial Heart

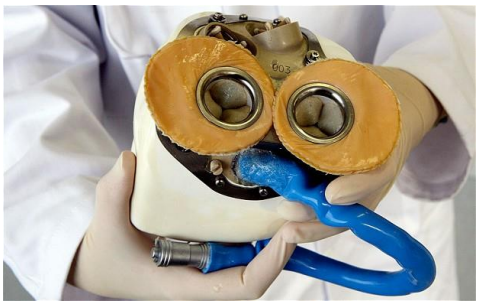


Human Heart

What Are the Risks of a Total Artificial Heart?

Getting a total artificial heart (TAH) involves some serious risks. These risks include:

- blood clots
- bleeding
- infection
- Devices malfunctions , power fail
- There is small risks of death during the surgery, because of these risks, only a small number of people currently have TAHs.



- The total artificial heart can beat up 100,000 times every 24 hours , the devices always need maintenance or power charging ;Medical doctors and engineers are working in research teams in order to created a total artificial heart that can offer a pumping function similar to the natural heart

https://www.telegraph.co.uk/news/worldnews/europe/france/10532427/France-implants-its-first-artificial-heart.html