6.2 The blood system & D4 – The Heart

Essential idea: The blood system continuously transports substances to cells and simultaneously collects waste products.

The image shows a capillary in adipose tissue (body fat). You can clearly see the red blood cells in the capillary lumen. Pores in the capillary wall allows plasma to leak into surrounding tissues facilitating the exchange of substances with body tissues.

By Chris Paine

https://bioknowledgy.weebly.com/

http://medcell.med.yale.edu/histology/blood_vessels_lab/images/capillary.jpg

6.2 -Understandings

	Statement	Guidance
6.2.U1	Arteries convey blood at high pressure from the ventricles to the tissues of the body.	
6.2.U2	Arteries have muscle cells and elastic fibres in their walls.	
6.2.U3	The muscle and elastic fibres assist in maintaining blood pressure between pump cycles.	
6.2.U4	Blood flows through tissues in capillaries. Capillaries have permeable walls that allow exchange of materials between cells in the tissue and the blood in the capillary.	
6.2.U5	Veins collect blood at low pressure from the tissues of the body and return it to the atria of the heart.	
6.2.U6	Valves in veins and the heart ensure circulation of blood by preventing backflow.	
6.2.U7	There is a separate circulation for the lungs.	
6.2.U8	The heart beat is initiated by a group of specialized muscle cells in the right atrium called the sinoatrial node.	
6.2.U9	The sinoatrial node acts as a pacemaker.	
6.2.U10	The sinoatrial node sends out an electrical signal that stimulates contraction as it is propagated through the walls of the atria and then the walls of the ventricles.	
6.2.U11	The heart rate can be increased or decreased by impulses brought to the heart through two nerves from the medulla of the brain.	
6.2.U12	Epinephrine increases the heart rate to prepare for vigorous physical activity.	

6.2 - Applications and Skills

	Statement	Guidance
6.2.A1	William Harvey's discovery of the circulation of the blood with the heart acting as the pump.	
6.2.A2	Pressure changes in the left atrium, left ventricle and aorta during the cardiac cycle.	
6.2.A3	Causes and consequences of occlusion of the coronary arteries.	
6.2.S1	Identification of blood vessels as arteries, capillaries or veins from the structure of their walls.	
6.2.S2	Recognition of the chambers and valves of the heart and the blood vessels connected to it in dissected hearts or in diagrams of heart structure.	

D4 - Understandings

	Statement	Guidance
D4. U1	Structure of cardiac muscle cells allows propagation of stimuli through the heart wall.	Include branching and intercalated discs in structure of cardiac muscle
D4. U2	Signals from the sinoatrial node that cause contraction cannot pass directly from atria to ventricles	
D4. U3	There is a delay between the arrival; and passing on of a stimulus at the atrioventricular node.	
D4. U4	This delay allows time for atrial systole before the atrioventricular valves close	
D4. U5	Conducting fibres ensure coordinated contraction of the entire ventricle wall.	
D4. U6	Normal heart sounds are caused by the atrioventricular valves and semilunar values closing causing changes in blood flow.	

D4 - Applications and Skills

	Statement	Guidance
D4. A1	Use of artificial pacemakers to regulate heart rate	
D4. A2	Use of defibrillation to treat life-threatening cardiac conditions	
D4. A3	Causes and consequences of hypertension and thrombosis	
D4. S1	Measurement and interpretation of the heart rate under different conditions.	
D4. S2	Interpretation of systolic and diastolic blood pressure measurements	
D4. S3	Mapping of the cardiac cycle to a normal ECG trace	
D4. S4	Analysis of epidemiological data relating to the incidence of coronary heart disease	

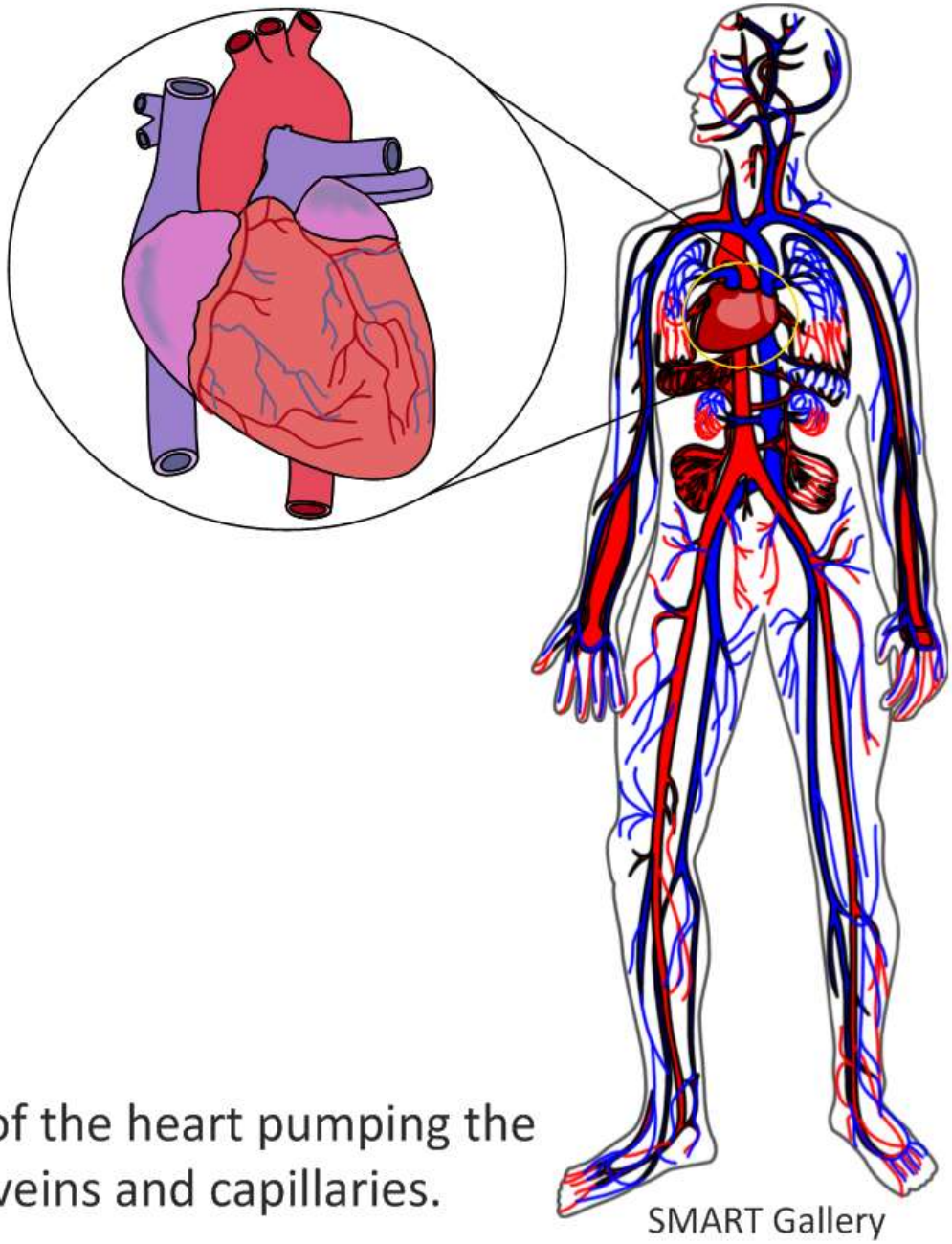
The Transport System

The following are transported around the body in the blood:

- oxygen
- nutrients

- antibodies
- hormones
- heat

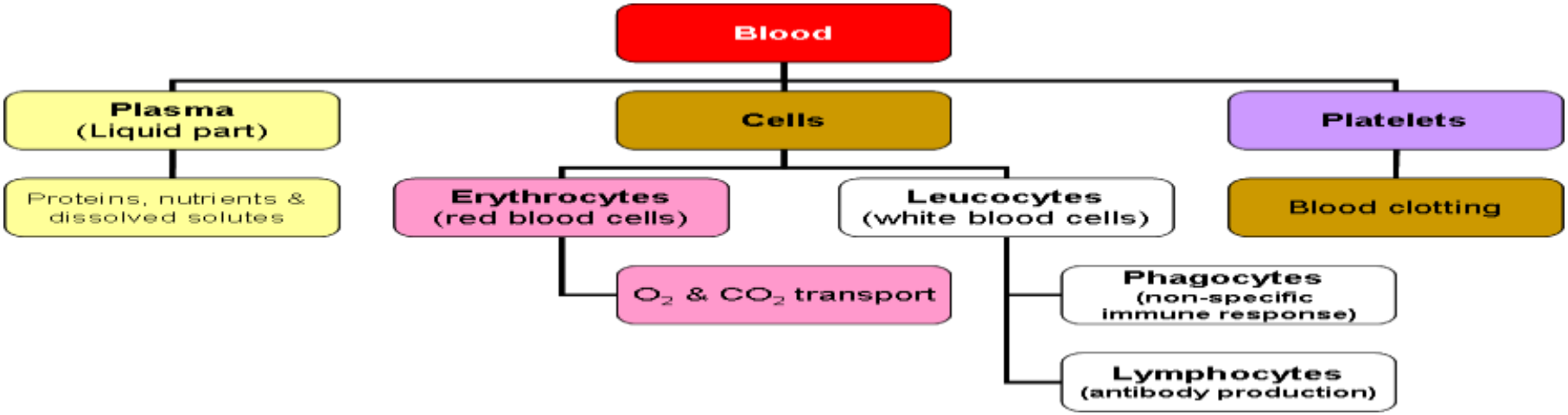
- carbon dioxide
- urea



SMART Gallery

This is achieved through the beating of the heart pumping the blood through a network of arteries, veins and capillaries.

Blood Composition



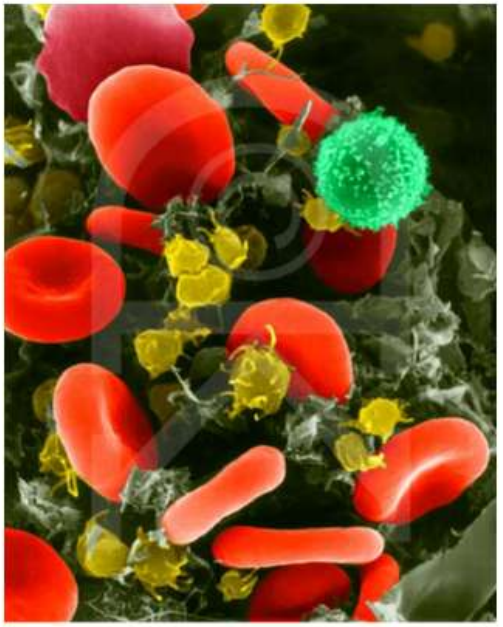
Components of Blood

Plasma

Dissolves or carries all other components of blood, nutrients, wastes.

Erythrocytes (Red blood cells)

Transport oxygen in haemoglobin molecules.



http://www.denniskunkel.com/

Leucocytes (White blood cells)

Phagocytes 'eat up' pathogens and dead cells.
Lymphocytes (B-cells, T-cells) for the immune response.

Platelets

Clotting of blood following damage to cells or erythrocytes.

http://www.esnips.com/doc/d6a51b8b-feb9-41f7-adaa-f3d6d495d66f/Blood

Blood Vessels: Structure and Function

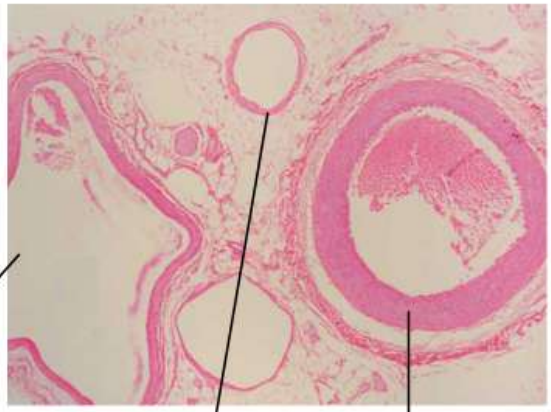
There are three main types of blood vessel:

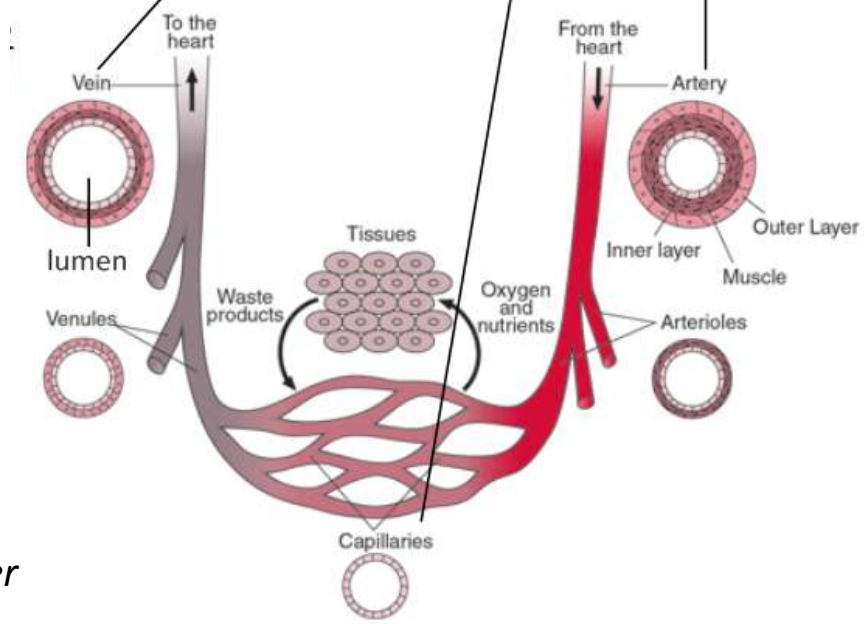
Arteries carry high pressure blood away from the heart to tissues that need it

Capillaries are very small (< 10 µm diameter) and therefore can penetrate virtually every tissue in the body. Blood moves slowly through them under low pressure providing opportunities for the exchange of substances.

Veins carry the low pressure blood back to the heart using valves to ensure blood flows in the correct direction.

n.b. arteries and veins tend to be large structures, smaller arteries are known as arterioles and correspondingly smaller veins are venules.





http://www.bioclix.org/images/arteryvein.jpg

http://www.merck.com/media/mmhe2/figures/MMHE_03_020_03_eps.gif

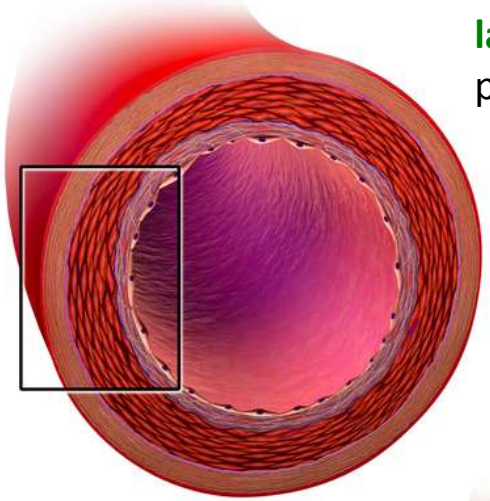
The structure of arteries

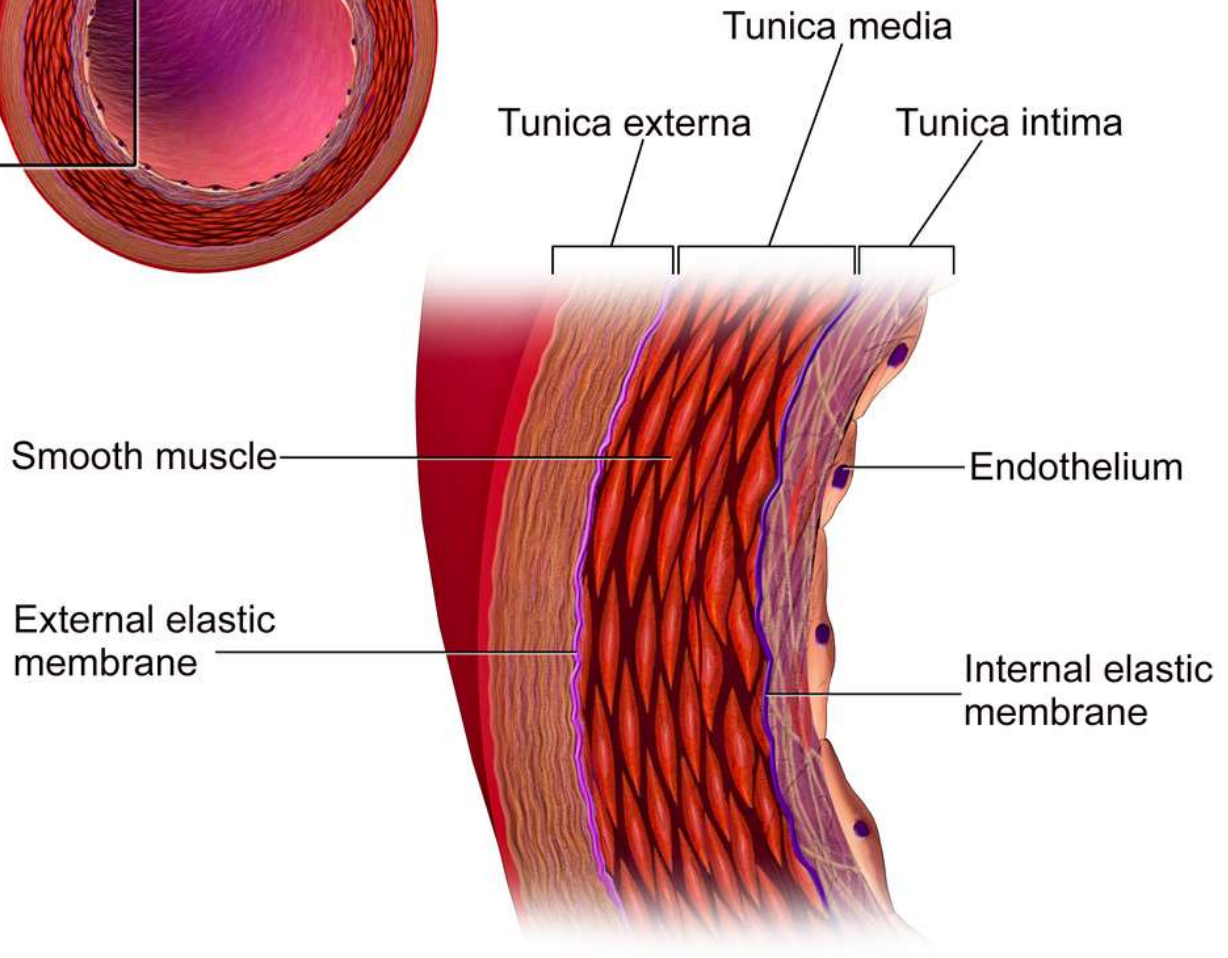
Relatively (to the wall) **small lumen** maintains **high blood pressure**.

Muscle contracts to decrease the size of the lumen. This causes an increase blood pressure and therefore maintains high blood pressure between the pulses of high pressure blood travelling from the heart.

Elastic fibres stretch to increase the lumen with each pulse of blood. After the pulse of blood passes the fibres recoil decreasing the lumen size and therefore helping to maintain a high blood pressure.

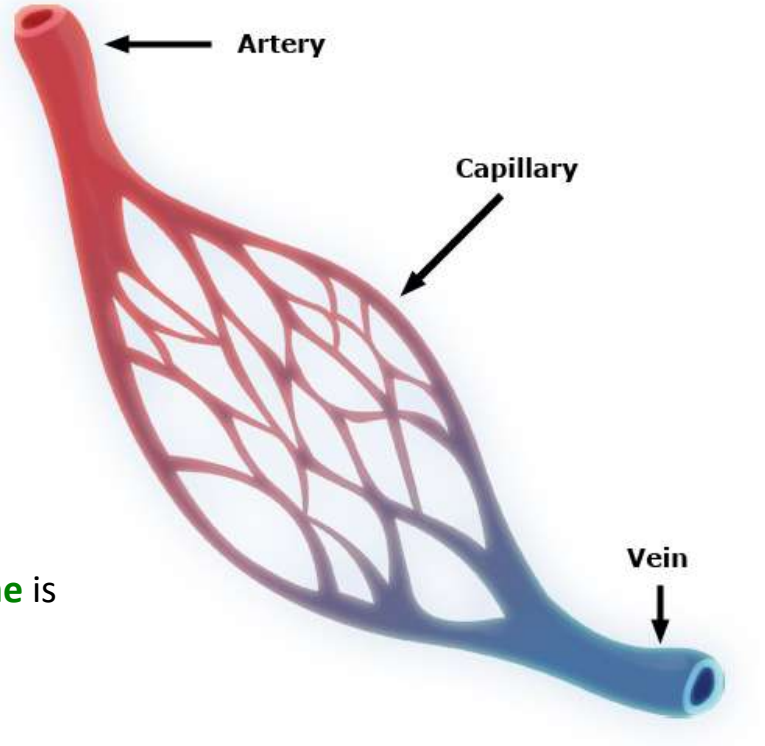
Thick muscular wall and fibrous outer layer help the artery to withstand high pressure





https://commons.wikimedia.org/wiki/File:Blausen_0055_ArteryWallStructure.png

The structure of capillaries



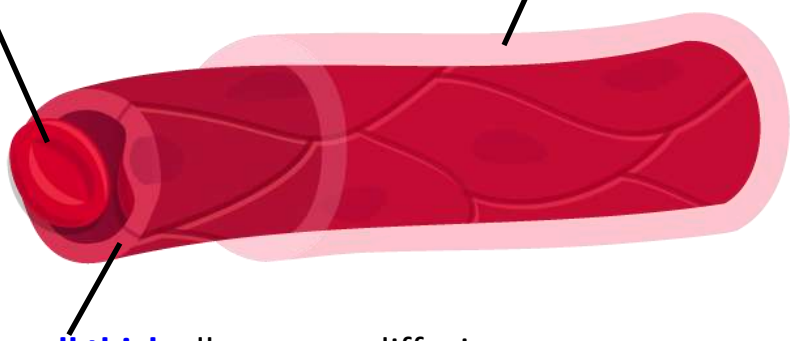
Capillaries are the smallest blood vessels and are adapted for the exchange of substances to and from the blood.

This enables tissues to gain nutrients and molecules such as oxygen and to rid themselves of waste material.

Capillaries also allow substances to enter and leave the organism, e.g. gas exchange of oxygen and carbon dioxide in the lungs.

Blood travels **slowly** under **low pressure** allowing more opportunity for exchange.

Basement membrane is **permeable** to many substances



Wall is one cell thick allows easy diffusion of substances in and out of the capillary due to the short diffusion distance.

Due the the massive number of capillaries present and the small lumen the surface area available for the exchange of substances is very large.

The walls and membrane can contain **pores** to further aid the diffusion of substances

Image adapted from: https://commons.wikimedia.org/wiki/File:Capillary.svg
https://commons.wikimedia.org/wiki/File:Capillary_system_CERT.jpg

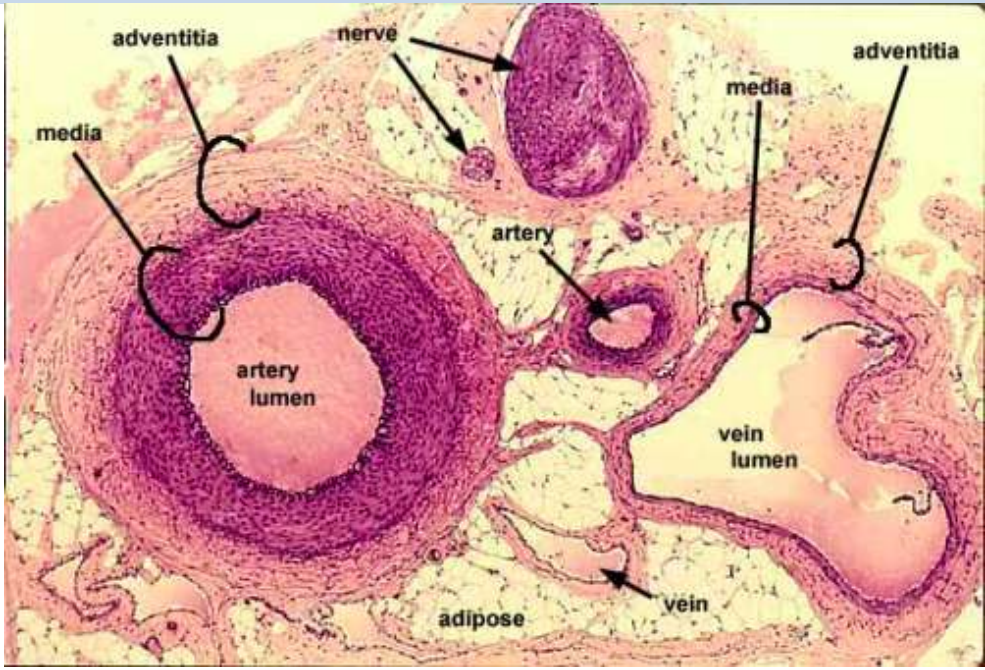
6.2.U5 Veins collect blood at low pressure from the tissues of the body and return it to the atria of the heart. AND
6.2.U6 Valves in veins and the heart ensure circulation of blood by preventing backflow.

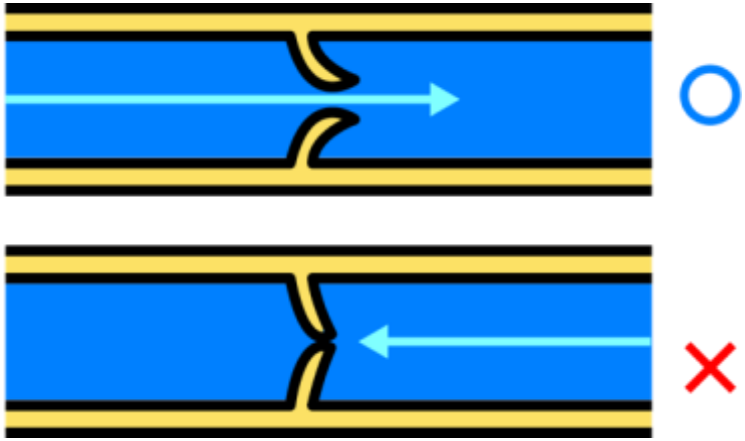
The structure of veins

Veins return blood to the heart for re-circulation.

The **large lumen** (compared to arteries and the thickness of the wall) means that the blood is under **low pressure**.

Because there is less pressure to resist the **walls of the veins are thinner and less elastic** than arteries. They also contain **less muscle** than the arteries.



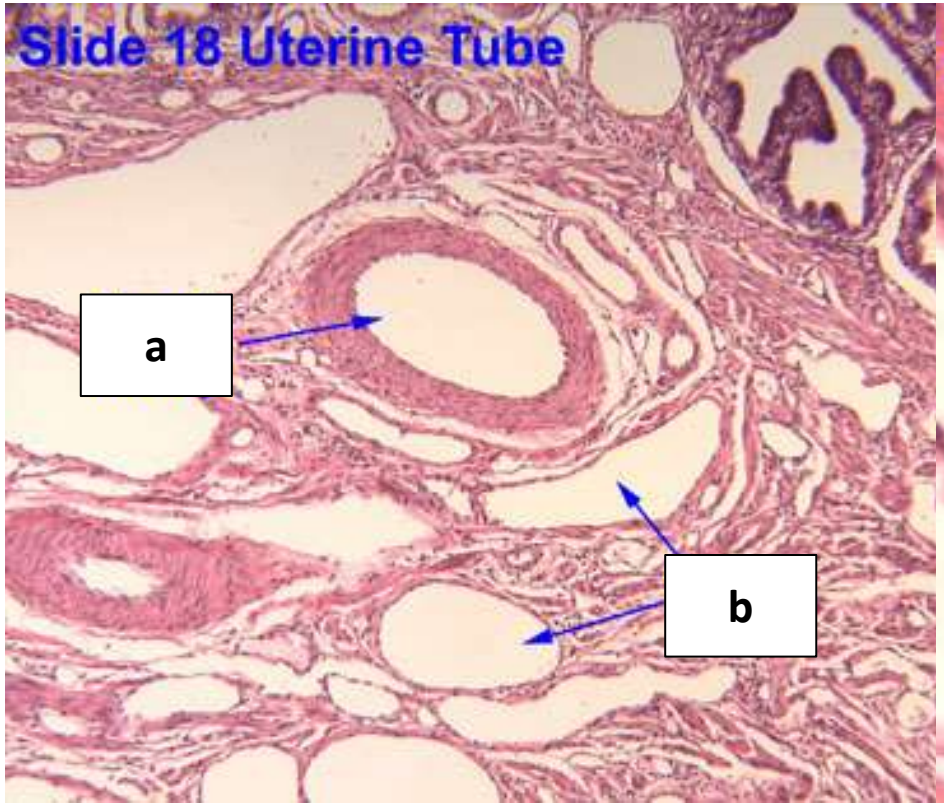


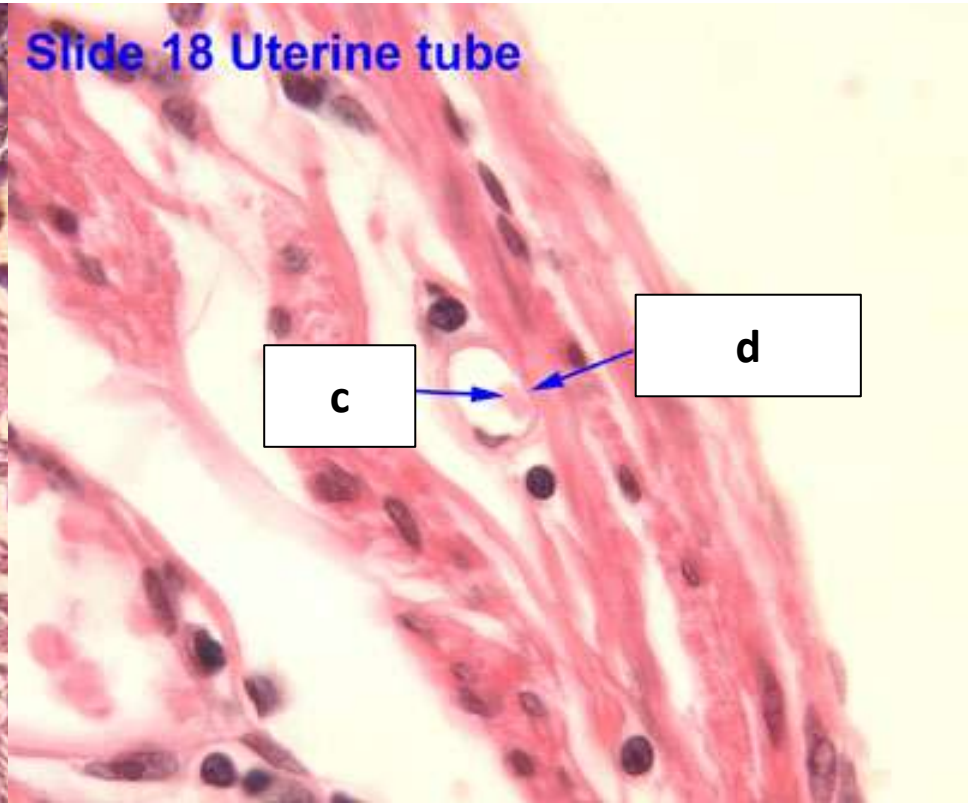
Because of the low pressure **valves are required to prevent back-flow of the blood** and therefore ensure that the blood moves towards to heart.

http://40.media.tumblr.com/tumblr_m0dwjt3WKQ1qzcf71o1_500.jpg

https://commons.wikimedia.org/wiki/File:Venous_valve.svg

Identify the labelled structures using your understanding of blood vessels.





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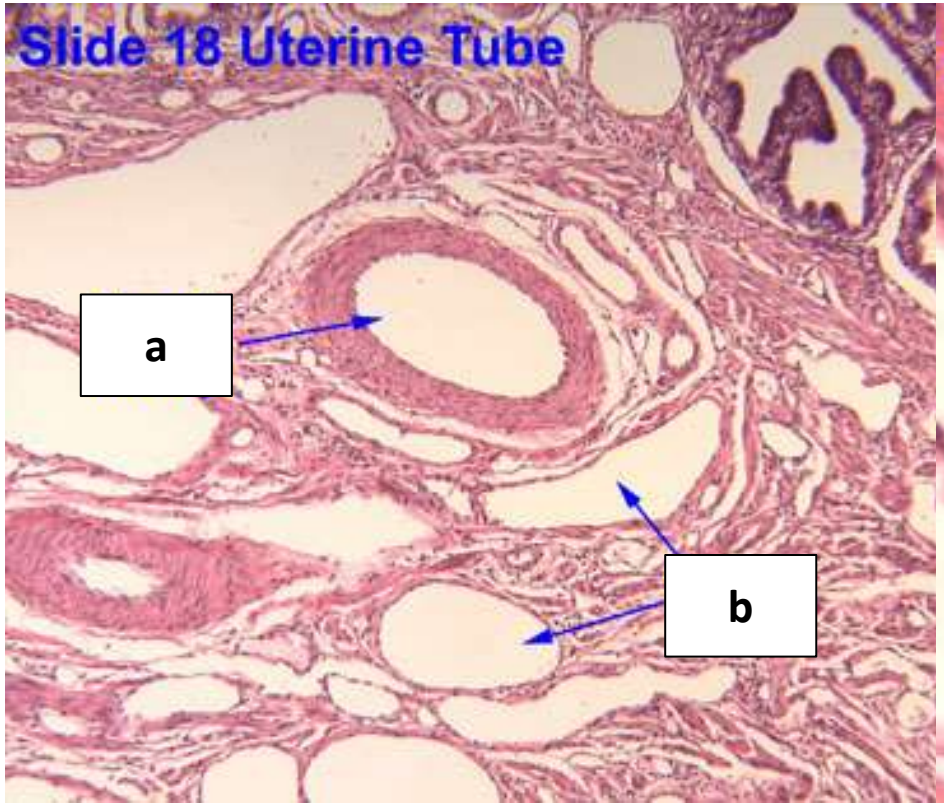

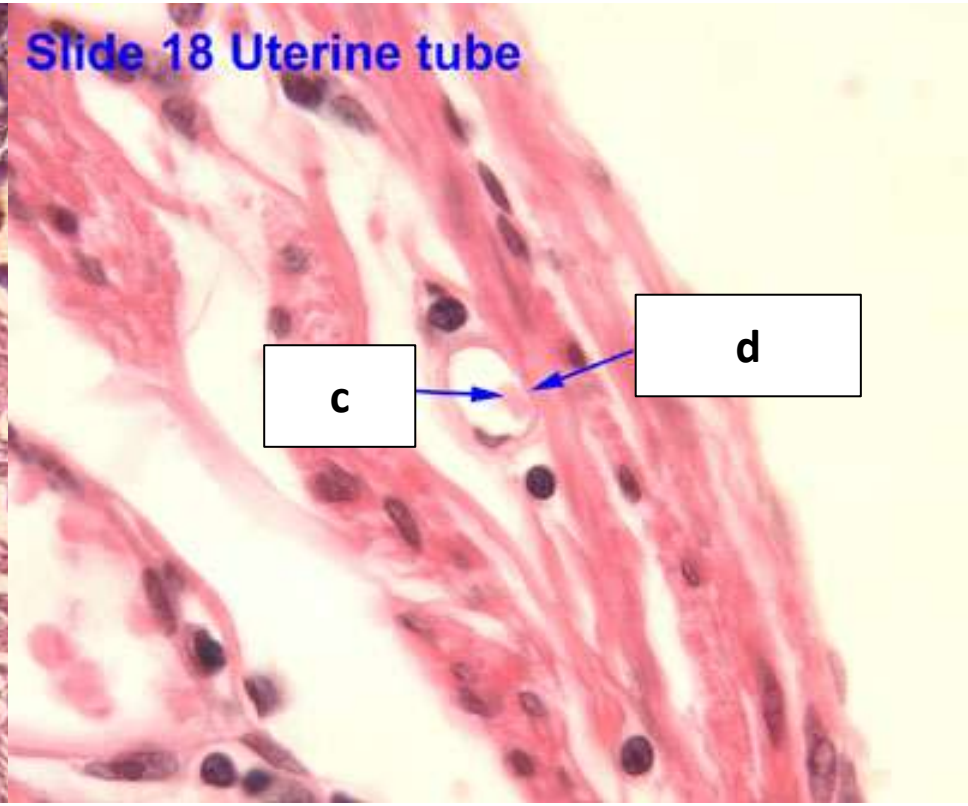

https://www.ouhsc.edu/histology/Text%20Sections/Cardiovascular.html

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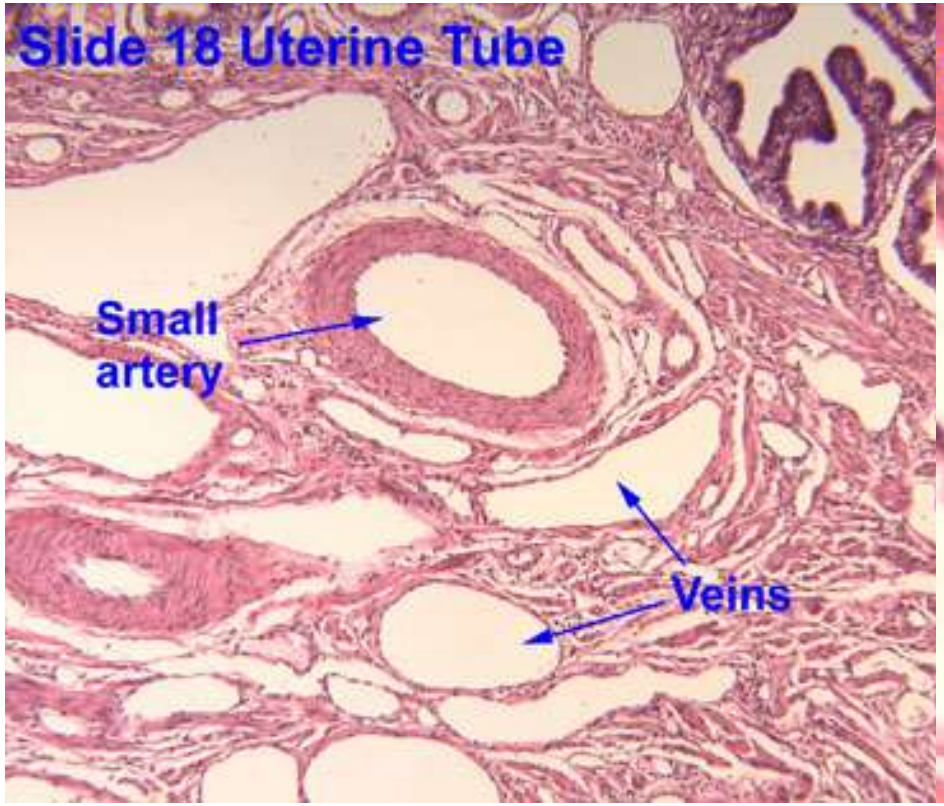
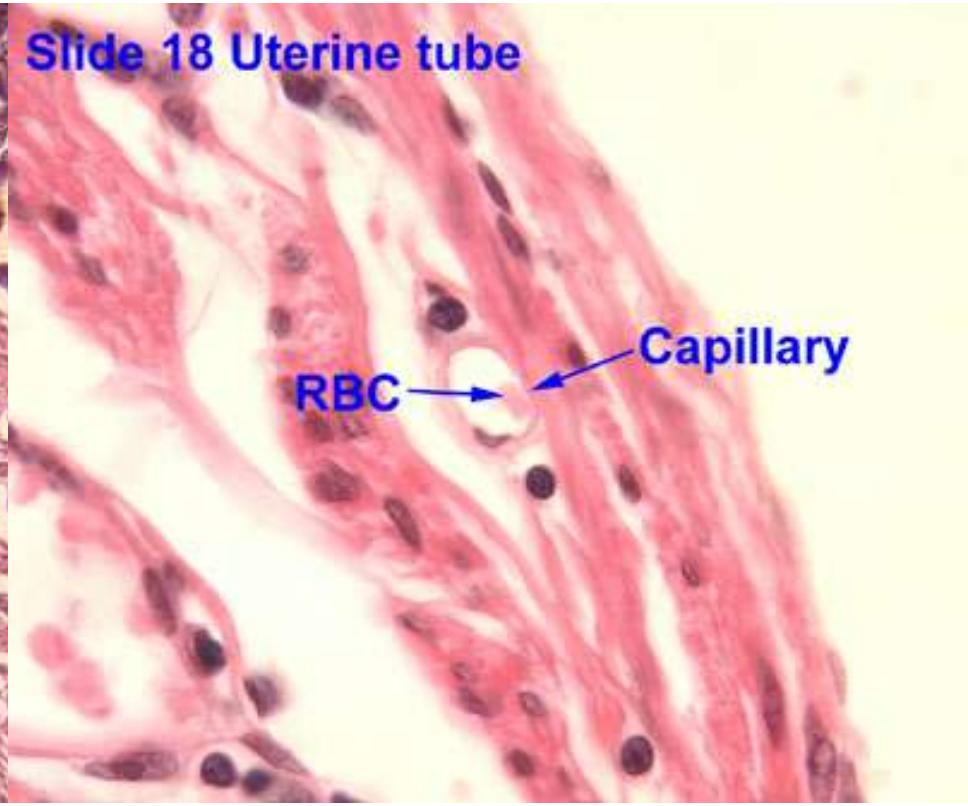


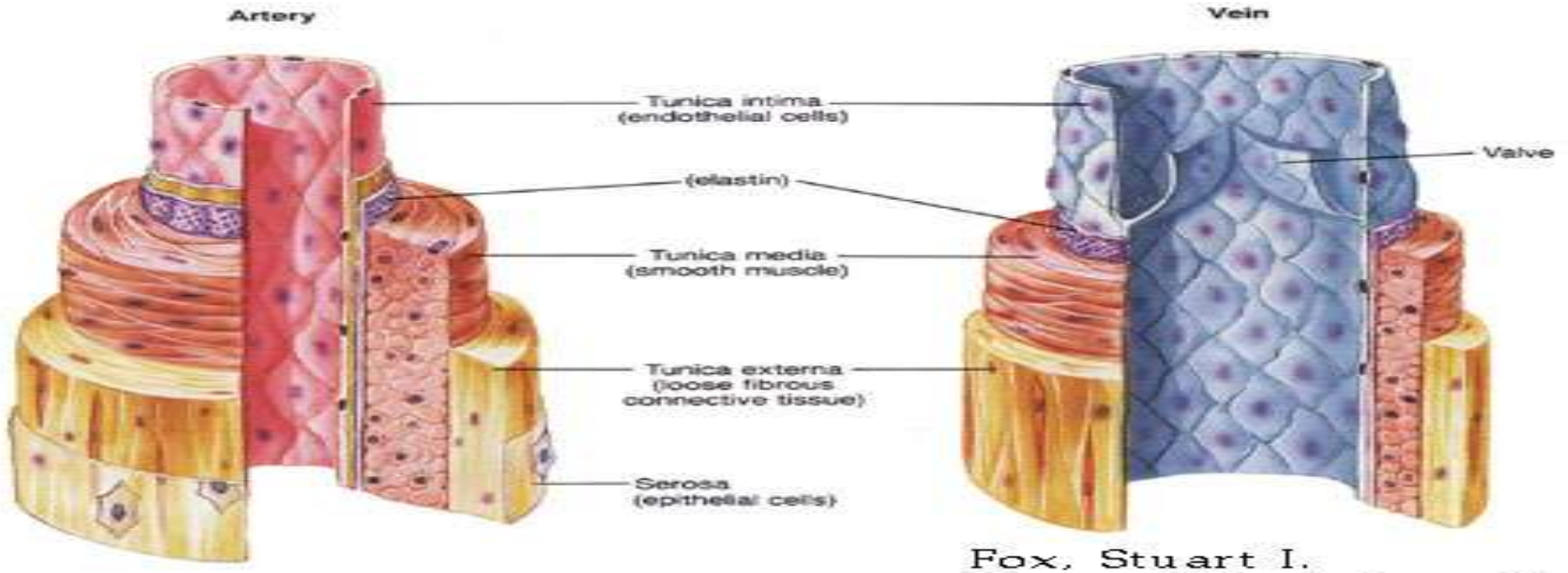


https://www.ouhsc.edu/histology/Text%20Sections/Cardiovascular.html

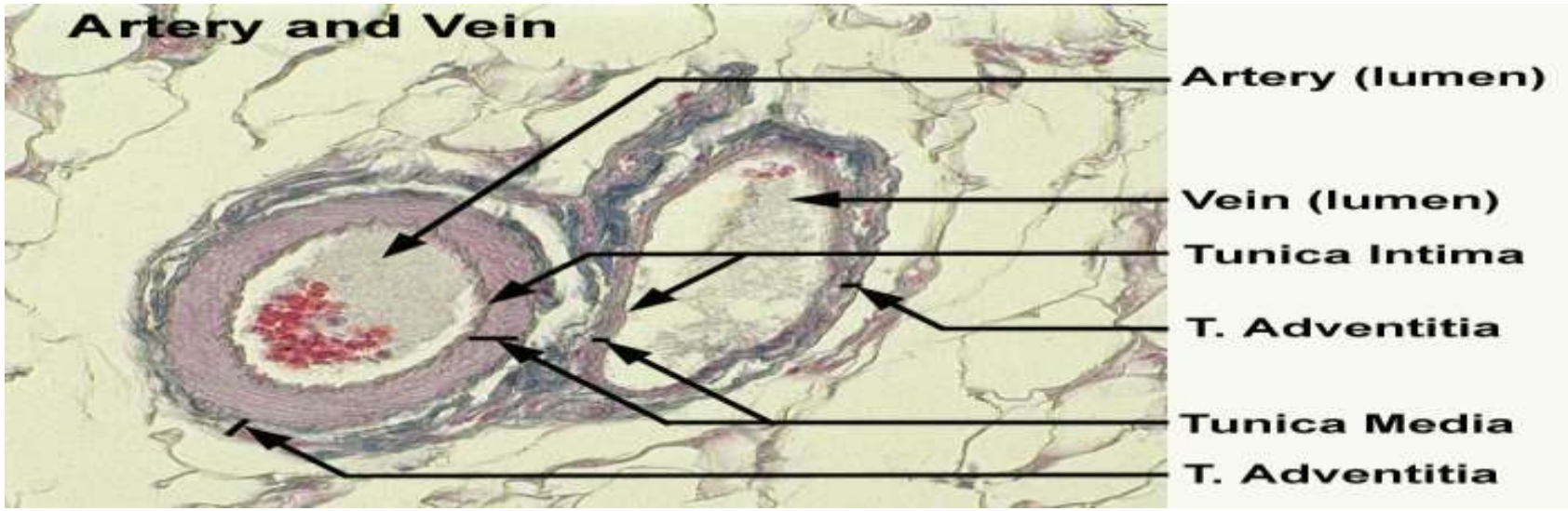
Blood Vessels

ARTERIES	CAPILLARIES	VEINS
Move blood away from the heart	Exchange of materials between blood and tissues	Move blood towards the heart
Has thick muscular walls	Thin walls 1 cell layer thick	Has thin walls
Narrow lumen	1 cell at a time	Wide lumen
No valves	No valves	Valves to prevent backflow
Move blood at high speed	Move blood at low speed. Cells move single file	Move blood at moderate speed
High pressure (blood spurts)	Low pressure	Low pressure (blood flows)
Generally O2 rich (bright red blood)	Links arterioles and venules	Generally O2 low (dark red blood)

Blood Vessels



Fox, Stuart I.
Human Physiology 4th
Brown Publishers



6.2.A1 William Harvey's discovery of the circulation of the blood with the heart acting as the pump.

William Harvey was an English physician who made a key contribution to our knowledge of anatomy and physiology. He was the first to describe completely the systemic circulation.

Repeat Harvey's experiment with guidance from The Naked Scientists:

- http://www.thenakedscientists.com/HTML/experiments/exp/veins/

Learn more about him:

- http://www.indiana.edu/~liblilly/anatomia/bloodcirc.html
- http://www.bbc.co.uk/history/historic_figures/harvey_william.shtml
- http://www.sciencemuseum.org.uk/broughttolife/people/williamharvey.aspx

https://commons.wikimedia.org/wiki/File:William_Harvey_%281578-1657%29_Venenbild.jpg

http://md.rcm.upr.edu/romanfranco/wp-content/uploads/sites/41/2015/02/harveypic.jpg

Nature of Science: Theories are regarded as uncertain - William Harvey overturned theories developed by the ancient Greek philosopher Galen on movement of blood in the body. (1.9)

Theories are by definition the **best accepted explanations** and predictions of **natural phenomena**. Although they are usually thoroughly tested based on evidence and reason theories theories are the only the current best accepted explanation. Theories if successfully questioned can be modified or even **rejected/falsified** if a better explanation arises.

Galen (129 - c216) thought that "blood is created in the liver from ingested food and flows to the right side of the heart. Some of it flows to the lungs where it gives off 'sooty vapors' and some flows through invisible pores into the left side of the heart, where it gains 'vital spirits' when mixed with pneuma brought in by the trachea."

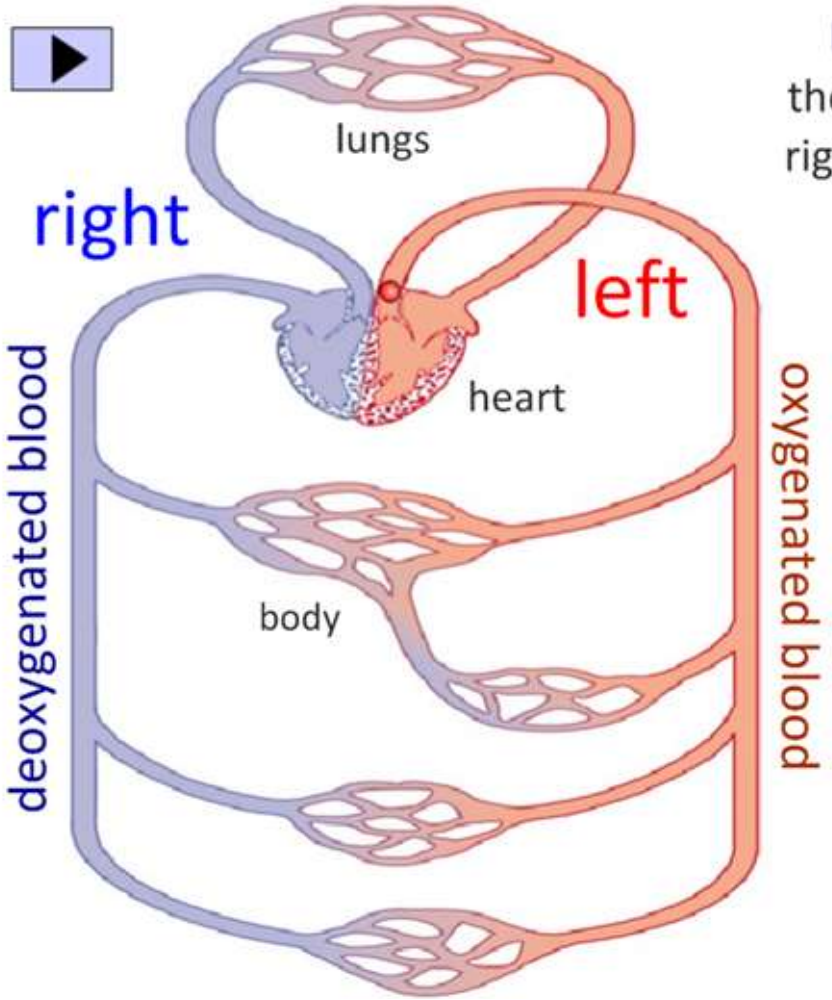
http://membercentral.aaas.org/blogs/scientia/circulatory-system-galen-harvey

Galen's ideas were first challenged by by an Arab physician, Ibn-al-Nafiz in the thirteenth century, but despite this Galen's theory remained accepted by society until William Harvey (1578 - 1657) published "De Motu Cordis" in 1628. Even then it took many years for his theory of systemic circulation (similar to modern accepted theory) to succeed Galen's.

http://famousbiologists.org/wp-content/uploads/2013/06/galen.jpg
https://commons.wikimedia.org/wiki/File:William_Harvey_%281578-1657%29_Venenbild.jpg
http://md.rcm.upr.edu/romanfranco/wp-content/uploads/sites/41/2015/02/harveypic.jpg

Double Circulation

Blood passes through the heart twice on one circuit of the body.



Deoxygenated blood (low O_2, high CO_2) returns to the heart via the right atrium. It is pumped from the right ventricle to the lungs, where carbons dioxide is offloaded and oxygen is picked up.

It is now oxygenated blood (high O_2, low CO_2).

Oxygenated blood enters the left atrium and is pumped from the left ventricle to the body, where oxygen is used for respiration and carbon dioxide is collected as a waste product.

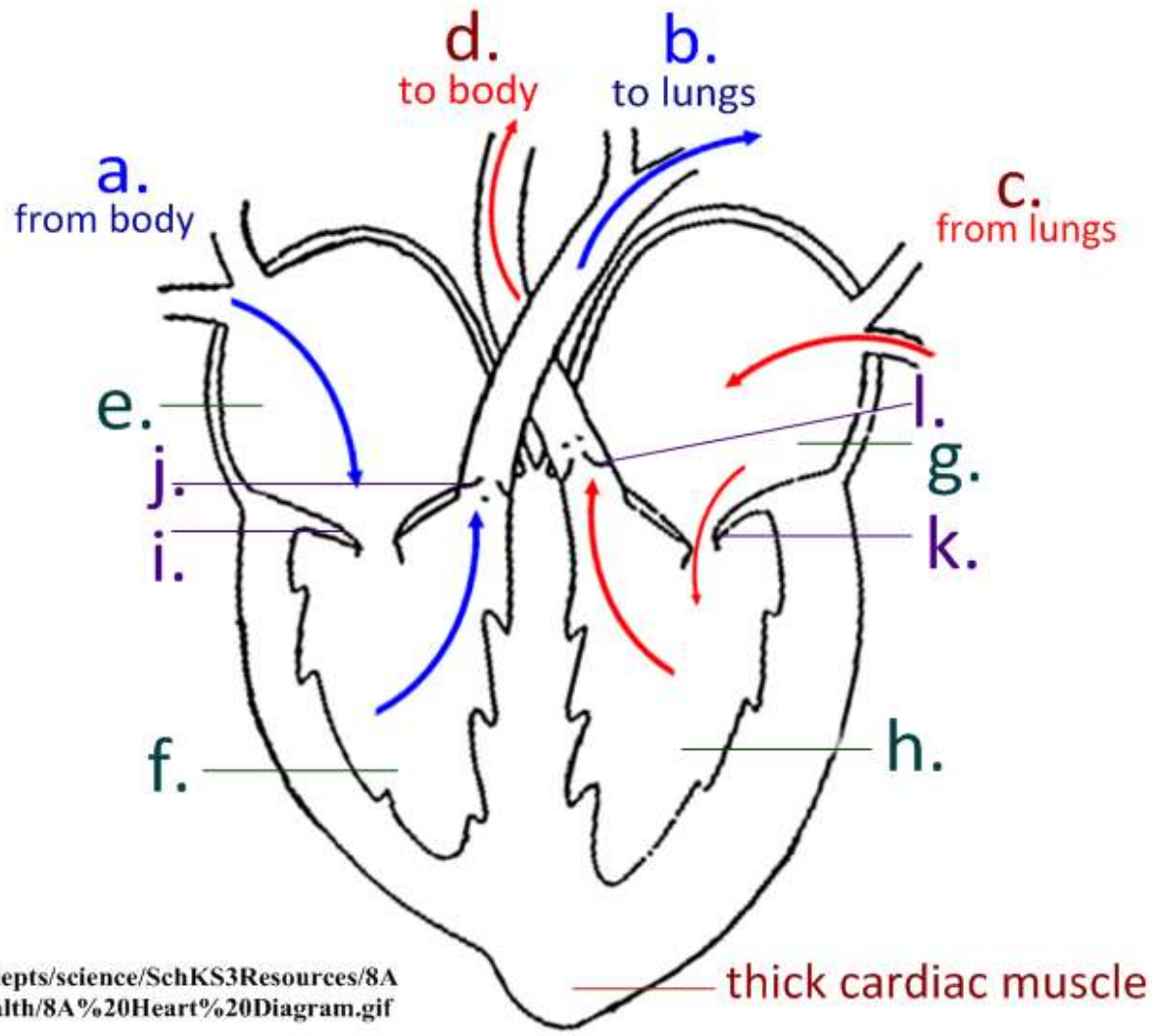
And now it's deoxygenated, it makes its way back to the right atrium and the cycle continues.

http://www.kscience.co.uk/animations/blood_system.swf

6.2.S2 Recognition of the chambers and valves of the heart and the blood vessels connected to it in dissected hearts or in diagrams of heart structure.

Label the heart diagram

R I G H T



L E F T

Image from:
http://www.pcc-web.com/depts/science/SchKS3Resources/8A%20Energy%20&%20Health/8A%20Heart%20Diagram.gif

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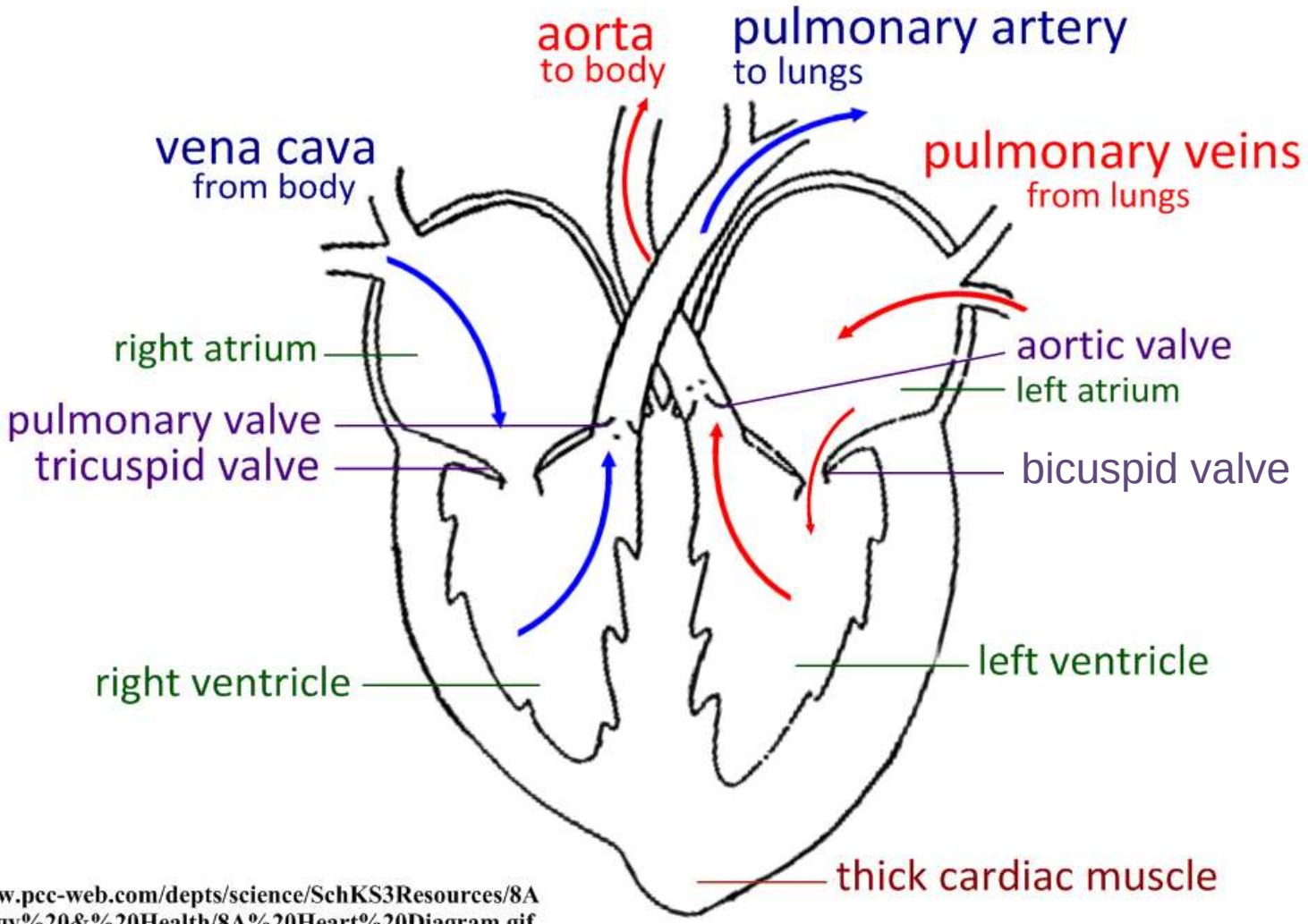
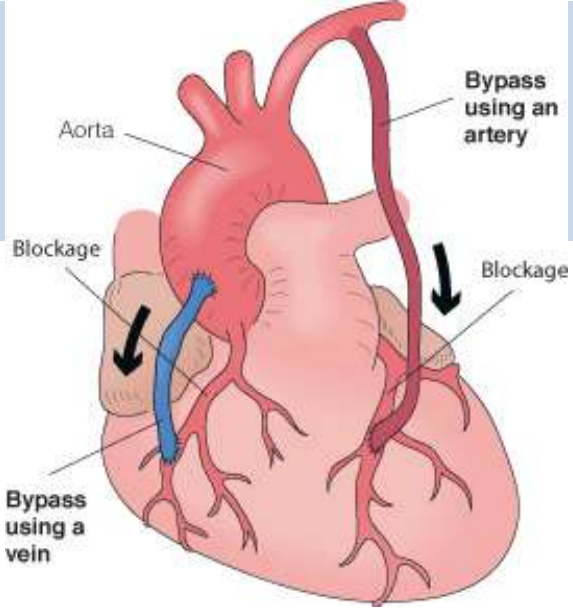


http://www.pcc-web.com/depts/science/SchKS3Resources/8A%20Energy%20&%20Health/8A%20Heart%20Diagram.gif

Now try to label this heart: http://sciencelearn.org.nz/Contexts/See-through-Body/Sci-Media/Animation/Label-the-heart

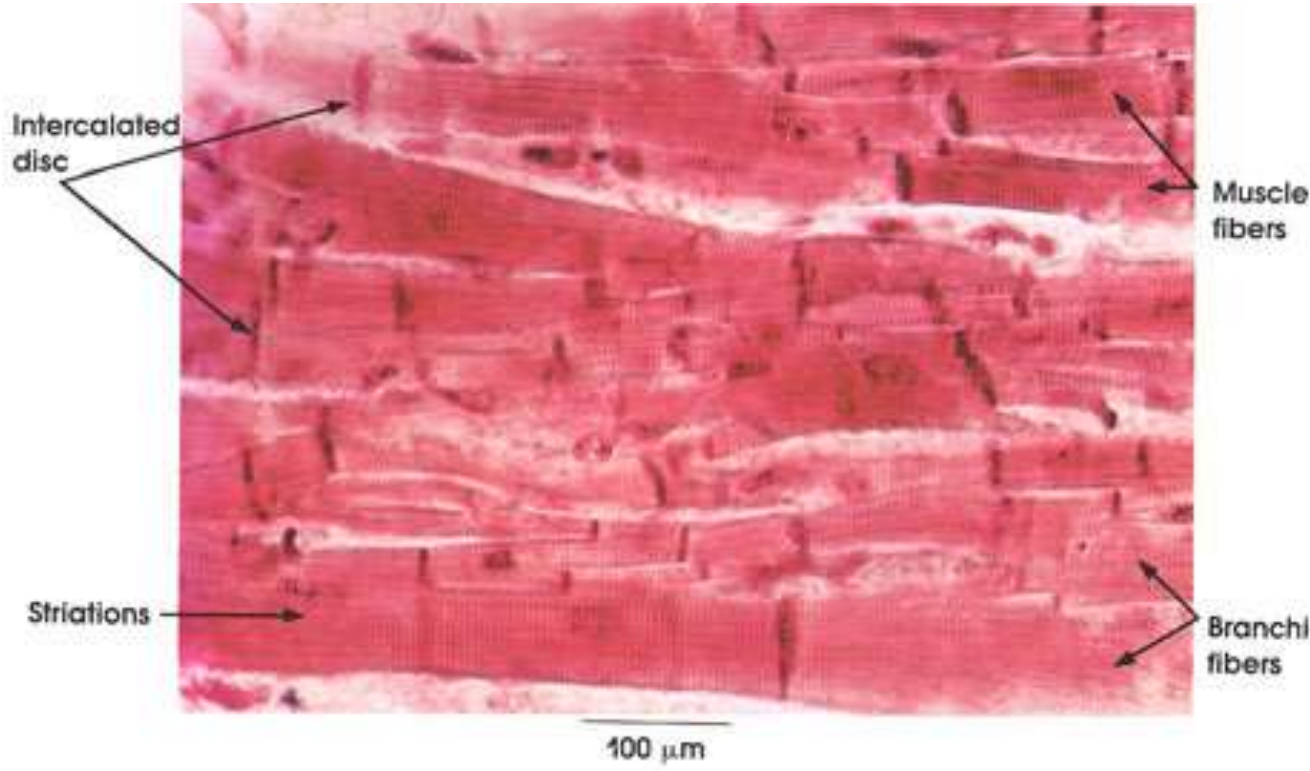
Cardiac Muscle Structure



Coronary arteries flow directly from the aorta and supply the heart muscle with oxygen and glucose

Cardiac muscle is striated and branched with intercalated discs.

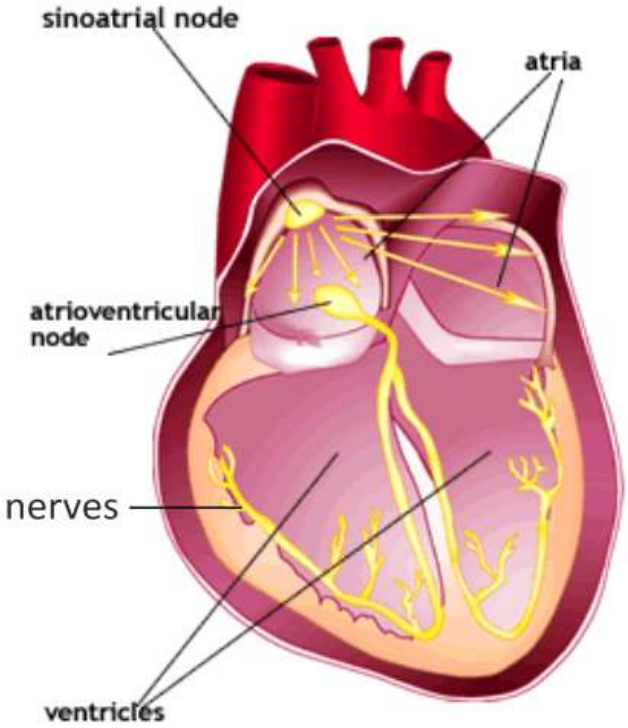
This allows nerve impulses to spread rapidly and heart muscle to contract rapidly and together



6.2.U8 The heart beat is initiated by a group of specialized muscle cells in the right atrium called the sinoatrial node. AND 6.2.U9 The sinoatrial node acts as a pacemaker. AND 6.2.U10 The sinoatrial node sends out an electrical signal that stimulates contraction as it is propagated through the walls of the atria and then the walls of the ventricles.

Control of the Heart Beat

Beating of the heart is due to myogenic muscle contraction.

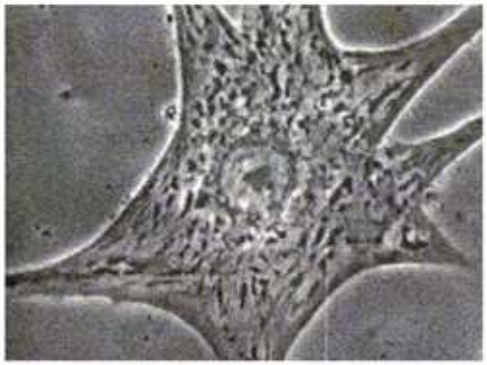


http://www.mda.org/publications/Quest/q106resup.html

This means the myocyte (muscle cell) itself is the origin of the contraction and is not controlled externally.

A region of myocytes called the sinoatrial node (pacemaker) controls the rate of the heartbeat.

Cardiac cell contracting:



http://www.emc.maricopa.edu/faculty/farabee/BIOBK/heartbeat.gif

http://www2.estrellamountain.edu/faculty/farabee/Biobk/heartbeat.gif

A wave of excitations is sent from the sinoatrial node, causing the atria to contract. This excitation is conducted to the atrioventricular node, where it is passed through nerves to the muscles of the ventricles, causing them to contract.

Myogenic initiation of the contraction means that the heart does n stop beating - it is not a conscious process.

Cardiac muscle is indefatigable - what does this mean and how would you expect the histology of it to differ from regular muscle tissue?

6.2.U11 The heart rate can be increased or decreased by impulses brought to the heart through two nerves from the medulla of the brain. AND 6.2.U12 Epinephrine increases the heart rate to prepare for vigorous physical activity.

Control of the Heart Beat

Heart rate can be controlled by the autonomic nervous system - the part of the nervous system that responds automatically to changes in body conditions.

Where myocardial contraction maintains the beating of the heart, we may need to speed up or slow down heart rate.

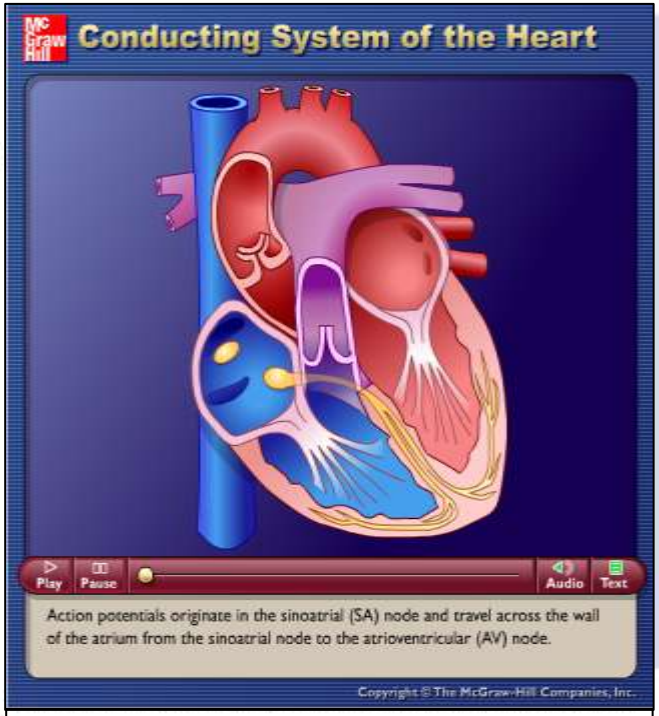
When exercising, more CO_2 is present in the blood. This is detected by chemoreceptors in the brain's medulla oblongata, resulting in a a nerve signal being sent to the SA node to speed the heart rate.

When CO_2 levels fall, another nerve (Vagus) reduces heart rate.

The hormone adrenalin causes a rapid increase in heart rate in fight-or-flight responses, preparing the body for action.

This effect can be mimicked by stimulant drugs.

n.b. adrenalin is also known as epinephrine

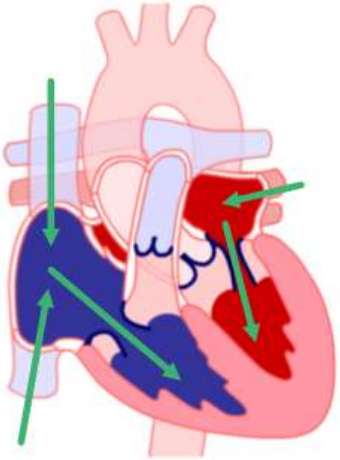


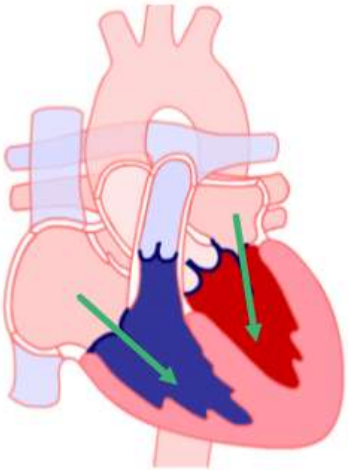
http://goo.gl/YeoeJ

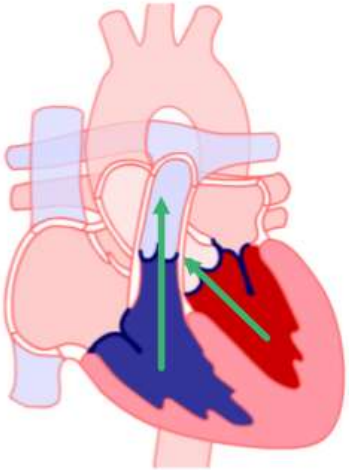
Can you convert the control of the heart beat into a flow chart?

How is it an example of negative feedback control?

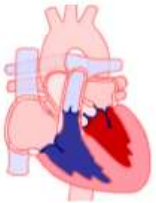
The Cardiac Cycle







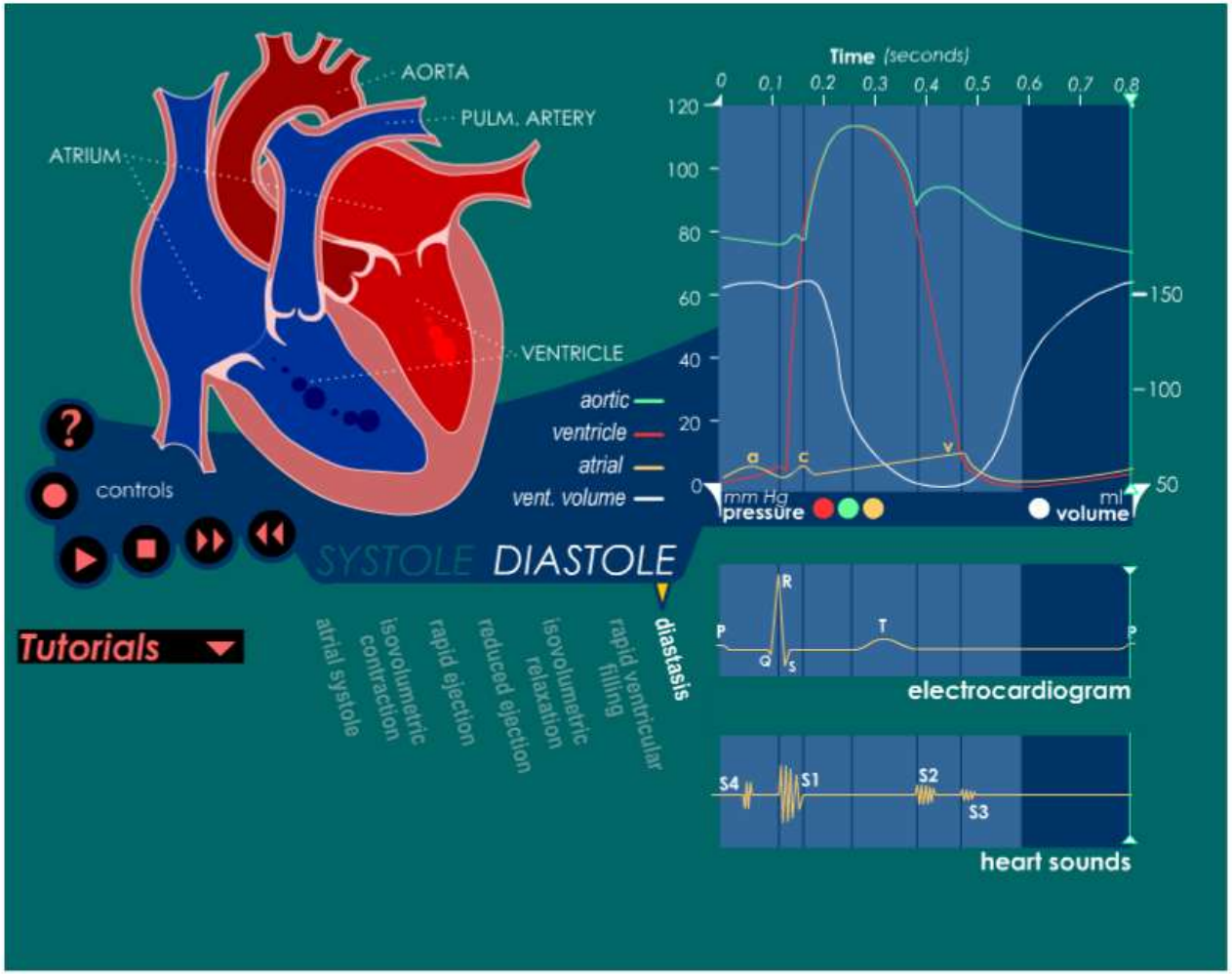
DIASTOLE	ATRIAL SYSTOLE	VENTRICULAR SYSTOLE
Atria and ventricles relaxed	Atria contract Ventricles relaxed	Atria relaxed Ventricles contract
Blood flows into heart from veins	Blood pushed into atria	Blood pushed into arteries
AV valves open	AV valves open	AV valves closed (heart sound 1)
SL valves closed (heart sound 2)	SL valves closed	SL valves closed



http://www.medmovie.com/p_in_interactives.htm

The Cardiac Cycle

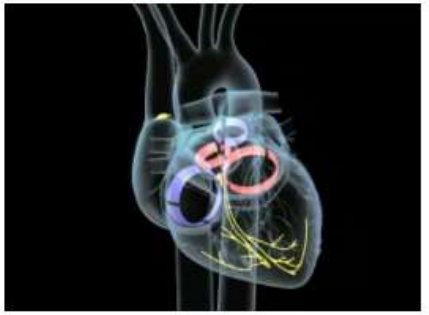
click on the tutorials for a description of what happens at each stage (opens a new webpage)



http://library.med.utah.edu/kw/pharm/hyper_heart1.html

Can you follow the actions of the heart on the graphs?

Top-quality animations available from www.medmovie.com :



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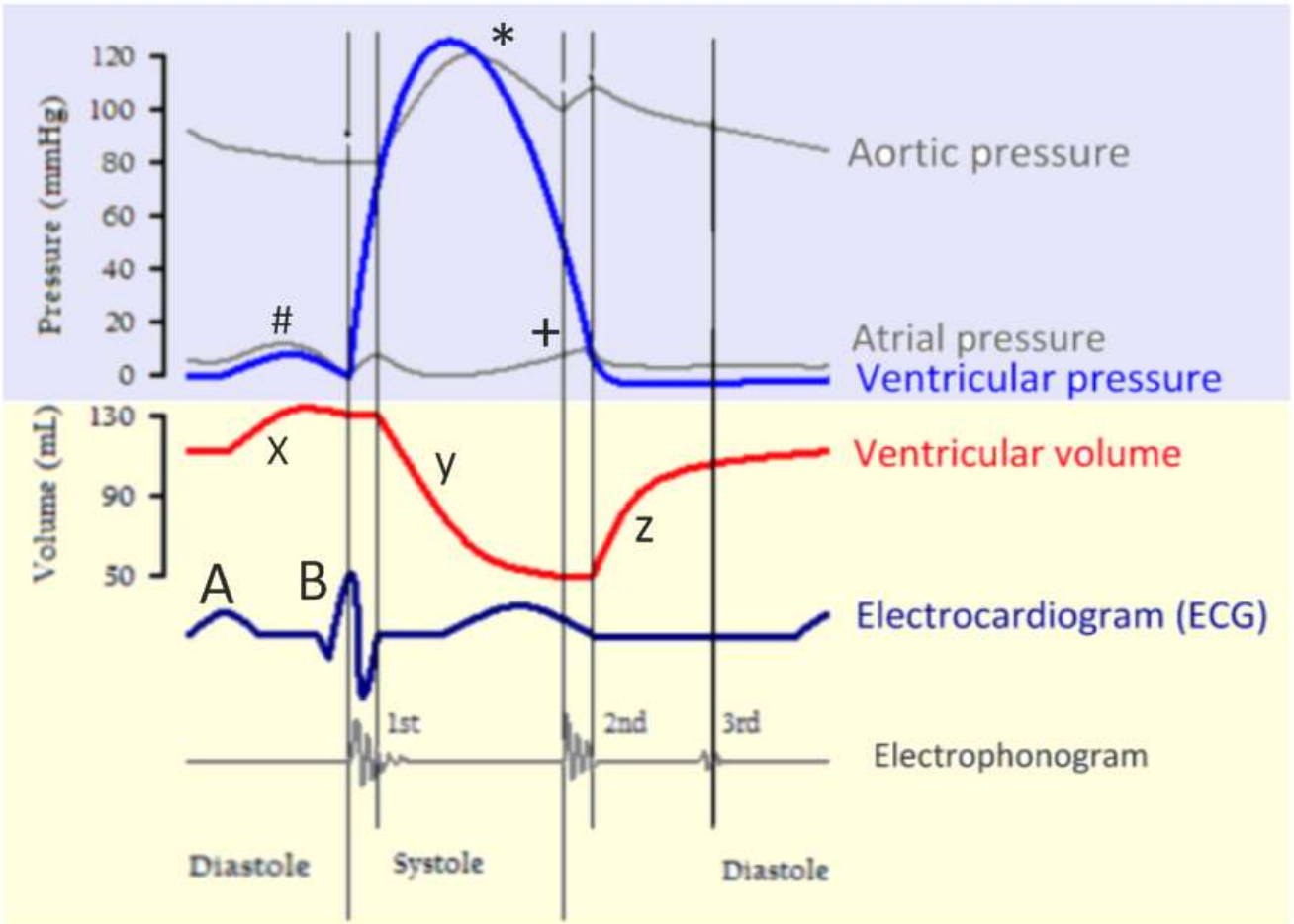
The Cardiac Cycle



* Why does the ventricular pressure increase just before the aortic pressure here?

Atrial pressure increases at points # and + but for different reasons. Why?

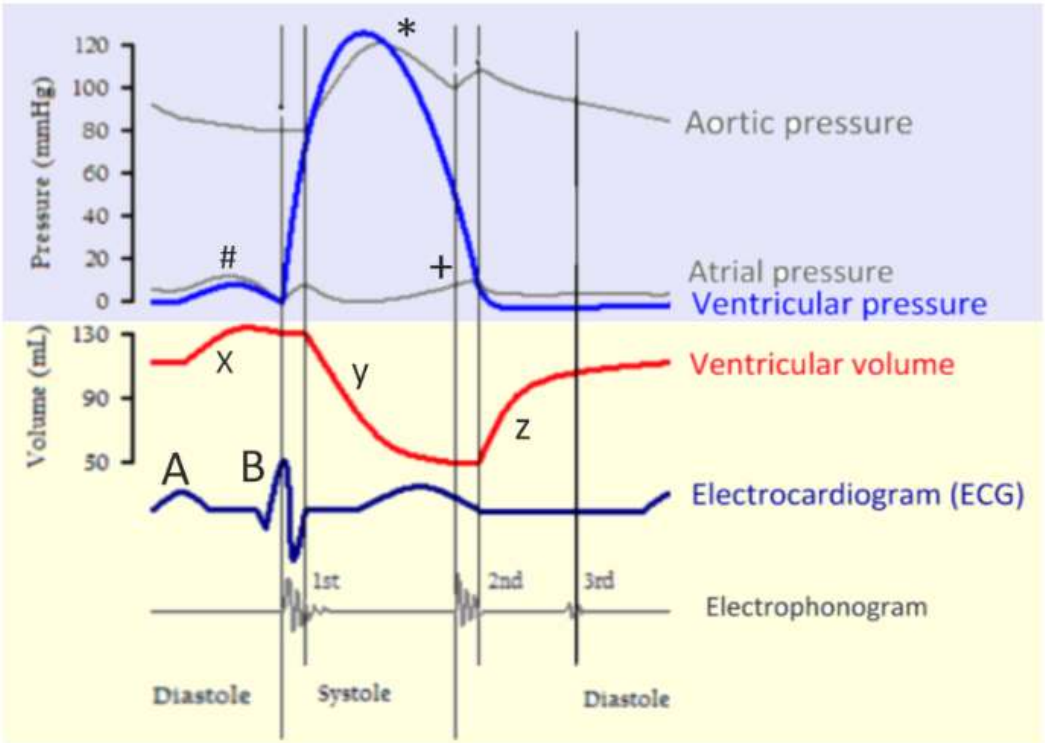
Describe what is happening to ventricular volume at points x, y and z.

A and B represent impulses sent in contractions. Which ones?

Which valves are closing to create the 1st and 2nd heart sounds?

Adapted from
http://en.wikipedia.org/wiki/Cardiac_cycle

The Cardiac Cycle



* Ventricular pressure increases as ventricle contracts. This forces blood into the aorta, increasing aortic pressure.

\# Shows the increase in atrial pressure die to atrial contraction.
\+ Shows the increase in atrial pressure due to the inflow of blood returning to heart from the veins following systole.

Ventricular volume:
- x - increases as atrial contraction forces blood into the ventricle
- y - decreases as ventricular contraction forces blood into the aorta
- z - increases as blood returns to the heart following systole.

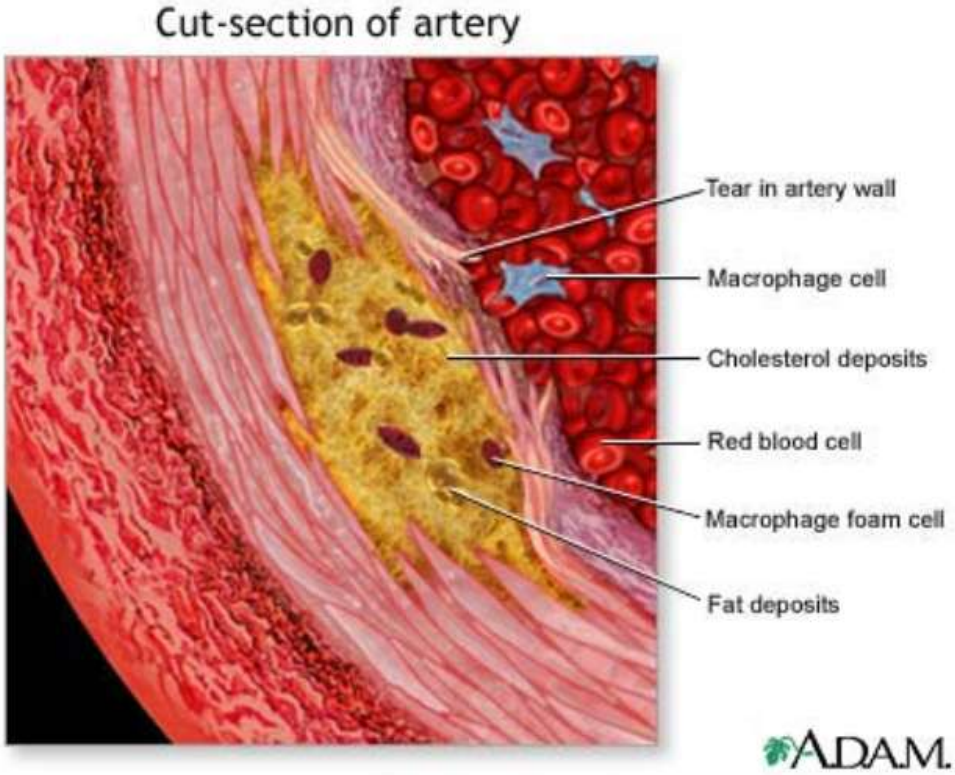
ECG impulses:
A shows the atrial contraction

B shows the ventricular contraction

Heart Sounds:
1st is caused by the closing of the AV valves at ventricular contraction

2nd is caused by closing of SL valves after systole (pressure in ventricle is lower than in aorta - backflow of blood closes valve)

http://www.uphs.upenn.edu/news/News_Releases/jan07/MTP-inhibition-reduce-high-cholesterol-photo.htm



Atherosclerosis

Degenerative disease -
areas of the artery wall become damaged.

Macrophages release growth factors, encouraging growth of fibrous tissue.

Cholesterol builds up in damaged areas. This eventually forms plaque and the artery wall loses elasticity.

As build-ups of cholesterol and plaque form, the lumen narrows, restricting blood flow.

If plaque ruptures, blood clotting is triggered. Blood clots are known as coronary thrombosis.

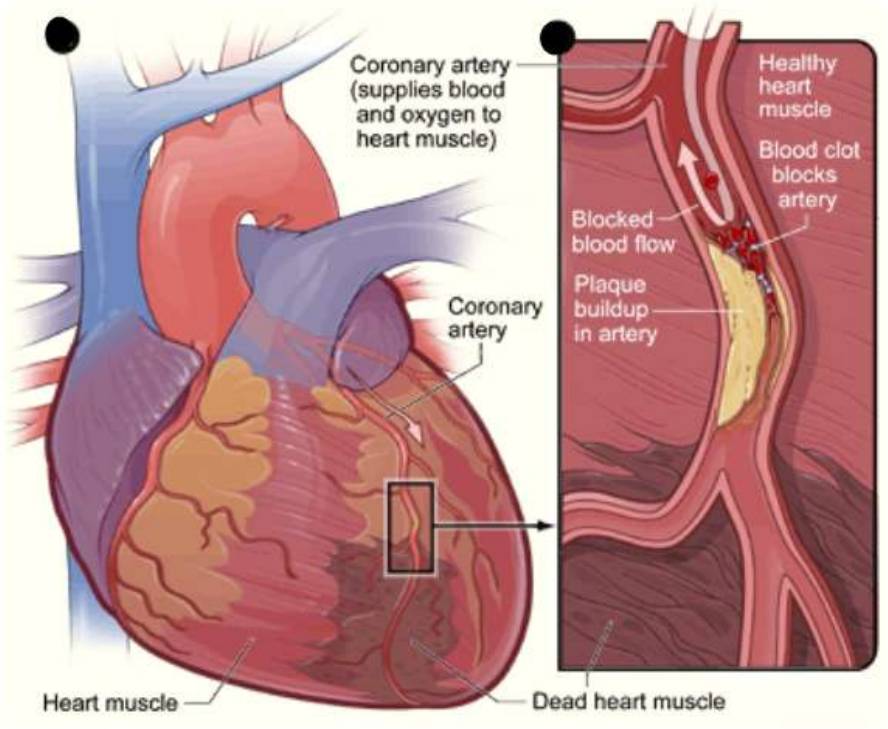
http://www.hhmi.org/biointeractive/obesity/heart_attack.html

Coronary Heart Disease

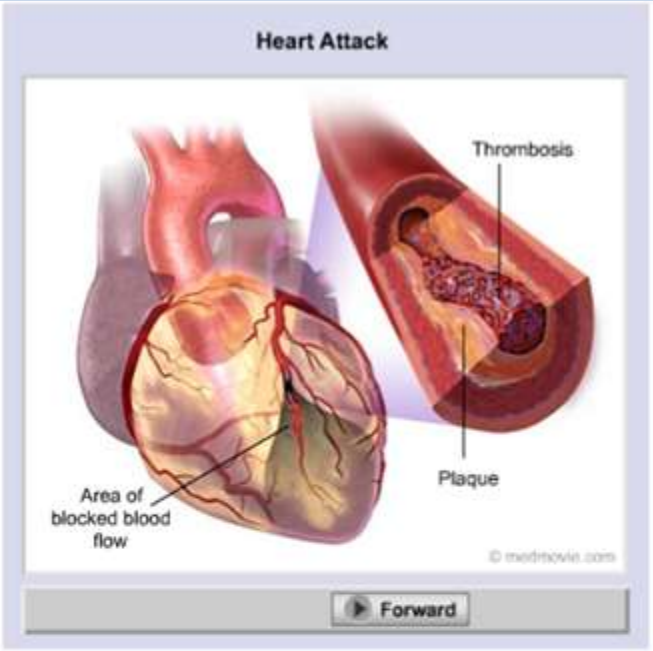
Atherosclerosis can lead to blood clots, and if these clots occur in myocardial tissue, we call it coronary heart disease.

A myocardial infarction (heart attack) occurs if a coronary artery becomes completely blocked.

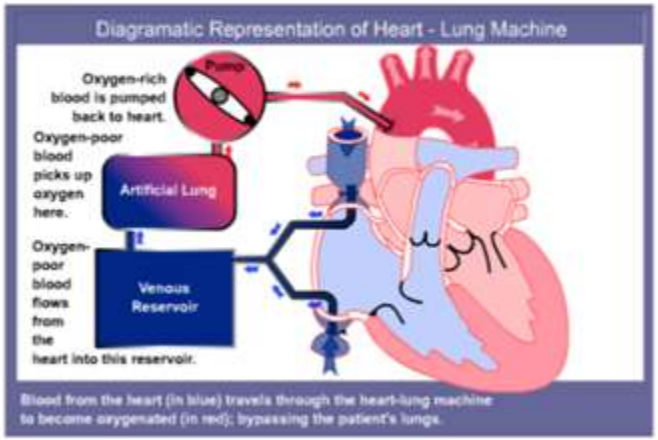
Coronary muscle tissue dies as a result of a lack of blood and oxygen.



http://www.web-books.com/eLibrary/Medicine/Cardiovascular/HeartAttack.htm



A heart bypass can repair blocked arteries.



http://www.medmovie.com/medialibrary/index.htm#

Risk Factors in Coronary Heart Disease

Genetic – some people predisposed for high cholesterol levels / high blood pressure

Age – older people greater risk / less elasticity in arteries

Sex – males at great risk than females

Smoking – constricts blood vessels / increases blood pressure/heart-rate / decreases oxygenation of heart muscle/ increased fibrinogen and platelets in blood lead to more clotting

Diet – increases fat/cholesterol/LDL in blood / leads to plaque formation in arteries

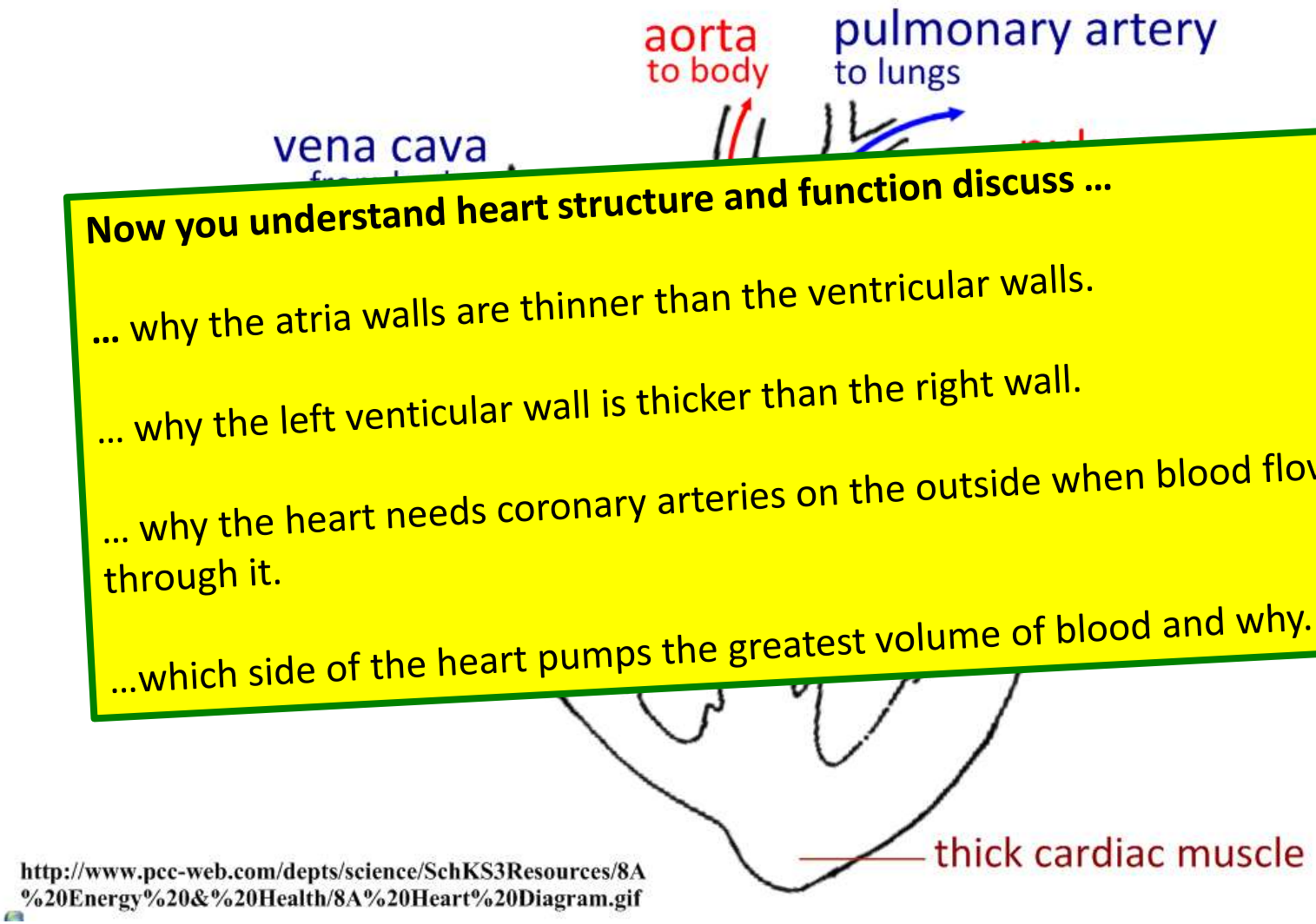
Exercise – lack of exercise increases risk due to weakened circulation

Obesity – increase in blood pressure / leads to plaque formation in arteries

Stress - stress has been linked to increased cortisol hormones in the blood, causing increased atherosclerosis

6.2.S2 Recognition of the chambers and valves of the heart and the blood vessels connected to it in dissected hearts or in diagrams of heart structure.

Label the heart diagram



Now you understand heart structure and function discuss …

… why the atria walls are thinner than the ventricular walls.

… why the left venticular wall is thicker than the right wall.

… why the heart needs coronary arteries on the outside when blood flows through it.

…which side of the heart pumps the greatest volume of blood and why.

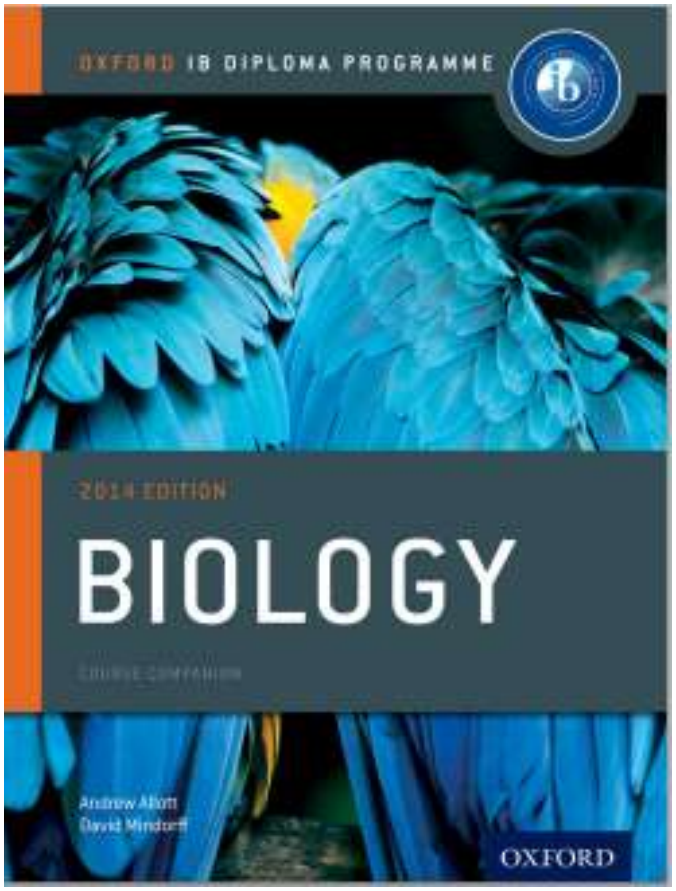
http://www.pcc-web.com/depts/science/SchKS3Resources/8A%20Energy%20&%20Health/8A%20Heart%20Diagram.gif

Now try to label this heart: http://sciencelearn.org.nz/Contexts/See-through-Body/Sci-Media/Animation/Label-the-heart

Bibliography / Acknowledgments

BioNinja

Your one-stop biology resource



Bob Smullen