YYC Science Bowl

Biology Guide

Human Physiology

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Human Nutrition

Nutrition and Malnutrition

Nutrition is the intake of nutrients, the chemical substances found in our food. Nutrients are integral to human survival and development and they primarily come through two sources; being synthesized by the body itself and through our diet (essential nutrients). Essential nutrients can be classified under 4 groups:

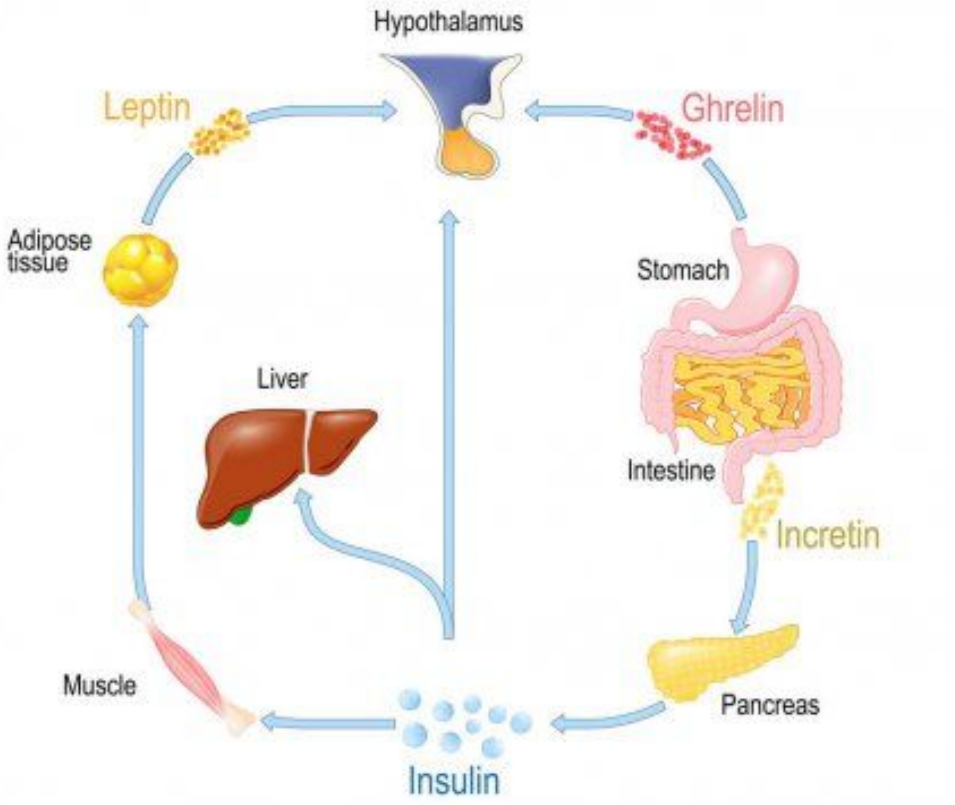
1. Minerals: These are specific elements such as iron, calcium, potassium, sodium etc.
2. Vitamins: These are a diverse array of chemical compounds that are mandated in small quantities such as thiamine, pantothenic acid, ascorbic acid, calciferol etc.
3. Amino Acids: Protein synthesis through ribosomes mandates some of the 20 amino acids
4. Fatty Acids: Protein synthesis through ribosomes mandates fatty acids like omega-3 fatty acids.

*Carbohydrates are always present in the human diet but none, in particular, are essential to life functions.

Irregular nutrition is termed as malnutrition and there are different types of malnutrition depending on the specific nutrient in excessive or insufficient proportions.

Energy in the Diet

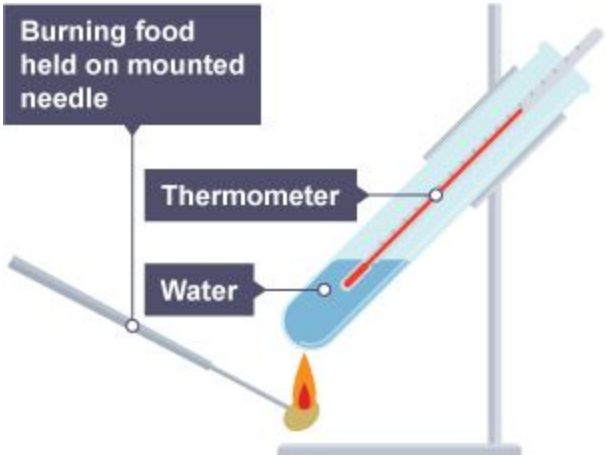
Aerobic cell respiration requires a source of energy such as through carbohydrates, lipids and amino acids. When these sources are insufficient, the human body resorts to reserves of glycogen and fats. Glycogen and fat reserves are used up in starvation and the body resorts to breaking down body tissue to continue respiration. The same occurs with anorexia when you do not eat sufficient nutrients despite it being available. Anorexia can sometimes cause the heart muscle to be broken down as well. Obesity is another condition in which there is a prolonged excessive intake of energy in the diet than what is used during cellular respiration causing excessive storage of fat in adipose tissue. People with obesity are subject to health issues like excessive high blood pressure (hypertension) and Type II diabetes. The control of appetite or satiety is administered by leptin which is produced by the adipose tissue and acts upon the hypothalamus.



Calorimetry

The energy content of food can be measured through combustion such as by burning food in a calorimeter which traps heat from the resulting combustion. The following equation can be used to calculate energy content in food:

$$Energy\ content\ in\ food\ (J/g) = \frac{temperature\ rise\ (°C) \cdot water\ volume\ (mL) \cdot 4.2\ J}{mass\ of\ food\ (g)}$$



Cholesterol and Heart Disease

A correlation between high levels of cholesterol in the blood plasma and coronary heart disease (CHD). Despite that, lower cholesterol levels have not shown to decrease the risk of CHD due to the following reasons:

- The human diet is not the only source of cholesterol due to the synthesis of cholesterol by the liver
- A lot of research is focused on total cholesterol levels in the body whilst only cholesterol in low-density lipoproteins (LDL) is of concern when it comes to CHD
- Genetic factors outweigh dietary factors as you can have high cholesterol even with a low cholesterol diet
- Reducing dietary cholesterol has minimal effects on blood cholesterol and thus has little effect on the risk of CHD
- There is a positive correlation between dietary intake of saturated fats and intake of cholesterol which might indicate that saturated fats are responsible for an increased risk of CHD

Deficiency Diseases and Gastrointestinal Diseases

Vitamin D Deficiency

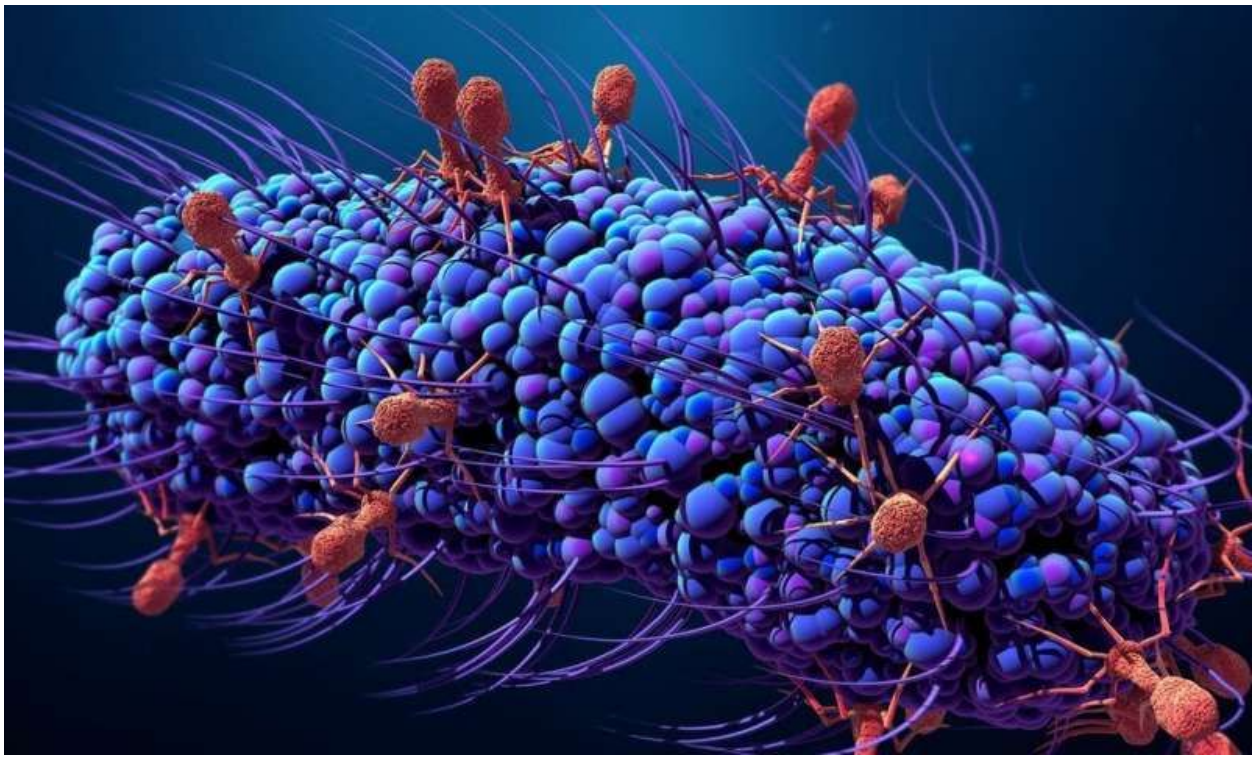
Deficiency in Vitamin D in the body causes an insufficient amount of calcium to be absorbed in the gut. Thus the symptoms of vitamin D deficiency are parallel to that of calcium deficiency which is called osteomalacia (called rickets in children). Osteomalacia is when calcium salts aren't deposited or absorbed which causes the softening of bones due to inadequate bone mineralization. Vitamin D is found in sources like oily fish, cheese, liver, eggs, milk, butter etc. Under ultraviolet light (UV) during the summer months, Vitamin D can be synthesized by the skin. The liver can also store enough vitamin D during the summer to counter a deficiency in winter due to the lower levels of UV light during the winter months.

Vitamin C Deficiency

The synthesis of collagen fibres in body tissues like the skin and blood vessel walls mandates ascorbic acid. Humans can't synthesize ascorbic acid and thus must be taken through vitamin C in the diet. A defining in vitamin C is known as scurvy and it can affect humans but not many other mammals as they have the enzymes required for the synthesis of ascorbic acid. Despite that scurvy is not specific to humans as scurvy has successfully been induced in guinea pigs, apes and chimpanzees.

Cholera

The bacterium *Vibrio cholerae* causes an infection in the gut known as cholera as it releases toxins that bind to receptors on intestinal cells. These toxins enter the cells through endocytosis and stimulate the release of chloride and bicarbonate ions from the cells into the intestine. Subsequently, water flows by osmosis into the intestine resulting in watery diarrhea and water is also drawn from the blood to counter the loss in intestinal cells. The subsequent result is severe dehydration which can be fatal if the patient is not treated in time.



Excessive Gastric Acid Secretion

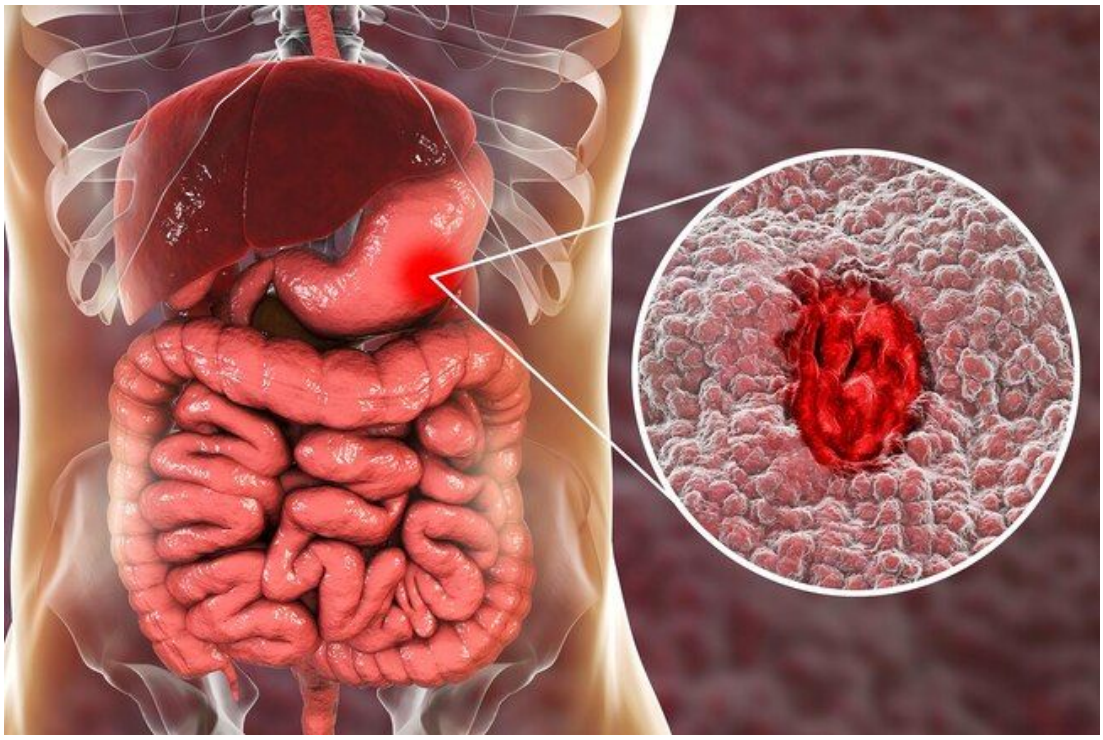
H+/K+-ATPase is a proton pump in parietal cells in the stomach epithelium that secretes acid into the stomach. These pumps interchange protons from the cytoplasm for potassium ions from the stomach contents. This results in an H+ gradient of 3,000,000:1 causing stomach contents to be acidic and corrosive. Although a natural mucous barrier is present to protect the lining of the stomach, it may break down resulting in damage to the stomach lining and bleeding (this is called an ulcer). Heartburn occurs when there is a problem with the circular muscle at the top of the stomach located at the entry of acid stomach contents to the esophagus in which acid reflux in unable to be controlled. Proton-pump inhibitors (PPIs) are drugs that can treat these diseases by binding to H+/K+-ATPase which prevents proton pumping and makes stomach contents less acidic.

Phenylketonuria

Phenylalanine is an essential amino acid whilst tyrosine isn't as phenylalanine can synthesize it with the addition of phenylalanine hydroxylase. Phenylketonuria (PKU) is a recessive genetic disease that occurs when blood phenylalanine levels are too high due to a mutation that results in an insufficient amount of phenylalanine hydroxylase. It can be treated with a diet with low levels of phenylalanine (thus foods like cheese, meat and fish must be limited) and if amounts in the diet are insufficient, tyrosine supplements can also be taken. Symptoms of PKU such as mental retardation (due to reduced head and brain growth) only occur after birth as the mother's body regulates concentrations of phenylalanine in the fetus. Phenylalanine levels are tested after birth allowing for early diagnosis of PKU and effective treatment.

Stomach Ulcers

The partial digestion of the stomach acid by the enzyme pepsin and hydrochloric acid in gastric juice results in open sores called stomach ulcers. Barry Marshall and Robin Warren discovered that the main cause of ulcers is due to an infection by the bacterium *Helicobacter pylori*. These scientists treated ulcers with antibiotics that targeted *H.pylori* yet their treatment was slow to be accepted by doctors as they relied on inaccurate existing knowledge of the causes of the ulcer, notably stress and excessive acid secretion.



Digestion and Absorption

Secretion of Digestive Juices

Exocrine and endocrine are the two types of glands. Endocrine glands are ductless and secrete hormones directly into the blood. Exocrine glands secrete through ducts onto the surface of the body or the lumen of the gut such as digestive juice.

Early Research into Gastric Juice

In 1882, Alexis St.Martin survive a gunshot injury but he was left with a stomach accessible from the outside due to the dynamics of its healing process. A surgeon named William Beaumont treated the wound and subsequently conducted a multitude of experiments over a period of a decade on Alexis by digesting samples of food in gastric juice from his stomach. His discoveries were indicative of the fact that digestion is both a chemical and a physical process. His research and similar research process are denoted as an example of serendipity as it occurred by an event of chance.

Gastric Juice Activity

The cells in the epithelium of the stomach secrete gastric juice whilst parietal cells secrete hydrogen ions. These processes ensure that stomach pH remains around a pH of 1-3 and this fights pathogens that are ingested in our diet that might cause food poisoning. The acidity also promotes hydrolysis reactions such as hydrolysis by pepsin of peptide bonds in polypeptides. Chief cells secrete pepsin in an inactivated form called pepsinogen which stomach acid converts to active pepsin.

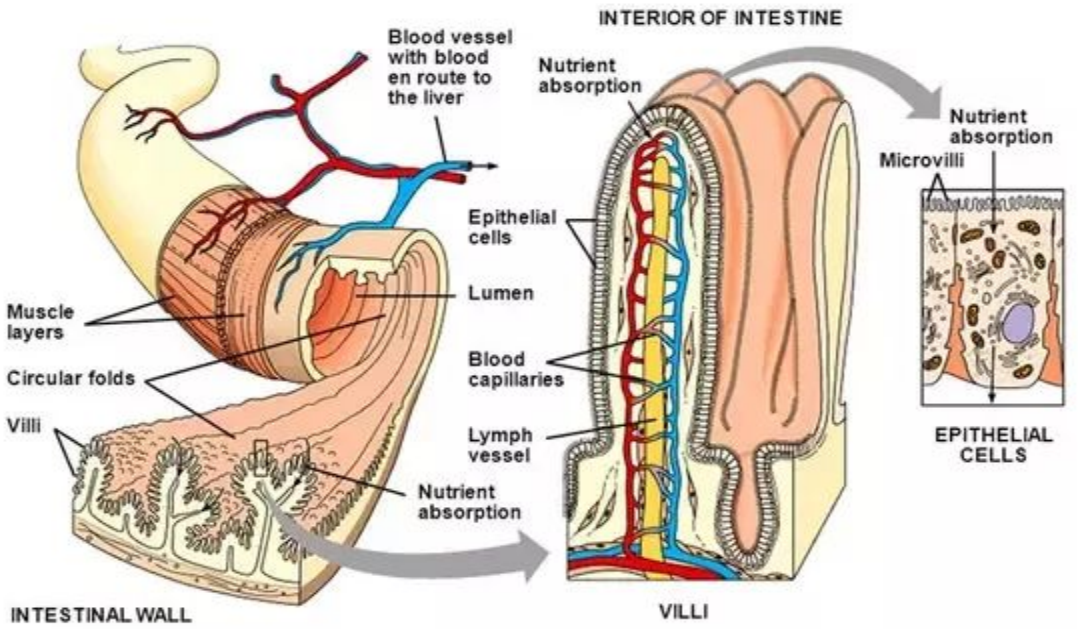
Control of Gastric Juice Secretion

Both nerves and hormones control the secretion of gastric juices. Take for example the control of the content and volume of gastric juice. Both the sight and smell of food triggers nerve impulses to parietal cells which begin secreting acid (this is known as a reflex action). Furthermore, sodium and chloride ions are secreted causing the osmosis of water into the stomach to form gastric juice. As food enters the stomach, chemoreceptors detect amino acids whilst stretch receptors respond to the changes of the stomach wall. These impulses from the receptors are sent to the brain which in turn sends impulses via the vagus nerve to endocrine cells in the walls of both the duodenum and stomach which triggers the secretion of gastrin. Gastrin is a hormone that stimulates further acid secretion by parietal cells and pepsinogen by chief cells. Secretin and

somatostatin are two other hormones that inhibit gastrin secretion if the stomach contents get too acidic.

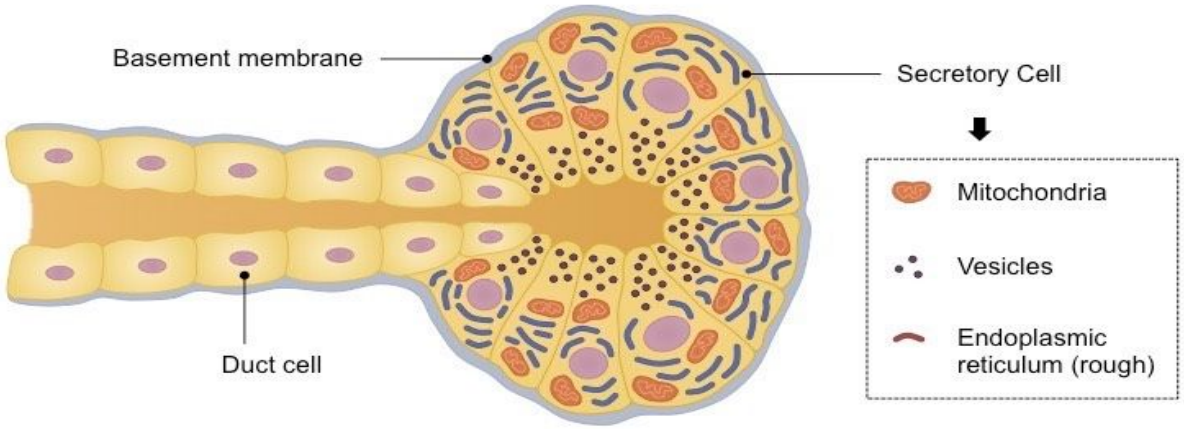
Villus Epithelium Cells

Two components of epithelium cells on the villus surface adapt them to their role, namely microvilli and mitochondria. Microvilli are protrusions of the apical plasma membrane (1µm by 0.1 µm) that are intended to increase the surface area of the plasma membrane exposed to digested foods in the ileum and thus increases food absorption. Mitochondria are scattered throughout the cytoplasm and produce the ATP required for the adsorption of digested foods by active transport.



Exocrine Gland Cells

Exocrine gland cells secrete digestive enzymes and can be identified by the large amounts of the following: rough endoplasmic reticulum, Golgi apparatus and secretory vesicles.



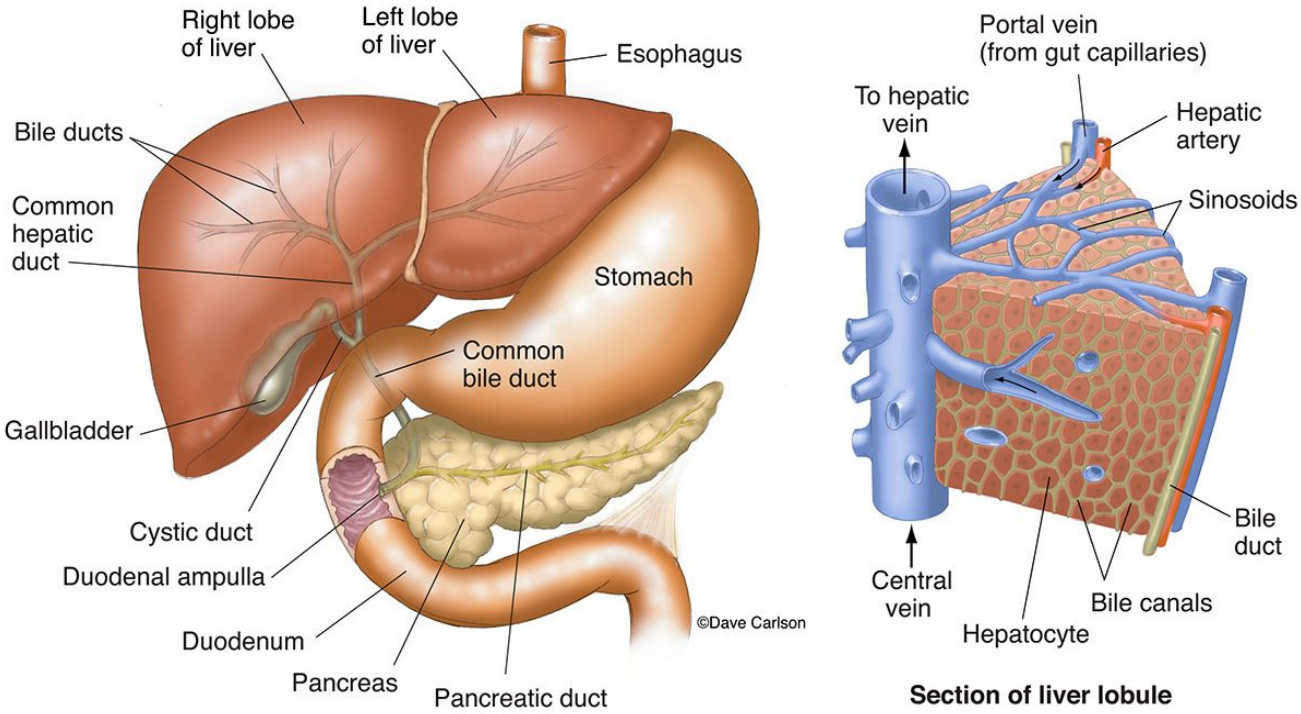
Fibre and Feces

Dietary fibre refers to the material that is not digested or absorbed and subsequently pass through the small and large intestine and is egested. Common indigestible substances for humans include cellulose, lignin, pectin and chitin. Mean residence time is the average time that food remains within the gut. There is a positive correlation between the fibre content of the food consumed and the mean residence time. A low-fibre diet yields a slow rate of transport through the gut causing constipation and increasing the risk of bowel cancer, hemorrhoids and appendicitis.

Liver

Functions

The liver is comprised of hepatocytes that carry out many important functions.



Detoxification: Toxic substances are absorbed from the blood by these hepatocytes and they are converted into non-toxic or less toxic substances through a series of chemical reactions.

Breakdown of erythrocytes: Erythrocytyes (also known as red blood cells) have a relatively short lifespan of 120 days. There are Kupffer cells in the walls of the liver's sinusoids that are

specialized macrophages that absorb and break down damaged red blood cells by phagocytosis and recycle their components. The hemoglobin is split into 2 components: heme groups and globins. Globins are subsequently hydrolyzed into amino acids that are released into the blood. Heme groups have their iron component removed leaving behind a yellow substance called bile pigment or bilirubin. Both the iron and the bile pigment are released into the blood. The bile pigment is used primarily for bile production within the liver whilst the iron is transferred to the bone marrow to be used in the production of hemoglobin for new red blood cells.

Conversion of cholesterol into bile salts: Hepatocytres also convert cholesterol into bile salts which are a component of the bile that is produced in the liver. As bile is secreted into the small intestine, the bile salts emulsify droplets of lipid which greatly increases the speed of the lipid digestion by lipase. Additionally, hepatocytes can also synthesize cholesterol if the amount in the diet is insufficient.

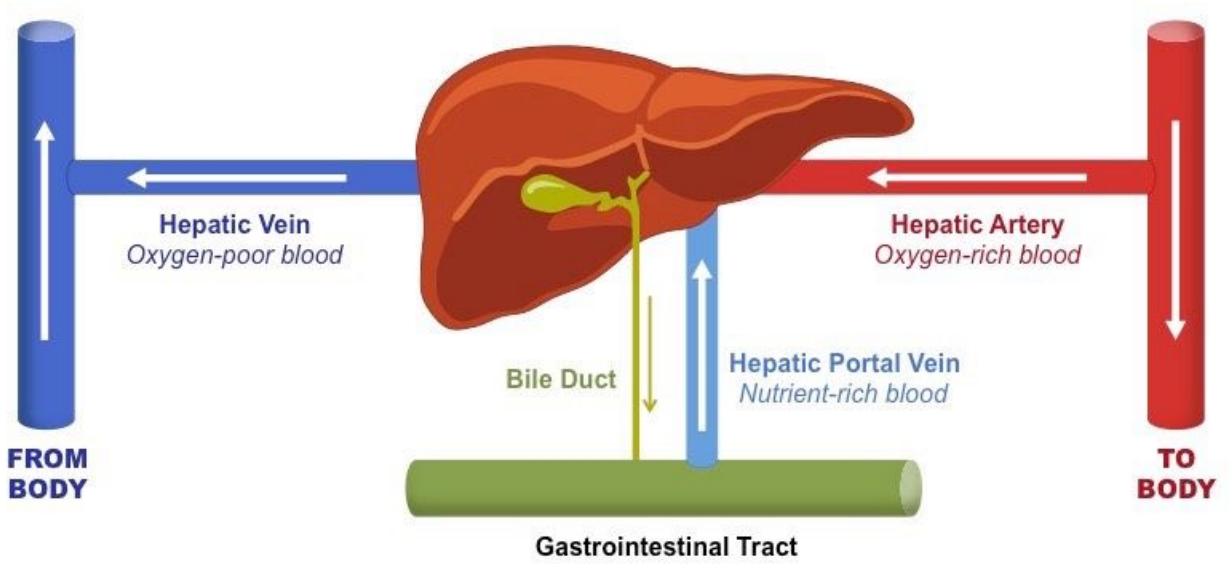
Production of plasma proteins: The rough endoplasmic reticulum of hepatocytes produces roughly 90% of all proteins in blood plasma including things such as albumin and fibrinogen. Furthermore, plasma proteins are processed by the Golgi apparatus in the hepatocytes before being released into the blood.

Nutrient storage and regulation: Blood that has passed through the wall of the gut and has absorbed digested food flows through the hepatic portal vein to the liver where it then passes through the sinusoids and comes in direct contact with the hepatocytes. This ultimately allowed hepatocytes to play a role in regulating the levels of some nutrients. Take for example high blood glucose levels in which insulin triggers hepatocytes to absorb glucose and convert it to glycogen for storage. On the other hand, low blood glucose levels result in the stimulation of hepatocytes by glucagon to break down glycogen and subsequently release glucose into the blood. Additionally, iron, retinol (vitamin A) and calciferol (vitamin D) are also stored in the liver when they are in surplus and released when there is insufficient supply in the blood

Blood Flow

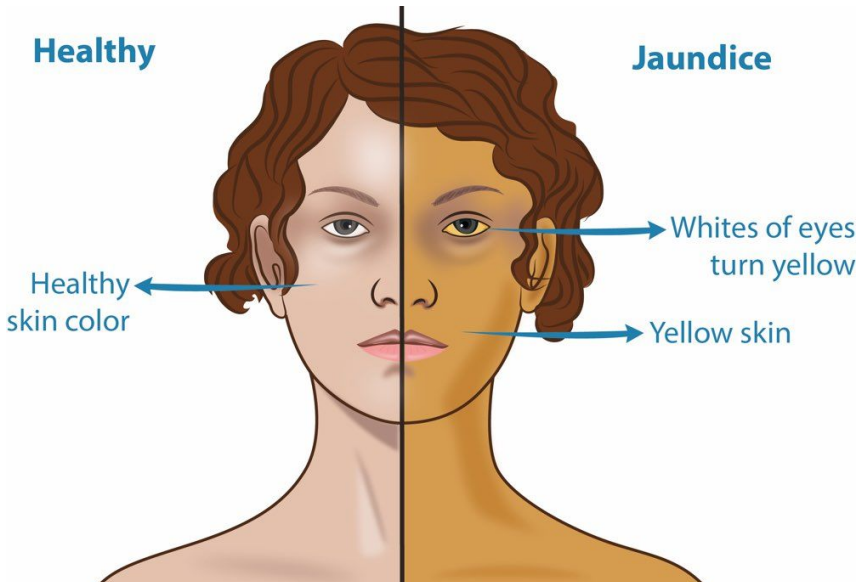
Blood is supplied to the liver through two vessels: the hepatic portal vein and the hepatic artery. Blood from the hepatic portal vein is actually deoxygenated because it has already flowed through either the walls of the stomach or the intestines. The hepatic portal vein inside the liver divides up into vessels called sinusoids. Sinusoids are wider than normal capillaries and have walls that consist of a single layer of extremely thin cells. Additionally, there are numerous pores or gaps in between each of these cells which allows blood flowing along the sinusoids to have close contact with the surrounding hepatocytes. The hepatic artery supplies the liver with oxygenated blood from the left side of the heart via the aorta. The hepatic artery also branches to form capillaries that join the sinusoids at various locations along their length and thus provide

hepatocytes with the oxygen mandated to conduct aerobic cell respiration. The sinusoids also drain into wider vessels that are branches of the hepatic vein. Blood from the liver is also carried by the hepatic vein to the right side of the heart through the inferior vena cava.



Jaundice

Jaundice is a condition in which the skin and the eyes become yellow due to the accumulation off bilirubin (also called bile pigment) in the blood plasma. The causes of jaundice lie within a multitude of disorders in the liver, gall bladder or bile duct that prevent the excretion of bilirubin in bile. Examples of these conditions include hepatitis, liver cancer and gallstones. Higher than average bilirubin levels in the blood plasma poses a serious threat to infants if it is prolonged for long periods of time as it may cause a form of brain damage that results in deafness and cerebral palsy. On the other hand, adult patients with jaundice merely experience a sensation of itchiness.



High-Density Lipoprotein

Cholesterol is often associated by many people with coronary heart disease and other serious health problems. However, this is not really accurate as cholesterol is indeed a normal component of plasma membranes and hepatocytes actually synthesize cholesterol to be used by the human body. High levels of blood cholesterol are not necessarily a bad thing but it really depends on whether the cholesterol is being carried to or from body tissues. Lipoproteins are small droplets coated in phospholipids and are the things in which cholesterol is transported. There are two types of lipoproteins: low-density lipoproteins and high-density lipoproteins. Low-density lipoproteins (LDL) is thought of as the bad cholesterol as it carries cholesterol from the liver to the body tissues. High-density lipoproteins (HDL) is thought of as the good cholesterol as it collects cholesterol from the body tissues and carries it back to the liver in order to be removed from the blood.

Cardiac Cycle

Events of Cardiac Cycle

The beating of the human heart consists of the following actions:

1. The walls of the atria contract, pushing blood from the atria into the ventricles through the atrioventricular valves, which are open. The semilunar valves are closed, so the ventricles fill with blood.

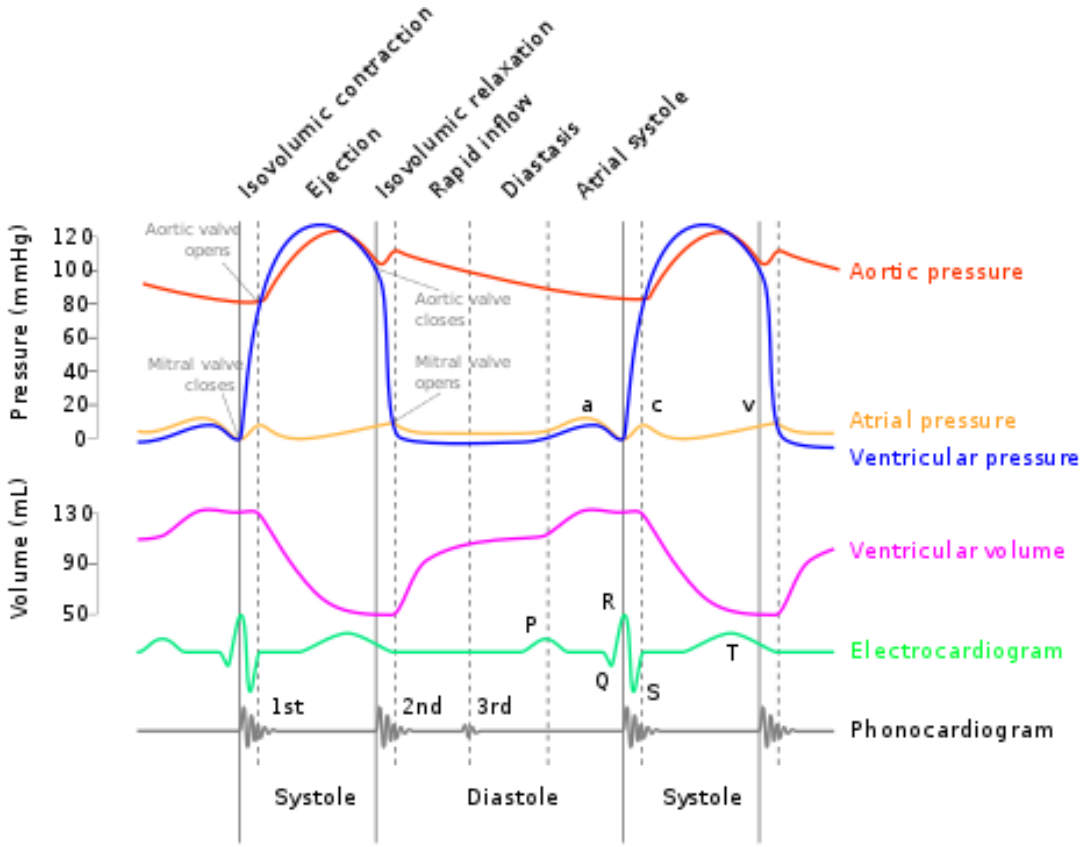
2. The walls of the ventricles contract powerfully and the blood pressure rapidly rises inside them. This first causes the atrioventricular valves to close, preventing back-flow to the atria and then causes the semilunar valves to open, allowing blood to be pumped out into the arteries. At the same time, the atria start to refill by collecting blood from the veins.

3. The ventricles stop contracting so pressure falls inside them. The semilunar valves close, preventing back-flow from the arteries to the ventricles. When the ventricular pressure drops below the atrial pressure, the atrioventricular valves open. Blood entering the atrium from the veins then flows on to start filling the ventricles.

The next cardiac cycle begins when the walls of the atria contract again

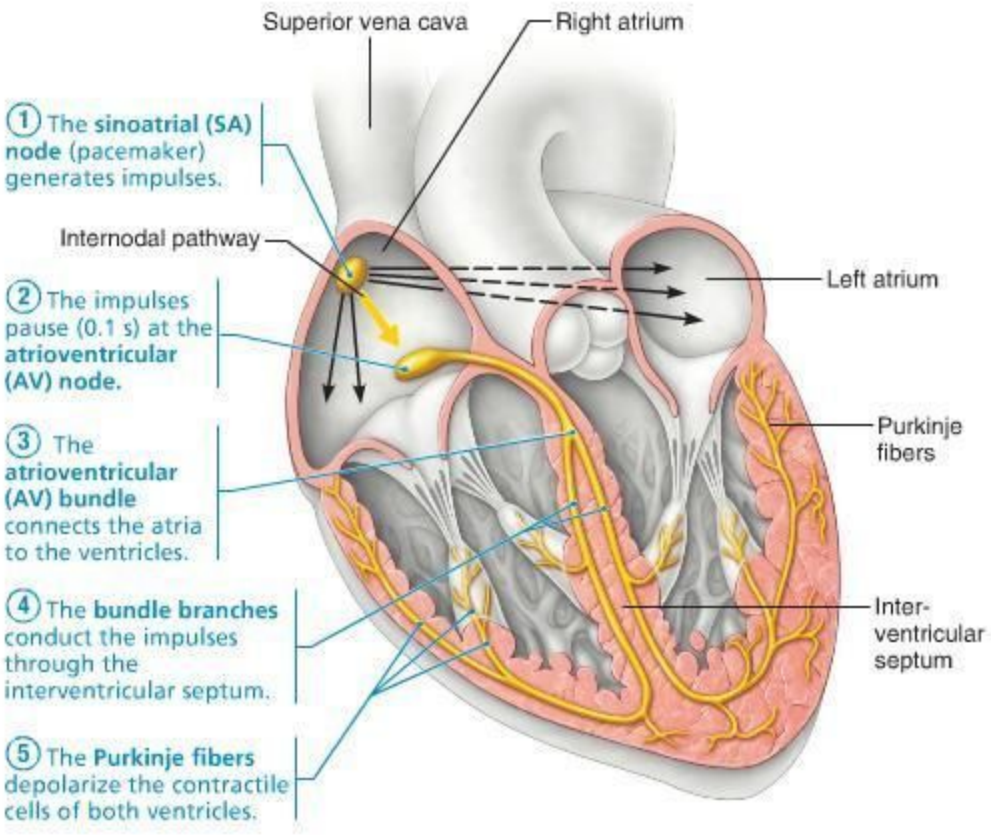
The figure below shows the changes in pressure and volume in the left atrium, left ventricle and aorta during two rounds of the cardiac cycle. It also shows electrical signals emitted by the heart

and recorded by an ECG (electrocardiogram) and sounds generated by the beating heart as recorded by a phonocardiogram.



Control of Cardiac Cycle

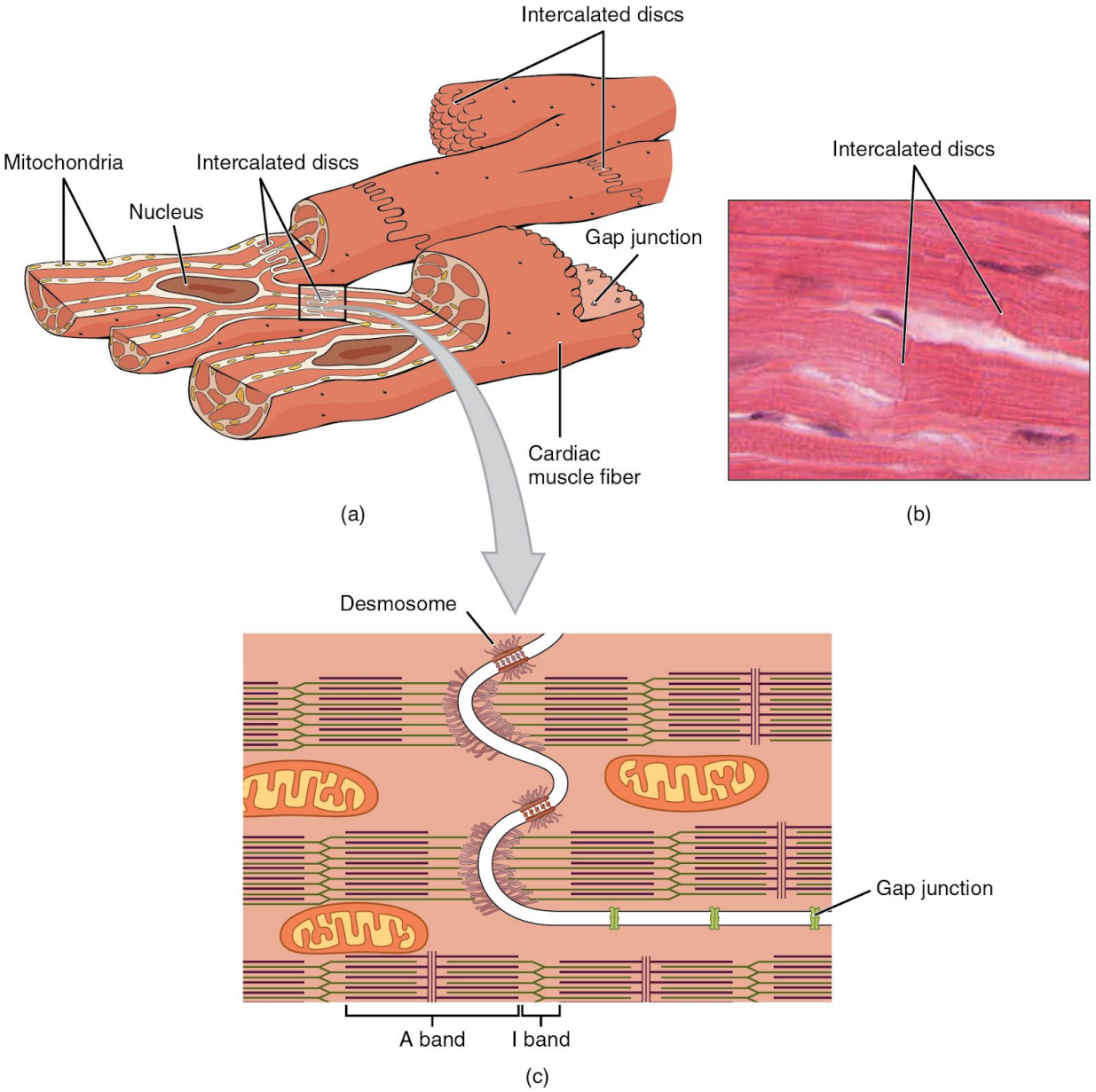
Cardiac muscle cells have a special property of being able to stimulate each other to contract. Intercalated discs between adjacent cardiac muscle cells allow impulses to spread through the wall of the heart, stimulating contraction. A small region within the wall of the right atrium called the sinoatrial node (SA node) initiates each impulse and thus acting as the natural pacemaker of the heart. The impulses generated by the SA node spread in all directions through the walls of the atria but a layer of fibrous tissue prevents it from spreading directly into the walls of the ventricles. Instead, impulses have to travel to the ventricles via the atrioventricular node (AV node) which is situated in the wall of the right atrium near the junction between the atria and the ventricles.



These impulses are able to reach the AV node 0.03 seconds after having been emitted from the SA node. There is a delay of 0.09 seconds before the impulses pass on from the AV node and this gives the atria time to pump blood into the ventricles before they contract. Impulses are sent from the AV node along conducting fibres that pass through the septum between the left and right ventricles, to the base of the heart. Furthermore, narrower conducting fibres branch out from these bundles and carry these impulses to all parts of the walls of the ventricles, coordinating an almost simultaneous contraction throughout the ventricles.

Cardiac Muscle

Cardiac muscle consists of a multitude of junctions that have a zigzag shape and are called intercalated discs. Within these structures, there are cytoplasmic connections between the cells that allow the movement of ions and therefore rapid conduction of electrical signals from one cell to the next. Other components of cardiac muscle include both sarcomeres and mitochondria. Another property of cardiac muscle cells is that they are branched. This feature allowed electrical stimuli to be rapidly propagated through the cardiac muscle within the walls of the heart.



Cardiology

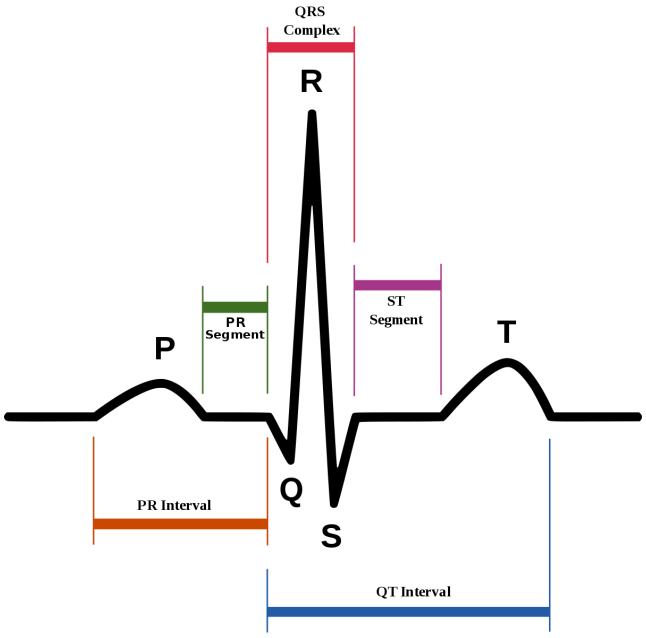
Stethoscopes and Heart Sounds

The invention of the stethoscope took place in the early 19th century and little has changed since around 1850. A stethoscope consists of a chest piece with a diagram intended to pick up sounds and flexible tubes intended to convey the sounds to the listeners' ears. Inevitably, the introduction of the stethoscope led to a greatly revised and improved understanding of the

dynamics of the human heart and other internal organs. Normal heart sounds detected with a stethoscope are a ‘lub’ due to the atrioventricular valves closing (this is the first sound) and a ‘dup’ due to the semilunar valves closing (this is the second sound). Any other sounds are called murmurs and these usually are indicative of health problems such as leaking heart valves.

Electrocardiograms

An electrocardiogram (ECG) can be used to detect electrical signals from the heart. Data-logging electrocardiogram sensors can be used to produce a graph as shown in the figure. The P-wave is caused by atrial systole which is the contraction of the atria. The QRS wave is caused by ventricular systole. The T-wave occurs during ventricular diastole. Doctors use changes to both the sizes of the peaks and the lengths of the intervals to detect heart problems.



Measuring Heart Rate

Heart rate can easily be measured using either the radial pulse at either the wrist or the carotid pulse in the neck. This rate is measured as the number of beats per minute. The specific heart rate depends on factors such as the body’s demand for oxygen, glucose and for the removal of carbon dioxide. Subsequently, there is a positive correlation between the intensity of physical exercise and heart rate.

Measuring Blood Pressure

To measure a person’s blood pressure, a cuff is placed around their upper arm and is subsequently inflated in order to constrict the arm and also prevent blood from the arteries from

entering the forearm. The cuff is then slowly deflated and the doctor uses a stethoscope in order to listen for sounds of blood flow through the arteries. These sounds occur when the cuff pressure drops below the systolic pressure. The cuff is deflated to the point where there are no more sounds which happens when the cuff pressure drops below the diastolic pressure. The following table highlights are both the diastolic and systolic pressures are to be interpreted.

Blood Pressure Stages

Blood Pressure Category	Systolic mm Hg (upper #)		Diastolic mm Hg (lower #)
Normal	less than 120	and	less than 80
Elevated	120-129	and	less than 80
High Blood Pressure (Hypertension) Stage 1	130-139	or	80-89
High Blood Pressure (Hypertension) Stage 2	140 or higher	or	90 or higher
Hypertensive Crisis (Seek Emergency Care)	higher than 180	and/or	higher than 120

Source: American Heart Association

Hypertension and Thrombosis

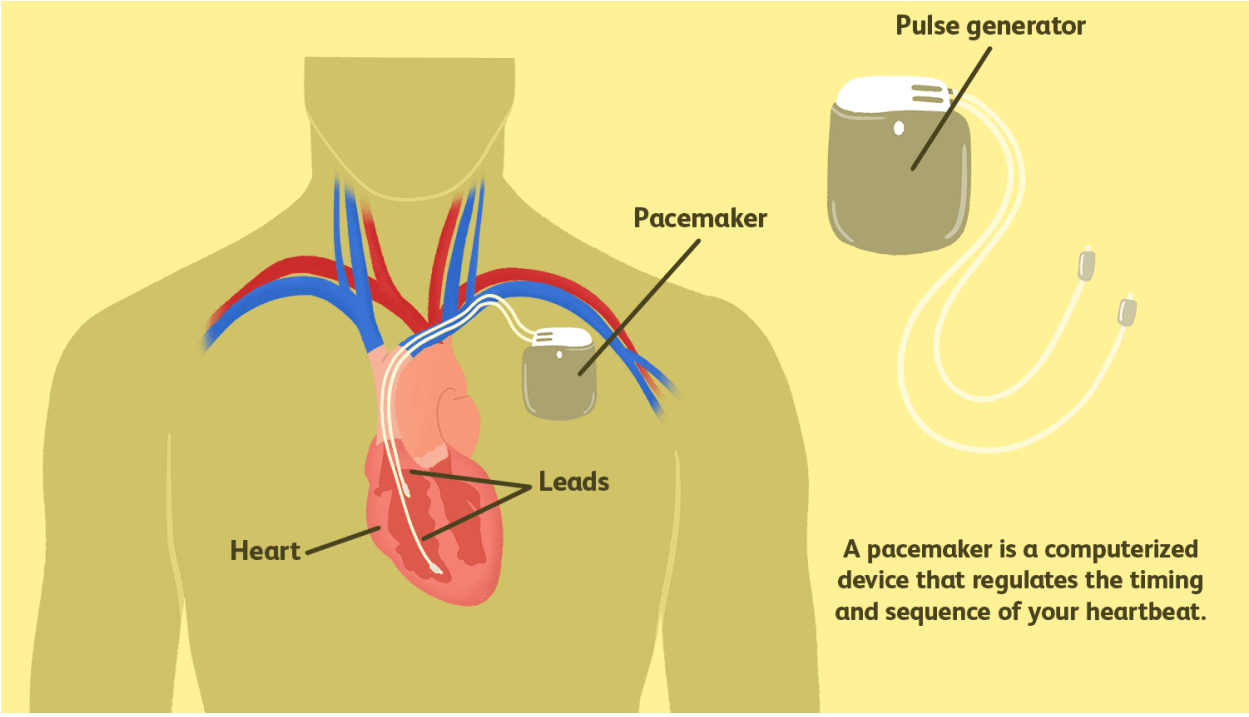
Despite the fact that the causes of hypertension are not clear, there are a series of risk factors that are associated with hypertension that may give rise to the condition itself. Risk factors for hypertension include obesity, the lack of exercise, consumption of excess salt, drinking of too much coffee or alcohol and genetic factors such as having relatives diagnosed with hypertension. If hypertension is left untreated, it can cause damage to the kidneys and also cause either a heart attack or a stroke. Thrombosis is a condition in which there is a formation of blood clots inside blood vessels and its direct causes are also unknown. However, risk factors of thrombosis include high HDL (high-density lipoprotein) levels in the blood, high levels of saturated fats and trans-fats in the diet, inactivity (such as on flights), smoking, hypertension and genetic factors. Furthermore, thrombosis in coronary arteries causes a heart attack whilst causes a stroke in the carotid arteries that carry blood to the brain.

Coronary Heart Disease

Coronary heart disease is when there is damage to the heart due to either blockages or interruptions to the supply of blood in the coronary arteries. Analysis of epidemiological data is used for the investigation of coronary heart disease as experimentation on human patients is considered unethical.

Artificial Pacemakers

Artificial pacemakers are medical devices that are surgically fitted in patients who either have a malfunctioning sinoatrial node or have a block in the signal conduction pathway in their hearts. Artificial pacemakers ensure the regulation of heart rate and subsequently ensures that the heart follows a steady rhythm. Artificial pacemakers can either provide a regular impulse or only when a heartbeat is missed. It consists of a pulse generator and a battery that is placed under the skin below the collar bone. There are wires threaded through the veins in order to deliver the electrical stimuli to the right ventricle.



Defibrillators

One of the characteristics of a heart attack is ventricular fibrillation which is the twitching of the ventricles due to the rapid and chaotic concentration of individual muscle cells. This subsequently makes the heart incompetent in terms of pumping the blood. The first thing that first responders do when treating a patient having a heart attack is that they apply the two

paddles of a defibrillator to the chest of the patient in a diagonal line with the heart situated in the center. A defibrillator first detects whether or not the ventricles are fibrillating and if they are, it delivers an electrical discharge meant to stop the fibrillation and thus restore a normal heart rhythm.