

# Digestion processes and enzymes



Spaghetti Bolognese is not only delicious but a highly nutritious meal containing the seven key components of a balanced diet, which is: Proteins, fats, carbohydrates, vitamins, minerals, water and fibre. The table below shows the ingredients within spaghetti bolognese which give us our seven components and the reason they are needed by the human body.

As this happens saliva produced from the salivary glands lubricates the mouth as well as coating the bolus of food. The production of Saliva is stimulated by the brain, the sight, smell and even the thought of food will get your digestive juices going. The salivary glands also produce an enzyme called amylase; this starts the chemical process of breaking down carbohydrates - starch into maltose. As well as the teeth, both jaws and the tongue are involved in mechanical breakdown of the food, the tongue pushing the chewed food to the back of the mouth towards the esophagus. When chewed, the food passes to the pharynx, at this point there is an involuntary reflex - swallowing, preventing the food from entering the lungs. Food then enters the esophagus by pressing on the epiglottis ensuring it does not enter the windpipe, (this is where the phrase food going down the wrong way is coined) the food travels down the esophagus by peristalsis and slowly moves the food into the stomach.

Digestion is the process whereby food particles are mechanically and chemically broken down from large molecules into smaller molecules that can be used by cells; this happens when enzymes are mixed with food the chemical reaction is known as hydrolysis.

The three main digestive enzymes are protease which breaks up proteins into amino acids, lipase which breaks down fats into glycerol and fatty acids and amylase which breaks carbohydrates into monosaccharide's (simple sugars) polypeptides, these are molecules which are small enough to travel through the cell membrane to be utilised. Vitamins, minerals and water are not digested as they are small enough already to be absorbed. Fibre is not digested however it is essential to the digestive system as it is needed to help push food around the digestive tract

How is this done? Enzymes are made of protein and aid chemical reactions by acting as a biological catalyst. It does this by lowering the activation energy, which in-turn speeds up the rate of the reaction, turning a substrate into a product. This is where the chains holding the chemicals bonds together are broken down. For example: The enzyme produced within saliva is amylase, amylase acts upon the substrate starch; a chemical reaction takes place breaking down the starch into maltose.

**Table 2**

Substract	Products	Enzyme	Produced by
Starch	Maltose	Pancreatic amylase	Pancreas
Maltose	Glocose	Maltase	Intestinal Cells
Proteins	Smaller polypeptides	Endopeptidase: trypsin	Pancreas

Smaller polypeptides	Amino acids	Dipeptides Exopeptidase	Pancreas
Sucrose	Glucose/fructose	Sucrase	Intestinal cells
Lipids	Glycerol	Lipases	Pancreas
Lactose	Glucose	Lactase	Intestinal cells

As table 2 shows the digestive enzymes are produced in various organs within the digestive system. Each enzyme has a specific function for example a protein enzyme will not digest starch. The enzyme has an area where the substrate is able to bind; they can do this as an area of their structure is complementary to the substrate's area. This area is known as the active site. The substrate attaches onto the active site, when it fits exactly, like a key in a lock. This is known as the lock and key method. When the substrate meets the active site it can also change the shape of the enzyme which improves the fit causing reaction to occur. This is an induced fit.

The conditions for enzymes to work are important, enzymes need to be the correct shape in order to do their job correctly however as they are made of protein they can be affected by heat, temperature and pH levels, should the pH level become acidic and/or the temperature change it will affect the shape and therefore the enzyme will not be able to work. Therefore most enzymes work at body temperature and around pH 7 (neutral or slightly alkaline).

An exception of this is in the stomach. The digestive enzyme called pepsinogen is produced in the glands of the stomach lining however is

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activated into pepsin by hydrochloric acid (found in gastric juice, the hydrochloric acid kills any bacteria found in food molecules this is why it is acidic) this enzyme works at pH 2. Pepsin is the enzyme needed for protein digestion therefore the initial stages of protein digestion occur in the stomach. The Stomach digests proteins by hydrolytic endopeptidase, which breaks protein (peptide) bonds in the middle of polypeptides

The stomach is lined with mucosa, mucus which protects the stomach wall from hydrochloric acid and pepsin. At this stage the food particles which have entered the stomach have been chewed resembling mush, the stomach's muscles lie in varying directions when they contract, they act as a churner, churning the mush further. Here molecules are broken down further by mechanical breakdown. At this point the mush mixes with gastric juices secreted by the stomach lining; the enzyme pepsin starts to digest the protein found in the meat of the spaghetti Bolognese, whilst the enzyme lipase starts to digest the fat molecules found within the cheese.

Carbohydrates spend the least amount of time being digested in the stomach followed by proteins and then fats. The mush is now called Chyme and is moved by peristalsis into the small intestine, it takes around 4 hours from eating a meal for this to happen.

## **Organs of the digestive system**

The digestive system is a long tube around 6 - 9 metres long from the mouth to the anus with compartments such as: Mouth, Esophagus, Stomach, Small intestine, large intestine and anus. Accessory digestive organs such as the liver and pancreas play a part in digestion and are connected to the main system.

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The liver produces digestive juice known as bile. Bile is stored between eating in the gallbladder. When eating, bile is squeezed out of the gallbladder, through the bile ducts. The bile enters the intestine mixing with the fat in food. The bile acids dissolve fat by emulsification, into the watery contents of the intestine. After fat is dissolved, it can then be digested by enzymes from the lining of the intestine and pancreas. The liver is involved in producing proteins, fibrogen (helping blood to clot) and detoxifies by breaking down excess amino acids and removing bacteria or reducing levels of poison for example from alcohol.

The pancreas is a small and flat organ situated behind the stomach it is connected to the duodenum by a tube called the pancreatic duct. The Pancreas unusually functions as both an endocrine and exocrine gland. The endocrine system is made up of glands which secrete certain hormones into the bloodstream in order to maintain the body. This can include processes such as growth and tissue function. The exocrine system does the opposite and secretes hormones etc into the external environment.

Endocrine function - The pancreas contains cells islets of Langerhans (named after their founder) the two types of cells are alpha and beta cells which secrete both insulin and glucagon hormones into the bloodstream. When glucose levels increase for example after eating the beta cells secrete insulin. Insulin increases the cells rate in which it absorbs glucose therefore decreasing the glucose levels. If too much glucose is present in the body it will instruct the liver to store it, converting the glucose-into its reserve glycogen. On the other hand when glucose levels in the bloodstream decrease to a certain point, the alpha cells release glucagon hormone. This

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hormone signals the liver to convert glycogen back into glucose. This is known as negative feedback and regulates the glucose levels in the body by opposing changes that are not of the norm. Here homeostasis occurs maintaining the internal environment within the body.

Exocrine function - The Pancreas is signalled to secrete pancreatic juices into the small intestine, when the food reaches the upper part of the small intestine, the duodenum (this is done by a hormone known cholecystokinin-CCK). CCK will also signal the gall bladder to release bile essential to the digestion of fats. The pancreatic juices contain digestive enzymes involved in breaking down fats (lipase), proteins (trypsin) and carbohydrates (amylase) found in the chyme (part digested food). The pancreas also secretes bicarbonate ions; these ions reduce stomach acidity which is important to let the food travel into the small intestine without being acidic. This is part of the feedback loop and homeostasis.

The body moves food through the digestive tract through a process called Peristalsis. Peristalsis is a series of muscles which contract - like waves moving the food. Peristalsis begins in the esophagus (Figure 1) when a bolus of food is swallowed. The wave motion of the smooth muscles in the esophagus helps to slowly push the food into the stomach, where it is churned into a mush like mixture called chyme.

Peristalsis continues in the small intestine where it mixes the chyme, allowing nutrients to be absorbed into the bloodstream through the walls of the small intestine

Peristalsis in the large intestine occurs where water from any undigested food is absorbed into the bloodstream. It also helps move urine from the kidneys to the bladder as well as bile to the duodenum from the gall bladder.

The final stages of digestion occur in the small intestine, where the already broken down food molecules of carbohydrates, proteins and fats are digested even further and absorption occurs, this happens once the molecules are small enough to enable them to be absorbed by cell membranes. Although some absorption occurs in the stomach, most absorption happens in the small intestine, where the digested molecules are able to pass through the wall of the small intestine and into the bloodstream where they can be carried through the body.

The small intestine is made up of the duodenum which is the upper part of the small intestine and the ileum which is made up of sub mucosa, circular muscle mucosa and the longitudinal muscle. The small intestine is adapted for its function, absorption. The wall of the small intestine is thin and has a large surface area; the reason for this is to allow absorption to happen more efficiently.

The small intestine is made up of two structures villi covered in enterocytes their function to absorb nutrients and crypts of leibrkuhn, villi covered in epithelium cells folding inwards lined with younger epithelial cells for secretion. Enterocytes are initially at the bottom of the crypts they travel up the wall of the crypt during their life span, before briefly staying on the villi and absorbing nutrients. Most nutrients including amino acids and sugars



cross the epithelium cells on the villi and transfer into the body and capillary network.

Singular villi are known as villus the epithelial cells on the villi have microvilli - the brush border these together increase the surface area for absorption by sticking out catching molecules. Villi contain blood capillaries which carry away the absorbed food molecules. When substances can pass through the brush border (Table 2) this is usually though passive transport through diffusion which is the movement of ion molecules from a region of high concentration to low concentration. In diffusion molecules are random and only diffuse when the molecules find a route to get through. Because there is no energy behind the molecules it is a normally a slow process.

Facilitated diffusion is where molecules need to be assisted to find their way through the cell membrane such as glucose.

Osmosis is the way water molecules move from an area of low to high concentration through a semi permeable membrane. Elaborate

Active transport - Is whereby molecules move across the cell membrane from a low to high region of concentration and therefore require energy from the cell. Carrier proteins will pick up these certain molecules and take them across the membrane against the concentration

Macromolecules such as proteins rely on active transport requiring energy as they move from an area of low to high concentration across the cell membrane.

Shows the food cells passing through the wall of the small intestine into the blood stream

Digestible carbohydrates from the pasta within spaghetti Bolognese - starch and sugar are broken down even further in order to be absorbed, starch has already been split into maltose by amylase enzymes, and at this stage the brush border enzyme maltase splits maltose into glucose whereby it can be absorbed into the blood, sugars (sucrose) are digested into glucose and fructose by the enzyme sucrase also produced in the small intestine, initially the glucose will be absorbed via facilitated diffusion however as the body uses glucose as energy it will continue to absorb glucose into the blood via active transport. The carbohydrates are used to provide energy for the work of the body. Protein from the mince meat is broken down into its smallest form amino acids by peptidases another brush border enzyme. The small molecules are able to be absorbed through the small intestine by transporters where they are then carried into the blood to build and repair body tissues. Fats from the cheese within the meal provide energy for the body. Fats are emulsified in bile produced by the liver and broken down further by the enzyme lipase into fatty acids and cholesterol. Small molecules of fatty acids and cholesterol are passed into vessels - lymphatic's near the intestine. The blood carries the fat to storage depots in different parts of the body until it is needed for energy. Another critical part of food is vitamins found in the tomatoes within spaghetti Bolognese; these vitamins are absorbed through the small intestine through passive transport. Vitamins B and C are water soluble; Vitamins A D and E are stored in fat tissues. It is essential to take in Vitamins B and C on a daily basis because they are water

soluble, they only stay in the body for a short period of time; if the vitamins aren't used they are excreted. Water and salt. Most material absorbed in the small intestine is water which also contains dissolved salt. Salt and water come from any food and liquid swallowed and digestive juices. Assimilation - after the molecules have been absorbed they need to be converted into a useable form. The molecules enter the capillary networks (which enter the lymphatic system) and into the hepatic portal vein which is the short vein carrying blood to the liver the nutrients are then released at intervals into general circulation. Egestion - Is the removal of undigested material from the digestive tract. Excess water is reabsorbed into the body via the large intestine. The undigested food is then stored in the lower part of the large intestine, until it is released from the body as faeces. Fibre found in the pasta and vegetables such as tomatoes within spaghetti Bolognese is essential for this process to work as it pushes waste through the system as it is not broken down by enzymes.

The absorbed nutrient is delivered to cells around the body. Each cell is made up of Mitochondria is the energy manufacturers of the cell and where cellular respiration occurs. The structure of the mitochondria means the outer membrane can cover the nutrient whilst the inner membrane folds over it many times increasing its surface area and therefore reactions. Inside of the mitochondria is the matrix filled water and protein, the nutrients which the cell receives are taken in and mixed with oxygen, at this point the nutrients can now be used by the cells. Adenosine Triphosphate (ATP) is also synthesised in the mitochondria which is crucial to provide energy within cells and enable everyday bodily functions.

The nervous system is very complex and is known as the control centre. Its job surrounding homeostasis is vital to the body as it senses, identifies, interprets and reacts to any changes, external and internal by communicating electrochemical signals through the nerves to effectors (muscles and glands). The nervous system has five sensory organs which include: eyes, ears, nose, tongue and the skin accounting for taste, touch, balance etc. The organs are sensitive to receptors, for example the tongues taste receptors can be stimulated chemically by sweetness/sourness. The sight and smell and even the thought of food stimulates the production of digestive juices, involving both the nervous system and homeostatic mechanisms. There are three types of nerve cells - sensory, relay and motor.

The sensory nerve (or afferent nerve) carries information inwards to the central nervous system made up of the brain and spinal cord. The information starts at the receptor and ends at the synapse which is a gap between neurons allowing information to pass through. Different nerves carry information about temperature touch taste etc to the brain.

The motor nerve is also known as the efferent nerve it does the opposite of the sensory nerve carrying impulses outwards from the central nervous system, bringing activity within a muscle or gland.

interneuron sends messages from the sensory to the appropriate motor neuron by the release of neurotransmitters, chemicals which carry the signal from the synapse to the appropriate motor neuron.. The functions of the neurons can be defined in the reflex arc below -

The presence of food in the stomach and small intestine stimulates sensory neurons; the nervous system sets away a response to ensure the correct digestive secretions/juices are produced. Example -

- Food in the stomach is the stimulus
- Sensory neuron delivers information to the brain
- Brain sends message to the motor neuron
- Motor neuron signals effector in this case - gastrin production
- Gastric juice is produced which is acidic
- The receptor cell picks up this information - sensory neuron advises brain
- Brain relays information to motor neuron stimulating effector in this case pancreas to produce - bicarbonate ions which neutralise acidity.
- If too many bicarbonate ions produced then the receptor cells will pick this information up, continuing information is passed in a loop to ensure the body's functions are maintained such as PH, blood pressure and temperature this is known as homeostasis.

In Greek homeostasis means the " same state", the body is constantly trying to maintain its internal environment despite any external change. An example of this is if temperature outside drops the body will make alterations generating body heat, whereby the internal temperature remains constant, therefore the nervous system plays an integral part in homeostasis and maintaining body function. Homeostasis is controlled by negative feedback which works in a loop. Negative feedback loops are made up of a receptor, control centre and an effector. The receptor is responsible for monitoring the body's internal conditions and will sense any changes.

Connected to the receptor is the control centre, the control centre interprets the information received from the receptors. Normally the control centre is the brain. When the brain receives information regarding any changes it will send out a signal through the nerves. It is these signals that prompt a change in function to correct the change and bring the body's conditions back to the norm.

The effectors are the muscles and organs receiving signals from the control centre, the effectors will change to correct any change.

The hepatic portal vein runs through the sub mucosa in the small intestine and is a transport system taking absorbed nutrients as well as blood from digestive organs such as the stomach, pancreas, small and large intestine and gall bladder to the liver. When in the liver the blood filled with nutrients and toxins which have been absorbed is cleaned and then transported to the vena cava through hepatic veins. At this point the blood is taken to the heart for general circulation. The nutrients are transported in the blood by a system of blood vessels to the cells, exchange of substances occurs through the smallest blood vessels, capillaries. The mechanism of transport for the blood/nutrients is the contraction of the heart- collectively this known as the cardiovascular system.

How does the cardiovascular system work?

The heart is a muscle with each beat it pumps blood around the body this can be described in two separate circuits. Pulmonary and systemic. The circuits are separate which means the blood passes through the heart twice.

Blood is taken to the lungs to be oxygenated where carbon dioxide is removed and haemoglobin in the red blood cells takes up oxygen, before going back to the heart. This is known as the pulmonary system.

The systemic circuit carried nutrient rich blood around the body, delivering oxygenated blood. When it returns to the heart the blood is deoxygenated.

Blood is made up of four components: plasma, red blood cells, white blood cells and platelets, the blood is transported through blood vessels of which there are three types: arteries, veins and capillaries.

The arteries carry blood away from the heart under high pressure; they are adapted to their function but having thick muscular walls and small lumen.

Veins carry blood to the heart under low pressure they are adapted to their function as they have thin walls, large lumen and valves preventing blood from flowing backwards.

Capillaries are found in muscles and in the lungs they are microscopic and carry blood under very low pressure; they are known as the communicators between the arteries and veins and have thin walls to allow oxygen and the important nutrients to pass through into the organs in exchange for carbon dioxide.

The Cardiovascular system transports antibodies, hormones to organs and the absorbed nutrients from food ingested to the cells in the body, the nutrients are used for various functions for example the formation of new proteins, enzymes, cell membranes and energy. Carbohydrates from pasta etc are digested into simpler sugars - glucose. Glucose is the main

respiratory substrate (used in respiration as fuel). The glucose is gained through digestion and oxygen is acquired through breathing.

Because of the way the digestive tract functions it is dependent upon the respiratory system: using muscular contractions to break up food and move it along the tract depends upon oxygen to function, without oxygen, the digestive tract would stop working. On the other hand your respiratory tract could not function without the products of digestion. Muscles need fuel to contract, and the fuel they used is in the form of carbohydrate (glucose). The digestive tract provides cells of the respiratory muscles with fuel. Cells are dependent on both systems. In order to produce energy, cells use nutrient molecule fuel in oxygen. The two systems working together give your cells what they need to produce energy, which in turn build cells and grow.

Aerobic respiration needs oxygen to generate energy (ATP). This is done through cellular respiration. ATP is made up of phosphate chain (3 groups), adenine and ribose. The manufacture of ATP is done in three steps Glycolysis, krebs cycle and electron transport. The two systems working together give your cells what they need to produce energy, which in turn build cells and grow.

Example -  $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$

Respiratory substrate (Glucose) + oxygen → carbon dioxide + water + energy

The cardiac cycle is events which occur with every heartbeat. The frequency of the cycle is known as the heart rate. The heart is made up of four



chambers connected by valves. The upper chambers are known as the left and right atria and the lower chambers are the right and left ventricle. The two phases of the cardiac cycle are diastole phase - this is where the hearts ventricles relax and the heart fills up with blood. The systole phase is where the ventricles contract pumping blood to the arteries. The upper chamber, the atria receives blood from the vena cava as it is returned to the heart. The left atrium received blood from the lungs by the left and right pulmonary vein. The lower chamber, the ventricles pump blood out of the heart. The right ventricle pumps the blood via the pulmonary artery to the lungs. The left ventricle is responsible for pumping the blood into general circulation through the body therefore is the biggest and most muscular chamber of the heart. This is pumped aorta, which branches off into smaller vessels until all the tissues of the body receive the oxygen carried in the blood.

The inhalation and exhalation of air through breathing involves the diaphragm muscle which is between the chest and abdomen. When inhaling the intercostal muscles contract pulling the chest walls up and out, the diaphragm muscles contract and flatten increasing the chest capacity, the lungs increase in size causing the pressure to fall; this means the air rushes in through the nose and mouth. When breathing out the opposite happens, the intercostals muscles relax where by the chest walls move in and down, the diaphragm relaxes and bulges out reducing the chests size. The lungs therefore decrease in size which increases the pressure causing the body to breathe out. Breathing allows air into the body whereby oxygen is obtained and carbon dioxide expelled (a form of excretion). The pathway air travels involves the air moving down the pharynx, larynx, trachea and windpipe until

reaches the bronchial tubes. Most of the dust and or bacteria are filtered through the nose by mucous membranes; the air travelling through the nose is also warmed so it reaches body temperature quicker.

The air then moves to the bronchia and into the alveoli. The main function of the respiratory system is the intake of oxygen into the bloodstream in order for oxygen to be delivered to all of the body. This is done when human beings breathe, inhaling oxygen and exhaling carbon dioxide. The exchange of oxygen and carbon dioxide happens in the alveoli found in the lungs; they can be described as air sacs surrounded by capillaries for good blood supply. They have a large surface area and are moist which improves diffusion. When oxygen is inhaled it passes into the alveoli, diffusing through the capillaries into the blood in the arteries, the red blood cells have a hemoglobin molecule for oxygen therefore each red blood cell captures the oxygen as it diffuses into the blood, where it is able to travel around the body. Meanwhile the blood from the veins releases carbon dioxide into the alveolus. This follows the path out of lungs when exhaling.

### Alveoli

Breathing is automatic and controlled by the respiratory centre at the base of the brain. Sensory organs in the brain and in the aorta monitor the blood sensing oxygen and carbon dioxide levels. Increased carbon dioxide is the strongest stimulus to breathe. On the other hand when the carbon dioxide in the blood is low, the brain decreases the frequency and depth of breaths. Again this can be related back to homeostasis.

### Breathing mechanism

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## **EXCRETION –**

The excretory system is vital to homeostasis as not only must it be able to get rid of waste products it must, keep water salt and any other substances found in the body at correct levels.

The three systems involved in excretion are the respiratory systems - this is whereby lungs remove  $CO_2$  and water - elaborate

Integumentary - blood vessels in the skin area able to dilate allowing more heat to escape elaborate

Sweat glands produce sweat which is made up of urea salts and water drawings heat from the body to evaporate it - elaborate

Urinary -

The urinary system eliminates harmful wastes from the body whilst regulating water, acids, ions and salts in the blood. The urinary systems comprises of Kidneys, Ureters, Urinary bladder and Urethra. Kidneys remove a combination of urea, water and salts commonly known as urine.

The outer kidney (cortex) contains the glomerus and bowmans capsule. The middle of the kidney (medulla) is made up of the loop of henle and collecting duct. The kidney has a unit for filtration known as the nephron unit located in the cortex and medulla.

The nephron unit conducts two steps filtration and reabsorption purifying the blood.

The renal artery carries blood to the kidneys as the blood enters the glomerulus it is under very high pressure, the glomerulus acts as a sieve, the blood plasma moves it into the Bowman's capsule where it is known as filtrate. The filtrate contains, water, sodium, potassium, uric acid, salt vitamins etc. Anything which the body finds useful within the filtrate is reabsorbed back into the capillary network example - water is reabsorbed through osmosis whereas glucose and amino acids can be reabsorbed by active transport. The loop of Henle is designed to assist in this process as the descending side of the loop is thick therefore easier for water to be reabsorbed and harder for urea. The filtrate left is now urine which is collected in the collecting duct moves to the ureter, urinary bladder and out of the body via the urethra. The kidney ensures water balance, blood pressure, blood composition; blood pH and waste removal are at the optimum levels again maintaining homeostasis.

In a human being every cell is made up of proteins (amino acids) they are essential to every organism. The enzymes which catalyse chemical reactions and the hormones used to maintain and regulate are proteins. Excess protein cannot be stored by the body, therefore must be broken down, which occurs by a process called deamination which takes place in the liver, where the amine group is removed by the chemical reaction hydrolysis breaking the ester bond. Amino acids are formed with a carboxyl group and an amino group. They are made up of carbon, hydrogen, oxygen and nitrogen. The body can manufacture around 10/20 amino acids, the other 10 are essential and therefore must be ingested in the diet.

Deamination is a way in which the body can remove nitrogen (waste product) from amino acids. The amino group is removed ( $-NH_2$ ) and reacts with carbon dioxide which forms ammonia which is a highly toxic waste product of the body, leaving the rest of the amino