

14

Human Digestive System

The human digestive system helps to digest food into small, soluble molecules and absorbs these nutrients into our bloodstream. These nutrients are then used by the body cells for processes such as growth, tissue repair and respiration. The digestive system is made up of many parts. Each of these parts performs a specific function, which supports the overall function of digesting and absorbing nutrients into our bloodstream. Understanding how our digestive system work is crucial to helping us diagnose and treat diseases related to our digestive system.

- Function of the human digestive system (14.1)
- Parts of the digestive system (14.2)
- Food tests (14.3)

14.1 Function of the Human Digestive System

1. The human digestive system digests and absorbs food into the bloodstream.
2. The digestive system undergoes the following processes.
 - (a) Ingestion (taking in of food)
 - (b) Digestion (breaking food down into small, soluble substances)
 - (c) Absorption (absorption of small, soluble substances into circulatory system)
 - (d) Assimilation (using nutrients for cellular processes)
 - (e) Egestion (removal of undigested food)
3. Food needs to undergo two types of digestion.
 - (a) **mechanical digestion** where food is physically broken down into smaller pieces so that there is a **larger surface area** for chemical reactions (**chemical digestion**) to occur
 - (b) **chemical digestion** where large, insoluble food molecules are digested into small, soluble molecules
4. The main constituents of food are **carbohydrates**, **fats** and **proteins** which are large molecules. They are too large to be absorbed by the body.

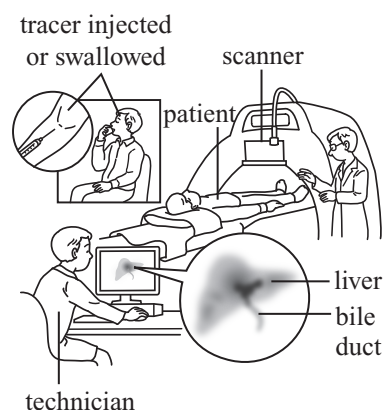


Fig 14.1 One of the ways to detect diseases affecting the digestive tract is radionuclide scanning. This is a test in which the patient swallows, inhales, or is injected with a small amount of radioactive material. Images of organs and areas of the body are produced using a special camera used to detect the radioactivity. Tumors are particularly visible using radionuclide scanning and can be used to detect cancer. This process allows doctors to visualise parts of the digestive system that cannot be seen with an X-ray.

5. The large food molecules are chemically broken down into smaller molecules so that they can be absorbed into the bloodstream.
6. The blood then transports these small molecules to all cells in the body. The cells then use the energy obtained from these small molecules to carry out important life processes including respiration, growth and tissue repair.

Chemical Digestion

1. The food eaten must be digested before it can be absorbed by the small intestine to be used by the cells in the body.
 - (a) **Carbohydrates** (starch) will be digested into **glucose**. Other carbohydrates can be digested into fructose and galactose.
 - (b) **Proteins** will be digested into **amino acids**.
 - (c) **Fats** will be digested into **fatty acids** and **glycerol**.
2. Each individual will require different amount of nutrients depending on their stage of development and lifestyle. An active teenager will need more carbohydrates to support their physical activity while an adult with a more sedentary lifestyle will require less carbohydrates.
3. The different constituents of food such as carbohydrates, proteins and fats are digested by different **enzymes** that are highly specific for each constituent.
4. **Enzymes** are proteins that speed up biological reactions.

Extra

- The breaking down of large food molecules does not take place directly to give the desired small food molecules. It occurs in stages to give shorter (simpler) molecules.
- There are many sugars such as maltose, sucrose and lactose. Maltose is made of two glucose units and therefore can be further broken down into two glucose molecules. Glucose, fructose and galactose are some of the simplest sugar molecules.

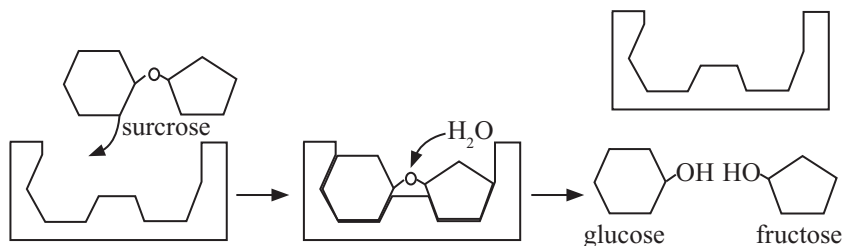


Fig 14.2 This model, called the lock-and-key hypothesis, explains why each type of enzyme catalyses only one type of reaction.

5. Optional for **N(A)**

The three main categories of enzymes are:

- carbohydrases** that act on carbohydrates,
- proteases** that act on proteins,
- lipases** that acts on fats.

6. Different organs in the alimentary canal produce their own enzymes.

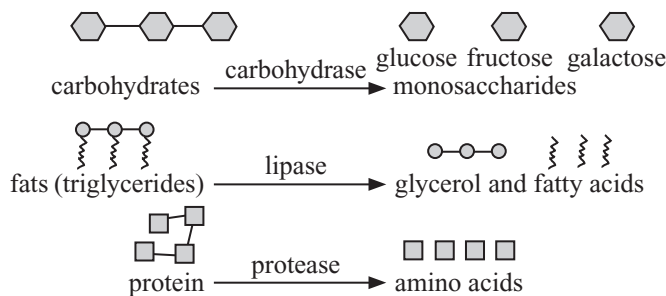
Optional for **N(A)**

Fig 14.3 The three main categories of enzymes

14.2 Parts of the Digestive System

- The digestive system consists of two parts:
 - the alimentary canal (mouth $\rightarrow$ oesophagus $\rightarrow$ stomach $\rightarrow$ small intestine $\rightarrow$ large intestine $\rightarrow$ rectum $\rightarrow$ anus)
 - the accessory organs and glands (salivary glands, gall bladder, liver and pancreas)

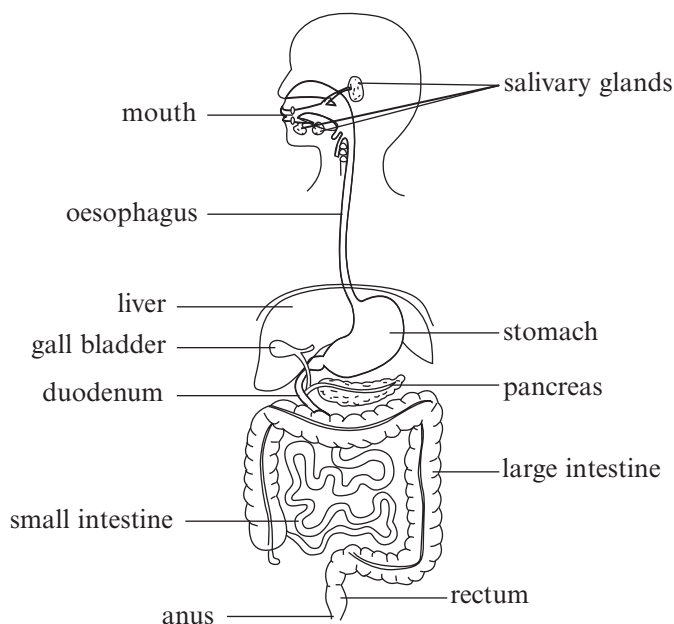


Fig 14.4 The diagram above shows the organs in the alimentary canal and accessory organs (and glands) related to the digestive system.

Extra

More examples of enzymes:

- Pectinase is added during the manufacture of fruit juices to speed up the breakdown of pectin in cell wall, releasing more juice.
- Lactose-free milk (suitable for people who are lactose intolerant) is made by adding lactase to milk, breaking down lactose into simple sugars.
- Cellulase is needed to digest cell wall in order to isolate genetic material from plant cell.
- Catalase, a common enzyme, protects bacteria from oxidative damage by reactive oxygen species (a type of unstable molecule that contains oxygen and that easily reacts with DNA and RNA in a cell).

2. The table shows the respective functions of the organs found in the alimentary canal of a human.

Organ	Primary functions
Mouth	- Salivary glands secrete mucin to soften food. - Tongue has taste buds to taste the food and rolls the food into a small ball known as bolus. Bolus is swallowed into the oesophagus. - Mechanical digestion by cutting and grinding actions of the teeth. - Optional for N(A) Chemical digestion: salivary amylase breaks down starch into maltose. $\text{starch} \xrightarrow{\text{salivary amylase}} \text{maltose}$
Oesophagus	- A long tube that directs the food mass into the stomach. - No new digestion takes place here. - Food is pushed down to stomach via peristalsis (a series of muscle contractions).
Stomach	- More mechanical digestion—mixing, crushing and grinding by churning of the stomach. - Secretes gastric juice that contains hydrochloric acid, HCl, and a protease. - Acidic medium provides optimum pH for enzymes in gastric juice to work and kills germs. - The acidic pH denatures salivary amylase in bolus and stops digestion of starch. - Stomach wall has a mucus lining that protects it from the acidic medium. - Optional for N(A) Chemical digestion: protease digests proteins into polypeptides $\text{proteins} \xrightarrow{\text{protease}} \text{polypeptides}$ - Acidic liquified food is released out of the stomach and into the duodenum as chyme.
Duodenum (small intestine)	- Chyme is pushed along the intestines by peristalsis. - Alkaline intestinal juice containing enzymes are secreted into duodenum. - Pancreas secretes pancreatic juice containing enzymes and bicarbonate HCO_3^- into the duodenum. - Alkaline digestive juice and bicarbonate neutralise the acidic chyme. - Gall bladder secretes alkaline bile into the duodenum. - Alkaline environment provides an optimum pH for digestive enzymes in the duodenum to work. - Mechanical digestion: Fats are emulsified (broken into smaller fat globules) by bile. - Optional for N(A) Chemical digestion: Fats are digested into glycerol and fatty acids by lipase in intestinal and pancreatic juice. $\text{fats} \xrightarrow{\text{lipase}} \text{glycerol} + \text{fatty acids}$ - Optional for N(A) Chemical digestion: Proteins / polypeptides are digested into amino acids by proteases. $\text{proteins / polypeptides} \xrightarrow{\text{protease}} \text{amino acids}$ - Optional for N(A) Chemical digestion: Carbohydrates are digested into simplest sugars by carbohydrases. $\text{starch} \xrightarrow{\text{amylase}} \text{maltose} \xrightarrow{\text{maltase}} \text{glucose}$

Organ	Primary functions
Small intestine (jejunum and ileum)	Absorption of sugars, amino acids, fatty acids, glycerol and water.
Large intestine (Colon)	- Only indigestible food such as dietary fiber enters the large intestine. - Absorption of remaining water, mineral salts and vitamins.
Rectum	Stores the undigested food before it is passed out of the body
Anus	The hole through which faeces are passed out of the body (egestion).

Table 14.1 Functions of the parts of the digestive system

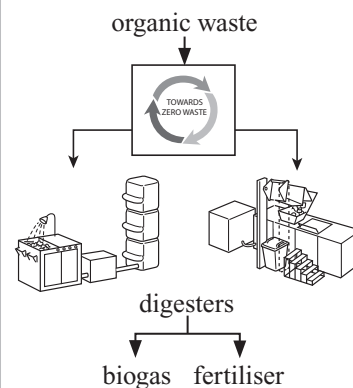
3. The digestive system has many bacteria (called probiotics) living in it. These bacteria help us to digest our food. This is an example of mutualism in which humans provide the bacteria with semi-digested food (fuel), while the bacteria digest the food and release amino acids and vitamins. (See Chapter 12 for interrelationships between organisms)

Extra

- Butanoic acid $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$, the fuel needed by colon cells, is produced when good bacteria in the large intestine break down dietary fibre. Studies have found that there is a correlation between Western diet, which tends to be high in fats and low in fiber, and increased risk of colon cancer. We know that colon cancer begins with gene mutation in a stem cell which divides rapidly. However, more studies are needed to understand how fiber or butanoic acid reduces the risk of colon cancer.
- In normal digestion, the enzyme lactase digests lactose (a sugar found in milk) to glucose and galactose. Some people suffer from lactose intolerance as their small intestine does not produce enough lactase. As the undigested lactose travels to the large intestine, the intestines lose water through osmosis leading to diarrhoea (watery stool).

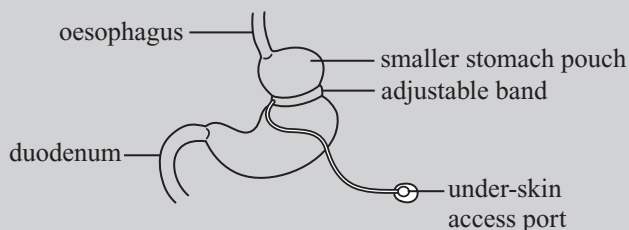
Note

A digester is a large tank where bacteria produce enzymes to digest organic matter such as food waste and sewage. This decreases the volume of the solid waste and turns some of the waste into fertiliser. Anaerobic digester also produces biogas (methane and carbon monoxide) which is a fuel. (See Chapter 12 for sewage treatment)



SCIENCE AROUND US

Obese patients are at risk of many health problems such as diabetes. To help them lose weight, a surgery known as gastric banding can be performed. This surgery helps the person to eat less.



- (a) Describe the role of the stomach in controlling the amount of food a person eats. [1]
- (b) Explain how gastric banding helps the patient eat less. [3]

ANSWER

- (a) When the stomach stretches to a point, the person feels full and stops eating.
- (b) As the stomach is smaller due to the band, the amount of food the stomach can hold is reduced. Hence, the stomach will be full faster / reaches the maximum stretch faster.

Bile

1. Fats which are insoluble in water tend to conglomerate as fat globules. This makes the digestion of fats inefficient and hence, fats need to be emulsified (made into fine droplets) in the small intestine before being digested.

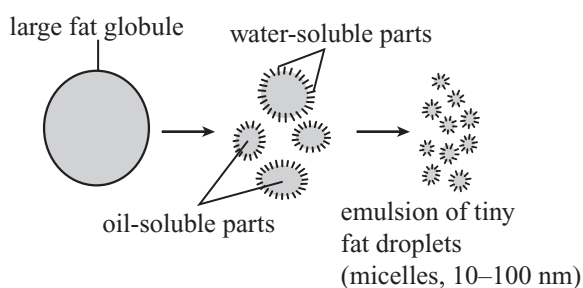


Fig 14.5 The bile salt are detergent-like molecules with water-soluble parts and oil-soluble parts.

2. The bile does not digest fats as it does not contain enzymes. It emulsifies the fats. This means that it breaks down the fat globules into tiny droplets (called micelles). This is to increase the surface area for action by lipase.

Peristalsis

Extension Knowledge

1. Food moves down the alimentary canal through contraction and relaxation of muscles.
2. This rhythmic wave-like contraction of muscles mixes and propels food in the alimentary canal. This action is called **peristalsis**.

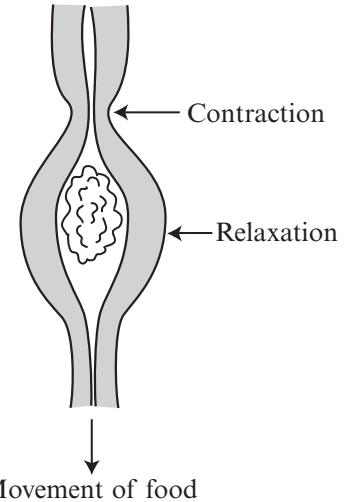


Fig 14.6 Peristalsis is an involuntary wave-like movement of circular muscles in hollow tubes.

Small Intestine (ileum): Adaptations for Absorption

Extension Knowledge

1. Sugars, amino acids, glycerol and fatty acids are absorbed into the bloodstream via the surface of the small intestines (by processes such as diffusion).
2. For fast absorption of digested food, the small intestine needs to have a large surface area. This is achieved with **folds**, and the **villi** and **microvilli**.

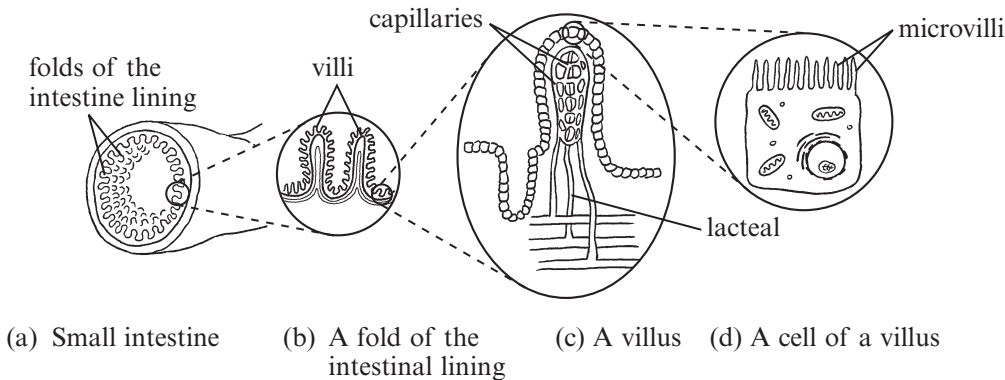


Fig 14.7 Adaptations of the small intestine for absorption

3. Villi (singular: villus) are finger-like structures on a fold, while microvilli are finger-like structures on a cell of a villus.
4. A network of blood capillaries and lacteal are found below each villus to absorb digested food.
5. Fatty acids and glycerol are absorbed into vessels called the **lacteals**.
6. Glucose and amino acids are absorbed into the **blood capillaries**.

Structure	Function
Has folds, villi and microvilli	Increases surface area to volume ratio for faster rate of absorption
Network of blood capillaries and lacteal under each villus	Carries away absorbed digested food quickly and maintains a diffusion gradient
Epithelial cell wall is one-cell thick	Faster diffusion of nutrients from small intestine into blood capillaries and lacteals.

Table 14.2 The structure-function relationship of small intestines for absorption

SCIENCE AROUND US

If a part of the small intestine is blocked, a small bowel resection surgery may be performed to remove the diseased part of the small intestine and join the healthy parts together. If a large amount of the small intestine is removed, the patient may need to receive liquid nutrition through an intravenous drip for some time.

- Explain why the patient requires liquid nutrition through intravenous drip if a large part of the small intestine is removed. [3]
- A common side effect of the surgery is diarrhoea. Suggest why. [1]

ANSWER

- Most of the digestion and absorption of nutrients occur in the small intestine. When a large part of the small intestine is removed, most nutrients cannot be absorbed by the body into the bloodstream. Nutrients need to be replenished into the bloodstream directly.
- Insufficient absorption of water by the small intestine.

Liver

Extension Knowledge

- Besides producing bile, the liver has many other important functions in the assimilation of glucose and amino acids and helps in the breakdown of urea and alcohol.
- The hepatic portal vein transports blood rich in absorbed nutrients from the small intestine to the liver. ('Hepatic' means of or relating to the liver.)

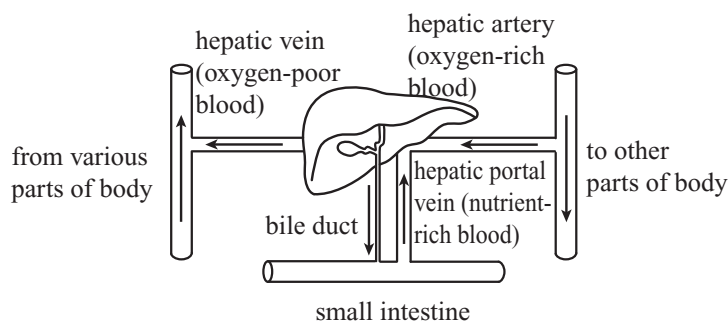


Fig 14.8 The liver receives blood from the hepatic artery and hepatic portal vein. The hepatic artery delivers oxygenated blood from the general circulation. The hepatic portal vein delivers deoxygenated blood containing nutrients from the small intestine.

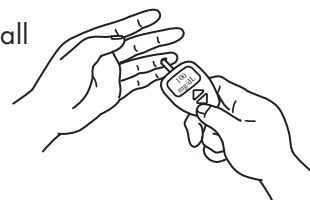
Glucose Metabolism

Extension Knowledge

1. After a carbohydrate-rich meal, blood from the hepatic portal vein is high in glucose concentration. As glucose-rich blood passes through the pancreas, pancreatic cells release insulin (a hormone) into the bloodstream.
2. Insulin signals the liver to take in excess glucose from the blood into its cells. Inside the liver cells, glucose is converted to glycogen and stored within the liver.
3. If blood glucose concentration is low, pancreatic cells release glucagon (hormone) into the bloodstream. Glucagon signals the liver cells to convert glycogen into glucose which is then released into the blood stream.
4. Some individuals are unable to make insulin, resulting in a constant high blood glucose concentration. Over time, this can result in heart disease, loss of vision and kidney disease.
5. These individuals have Type I diabetes and require regular insulin injection.
6. Overconsumption of food rich in carbohydrates and lack of exercise can result in Type II diabetes where the body cells no longer respond to insulin. This causes blood sugar level to remain high.
7. Type II diabetes can be prevented through a balanced diet and a healthy lifestyle.
8. Insulin can be manufactured by inserting the gene responsible for the production of insulin into a plasmid (a circular DNA molecule) and then inserting the recombinant plasmid into a bacterium. (See Chapter 6 for genetic engineering)

Extra

Diabetics need to monitor their blood glucose level closely. This is usually done by pricking the skin using a fine needle and putting a small amount of blood into a reader that will detect the glucose level in the blood. Non-invasive methods of reading blood glucose levels such as using a stick-on patch that can continuously track blood glucose level can help to make monitoring blood glucose level easier. The data can be sent to a smart phone or smart watch and provide more accurate data to the patient to inform them of their lifestyle options.



Amino Acid Metabolism

Extension Knowledge

1. Excess amino acids consumed are broken down in the liver.
2. Excess amino acids undergo deamination where they are broken down into ammonia and an acid.
3. Ammonia can be converted into urea in the liver and transported to the kidneys for excretion in the urine.

Fat Metabolism

Extension Knowledge

1. Fatty acids are broken down to be used as a substrate in respiration.
2. Excess carbohydrates and proteins are converted into fatty acids and triglycerides which are then exported and stored in fat tissues (adipose).
3. Fats are also used to synthesise cholesterol in the liver.

Breakdown of Red Blood Cells

Extension Knowledge

1. Worn out or aging red blood cells are broken down in the liver.
2. Haemoglobin from red blood cells is also broken down and the iron is stored in the liver.

Breakdown of Alcohol

Extension Knowledge

1. Alcohol consumed is broken down in the liver. Most of the alcohol is broken down by alcohol dehydrogenase (ADH) into acetaldehyde which is further broken down into acetate by aldehyde dehydrogenase (ALDH).

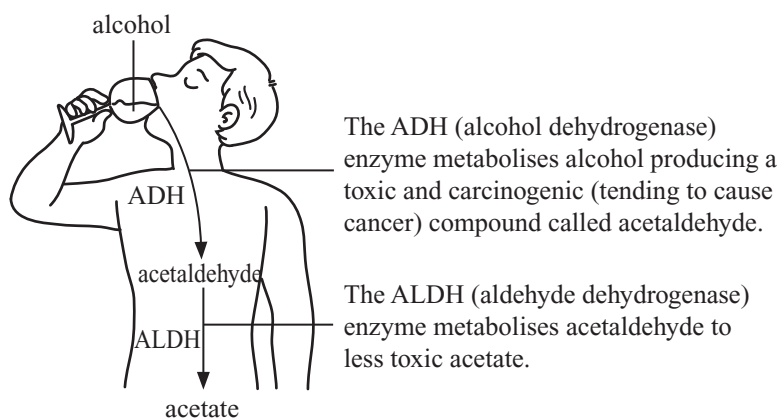


Fig 14.9 ADH and ALDH are the primary enzymes involved in alcohol metabolism in the liver.

- Excessive consumption of alcohol results in reduced self-control, depression and increased reaction times.
- Long-term overconsumption of alcohol can lead to liver cirrhosis (scarring of liver) due to destruction of liver cells.

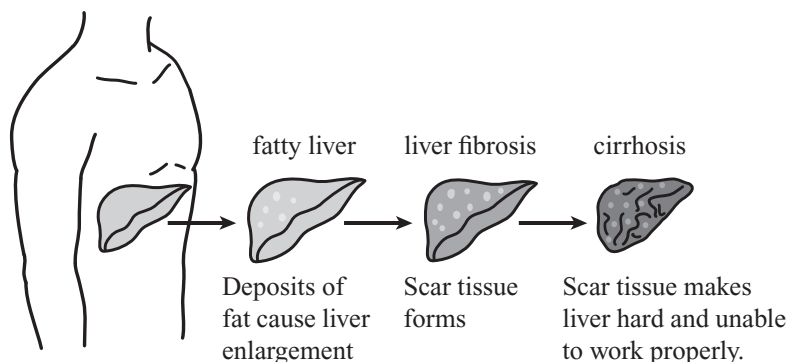


Fig 14.10 Stages of liver disease

- Alcohol abuse also has social implications such as domestic abuse. It worsens relationships with friends and family members and negatively affects a person's ability to work.
- Pregnant mothers who drink may cause the foetus to be born with foetal alcohol syndrome. Foetal alcohol syndrome causes brain damage and growth problems.

14.3 Food Tests

- The table below shows the different methods used to test foods.

Food constituent	Reagent	Procedure	Observation	Conclusion
Starch	Iodine solution	Add a few drops of iodine solution into the liquid food sample.	The yellow brown iodine solution turns dark blue.	Starch is present.
			The iodine solution remains yellow brown.	Starch is absent.

Extra

Some people may have malfunctioning aldehyde dehydrogenase enzyme, resulting in the build up of acetaldehyde in their bloodstream. These individuals cannot tolerate alcohol well and may experience symptoms such as flushing of the face, hot sensations, nausea and heart palpitations (heart beating faster than normal) after consumption of alcohol.

Food constituent	Reagent	Procedure	Observation	Conclusion
Reducing sugar	Benedict's solution	Add an equal volume of Benedict's solution into the liquid food sample. Shake to mix. Put in boiling water bath for 2 minutes.	The blue Benedict's solution turns brick red.	Large amounts of reducing sugars (such as glucose) are present.
			The blue Benedict's solution turns orange.	Moderate amounts of reducing sugars are present.
			The blue Benedict's solution turns yellow.	Low amounts of reducing sugars are present.
			The blue Benedict's solution turns green.	Trace amounts of reducing sugars are present.
			Benedict's solution remains blue.	Reducing sugar is absent.
Protein	Biuret solution	Add a few drops of Biuret solution into the liquid food sample. Shake to mix.	The blue Biuret solution turns deep purple.	Proteins are present.
			Biuret solution remains blue.	Proteins are absent.
Fat	Ethanol and distilled water	Add 2 cm ³ of ethanol to food sample. Shake to mix. Decant ethanol into new test tube. Add 2 cm ³ of distilled water.	Cloudy, white emulsion is formed.	Fats are present.
			Solution remains clear.	Fats are not present.

Table 14.3 Tests for food

Extra

- When a urine sample tested with Benedict's solution shows the presence of simple sugar in the urine, it indicates that the person is diabetic.
- When a urine sample tested with Biuret solution shows the presence of proteins in the urine, it indicates that the person suffers from a kidney failure. This is because a non-functional kidney may allow proteins to pass from the blood into the urine.

Food-borne Diseases

1. When a person eats **contaminated food or drinks**, he may end up getting food-borne diseases.
2. Food-borne diseases or **food poisoning** are usually caused by **bacteria** that contaminate the food through:

- (a) cross-contamination—bacteria passing from dirty hands or utensils to the food, or from raw food to the cooked food,
 - (b) the food being exposed to the air in room temperature,
 - (c) improperly cooked or unhygienically prepared food.
3. The most common **symptoms** of food-borne diseases are diarrhoea, vomiting, fever, stomach cramps and dehydration. Serious food poisoning or delays in seeking immediate medical attention may cause death.
4. The methods (or practices) that can prevent food-borne diseases efficiently include:
 - (a) practising good personal hygiene (washing hands before and after handling food or using the washroom),
 - (b) washing fruits and vegetables thoroughly before consuming them,
 - (c) washing utensils and crockery thoroughly before using them,
 - (d) freezing or refrigerating food to prevent bacterial growth,
 - (e) cooking food thoroughly to kill bacteria,
 - (f) keeping cooked food covered to prevent flies or other insects from the food,
 - (g) checking the expiry date of the food product before purchasing.

Extra

Common bacteria that cause food-borne diseases include salmonella, some strains of E-coli and Vibrio cholerae. Common viruses that cause food-borne diseases include Norovirus and hepatitis A (which causes inflammation of liver).

Balanced Diet**Extension Knowledge**

1. A **balanced diet** is one that gives our body the right amount of nutrition (carbohydrates, proteins, fats, vitamins, minerals, fibres and water) it needs to be healthy.

Constituent of food	Function	Sources
Carbohydrates	• Provide energy quickly	Rice, noodles, pasta, potatoes, bread
Proteins	• Build and repair muscles	Soy beans, tofu, egg, meat, fish
Fats	• Provide energy slowly	Oils, dairy products, nuts, fish

Constituent of food	Function	Sources
Vitamins	• Vitamin A—important for vision • Vitamins B—to form red blood cells • Vitamin C—important for skin and gums • Vitamin D—to absorb calcium from small intestine	Fresh fruits and vegetables
Minerals	• Calcium—for healthy bones and teeth • Iron—for metabolism and formation of haemoglobin in red blood cells	Fresh fruits and vegetables
Fibres	• Cellulose—to add volume to undigested food • Maintains peristalsis	Fresh fruits and vegetables, wholegrain cereals
Water	• For formation of blood and cytoplasm • Enzymes only work in solution	Drinks, fresh fruits and vegetables

Table 14.4 Functions and sources of constituents of food

2. **Vitamins** are organic compounds that living things require in small amounts. The body cannot synthesise these compounds.
3. Deficiency in vitamins and minerals leads to diseases. For example, lack of vitamin D or calcium leads to rickets in which the bones become soft, weak and deformed.

Obesity

Extension Knowledge

1. Being healthy is not only about a balanced diet. It involves using the energy consumed in physical activities or exercises.
2. In developed countries, there is a rise in cases of **obesity** in children.
3. Obesity is a disorder in which the body accumulates **excess body fat** leading to negative effects on health.
4. The health consequences of obesity include coronary heart disease, Type II diabetes, cancer and stroke.
5. One of the main causes of obesity is the **large consumption of sugar**.
6. Other causes of obesity include:
 - (a) **behavioural factors** such as consumption of fast foods, foods high in carbohydrates or fats, snacking and alcohol,
 - (b) **genetic factors**,
 - (c) **social factors** such as having sedentary lifestyles, for instance, watching the television or playing computer games excessively without any exercise at all.

Note

Obesity causes increased levels of fatty acids and inflammation, leading to insulin resistance (cells become less sensitive to insulin), which in turn can lead to Type II diabetes.