HUMAN DIGESTIVE SYSTEM
How life works at the physiological level

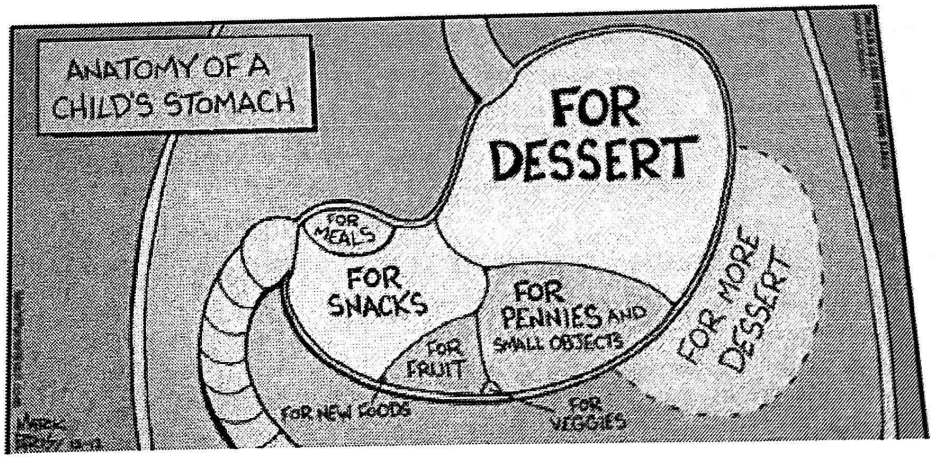
Date: 20 April 2022

Learning Outcomes

At the end of the chapter, you should be able to:

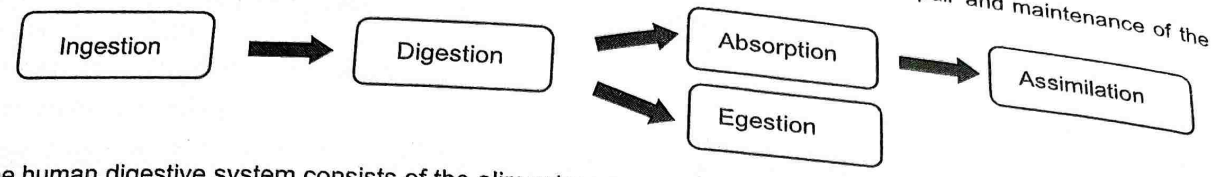
1. describe the functions of main regions of the alimentary canal and the associated organs: mouth, salivary glands, oesophagus, stomach, duodenum, pancreas, gall bladder, liver, ileum, colon, rectum and anus in relation to **ingestion, digestion, absorption, assimilation** and **egestion** of food, as appropriate — online/class
2. describe **peristalsis** in terms of rhythmic wave-like contractions of the muscles to mix and propel the contents of the alimentary canal — online/class
3. describe chemical digestion in the alimentary canal, the functions of a typical **amylase, protease and lipase**, listing the substrate and end-products — online/class
4. describe the structure of a **villus** and its role, including the role of capillaries and lacteals in absorption — online/class
5. state the function of the **hepatic portal vein** as the transport of blood rich in absorbed nutrients from small intestine to the liver — online/class
6. state and explain the role of the **liver** in: — online/class
   - carbohydrate metabolism
   - fat digestion
   - breakdown of red blood cells
   - metabolism of amino acids and the formation of urea
   - breakdown of alcohol
7. describe the effects of **excessive consumption of alcohol**: reduced self-control, depressant, effect of reaction times and damage to liver. — online/class

Use the knowledge gained in this section in new situations or to solve related problems.



Introduction

Nutrition is the process by which organisms obtain food and energy for growth, repair and maintenance of the body. In humans, it consists of a sequence of different processes:



The human digestive system consists of the alimentary canal and associated organs.

Food we consume are complex organic molecules which are too large to pass through the cell membrane to enter body cells directly.

Digestion is the process that **breaks down complex food substances into simple, soluble molecules that are small enough to be absorbed into the body cells.**

Food digestion takes place in the **alimentary canal**, a long, muscular tract which extends from the mouth to anus. The soluble products are absorbed and the undigested residue is egested.

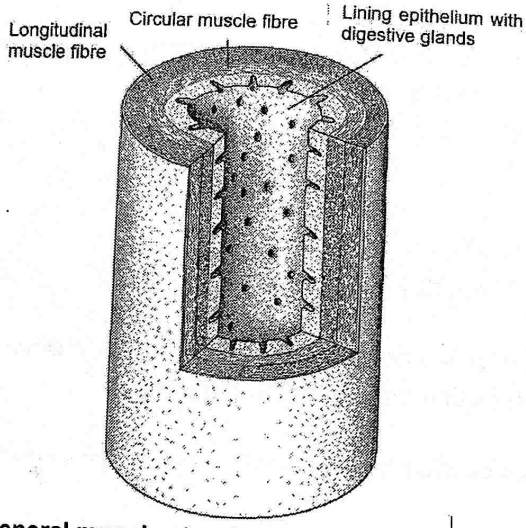


Figure 1 General muscle structure of the alimentary canal

Digestion involves both physical and chemical processes.

- **Physical** digestion: **mechanical** breakdown of food into **smaller particles** to provide a large surface area to volume ratio for faster rate of chemical digestion by digestive enzymes e.g. chewing, churning action of stomach, emulsification of fats
- **Chemical** digestion: breakdown of large food molecules into **small soluble molecules** catalysed by digestive **enzymes through hydrolytic reactions.**

Structures and functions of the alimentary canal and the associated organs

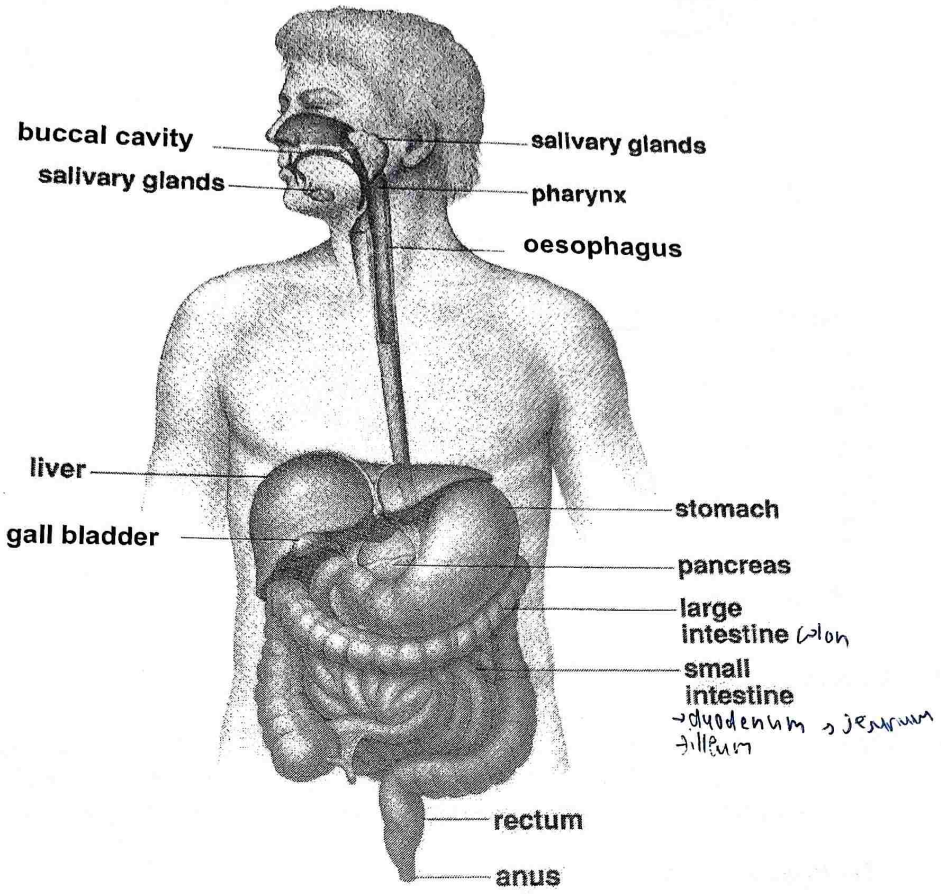


Figure 2 Human Digestive System

1. Digestion in the mouth

- The act of taking food into the mouth is called **ingestion.**
- **Chewing** (a form of physical digestion) breaks down the food into pieces to increase surface area to volume ratio for faster rate of chemical digestion by digestive enzymes.
- Saliva, produced by the salivary glands in the mouth, would moisten and soften food.
- It also contains the enzyme **salivary amylase** which digests **starch into maltose.**

Organ	Gland	Secretion	Enzyme	Enzyme action
Mouth (optimum pH 6.5 to 7.5)	Salivary gland	Saliva	Salivary amylase	Starch —(Salivary amylase)→ maltose

Tongue is very important!

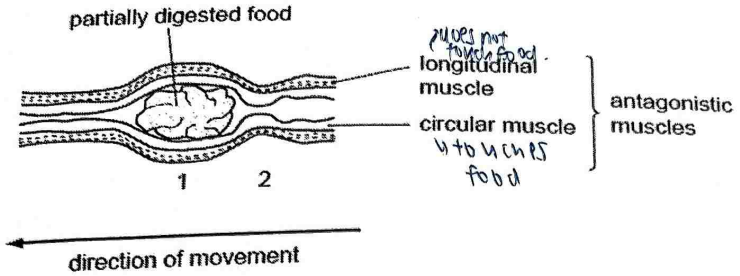
- The thoroughly chewed food is rolled into a **bolus** in preparation for swallowing.
- After swallowing, the bolus enters the oesophagus. The digestion of starch continues in the oesophagus.
- The bolus is moved along the oesophagus by **peristalsis, a rhythmic, wave like muscular contractions of the wall** towards the stomach. Peristalsis occurs throughout the alimentary canal.

~~Food~~ Peristalsis occurs throughout the whole digestive system!

1-c when 1 muscle contracts, the other relaxes and vice versa.

Thinking time!

The diagram shows a section of the small intestine in which partially digested food is being pushed along.



What is the state of the longitudinal muscles at 1and 2?

	1	2
A	contracted	contracted
B	contracted	relaxed
C	relaxed	contracted
D	relaxed	relaxed

(B) ✓

Answer: B

2. Digestion in the stomach

- The stomach is an elastic, muscular bag, with thick muscular walls.
- In the presence of food, gastric glands contain in the stomach will secrete gastric juice.
- The **gastric juice** consists of mainly hydrochloric acid and two enzymes, pepsin and *rennin**.

a) **Hydrochloric acid**:
- provide an acidic medium suitable for the action of the enzymes in the stomach
- kills bacteria in food
- changes inactive forms of enzymes to the active forms: converts pepsinogen (inactive form) to pepsin (active form)

b) **Pepsin** (a protease)
Pepsin digests **proteins to polypeptides** by hydrolysis.
Optimum pH provided by HCl

c) ***Rennin* (*Enrichment, not in syllabus)**
Converts soluble milk protein caseinogen into insoluble casein, causing coagulation of milk.

- The food is **churned** (a form of physical digestion) and mixed with the gastric juice by the peristaltic contractions of the stomach wall for hours.
- The partly digested food becomes liquefied, forming **chyme**, which passes into duodenum (first part of the small intestine) in small amounts. semi-liquid

Organ	Gland	Secretion	Enzyme	Enzyme action
Stomach (optimum pH 2)	Gastric gland	Gastric juice (contains HCl, water, pepsin, rennin)	Pepsin	Protein —pepsin→ polypeptides
			*Rennin**	Caseinogen (soluble) —rennin→ casein (insoluble)

3. Digestion in small intestine

- The small intestine consists of the **duodenum**, **jejunum** and highly coiled **ileum**.
- The lining of the walls of the small intestine contains glands which secrete digestive enzymes.
- The **liver, gall bladder** and **pancreas** are not part of the alimentary canal but are associated with it.
- The pancreas is a gland lying below the stomach which produces several digestive enzymes
- The liver is the largest gland that produces **bile**. Bile is an alkaline greenish-yellow liquid containing bile salts and bile pigments. Bile is stored in the gall bladder.
- The duodenum, the first part of the small intestine, receives chyme from the stomach and secretions from the gall bladder and pancreas.

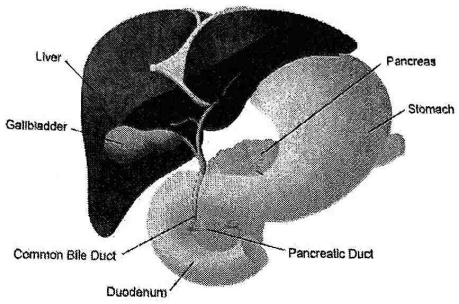


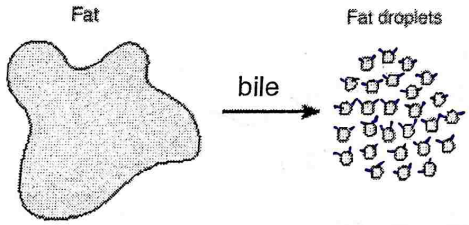
Figure 3 Associated organs

Liver

Liver produces bile (thick, yellow-green fluid).

Bile

- **function to emulsify fats**, to physically break them down into tiny fat droplets to **increase surface area to volume ratio** for **faster digestion by lipase**
- does not contain any digestive enzymes
- creates an alkaline environment (pH 8.5) for enzymes action and to reduce the acidity of the chyme



Pancreas

Pancreas secretes pancreatic juice containing:

- Pancreatic amylase
- Pancreatic lipase
- Trypsin (a protease)

Bile enters the duodenum via the bile duct

Pancreatic juice is secreted into the duodenum by the pancreas via pancreatic duct.

Duodenum (first part of small intestine)

The digestion of starch, proteins and lipids take place in the duodenum.

- Small intestine secretes intestinal juice which contains digestive enzymes (e.g. peptidase, maltase, sucrose, lactase, intestinal lipase) needed to complete the digestion of carbohydrates, proteins and fats.
- At the end of the digestive process, **all carbohydrates are digested into monosaccharides such as glucose, fructose and galactose.**
- **Polypeptides are digested into amino acids**
- **Fats are digested into fatty acids and glycerol.**

Organ	Gland	Secretion	Enzyme	Enzyme action
Small intestine (optimum pH 8.5)	Pancreas	Pancreatic juice	Pancreatic amylase	Starch —pancreatic amylase→ maltose
			Trypsin	Protein —trypsin→ polypeptides
			Pancreatic lipase	Emulsified fat —lipase→ fatty acids + glycerol
	Intestinal gland	Intestinal juice	Peptidase	Polypeptides —peptidase→ amino acids
			Maltase	Maltose —maltase→ glucose
			Sucrase	Sucrose —sucrase→ glucose + fructose
			Lactase	Lactose —lactase→ glucose + galactose
			Intestinal lipase	Emulsified fat —lipase→ fatty acids + glycerol

Thinking time!

- Pepsin and trypsin are released in inactive form. It is only converted to its active form when food is present. Why?
- How is the stomach protected from effects of gastric juice?
- Which three organs produce enzymes that digest protein? What are the final products of protein digestion?

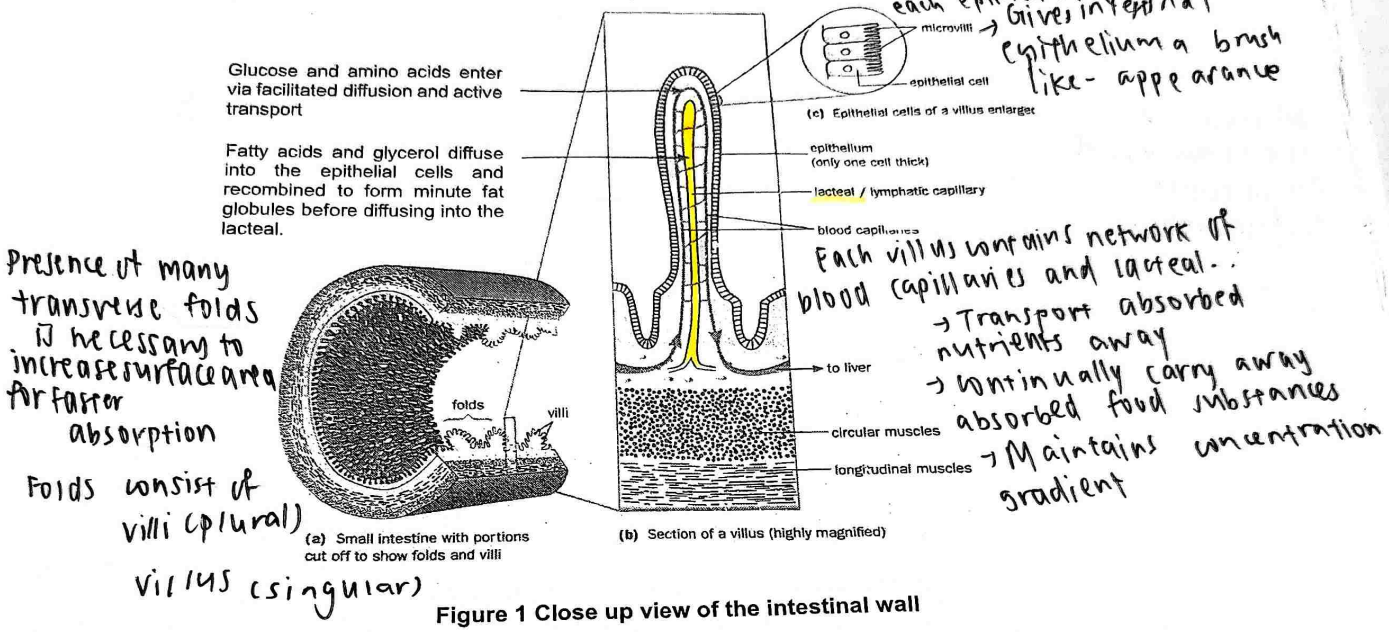
☺ *Read more

4. Absorption in small intestine

increase S.A to volume ratio

- Products of digestion such as **monosaccharides (glucose, fructose and galactose), amino acids, fatty acids, glycerol and water are absorbed** throughout the **small intestine**, especially the ileum.
- These products must be transported across the epithelium into the blood stream.

Small projections on each epithelium cell → Gives intestinal epithelium a brush like- appearance



Presence of many transverse folds is necessary to increase surface area for faster absorption

Folds consist of villi (plural)

villus (singular)

Each villus contains network of blood capillaries and lacteal.
→ Transport absorbed nutrients away
→ Continually carry away absorbed food substances
→ Maintains concentration gradient

Figure 1 Close up view of the intestinal wall

Adaptations of the small intestine for absorption

Adaptations	Functions
Small intestine is **long**. (6 – 7m)	To provide sufficient **time** for absorption to take place.
Inner walls of the small intestine have many transverse **folds** bearing many finger-like projections called **villi**. Each villus possesses numerous **microvilli**. (See Figure 4 and 5)	To increase **surface area to volume ratio** for faster absorption of digested food substances by diffusion.
The **epithelium** of the villus is **one cell thick**.	To reduce the **distance** for digested products to diffuse into the capillaries and lacteal.
The small intestine consists of a **dense network** of blood capillaries and lacteal within the villi.	This continuous transport of digested food substances maintains a **steep concentration gradient** for faster absorption of digested products by diffusion.

Figure 5 shows a close up view of the cellular structure of an epithelial cell.

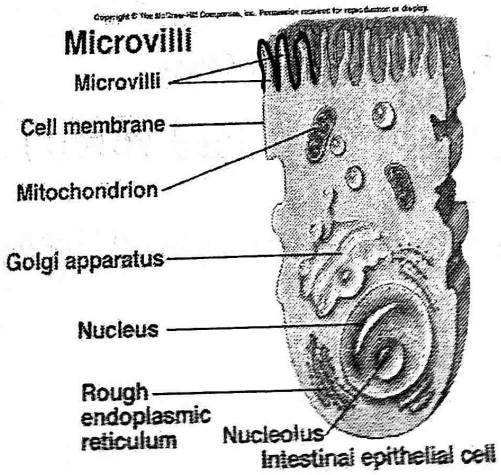


Figure 5 Intestinal epithelial cell

How does the absorption of digested products and water take place?

- **Glucose** and **amino acids** are absorbed by **facilitated diffusion** into the blood capillaries of the villi.
- They are also absorbed by **active transport** where there is a lower concentration in the intestinal lumen than in the blood capillaries.
- **Fatty acids** and **glycerol** diffuse into the epithelial cells and **recombined** to form minute **fat globules** before **diffusing** into the **lacteal**.
- Most water and minerals are absorbed in the large intestine.

microvilli in the epithelium of villi increases surface area.

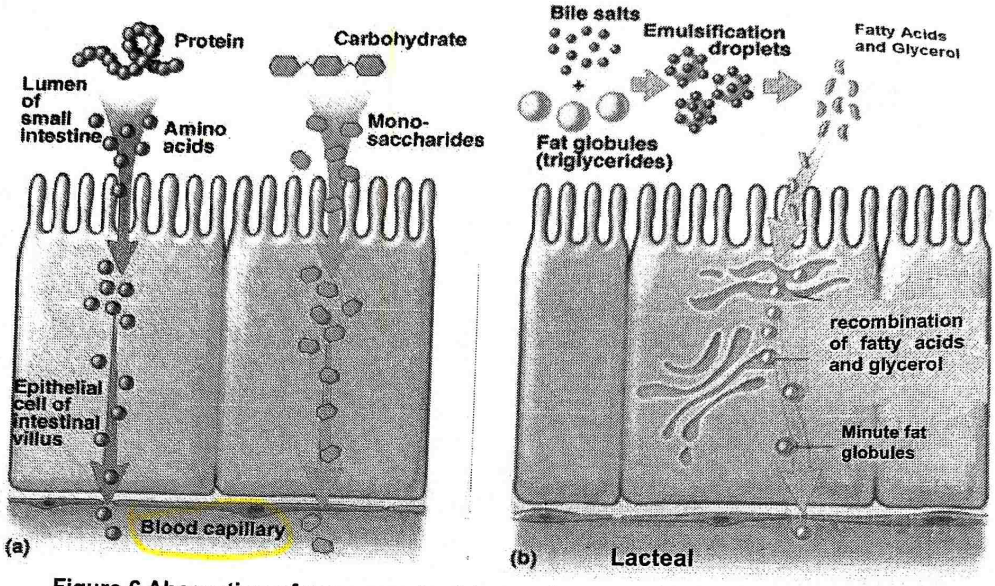


Figure 6 Absorption of monosaccharides, amino acids and fat globules

Summary Table:

Substance	Transport Process
Monosaccharides	Facilitated diffusion and active transport
Amino acids	Facilitated diffusion and active transport
Fat globules (recombined from fatty acids and glycerol in the epithelial cells)	Simple diffusion
Water	Osmosis
Minerals	Facilitated diffusion and active transport

- Blood capillaries of the small intestine join to form venules which then join to form the **hepatic portal vein**. Hepatic portal vein carries **mainly glucose and amino acids** to the liver to be processed.
- Fat globules are transported away from small intestine by the **lacteal**.

connects the digestive system to the liver.

Fats cannot go into the bloodstream (不会去输往) (clogs the blood vessels)

Fats leave larger lymphatic vessels into bloodstream, distributed around the body.

5. Assimilation of absorbed nutrients

Assimilation is the **utilisation of absorbed nutrients and how the body deals with the excess nutrients.**

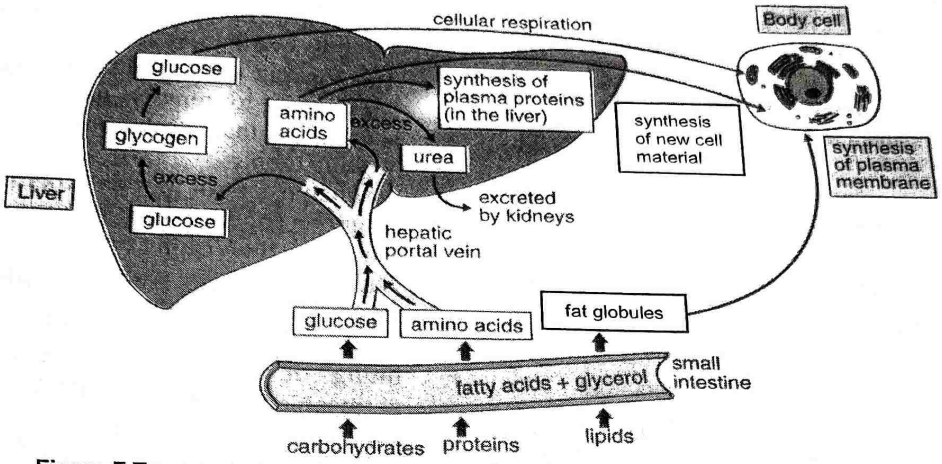


Figure 7 Transport of nutrients and assimilation in the liver and body cells

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A. Assimilation of glucose

- Glucose is a **substrate for respiration** to release energy for cellular activities.
- **Excess glucose is converted into glycogen** by the liver cells and stored. This is stimulated by **insulin** (a hormone), produced by the **pancreas**.
- Glycogen is converted into glucose by the liver cells when blood glucose level is low. This is stimulated by **glucagon** (a hormone), produced by the **pancreas**.

Glucose ⟶ (After a heavy meal, insulin stimulates liver to convert) Glycogen

Glycogen ⟶ (During fasting, glucagon stimulates liver to convert) Glucose

B. Assimilation of amino acids

- Required to make new cell materials that is used for growth and repair of worn-out parts of the body.
- Required to make enzymes and hormones
- **Excess amino acids are deaminated in the liver. Their amino group is removed and converted into urea.**

Excess $H_2N-\underset{\displaystyle R}{\overset{\displaystyle H}{\underset{|}{\overset{|}{C}}}}-COOH$ (amino group.) —**Deamination**→ Amino group is removed and converted into **urea** to be excreted in the urine — Transported to kidney for excretion

→ Remaining carbon residue is converted into glucose

C. Assimilation of lipids

- Required to maintain **cell membranes**
- Required in the production of **steroids hormones**
- Fats are required to **protect vital organs** such as the heart and kidneys
- When there is inadequate supply of glucose, fats will be broken down in the liver to provide energy.
- **Excess fats** are stored in **adipose tissues** under the skin
  - In adipose cells, fat droplets can collect in the cytoplasm and their fat droplets increase in size and number to form one large globule of fat in the middle of cell, pushing the cytoplasm into a thin layer and nucleus to one side. Groups of fat cells form adipose tissue (see Figure 8).

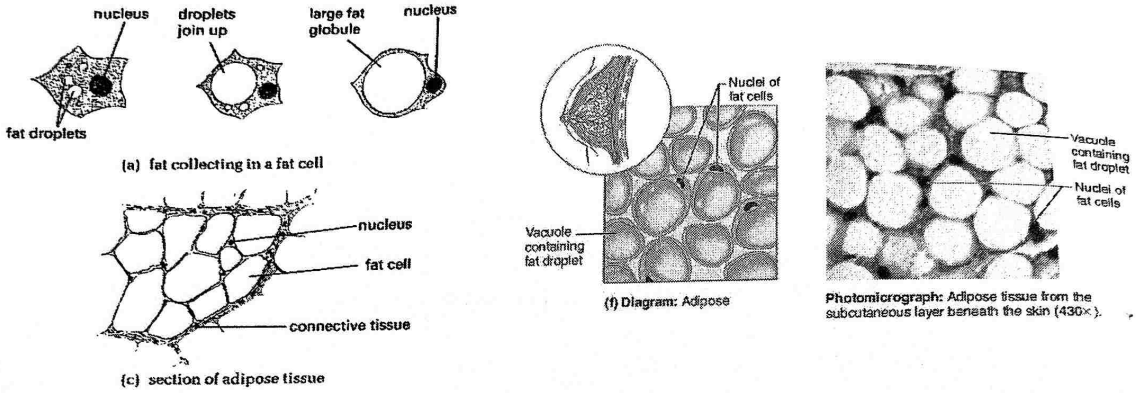


Figure 8 Adipose tissue

6. Large intestine → Rectum →Anus

- After the absorption of the nutrients in small intestine, the undigested and unabsorbed matter enters the large intestine.
- The undigested and unabsorbed matter consists of a mixture of water, bile pigments, dead cells from intestinal lining, dead & live bacteria and mainly cellulose from plant cells.
- The movement of undigested materials along the large intestine is by **peristalsis**.
- The large intestine **absorbs** of the **water** and **minerals** into the **blood stream**.
- Absorption of water from the undigested remains in the large intestine results in the formation of **faeces**.
- The walls of the large intestine secrete mucus which helps to bind the faeces along the large intestine.
- The faeces are temporarily stored in the rectum and as it accumulate, pressure in the rectum increases, causing a 'desire' to expel the faeces through the anus.
- When rectum is full, the muscles of the rectal wall contract to egest the faeces.
- The passing out of faeces via the anus from the body is known as **defecation/egestion**.

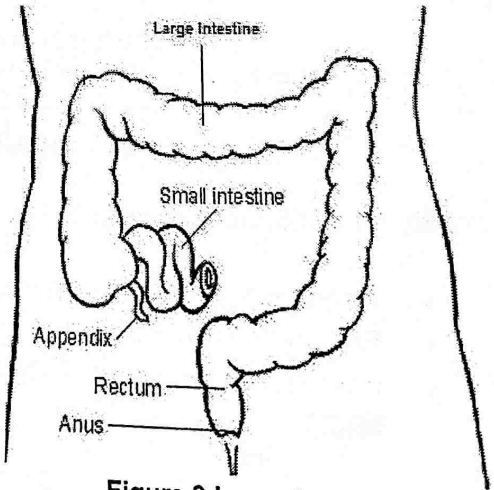


Figure 9 Large intestine

Source: http://www.patient.co.uk/health/rectal-bleeding-blood-in-faeces

Caecum
Ascending colon
Transverse colon
Descending colon
Rectum

7. **Functions of the Liver**

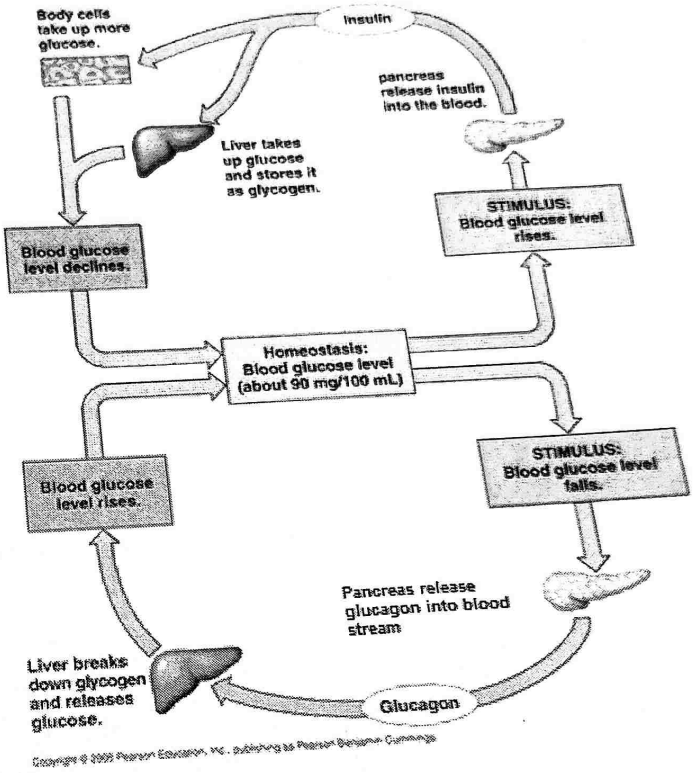
a) **Bile production**

- **Liver produces bile**.
- Bile emulsifies lipids to increase the surface area to volume ratio of the lipids for lipase to act on.
- Bile is stored temporarily **stored** in the **gall bladder** before use.

b) **Regulation of blood glucose**
(Link to Homeostasis in Y4 Biology)

- After a meal, blood glucose concentration increases.
- Insulin stimulates the liver cells to **convert excess glucose into glycogen** for storage.
- During fasting or after a long time after a meal, blood glucose concentration decrease.
- Glucagon stimulates the liver cells to **break down glycogen to glucose to be released into the bloodstream**

Note: Insulin and glucagon are hormones; they do not take part in the conversion between glucose and glycogen. The enzymes in the liver cells do the conversion.



Source: http://www.orko.cz/Varia/Pro%20Katku/Campbell%20obr%E1zky/45_Art_for_Students/45_12InsulinGlucagon_5-L.jpg

c) **Protein synthesis of proteins in blood**

Ribosomes in the liver cells synthesize plasma proteins (e.g. albumins, globulins, and fibrinogen) from the amino acids absorbed from the diet.

d) **Deamination of excess amino acids**

- **Excess amino acids** cannot be stored by the body and must be **deaminated**.
- Amino groups are removed and converted into **urea** which will be removed by the kidneys.
- Carbon residues of the deaminated amino acids are converted into glucose.

e) **Breakdown of red blood cells**

The liver breaks down the haemoglobin and stores the released iron.

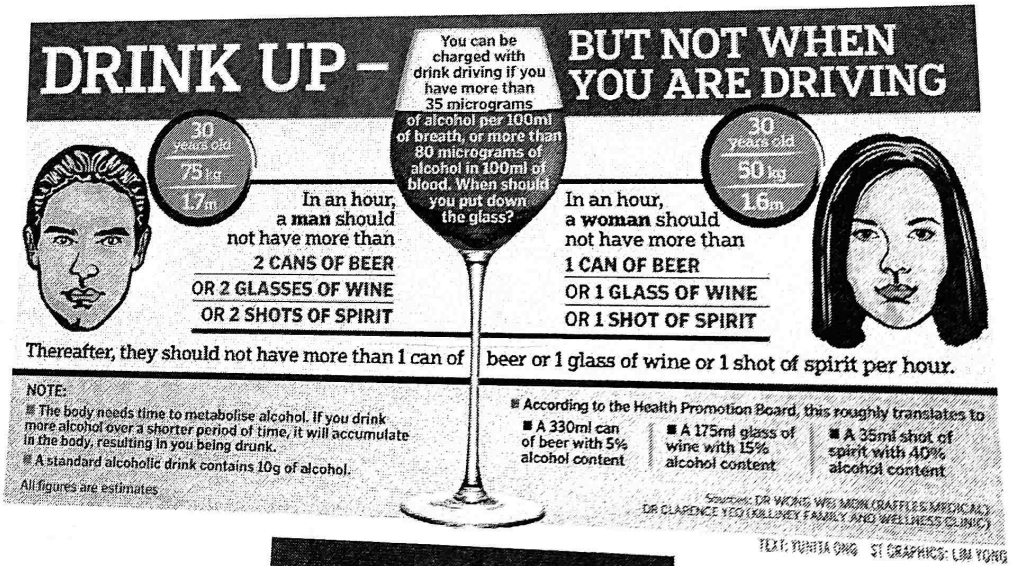
alcohol → alcohol dehydrogenase → acetaldehyde

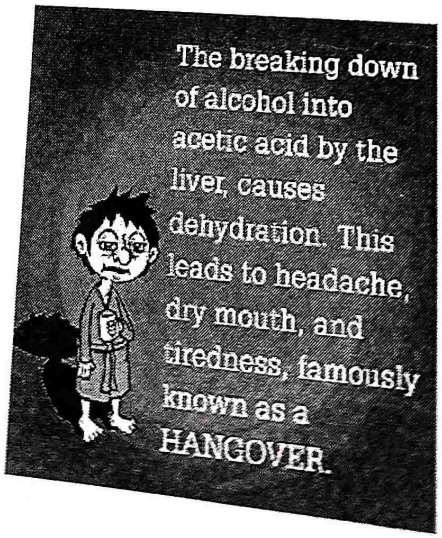
f) Detoxification

- Liver cells convert harmful substances (nitrogenous wastes such as ammonia, nicotine, medicines) into harmless ones – detoxification.
- Alcohol is broken down in the liver and then removed from the body system.
- Liver cells produce enzymes (**alcohol dehydrogenase**) that break down alcohol to **acetaldehyde**, which can be further broken down to glucose that can be used in respiration to provide energy for cellular activities.
- Hydrogen peroxide is a toxic by-product of cellular activities. It is broken down into water and oxygen by the enzyme **catalase** in the liver cells.

Effects of excessive alcohol consumption:

- Alcohol is a depressant (a drug that slows down the working of the brains and the nervous system)
- Affects area of cerebrum which control behaviour, speech, personality, memory and judgement resulting in **reduced self-control**
- Depresses motor centre of the brain resulting in poor coordination and sluggish reflexes resulting in **longer reaction times / slower reflex action**
- Stimulates acid secretion in stomach and increases the risk of gastric ulcers
- Long term alcohol abuse may lead to **cirrhosis of the liver** whereby the liver cells are destroyed and replaced with fibrous scar tissue. The liver is less able to function. This can lead to liver failure and subsequently death.
- Addiction, alcoholic suffers from withdrawal symptoms (delirious state, uncontrollable shaking) if alcohol is withheld.
- May result in mental retardation, stunted growth, damaged organs and other birth defects in the foetus of pregnant mothers.
- Social effects: neglect family and work, create family and financial problems, increases crime rate, STDs.





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