HETEROTROPHIC NUTRITION

This is a type of nutrition in which organisms obtain or feed on an organic source of carbon. Such organisms are called **heterotrophs** or heterotrophic organisms. They include animals, fungi, and most bacteria.

The way in which heterotrophs obtain their food varies considerably. However, the way in which it is processed in to the usable form within the body is very similar in most of them. It involves the following processes:

1. **Digestion**: reducing large complex food molecules in to simpler soluble molecules.
2. **Absorption**: taking the soluble molecules from the gut or alimentary canal (region of digestion) in to the tissues of the organism.
3. **Assimilation**: using the absorbed nutrients for a particular reason.

FORMS OF HETEROTROPHIC NUTRITION

They include the following: Holozoic nutrition, saprophytism/saprotrophic nutrition, mutualism and parasitic nutrition.

1. HOLOZOIC NUTRITION:

This applies mainly to free-living animals which have a specialized digestive tract, the alimentary canal. E.g. **Most animals**

Holozoic nutrition involves the following processes.

- **Ingestion**: This is the taking in of food
- **Digestion**: This is the breakdown of large molecules in to smaller simpler soluble molecules.

There are two types of digestion i.e.

a) **Mechanical digestion**. This involves the mechanical or physical breakdown of the food for example using teeth and the churning action of the stomach walls.
b) **Chemical digestion**. This involves the action of enzymes. The type of chemical process that enzymes catalyze during digestion is hydrolysis. Digestion may be either extracellular (inside the cell) as in **fungi** and **mammals** or intracellular (inside the cell) as in **protozoans**.

- **Absorption**: This is the uptake of the soluble molecules from the digestive region across a membrane and in to the body tissues.
- **Assimilation**: This is the using of the absorbed molecules to provide either energy of materials to be incorporated in to the body.
- **Egestion:** This is the elimination from the body of undigested waste food materials.

Some of the groups of animals and their nutrients are discussed below:

Herbivores – feed on plants e.g. zebra, goats, etc.

Carnivores – feed on other animals e.g. lions, cats, etc.

Omnivores – feed on a mixed diet of animal and plants e.g. pigs, man etc.
Microphagous feeders – take in food in form of small particles e.g. earthworms and filter feeders like mussel.
Fluid feeders – ingest food in liquid form e.g. aphids, butter flies and mosquitoes.
Macrophagous feeders – take in food in form of relatively large pieces e.g. hydra, sea anemones and sharks.

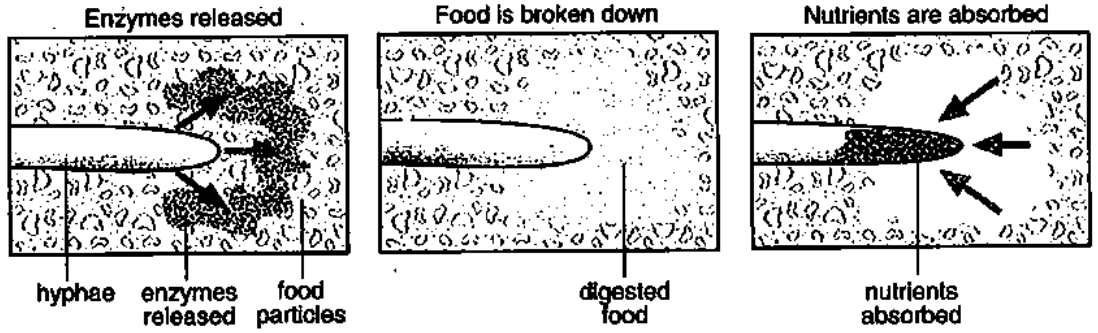
2. SAPROTROPHIC NUTRITION

This is the feeding on dead or decaying organic matter. Such organisms are called **saprotrophs** or **saprophytes** or **saprobes**. They include fungi and most bacteria**.**

The process of saprotrophic nutrition in fungi

Mucor and *Rhizopus stolonifer* (common bread mold) are common fungi known as pin molds.
They are often found growing on bread and soil.
The hyphae of the fungal mycelium penetrate the food on which they grow and secrete hydrolyzing enzymes from the tips. This results in extracellular digestion as follows;
Carbohydrase and protease enzymes carry out the extracellular digestion of starch to glucose and proteins to amino acids respectively.
The soluble products of digestion (glucose and amino acids) are then absorbed by the fungal hyphae cells by facilitated diffusion. The thin, much branched nature of the mycelium of *Mucor* and *Rhizopus* ensures that there is a large surface area for digestion.
Glucose is used during respiration to provide energy for the organism's metabolic activities, whilst glucose and amino acids are used for growth and repair. Excess glucose is converted to glycogen ant fat and excess amino acids to protein granules for storage in the cytoplasm.

Summary



Note

Saprotrophs feed on the dead organic remains of plants and animals and contribute to the removal of such remains by decomposing them.

Many of the simple substances formed are not used by the saprotrophs themselves but are absorbed by plants. Hence, saprophytes provide important links in nutrient cycles by making possible the return of vital chemical elements such as nitrogen, carbon etc. from the dead bodies of organisms to living ones.

3. SYMBIOSIS : MUTUALISM, PARASITISM AND COMMENSALISM

Symbiosis term means living together; hence it is the living together in close association of two or more organisms of different species.

Three common types of symbiotic relationships are mutualism, parasitism and commensalism.

a) Mutualism

This is a close association between two organisms of different species which is beneficial to both partners.

Examples

- Sea anemone (*Calliactis)* and Hermit crab

The anemone attaches itself to a shell used by a crab. The anemone obtains nourishments from the scraps of food left by the crab, and is transported from place to place when the crab moves. The crab in turn is camouflaged by the anemone and may also be protected by the stinging cells in its tentacles. This occurs in marine habitats.

- Herbivorous animals, ants and cellulose – digesting bacteria and ciliates

Cellulose – digesting bacteria and ciliates can only survive in the anaerobic conditions found in a ruminant alimentary canal. Here, the bacteria and ciliates feed on the cellulose contained in the host's diet, converting it into simple compounds which the ruminants is then able to digest, absorb and assimilate itself.

- Root nodules and *Rhizobium* bacteria

Here, the *Rhizobium* bacteria obtain nutrients and protection from the roots of the leguminous plants. The bacteria in turn converts free atmospheric nitrogen in to nitrates in the soil which the plant absorbs using the root hair cells by active transport.

- *Mycorrhizae* (fungus and plant roots)

This association enables the entry of mineral nutrients in to roots. The fungus receives organic nutrients mainly carbohydrates and vitamins from the plants and in turn absorbs mineral salts (PO_4^{3-}, NH_4^+, K and NO_3^-) and water, which can pass to the plant root.

- Lichen

This is a symbiotic association between a photosynthetic microorganism and a fungus in which millions of photosynthetic cells are held in a mass of fungal hyphae. Lichens grow on the surfaces of rocks, rotting logs, trees and roofs in various forms. The photosynthetic partners are unicellular or filamentous green algae or cyanobacteria.
The algae provide carbon compounds; the cyanobacteria also fix nitrogen and provide organic nitrogen. The fungi provide their photosynthetic partners with a suitable environment for growth.

- Hydra – chlorella symbiosis

Chlorella are unicellular green algae found in the endoderm of the marine cnidarian, hydra. They are also photosynthetic and supply hydra with maltose. Where one organism lives symbiotically inside the cells of another, the relationship is referred to as **endosymbiosis.**

b) Parasitism

This is a close association between two organisms of different species which is beneficial to one (the parasite) and harmful to the other (the host). The parasite obtains food and shelter from the host.
A successful parasite is able to live with the host without causing it any great harm.
Parasite which live on the outer surface of a host are termed **ectoparasites** e.g. ticks, fleas and leeches. Such organisms do not always live a fully parasitic existence.
Those that live within a host are **endoparasites** e.g. plasmodium, the tapemorms, *Taenia* and the liverfluke, *Fasciola hepatica.*

Adaptations of parasites to their mode of feeding

Reproductive adaptations

- Hermaphrodite condition allowing self – fertilization if necessary.
- Enormous number of reproductive bodies i.e. eggs, cysts and spores.
- Resistance of reproductive bodies when external to the host.
- Employment of specialized reproductive phases in the life cycle.
- Use of secondary hosts as vectors.

Structural adaptations

- Absence or degeneration of of feeding and locomotory organs – characteristic of gut parasites.
- Highly specialized mouth parts as in fluid feeders.
- Attachment organs such as hooks and suckers.
- Outer covering resistant to attack by enzymes.

- Reduction of sense organs associated with the constancy of the parasite's environment.

Physiological adaptations

- Enzyme production to digest host tissue external to parasite.
- Anticoagulant production in blood feeders.
- Chemo – sensitivity in order to reach the optimum location in the host's body.
- Production of digestive enzymes to aid penetration.
- Ability to respire adequately in anaerobic conditions.

c) Commensalism

This is a close association between two organisms of different species which is beneficial to one (the commensal) and does not affect the other (the host)

Examples

- Colonial hydrozoan (*hydractinia*) and Hermit crab.

The hydrozoan attaches itself to whelk shell inhabited by the crabs. It obtains nourishment from the scraps of food left by the crab after it has eaten, and the crab is not affected.

- An orchid or lichen and a tree

FEEDING MECHANISMS IN DIFFERENT ANIMALS

1. FILTER FEEDING

Organisms that feed in this way are called **filter feeders**. They strain small particles of organic matter from water. Examples include: molluscs e.g. the common mussel (*Mytilus edulis).*

Inside the shell are two large gills, one on each side. The gills are covered with fine beating hairs called **cilia**. The movement of the cilia causes a current of water to enter the animal via one tube (the inhalant siphon) and leaves via another tube (the exhalent siphon). The water which enters contains the food of mussels such as protozoa and algae.

The many secretory cells in cilia produce sticky mucus that traps the food particles. The trapped food is then swept by special bands of cilia towards the mouth which is located near the front end of the gill.

Ciliated structures surround the mouth and sort out the food particles before they enter the mouth.

The gut of the mussel consists of a stomach and short intestine which ends at the anus near the exhalent siphon.

2. FEEDING WITH TENTACLES

This occurs in cnidarians like jelly fish, sea anemones and the hydra of fresh water.
They are carnivores and possess tentacles for capturing food, the tentacle surrounds the mouth.
There is no true gut, only a simple sac called **enteron** with one opening the mouth. Food is placed in the mouth and any undigested remains eventually leave through the mouth.
Along the outside surface of the tentacles are batteries of stinging cells called **nematoblasts**. These cells release poison which can paralyze and even kill the prey.
The animal grasps the prey with its tentacles which pass it to the mouth for ingestion.
The mouth opens widely and the prey enters the enteron for the first extracellular phase of digestion.
Once the food has been reduced to small fragments, they are engulfed by phagocytosis in to cells lining the enteron and digestion is finished by intracellular digestion. The prey of hydra includes the water flea (*Daphnia*), Cyclops and small crustaceans.

3. DETRITUS FEEDING

Detritus is fresh or decaying organic matter. It is commonly found at the soil surface.
An organism which is specialized for feeding on detritus is called a **detritivore**. Example: earthworms.
The earthworm consumes fragments of detritus especially vegetation at the soil surface and burrows.
The pieces of food are torn off, moistened by alkaline secretions of the pharynx and swallowed.
Digestion and absorption of food occurs at various points along the straight gut, and any undigested matter is egested from the anus as **worm casts**.

4. BITING AND CHEWING MOUTHPARTS

Many insects are herbivores and have mouth parts for biting and chewing vegetation. Many insects are also pests because they attack crops. Examples include locusts, grasshoppers, cockroaches, etc.

5. FLUID FEEDING

Some insects feed on fluids using specialized mouth parts for sucking e.g. butterfly or piercing and sucking e.g. aphids and mosquitoes.

6. CARNIVORES

These are flesh – eating mammals. They include cats, cheetah, hyenas, etc.
They have the following adaptations for their diet

- They have a short alimentary canal for easy chemical digestion of meat.
- They have a very good or acuity vision such as cats, this enables them to see food at night.
- They have sharp pointed canines and incisor teeth for tearing and cutting flesh.
- They have well developed leg muscles for swift locomotion to capture their prey.
- Carnivores have strong jaws to firmly grasp prey.
- The vertical movement of the jaw is less restricted allowing a wide gape for capturing and killing prey.
- They possess strong sense of smell for locating prey.
- Their teeth are adapted to catching and killing prey, cutting flesh from carcass, cracking bones so that the food is reduced to proportions that can be swallowed.
- The position and shape of their teeth are used to perform specific function i.e. they have the carnassial teeth which help in crashing of bones.
- They have numerous teeth to improve on the efficiency of mechanical digestion, as shown in their dental formula e.g. for a dog (42 teeth) $\mathrm{I}\frac{3}{3}\ C\frac{1}{1}\ PM\frac{4}{4}\ M\frac{2}{3}$.
- The teeth of the upper jaw overlap those of the lower jaw. This slices the meat in to manageable pieces.

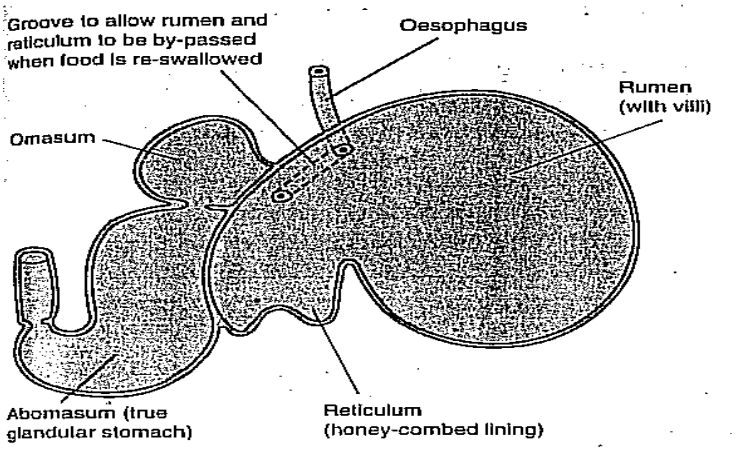
7. HERBIVORES

These digest plant material. They include cows, giraffes, goats etc.
They show the following adaptations towards their diet.

- A horny pad which replaces the upper front teeth (incisors and canines) against which the chisel – shaped lower incisors and canines bite when the animal is cropping grass.
- A pronounced gap, the diastema, between the incisors and premolars. This provides space in which newly nibbled food can be separated from that being ground down at the back of the mouth.
- The cheek teeth (molars and premolars) have ridged surfaces which form an effective grinding surface not dissimilar to that of a coarse file.
- The jaws easily move from side to side to allow food to be broken – down between the ridged teeth.
- The teeth grow continuously throughout the herbivore's life. This is essential as the grinding action of the teeth wears them away.
- The alimentary canal is relatively long to increase the surface area for digestion because digestion of plant material is difficult.
- The stomach is divided in to a number of chambers, some of which produce digestive enzymes to break down the food. Others, including the rumen house bacteria and protozoa which produce the enzyme cellulase, essential to break down

the cellulose in plant material. Herbivores with these multichambered stomachs are called **ruminants**. E.g. deer, giraffe, antelopes, cattle, etc.

The ruminant stomach



Cellulose digestion in ruminant

This is aided by the bacteria and protozoa.
When swallowed, the food enters the first two chambers, the rumen and reticulum. It is here that the microorganisms carry out extracellular digestion of the cellulose by secreting cellulase.

The product of this digestion are either absorbed by the walls of the rumen and reticulum which have villi or honey-combed ridges for this purpose , or are absorbed by the microorganisms and digested later. The waste gases of the bacterial fermentation, largely carbon dioxide and methane are expelled via the mouth and carboxylic acids such as ethanoic acid are formed.

After some hours in the safety of sheltered position, the herbivore regurgitates the food in to the mouth, where it thoroughly chews it, **chewing the curd**. On being re-swallowed, the food enters the final two chambers of the stomach, the omasum and the abomasum (true stomach) where the usual process of protein digestion in acid conditions takes place.
Also present in the rumen are protein- synthesizing bacteria which use ammonia as their source of nitrogen. These bacteria are engulfed by the protoctists which in turn are digested by the ruminant's enzymes further along the alimentary canal, hence the herbivore utilizes the low protein nutrients in their diet.

In non-ruminant herbivores like rabbits and horses, the caecum and appendix are much enlarged and accommodate the microorganisms. Some absorption of the products of this digestion takes place through the walls of the caecum. In rabbits, the yield is improved by the re-swallowing of the material from the caecum after it has left the anus- a process known as **coprophagy**.

8. OMNIVORES

These are mammals which feed on both plants and animal materials e.g. Humans and pigs. They have a mixed diet of flesh and plant vegetation. However, humans do not digest cellulose in the plant material.

9. CARNIVOROUS PLANTS

These are plant species which can trap and feed on small animals, particularly insects. They inhabit areas deficient in nitrates. They include butterworts, sundews, bladderwort, Venus fly trap and pitcher plants.

All have green leaves and obtain their carbohydrates by photosynthesis, but they obtain nitrogen from the bodies of their victims.

The insect is attracted by colour, scent or sugary bait, then trapped, killed and extracellular digested by a fluid rich in protease enzymes. The amino acids are absorbed in to the plant.

NUTRITION IN HUMAN BEINGS

THE ALIMENTARY CANAL (THE GUT)

Digestion and absorption occurs in the alimentary canal or gut which runs from the mouth to the anus. Food can only be absorbed in to the body after it has been ingested and broken down physically by the teeth and muscles of the gut (physical/mechanical digested) and chemically by its enzymes in to molecules of a suitably small size to be absorbed through the gut wall(chemical digestion). From here, the nutrients enter the blood or lymph and delivered to cells of the body tissues for assimilation. Undigested food is egested through the anus.

Note

The alimentary canal is connected by other organs and glands, these are called **accessory structures**. They include teeth, tongue, salivary gland, liver, gall bladder and pancreas. These are organs, glands and tissues that enable digestive processes through secretion of fluids or chemicals, but the food does not actually pass through them. The alimentary canal together with accessory structures forms the **digestive system.**

Longitudinal section through the gut

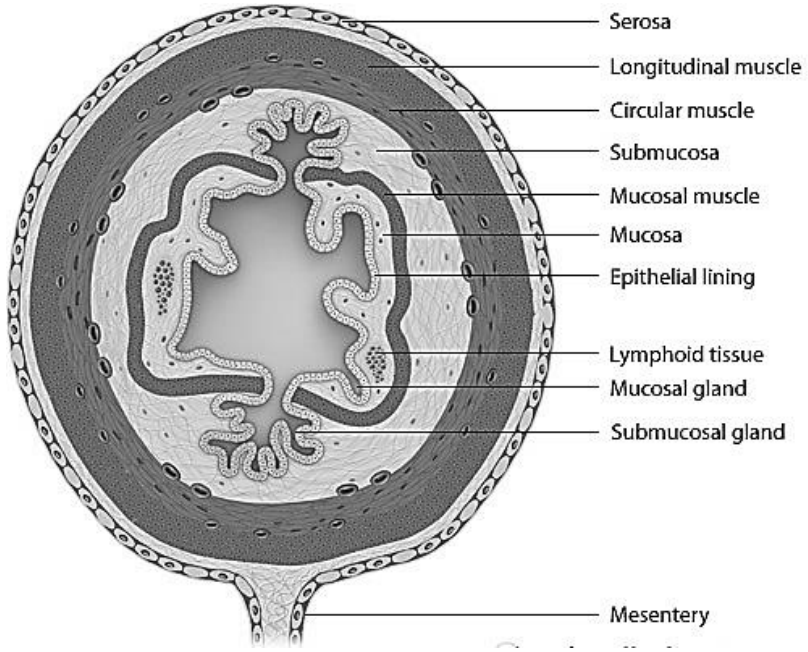
Although each different region of the gut possesses its own special characteristics, all have a basic common structure consisting of 4 distinct layers, the mucosa, submucosa, muscularis externa and serosa.

Mucosa: this is the innermost layer of the gut. It secretes mucus that lubricates food and prevents digestion of the gut walls by its own enzymes. The epithelial cells have microvilli containing enzymes in their surface membranes. This layer also contains connective tissue in which blood and lymph vessels run.

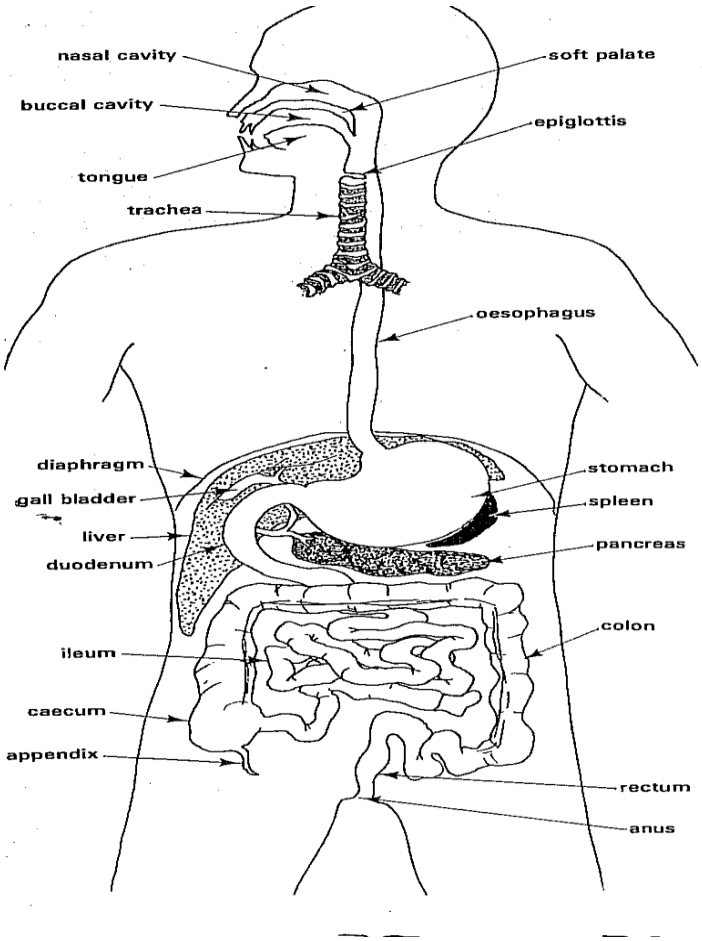
Submucosa: This is a layer of connective tissue containing nerves, blood and lymph vessels, collagen and elastic fibres. In the duodenum, it contains some mucus – secreting glands.

Muscularis externa: This layer is composed of the inner circular muscle which is involuntary. Between the muscles is a plexus (mass of nerve tissues) from the autonomous nervous system which control peristalsis.

Serosa: This is the outermost coat of the gut wall. It is composed of loose fibrous connective tissue. The whole outer surface of the gut is covered by a peritoneum, a tissue that forms the mesenteries.



Structure of the human gut



Buccal cavity:

This is the chamber just inside the mouth in which food is chewed. During chewing, the muscular tongue moves food around the mouth, mixes and moistens it with saliva. The tongue possesses taste buds that contain receptors sensitive to sweet, bitter, sour and salty substances.

Sight and the olfactory (smell) receptors of nose stimulate salivary glands to secrete **saliva** by an innate or conditioned reflex. Saliva is a watery secretion containing the enzyme **salivary amylase** (ptyalin) and **lysozyme**, **mucus**, **mineral salts** like chloride ions.

Mucus lubricates food for easy swallowing.
Salivary amylase begins the chemical digestion of starch to maltose.
Lysozyme kills bacteria by breaking down their cell walls.
Chloride ions activate salivary amylase.

Eventually, the semi-solid partially digested food particles are stuck together and molded in to a **bolus** or **pellet** by the tongue which is then pushed towards the pharynx and then swallowed in to the oesophagus by reflex action.

Oesophagus

This is a narrow muscular tube lined by stratified squamous epithelium containing mucus glands. It quickly conveys food and fluids by **peristalsis** from the pharynx to the stomach.

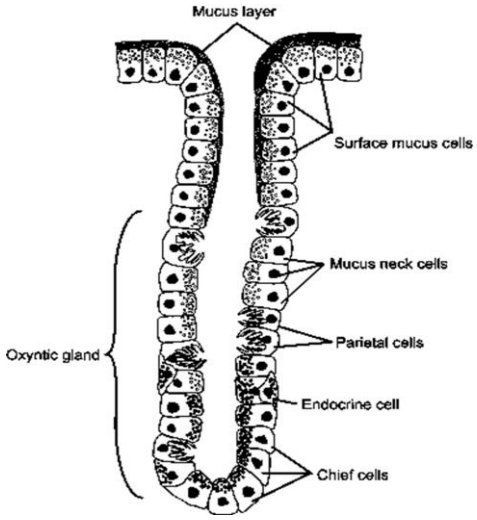
Peristalsis is an involuntary wave of muscular contraction and relaxation that occurs to move food, waste matter and other contents through the gut.

Stomach

This is a muscular bag situated below the diaphragm on the left side of the abdominal cavity which stretches to take in food. It stores food temporarily after meals, releasing food slowly in to the rest of the gut. It continues mechanical digestion of food by the churning action of its muscular walls. It is where chemical digestion of proteins begins. The thick mucosa has goblet cells that produce mucus containing a glycoprotein **mucin**; this provides a barrier that prevents the stomach being self – digested by its enzymes.

The main part of the stomach contains numerous gastric pits, leading in to tubular **gastric glands**. The glands are lined with cells which secrete the **gastric juice** containing **dilute hydrochloric acid** solution from parietal/oxyntic cells and gastric lipase and inactive enzymes **pepsinogen** and **prorennin** from chief/zymogen/peptic cells.

The gastric gland or pit

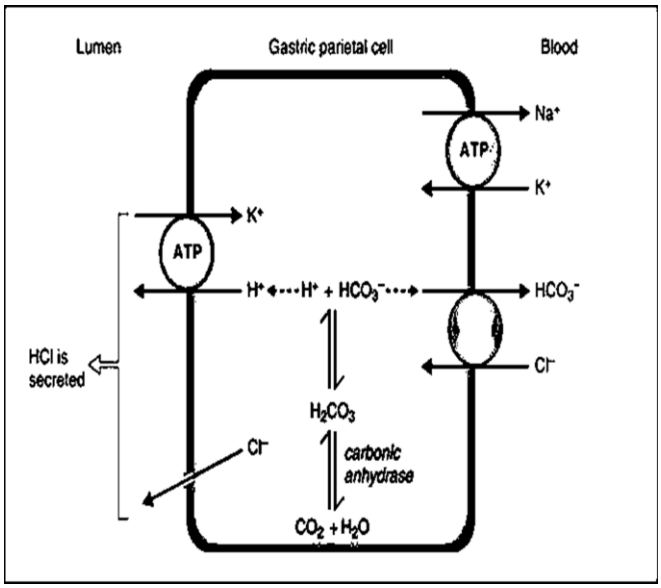


Process of hydrochloric acid secretion in to the stomach

Hydrochloric acid is produced by parietal cells through a complex series of reaction, catalyzed by the enzyme carbonic anhydrase. Carbon dioxide that diffuses from the capillaries reacts with water to form carbonic acid, which dissociates in to bicarbonate ions and hydrogen ions.

The bicarbonate ion is transported in to the blood stream by an ion exchange molecule in the plasma membrane which exchanges bicarbonate ions exiting parietal cells for chloride ions entering.

Hydrogen ions are actively pumped in to the duct of gastric gland and the negatively charged chloride ions diffuse with the positively charged hydrogen ions. Potassium ions are counter pumped in to the parietal cell in exchange for hydrogen ions.
The net result is production of hydrochloric acid in the parietal cells and its secretion in to the duct of gastric glands.



Dilute hydrochloric acid;

- Makes the stomach contents pH 1 – 2.5, ideal for optimum activity of stomach enzymes.
- Kills many bacteria thus acting as a defense mechanism.
- It denatures many proteins making them unfold and so easier to digest.
- It loosens fibrous and cellular components of tissues.
- It converts prorennin and pepsinogen to their active forms **rennin** and **pepsin** respectively and begins the hydrolysis of sucrose to glucose and fructose.

Pepsin hydrolyses proteins in to smaller polypeptides.
Rennin coagulates casein, the soluble protein in milk in to the insoluble calcium salt of **casein** in the presence of calcium ions, **caseinogen**. This calcium salt is then digested by pepsin.
The stomach walls also contain endocrine cells which secrete the hormone **gastrin**.

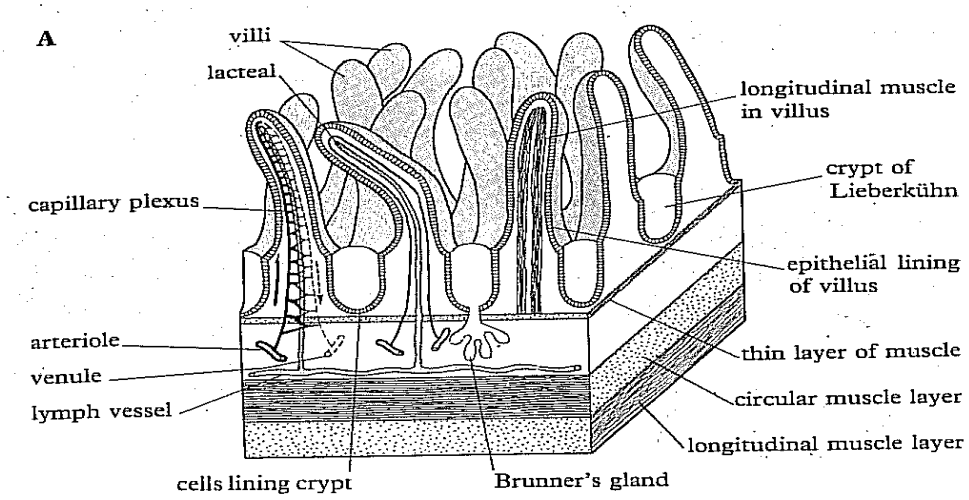
Small intestine

The first part of the small intestine is the duodenum. It is short and pancreatic and bile ducts open in to it. The duodenum leads to the ileum which is long and contains numerous finger – like projections called **villi**, whose walls are richly supplied with blood capillaries and lymph vessels and contains smooth muscles. The individual cells on the surface of the villi possess tiny microvilli on their free surface.

At the base of the villi, the epithelium folds inwards in places to form narrow tubes called **Crypts of Lieberkuhn**, where new epithelial are made to replace the shed ones from the villi. The **Brunner's gland** in the crypts secretes intestinal juice, a slightly alkaline fluid containing water and mucus. **Paneth cells** in the crypts secrete

lysozyme, the antibacterial enzyme. Throughout the small intestine, special epithelial cells called **goblet cells** secrete **mucus**, a protective barrier. The **duodenum** also secretes an alkaline fluid which helps to neutralize the acid of the stomach and provides an optimum pH of 7 -8 for the enzymes of the small intestine.

Structure of the ileum



Digestion by enzymes in the small intestine

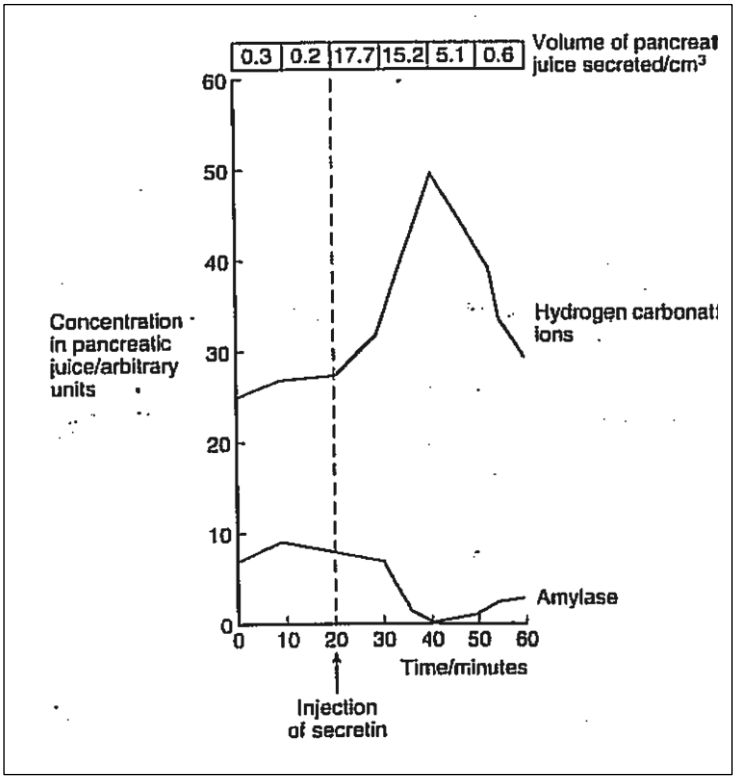
Duodenum

This is the main site of digestion in the gut. The agents of digestion come from three sources: the liver, pancreas and walls of the small intestine.

The liver produces **bile** which after storage in the gall bladder, flows down the bile duct in to the duodenum. The digestive components are the **bile salts** (sodium taurocholate and glycocholate). These emulsify fats by lowering their surface tension, causing them to break up in to numerous droplets.

In this way, the total surface area of the fat is increased, thereby facilitating the digestive action of the enzyme lipase. This is a physical digestion. Bile also contains sodium bicarbonate, which neutralizes the acid from the stomach. The pH of the small intestines is **alkaline**, which favour the action of the various enzymes.

Effect of secretin injection on the secretion of pancreatic juice by the pancreas



Explanation of the graph

From 20 minutes to 30 minutes of Secretin injection, the volume of pancreatic juice rapidly increases, gradual increase of bicarbonate ions and gradual decrease of pancreatic amylase enzyme. Because up on injection in to blood, secretin hormone circulates to reach the pancreas and liver, first in low concentration from 20 to 30 minutes, gradually stimulating pancreatic secretion of watery hydrogen carbonate ions from acinar cells and gradually stimulating secretion of somatostatin hormone which gradually inhibits secretion of pancreatic amylase enzyme.

From 30 minutes to 40 minutes of secretin injection, the volume of pancreatic juice decreases gradually, rapid increase of hydrogen carbonate ions to maximum and rapid decrease of amylase enzyme. Because there is now much secretin concentration in blood circulation, which rapidly stimulates pancreatic acinar cells to rapidly secrete hydrogen carbonate ions and also greatly stimulates secretion of a somatostatin hormone which rapidly inhibits secretion of pancreatic amylase secretion.

From 40 minutes to 60 minutes of secretin injection, the volume of pancreatic acid rapidly decreases, hydrogen carbonate ions rapidly decrease and amylase gradually increases and remains constant. Because high pH (alkalinity) due to hydrogen carbonate ions inhibits the working of secretin hormone, causing less stimulation of acinar cells hence rapid decrease in secretion of hydrogen carbonate ions. Somatostatin hormone secretion decreases hence decreasing the inhibition of pancreatic exocrine cells causing increased amyase enzyme secretion.

Some of these enzymes are constituents of pancreatic juice which flows in to the duodenum from the pancreas via the pancreatic duct. The main pancreatic enzymes are:

- **Pancreatic amylase** which breaks down starch to maltose.
- Inactive precursor **trypsinogen** which is activated by enzyme **enterokinase** from the wall of the small intestine to **trypsin** an endopeptidase which breaks down proteins in to polypeptides and dipeptides.
- **Pancreatic lipase** which breaks down fat in to fatty acid s and glycerol.
- **Nucleases** which break down nucleic acids in to nucleotides.
- **Peptidases** which release free amino acids from polypeptide chains.

Ileum

The secretory cells in the walls of the small intestine (ileum) produce mucus and a variety of enzymes (**intestinal juice/ succus entericus**) that complete the digestion of the various compounds already started by the other secretions. These include:

- **Maltase** which hydrolyses maltose to maltase.
- **Peptidases** (erepsin) which break down polypeptides to free amino acids.
- **Sucrase** which hydrolyses sucrose to glucose and fructose.
- **Lactase** which hydrolyses lactose to glucose and galactose.
- **Nucleotidases** which split nucleotides in to their constituent subunits.

Large intestine/colon

No digestion takes place in the colon. The colon and caecum remove about 90% of any remaining liquid. Some metabolic wastes and inorganic substance like calcium and iron in excess in the body are excreted in to the colon as well. Epithelial cells secrete mucus which lubricates the solidifying undigested food remains known as **faeces**. Many symbiotic bacteria present in the colon synthesize amino acids and some vitamins, especially vitamin K which is absorbed in to the blood stream.

NERVOUS AND HORMONAL CONTROL OF DIGESTIVE SECRETIONS

Secretion of digestive and other substance is only done when there is digestive work to be done so that to prevent wastage of energy and materials. The overall control of digestion is controlled/coordinated and regulated by both the nervous and endocrine system as discussed below.

1. Saliva

Secretion of saliva in to the buccal cavity from the salivary glands is controlled by two types of reflex action; **unconditioned** (inborn) reflex and **conditioned** reflex.

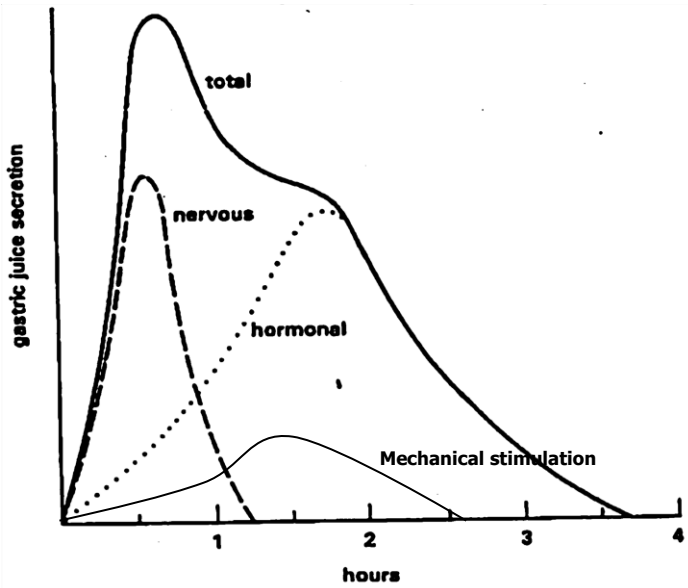
The inborn reflex occurs when food is present in the buccal cavity. Its contact with the taste buds of the tongue stimulate receptors sensitive to sweet, salty, sour and bitter tastes. The sensory neurones carry impulses from the receptors to the brain. From there, nerve impulses travel along the motor neurones to the salivary glands, the effectors which are stimulated to secrete saliva.
The conditioned reflex occurs after sight, smell or thinking of food. The eye, the ear and the olfactory (smell) receptors in the nose are the important receptors, these stimulate saliva production

2. Gastric juice

Secretion of gastric juice occurs in 3 phases i.e. the **nervous** phase, **gastric** phase and **intestinal** phase.
In the **nervous phase**, the presence of food in the buccal cavity and its swallowing triggers reflex nerve impulses from the brain to the stomach. The sight, smell, taste and thought of food also triggers the same reflex. The gastric glands of the stomach are stimulated to secrete gastric juice before food reaches the stomach. It lasts for about one hour.

In the **gastric phase** in the stomach, both nervous and hormonal systems control. Stretching of the stomach by the food it contains stimulates stretch receptors in the stomach walls. These send impulses to Meissner's plexus, then to the gastric glands stimulating the flow of gastric juice. Stretching the stomach and presence of food also stimulates endocrine cells in the stomach wall to secrete a hormone **gastrin**. This travels through blood stream to gastric glands and stimulates them to produce gastric juice rich in HCl for about 4 hours.

In the **intestinal phase** in the small intestine, acidified chyme enters and makes contact with the walls of the duodenum; this triggers both nervous and hormonal responses. These cause secretion of 3 hormones; **Enterogasterone**, **cholecystokinin (CCK)**/pancreozymin and **secretin**. Enterogasterone travels through bloods stream to the stomach and inhibits further secretion of gastric juice and slows the release of chyme from the stomach. As shown below.



Explanation of the graph

Nervous control

From 0 to 30 minutes, gastric juice secretion increases rapidly to the maximum. From 30 minutes to 45 minutes, gastric juice secretion decreases rapidly. This is because nervous secretion is shorter and instantly rapid as compared to hormonal and mechanical phases.

Hormonal control

From 0 to 1 hour, gastric juice secretion increases gradually then increases rapidly from 1 to 2 hours to the maximum. From 2 to $3^{3}/_{4}$hours, gastric juice secretion decreases rapidly. This is because hormonal secretion is longer lasting and initialy gradual as compared to the cephalic phase

Mechanical control

Volume of gastric juice produced during mechanical stimulation (food stretching stomach and duodenal walls) increases gradually from 0 to 1 hour, then increases rapidly to a maximum after 2 hours, then decreases rapidly and ceases after 2.8 hours.

3. Pancreatic juice and bile

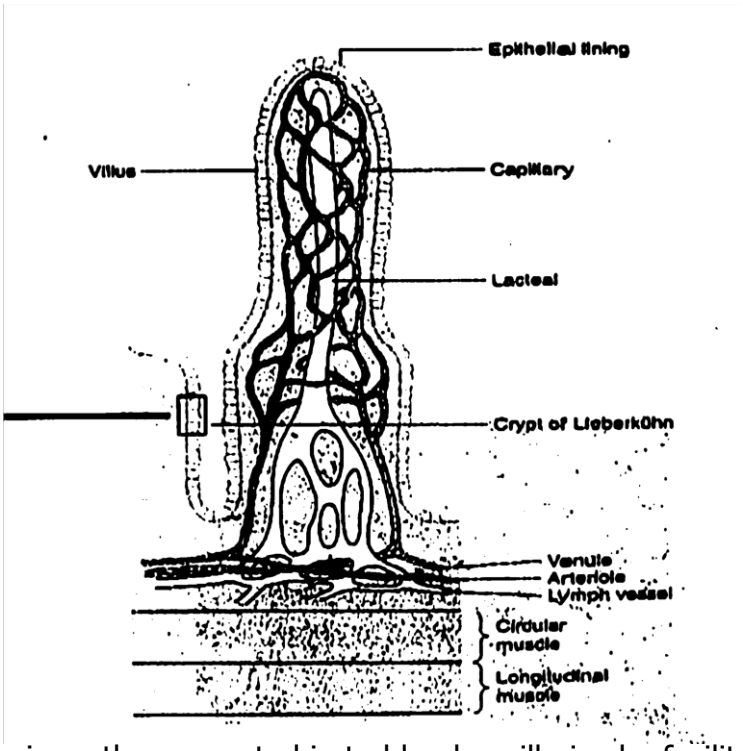
Secretin and **CCK** are produced in the duodenum when acidified chyme enters it from the stomach.

Secretin is an anti-acid hormone; it stimulates the production of non-enzymatic/mineral salts (HCO_3^-) in the pancreas and the liver, making the pancreatic juice and the bile more alkaline as a result. This helps to neutralize the acid from the stomach. CCK stimulates synthesis of digestive enzymes by the pancreas and the contraction of the gall bladder to release bile in to the duodenum. Bile is made in the liver but stored and concentrated in the gall bladder. It has a pH of 7.6 – 8.6. The secretion of bile and pancreatic juice is also stimulated by nervous reflexes.

ABSORPTION OF FOOD

Absorption of the end – products of digestion occur through the **villi** in the ileum.

Detailed structure of the villi



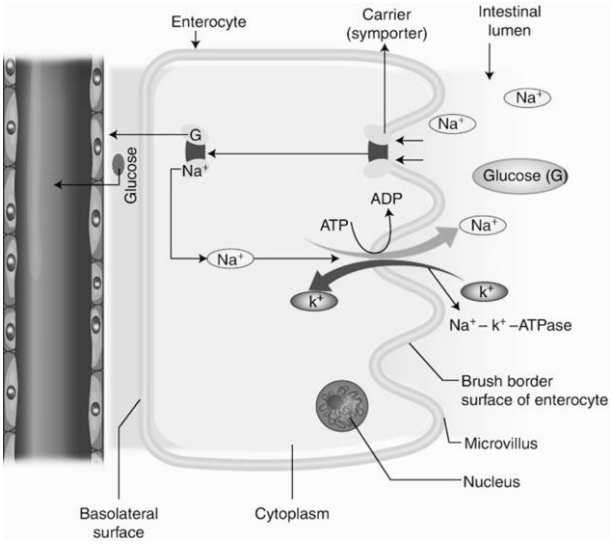
Process of food absorption

Glucose and galactose are absorbed by means of a **secondary active transport**. This is a form of active transport across a biological membrane in which a transporter protein couples the movement of an ion like Na^+ or H^+ , down its electrochemical gradient to the uphill movement of another molecule or ion against a concentration gradient or electrochemical gradient. This requires energy. Glucose and galactose are cotransported in to epithelial cells of villi with sodium ions, then exported in to blood capillaries by facilitated diffusion.

Amino acids through the secondary active transport mechanism with sodium ions, are cotransported from intestinal lumen in to small intestinal epithelial cells with sodium ions, and then exported to capillaries by facilitated diffusion.

Summary of absorption of glucose

Tripeptides and dipeptides are absorbed through secondary active transport but with hydrogen ions not sodium ions. In the mechanism, oligopeptides (dipeptides and tripeptides) are cotransported from intestinal lumen in to villi epithelial cells with protons (H^+). Oligopeptides are then hydrolyzed by cytoplasmic peptidases in to amino acids, which are exposed in to blood capillaries by facilitated diffusion.

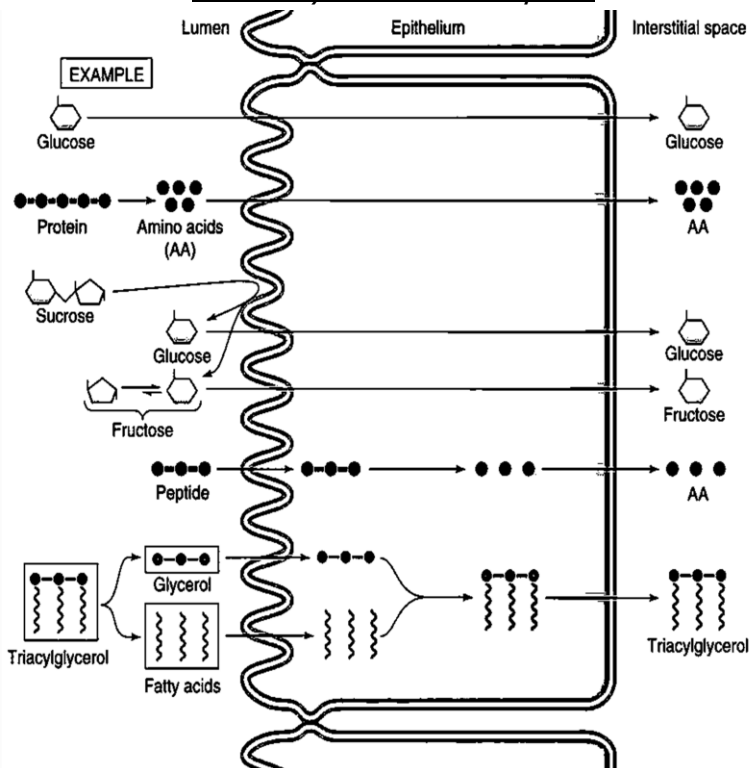


From the villi, the blood capillaries containing glucose, galactose, fructose, amino acids and oligopeptides join to form the **hepatic portal vein** which delivers the absorbed food to the liver.

Short chain fatty acids move in to the epithelial cells of villi by simple diffusion, they are exported in to blood capillaries by simple diffusion.

Monoglycerides and long chain fatty acids simply diffuse in to the columnar epithelial cells of the villi, where they are reconverted in to lipids. Proteins present in the epithelial cells coat the lipid molecules to form lipoprotein droplets called **chylomicrons**. These pass out of the epithelial cells by exocytosis and in to the lymphatic vessels in the villi, hence make the lymph appear white. The chylomicrons are carried by lymph in the lymphatic system to veins near the heart where they enter blood plasma. An enzyme in the plasma then hydrolyses the lipids back to fatty acids and glycerol, a form taken up by cells.

Summary of food absorption



Describe how the ileum is suited to its functions

The ileum is long and highly folded for increased surface area in absorption of soluble food substances; it has numerous finger – like projections called villi which increase the surface area for absorption of soluble food; the epithelial cells of the ileum have microvilli which further increase the surface area for efficient food absorption; the epithelium is thin to reduce diffusion distance form soluble food substances to allow fast diffusion rates; villi have dense network of blood capillaries to rapidly carry away digested food from the absorption area which maintains a steep diffusion gradient of the soluble foods; the epithelium of the ileum is permeable to allow movement of soluble food substances across with minimum resistance; villi have permeable lacteal, a branch of the lymphatic system for carrying away fats; the epithelial cells also have numerous mitochondria to generate enough ATP energy for active transport of some ions and food substances; the inner surface of the ileum is lined with a lot of mucus to prevent autolysis (self – digestion) by proteolytic enzymes.

Adaptations of the villi to absorption of digested food

Large surface area by microvilli or protrusions of exposed parts for fast uptake of soluble substances; epithelium only one cell layer thick to reduce diffusion distance; protein channels allow facilitated diffusion and active transport; numerous mitochondria to provide ATP for active uptake of some nutrients; blood capillaries close to epithelium or surface to reduce diffusion distance during absorption of glucose or amino acids; lacteal or lymphatic vessel is permeable or has large surface area at centre to absorb fatty acids and glycerol; tight junctions between adjacent villi enable controlling absorption of substances.

ASSIMILATION OF FOOD: THE FATE OF ADSORBED FOOD

Monosaccharides and amino acids are both absorbed in to blood capillaries in the villi by diffusion and passed to the liver in the hepatic portal vein.

Glucose

Most of the glucose is stored in the liver cells or in muscle cells as glycogen and fats, stored in the adipose tissue underneath the skin, though some leaves the liver in the hepatic vein to be distributed round the body cells, needed for respiration to release ATP or for use in other functions such as formation of glycoproteins involved in cell to cell recognition mechanisms and production of mucus

Amino acids

These are used for the synthesis of proteins. They are usually important for growth and repair, being some of the main constituents of protoplasm. Enzymes, antibodies and some hormones like insulin are proteins. Amino acids are used in the formation of the plasma membrane components like glycoproteins, channel proteins and others. Formation of body structures like hairs, nails, hooves and cell membrane. Suring starvation, amino acids are oxidized to release energy.

Surplus amino acids cannot be stored and thus are deaminated in the liver. Their amino groups are removed and converted to urea which is taken through blood to the kidneys for excretion in urine. The remainder of the amino acid (a **keto acid**) is converted to glycogen and stored or incorporated in the respiration at the Krebs cycle.

Fats

Absorbed fats bypass the liver by entering the lymphatic system and being released in to veins near the heart. In the liver, long chain fatty acids are desaturated and then broken down to carbon dioxide and water by successive oxidation, giving metabolic water.

Excess Fats may be used during respiration in starvation when glucose is in inadequate. Fats are stored in adipose tissue below the skin where it also acts as an insulator, around the heart and kidneys and in the mesenteries. Some fat is incorporated in to cell membranes as phospholipids.

EGESTION: ELIMINATION

The semi – solid faeces consist of a small quantity of indigestible food (fibres) but mostly comprise the residual material from the bile juice and other secretions, cells sloughed off the intestinal wall, a little water and immense number of bacteria.
The wall of the large intestines produces mucus which in addition to lubricating the movement of faeces, helps to bind them together.
After 24 – 36 hours in the large intestine the faeces pass to the rectum for temporary storage before they are removed through the anus, a process known as **defaecation**. Control of this removal is by two sphincters around the **anus**, the opening of the rectum to the outside.

BASAL METABOLIC RATE (BMR)

This is the minimum energy a body requires at rest to perform vital functions like heartbeat, breathing, peristalsis, impulse transmission, synthesis of biological molecules like proteins, etc.

However, beside maintaining the BMR the body also requires energy to sustain body activities like muscle contraction during movement, locomotion and generation of heat to maintain body temperature at about $37^{o}C$.

Factors which determine BMR

There are many factors that influence the BMR value of an individual, these include the following: age, sex, genetics, muscle mass, diet, drugs, environment factors like temperature, body mass, nature of physical activity engaged in and hormonal factors e.g. during pregnancy.

Sex: At about 2.5 years and below, BMR in males and females is equal because infants basically have identical composition of carbohydrates, fats and proteins. From 2.5 years throughout life, the BMR of males is slightly higher than the BMR in females. This is because males usually more body muscle than females while females usually have more fats than females per unit body mass and surface area. The more muscle tissue in the body, the more energy the body needs just to function e.g. to conduct impulses and biosynthesis compared to fat cells that largely store fat, with little biosynthesis.

Age: Infants and children have relatively high BMR than old aged adults because at infancy and childhood, much of the energy consumed is used in biosynthesis of cellular components required for growth. At adulthood, biosynthesis is greatly reduced since growth has stopped, little energy is used for repair and regeneration of tissues.

Diet: Certain aspects of one's diet can also affect metabolism e.g. inadequate intake of iodine for optimal thyroid function can slow down body metabolism.

Hormonal factor e.g. during pregnancy and lactation: hormonal imbalances caused by certain conditions, including hypo – and hyperthyroidism, can affect the metabolism. Expectant and lactating mothers require more energy to support foetal and baby growth respectively.

Muscle mass: This is the amount of muscle tissue in the body. Muscles require more energy to function than fats. The more muscle tissue in the body, the more energy the body needs just to exist.

Body size: Larger bodies tend to have a higher BMR because they usually have larger internal organs and fluid volume to maintain. Taller people have a larger skin surface, therefore have higher metabolism to maintain a constant temperature.

Genetics: Genotypes and genetic diseases or disorders determine the rate of BMR.

Physical activity: Regular exercise increases muscle mass and causes the body to burn more kilojoules as a faster rate, even when at rest.

Drug content in the body: Some drugs like caffeine and nicotine can increase your metabolic rate while medication including some antidepressants and anabolic steroids can contribute to weight regardless of what you eat.

Environmental factors like temperature: Weather can also have an effect on body metabolism, is it is very cold or very hot, the body works harder to maintain its constant temperature and that increases the metabolic rate.

BALANCED DIET

This is a meal that contains the corrects proportions and quantity of proteins, carbohydrates, lipids, vitamins, mineral salts, water and dietary fibres or roughages required to maintain health.

Much carbohydrates and lipids are for energy production, proteins are for body growth and repair, vitamins and mineral salts are for protection of good health, water is a solvent while roughages stimulate peristalsis to prevent constipation. An imbalanced diet can lead to deficiency diseases.

Table below shows vitamins, their sources, functions and deficiency diseases due to their malnutrition in diets

Vitamin	Sources	Functions	Deficiency Disease
Vitamin A (Retinol)	Liver oil, Fish, Carrot, Milk, spinach and fruits such as Papaya and mango	Vision and growth	Night blindness, Xerophthalmia Keratinisation of skin
Vitamin B_1 (Thiamine)	Yeast, Milk, Cereals, Green vegetables, Liver, Pork	Co – enzyme in the form of Thiamine pyro phosphate (TPP) in glycolysis	Beri – Beri (peripheral nerve damage)
Vitamin B_2 (Riboflavin)	Soybean, Green vegetable Yeast, Egg white, Milk, Liver kidney	Co enzyme in the form of FMN (Flavin mono nucleotide)and FAD (Flavin adenine dinucleotide) in redox reactions	Cheilosis (lesions of corner of mouth, lips and tongue)
Vitamin B_3 (Niacin)	Cereals, Green leafy vegetables, Liver, Kidney	Co enzyme in the form of NAD and $NADP^+$ in redox reactions.	Pellagra (photo sensitive dermatitis)
Vitamin B_5 (Pantothenic acid)	Mushroom, Avocado, Egg yolk, Sunflower oil	Part of coenzyme A in carbohydrate protein and Fat metabolism	Inadequate growth
Vitamin B_6 (Pyridoxine)	Meat, Cereals, Milk, Whole grains, Egg.	Co enzyme in amino acid metabolism, formation of Heme in Hemoglobin	Convulsions
Vitamin B_7 (Biotin)	Liver, kidney, Milk, Egg yolk, Vegetables, Grains	Co enzyme in fatty acid Biosynthesis	Depression, Hair loss, muscle pain.
Vitamin B_9 (Folic acid)	Egg, Meat, Beet root, Leafy vegetables, Cereals, Yeast	Nucleic acid synthesis, maturation of red blood cells	Megaloblastic anaemia

Table below shows the mineral elements in animals, their sources, function and deficiency diseases they cause in case of their malnutrition

Mineral	RDA/AI		Best Sources	Functions
	Men	Women		
Calcium	1,000mg	1,000mg	Milk and milk products	Strong bones, teeth, muscle tissue; regulates heart beat, muscle action, and nerve function; blood clotting
Chromium	35ug	25ug	Corn oil, clams, whole-grain cereals, brewer's yeast	Glucose metabolism (energy); increases effectiveness of insulin
Copper	900ug	900ug	Oysters, nuts, organ meats, legumes	Formation of red blood cells; bone growth and health; works with vitamin C to form elastin
Fluoride	4mg	3mg	Fluorinated water, teas, marine fish	Stimulates bone formation; inhibits or even reverses dental caries
Iodine	150ug	150ug	Seafood, iodized salt	Component of hormone thyroxine, which controls metabolism
Iron	8mg	18mg	Meats, especially organ meats, legumes	Hemoglobin formation; improves blood quality; increases resistance to stress and disease
Magnesium	420mg	320mg	Nuts, green vegetables, whole grains	Acid/alkaline balance; important in metabolism of carbohydrates, minerals, and sugar (glucose)
Manganese	2.3mg	1.8mg	Nuts, whole grains, vegetables, fruits	Enzyme activation; carbohydrate and fat production; sex hormone production; skeletal development
Molybdenum	45ug	45ug	Legumes, grain products, nuts	Functions as a cofactor for a limited number of enzymes in humans
Phosphorus	700mg	700mg	Fish, meat, poultry, eggs, grains	Bone development; important in protein, fat, and carbohydrate utilization
Potassium	4700mg	4700mg	Lean meat, vegetables, fruits	Fluid balance; controls activity of heart muscle, nervous system, and kidneys
Selenium	55ug	55ug	Seafood, organ meats, lean meats, grains	Protects body tissues against oxidative damage from radiation, pollution, and normal metabolic processing
Zinc	11mg	8mg	Lean meats, liver, eggs, seafood, whole grains	Involved in digestion and metabolism; important in development of reproductive system; aids in healing

MILK

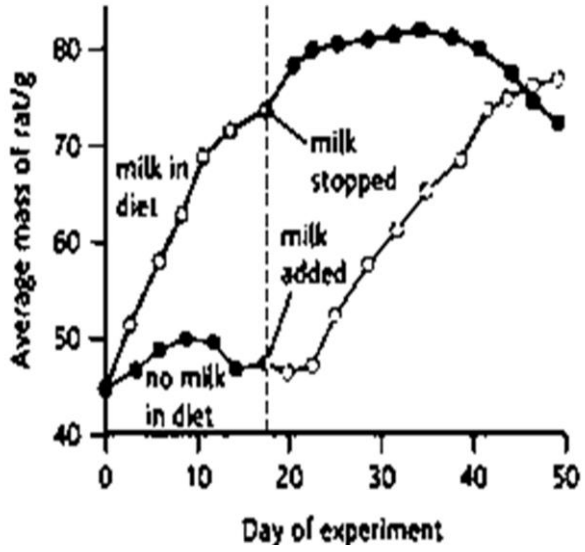
The only food that most mammals receive during the first weeks of their lives is milk. It provides an almost a complete diet during this stage of their development, containing carbohydrate, proteins, fat, minerals (especially calcium, magnesium, phosphorous and potassium) and a variety of vitamins.

The one major element that milk lacks is **iron**, a constituent of haemoglobin in blood. However, this problem is overcome by the embryo gaining iron from its mother and storing it in its body before. It stores in the liver enough to allow development until it begins to ingest solid food.

Gowland Hopkins experiment to investigate the effect of feeding milk on young rats.

In the experiment, two groups of young rats were used. Group A were fed on a diet of purified casein, starch, glucose, lard, minerals and water only for the first 18 days. Group B were fed on a diet of purified casein, starch, glucose, lard, minerals and water **plus** an extra of $3cm^3$ of milk daily for the first 18 days. After 8 days, milk was given to group A rats and removed from group B's diet.

Results or observations



Description

Group A rats increased in mass gradually from 0 day to 10 days, mass decreased gradually until 12 days, mass remained relatively constant up to 22 days, then mass increased rapidly from 22 days to 50 days.

Group B rats increased rapidly in mass from 0 day to 18 days, then gradually increased in mass from 18 days to 23 days, stopped growing from 23 days to 40 days and gradually decreased in mass or lost weight thereafter.

Explanation

Group A rats resumed growth and increased in weight after 18 days while group B rats stopped growing and lost weight after 18 days. While the $3cm^3$ of milk had an insignificant food value in terms of carbohydrates, fats, proteins and minerals, the milk contains an extra nutrient which the rats needed to be able to grow and develop.

Conclusion
Hopkins' experiment revealed that, to grow, animals needed small amounts of other substances he called **accessory food factors** now known as **vitamins**.

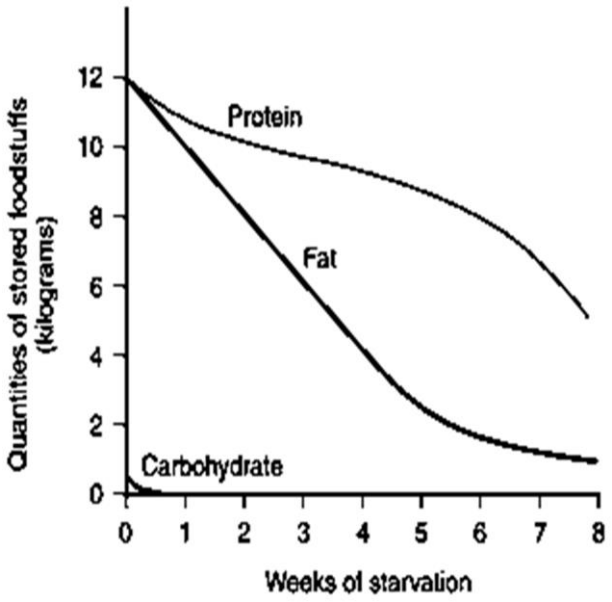
Effect starvation and general under eating on food stores in the body
The body must maintain a supply of energy for survival. During starvation, energy reserves gradually get used up until death results. Causes of starvation may include fasting, anorexia nervosa, bulimia nervosa, depression, famine or diseases

Explanation

Glycogen, proteins and fats are all metabolized during starvation.

Exhaustion of blood glucose stimulates glucagon secretion and insulin secretion is inhibited. Within the 24 hours, the very low glycogen amount stored in the liver and muscles decreases rapidly to depletion because glycogen is broken down in to glucose for oxidation to release energy, while the amounts of fats and proteins remain high. Anaerobic breakdown of glycogen in skeletal muscle is also stimulated.

Graph of effect of starvation on food stores



Within week 1, a few hours after depletion of carbohydrates or glycogen, the amount of fats decreases rapidly while the amount of proteins decreases gradually until about 6 weeks of starvation. This is because fats are hydrolyzed rapidly in to fatty acids and glycerol white oxidation of amino acids releases energy. The liver metabolizes fatty acids in to ketone bodies that are degraded to release energy. Accumulation of ketones causes ketosis, by condition characterized by blood becoming acidic. Fatty acids in skeletal muscles are broken down to release energy, thus decreasing the use of glucose by tissues other than the brain. Glycerol is converted in to small amount of glucose, but most of the glucose is formed from the amino acids of proteins. The brain begins to use ketone bodies as well as glucose for energy. Dependency on fats for energy release decreases the demand for glucose, protein breakdown reduces but does not stop.

The liver degrades non – essential proteins in to glucose for the brain in a process called gluconeogenesis, which involves converting carbon skeleton in to pyruvate or Krebs' cycle intermediates and excreting amino groups from the body.

From 6 weeks to 8 weeks, amount of fat decreases slowly to very low levels while amount of proteins decreases rapidly. This is because as fat reserves or stores are getting depleted, metabolism of fats to release energy occurs gradually and the body begins to rapidly breakdown essential proteins, leading to loss of liver and heart function as these organs are broken down for fuel metabolizing proteins as the major energy source. Muscles, the largest source of proteins in the body are rapidly depleted.