MARUDHAR KESARI JAIN COLLEGE FOR WOMEN VANIYAMBADI

PG AND RESEARCH DEPARTMENT OF BIOCHEMISTRY

E-NOTES

SUBJECT NAME: PHYSIOLOGY AND NUTRITION

SUBJECT CODE : CBC53

SYLLABUS

UNIT – II

DIGESTION

Definition, Digestive system of man, Physical and Chemical process of digestion. structure and function of microvillus, Salivary digestion, gastric digestion-mechanism of HCL formation, intestinal digestion-liver, pancreas, intestinal juice, Role of bile salt in Digestion, Digestion and absorption of carbohydrates, proteins, and lipids.

Digestion

Digestion is the process your body goes through to break the food you eat into substances that it can absorb and use. Chewing is an important first step in digestion, because your teeth make food small enough to swallow.

Human Digestive System

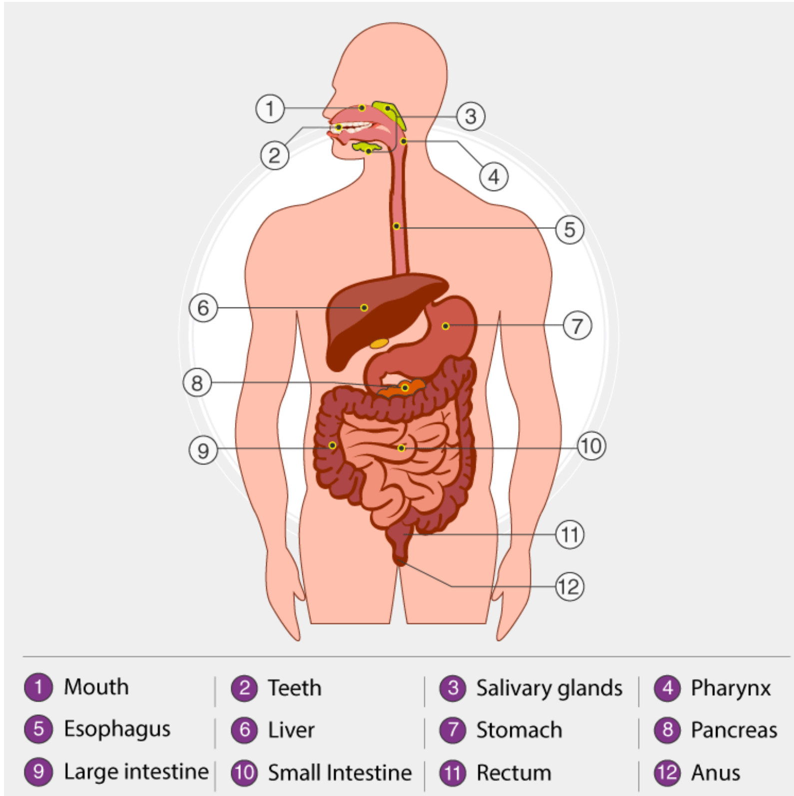
The digestive system of the human body comprises a group of organs working together to convert food into energy for the body. Anatomically, the digestive system is made up of the gastrointestinal tract, along with accessory organs such as the liver, pancreas and gallbladder. The hollow organs that make up the gastrointestinal tract (GI tract) include the mouth, stomach, oesophagus, small intestine and large intestine that contains the rectum and anus.

Human Digestive System and Nutrition involve the intake of food by an organism and its utilization for energy. This is a vital process which helps living beings to obtain their energy from various sources. The food which we eat undergoes much processing before the nutrients present in them are utilized to generate energy. This processing is known as digestion. Humans and other animals have specialized organs and systems for this process.

The digestion process involves the alimentary canal along with various accessory organs and organ systems. In humans, the process is quite simple due to our monogastric nature. This means that we have a one-chambered stomach, unlike other animals such as cows, which have four chambers.

Some parts of nervous and circulatory systems also play a significant role in the digestion process. A combination of nerves, bacteria, hormones, blood and other organs of the digestive system completes the task of digestion.

The diagram given below represents different parts of the human digestive system that convert food into essential nutrients absorbed by the body.



Parts of the Human Digestive System

The digestive system of the human body comprises a group of organs that work together in converting food into energy and other basic nutrients to power the body. The food we take in is digested and utilized by our body, and the unused parts of the food are defecated.

The digestive system of the human body is the sum of the gastrointestinal tract (GIT; also called alimentary canal) and accessory organs (tongue, liver, pancreas, etc.). These two parts together help in the digestion process.

The alimentary canal is the long tube through which the food that we eat is passed. It begins at the mouth (buccal or oral cavity), passes through the pharynx, oesophagus or food pipe, stomach, small intestines, large intestines, rectum and finally ends at the anus. The food particles gradually get digested as they travel through various compartments of the alimentary canal.

Accessory organs are organs which participate in the digestion process but are not actually a part of GIT. They stimulate the digestion by releasing certain enzymes that help in breaking down the food.

Let us have a detailed look at the digestive system of the human body, along with its parts and functions:

Mouth

Food starts its journey from the mouth or the oral cavity. There are many other organs that contribute to the digestion process, including teeth, salivary glands, and tongue. Teeth are designed for grinding food particles into small pieces and are moistened with saliva before the tongue pushes the food into the pharynx.

Pharynx

A fibromuscular y-shaped tube attached to the terminal end of the mouth. It is mainly involved in the passage of chewed/crushed food from the mouth through the oesophagus. It also has a major part in the respiratory system, as air travels through the pharynx from the nasal cavity on its way to the lungs.

Oesophagus

This is a muscular tube that connects the pharynx, which is a part of an upper section of the gastrointestinal tract. It supplies swallowed food along with its length.

Stomach

It serves as a muscular bag which is situated towards the left side of the abdominal cavity, beneath the diaphragm. This vital organ acts as a storage for the food and provides enough time to digest meals. The stomach also produces digestive enzymes and hydrochloric acid that maintains the process of digestion.

- **Mucous**: It is an aqueous secretion produced by the mucous membranes. It functions by protecting the stomach lining and gastric pits from the acid, which is produced by the glands to destroy the bacteria that entered along with the food particles.
- **Digestive enzymes**: They are the group of enzymes which functions by breaking down polymeric macromolecules like biopolymers into their smaller and simpler substances.

- **Hydrochloric acid**: It is the digestive fluid formed by the stomach during the process of digestion. It functions by destroying harmful microorganisms present in the food particles.

Small Intestine

The small intestine is a thin, long tube of about 10 feet long and a part of the lower gastrointestinal tract. It is present just behind the stomach and acquires a maximum area of the abdominal cavity. The complete small intestine is coiled and the inner surface consists of folds and ridges.

Large Intestine

This is a thick, long tube measuring around 5 feet in length. It is present just beneath the stomach and wraps over the superior and lateral edges of the small intestine. It absorbs water and consists of bacteria (symbiotic) that support the breakdown of wastes to fetch small nutrients.

Rectum

Waste products are passed into the end of the large intestine called the rectum and eliminated out of the body as a solid matter called stool. It is stored in the rectum as semi-solid faeces which later exits from the body through the anal canal through the process of defecation.

Accessory Organs

Pancreas

It is a large gland present just behind the stomach. It is short with its anterior connected to the duodenum and posterior pointing towards the left part of the abdominal cavity. The pancreas releases digestive enzymes to complete the process of chemical digestion.

Liver

The liver is a roughly triangular, reddish-brown accessory organ of the digestive system located to the right of the stomach. It produces bile, which helps in the digestion of fat in the small intestine. The bile is stored and recycled in the gallbladder. It is a small, pear-shaped organ which is located just next to the liver.

Digestion Process

The process of digestion begins from the mouth and ends in the small intestine – the large intestines' main function is to absorb the remaining water from the undigested food and enable bacterial fermentation of materials that can no longer be digested.

The alimentary canal or the gastrointestinal tract is a series of hollow organs and tubes that begins from the mouth cavity and continues into the pharynx, through the stomach, small intestines, large intestines, and finally ending at the anus. Food particles gradually get digested as they travel through various compartments of the gastrointestinal tract.

The digestion process takes place in the following steps.

Ingestion

The very first step involves mastication (chewing). The salivary glands, along with the tongue, helps to moisten and lubricate food, before being pushed down into the food pipe.

Mixing and Movement

It involves the process of lubricating and manipulating food and pushing it down the food through the food pipe (using peristalsis), and into the stomach.

Secretion

The stomach, small intestine, liver, and pancreas secrete enzymes and acids to aid the process of digestion. It functions by breaking down food particles into simple components and easily absorbable components.

Digestion

The process of converting complex food particles into simpler substances in the presence of enzymes and acids secreted by different digestive organs.

Absorption

This process begins in the small intestine where most of the nutrients and minerals are absorbed. The excess water in the indigestible matter is absorbed by the large intestines.

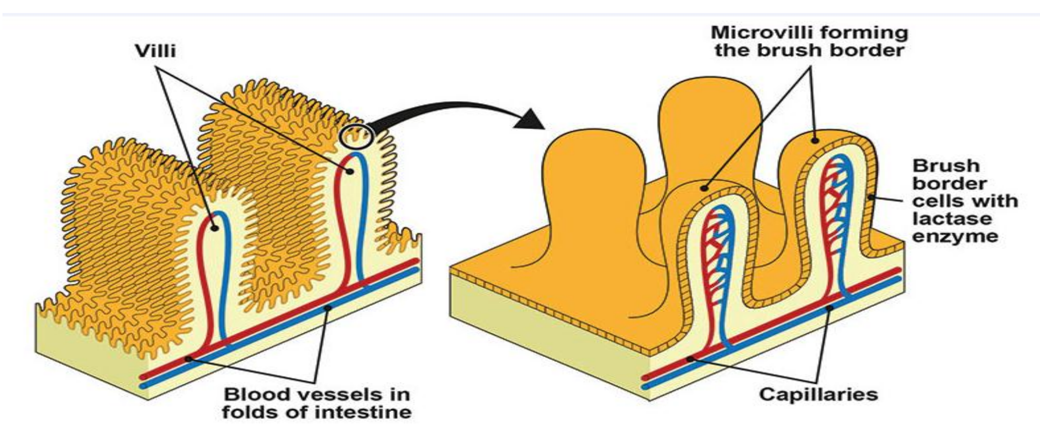
Excretion

The process of removing indigestible substances and waste by-products from the body through the process of defecation.

Microvilli

- Microvilli, in the most simplistic terms, are tiny little microscopic projections that exist in, on, and around cells.
- They can exist on their own or in conjunction with villi (projections of some mucous membranes, most specifically of the small intestine, which are tiny folds that project out like numerous fingers).
- On each of the villi, there are even smaller folds that stick out like fingers called microvilli.
- Microvilli are most often found in the small intestine, on the surface of egg cells, as well as on white blood cells.
- Thousands of microvilli form a structure called the brush border that is found on the apical surface of some epithelial cells, such as the small intestines.

Structure of Microvilli



- Microvilli form a rather polymorphic class of surface protuberances that are regularly packed in some tissues and loosely positioned in others.
- Generally, they are shorter and smaller in diameter than **cilia**. They are commonly about 0.1 μm diameter and range in length from a fraction of a micrometer to about 2 μm.
- Microvilli are essentially bundles of cross-linked actin fibers.
- Although they are cellular extensions, there are little or no cellular organelles present in the microvilli.
- However, they are covered in their own plasma membrane, which encloses cytoplasm and microfilaments.
- Each microvillus has a dense bundle of cross-linked actin filaments, which serves as its structural core.
- 20 to 30 tightly bundled actin filaments are cross-linked by bundling proteins fimbrin (or plastin-1), villin and espin to form the core of the microvilli.
- Actin filaments, present in the cytosol, are most abundant near the cell surface. These filaments are thought to determine the shape and movement of the plasma membrane.
- The nucleation of actin fibers occurs as a response to external stimuli, allowing a cell to alter its shape to suit a particular situation.
- In the enterocyte microvillus, the structural core is attached to the plasma membrane along its length by lateral arms made of myosin 1a and Ca2+ binding protein calmodulin.
- The space between microvilli at a cell's surface is called the intermicrovillous space. Intermicrovillous space increases with the contractile activity of myosin II and tropomyosin and decreases when contraction ceases.

Functions of Microvilli

- The microscopic microvilli effectively increase the surface area of the cell and are useful for absorption and secretion functions.
- In the intestine, they work in conjunction with villi to absorb more nutrients and more material because they expand the surface area of the intestine.
- The microvillar membrane is packed with enzymes that aid in the breakdown of complex nutrients into simpler compounds that are more easily absorbed. For example, enzymes that digest carbohydrates called glycosidases are present at high concentrations on the surface of

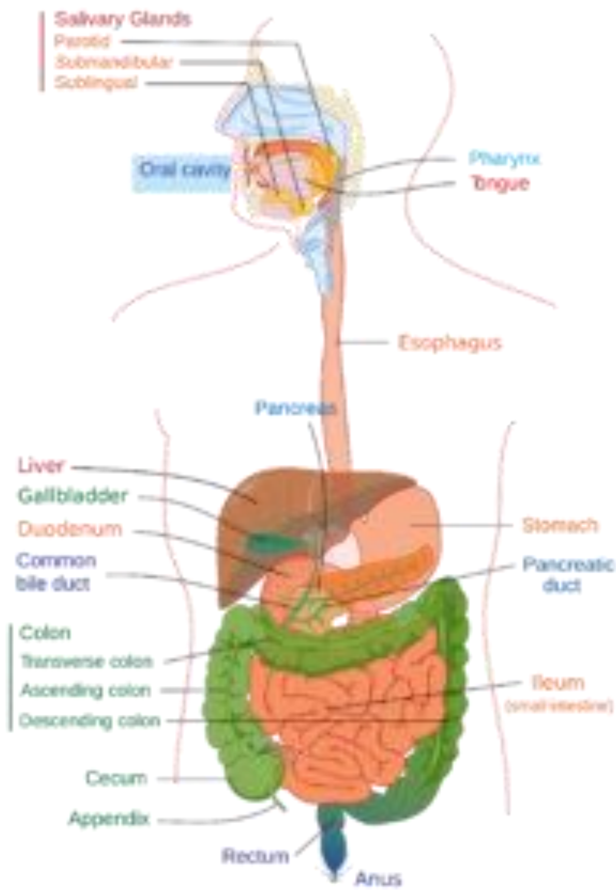
enterocyte microvilli. Thus, microvilli not only increase the cellular surface area for absorption, but they also increase the number of digestive enzymes that can be present on the cell surface.

- They play a role in egg cells as they help in anchoring the sperm to the egg, thus allowing for easier fertilization.
- In white blood cells, the microvilli act as an anchoring point. They aid in the migration of white blood cells.
- The second type of proposed function is to store membrane and microfilament materials. Motility is another function of microvilli. The microvilli on the cell surface may sweep unwanted materials toward a resorptive area of the cell.
- They are also involved in a wide variety of other functions, which include absorption, secretion, cellular adhesion, and mechanotransduction.

Digestion of Carbohydrate

It is an important process that breaks down the proteins, fats, carbohydrates, vitamins, minerals into simpler forms so that it can be absorbed easily into the body cells. During this process, proteins are converted into amino acids, carbohydrates are converted into simple sugars and fats are broken down into fatty acids and glycerol.

Many digestive enzymes and hormones act on food, at various stages during the process of digestion. The whole process occurs in a sequential manner.



The following table shows the digestive process in a simple format.

Organ	**Movement**	**Digestive juices/enzymes added**	**Food that is broken down**
Mouth	Chewing	Saliva	Starch(Carbohydrate)

Oesophagus	Peristalsis	—-	—-
Stomach	Churning	Stomach acid and Digestive Enzymes	Proteins
Small Intestine	Peristalsis	Digestive Juices	Carbohydrates, proteins, starch
Pancreas	——	Pancreatic juice	Carbohydrates, Fats, proteins
Liver	——	Bile	Fats
Large Intestine	Peristalsis	—-	Bacteria act on the remaining food particles.

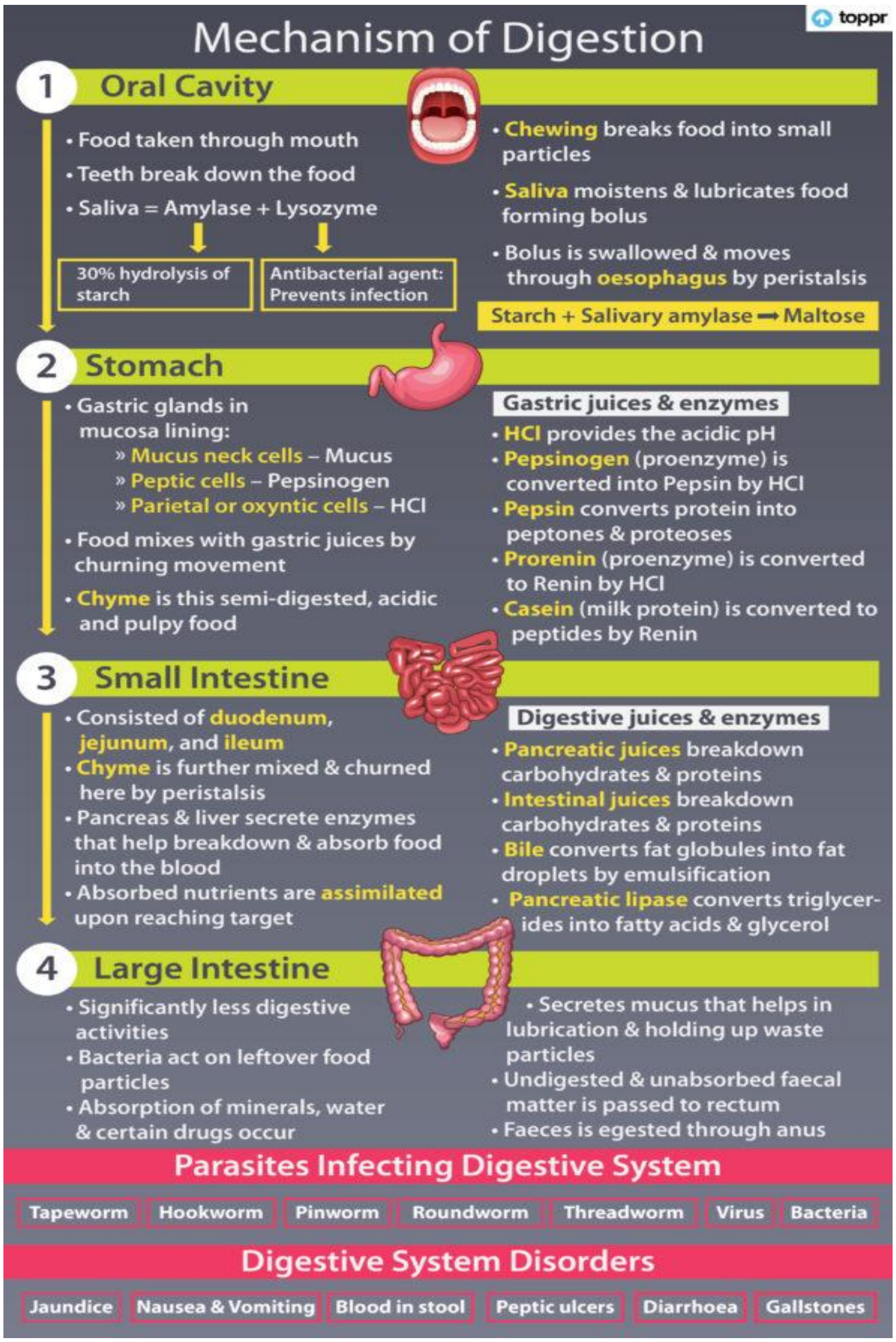
Mechanism of Digestion

The digestion process can be divided into different stages, such as digestion in the:

- Oral cavity
- Stomach
- Small intestine

- Large intestine

Digestion includes a complex combination of mechanical and chemical processes. Some of the activities in the process include ingestion and propulsion of food, mechanical or physical digestion, chemical digestion, absorption, and defecation.



Digestion in the Oral Cavity

When food is taken in through the mouth, chewing and mixing of the food occurs. There is also a chemical breakdown of carbohydrates, due to the action of saliva from the salivary glands. 30% of the starch is hydrolyzed by the action of amylase, which is a salivary enzyme. The other enzyme, lysozyme is an antibacterial agent that prevents infections.

$$\text{Starch} + \text{Salivary amylase} \rightarrow \text{Maltose}$$

Mastication of food and swallowing of food are the important activities that take place here in the oral cavity. Food is broken down into smaller particles by the chewing action of teeth. As saliva is added, it mixes with the food particles, slowly moistening and lubricating the food. This small ball is called a bolus, which is then swallowed. The pharynx helps in the movement of the bolus into the oesophagus, from where it moves to the stomach through the peristaltic movements of the oesophagus.

Digestion in the Stomach

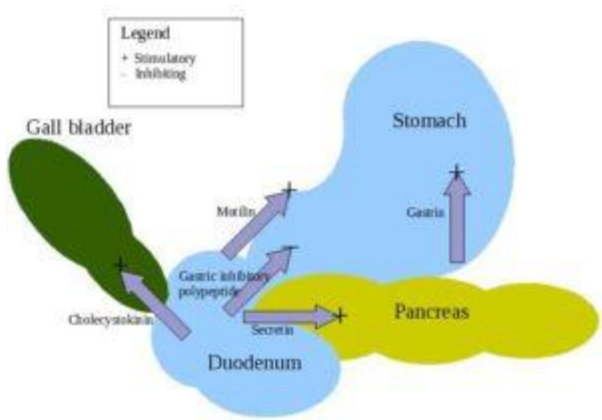
When food reaches the stomach, it stays for approximately 4 to 5 hours. There are various gastric glands in the mucosa lining of the stomach. The mucus neck cells secrete mucus. The Peptic Cells secrete the proenzyme pepsinogen. The Parietal or Oxyntic Cells secrete HCl (Hydrochloric acid) and intrinsic factor that is essential for vitamin B12 absorption.

Food in the stomach gets mixed thoroughly with the gastric juices through the churning movements of the stomach muscle. This mass of food that is semi-digested, acidic and pulpy is called the chyme. It is mostly the proteins that get digested in the stomach. The mucus and the bicarbonates of the gastric juice help in protecting the mucosal epithelium from the highly acidic HCl. Mucus also helps in lubricating the food.

The different chemical reactions that take place in the stomach are summarised as follows.

- **Gastric juices and enzymes:**
    - HCl provides the acidic pH.
    - Pepsinogen(proenzyme) is converted into Pepsin by HCl
    - Pepsin, in turn, converts protein into peptones & proteoses.
    - Prorenin (proenzyme) is converted into Renin by HCl.
    - Casein (milk protein) is converted into peptides by Renin.

After the action of the gastric juices and enzymes, food then enters the small intestine.



Digestion in the Small Intestine

In the small intestine, further digestion takes place. Due to the various movements of this organ, the chyme is further mixed and churned. There are many enzymes that are secreted into the small intestine from organs such as pancreas, liver; apart from the intestinal juices. All these react with the food particles and digest them into smaller particles that can be absorbed into the bloodstream.

The different chemical reactions that occur are summarised below:

- **Pancreatic juices:**

- Amylase converts starch into Maltose.

- Enterokinase converts Trypsinogen into Trypsin
- Trypsin converts proteins into Dipeptides
- Trypsin converts Chymotrypsinogen into Chymotrypsin.
- Chymotrypsin converts peptones into Dipeptides.
- Trypsin converts Procarboxypeptidase into Carboxypeptidase.
- Carboxypeptidase converts proteoses into Dipeptides.
- Trypsin converts Proelastase into Elastase.
- Elastase converts elastin into Dipeptides.
- Pancreatic amylase converts polysaccharides (Starch) into Disaccharides.
- Nucleases in the pancreatic juice, act on nucleic acids and form nucleotides and nucleosides.

- **Intestinal juices:**

- Maltase converts maltose into glucose.
- Sucrase converts sucrose into glucose & fructose.
- Lactase converts lactose into glucose & galactose.
- Aminopeptidases convert peptides into amino acids.
- Dipeptidases convert dipeptides into amino acids

$$\text{Dipeptides} \xrightarrow{\text{Dipeptidases}} \text{Amino acids}$$

$$\text{Maltose} \xrightarrow{\text{Maltase}} \text{Glucose} + \text{Glucose}$$

$$\text{Lactose} \xrightarrow{\text{Lactase}} \text{Glucose} + \text{Galactose}$$

$$\text{Sucrose} \xrightarrow{\text{Sucrase}} \text{Glucose} + \text{Fructose}$$

$$\text{Nucleotides} \xrightarrow{\text{Nucleotidases}} \text{Nucleosides} \xrightarrow{\text{Nucleosidases}} \text{Sugars} + \text{Bases}$$

$$\text{Diand Monoglycerides} \xrightarrow{\text{Lipases}} \text{Fatty acids} + \text{Glycerol}$$

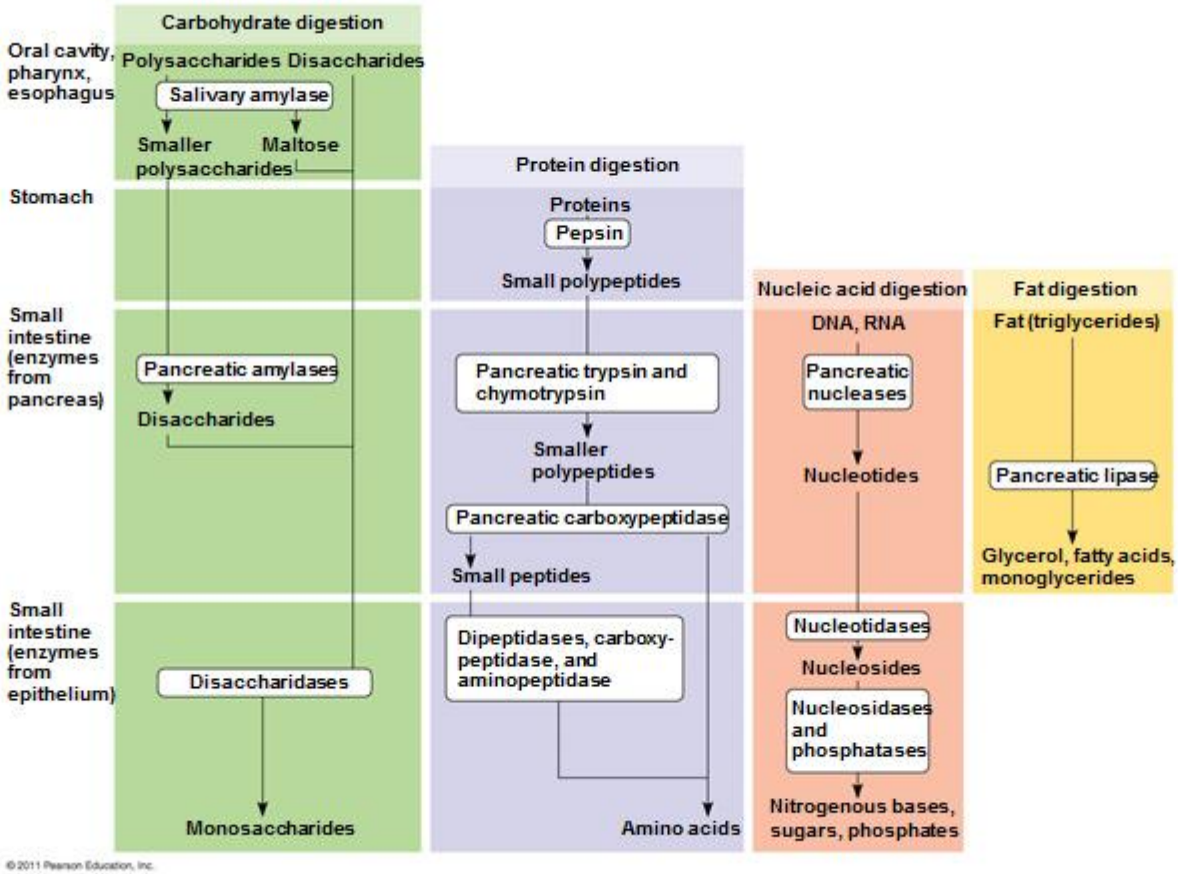
- **Bile** -Bile converts fat globules into fat droplets through a process called emulsification. Fats are broken down into diglycerides and monoglycerides.
- **Pancreatic lipase** – It converts triglycerides into fatty acids & glycerol.

The biomacromolecules are broken down in the duodenum region. All the simpler forms of the digested food are absorbed in the jejunum and ileum regions. Any leftover undigested, unabsorbed food particles are then passed on to the large intestine.

Digestion in the Large Intestine

In the large intestine, the digestion activity is significantly less. Here, bacterial action on the leftover food particles occurs. Minerals, water, and certain drugs are absorbed in the large intestine. The mucus secreted by the large intestine helps in holding the waste particles, apart from lubricating it.

Any undigested and unabsorbed waste particles called as the faecal matter, are then passed to the rectum, from where it is eliminated through the anus.



Control of the Digestive Processes

The digestive processes are controlled by the hormones and the nerves. There is a constant flurry of signals between the brain and the alimentary canal. Hormones control the digestion process by signalling the body at appropriate times to make the digestive juices. They also send signals to the brain to indicate being hungry or full. The nervous system, through the brain and spinal cord, controls the digestive processes.

Bile salts

Bile salts are one of the primary components of bile. Bile is a greenish-yellow fluid made by your liver and stored in the gallbladder. In addition to bile salts, bile contains cholesterol, water, bile acids, and the pigment bilirubin.

Bile salts help with the digestion of fats. They also help the body absorb fat-soluble vitamins, like vitamins A, D, E, and K.

Bile and bile salts are made in the liver and stored in the gallbladder between meals.

Function in the body

The role of bile and bile salts in the body is to:

- aid digestion by breaking down fats
- help absorb fat-soluble vitamins
- eliminate waste products

After you eat and there are fats present in your digestive tract, your hormones send a signal to the gallbladder to release bile.

The bile is released directly into the first part of the small intestine, called the duodenum. This is where most of the process of digestion happens. The bile helps break down and digest the fats present in food.

Another primary function of bile that bile salts help with is the removal of toxins. Toxins are secreted into the bile and eliminated in feces. A lack of bile salts can cause a buildup of toxins in the body.

bile salt deficiency can cause problems with the formation of hormones, since all hormones are made from the broken-down parts of fats.

Dietary carbohydrates include starches, sugars, and fibre.

- **Use of Dietary Carbohydrates as Energy**. Glucose is the primary energy source of the body. Major dietary sources of glucose include starches and sugars.

- **Digestion of Carbohydrates**. Dietary carbohydrates are digested to glucose, fructose and/or galactose, and absorbed into the blood in the small intestine.The digestion and absorption of dietary carbohydrates can be influenced by many factors.
- **Absorption of Carbohydrates**. Absorbed carbohydrate molecules are used immediately for energy or stored in various forms in the muscles, liver or adipose tissue for future use.

Use of Dietary Carbohydrates as Energy

Dietary carbohydrates include starches, sugars and fibre that are mostly found in grain products, vegetables and fruit, milk products, and meat alternatives such as nuts, seeds, and legumes Starches and sugars are the major dietary sources of glucose, which is the primary energy source in the body:

- The brain relies primarily on glucose to function; restricting the brain's glucose supply can impair memory and ability to focus.
- Muscles use glucose for energy, especially during high-intensity exercise.

Digestion of Carbohydrates

The digestive system works like a giant food processor. During digestion, starches and sugars are broken down both mechanically (e.g. through chewing) and chemically (e.g. by enzymes) into the single units glucose, fructose, and/or galactose, which are absorbed into the blood stream and transported for use as energy throughout the body.

Digestion of starches into glucose molecules starts in the mouth, but primarily takes place in the small intestine by the action of specific enzymes secreted from the pancreas (e.g. α-amylase and α-glucosidase). Similarly, the disaccharides sucrose, lactose, and maltose are also broken down into single units by specific enzymes

Absorption of Carbohydrates

The end products of sugars and starches digestion are the monosaccharides glucose, fructose, and galactose. Glucose, fructose, and galactose are absorbed across the membrane of the small intestine and transported to the liver where they are either used by the liver, or further distributed to the rest of the body

Absorption of Fructose

There are two major pathways for the metabolism of fructose (5, 6): the more prominent pathway is in the liver and the other occurs in skeletal muscle. The breakdown of fructose in skeletal muscle is similar to glucose. In the liver and depending on exercise condition, gender, health status and the availability of other energy sources (e.g. glucose), the majority of fructose is used for energy production, or can be enzymatically converted to glucose and then potentially glycogen, or is converted to lactic acid (See figure below).

The notion that fructose is an unregulated energy substrate and directly fuels fat synthesis in the liver is not supported by the scientific literature; within the normal consumption range very minimal amounts (<1%) of fructose are converted to fat (5, 6). It is important to note that the metabolism of fructose involves many regulated reactions and its fate may vary depending on nutrients consumed simultaneously with fructose (e.g. glucose) as well as the energy status of the body.

Factors that Affect Absorption of Carbohydrates

A number of factors affect carbohydrate digestion and absorption, such as the food matrix and other foods eaten at the same time

Glycemic Index (GI) is a scale that uses a numbering system to rank carbohydrate rich foods as "high GI", "medium GI", and "low GI" based on the rate that glucose-containing carbohydrates are digested and absorbed, and the rate they increase blood glucose levels. Foods with a high GI are more quickly digested, and cause a larger increase in blood glucose level compared to foods with a low GI. Foods with a low GI are digested more slowly and do not raise blood glucose as high, or as quickly, as high GI foods. Examples of factors that affect carbohydrate absorption are described in the table below:

Factors that Affect Carbohydrate Absorption	Examples
Cooking: Foods that are less cooked or processed are digested more slowly and have a lower GI than foods that are more cooked or processed.	Less processed foods, such as slow cooking oats or brown rice, have a lower GI than more processed foods such as instant oats or instant rice. Pasta cooked 'al dente' (tender yet firm) has a lower GI than pasta cooked until very tender.
Fibre: Fibre helps to slow digestion of carbohydrate foods. High-fibre foods tend to have a lower GI than low fibre foods.	High fibre foods such as whole grain breads, oats, beans, and lentils, have a lower GI than low fibre foods such as white bread and rice cereal.
Fat and Protein: Fat or protein eaten along with carbohydrate helps to slow down digestion and reduces the GI of carbohydrate.	A snack that includes carbohydrate with protein or fat has a lower GI than a snack with carbohydrate only. For example, crackers with peanut butter have a lower GI than crackers alone.
Acids in Foods: Acids in foods slow the time it takes for the stomach to empty after eating. Acids lower the GI of carbohydrate foods.	Vinegar, lemon juice, or citrus fruits added to foods will lower the GI of those foods.

Digestion of Protein

Protein is one of the most important substances in your body. Your muscles, hair, eyes, organs, and many hormones and enzymes are primarily made out of protein. It also helps to repair and maintain your body tissues.

However, not all protein is created equal, and there are things you can do to help your body use it more efficiently.

Protein is a very large nutrient that's made up of smaller substances called amino acids. There are 20 amino acids, but your body can only make 11 of them. The other nine are called essential amino acids, and you can only get them through your diet.

High-quality protein sources, such as meat, fish, eggs, and dairy products, contain all nine of the essential amino acids. These are also called whole proteins or complete proteins.

Other protein sources, such as nuts, beans, and seeds, only contain some essential amino acids. However, you can combine some of these protein sources, such as rice and beans, to create a complete protein that contains all nine essential amino acids.

The role of enzymes

Protein digestion begins when you first start chewing. There are two enzymes in your saliva called amylase and lipase. They mostly break down carbohydrates and fats.

Once a protein source reaches your stomach, hydrochloric acid and enzymes called proteases break it down into smaller chains of amino acids. Amino acids are joined together by peptides, which are broken by proteases.

From your stomach, these smaller chains of amino acids move into your small intestine. As this happens, your pancreas releases enzymes and a bicarbonate buffer that reduces the acidity of digested food.

This reduction allows more enzymes to work on further breaking down amino acid chains into individual amino acids.

Some common enzymes involved in this phase include:

- trypsin

- chymotrypsin
- carboxypeptidase

Protein absorbed

Protein absorption also happens in your small intestine, which contains microvilli. These are small, finger-like structures that increase the absorptive surface area of your small intestine. This allows for maximum absorption of amino acids and other nutrients.

Once they've been absorbed, amino acids are released into your bloodstream, which takes them to cells in other parts of your body so they can start repairing tissue and building muscle.

Protein combination	**Examples**
whole grains and legumes	brown rice with lentils or pasta salad with kidney beans
nuts and whole grains	nut butter on whole grain toast
legumes with seeds	hummus, which contains chickpeas and sesame seed paste
vegetables and nuts	green bean almondine
vegetables and whole grains	broccoli and whole grain pasta

It was previously believed that vegetarian proteins must be consumed at the same meal in order for the body to form complete proteins. Now it's known that the body can pool proteins from various foods throughout the day to form complete proteins when needed.

Digestion and Absorption of Lipids

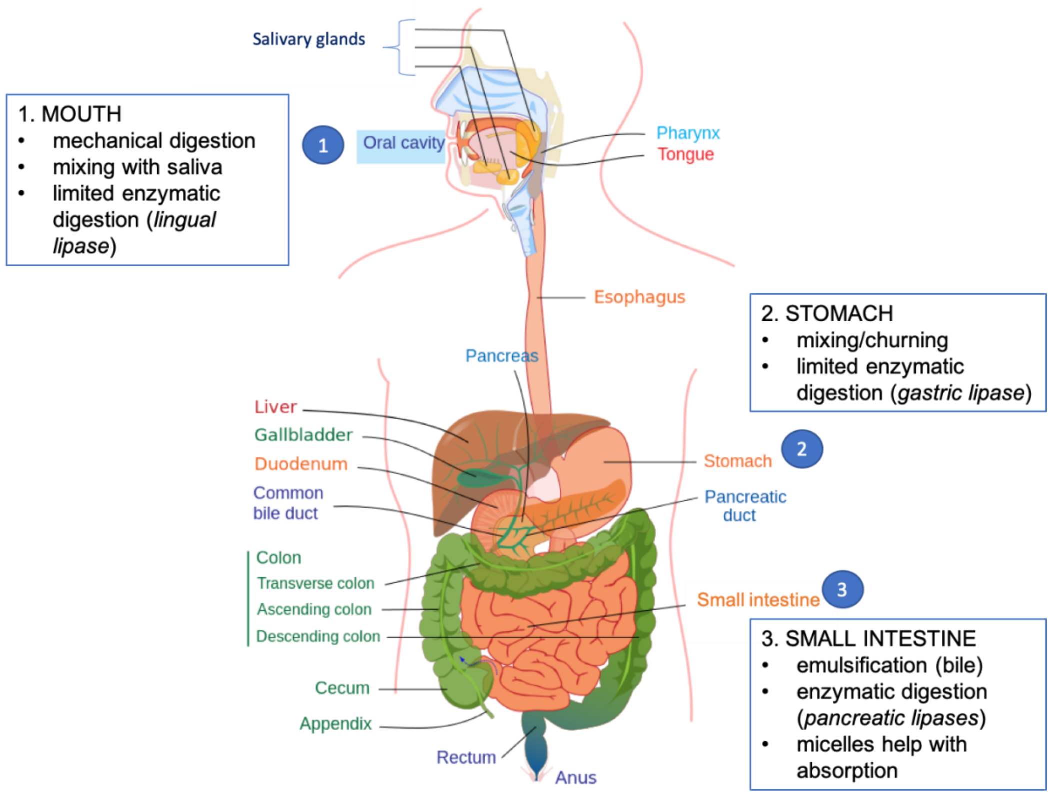
Lipid digestion and absorption pose some special challenges. Triglycerides are large molecules, and unlike carbohydrates and proteins, they're not water-soluble. Because of this, they like to cluster together in large droplets when they're in a watery environment like the digestive tract. The digestive process has to break those large droplets of fat into smaller droplets and then enzymatically digest lipid molecules using enzymes called **lipases**. The mouth and stomach play a small role in this process, but most enzymatic digestion of lipids happens in the small intestine. From there, the products of lipid digestion are absorbed into circulation and transported around the body, which again requires some special handling since lipids are not water-soluble and do not mix with the watery blood.

1. LIPID DIGESTION IN THE MOUTH

A few things happen in the mouth that start the process of lipid digestion. Chewing mechanically breaks food into smaller particles and mixes them with saliva. An enzyme called **lingual lipase** is produced by cells on the tongue ("lingual" means relating to the tongue) and begins some enzymatic digestion of triglycerides, cleaving individual fatty acids from the glycerol backbone.

2. LIPID DIGESTION IN THE STOMACH

In the stomach, mixing and churning helps to disperse food particles and fat molecules. Cells in the stomach produce another lipase, called **gastric lipase** ("gastric" means relating to the stomach) that also contributes to enzymatic digestion of triglycerides. **Lingual lipase** swallowed with food and saliva also remains active in the stomach. But together, these two lipases play only a minor role in fat digestion (except in the case of infants, as explained below), and most enzymatic digestion happens in the small intestine.



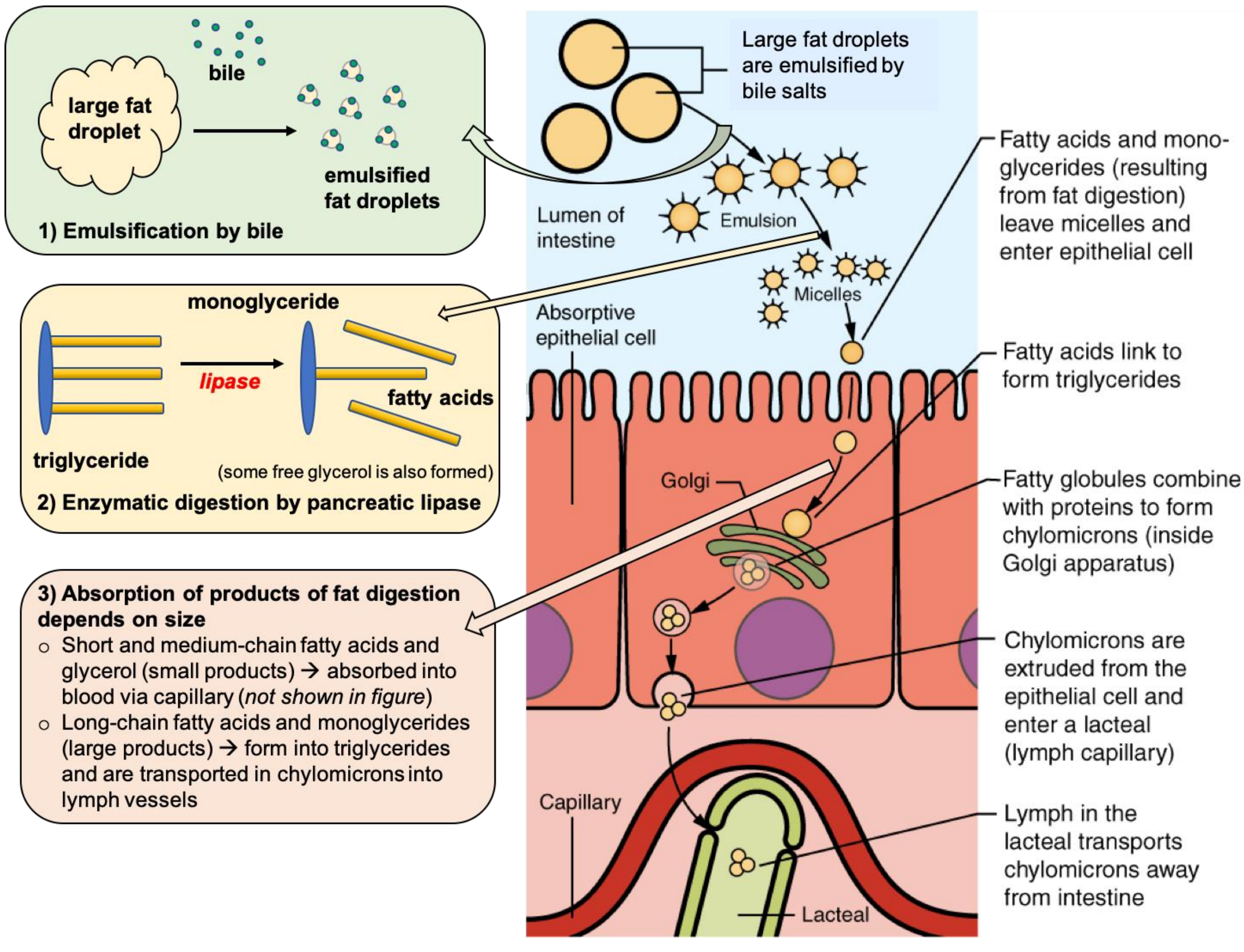
3. LIPID DIGESTION IN THE SMALL INTESTINE

As the stomach contents enter the small intestine, most of the dietary lipids are undigested and clustered in large droplets. **Bile**, which is made in the liver and stored in the gallbladder, is released into the duodenum, the first section of the small intestine. Bile salts have both a hydrophobic and a hydrophilic side, so they are attracted to both fats and water. This makes them effective emulsifiers, meaning that they break large fat globules into smaller droplets. Emulsification makes lipids more accessible to digestive enzymes by increasing the surface area for them to act.

The pancreas secretes **pancreatic lipases** into the small intestine to enzymatically digest triglycerides. Triglycerides are broken down to fatty acids, monoglycerides (glycerol backbone with one fatty acid still attached), and some free glycerol. Cholesterol and fat-soluble vitamins do not need to be enzymatically digested

4. LIPID ABSORPTION FROM THE SMALL INTESTINE

Next, those products of fat digestion (fatty acids, monoglycerides, glycerol, cholesterol, and fat-soluble vitamins) need to enter into the circulation so that they can be used by cells around the body. Again, bile helps with this process. Bile salts cluster around the products of fat digestion to form structures called **micelles**, which help the fats get close enough to the microvilli of intestinal cells so that they can be absorbed. The products of fat digestion diffuse across the membrane of the intestinal cells, and bile salts are recycled back to do more work emulsifying fat and forming micelles.



Lipid digestion and absorption in the small intestine.

Once inside the intestinal cell, short- and medium-chain fatty acids and glycerol can be directly absorbed into the bloodstream, but larger lipids such as long-chain fatty acids, monoglycerides, fat-soluble vitamins, and cholesterol need help with absorption and transport to the bloodstream. Long-chain fatty acids and monoglycerides reassemble into triglycerides within the intestinal cell, and along with cholesterol and fat-soluble vitamins, are then incorporated into transport vehicles called chylomicrons. **Chylomicrons** are large structures with a core of triglycerides and cholesterol and an outer membrane made up of phospholipids, interspersed with proteins (called apolipoproteins) and cholesterol. This outer membrane makes them water-soluble so that they can travel in the aqueous environment of the body. Chylomicrons from the small intestine travel first into lymph vessels, which then deliver them to the bloodstream.

Chylomicrons are one type of lipoprotein—transport vehicles for lipids in blood and lymph. We'll learn more about other types of lipoproteins on the next page.