8. THE DIGESTIVE (GASTROINTESTINAL) SYSTEM

Our body must constantly renew its cells, sustain a balance in vital substances such as water and electrolytes and most importantly, replenish the energy spent. This is accomplished through what we eat and drink. The necessary energy is acquired through food, which consists mainly of *fat, protein and carbohydrates*, along with vital substances such as *vitamins*. The procedure that transforms food intake into easily absorbed substances is called **digestion**. The digestive tract is actually a long muscular tube that starts from the mouth and ends at the anus. Food and liquids are propelled along this tube by a rhythmic motion called **peristalsis**. Several **glands** empty their produce (enzymes) in the lumen of the digestive tract, aiding in breaking down the complex structures of food into simple structures that can be absorbed at the cellular level.

The organs of the digestive system are spread from the head to the pelvic region. The **"upper part"** of the digestive tract is located at the **head and neck region** and consists of the **mouth** and the middle and lower parts of the **pharynx** until the beginning of the **esophagus**. In this "upper part" the food is received by use of the **lips, tongue and teeth**; the food is chewed, mixed with saliva and swallowed in small bites. Digestion already begins at the mouth level with the aid of enzymes present in the **saliva** (for example, breakdown of *starch* that is present in bread is responsible for the sweet taste of bread). The *senses* (taste and smell) are acting as a control for the chemical constitution of food.

The **"lower part"** of the digestive system is located in the trunk, namely the **thoracic, abdominal and pelvic region.** The **esophagus** is connecting the mouth to the **stomach**, which is the most dilated part of the gastrointestinal tract. In the stomach the food is collected and further digested by the aid of *gastric juices*. The gastric juice (chyme) then enters through the **pyloric valve** into the **small intestine** (the *duodenum*, the *jejunum* and the *ileum*). Here the food is further digested by the aid of important enzymes secreted by two major organs: the **liver** and the **pancreas**. In the small intestine the digestion is completed and most important nutrients are absorbed. What is not absorbed enters the **large intestine** (the *ascending*, *transverse* and *descending colon*) where mainly water and electrolytes are reabsorbed from the intestinal juice. In that way, the contents of the large intestine become dehydrated and firm, forming the stools (*feces*), that enter the lowest part of the colon, the **rectum**. When the rectum fills up with stools, the need for passage of stools leads to *defecation*.

Peristalsis is the mechanism by which a forward movement of the contents in a muscular tube is achieved. Peristalsis is the main action of food and water movement in the gastrointestinal tract. This is mainly achieved by a **ring-like contraction** of the circular smooth muscle fibers. Consecutive contractions are responsible for the forward movement of the gastrointestinal contents. It is easy to understand this mechanism: just imagine that you hold an elastic, soft tube in your hands and you start squeezing it with your wrapped-around fingers.
The initial signal is usually local **dilation** of the muscular tube ie the esophagus; once peristalsis has started, it propagates along the entire gastrointestinal tract in waves. Note that peristalsis is not restricted to the gastrointestinal tract: it is a common feature of hollow, muscular tube-like organs. Thus, peristaltic waves are also present in the urinary tract (***ureters***), the ***biliary tract*** and in the ***ducts*** of most major glands of the body.

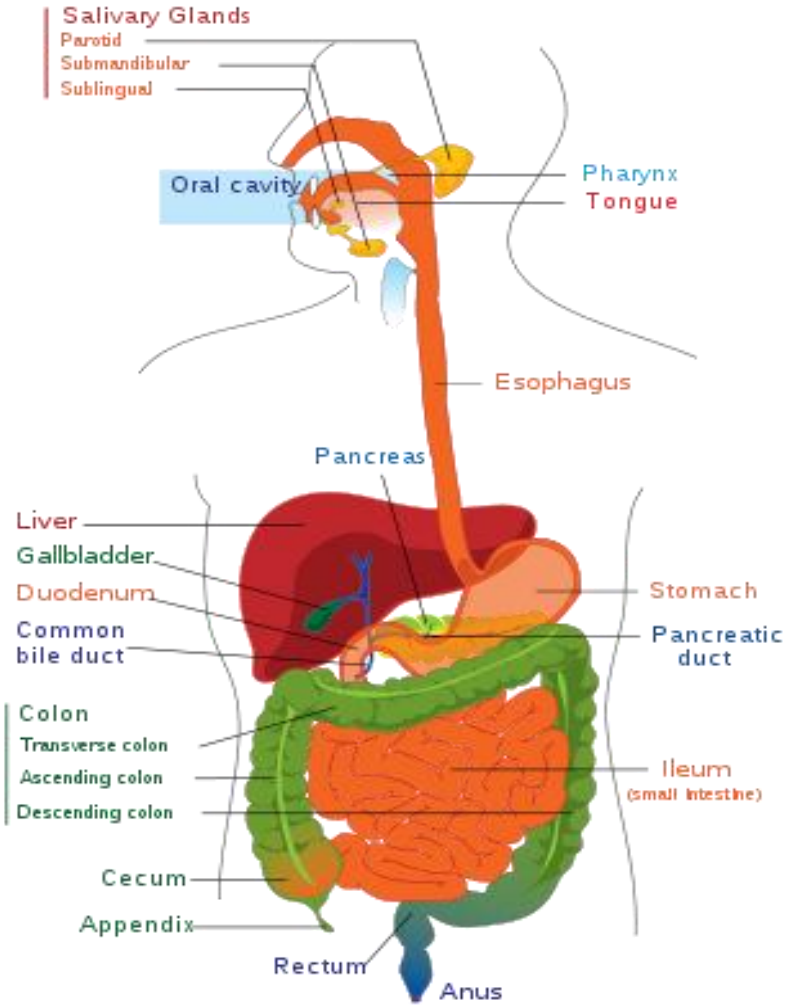

Fig 8.1 Overview of the gastrointestinal tract.

The mouth.

The mouth is the “reception” of food and liquids. It has strong muscular and bony walls and features the **teeth**, which are responsible for the initial breakdown of food into smaller parts that can be swallowed. The **oral vestibule** is the anterior limit of the **oral cavity**, lined by the **dental arches**. Here the food is grinded (masticated) by the teeth and mixed by the **tongue** with saliva. **Saliva** is produced by the salivary glands (the **parotid** gland, the **sublingual** glands and the **submaxillary** glands). It consists of water and enzymes, mainly ptyalin (α-amylase) which is responsible for the enzymatic breakdown of *starches*. Once the food is chewed and mixed it forms a softer ball called ***bolus***. This is swallowed by movements of the tongue, the **palate** and the **upper pharynx**, which coordinate their movements in a way that the food will be directed to the lower part of the pharynx and the **esophagus**. At that point respiration is automatically interrupted, in order to prevent accidental passage of food into the **larynx**.

Proper chewing is very important in digestion. First, it breaks down food into smaller bites that can be easily swallowed. That in turn allows for better mixing of food with the salivary enzymes and mucous, that further aids passage through the esophagus. Moreover, proper digestion depends on the surface of the food that comes in contact with the gastric and intestinal juice. It is therefore critical that mastication (chewing) is as thorough (and slow) as possible.

The esophagus.

This is a 25-30 cm long muscular tube that connects the **pharynx** to the **stomach**. The esophagus is not very elastic because it lies in the thoracic cavity under **tension**. This tension aids ingestion and also prevents backflow from the stomach. This is accomplished by the formation of a *functional* sphincter at the entrance of the stomach, the g**astroesophageal sphincter**. This sphincter is very important for preventing g**astroesophageal reflux**, thus protecting the inner lining of the esophagus from the destructive acids of the gastric juice. The inner lining of the esophagus is **stratified squamous epithelium**, just like the rest of epithelium that covers the oral and nasal cavities. However, it also features muciparous glands; production of **mucous** aids the movement of food bole towards the stomach by lubrication.

The nerve supply of the esophagus is through the vagal trunks (left and right **vagus** nerves) that also coordinate peristalsis. Once a food bole enters the esophagus, it can only move to one direction: to the stomach. As the food descends to the stomach, the last part of the esophagus (the gastroesophageal sphincter) relaxes ahead of the peristaltic wave, so that the bolus enters the stomach.

Note that food propelling through the esophagus is conducted by **peristalsis**. Although gravity may aid bole movement, we can still ingest food (or even liquids!) even when lying down or hanging upside down!

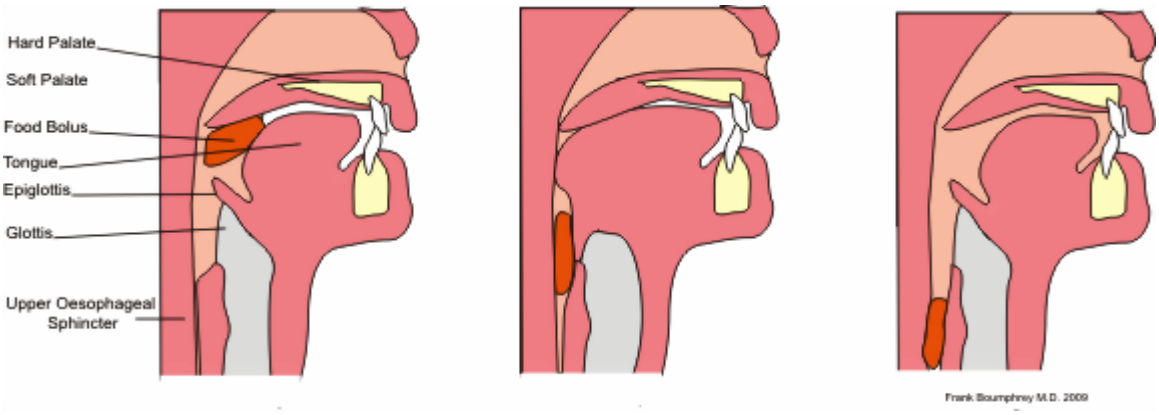

Fig. 8.2 The mouth and pharynx during swallowing.

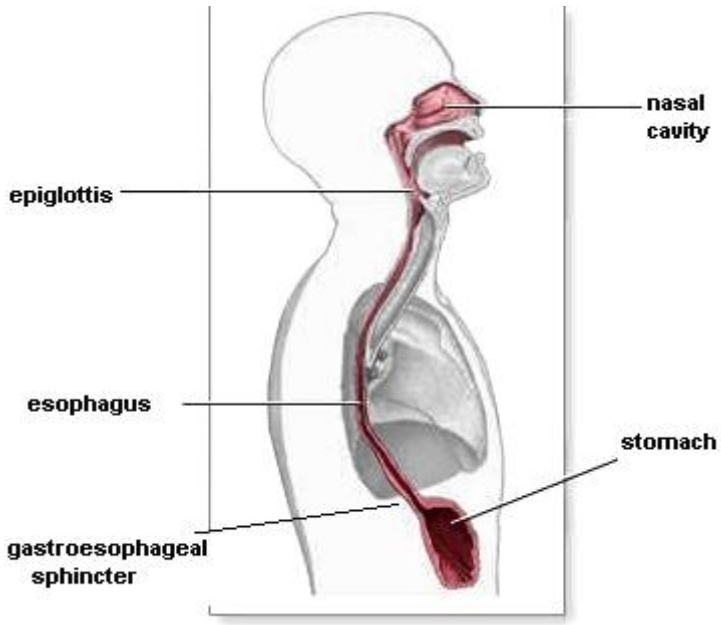

Fig. 8.3 The esophagus.

The stomach.

The stomach is a dilated "sack" of the alimentary tract, useful for storing, mixing and digesting food until the gastric contents are prepared to enter the small intestine as ***chyme***. This sack can normally hold about one and a half liter of food but it can gradually expand and accommodate much larger amounts. The walls of the stomach are muscular, comprising several layers: an **outer longitudinal**, a **middle circular** and a **deeper oblique layer**. This architecture allows for strong, multiple movements of the stomach that ensure that the food is well mixed.

The stomach can be divided into the following parts:

- **Fundus**: it is dome-shaped, the most upper part of the stomach.
- **Body**: the largest part of the stomach, from the fundus to the angled notch (incisura angularis).
- **Pyloric antrum**: the lowest part of the stomach.
- **Pylorus**: the narrow, tube-like part that leads to the duodenum through the pyloric sphincter.

The inner lining of the stomach is the **gastric mucosa** that is rich with **gastric glands**. These glands contain mainly 3 kinds of cells and produce enzymes and hydrochloric acid. The main enzyme produced by the **chief cells** is ***pepsinogen***, which is transformed to ***pepsin***, a protein-splitting enzyme, in the presence of HCl. ***Hydrochloric acid*** produced by the **parietal cells** is also vital for killing pathogens (microbes) that may enter the gastrointestinal tract by the food or water intake. Moreover, the gastric mucosa produces ***mucous*** by **goblet and mucous cells**; this film of mucous is protecting the inner lining of the stomach from self-destruction! The parietal cells that produce HCl are also the source of a substance called **intrinsic factor**, which aids absorption of **vitamin B_{12}**. Lack of the intrinsic factor leads to vitamin B_{12} deficiency and **anemia** (*pernicious anemia*). Other hormones produced by gastric glands include *glucagon* and *serotonin*.

Secretion of gastric juice can occur even with empty stomach: this is called the **cephalic phase**. It is regulated by ***parasympathetic*** impulses in the vagus nerves in response to eg sight of food, a nice smell or taste. When (eventually) food will reach the stomach, the distention of the mucosa will further stimulate the release of a hormone called **gastrin**, which in turn will increase the production of gastric juice (**gastric phase**). Finally, when chyme enters the ***duodenum***, small quantities of gastric juice are further produced (**intestinal phase**).

Gastric ulcers are erosions of the gastric mucosa that may cause painful symptoms and even bleeding in the stomach. They are usually caused by overproduction of hydrochloric acid and pepsinogen in conjunction with diminished mucous production. Thus the protective layer of the gastric mucosa is affected and the acid is eroding the mucosa, causing **inflammation**. However, it is not simply a chemical imbalance. Today we believe that a strain of the **bacterium Helicobacter Pylori**, which is commonly present in the bacterial flora of the GI tract is responsible for the development of inflammation and, eventually, ulcers. Nowadays, gastric ulcers are treated with a combination of antibiotics and anti-acids.
Ulcers frequently occur also in the duodenum (**duodenal ulcers**). This situation is much more common that gastric ulcer and affects patients around their 30s, with lots of anxiety and frustration in their lives. This is usually caused by extreme vagal **parasympathetic stimulation** eg in chronic **stress** situations.

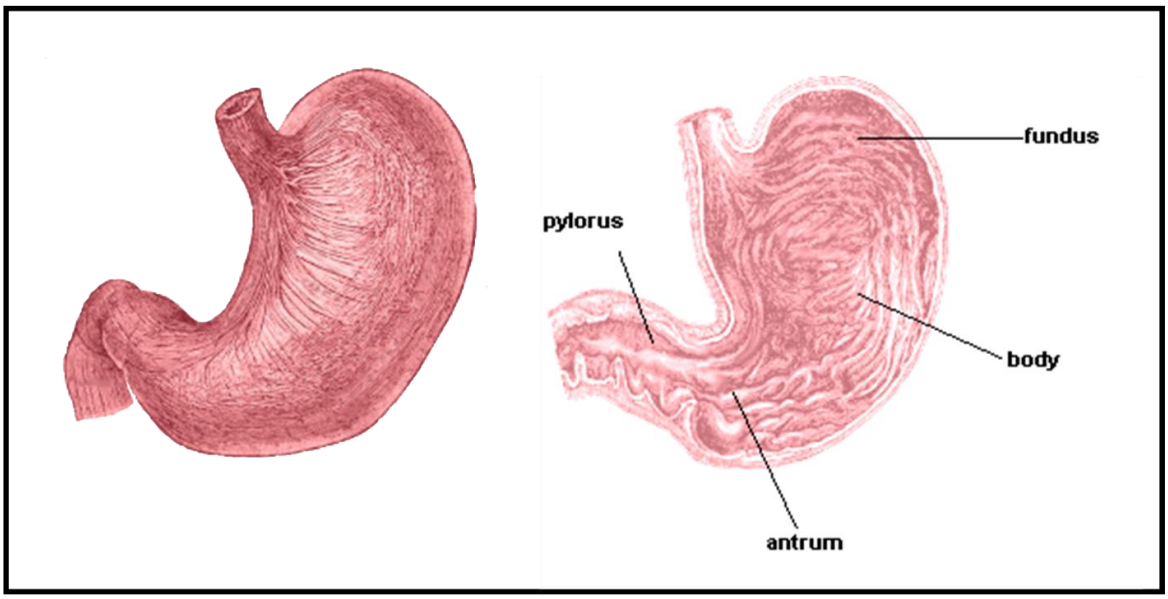

Fig. 8.4 The stomach (outer and inner surface).

The liver.

The liver is located at the upper right part of the abdominal cavity, just underneath the diaphragm. It is a large organ, the largest after the skin, weighing about 1.5 kg in the adult. Actually it is the biggest **gland** of the body, with very important functions. It is covered by peritoneum and attached to the diaphragm and abdominal wall by 4 peritoneal folds (**ligaments**). The liver has two **lobes** (right and left) that can be further separated in 8 **lobules**, according to their distinct arterial and venous supply.

The liver has many distinct roles and functions. The one related to digestion in the alimentary tract is the production of **bile**. The bile has a concentration of **bile salts** that allow for emulsification of neutral fats and the absorption of fatty acids, cholesterol and certain vitamins. The bile is secreted by the **liver cells,** collected in the **hepatic ducts** and stored in the **gallbladder**. When a fatty meal is consumed, large quantities of bile are expelled from the gallbladder into the **duodenum** through the **cystic duct** and the **bile duct**. The final part of the bile duct empties in the duodenum through a common duct (**hepatopancreatic ampulla**) with the pancreas. The **sphincter of Oddi** prevents backflow of duodenal contents into the bile and pancreatic ducts.

Other important functions of the liver include the production and storage of **glycogen** and **vitamins**, the synthesis of important blood **proteins** (albumin), removal and **killing of certain bacteria** from the blood circulation and **phagocytosis of old red cells**. Another very important liver function is the filtration and removal of **toxic substances in the blood.**

The great filtration capacity of the liver is based on its **unique blood supply**. The blood vessels that bring blood to the liver are the **hepatic arteries** and the **portal veins**. The arterial and venous blood is conducted to the central vein of each liver lobule by the **liver sinusoids**. Here O2, nutrients and toxic substances are extracted by the hepatic cells. Then the blood leaves the liver and enters the circulation by the **hepatic veins** that empty into the **inferior vena cava**.
The blood from the portal vein comes from **capillaries** in the whole lower alimentary tract (stomach, small and large intestine). That means that every substance absorbed through the alimentary tract will have to pass through the liver first, before it enters the circulation. In this way the liver not only regulates the distribution of nutrients but also controls toxins, drugs and harmful substances.

The pancreas

The pancreas is a retroperitoneal organ (behind the peritoneal cavity), lying at the upper left quadrant of the abdomen. It is an important gland attached to the GI tract with two distinct functions: it produces **insulin** (*see: endocrine glands*) and secretes a **juice rich in enzymes** that hydrolyze fats (**lipase**), proteins (**peptidase**) and carbohydrates (**amylase**). A hormone called **cholecystokinin**, secreted by the intestinal wall when food (especially fats) is present, is responsible for both contraction of the gallbladder and increased secretion of pancreatic juice. The latter is carried through the pancreatic duct to the hepatopancreatic ampulla (see above) where it is expelled (by peristalsis) into the duodenum.

Obstruction of the bile duct by a **gallstone** at the ampulla level may cause increased pressure and reflux of bile into the pancreatic duct and inflammation of the pancreas (**pancreatitis**). If the gallstone gets impacted at a higher level in the bile duct, then the bile can not enter into the duodenum and refluxes into the hepatic ducts and eventually the liver sinusoids causing **jaundice** (yellow coloring of skin and the eye-white).

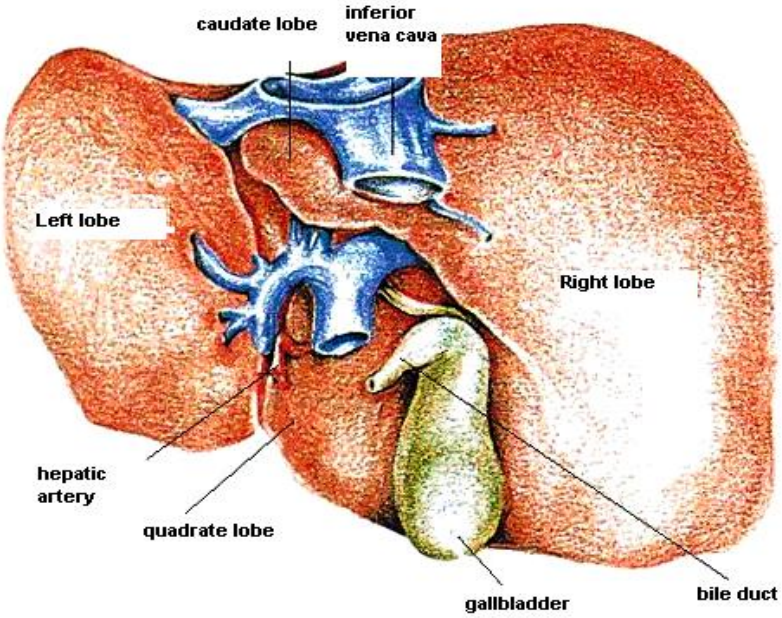

Fig. 8.6 The liver and gallbladder.

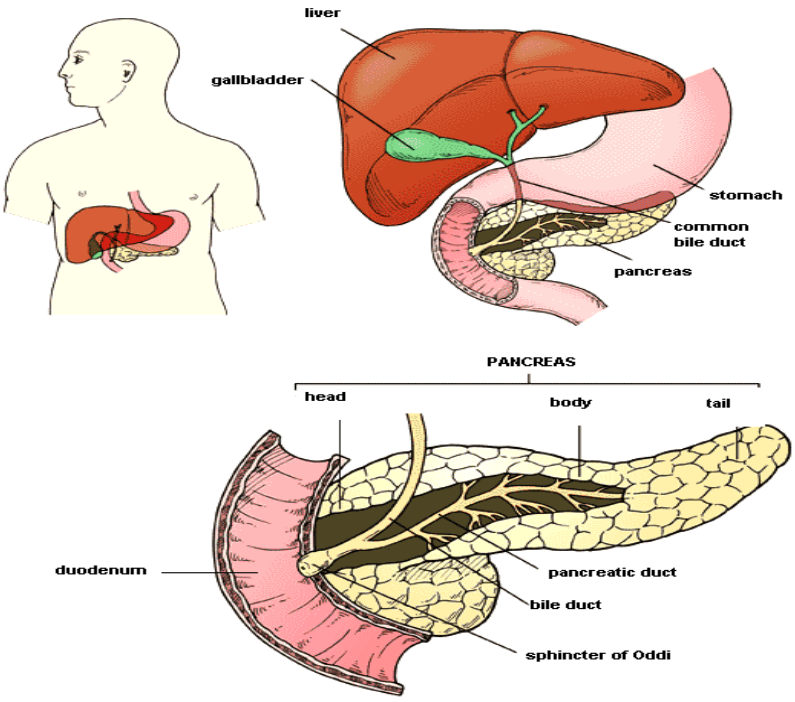

Fig. 8.7 The pancreas. pancreatic and hepatic ducts

The small intestine.

The small intestine begins right after the **pyloric sphincter**, with the C-shaped, approx. 25 cm long **duodenum**. The duodenum receives bile and pancreatic juice. The second part of the small intestine is the approx. 1.5-2m long **jejunum**, which is characterized by deep folds in the mucosa and submucosa. The next part, the **ileum** extends for approx. 2-2.5m up to the **ileocecal valve**, the point at which the small intestine is connected to the first portion of the large intestine (the cecum).

The small intestine is coiled inside the abdominal cavity, with the loops of intestine packed close together; however the **coils** move as peristaltic waves run through their length. The small intestine is the site of maximal **absorption** of nutrients. This is augmented by the structure of the intestinal wall lining which features **plications** (plicae), with numerous finger-like projections of the mucosa, called **villi**. Each villus contains a **capillary network** and a **lymph vessel**; it is through these vessels that absorption of food molecules is accomplished.

The large intestine (colon).

The first part of the large intestine is called **cecum**. The **ileocecal valve** allows unidirectional passage of chyme to the cecum and prevents backflow of the contents of the cecum into the ileum. This is important because the ***bacterial flora*** in the large intestine is quite rich, compared to the limited flora of the small intestine. From the cecum extends the **vermiform appendix**, a projection of the intestine rich in lymphatic tissue that may serve to resist infections. The colon then continues as **ascending, transverse and descending colon** down to the **sigmoid colon** and **rectum**. The terminal opening is at the **anal canal** and the **anus**, which in turn presents two valve mechanisms that prevent leakage of stools.

Appendicitis is the inflammation of the vermiform appendix. It is a common inflammation of the abdominal area, occurring at all ages but especially in young people. The appendix is rich in **lymphoid tissue** in its wall. Bacteria, viruses or acute obstruction of its narrow lumen by feces may cause an acute **inflammation**. The distention of the appendix is causing severe **pain** in the abdomen while if the inflammation goes unnoticed, there is danger of rupture of the appendix and generalized **peritonitis**.

The **diameter** of the colon is quite larger than the small intestine, however the lining of the colon *does not have plications* like the small intestine does. This is because the colon is not responsible for nutrient absorption. Its main function is to **absorb water, electrolytes and vitamins**. The undigested waste from the ileum is thus dehydrated and stools (**feces**) are formed. When the **rectum** is full of stools activation of a neural reflex (**defecation reflex**) is causing movement of the bowel in order to expel the stools (feces) through the anal canal. This is due to stimulation of **stretch receptors** in the rectal wall. Increasing abdominal pressure by straining aids defecation.

The **movements** of the large intestine are **slower** that those of the small intestine. Stools are slowly formed as water is being absorbed by the mucosa. However, certain ***irritating factors*** may cause abrupt and frequent spasms of the colon, leading in quick passage of watery, loose content through the lumen before any water gets absorbed. This is called **diarrhea** and can be provoked by many factors such as microbes, viruses, toxins and chemical substances. Persistent diarrhea is causing an excess loss in water and electrolytes which, if not replenished by oral intake, may lead to **dehydration**, **electrolyte imbalance** and death. This is common with **cholera**, a type of diarrhea caused by the bacterium *Vibrio Cholerae*.

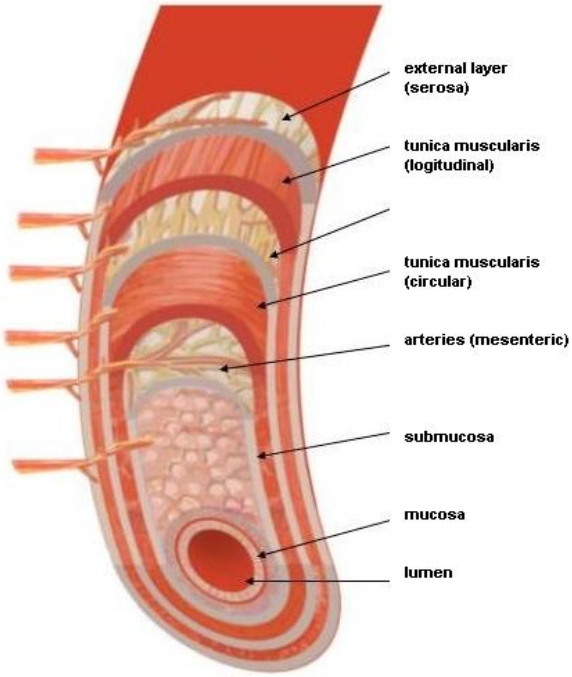

Fig. 8.8 The wall layers of the small intestine.

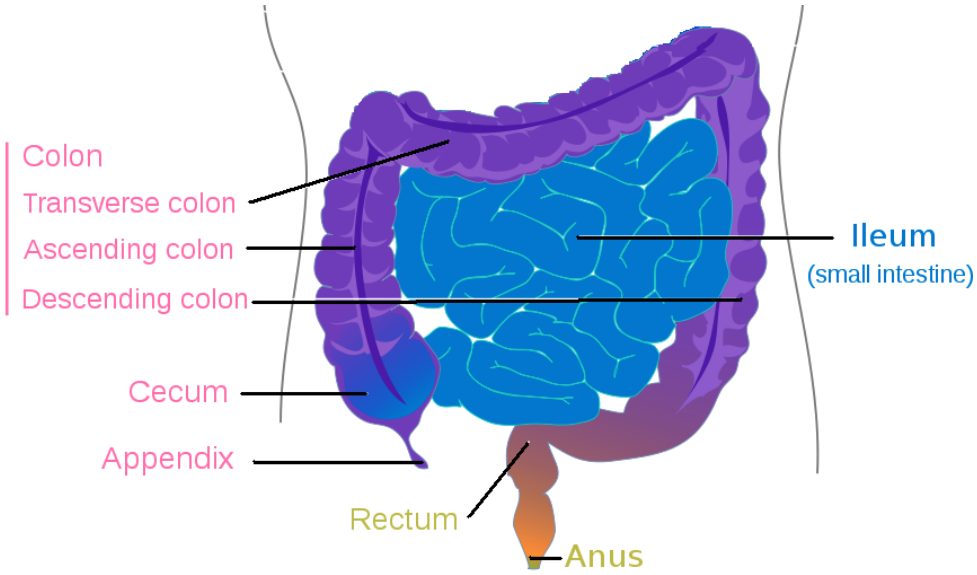

Fig.8.9 The large intestine (the colon).