Zonation and Functions of the GI Tract

A. <u>The Mouth</u>

The mouth is the opening of the GI tract. It receives food, tastes it and prepares it for swallowing. The average volume of the adult mouth is 72ml in men and 55ml in women. It is lined by mucous membranes and consists of two major regions:

i. Vestibule – the space between the inner surface of the cheeks/lips and the teeth;
ii. Oral cavity proper – the space beyond the teeth, largely occupied by the tongue, where food is chewed and mixed with saliva before being swallowed.

Salivary glands

The mouth has three pairs of salivary glands, all innervated by the parasympathetic branch of the autonomic nervous system:

i. Sublingual glands – located below the tongue;
ii. Submandibular glands – located below the mandible;
iii. Parotid glands – located to the side of the earlobes.

B. <u>The oesophagus</u>

The oesophagus, around 25cm in length, connects the mouth to the stomach via the pharynx. The oesophagus secretes large amounts of mucus that act as a lubricant, ensuring the smooth transit of the food bolus.

After having been swallowed, the food bolus passes through the upper oesophageal sphincter (UOS), stretching the oesophageal wall and triggering peristalsis. The UOS closes rapidly and tightly to prevent regurgitation of food into the pharynx and mouth. The transit time of food through the oesophagus varies according to factors such as age, health and the nature of the food consumed, but is typically 6-15 seconds.

Once the food bolus reaches the lower portion of the oesophagus, the lower oesophageal sphincter (LOS) dilates, allowing it to pass into the stomach. The LOS (also called the cardiac sphincter due to its proximity to the heart) closes as soon as the bolus enters the superior portion of the stomach to prevent regurgitation of highly acidic gastric juices into the oesophagus.

The oesophagus is the first portion of the GI tract in which the four layers of the gut wall – the mucosa, submucosa, muscularis and serosa – are recognisable.

C. <u>Stomach</u>

The stomach, located in the upper left quadrant of the abdomen, is a J-shaped organ composed predominantly of involuntary smooth muscle. A bolus of food enters the stomach through the lower oesophageal sphincter, which rapidly closes to prevent regurgitation of gastric secretions.

Anatomically, the stomach is divided into three main regions:

i. Fundic region or fundus – top left, dome-shaped region;
ii. Stomach body – the expansive main stomach chamber;
iii. Pyloric region or pylorus – funnel-shaped lower region connecting the stomach and duodenum.

A typical adult human stomach is around 30.5cm long and 15.2cm wide, with an average capacity of around 1.5L. It acts simultaneously as a reservoir for ingested food and a mixing and digestion chamber. The inner mucosal lining of the stomach has prominent folds, the rugae, which allow it to expand to up to 50 times its empty volume.

Gastric pits

The mucosal lining of the stomach contains around 35 million small depressions, the gastric pits, which produce around 2L of gastric juice per day. Gastric pits are lined by the following secretory cells:

i. **Mucous (or goblet) cells** They produce copious amounts of mucus, protecting the delicate mucosal lining of the stomach. They are found across the mucosal epithelial lining and deeper within each gastric pit, where they are known as mucous neck cells.
ii. **Parietal cells** They secrete hydrochloric acid (HCl) and intrinsic factor. HCl is a component of gastric juice, which not only supports chemical digestion but also activates the enzyme pepsin. It is produced at high concentrations, giving the stomach a pH of around 2.5-3.5; this high acidity helps the stomach sterilise ingested food. IF is a small protein that binds to vitamin B12 and transports it across the wall of the intestine into the blood.
iii. **Chief cells** They secrete the inactive enzyme precursor pepsinogen, which is converted into the active enzyme pepsin upon exposure to HCl. Pepsin plays a role in protein digestion and enhances the bacterial killing activity of HCl. Chief cells also secrete gastric lipase, which, together with salivary lipase, initiates fat digestion.
iv. **Endocrine cells** They synthesise various hormones and release them into the blood. As an example, endocrine cells called G cells produce the hormone gastrin, which regulates the secretion of gastric juice. Other endocrine cells called P/D1 cells release the hunger hormone ghrelin, which plays a role in regulating appetite and food intake.

Functions

1. Protein digestion

The process of protein digestion starts in the stomach. HCl slowly denatures proteins (for example, actin and myosin from meat), causing structural changes that expose the peptide bonds between adjacent amino acids. This enhances subsequent chemical digestion by proteases. Activated pepsin present in the gastric juice cleaves the initial protein molecules (which can consist of thousands of amino acids) into smaller chains called polypeptides. Pepsin is referred to as an endopeptidase because it acts predominantly by attacking the peptide bonds in the centre of proteins to create polypeptides, which are further broken down in subsequent regions of the GI tract

2. Fat digestion

In the stomach, fat digestion is amplified by gastric lipase, which is synthesised by the chief cells. Gastric lipase remains stable and active over a broad pH range (2-7); like salivary lipase, however, it functions optimally at a pH of 4-5.4 and so achieves its maximal efficiency in the stomach.

3. Formation of chyme

When food is present, the muscular layer of the stomach wall – known as the muscularis – undergoes regular rhythmic contractions that help mix the food with the gastric secretions to speed up the process of chemical digestion. The muscularis consists of the same circular and longitudinal layers of smooth muscle found in other gut regions, but it also possesses an additional inner layer of oblique smooth muscle fibres. These three layers of muscle allow the stomach to perform the vigorous churning motions that are essential for efficient mechanical digestion. Gradually, most solid pieces of food are mechanically and chemically digested, resulting in a semi-solid, thick and soupy material called chyme.

4. Passage of chyme into the duodenum

The pylorus connects the stomach directly to the duodenum, which forms the first segment of the small intestine. At regular intervals – typically every 20 seconds – the pyloric sphincter (a small ring of smooth muscle) dilates to allow small portions of acidic chyme to pass into the duodenum. A slow, gradual release of chyme is essential to allow time for the acidic contents of the stomach to be neutralised by alkaline pancreatic juice before they reach the small intestine.

5. Food absorption

Simple sugars such as glucose, galactose and fructose are readily absorbed in stomach, particularly when in high concentration. The stomach is excellent at absorbing water, taking approximately 20 minutes to absorb 50% of the ingested volume of water.

6. Hunger and satiety

When the stomach is empty, P/D1 cells of the gastric pits release the peptide hormone ghrelin. Ghrelin is often referred to as the ‘hunger hormone’, as it circulates in the blood and interacts with receptors in the hypothalamus and other regions of the brain to promote powerful sensations of hunger.

D. Small Intestine

The small intestine consists of duodenum, jejunum and Ilium.

1. Duodenum

The duodenum is U-shaped and approximately 25-38cm long. It consists of four regions:

i. Superior region: an enlarged upper area of around 2cm called the duodenal bulb, which continues the pyloric sphincter and is connected to the liver by the hepatoduodenal ligament.
ii. Descending region: this extends downwards into the abdominal cavity from the superior duodenal flexure; approximately halfway down is the major duodenal papilla, the entry point of the common bile duct and pancreatic duct, which fuse before entering the duodenum. The entry of bile and pancreatic juice into the duodenum is regulated by a small ring of muscle, the sphincter of Oddi.
iii. Horizontal or transverse region: the largest section of the duodenum (10-12cm long) and the main area of mineral absorption.
iv. Ascending region: this passes slightly upwards into the abdominal cavity before connecting to the jejunum at the duodenojejunal flexure.

2. Jejunum

The jejunum makes up two-fifths of the total length of the small intestine and is about 0.9m in length. It starts at the duodenojejunal flexure and ends at the ileum. There is no clear border between the jejunum and the ileum. Histologically, the jejunum differs from the rest of the small intestine by the absence of Brunner’s glands and Peyer’s patches. A vast surface area is a prerequisite for the optimal absorption of nutrients, so the wall of the jejunum contains the following features that increase its surface area:

i. Circular folds;
ii. Villi;
iii. Microvilli.

3. Ileum

The ileum is the longest part of the small intestine, making up about three-fifths of its total length. It is thicker and more vascular than the jejunum, and the circular folds are less dense and more separated. At the distal end, the ileum is separated from the large intestine by the ileocaecal valve, a sphincter formed by the circular muscle layers of the ileum and caecum, and controlled by nerves and hormones. The ileocaecal valve prevents reflux of the bacteria-rich content from the large intestine into the small intestine. The ileum is rich in immune tissue (lymphoid follicles). A characteristic feature is Peyer's patches, found lying in its mucosa, which are an important part of gut-associated lymphoid tissue. One Peyer's patch is around 2-5cm long and consists of around 300 aggregated lymphoid follicles. These are concentrated in the distal ileum and serve to keep bacteria from entering the bloodstream.

Peyer's patches are most prominent in young people and become less distinct with age, which reflects the age-related reduction in activity of the gut's immune system.

Functions of the Duodenum

1. **Digestion**

The duodenum is primarily a region of chemical digestion. It receives secretions from the liver and pancreas, and its mucosa contains large numbers of mucus-producing (goblet) cells and Brunner's glands, which secrete a watery fluid that is rich in mucus and bicarbonate ions. As in the stomach, mucus acts as a protective barrier against autodigestion and lubricates the passage of chyme.

2. **Hormone production in the duodenum**

The pyloric sphincter, which separates the stomach and duodenum, periodically opens to release small portions of acidic chyme. This sudden increase in acidity stimulates the release of several hormones including:

i. Secretin
ii. Cholecystokinin
iii. Gastric inhibitory polypeptide
iv. Vasoactive intestinal peptide

3. **Absorption**

The mucosal lining of the duodenum also contains tall columnar epithelial cells and extends into circular folds and finger-like projections (villi), which increase the surface area for nutrient absorption.

Functions of Jejunum and Ileum:

1. **Digestion and Absorption of Food**

The main function of the jejunum and ileum is to finish chemical digestion and absorb these nutrients along with water and vitamins. Each day, approximately 8L of water (from dietary ingestion as well as GI tract secretions and juices, including saliva), several hundred grams of carbohydrates, ≥100g of fat, 50-100g of amino acids and 50-100g of salt ions pass through the wall of the small intestine and into the blood. The transport of nutrients across the membranes of the intestinal epithelial cells into the villi, and subsequently into blood capillaries and lacteals, occurs either passively or actively. Water and some vitamins can cross the gut wall passively. In addition, certain molecules – such as glucose, amino acids and vitamin B12 – have their own carriers or transporters, which they use to get absorbed across the gut wall into the bloodstream.

2. **Movement towards the Large Intestine**

When most of the chyme has been absorbed, the walls of the small intestine become less distended and segmentation gives way to peristalsis, which helps move unabsorbed matter along towards the large intestine. With each repeated peristaltic contraction, chyme and waste slowly move down the small intestine. When motility in the ileum increases, the ileocaecal valve relaxes, allowing food residue to enter the large intestine at the caecum.

E. **The Large Intestine**

The large intestine is approximately 1.5m long and comprises the following parts:

1. Caecum and appendix

The caecum is about 6cm long and extends downwards into the appendix, a winding tubular sac containing lymphoid tissue. The appendix is thought to be the vestige of a redundant organ; its narrow and twisted shape makes it an attractive site for the accumulation and multiplication of intestinal bacteria.

2. Colon

At its other end, the caecum seamlessly joins up with the colon, this is the longest portion of the large intestine. Food residue starts by travelling upwards through the ascending colon, located on the right side of the abdomen. The ascending colon bends near the liver at the right colic flexure (or hepatic flexure) and becomes the transverse colon, passing across to the left side of the abdomen. Just above the spleen at the left colic flexure (or splenic flexure), the transverse colon becomes the descending colon, which runs down the left side of the abdomen. Before the next bend, the descending colon transforms into the sigmoid colon.

The colon has a segmented appearance; its segments, which are caused by sacculation, are called haustra. The ascending colon, descending colon and rectum are located in the retroperitoneum (outside the peritoneal cavity). The transverse and sigmoid colon are attached to the posterior abdominal wall by the mesocolon.

3. Rectum, anal canal and anus

Distally, the large intestine opens into the rectum, which is continued by the anal canal. The rectum forms the final 20cm of the GI tract. It is continuous with the sigmoid colon and connects with the anal canal and anus. The rectum ends in an expanded section called the rectal ampulla, where faeces are stored before being released; the rectum is usually empty since faeces are not normally stored there for long.

The anal canal located in the perineum (outside the abdominopelvic cavity), is 3.8-5cm long and opens to the exterior of the body at the anus. It has two sphincters:

i. Internal anal sphincter, which is controlled by involuntary muscles;
ii. External anal sphincter, which is made of skeletal muscle and is under voluntary control.

Except during defecation, both anal sphincters normally remain closed.

Functions of the large intestine

The large intestine has three major functions:

1. **Absorption of water and electrolytes**

i. The presence of food residues in the colon stimulates haustral contractions, which occur approximately every 30 minutes and last about one minute each. With each contraction, each haustrum distends and contracts, pushing the food residues into the next haustrum. The contractions also mix the food residues, thereby facilitating the absorption of water.
ii. The large intestine also absorbs electrolytes. Sodium ions are actively absorbed by the action of the odium/potassium pump; this moves sodium and potassium ions in opposite directions across cell membranes, fostering sodium absorption and potassium loss by releasing the hormone aldosterone.
iii. Antiperistaltic contractions move food residues back towards the ileocaecal valve, slowing transit down and giving more time to the large intestine to absorb water and electrolytes.

2. **Formation and transport of faeces**

i. Of every 500ml of food residue that enters the caecum each day, about 150ml become faeces. These contain mostly bacteria, old epithelial cells from the intestinal mucosa, inorganic waste, undigested food matter and fibre, as well as water to help it pass smoothly through the GI tract. They also contain small quantities of fats and proteins. Their characteristic brown colour is due to the presence of stercobilin and urobilin, breakdown products of haemoglobin from old red blood cells.
ii. Since chyme residue lingers in the large intestine for 12-24 hours, most of the 1.5L of fluid entering the large intestine every day is absorbed, leaving less than 100ml to pass out in the faeces. This small quantity of fluid gives faeces their semi-solid consistency. Faeces are also softened by dietary fibre. Mucus, secreted by goblet cells lining the entire colon, helps to bind dehydrated chyme and also lubricates the passage of faeces.

3. Chemical digestion by gut microbes

The large intestine does not secrete its own digestive enzymes: in this part of the GI tract, chemical digestion occurs exclusively through the action of millions of colonic bacteria. Through fermentation, these bacteria break down some of the remaining carbohydrates, which releases the hydrogen, carbon dioxide and methane that create flatus (gas). Colonic bacteria also protect the intestine from potentially harmful bacteria coming from the external environment and can synthesise certain vitamins. Their role will be more fully explored in part 6 of this series.