digestive system part 2 (The Small Intestine)

Chyme released from the stomach enters the **small intestine**, which is the primary digestive organ in the body. Not only is this where most digestion occurs, it is also where practically all absorption occurs. The longest part of the alimentary canal, the small intestine is about 3-7 meters long in a living person (but about twice as long in a cadaver due to the loss of muscle tone). Since this makes it about five times longer than the large intestine, you might wonder why it is called "small." In fact, its name derives from its relatively smaller diameter of only about 2.54 cm (1 in), compared with 7.62 cm (3 in) for the large intestine. As we'll see shortly, in addition to its length, the folds and projections of the lining of the small intestine work to give it an enormous surface area, which is approximately 200 m^2, more than 100 times the surface area of your skin. This large surface area is necessary for complex processes of digestion and absorption that occur within it.

Parts

The small intestine is divided into three structural parts.

- The **duodenum** is a short structure ranging from 20 cm (7.9 inches) to 25 cm (9.8 inches) in length, and shaped like a "C". It surrounds the head of the pancreas. It receives gastric chyme from the stomach, together with digestive juices from the pancreas(digestive enzymes) and the liver (bile). The digestive enzymes break down proteins and bile emulsifies fats into micelles. The duodenum contains Brunner's glands, which produce a mucus-rich alkaline secretion containing bicarbonate. These secretions, in combination with bicarbonate from the pancreas, neutralize the stomach acids contained in gastric chyme.
- The **jejunum** is the midsection of the small intestine, connecting the duodenum to the ileum. It is about 2.5 m long, and contains the plicae circulares, and villi that increase its surface area. Products of digestion (sugars, amino acids, and fatty acids) are absorbed into the bloodstream here. The suspensory muscle of duodenum marks the division between the duodenum and the jejunum.
- The **ileum**: The final section of the small intestine. It is about 3 m long, and contains villi similar to the jejunum. It absorbs mainly vitamin B12 and bile acids, as well as any other remaining nutrients. The ileum joins to the cecum of the large intestine at the ileocecal junction.

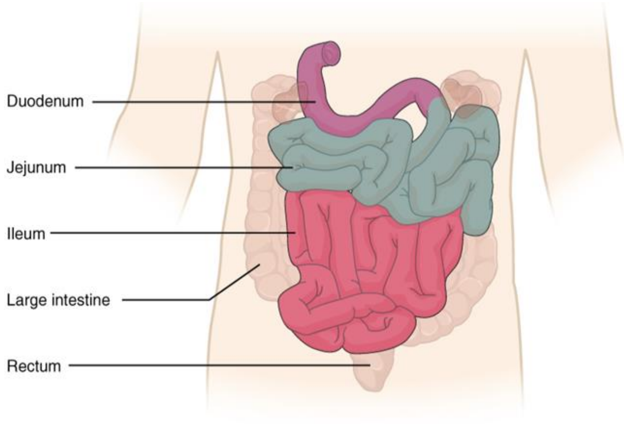

Figure 1. Small Intestine. The three regions of the small intestine are the duodenum, jejunum, and ileum.

The wall of the small intestine is composed of the same four layers typically present in the alimentary system. However, three features of the mucosa and submucosa are unique. These features, which increase the absorptive surface area of the small intestine more than 600-fold, include circular folds, villi, and microvilli (Figure 2). These adaptations are most abundant in the proximal two-thirds of the small intestine, where the majority of absorption occurs.

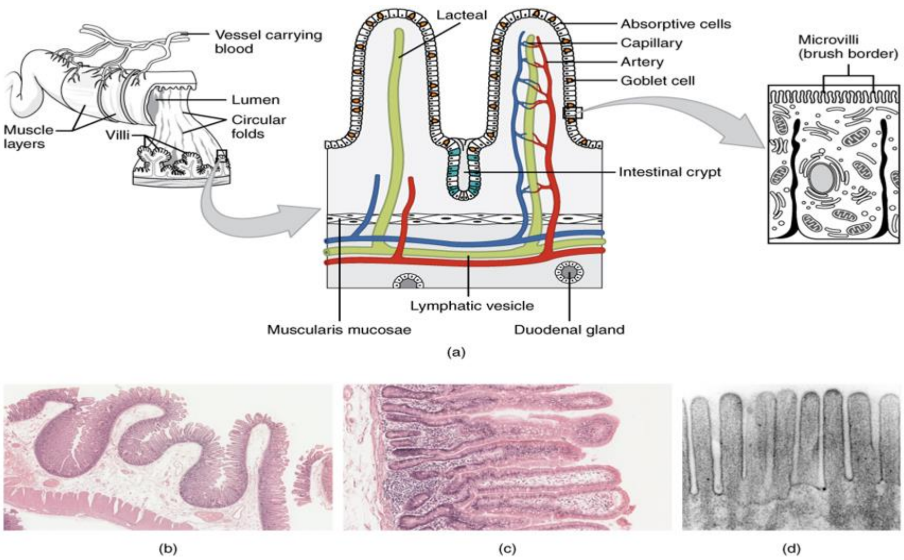

Figure 2. Histology of the Small Intestine. (a) The absorptive surface of the small intestine is vastly enlarged by the presence of circular folds, villi, and microvilli. (b) Micrograph of the circular folds. (c) Micrograph of the villi. (d) Electron micrograph of the microvilli. From left to right, LM x 56, LM x 508

Intestinal Glands

In addition to the three specialized absorptive features just discussed, the mucosa between the villi is dotted with deep crevices that each lead into a tubular **intestinal gland** (crypt of Lieberkühn), which is formed by cells that line the crevices (see Figure 2). These produce **intestinal juice**, a slightly alkaline (pH 7.4 to 7.8) mixture of water and mucus. Each day, about 0.95 to 1.9 liters (1 to 2 quarts) are secreted in response to the distention of the small intestine or the irritating effects of chyme on the intestinal mucosa. The submucosa of the duodenum is the only site of the complex mucus-secreting **duodenal glands**(Brunner's glands), which produce a bicarbonate-rich alkaline mucus that buffers the acidic chyme as it enters from the stomach.

The roles of the cells in the small intestinal mucosa are detailed in Table bellow.

Cells of the Small Intestinal Mucosa		
Cell type	**Location in the mucosa**	**Function**
Absorptive	Epithelium/intestinal glands	Digestion and absorption of nutrients in chime
Goblet	Epithelium/intestinal glands	Secretion of mucus
Paneth	Intestinal glands	Secretion of the bactericidal enzyme lysozyme; phagocytosis
G cells	Intestinal glands of duodenum	Secretion of the hormone intestinal gastrin

Cells of the Small Intestinal Mucosa		
Cell type	**Location in the mucosa**	**Function**
I cells	Intestinal glands of duodenum	Secretion of the hormone cholecystokinin, which stimulates release of pancreatic juices and bile
K cells	Intestinal glands	Secretion of the hormone glucose-dependent insulinotropic peptide, which stimulates the release of insulin
M cells	Intestinal glands of duodenum and jejunum	Secretion of the hormone motilin, which accelerates gastric emptying, stimulates intestinal peristalsis, and stimulates the production of pepsin
S cells	Intestinal glands	Secretion of the hormone secretin

Digestion in the Small Intestine

Mechanical Digestion:

The movement of intestinal smooth muscles includes both segmentation and a form of peristalsis called migrating motility complexes. The kind of peristaltic mixing waves seen in the stomach are not observed here.

Chemical digestion

The small intestine is where most chemical digestion takes place. Many of the digestive enzymes that act in the small intestine are secreted by he pancreas and liver and enter the small intestine via the pancreatic duct.

The three major classes of nutrients that undergo digestion are proteins, lipids (fats) and carbohydrates:

- Proteins are degraded into small peptides and amino acids before absorption. Chemical breakdown begins in the stomach and continues in the small intestine. Proteolytic enzymes, including trypsin and chymotrypsin, are secreted by the pancreas and cleave proteins into smaller peptides. Carboxypeptidase, which is a pancreatic brush border enzyme, splits one amino acid at a time. Aminopeptidase and dipeptidase free the end amino acid products.

- Lipids (fats) are degraded into fatty acids and glycerol. Pancreatic lipase breaks down triglycerides into free fatty acids and monoglycerides. Pancreatic lipase works with the help of the salts from the bile secreted by the liver and stored in the gall bladder. Bile salts attach to triglycerides to help emulsify them, which aids access by pancreatic lipase. This occurs because the lipase is water-soluble but the fatty triglycerides are hydrophobic and tend to orient towards each other and away from the watery intestinal surroundings. The bile salts emulsify the triglycerides in the watery surroundings until the lipase can break them into the smaller components that are able to enter the villi for absorption.

- Some carbohydrates are degraded into simple sugars, or monosaccharides (e.g., glucose). Pancreatic amylase breaks down some carbohydrates (notably starch) into oligosaccharides. Other carbohydrates pass undigested into the large intestine and further handling by intestinal bacteria. Brush border enzymes take over from there. The most important brush border enzymes are dextrinase and glucoamylase, which further break down oligosaccharides. Other brush border enzymes are maltase, sucrase and lactase. Lactase is absent in some adult humans and, for them, lactose (a disaccharide), as well as most polysaccharides, is not digested in the small intestine. Some carbohydrates, such as cellulose, are not digested at all, despite being made of multiple glucose units. This is because the cellulose is made out of beta-glucose, making the inter-monosaccharidal bindings different from the ones present in starch, which consists of alpha-glucose. Humans lack the enzyme for splitting the beta-glucose-bonds, something reserved for herbivores and bacteria from the large intestine.

Absorption

Digested food is now able to pass into the blood vessels in the wall of the intestine through either diffusion or active transport. The small intestine is the site where most of the nutrients from ingested food are absorbed. The inner wall, or mucosa, of the small intestine is lined with simple columnar epithelial tissue. Structurally, the mucosa is covered in wrinkles or folds called plicae circulares, which are considered permanent features in the wall of the organ. They are distinct from rugae which are considered non-permanent or temporary allowing for distention and contraction. From the plicae circulares project microscopic finger-like pieces of tissue called villi (Latin for "shaggy hair"). The individual epithelial cells also have finger-like projections known as microvilli. The functions of the plicae circulares, the villi, and the microvilli are to increase the amount of surface area available for the absorption of nutrients, and to limit the loss of said nutrients to intestinal fauna.

Each villus has a network of capillaries and fine lymphatic vessels called lacteals close to its surface. The epithelial cells of the villi transport nutrients from the lumen of the intestine into these capillaries (amino acids and carbohydrates) and lacteals (lipids). The absorbed substances are transported via the blood vessels to different organs of the body where they are used to build complex substances such as the proteins required by our body. The material that remains undigested and unabsorbed passes into the large intestine.

Absorption of the majority of nutrients takes place in the jejunum, with the following notable exceptions:

- Iron is absorbed in the duodenum.
- Folate (Vitamin B9) is absorbed in the duodenum and jejunum.
- Vitamin B12 and bile salts are absorbed in the terminal ileum.
- Water is absorbed by osmosis and lipids by passive diffusion throughout the small intestine.

- Sodium bicarbonate is absorbed by active transport and glucose and amino acid co-transport
- Fructose is absorbed by facilitated diffusion.