smell of food causes the brain to send nerve impulses via the vagus nerve from the medulla. Gland cells in the stomach wall are stimulated to secrete components of gastric juice. If chemoreceptors in the stomach wall detect peptides in the stomach contents or if stretch receptors detect distension of the stomach, impulses are sent to the brain. The brain responds by sending impulses via the vagus nerve to endocrine cells in the wall of the duodenum and the part of the stomach nearest to the duodenum, stimulating them to secrete gastrin. The hormone gastrin stimulates secretion of acid and pepsinogen by two types of exocrine gland cell in the stomach wall. Two other hormones, secretin and somatostatin, inhibit gastrin secretion if the pH in the stomach falls too low.

Exocrine glands

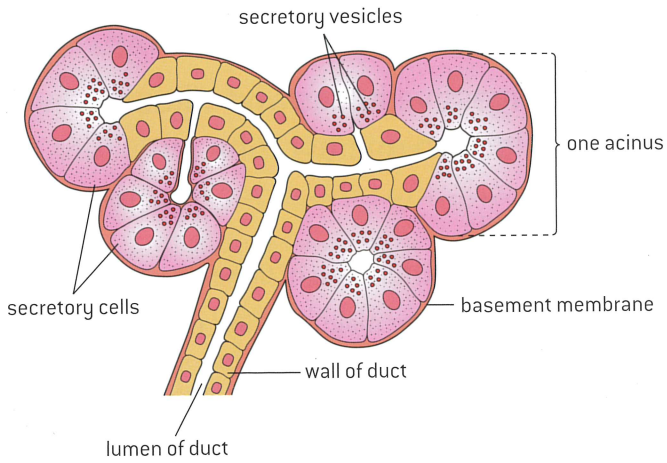
Exocrine glands secrete to the surface of the body or the lumen of the gut.

The passage through which food passes from mouth to anus is called the alimentary canal. Digestive juices are added to food in the alimentary canal at several points. Exocrine glands secrete the juices, including salivary glands, the pancreas, gland cells in the stomach wall and in the wall of the small intestine. The composition of the juices secreted by the glands is different, reflecting the processes that occur in each part of the alimentary canal (see table 1).

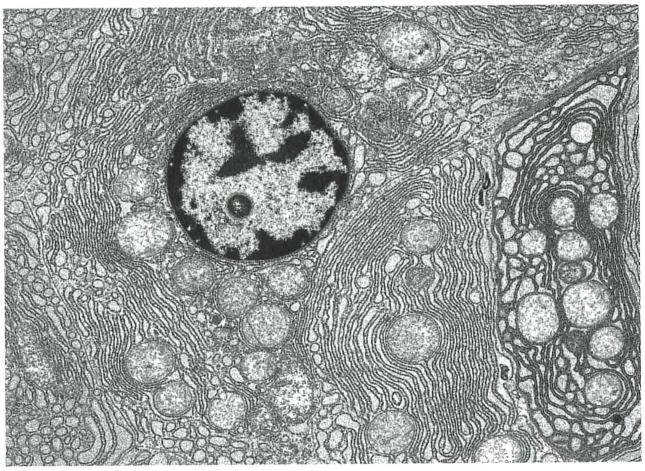
Digestive fluid	Source	Composition
saliva	salivary glands	water, electrolytes, salivary amylase, mucus, lysozyme
gastric juice	stomach	water, mucus, enzymes including pepsin, rennin and hydrochloric acid
pancreatic juice	pancreas	water, bicarbonate, enzymes including: amylase, lipase, carboxypeptidase, trypsinogen

▲ Table 1

Unlike endocrine glands, which secrete directly into the bloodstream, exocrine glands secrete into ducts. Figure 1 shows the arrangement of cells in part of an exocrine gland. Secretory cells are in groups around the duct branch. Each group of cells is called an acinus. The structure of the individual exocrine gland cells that secrete digestive enzymes is revealed in electron micrographs (figure 2). There is extensive endoplasmic reticulum for synthesis of enzymes. There are numerous mitochondria to provide ATP for protein synthesis and other cell activities. There are also large numbers of secretory vesicles containing enzymes. The process of exocytosis of these vesicles can sometimes be seen in progress where the plasma membrane of the cell is in contact with the duct.



▲ Figure 1 An exocrine gland



▲ Figure 2 An exocrine cell

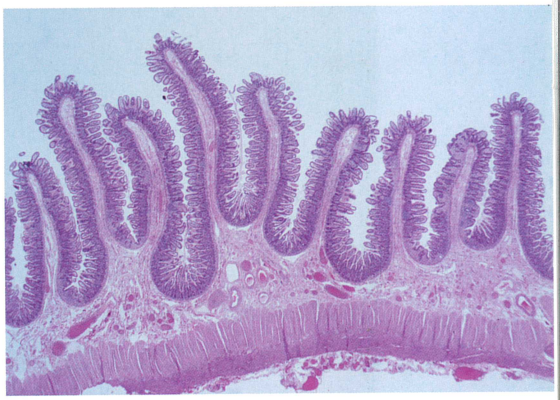
Adaptations of the villus

The structure of cells of the epithelium of the villi is adapted to the absorption of food.

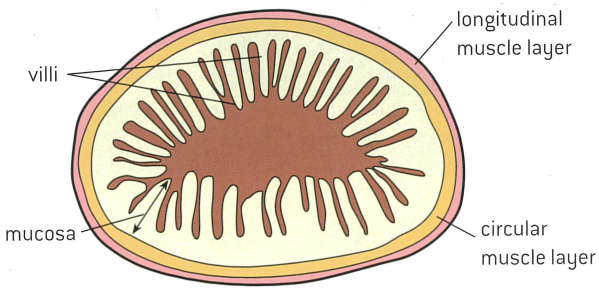
Figure 3 shows a longitudinal cross-section through the ileum, the site of a significant amount of the absorption that takes place in the small intestine.

The inner surface of the ileum has numerous folds. Each of the folds is covered in tiny projections called villi. Absorption takes place through the epithelial cells covering each villus.

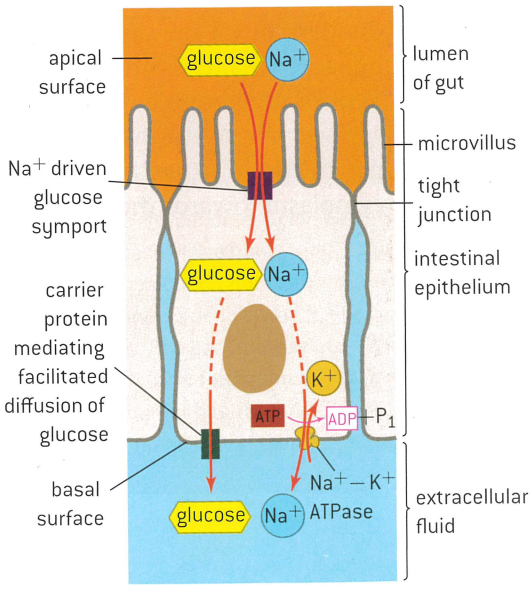
- Each epithelial cell covering the villus adheres to its neighbours through tight junctions, which ensure that most materials pass into the blood vessels lining the villi through the epithelial cell.
- The cell surface membrane on the intestinal lumen side has a number of extensions called microvilli. The collection of microvilli on the intestinal side of the epithelial cells is termed the brush border. The function of the brush border is to increase the surface area for absorption.
- Relatively high amounts of ATP are required to drive active transport processes. Thus epithelial cells have large numbers of mitochondria.
- Pinocytic vesicles are often present in large numbers due to absorption of some foods by endocytosis.
- The surface facing the lumen of the intestine is referred to as the apical surface and the surface facing the blood vessels is referred to as the basal surface. These surfaces have different types of proteins involved in material transport.



▲ Figure 3 Longitudinal section through the ileum wall



▲ Figure 4 Transverse section of ileum



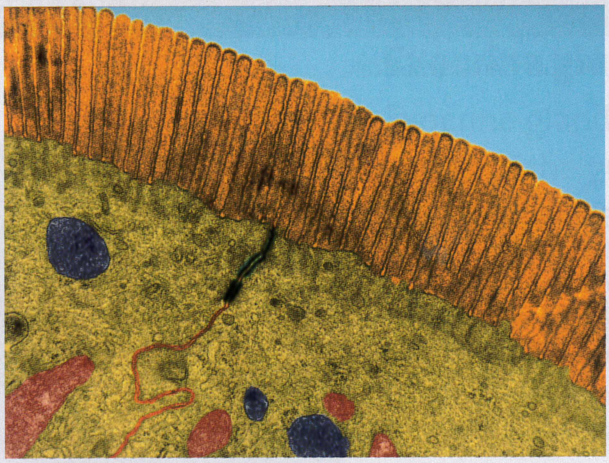
▲ Figure 5

Identification of exocrine glands

Identification of exocrine gland cells that secrete digestive juices and villus epithelium cells that absorb digested foods from electron micrographs.

Data-based questions: Adaptations of villus epithelium cells

The electron micrograph shows part of two villus epithelium cells. False colour has been used to distinguish between some of the structures that are present.



▲ Figure 6 Micrograph of villus epithelium cell

1 a) Identify the structures that have been coloured orange. [1]

b) Explain the function of these structures. [2]

c) Calculate the magnification of the electron micrograph, assuming that these structures are 0.85mm long. [3]

2 a) Identify which structures are mitochondria. [1]

b) Explain the need for large numbers of mitochondria in villus epithelium cells. [2]

3 Large numbers of vesicles are visible in the cytoplasm of the cells.

a) State the name of the process used to form these vesicles. [1]

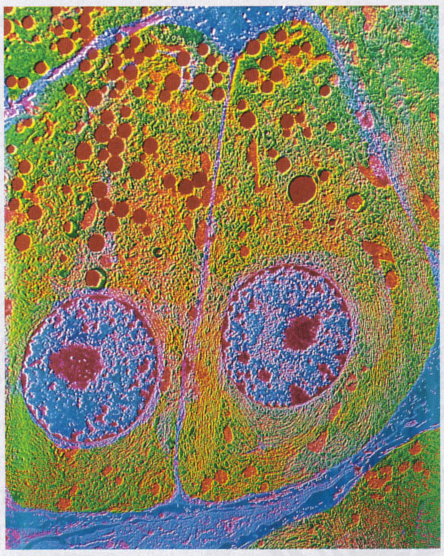
b) Predict the contents of the vesicles. [2]

4 Part of the junction between the two cells has been coloured blue.

a) State the name of this structure. [1]

b) Explain its function. [2]

Figure 7 is an electron micrograph showing two elongated, acinar cells of the exocrine human pancreas. Arranged in rounded glands, these cells secrete an alkaline, enzyme-rich fluid into the duodenum via the small duct (in blue) at top of image. Acinar cells are often pyramidal-shaped cells. Vesicles and granules will often be found at the surface next to the duct. In this image, granules of pancreatic enzymes are being carried through the cytoplasm towards the duct at the top.



▲ Figure 7

Discovering the chemical nature of digestion in the stomach

Serendipity and scientific discoveries: the role of gastric acid in digestion was established by William Beaumont while observing the process of digestion in an open wound caused by gunshot.

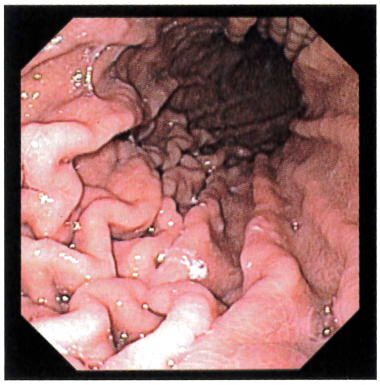
Alexis St. Martin was a Canadian fur trader who received a gunshot wound to his side. He survived the accident, but the wound healed in such a way that the inside of his stomach could be seen from the outside. William Beaumont, the surgeon who first treated the wound, used the opportunity to study the process of digestion. He continued to conduct investigations over an eleven-year period. He published his results in 1833. Beaumont is credited with overturning the notion that digestive processes within the stomach are solely physical providing evidence through his experiments of the chemical nature of digestion.

The role of acid conditions in the process of digestion

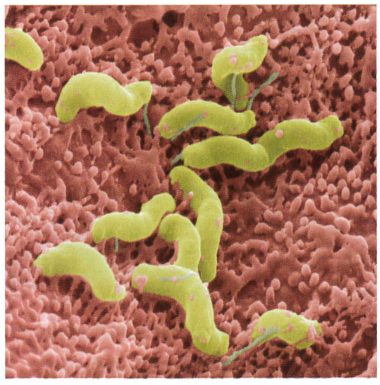
Acid conditions in the stomach favour some hydrolysis reactions and help to control pathogens in ingested food.

Acid is secreted by the parietal cells of the stomach. The acid disrupts the extracellular matrix that holds cells together in tissues. It also leads to the denaturing of proteins, exposing the polypeptide chains so that the enzyme pepsin can hydrolyse the bonds within the polypeptides.

Pepsin is released by chief cells as the inactive pepsinogen. The acid conditions within the stomach convert the inactive pepsinogen to pepsin. This ensures that the cells that produce pepsinogen are not digested at the same time as the protein in the diet.



▲ Figure 8 Interior of stomach



▲ Figure 9 *Helicobacter pylori* bacteria on the surface of the human gut. Colonies of *H. pylori* occur on the stomach mucous membrane in people who suffer from gastritis. This bacteria has been linked to stomach ulcer formation. *H. pylori* may also be a factor for gastric cancer as its presence increases the risk of stomach tumours

Bacterial infection as a cause of ulcers

Helicobacter pylori infection as a cause of stomach ulcers.

Stomach ulcers are open sores, caused by partial digestion of the stomach lining by the enzyme pepsin and hydrochloric acid in gastric juice. Stomach cancer is the growth of tumours in the wall of the stomach. Until recently, emotional stress and excessive gastric juice secretion were believed to be a major contributory factor in the development of stomach ulcers, but a bacterium, *Helicobacter pylori*, has been shown to be a more significant cause. This bacterium also seems to be associated with stomach cancer.

Proton pump inhibitors

The reduction of stomach acid secretion by proton pump inhibitor drugs.

There are several disease conditions of the stomach that are made worse by the release of acid. Stomach acid is corrosive so the body produces a natural mucus barrier which protects the lining of the stomach from being attacked by the acid.

In some people this barrier may have broken down allowing the acid to damage the stomach, causing bleeding. This is known as an ulcer. In others there may be a problem with the circular muscle at the top of the stomach that prevents fluid from escaping the stomach. If the muscle is not functioning, the acid escapes and irritates the esophagus. This is called "acid reflux" which can cause a symptom referred to as heartburn.

The production of the acidic environment within the stomach is achieved by a proton pump called the H^+, K^+-ATPase. This pump uses one ATP molecule to exchange two protons from the cytoplasm for two potassium ions in the lumen surrounding the parietal cell. One therapy that is increasingly prescribed for gastric diseases is proton pump inhibitors or PPIs.

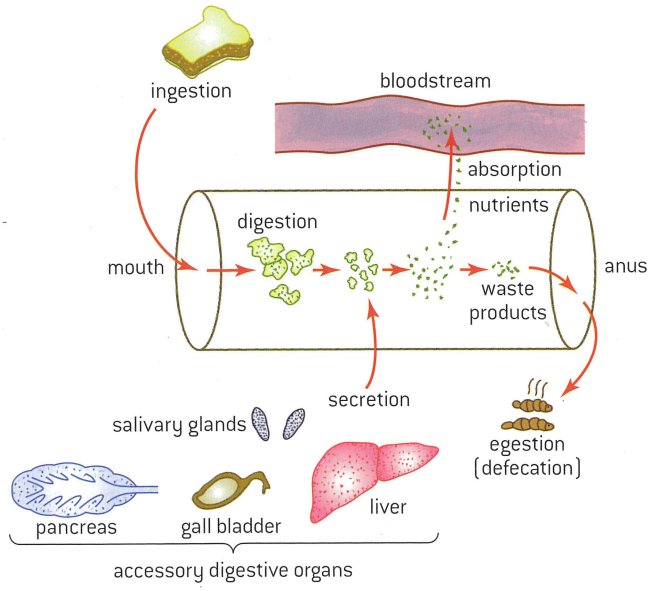
PPIs bind irreversibly to a single pump. The effect on the overall acid production system is not permanent as the pumps are normally recycled and replaced with new pumps.

The PPIs are consumed in an inactive form. Acid conditions in the vicinity of the parietal cells convert them to the active form close to their target.

Egestion

Materials not absorbed are egested.

Dietary fibre is the edible parts of plants that are resistant to being digested and are not absorbed from the small intestine. Examples include cellulose and lignin. As a consequence, there is a fraction of ingested food which never leaves the digestive tube. In addition, secretion into the digestive tube occurs. Some of what is added is excretory products such as bilirubin from the breakdown of red blood cells. A large volume of water is added to the tube in the process of digestion by secretions in the mouth, stomach and small intestine, and has to be reclaimed in the large intestine. The excretory products, the unabsorbed water and undigested dietary fibre are egested as feces.



▲ Figure 10

The role of dietary fibre

The rate of transit of materials through the large intestine is positively correlated with their fibre content.

Dietary fibre is material such as cellulose, lignin and pectin that cannot be readily digested. There are two categories of dietary fibre: soluble and insoluble. A healthy balanced diet contains fibre as it increases the bulk of material passing through the intestines and helps to prevent constipation as it draws water into the intestine. The higher the water content of the intestine, the faster the movement of fecal matter.

There are other possible benefits of fibre in the diet. The risk of various diseases of the large intestine may

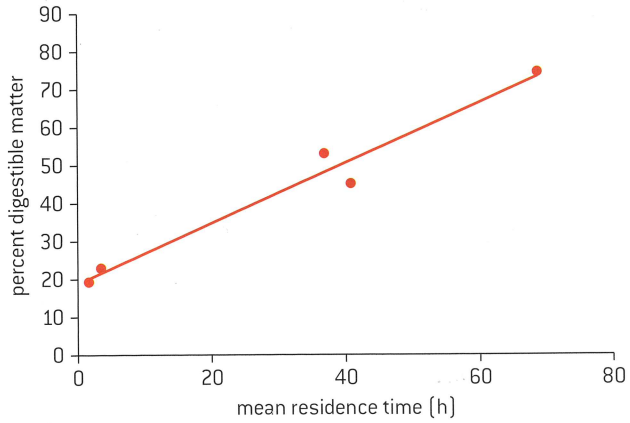
be reduced, including bowel cancer, hemorrhoids and appendicitis. The presence of bulky material in the stomach and intestines may increase feelings of satiety, reducing the desire to eat and the risk of obesity. Absorption of sugars may be slowed down, helping to prevent the development of type II diabetes. Foods of plant origin contain dietary fibre, especially whole-grain bread and cereals, vegetables such as cabbage and salads such as celery. Foods made from cultured fungi (mycoprotein) also contain dietary fibre.

Data-based questions: Dietary fibre and mean residence time

Figure 11 shows the correlation between digestible matter content (meaning less dietary fibre) and mean residence time (the length of time in the intestine).

1 Using the curve, determine the digestible matter content of a feces which has a mean residence time of 40 hours. [1]

2 Explain the relationship between digestibility and mean residence time. [3]



▲ Figure 11

Dehydration due to cholera

Dehydration due to cholera toxin.

Cholera is a disease caused by infection by the bacterium *Vibrio cholera*. The bacterium releases a toxin that binds to a receptor on intestinal cells. The toxin is then brought into the cell by endocytosis. Once inside the cell, the toxin triggers a cascade response that ultimately leads to the efflux of Cl^- and HCO_3^- ions from the cell into the intestine. Water follows by osmosis leading to watery diarrhoea. Water is drawn from the blood into the cells to replace the fluid loss from the intestinal cells. Quickly severe dehydration can result in death if the patient does not receive rehydration.

TOK

What role does conservatism play in science?

Thirty years ago, it was widely believed that emotional stress and lifestyle factors caused stomach ulcers. It is now recognized about 80 per cent of ulcers are caused by infection from *Helicobacter pylori*. The theory that ulcers were the consequence of an infection was put forward in the early 1980's by Barry Marshall and Robin Warren, two little-known Australian scientists. By the mid-1980s, they worked out an inexpensive treatment that cured about 75 per cent of patients. By 1988, they had shown definitively that antibiotics which killed *H. pylori* would cure ulcers for good. But the treatment did not become widely available until the early 1990s. Marshall attributes the slow take-up of their discovery to at least three different factors. The first problem is the inertia of existing beliefs. Doctors and drug companies had convinced themselves that they already knew the cause of ulcers: emotional stress. Marshall and Warren's infectious-agent theory had to displace the mindset. Also the blockbuster drugs of the time, Smith Kline Beecham's Tagamet and Glaxo's Zantac were both very good at putting ulcers into remission. The second problem lay in the way funding is allocated. Research grants are often awarded for three-year stints. When, in 1988, Marshall and Warren demonstrated that antibiotics could cure ulcers, many researchers who might have confirmed their result were already locked into research on acid-lowering drugs. Third, Marshall says that initially, they found it difficult for their publications to be noticed. Pharmaceutical companies fund an enormous amount of drug research in universities and hospitals. Pharmaceutical companies understandably tend to concentrate their efforts on conservative research that tends toward lucrative ongoing treatments rather than speculative ventures that might produce cheaper, permanent cures.