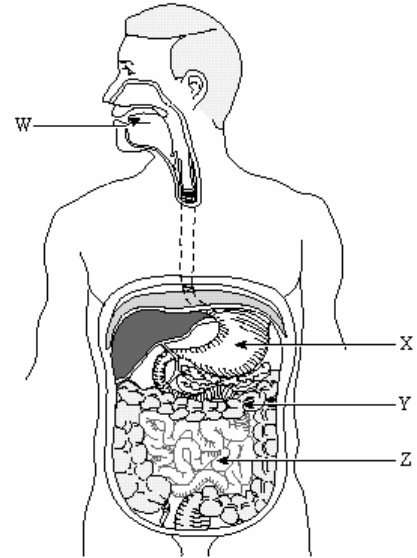


**In a nutshell...**

- The body uses a variety of **small molecules** (amino acids, fatty acids, glucose) for its metabolic needs. Food is **mechanically** and **chemically** broken down into these molecules during **digestion**, after which they can be taken up by body cells through the separate process of **absorption**.
- Food travels in a **one-way path** from mouth to esophagus to stomach to small intestine to large intestine to anus.
- Organs and structures in the digestive system are **specialized** for specific functions in digestion.
- **Digestive enzymes** are specific hydrolytic enzymes that have a preferred temperature and pH.
- Proper **nutrition** is necessary to health.



The four major processes in digestion are: **motility, secretion, digestion and absorption**

Two of these processes are highly regulated. These are: **motility and secretion.**

The parts of the digestive tract include: **mouth, pharynx, esophagus, stomach, small and large intestine**

The accessory structures which lie outside the tract include: **salivary glands, pancreas, liver and gall bladder.**

Ducts bring the secretions of the accessory structures into the tract.

- **DIGESTION:** the **mechanical** and **chemical** breaking down of ingested food into particles, then into **molecules small enough** to move through epithelial cells and into the internal environment.
- **ABSORPTION:** the passage of **digested nutrients** from the gut lumen into the blood or lymph, which distributes them through the body.
- **ELIMINATION:** the expulsion of **indigestible** residues from the body.

We will look at **DIGESTION** first.

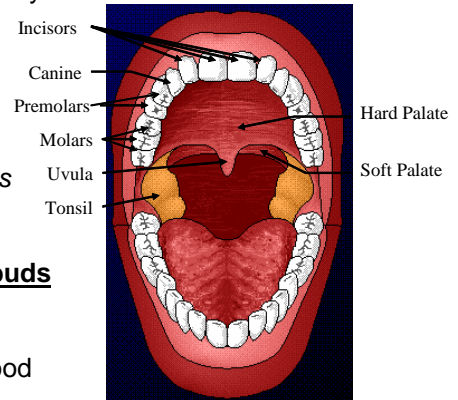
- During digestion, **proteins** are broken down into **amino acids**, **carbohydrates** into **glucose**, fat to **glycerol** and **fatty acids**, **nucleic acids** to **nucleotides**.
- Digestion is an **EXTRACELLULAR** process. It occurs within the **gut** (a tube that runs from **mouth** to **anus**).
- Digestion is achieved through the **cooperation of a number of body parts** and **organ systems**, and its **coordination** depends on the actions of several key **HORMONES**. Let's first look at the parts of the digestive system:

**Mouth**

- besides emitting pearls of wisdom, your mouth is **where digestion begins**.
- the mouth receives food, chews it up, moistens it, and starts to digest any starch in the food.

**Structure**

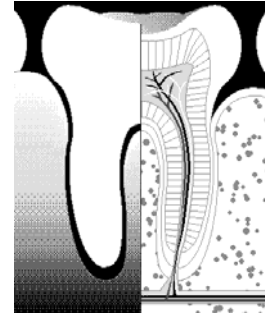
- divided into an anterior **hard palate** (contains several bones) and a posterior **soft palate**, which is composed of muscle tissue. That **thing** that hangs down in the back of your throat people think is their tonsils is really the **uvula**, and is the end part of soft palate. (*the tonsils lie on the sides of the throat*).
- **sense of hunger** is due to the combined sensations of **smelling** and **tasting** of food. **Olfactory** (scent) **receptors** in the nose, and **taste buds** on the tongue, remind you that you're hungry.



**Teeth**

- a normal adult mouth has **32 teeth**. The purpose of teeth is to chew food into pieces that can be swallowed easily.
- **different teeth types** aid this: **8 incisors** for **biting**, **4 canines** for **tearing**, **8 flat premolars** for **grinding**, and **12 molars** for **crushing**. (*wisdom teeth* are final molars which may or may not *erupt* properly) -- if not, they must be removed surgically).

- each tooth is shrouded by a tough, extremely hard layer of **enamel** (composed largely of **calcium salts**), **dentine** (a thicker, brownish bone-like material) and an inner layer of **nerves and blood vessels** called the **pulp**.
- "**cavities**" (proper name for cavities is "**caries**") are caused by **bacteria** in the mouth feeding on foods (like sugars) and giving off acids that corrode the tooth. "**Plaque**" is actually the living and *dead bodies of millions of bacteria*. **Fluoride** makes the tooth enamel stronger and more resistant to decay.
- Gum disease (inflammation of the gums = "**gingivitis**" is the *most common disease in the world!* If it spreads to the **periodontal membrane** (the lining of the tooth socket), it can cause **bone loss** in the socket and loosening of the teeth (= **peridontitis**).
- There are three sets of **SALIVARY GLANDS** that produce **SALIVA**:
  1. **parotid** (below ears)
  2. **sublingual** (below tongue)
  3. **submandibular** (under lower jaw).
- You can locate the duct opening of these with your tongue (**parotid** - by second upper molar, **sublingual** and **submandibular** flaps are under the tongue).



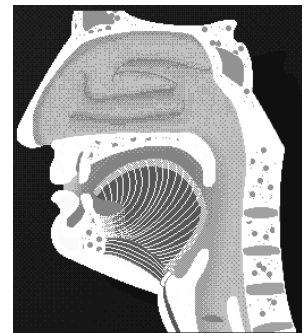
Chewing involves skeletal muscles of jaws, lip, cheeks and tongue and is controlled by cranial nerves. **The functions of chewing** are to 1) reduce the size of food to increase the surface area for enzymes to act and 2) move the food around mouth to stimulate taste and touch receptors and promote secretions of saliva

When you chew food, you moisten and lubricate it with **saliva**. You produce 1-2L of saliva per day secreted at rate of 4 ml/minute. Saliva contains **water**, **mucus**, **salivary amylase**, and **bicarbonate ions**. **The functions of saliva are to:** 1) soften and lubricate the food 2) neutralize acid produced by bacteria using bicarbonate ions in saliva (in doing this helps prevent tooth decay) 3) convert starch to maltose with maltase enzyme

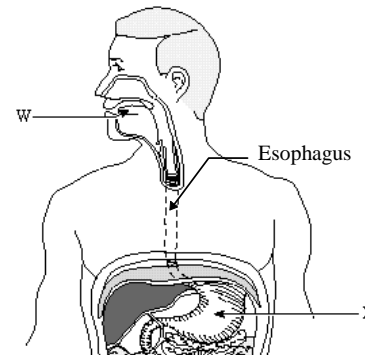
The salivary glands secrete saliva when messages are sent to the salivary center in the medulla when food is sensed and nerve impulses are sent back to the salivary glands causing the release of saliva

Thus, digestion **begins in the mouth**, even before the food is swallowed. Once food has been chewed, it is called a **bolus**.

- Food is then passed through the back of the mouth when you swallow. The first region that it enters is called the **PHARYNX**, which is simply **the region between mouth and esophagus** where **swallowing** takes place.
- Swallowing is a **reflex action** (requires no conscious thought).
- **To prevent food from going down your air passages**, some clever maneuvering is necessary. Note that it is **impossible** to breathe and swallow at the same time. *What is happening?*
- when you swallow, the following happens in order to block air passages:
  1. the **SOFT PALATE MOVES BACK** to cover openings to nose (nasopharyngeal openings).
  2. **TRACHEA (WINDPIPE) MOVES UP** under a flap of tissue called the epiglottis, blocking its opening. When food goes down the "wrong way" it goes into the trachea, and is then coughed back up.
  3. **opening to LARYNX** (larynx = "voice box") is called the "**glottis**." This opening is **COVERED** when the **trachea moves up** (you can see this by observing the movement of the **Adam's Apple** (part of the larynx) when swallowing). It gets covered by a flap of tissue called the **EPIGLOTTIS**.
- food then has **one route** to go ---> down the **ESOPHAGUS**.

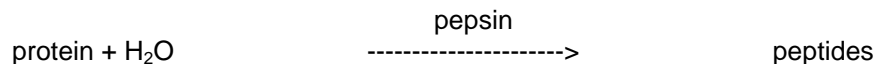
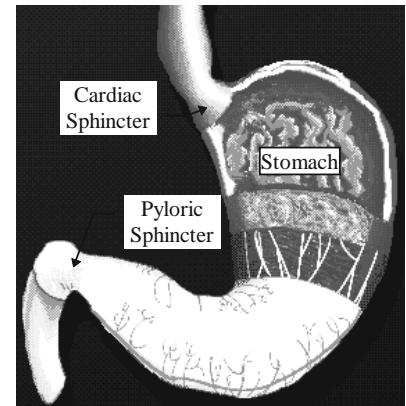


- **Esophagus:** a long muscular tube that extends from pharynx to stomach. Made of several types of tissue.
- The inner surface lined with **mucus membranes**. This layer is attached by connective tissue to a layer of **smooth muscle** containing both **circular** and **longitudinal** muscle.
- food moves down the esophagus through **PERISTALSIS** (*rhythmical contractions of the esophageal muscles*) at a rate of 2-4 cm/sec (It takes about 9 seconds for food to move from pharynx to stomach). If peristalsis occurs when there is no food in the esophagus, you will feel that there is a "lump" in your throat.
- Pressure differences caused by wave of muscle contractions allow contents to move in direction toward stomach
- Normal pressure usually prevents stomach contents from entering esophagus, but when it does creates heartburn (stomach acid irritation)
- Food bolus reaches the end of the esophagus and arrives at the **cardiac sphincter** connecting to the stomach. (sphincters function like **valves**. Made of muscles that encircle tubes, open them when they relax, close them when they contract).
- Normally, this sphincter prevents food from moving up out of stomach, but when **vomiting** occurs, a *reverse peristaltic wave* causes the sphincter to relax and the contents of the stomach are propelled outward.



### Stomach

- is a **thick-walled, J-shaped organ** that lies on left side of the body beneath the diaphragm.
- can stretch to hold 1.5 L of solids and/or liquids in an average adult (baby stomach holds 60 ml, cow stomach holds 300L)
- **three layers of muscle** contract to **churn** and **mix** its contents
- **pacemaker cells** at the tops of stomach stimulate contractions at a rate of 3/minute. The fuller the stomach, the more peristalsis.
- "hunger pains" are felt when an empty stomach churns.
- the mucus lining of the stomach contains inner **GASTRIC GLANDS** which produce **GASTRIC JUICE**. There are three types of cells in the stomach. **Mucus** cells secrete a protective coat, **parietal** cells secrete HCl (pH 3) which kill bacteria and help break food down and **peptic** cells which secrete **pepsinogen**. In the presence of HCl, pepsinogen forms **PEPSIN**, a **HYDROLYTIC ENZYME** that breaks down proteins into smaller chains of amino acids called **peptides**. (further on in the digestive tract they are broken down individual amino acids by other enzymes. This is the reaction that takes place.



- **Why doesn't the stomach digest itself?** 1) HCL could eat through but this is prevented by the mucus layer and the proposed mechanism in which HCl is not formed until it crosses the stomach lining 2) pepsin could digest protein in the stomach cells, but pepsin is inactive until it mixes with HCl
- **bacterial infections** (*Helicobacter pylori*) impair the ability of cells to produce mucus and are found to be associated with ulcers and stomach cancer. Thus, often ulcers are now cured with **antibiotics**.
- after **2 - 6 hours** (depending on the type of food), the food has been turned into a **semi-liquid food mass** called **ACID CHYME**, and the **stomach empties into the first part of the small intestine** (called the **duodenum**). This emptying is controlled by the **PYLORIC SPHINCTER** at the bottom of the stomach.

### Small Intestine:

- In our story, only some digestion has thus far taken place. Most of **digestion** and **absorption** of most nutrients occur in the small intestine.

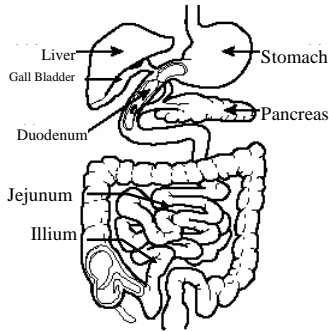
**General:** The site of most enzymatic hydrolysis of food and absorption of nutrients.

**Structure:** The human small intestine is about 6 m in length and tapers from about 3cm in diameter at the **pyloric sphincter** to about 1.5-2 cm at the **ileocecal valve** where it joins the large intestine.

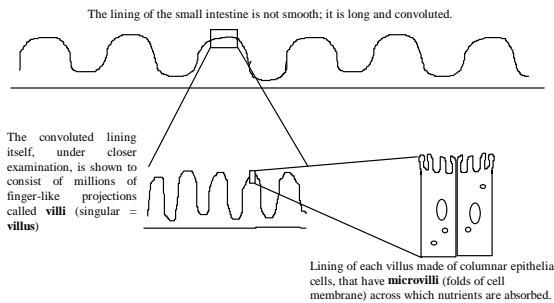
**Gross Structure:** The SI is made up of three major sections:

**Duodenum:** 25-30 cm long, receives food from the stomach, receives bile and pancreatic juice through the common duct about 10 cm along from the stomach. It is the site of most active enzyme production and digestion. **Jejunum:** 1-1.5 m long, has fewer intestinal glands, more specialized for absorption.

**Ileum:** 4-5 m long, produces no enzymes but does most of the absorption.



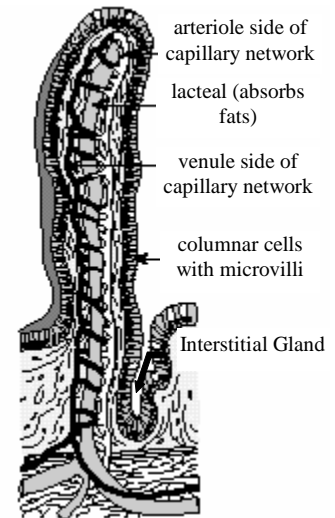
**B. The large surface area** of the SI (about 300 m<sup>2</sup>) is the result of several levels of folding:



- **Circular folds** in the submucosa slow the passage of food and increase the area. They are covered with...
- **Villi**, or microscopic fingerlike projections which are, in turn, covered with...
- **Microvilli**, or tiny cytoplasmic projections from the surface of individual columnar epithelial cells.

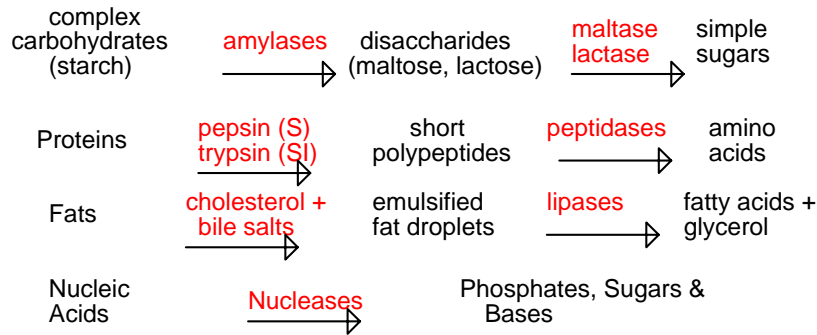
**C. The structural unit** of the SI is the villus (plural = villi). It has:

1. an outer layer of columnar epithelial cells. Some of these cells are covered in microvilli for absorption. Some are glandular cells which produce and release enzymes or mucus into the intestinal lumen. Some cells have digestive enzymes bound to their outer membrane.
2. a layer of **blood capillaries** that absorb the sugars and amino acids and carry them back towards the mesenteric vessels, the hepatic portal vein and the liver.
3. a small blind-ended lymph vessel called the **lacteal** that returns fluids and lipoprotein droplets to the blood stream.



### Functions of the Small Intestine

1. Neutralize the acidity of the acid stomach contents with bicarbonate from the pancreas
2. Mechanically mix the chyme with pancreatic juice, bile and intestinal secretions
3. Continue the breakdown of food



4. Absorb simple sugars and amino acids into the blood by active transport (requires ATP). Absorb fatty acids and glycerol, reassemble them into new fat molecules, coat them with lipoproteins and cholesterol and ship them out through the lacteals to enter the lymph system. The blood vessels from the villi in the small intestine merge to form the hepatic portal vein which leads to the liver. *(The hepatic portal system goes from capillaries of intestine to capillaries in liver for drop off of glucose-it's the only vein in the body that doesn't go back to heart before meets another capillary bed in lungs-no need to pick up oxygen-it's function is to drop off glucose and amino acids to liver)*

### The Pancreas

**Location:** just below and parallel with the stomach

**Structure:** two types of tissues:

1. produces and secretes **digestive juices** which goes through **pancreatic duct** to small intestine
2. islets of Langerhans produces and secretes **insulin and glucagon into blood** (glucagon from alpha cells and insulin from beta cells)

**Size:** ~ 10-15 cm long x 1-3 cm wide (tapering) x ~1-2 cm thick

**Connections:** a) good blood supply through vessels of the mesentery

- b) held in place by the mesentery connective tissue
- c) connects to the small intestine through the pancreatic and common ducts.

**Functions:** a) produces **bicarbonate ions** ( $\text{HCO}_3^-$ ), which neutralize stomach acids and make the pH of the intestine alkaline (7-8). Released through the pancreatic duct. SI enzymes optimum at basic pH

b) produces **digestive enzymes** - amylases, peptidases, lipases and nucleases - which are released through the pancreatic duct to the intestine.

the two functions above are **exocrine** - cell secretions are released into a duct. The two functions below are **endocrine** - cell secretions are released into the blood.

\*c) produces **insulin** which controls cellular uptake of glucose and its conversion into glycogen (insulin secreted when low glucose level in blood).

\*d) produces **glucagon** which stimulates the conversion of glycogen into glucose. (glucagon secreted when high glucose levels detected in blood)

e) 95% of water reabsorbed by osmosis and help of a  $\text{Na}^+$  pump into lacteals, then into lymph

*Just after eating-high glucose level so insulin secreted to cause cells to take up glucose in the liver and muscle, and glucose converted into glycogen for storage*

*When fasting-glucagon converts glycogen in liver and muscle into glucose*

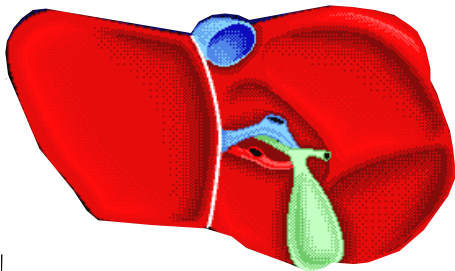
**Control:** When acid chyme arrives in the duodenum, the duodenal wall releases the hormones **secretin** and **CCK** (cholecystikinin). The hormones travel through the blood to the pancreas where they stimulate the production of pancreatic juice. Secretin is made in response to the presence of acid, CCK is a response to the presence of proteins and fats.

### The Liver

- a critically important organ in digestion & homeostasis

**Location:** Under the ribs but below the diaphragm on the right side of the body

Underside of liver showing gall bladder



**Size:** it is roughly triangular, lobed, about 1.5 kg

**Connections:** all blood from the intestines arrives at the liver via the **Hepatic Portal Vein** (this is the only blood vessel in the body which goes from a capillary bed -the intestines- to another capillary bed -the liver- without going back to the heart)

**Functions:** a) produces **bile** that emulsifies fats -breaks them into very small droplets with a large surface area for pancreatic lipase to work on. Bile is stored in **the gall**

**bladder**. (up to 1.5 L/day made). Bile is green because it contains pigments of hemoglobin breakdown from liver.

b) Converts **glucose** to **glycogen** after a meal and back to glucose in the hours between meals. Maintains blood sugar levels under the control of pancreatic hormones. Also interconverts carbohydrates to fats, amino acids to carbohydrates and fats.

c) Converts **hemoglobin** from old red blood cells into **bilirubin** or **biliverdin**, pigments which give bile its colour.

d) **Deaminates** amino acids from proteins in the diet, or from the recycling of worn-out body proteins, or from muscle breakdown in starvation conditions. The remainder of the amino acid is metabolized for energy. The amino group is converted to **urea** which is excreted through the kidneys.

e) produces blood proteins such as **albumin** which regulate the osmotic balance of the blood and **fibrinogen** which aids in blood clotting

f) breaks down and detoxifies a number of substances including: hormones circulating in the blood, alcohol, some antibiotics, many drugs, and toxins found in some foods.

g) stores iron and vitamins

h) makes cholesterol

### Disorders of Liver

- **Jaundice:** a **generalized condition** (there are numerous causes) many causes that gives a **yellowish tint** to the skin. This yellowish tint is due to the build up of **BILIRUBIN** (from the breakdown of red blood cells) in the blood, which is due to **liver damage** or **blockage of bile duct** (the latter is called "**obstructive jaundice**").
- Obstructive jaundice also causes **GALLSTONES** (made of cholesterol (insoluble) and  $\text{CaCO}_3$ ). Can block bile ducts. Therefore fat cannot be digested and causes pain. Removal of gall bladder often necessary.
- **Viral Hepatitis:** causes liver damage and jaundice. Two main types.
  - **Type A: *infectious hepatitis*** caused by unsanitary food, polluted shellfish.
  - **Type B: *serum hepatitis***: spread through blood contact (e.g. transfusions)
- **CIRRHOSIS:** usually caused **by chronic over-consumption of alcohol**.

ROH ---> Active Acetate -->---> Fatty acids

  - Liver fills up with fat deposits and scar tissue
  - Kills thousands of alcoholics per year

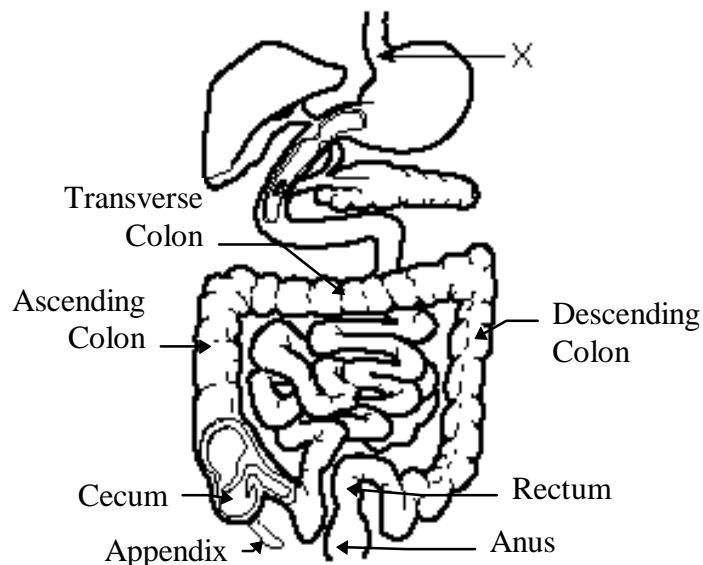
## Large Intestine

**Size:** ~1.5 m long, 6.5 cm in diameter

The large intestine (*LI*) joins with the small intestine (*SI*) in the lower right corner of the abdomen - near the iliac crest. The junction is at right angles but not quite at the end. There is a blind end to the *LI* called the **cecum**. Projecting from the cecum is the **appendix**.

The *LI* has four major parts: The **ascending colon** rises up the right side of the abdomen, the **transverse colon** crosses the top of the abdomen and the **descending colon** goes down the left side where it joins the **rectum**.

Indigestible food, excreted materials (bile pigments, heavy metals) and bacterial cells form **feces** which leave the digestive system through the **anus**. The anus is normally held closed by the internal (smooth) and external (skeletal) anal sphincters.



### Functions:

1. Mechanical Movement - **peristalsis** moves the feces along
2. Absorption - water and some salts are absorbed from the feces,
3. Bacteria (*E. coli*) work on undigested food from the SI and produce gases flatulence-about 1.5 L/day (mainly nitrogen gas, and carbon dioxide, with small amounts of hydrogen, methane and hydrogen sulphide), amino acids and some vitamins. The amino acids and vitamins (K) produced are absorbed through the intestinal lining. (The LI does **not** have villi like the SI)
4. **Defecation** - reflex contraction of the muscles lining the filled rectum force the sphincter muscles open and expel the feces.

Feces contains bile pigments, heavy metals and billions of *E. Coli*

## The Principal Digestive Enzymes!

Source & Enzyme	Substrate (what they act on!)	preferred pH	Product	Site of Action (Where they work)
<b>SALIVARY GLANDS</b>				
<b>Salivary Amylase</b>	Starches	neutral (~7)	maltose	Mouth
<b>STOMACH</b>				
<b>Pepsin</b>	Proteins	acidic (3)	peptides	Stomach
<b>PANCREAS</b>				
<b>Pancreatic Amylase</b>	Starches	alkaline (~7.5-8.5)	maltose	Small Intestine
<b>Lipase</b>	Fats	alkaline	FA's & glycerol	Small Intestine
<b>Trypsin</b>	Polypeptides	alkaline	peptides	Small Intestine
Chymotrypsin	<u>Poly</u> & <u>oligo</u> peptides	alkaline	amino acids	Small Intestine
Carboxypeptidase	Polypeptides	alkaline	amino acids	Small Intestine
Deoxyribonuclease	DNA	alkaline	nucleotide s	Small Intestine
Ribonuclease	RNA	alkaline	nucleotide s	Small Intestine
<b>LIVER</b>				
<b>Bile</b> (emulsifies)	Fat Globules	alkaline	smaller fat globules	Small Intestine

SMALL INTESTINE				
<u>Amino</u> peptidase	Polypeptides	alkaline	amino acids	Small Intestine
Tripeptidases	Tripeptides	alkaline	amino acids	Small Intestine
Dipeptidase	Dipeptides	alkaline	amino acids	Small Intestine
<b>Maltase</b>	Maltose	alkaline	glucose	Small Intestine
<b>Lactase</b>	Lactose	alkaline	glucose & galactose	Small Intestine
Sucrase	Sucrose	alkaline	glucose & fructose	Small Intestine
Enterokinase	Trypsinogen	alkaline	Trypsin	Small Intestine
Phosphatases	Nucleotides	alkaline	sugars, bases, phosphate	Small Intestine

- all reactions are hydrolytic—water added to split

Recall, besides pepsin, gastric juice also contains HCl and mucus.

As well as the pancreatic enzymes above, pancreatic juice contains  $\text{HCO}_3^-$ . Insulin and glucagon are secreted into the blood.

### Control of Digestive Gland Secretion

- **NERVOUS STIMULATION** from sight and smell receptors send messages to brain and cause release of saliva, gastric and pancreatic juices
- **the presence of food** in digestive system **triggers** digestive glands to secrete their **enzymes and bicarbonate to be released**—into ducts from exocrine glands
- the release of enzymes is controlled by **HORMONES** released from endocrine glands into blood
- There are **4 hormones** that we will look at: **gastrin, secretin, CCK, and GIP**.
- Recall at the beginning we said there were four processes in digestion: motility, secretion, digestion and absorption. **Motility and secretion are highly regulated through hormonal control**. Digestion and absorption depend on the amount of food eaten.
- when food is eaten, **sensory cells** in the stomach detect the presence of **peptides**. Other sensory receptors detect that the stomach is distending (i.e. **stretching**). This causes other stomach cells in the upper stomach to release **GASTRIN**, a hormone, into the **blood**. Gastrin travels through the blood to the lower stomach which causes the release of **gastric juices**, (HCl and pepsinogen)
- Most digestion of food occurs in the **duodenum**. Excess acid chyme seeps in to the duodenum from the stomach and is first **neutralized**. **SECRETIN**, a hormone produced by the small intestine, mediates this neutralization by stimulating the release of **SODIUM BICARBONATE** by the **pancreas**. Also secretin will decrease motor activity in the stomach
- The presence of **amino acids** or **fatty acids** in the duodenum triggers the release of **CHOLECYSTOKININ (CCK)**, which stimulates the release of **digestive enzymes by the pancreas** and **bile** by the **gallbladder**.
- A fourth hormone, **ENTEROGASTRONE** (also known as **Gastric Inhibitory Peptide**, or **GIP**), released by the small intestine, slows digestion by **INHIBITING stomach peristalsis** and **acid secretion** when acid chyme rich in **fats** (which require additional digestion time) enters the duodenum.

Here is a great lil' summary for you!

Hormone	Released by What Part/ in response to what?	Acts on What Part?	What does it do?
GASTRIN	upper part of stomach/in response to undigested protein in the stomach	Gastric juice secreting cells at top of stomach	Causes secretion of gastric juices



SECRETIN	Small intestine/Acid chyme from stomach	Pancreas	Causes pancreas to release $\text{NaHCO}_3$ and pancreatic enzymes and stomach to decrease motor activity
CCK	Small intestine/Acid chyme in stomach	Pancreas and Liver (gall bladder)	Causes liver to secrete bile and pancreas to secrete pancreatic juice (contains lipases).
GIP	Small intestine/ chyme rich in fats enter duodenum	Stomach	Inhibits stomach peristalsis and acid secretion (opposes gastrin)