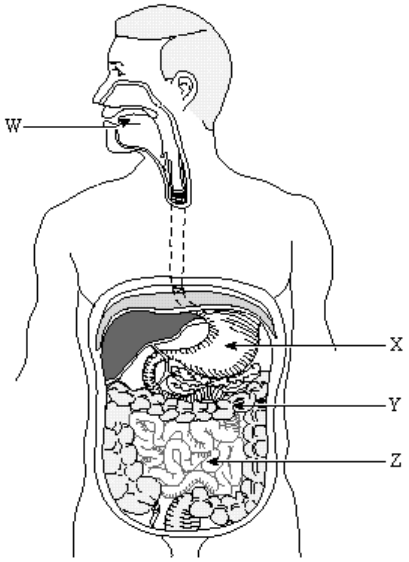
In a nutshell...

- *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.*



- **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.*

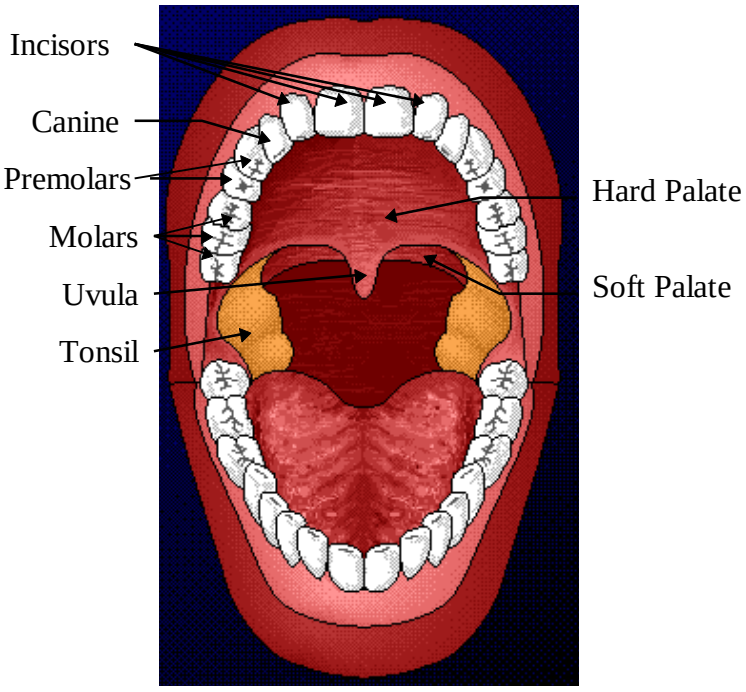
- During digestion, **proteins** are broken down into **amino acids**, **carbohydrates** into **glucose**, fat to **glycerol** and **fatty acids**, **nucleic acids** to **nucleotides**.
- Digestion is an **EXTRACELLULAR process**. It occurs within the **gut** (a tube that runs from **mouth** to **anus**).
- 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

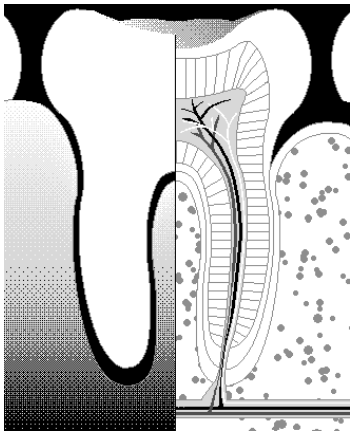
- divided into an anterior **hard palate** (contains several bones) and a posterior **soft palate**, which is composed of muscle tissue. That *thing* that hangs down in the back of your throat people think is their tonsils is really the **uvula**, and is the end part of soft palate. *(the tonsils lie 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.



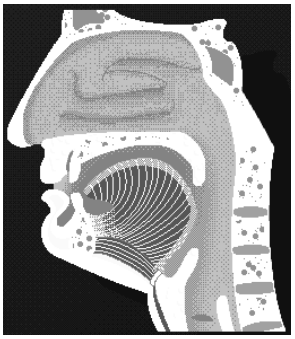
Teeth

- 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).

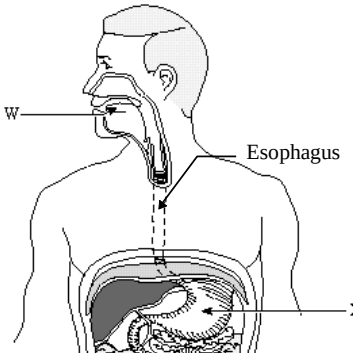
- each tooth is shrouded by a tough, extremely hard layer of **enamel** (composed largely of **calcium salts**), **dentine** (a thicker, brownish bone-like material) and an inner layer of **nerves and blood vessels** called the **pulp**.
- "**cavities**" (proper name for cavities is "**caries**") are 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*).
- When you chew food, you moisten and lubricate it with **saliva**. Saliva contains **water**, **mucus**, and **salivary amylase**, a **hydrolytic** enzyme that breaks down starch in the presence of water. **Starch is broken down to maltose** (a disaccharide of glucose), which is later broken down to glucose in the intestine.
- 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).

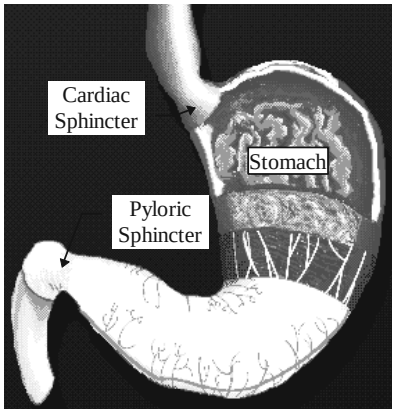


- ***To prevent food from going down your air passages***, some clever maneuvering is necessary. Note that it is **impossible** to breath and swallow at the same time. *What is happening?*
- when you swallow, the following happens in order to block air passages:
  1. the **SOFT PALATE MOVES BACK** to 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***). If peristalsis occurs when there is no food in the esophagus, you will feel that there is a "*lump*" in your throat.
- 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



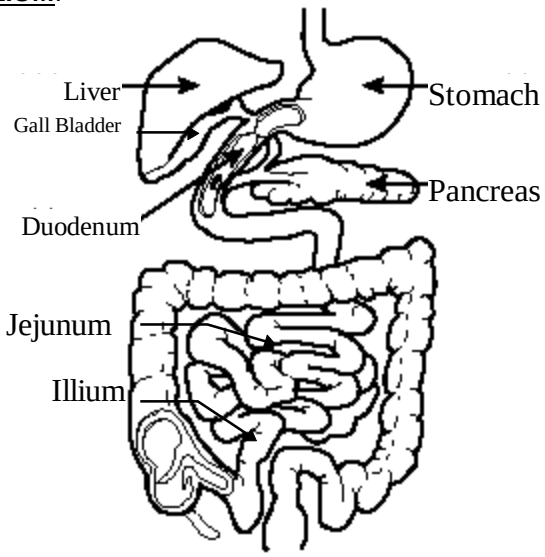
- is a **thick-walled, J-shaped organ** that lies on left side of the body beneath the diaphragm.
- can stretch to hold about half a gallon (**~2 liters**) of solids and/or liquids in an average adult.
- ***three layers of muscle*** contract to **churn** and **mix** its contents
- "hunger pains" are felt when an empty stomach churns.
- the mucus lining of the stomach contains inner **GASTRIC GLANDS** which produce **GASTRIC JUICE**. Gastric juice contains **PEPSINOGEN** and **HCl** (hydrochloric acid). When the two combine, 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.

$$\text{protein} + H_2O \xrightarrow{\text{pepsin}} \text{peptides}$$

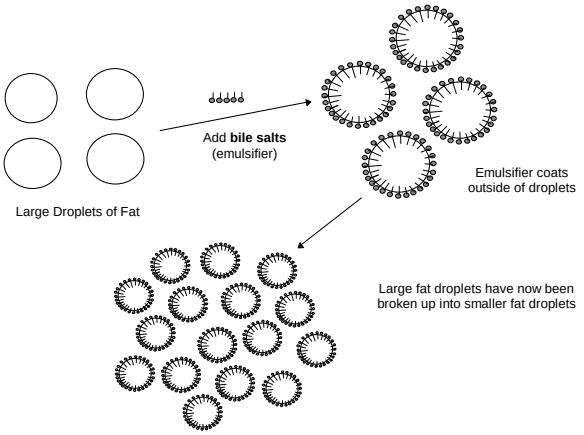
- HCl gives **stomach a pH of ~3**. Highly **corrosive**. This **kills bacteria** in food and helps break it down
- *Why doesn't the stomach digest itself?* This is because its **inner wall is protected by a thick layer of MUCUS secreted by mucosal cells**.
  - if HCl does penetrate, pepsin starts to digest the stomach lining ---> forms an **ULCER** (an **open sore** on the wall of the stomach). **Too much gastric juice** can cause ulcers, as can too much nervous stimulation (i.e. **stress**), since this will cause over-secretion of gastric juices).
  - however, the #1 cause of ulcers is actually a **bacterial infections** (*Helicobacter pylori*) that impair the ability of cells to produce mucus. Thus, most ulcers can now be 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: *The Food Processor*

- In our story, only some digestion has thus far taken place. Most of **digestion** and **absorption** of most nutrients occur in the small intestine.
- Divided into three zones: the **DUODENUM**, **JEJUNUM**, and **ILIUM**.
- is about **6 meters long** (~20 feet), compared to **1.5 m** (~ 5 feet) **for large intestine**.
- first **25 cm of small intestine** called the **DUODENUM**. The duodenum plays **a major role in digestion**. It is here that **SECRETIONS SENT FROM THE LIVER AND PANCREAS** break down **fat** and **peptides**, and secretions of the duodenum itself also break down other **nutrients**.
- the Liver **produces BILE**, which is sent to the duodenum via a **duct** from the **GALL BLADDER** (where bile is **stored**).
- **bile** is a **thick green liquid** (it gets its green colour from **byproducts of hemoglobin breakdown** (another function of the liver).
- bile contains **emulsifying agents** called **BILE SALTS** which break **FAT** into **FAT DROPLETS**.

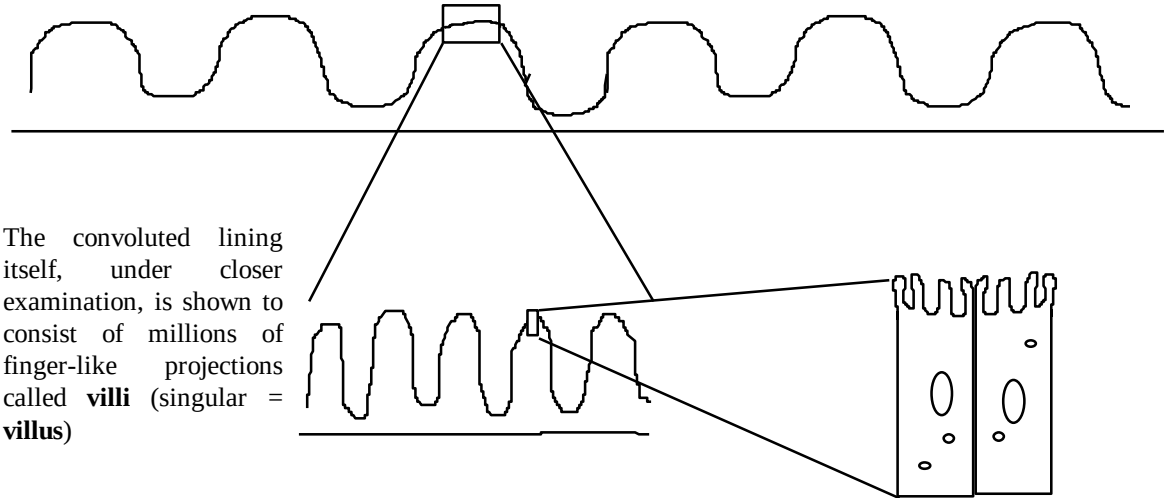


- **PANCREAS** sends **pancreatic juice** into duodenum through duct
- the juice contains **enzymes** and **sodium bicarbonate** (**$NaHCO_3$**)
- $NaHCO_3$ makes **the juice highly alkaline (pH ~ 8.5).** It **neutralizes the acid chyme** and make the small intestine pH basic
- pancreatic juice contains **hydrolytic enzymes** including **pancreatic amylase** (digests starch to maltose), **trypsin** (digests protein to peptides), and **lipase** (digests fat droplets to glycerol & fatty acids).
- *Note: the pancreas also has an **endocrine function**. It produces the hormones **INSULIN** and **glucagon**. Insulin is a **hormone** that causes glucose in the blood to be **taken up by cells** (i.e. **lowers blood [glucose]**). It is produced by different cells (**β cells** in "**islets of Langerhans**") in the pancreas than the ones that make pancreatic juice. Insulin is released directly into the **blood**, and it travels to target cells throughout the body. People who don't produce insulin or enough insulin, or who lack insulin receptors on target cells, will suffer from **diabetes**. Glucagon works opposite to insulin: Glucagon has the effect of **raising blood glucose concentrations**.*



- **walls of the duodenum and small intestine** are lined with millions of **INTERSTITIAL GLANDS** that produce juices containing enzymes that **finish the digestion** of protein and starch.
- secretions from the interstitial glands contain digestive enzymes: **peptidases** digest **peptides** to **amino acids.** also, **maltase** digests **maltose** (a disaccharide) to **glucose.** Other enzymes made here digest other **disaccharides** (e.g. lactase digests lactose, the sugar in milk).

The lining of the small intestine is not smooth; it is long and convoluted.



The convoluted lining itself, under closer examination, is shown to consist of millions of finger-like projections called **villi** (singular = **villus**)

Lining of each villus made of columnar epithelial cells, that have **microvilli** (folds of cell membrane) across which nutrients are absorbed.

- bile (bile is an emulsifying agent, not an enzyme) sent from the **gall bladder** to the duodenum emulsifies fat to fat droplets in the duodenum.
- secretions from **pancreas** arrive at the duodenum. These secretions contain trypsin, which breaks down proteins to peptides in the duodenum. Lipase from the pancreas breaks lipids to glycerol and fatty acids.

Comprehensive Summary of DIGESTIVE ENZYMES

- the breakdown of food (fats, carbohydrates, proteins) into molecules small enough to be absorbed requires the action of specific enzymes
- each enzyme has **specific site** where it works, and a **specific pH** range in which it can operate
- all are **hydrolytic enzymes** that catalyze a reaction of the substrate with **water**.

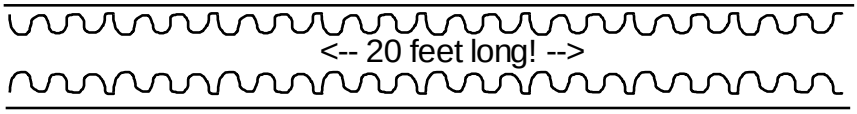
e.g.

$$\text{peptides} + H_2O \xrightarrow[\text{small intestine}]{\text{peptidases}} \text{amino acids}$$

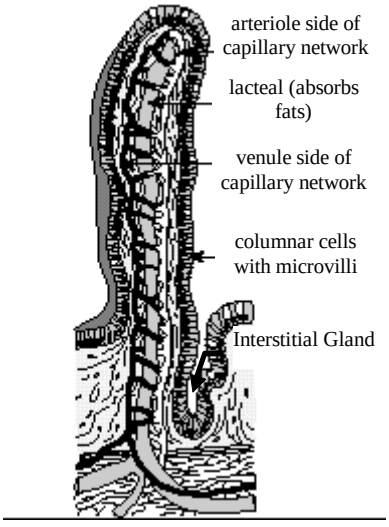
Source & Enzyme	Substrate (what they act on!)	preferred pH	Product	Site of Action (Where they work)
SALIVARY GLANDS				
Salivary Amylase	Starches	neutral (~7)	maltose	Mouth
STOMACH				
Pepsin	Proteins	acidic (3)	peptides	Stomach
PANCREAS				
Pancreatic Amylase	Starches	alkaline (~7.5-8.5)	maltose	Small Intestine
Lipase	Fats	alkaline	FA's & glycerol	Small Intestine
Trypsin	Polypeptides	alkaline	peptides	Small Intestine
Chymotrypsin	Poly & oligopeptides	alkaline	amino acids	Small Intestine
Carboxypeptidase	Polypeptides	alkaline	amino acids	Small Intestine
Deoxyribonuclease	DNA	alkaline	nucleotides	Small Intestine
Ribonuclease	RNA	alkaline	nucleotides	Small Intestine
LIVER				
Bile (emulsifies)	Fat Globules	alkaline	smaller fat globules	Small Intestine
SMALL INTESTINE				
Amino**peptidase**	Polypeptides	alkaline	amino acids	Small Intestine
Tripeptidases	Tripeptides	alkaline	amino acids	Small Intestine
Dipeptidase	Dipeptides	alkaline	amino acids	Small Intestine
Maltase	Maltose	alkaline	glucose	Small Intestine
Lactase	Lactose	alkaline	glucose & galactose	Small Intestine
Sucrase	Sucrose	alkaline	glucose & fructose	Small Intestine
Enterokinase	Trypsinogen	alkaline	Trypsin	Small Intestine
Phosphateses	Nucleotides	alkaline	sugars, bases, phosphates	Small Intestine

- The **STRUCTURE** of the small intestine is well related to its **FUNCTION** of **ABSORPTION**.

1. it is **LONG** with **CONVOLUTED** walls **to increase surface area**



2. surface area further increased by presence of **finger-like projections** called **VILLI** (a single one is called a "**villus**". Interstitial glands are at the **base** of each villi.
3. villi themselves are lined with columnar cells coated with **MICROVILLI**. Each villi contains **blood vessels** and **lymph vessels** (lacteal).



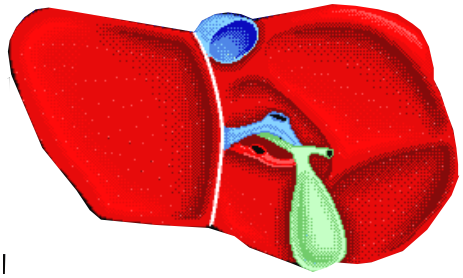
- **ABSORPTION** takes **place across the wall of each villus** ---> this can happen **passively** or **actively**. Recall that active transport across cell membranes requires **ATP**. The nutrient can now enter the blood or the lymphatic system, depending on what type it is.
- **Fatty acids** and **glycerol** are absorbed across the villi, are **recombined** into **fat** molecules in the epithelial cells of the villus. The fats then move into the **LACTEAL** of each villus and enter the **LYMPHATIC SYSTEM.**
- **sugars** and **amino acids** enter the **blood** through the capillary network.
  - The blood vessels from the villi in the small intestine merge to form the **HEPATIC PORTAL VEIN** which leads to the **liver**.

The Liver

- a critically important organ in digestion & homeostasis

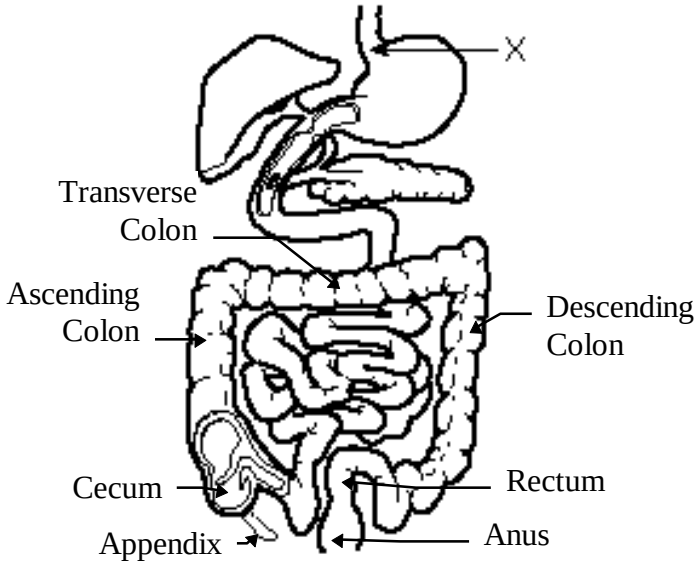
1. keeps blood concentrations of nutrients, hormones etc. **constant** (e.g. converts glucose to glycogen and back to keep blood glucose levels constant).
2. **Interconversions of nutrients** (e.g. carbohydrates to fats, amino acids to carbohydrates and fats).
3. **removes toxins from the blood** (**detoxifies**). Removes of unwanted particulate matter from the blood through the mediation of macrophages.
4. Production of **Bile**. Up to 1.5 liters of bile per day!
5. **Destroys old red blood cells**.
6. **Production of urea.** (deamination of amino acids and excretion of resulting ammonia as urea, uric acid, etc.)
7. **Manufacture of plasma proteins** such as fibrinogen and albumin.
8. **Manufacture of cholesterol**.
9. **Storage** of **iron**.
10. **Storage** of **vitamins**.
11. In embryos (of vertebrates) , the liver **makes Red Blood Cells**

Underside of liver showing gall bladder



Large Intestine

- consists of **COLON** and **RECTUM** (the rectum is the last 20 cm of the colon). Opening of rectum is called **ANUS**.
- colon has 3 parts (**ascending**, **transverse**, and **descending**)



Main Functions

- **REABSORPTION OF WATER** from indigestible food matter (**feces**)
- **absorption** of **certain vitamins**
- feces also contains **bile pigments**, **heavy metals**, and **billions of *E. coli***. While there is no question that they are parasites, they provide a valuable service for us. These bacteria **break down** some indigestible food, and in the **process produce some vitamins, amino acids**, and **other growth factors** that are in turn absorbed by the colon.

Control of Digestive Gland Secretion

- *generally speaking***, the presence of food** in digestive system triggers digestive glands to secrete their enzymes.
- more specifically, **HORMONES** control secretion of specific digestive juices.
- There are **4 hormones** that we will look at: **gastrin**, **secretin**, **CCK**, and **GIP**.

The Specifics! ***From start to finish***

- 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 to release **GASTRIN**, a hormone, into the **blood**.
- Gastrin travels through the blood and finally reaches **other cells** (takes about 1 minute) in the stomach that produce **gastric juices**, and stimulates its release.
- Most digestion of food occurs in the **duodenum**. The acid chyme seeps in 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**.
- 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 **G**astric **I**nhibitory **P**eptide, 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 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 NaHCO3 and pancreatic enzymes
CCK	Small intestine/Acid chyme in stomach	Pancreas and Liver (gall bladder)	Causes liver to secrete bile and pancreas to secrete pancreatic juice.
GIP	Small intestine/acid chyme rich in fats enter duodenum	Stomach	Inhibits stomach peristalsis and acid secretion (opposes gastrin)

Human Nutrition: ***You are what you don't eliminate!***

Main Classes of Nutrients

- carbohydrates
- proteins
- lipids
- vitamins & minerals

Carbohydrates

- primary source of **energy**
- diet should **consist primarily of complex carbohydrates** (not refined sugars)
- carbohydrates are digested eventually to **glucose**, which is stored by liver as **glycogen**
- glucose is only fuel **brain** will use

Fats

- most fats can be made by **liver** (linoleic acid is an exception)
- fats in food are mostly found in **animal products** (meat and dairy). These are especially high in **saturated fats**. (saturated fats tend to be solid at room temp.)
- **high fat and protein diets are number one cause of death in North America** (heart disease, strokes, hypertension, many forms of cancer, many other disorders and diseases).
- You should get about **15**% of your calories from fat. Most Americans and Canadians get between **40** and **60**% of their calories from fat!
- **high in calories** (> twice as many per gram (9.1) as carbohydrates or protein (4.4.))

Proteins

- protein is necessary for tissues, metabolism, enzymes etc.
    - it is **NOT** an energy food
- of twenty types of amino acids, 8 cannot be manufactured by humans --- called **essential amino acids**.
- **protein deficiency** is the most common form of malnutrition in **poorer countries**. The swollen abdomen of starving children is caused by **edema** due to the lack of plasma proteins in the blood.
- protein deficiency is ***not*** a problem in North America.
- most North Americans eat **more than 2 to 3 times** the amount of protein they need.
- **high protein diets are usually also high fat diets**.