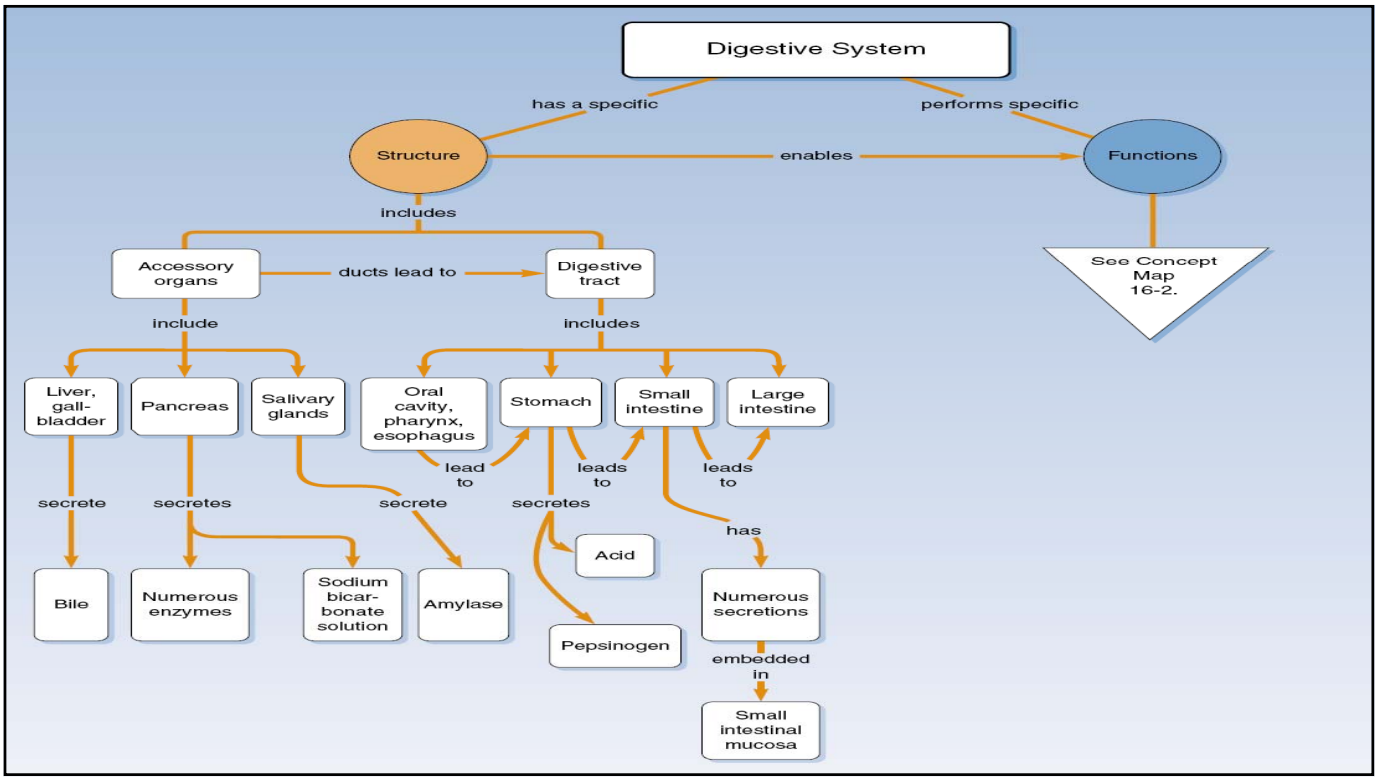
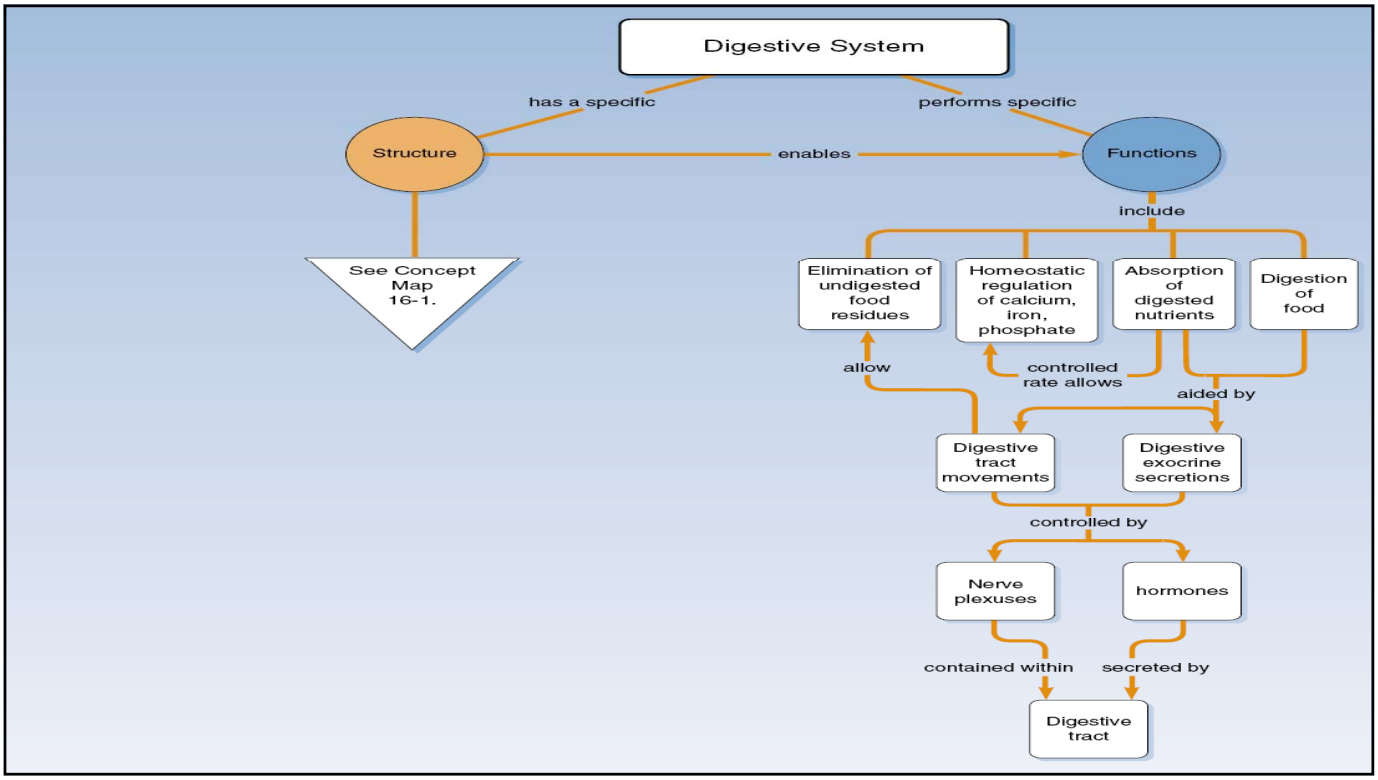
DIGESTIVE PHYSIOLOGY

D.HAMMOUDI.MD

Food Categories Enzyme

- 1. Complex carbohydrates + Amylase + Water → Simple sugars
- (e.g., starch, glycogen)
- 2. Proteins + Proteases + Water → Amino acids
- 3. Fats + Lipases + Water → Fatty acids and glycerol


Digestive System
has a specific
performs specific
Structure
enables
Functions
includes
Accessory organs
ducts lead to
Digestive tract
See Concept Map 16-2.
include
includes
Liver, gall-bladder
Pancreas
Salivary glands
Oral cavity, pharynx, esophagus
Stomach
Small intestine
Large intestine
lead to
leads to
leads to
secrete
secretes
secrete
secretes
has
Acid
Bile
Numerous enzymes
Sodium bicar-bonate solution
Amylase
Pepsinogen
Numerous secretions
embedded in
Small intestinal mucosa


Digestive System
has a specific
performs specific
Structure
enables
Functions
include
See Concept Map 16-1.
Elimination of undigested food residues
Homeostatic regulation of calcium, iron, phosphate
Absorption of digested nutrients
Digestion of food
allow
controlled rate allows
aided by
Digestive tract movements
Digestive exocrine secretions
controlled by
Nerve plexuses
hormones
contained within
secreted by
Digestive tract

TASTE

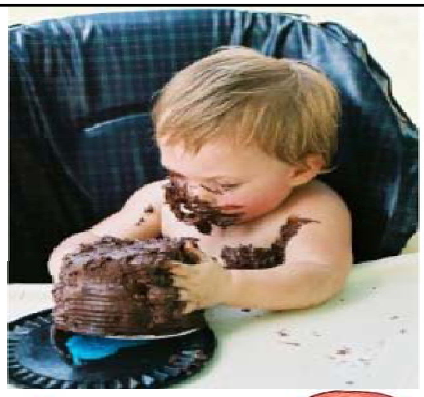
- The **filiform papillae, found at the**front of the tongue, are rough and are important in licking.
- The **fungiform papillae** and the **circumvallate papillae**, found toward the back of the tongue, all contain taste buds.
- There are four tastes: sweet, sour, salt, and bitter.

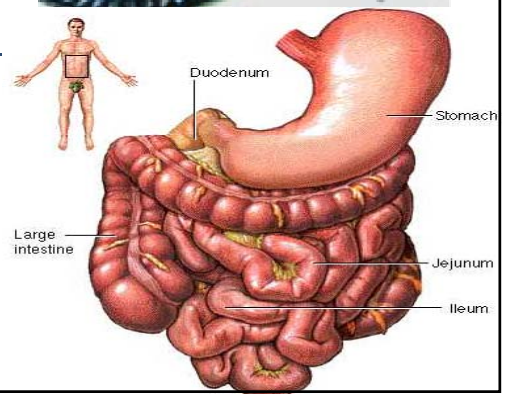
Saliva

- Saliva is 99.5% water, which provides a medium for dissolving foods. The remaining 0.5% consists of solutes:
- Chlorides which activate the salivary enzyme **amylase**
- Amylase initiates the breakdown of complex carbohydrates like starch and glycogen into simple sugars.
- Bicarbonates and phosphates, which are buffer chemicals, keep the saliva at a slightly acidic pH of 6.35 to 6.85.
- Urea and uric acid are waste products.
- Mucin forms mucus to lubricate food.
- The enzyme lysozyme destroys bacteria, thus protecting the mucous membrane from infection and the teeth from possible decay.

Digestive Process

- The GI tract is a "disassembly" line
  - Nutrients become more available to the body in each step
- **There are six essential activities:**
  - **Ingestion,**
  - **propulsion,**
  - **mechanical digestion**
  - **Chemical digestion,**
  - **absorption,**
  - **defecation**

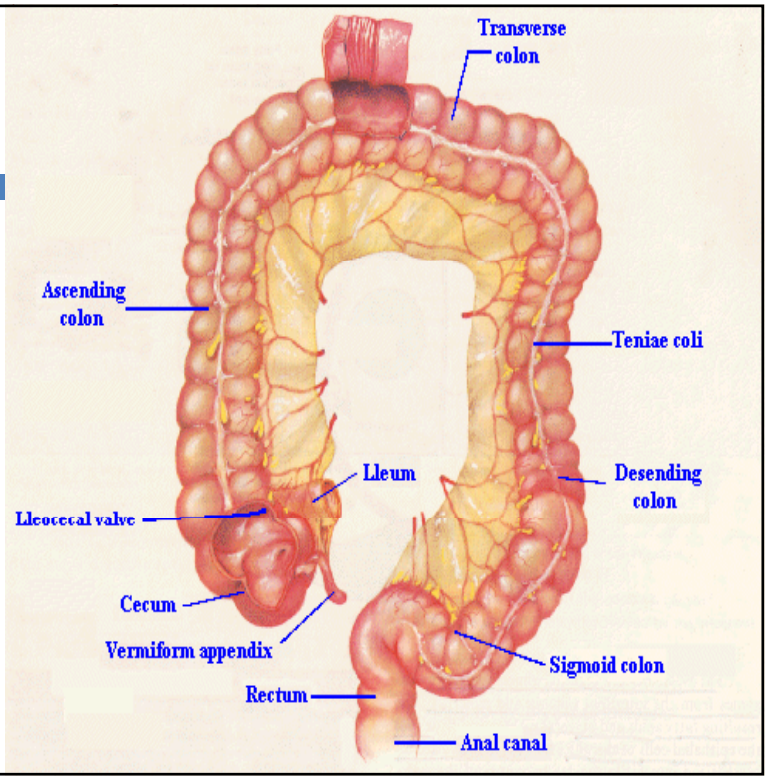




Digestion

8

- Processing of food
- Types
  - Mechanical (physical)
    - Chew
    - Tear
    - Grind
    - Mash
    - Mix
  - Chemical
    - Catabolic reactions
    - Enzymatic hydrolysis
      - Carbohydrate
      - Protein
      - Lipid

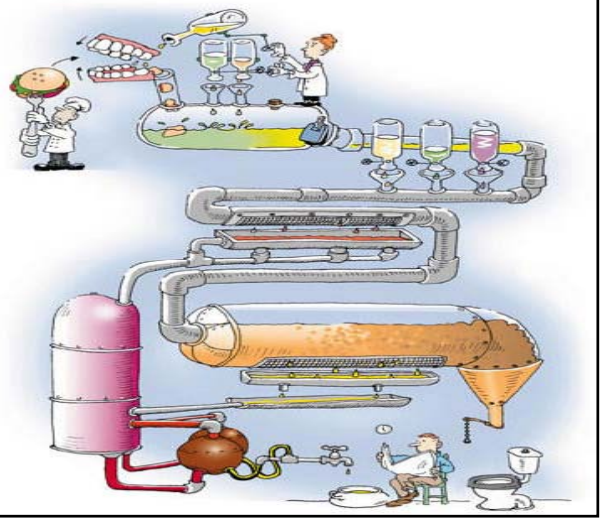


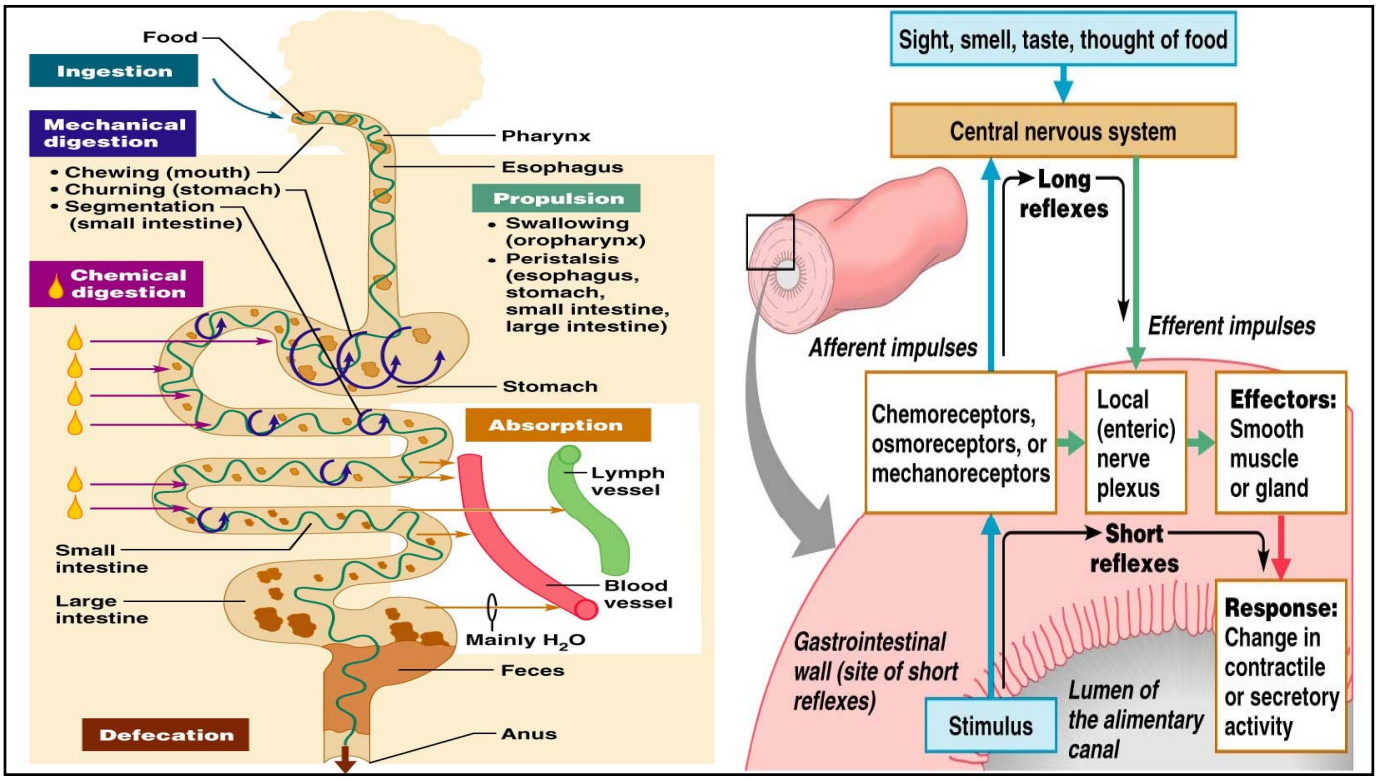
NEUROGENIC SECRETION:

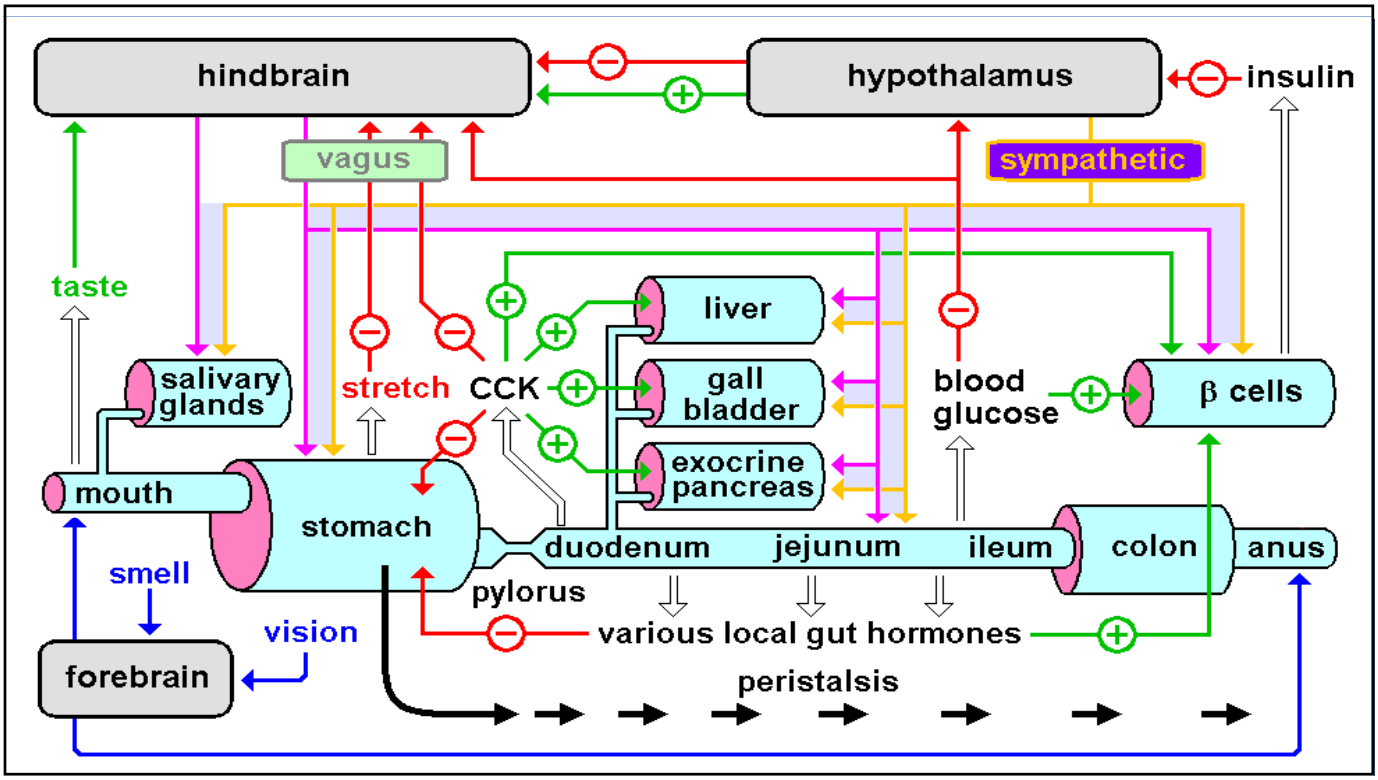
- Three secretomotor neurotransmitters for enterocytes:
  - **Substance P**
  - **ACh,** both preganglionic and postganglionic
  - **VIP,** Postganglionic
- Inhibitory neurons act on the preganglionics to prevent secretomotor excitation:
  - **Somatostatin**
  - **Sympathetics**
  - **Opioids:** Patients on opioids can become quite constipated and get a condition called "Narcotic Bowel."

Digestion, what is it?

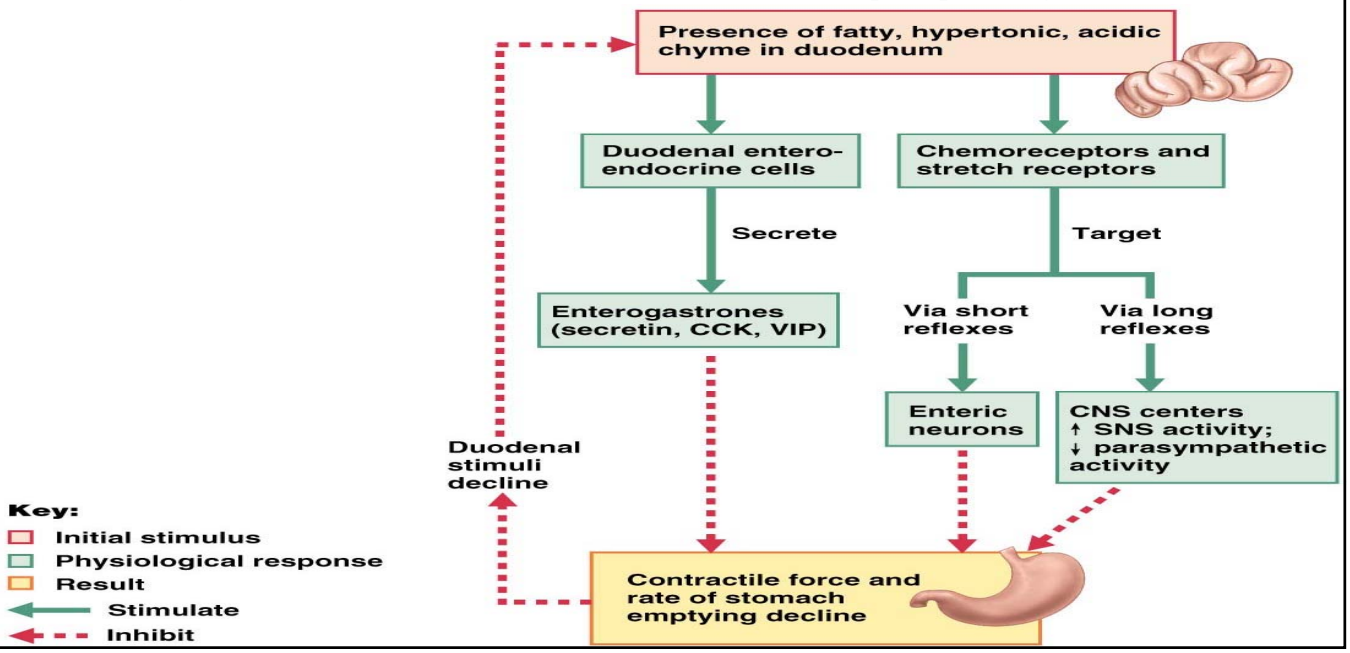
- Mechanical breakdown of fo
- Chemical breakdown of food
- Absorption of nutrients




Food
Ingestion
Mechanical digestion
• Chewing (mouth)
• Churning (stomach)
• Segmentation (small intestine)
Chemical digestion
Pharynx
Esophagus
Propulsion
• Swallowing (oropharynx)
• Peristalsis (esophagus, stomach, small intestine, large intestine)
Stomach
Absorption
Lymph vessel
Small intestine
Blood vessel
Large intestine
Mainly H_2O
Feces
Defecation
Anus
Sight, smell, taste, thought of food
Central nervous system
Long reflexes
Afferent impulses
Efferent impulses
Chemoreceptors, osmoreceptors, or mechanoreceptors
Local (enteric) nerve plexus
Effectors: Smooth muscle or gland
Short reflexes
Response: Change in contractile or secretory activity
Gastrointestinal wall (site of short reflexes)
Stimulus
Lumen of the alimentary canal


hindbrain
hypothalamus
insulin
vagus
sympathetic
taste
liver
salivary glands
stretch
CCK
gall bladder
blood glucose
β cells
exocrine pancreas
mouth
stomach
duodenum
jejunum
ileum
colon
anus
smell
pylorus
vision
various local gut hormones
forebrain
peristalsis

Regulation of Gastric Emptying

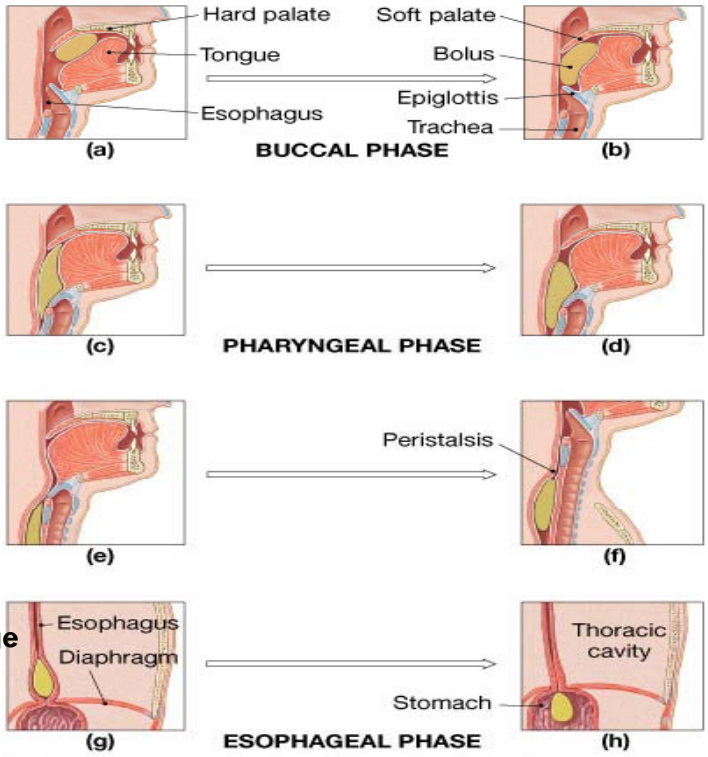


Gastrointestinal Tract Activities

- **Ingestion** – taking food into the digestive tract
- **Propulsion** – swallowing and peristalsis
  - Peristalsis – waves of contraction and relaxation of muscles in the organ walls
- **Mechanical digestion** – chewing, mixing, and churning food

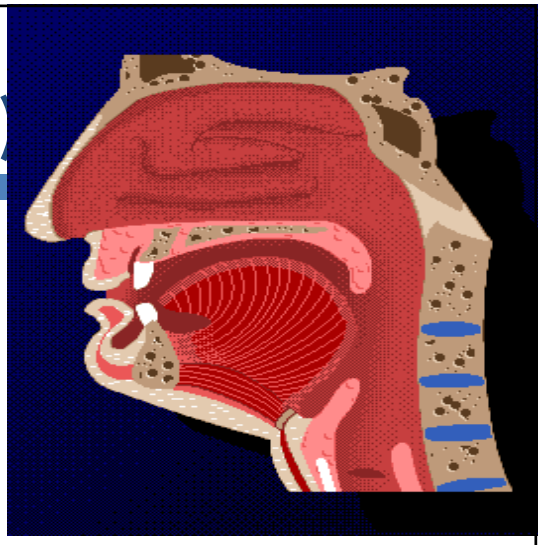
The Swallowing Process

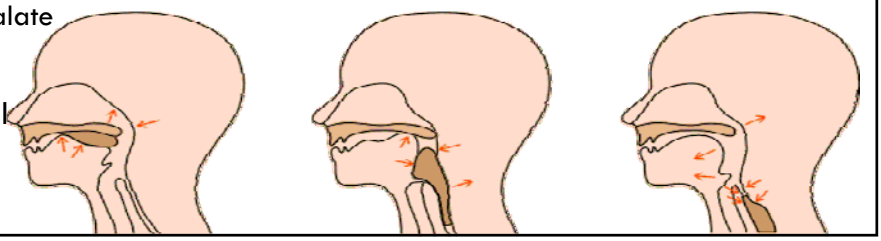
THREE STAGES:
A) ORAL STAGE - Voluntary stage
B) PHARYNGEAL STAGE - Involuntary stage
C) OESOPHAGEAL STAGE - Involuntary stage



Deglutition (swallowing)

- Sequence
  - Voluntary stage
    - Push food to back of mouth
  - Pharyngeal stage
    - Raise
      - Soft palate
      - Larynx + hyoid
      - Tongue to soft palate
  - Esophageal stage
    - Contract pharyngeal
    - Open esophagus
    - Start peristalsis



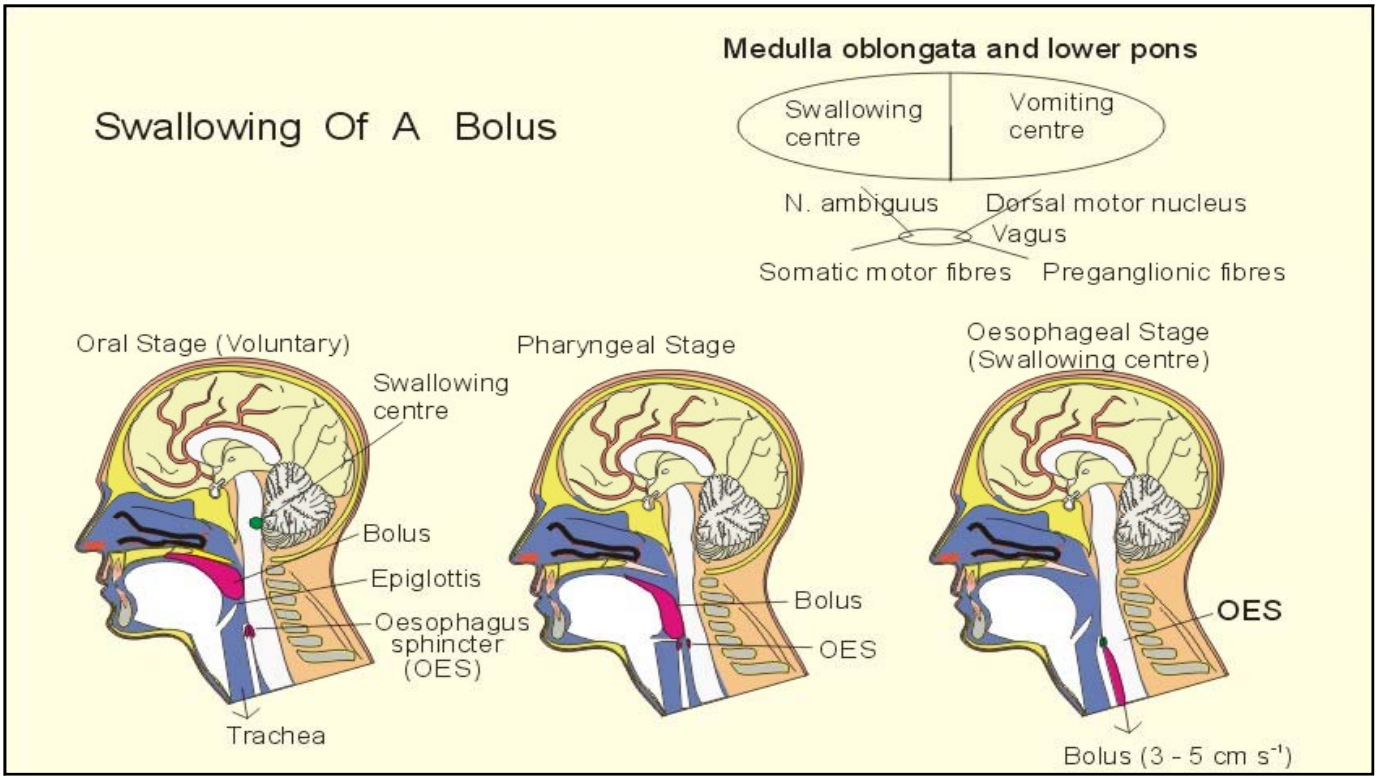


Deglutition (swallowing)

- Control
  - Nerves
    - **Glossopharyngeal**
    - **Vagus**
    - **Accessory**
  - Brain stem
    - Deglutition center
      - Medulla oblongata
      - Pons
  - Disorders
    - **Dysphagia**
    - **Aphagia**

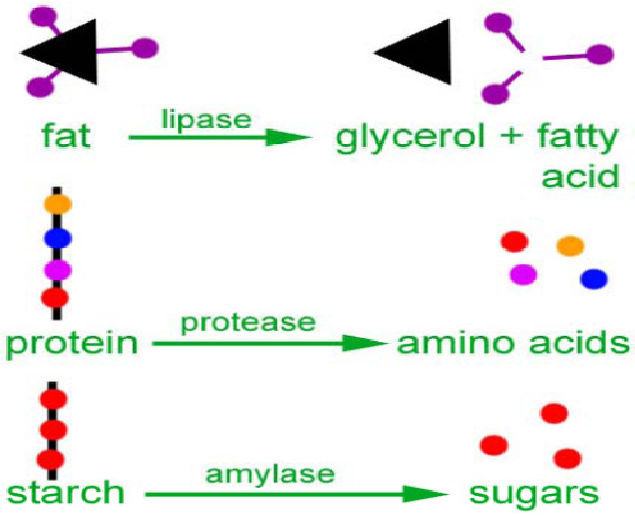
SWALLOWING REFLEX

Impulses travel in V, IX, X nerves to stimulate medulla,and efferent pass through V, VII, IX, X, XII nerves to pharynx and tongue



Gastrointestinal Tract Activities

- **Chemical digestion** – catabolic breakdown of food
- **Absorption** – movement of nutrients from the GI tract to the blood or lymph
- **Defecation** – elimination of indigestible solid wastes



Water Balance

- • Digestive tract receives about 9 L of water/day
- – .7 L in food, 1.6 L in drink, 6.7 L in secretions
- – 8 L is absorbed by small intestine and 0.8 L by large intestine
- • Water is absorbed by osmosis following the absorption of
- salts and organic nutrients
- • Diarrhea occurs when too little water is absorbed
- – feces pass through too quickly if irritated
- – feces contains high concentrations of a solute (lactose)

Absorption and Motility

- Transit time is 12 to 24 hours
  - – reabsorbs water and electrolytes
- Feces consist of water and solids (bacteria, mucus,
  - undigested fiber, fat and sloughed epithelial cells
- Haustral contractions occur every 30 minutes
  - – distension of a haustrum stimulates it to contract
- Mass movements occur 1 to 3 times a day
  - – triggered by gastrocolic and duodenocolic reflexes
- filling of the stomach and duodenum stimulates motility
- moves residue for several centimeters with each contraction

Absorption

The small intestine is the main site of absorption

•Most ***water-soluble nutrients*** such as monosaccharides, small fatty acids, and many amino acids are absorbed by either active transport or facilitated diffusion.

Once in the lining cells, they may pass freely into the numerous ***capillaries*** of the mucosa's connective tissue (the lamina propria).

The "finishing enzymes" (brush border enzymes) in the small intestine help to break up disaccharides and small chain polypeptides that are still just a wee bit to large to absorb through the membrane.

•***Fat-soluble nutrients*** cannot be absorbed so simply, and must be processed by the lining cells.

•After packaging lipids into little bubbles of membrane they are exuded from the cell and pass into lymphatic capillaries called ***lacteals*** in the villus.

• Like most nutrients, these will find themselves headed for the liver for processing.

GI Tract

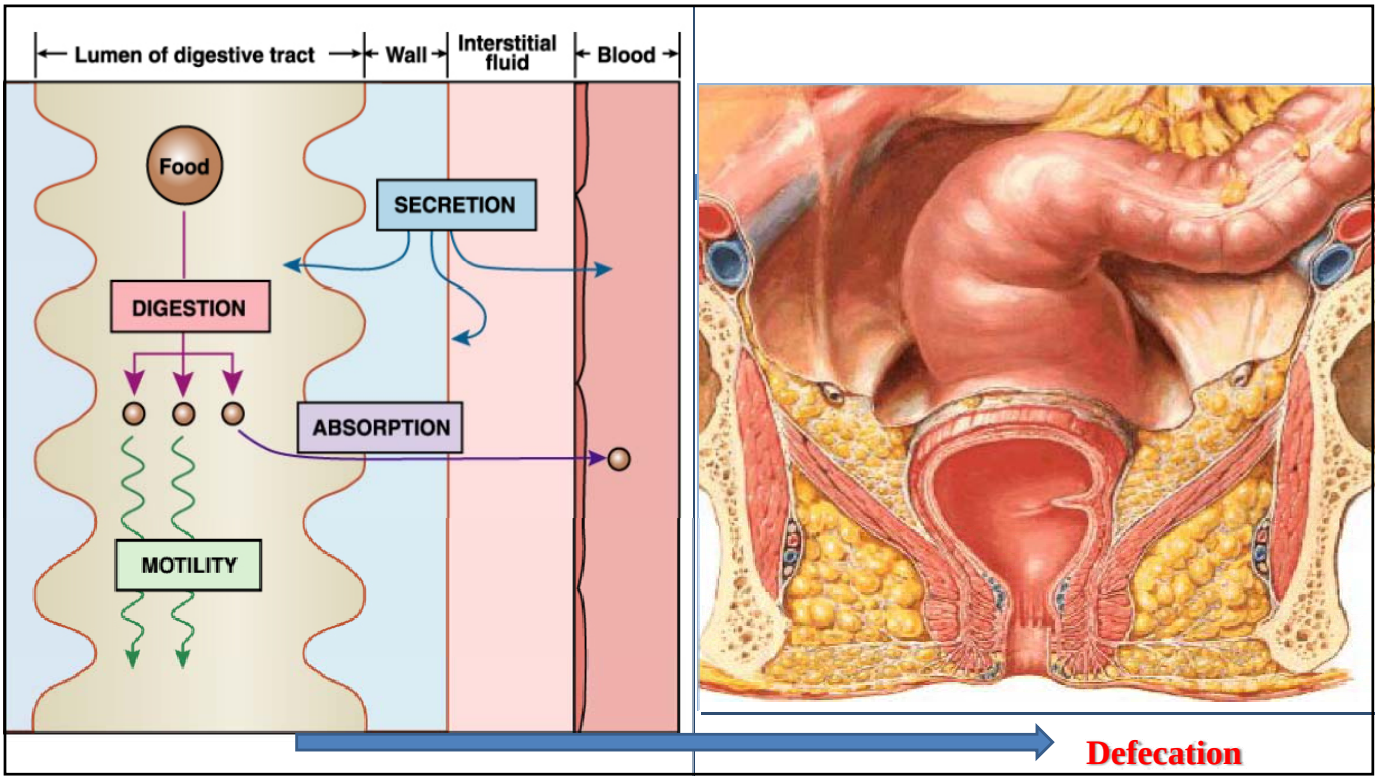
- External environment for the digestive process
- ***Regulation of digestion involves:***
  - **Mechanical and chemical stimuli** – stretch receptors, osmolarity, and presence of substrate in the lumen
  - **Extrinsic control** by CNS centers
  - **Intrinsic control** by local centers

Receptors of the GI Tract

- **Mechano- and chemoreceptors respond to:**
  - **Stretch, osmolarity, and pH**
  - **Presence of substrate, and end products of digestion**
- They initiate reflexes that:
  - Activate or inhibit digestive glands
  - Mix lumen contents and move them along

Nervous Control of the GI Tract

- **Intrinsic controls**
  - Nerve plexuses near the GI tract initiate short reflexes
  - Short reflexes are mediated by local enteric plexuses (gut brain)
- **Extrinsic controls**
  - Long reflexes arising within or outside the GI tract
  - CNS centers and extrinsic autonomic nerves



TYPES OF MOTILITY:

- **PERISTALSIS:** Propulsion of material in the **aboral** (away from mouth) direction.
  - Rate of peristalsis varies in region, but peristaltic generally gets slower as we move down the tract.
  - Peristalsis occurs by *segmental hyperpolarization followed by depolarization of muscle.*
  - Mechanism: Bolus of food in a particular location stimulates mechanoreceptors and chemoreceptors in the GI lumen, ultimately resulting in peristalsis:
    - *Relaxation* of the muscle occurs distal to the bolus, so that the food can go forward. This is mediated by VIP / NO.
      - Contraction of *Longitudinal Muscle* layer also occurs distal to bolus, because longitudinal contraction causes widening of the GI lumen.
    - *Contraction* of the muscle occurs proximal to the bolus, in order to propel the bolus forward.
    - There is a basal level of VIP inhibition in the muscle, and a bolus of food turns off this inhibition: distension of lumen by a bolus will cause *inhibition of release of VIP / NO* ------> contraction of proximal region.
- **RHYTHMIC SEGMENTATION:** Mixing and churning of materials without propelling them forward in the tract.
  - Only involved the circular muscle -- not longitudinal
  - Common in small and large intestine
- **TONIC CONTRACTION**: Blocking of the passage of material, as in **sphincters**.
  - Tonic Contraction *is myogenic* -- it doesn't depend on innervation.

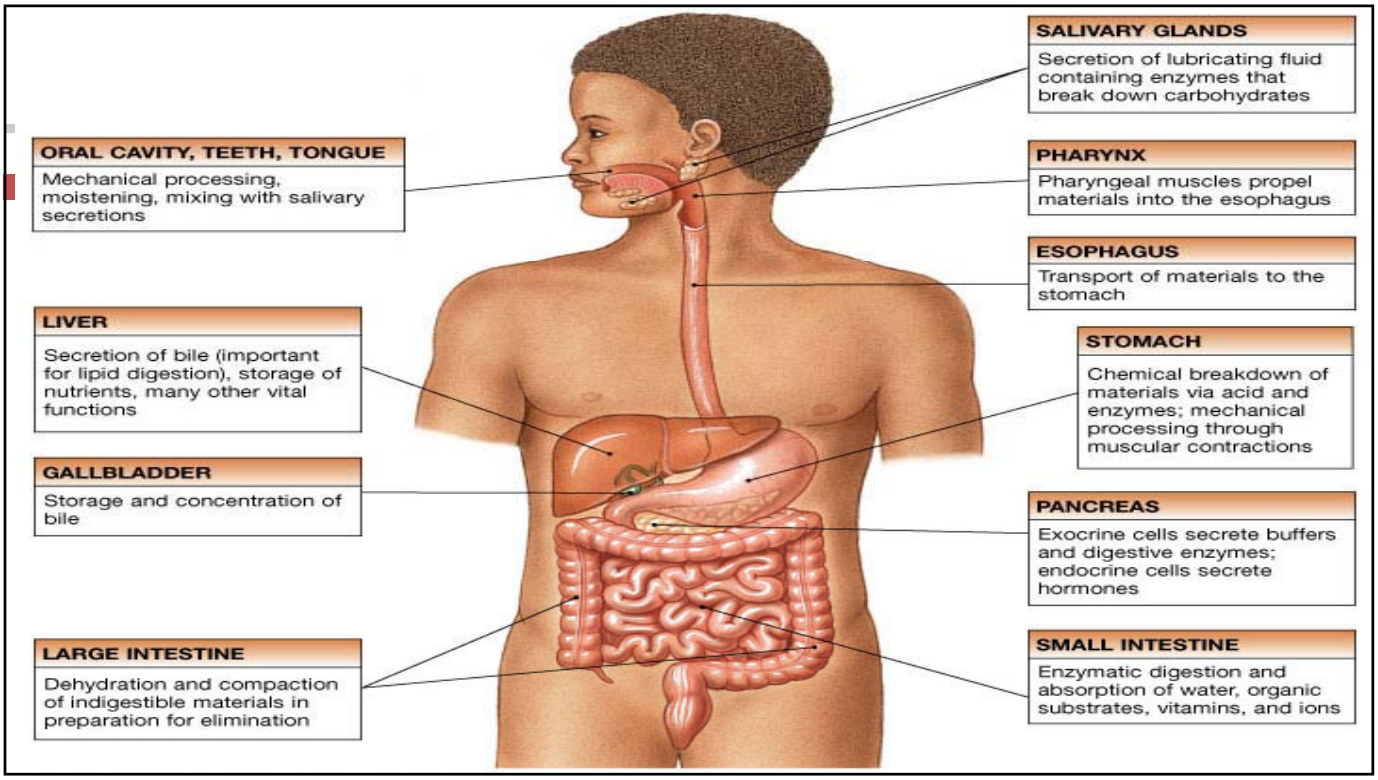
Digestive Enzymes

food stuff	first site	agents	products	absorbed form
carbohydrate	mouth	amylase	maltose	monosaccharide
protein	stomach	pepsin & HCl	peptides	amino acids
fats	duodenum	lipase & bile salts	fatty acids &	FA & glycerol

Digestive Enzymes

- Are secreted by:
  - salivary glands
  - tongue
  - stomach
  - pancreas
- Break molecular bonds in large organic molecules:
  - carbohydrates, proteins, lipids, and nucleic acids
  - in a process called hydrolysis

- Are divided into classes by targets:
  - carbohydrases:
    - break bonds between simple sugars
  - proteases:
    - break bonds between amino acids
  - lipases:
    - separate fatty acids from glycerides



Functions of the digestive system

- Ingestion
- Mechanical processing
- Digestion
- Secretion
- Absorption
- Excretion

Movement of digestive materials

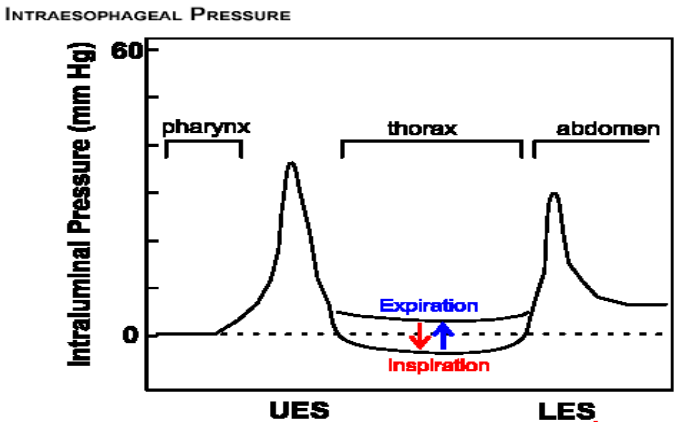
- Visceral smooth muscle shows rhythmic cycles of activity
  - Pacemaker cells
- Peristalsis
  - Waves that move a bolus
- Segmentation
  - Churn and fragment a bolus

Esophagus

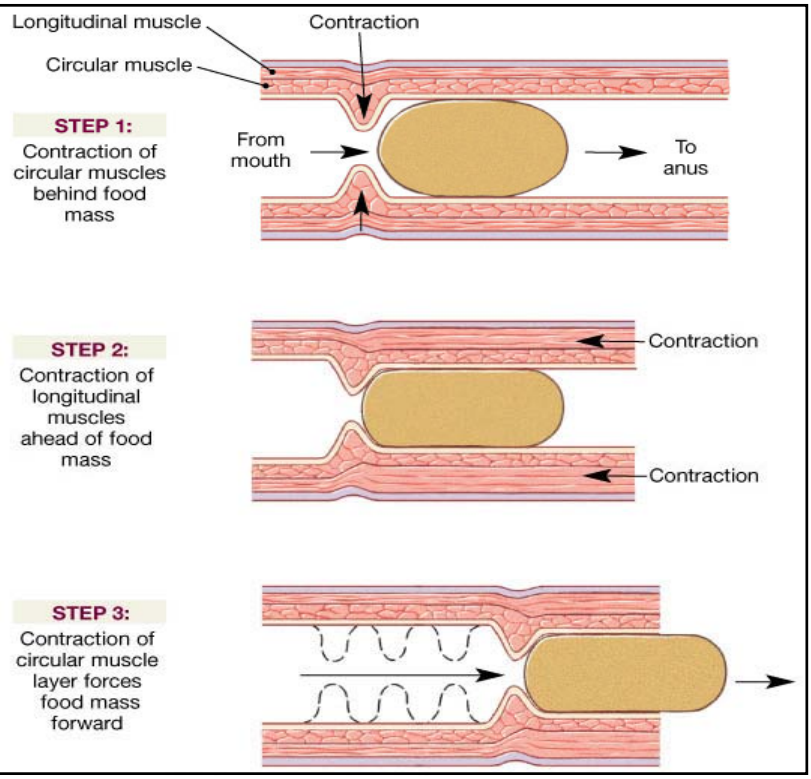
- Function – food passageway
- Location – from pharynx→stomach
- 1. passes thru mediastinum
- 2. behind the trachea
- 3. moves through diaphragm
- Esophageal sphincter – distal end of esophagus prevents regurgitation of food

Esophageal Peristalsis

- 1° Peristalsis:
  - Initiated by swallowing (not after vagotomy)
- 2° Peristalsis:
  - Caused by residual food in esophagus
- Vagal nuclei run the show (ambiguus, DMN)
- SM Peristalsis persists after vagotomy (enteric NS takes over)

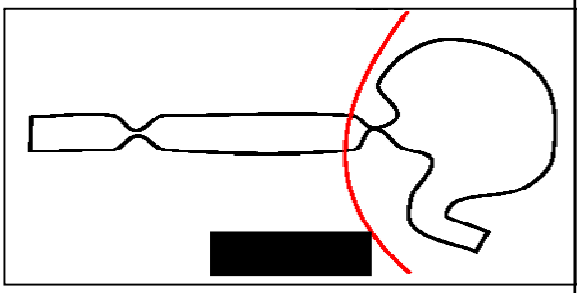


Peristalsis



Diseases of the Esophagus

- Achalasia:
  - Stenosis of LES, dilation of body of esophagus
    - "bird-beak" appearance on barium study
- Hiatal Hernia
  - LES protrudes into thoracic cavity
    - LES tends to be patent due to negative pressure in thoracic cavity
- LES Tone:
  - Increased by Ach, Gastrin
  - Decreased by Sympathetics, PGE_1



Control of the digestive system

- Movement of materials along the digestive tract is controlled by:
  - Neural mechanisms
    - Parasympathetic and local reflexes
  - Hormonal mechanisms
    - Enhance or inhibit smooth muscle contraction
  - Local mechanisms
    - Coordinate response to changes in pH or chemical stimuli

The Regulation of Digestive Activities

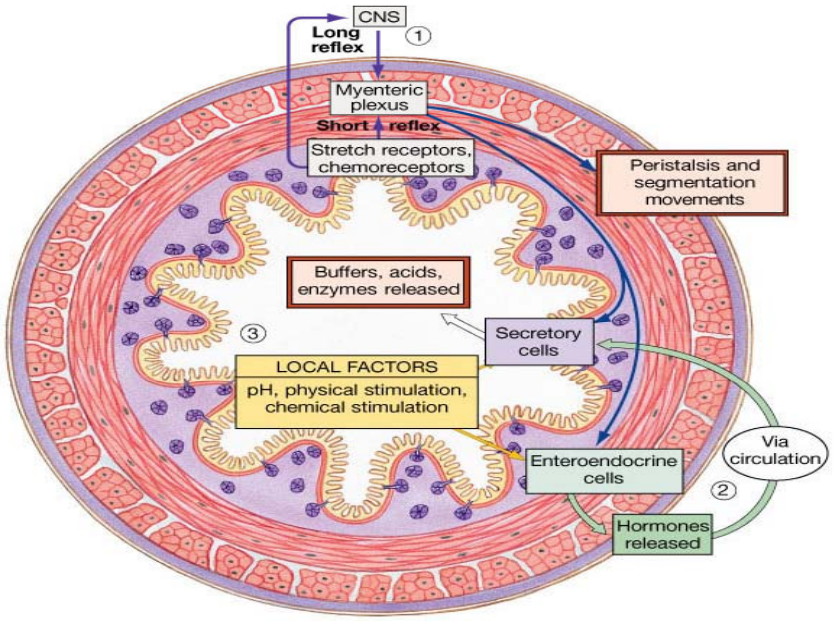


Figure 24.5

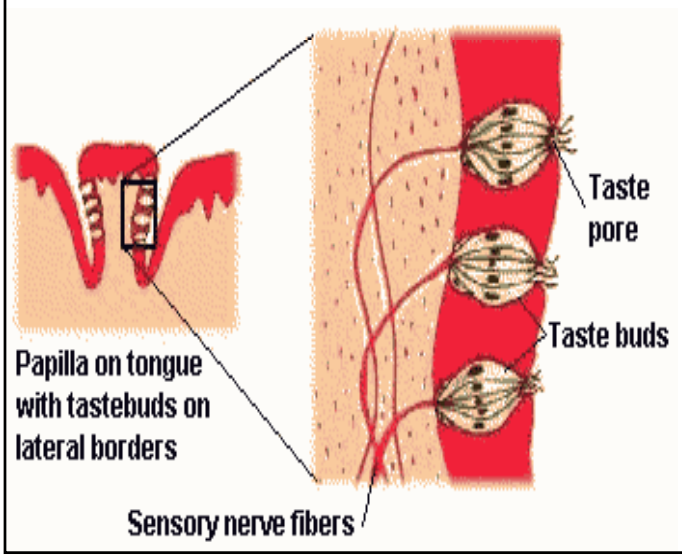
Functions of Saliva

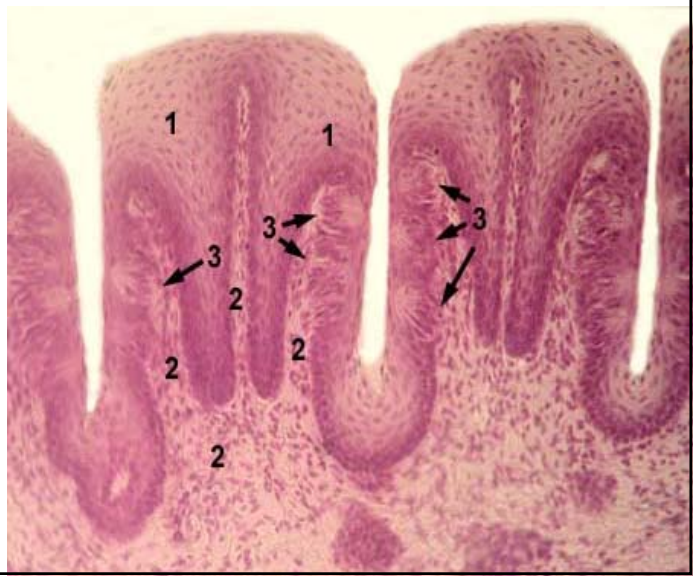
- ☐ Moistens ingested food and helps turn it into a semisolid bolus that is more easily swallowed.
- ☐ Moistens and cleanses the oral cavity structures.
- ☐ First step in chemical digestion occurs when amylase in saliva begins to break down carbohydrates.
- ☐ Contains antibodies and an antibacterial element called lysozyme that help inhibit bacterial growth in the oral cavity.
- ☐ Watery medium into which food molecules are dissolved so taste receptors can be stimulated.

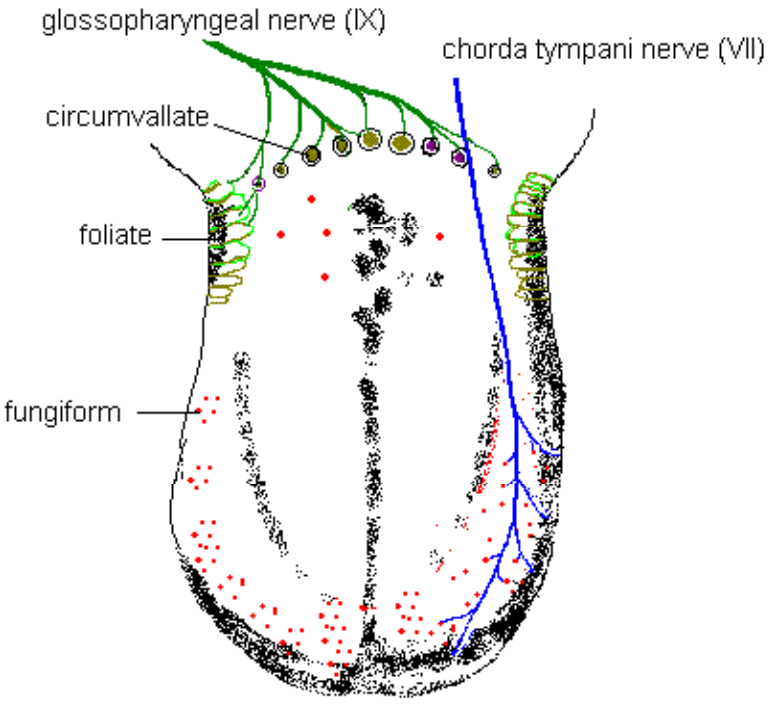
Salivary glands – what is their function?

- Two main purposes:
- 1. secrete saliva – chemical digestion
- 2. solvent – dissolves food – so can taste cleanses mouth and teeth

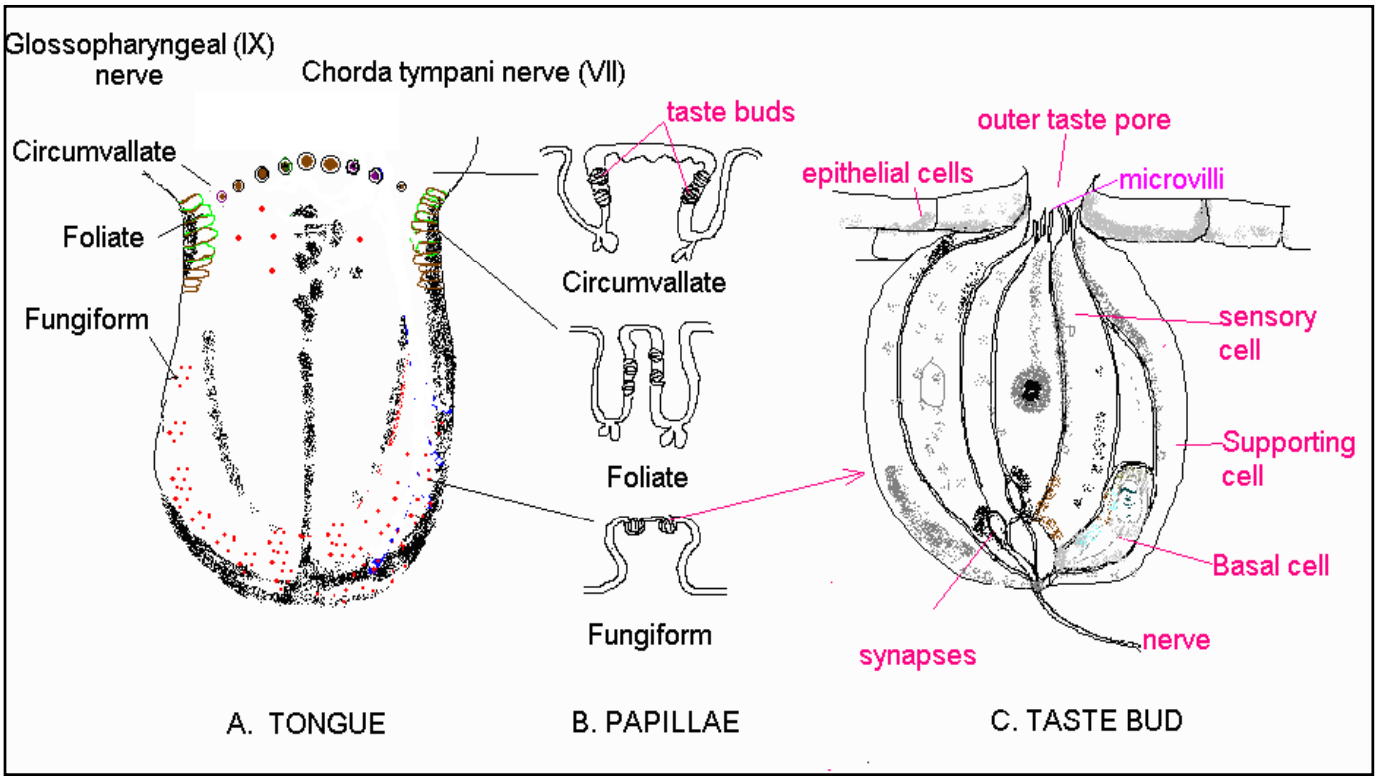
Taste physiology







- **Cells in taste bud**
- *Supporting cells* - contain microvilli, appear to secrete substances into lumen of taste bud.
- *Sensory receptor cell* - has peg-like extensions projecting into lumen. These contain the sites of sensory transduction.
- *Basal cells* - these differentiate into new receptor cells. They are derived from surrounding epithelium. The cells are continuously renewed every 10 days or so.

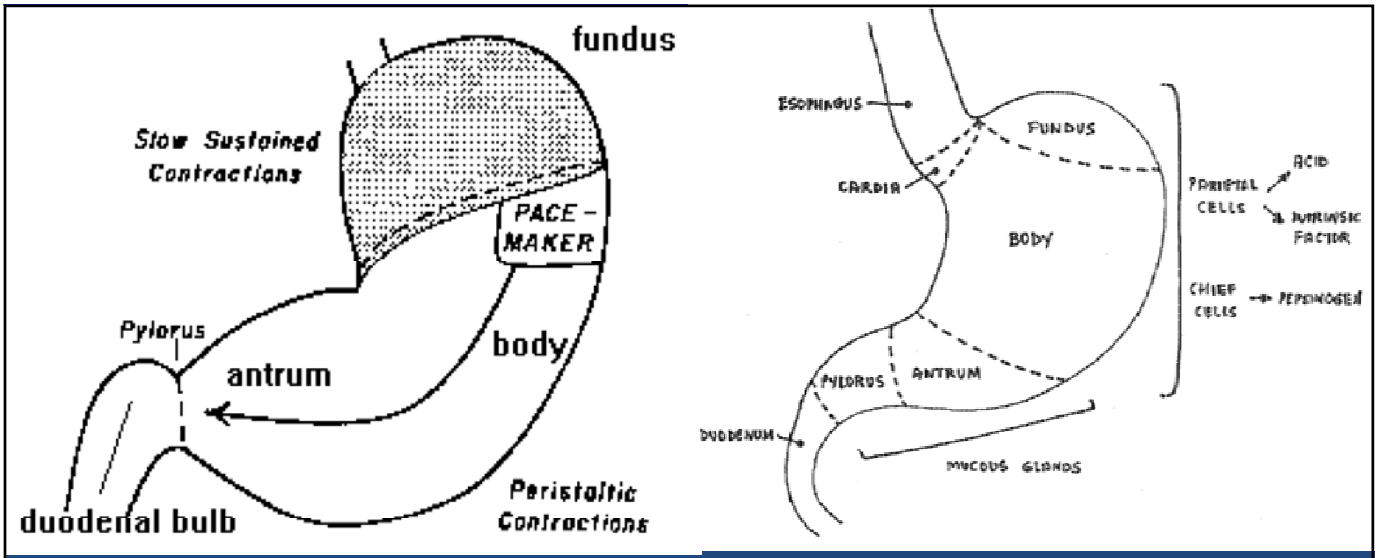


Taste physiology

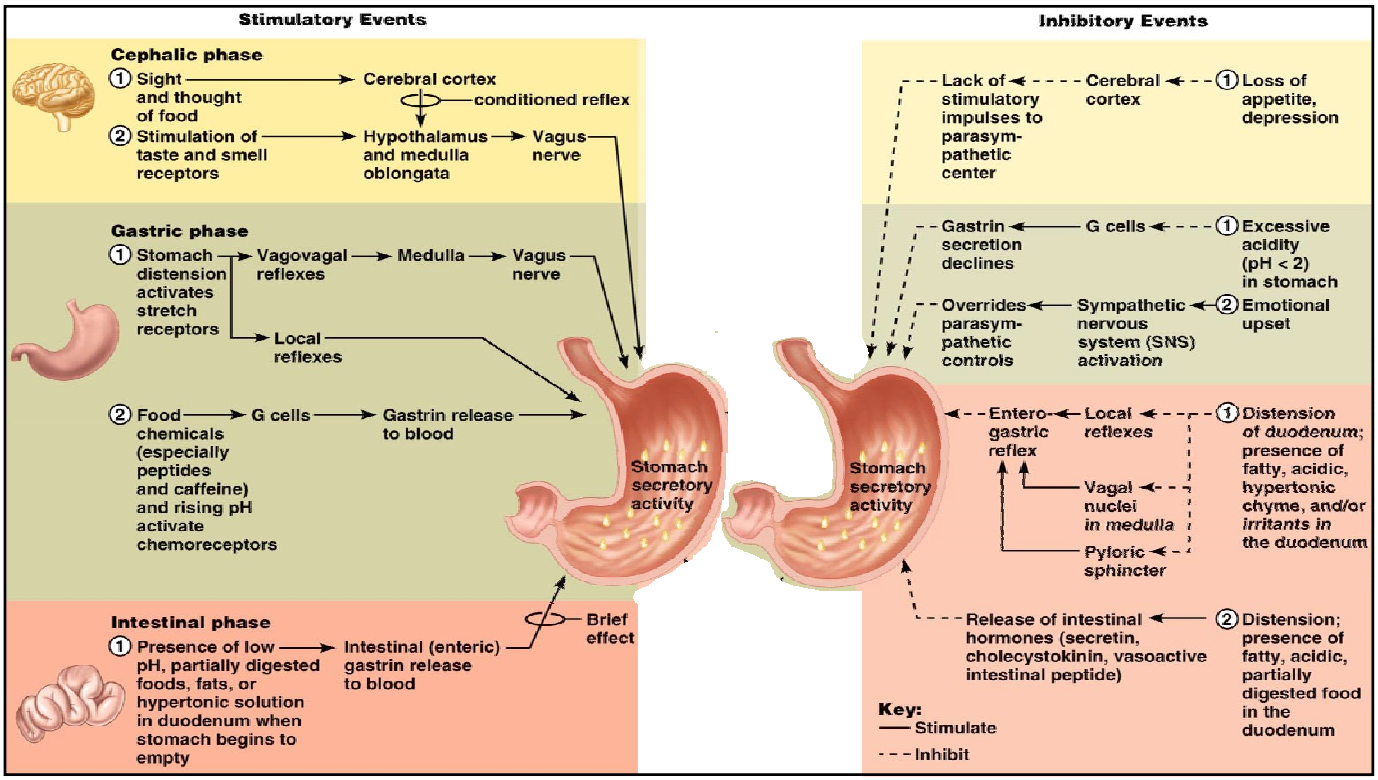
- The sense of taste is equivalent to excitation of taste receptors, and receptors for a large number of specific chemicals have been identified that contribute to the reception of taste. Despite this complexity, five types of tastes are commonly recognized by humans:
- Sweet - usually indicates energy rich nutrients
- Umami - the taste of amino acids (e.g. meat broth or aged cheese)
- Salty - allows modulating diet for electrolyte balance
- Sour - typically the taste of acids
- Bitter - allows sensing of diverse natural toxins

Examples of some human thresholds

Taste	Substance	Threshold for tasting
Salty	NaCl	0.01 M
Sour	HCl	0.0009 M
Sweet	Sucrose	0.01 M
Bitter	Quinine	0.000008 M
Umami	Glutamate	0.0007 M

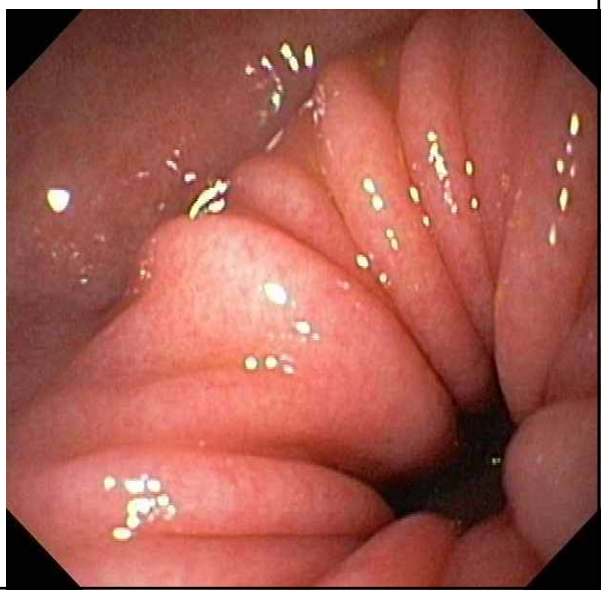


STOMACH PHYSIOLOGY



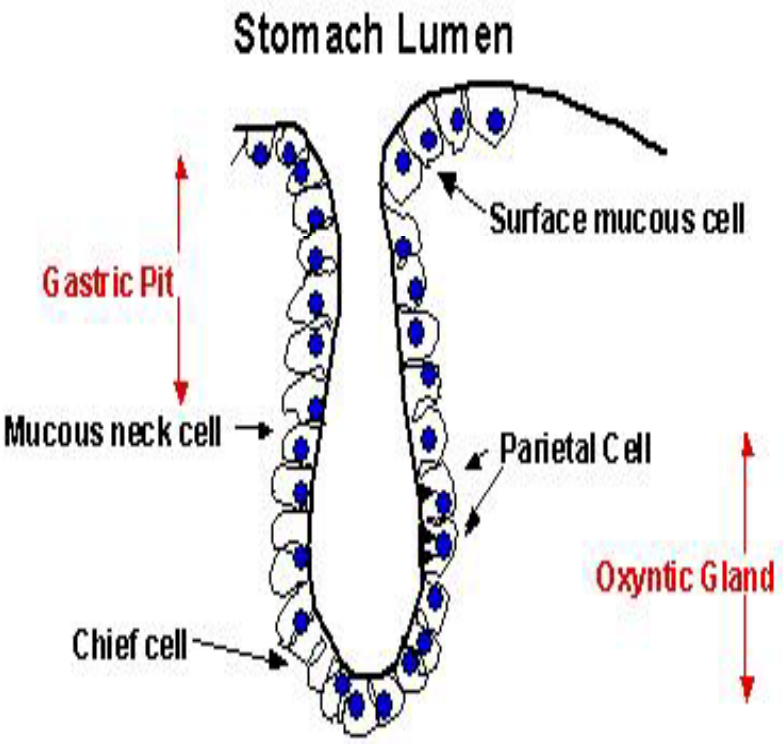
Gastric Secretions

- 3 Main cells:
  1. Mucous cells – mucous
  2. chief – digestive enzymes
     a. Pepsin – digests protein
     b. Alkaline substance – protects lining
     c. Intrinsic factor – absorbs Vitamin B12
  3. parietal cells → hydrochloric acid



Gastric Secretion

- Stomach secretes water, electrolytes (H+, K+, Na+, Cl-, HCO3-),
- enzymes with activity at acid pH (pepsin, lipase) and glycoproteins (intrinsic factor, mucins)



Gastric anatomy and physiology

Gastric Gland Structure

Gastric Pit

Gastric Gland

Generic Stomach Gland

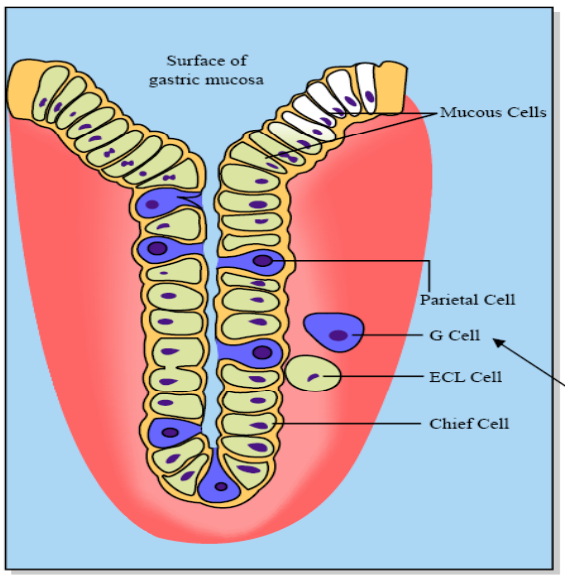


Figure by MIT OCW.

- 2 glandular elements in the stomach
  - ~ Gastric (oxyntic) gland
  - ~ Pyloric (antral) gland
- **Gastric gland** - body and fundus
  - ~ Oxyntic (parietal) cells
    - -HCl
    - - Intrinsic factor (B12 absorption)
  - ~ Peptic (chief) cells - pepsinogen
  - ~ ECL cells (enterochromafin-like): histamine
  - ~ Mucous secreting cells
- **Pyloric gland** - antrum
  - ~ Shallower pit
  - ~ Gastrin (G) cells - gastrin
  - ~ Peptic cells - pepsinogen (minor)
  - ~ ECL cells (enterochromafin-like): histamine
  - ~ Mucous secreting cells

Stomach

- J shaped
- Can hold about a liter

Functions:

- 1. receives food
- 2. mixes food with gastric juice
- 3. moves food to small intestine

Mixing in the Stomach

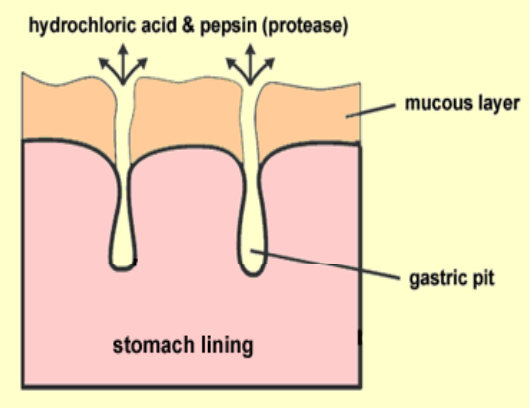
- Chyme – semifluid made by mixing food with digestive juices.

1. pushed toward small intestine
2. water moves right through
3. Movement thru fastest to slowest:

carbs→proteins→fats (4-6hrs for fats)

Microscopic Anatomy

- Parietal cells
  - Location- neck of gastric pit
  - Stimulated by Ach, Histamine and Gastrin
  - Secretes HCl + Intrinsic Factor
- Chief Cells
  - Location- base of gastric pit
  - Stimulus- Vagal
  - Secretes Pepsinogen (eventually leads to pepsin- digestive enzyme)



Microscopic Anatomy

- Antral Glands
  - Gastrin cells
    - Location- mucosa of distal stomach
    - Stimulus- amino acids
    - Secretion- Gastrin (stimulates HCl production by way of parietal cells)
  - Somatostatin
    - Location- mucosa of distal stomach + Duodenum
    - Stimulus- HCl or low pH in duodenum
    - Actions- Inhibits gastric emptying, Pancreatic secretions, and gallbladder contraction

TABLE 15.4 HORMONES OF THE DIGESTIVE TRACT

HORMONE	SOURCE	FUNCTION
Gastrin	Gastric cells, in response to food	Causes gastric glands to increase their secretory activity
Cholecystokinin	Intestinal wall cells, in response to proteins and fats in the small intestine	Causes gastric glands to decrease their secretory activity and inhibits gastric motility; stimulates pancreas to secrete fluid with a high digestive enzyme concentration; stimulates gallbladder to contract and release bile
Secretin	Cells in the duodenal wall, in response to acidic chyme entering the small intestine	Stimulates pancreas to secrete fluid with a high bicarbonate ion concentration

- Cardia – mucus, endocrine and undifferentiated cells
- Fundus & body – oxyntic glands
  - Parietal, chief, endocrine, mucus neck, undifferentiated cells
- Antrum & pylorus – pyloric glands
  - Endocrine, mucus neck, G-cells

- Endocrine cells
  - G cells – secrete gastrin
- Paracrine cells
  - D cells – secrete somatostatin
  - Enterochromaffin-like (ECL) cells – secrete histamine

Parietal Cell

- Stimulated by histamine, gastrin, acetylcholine
- Inhibited by somatosatin, prostaglandins

Somatostatin

- Secreted by D cells
- Stimulated by CCK
- Effects H^+ secretion via inhibitory effects on oxyntic ECL cells and pyloric G cells
- D cell in pylorus stimulated by acid

CCK

- Produced by duodenal endocrine cells in response to dietary fatty acids and amino acids
- In vitro stimulates parietal cells
- In vivo inhibits acid production through D cells

Secretin

- Produced by duodenal S cells in response to H^+
- Inhibits gastric acid secretion, stimulates pancreatic HCO_3^- production

Pepsinogens

- Pepsins cleave peptide bonds formed by phenylalanine and tyrosine
- PG secretion stimulated by acetylcholine analogs, histamine, gastrin, secretin
- Inhibited by somatostatin

Intrinsic Factor

- Secreted by parietal cells
- Binds cobalamin(B_{12}) to facilitate absorption
- 2 cobalamin binding proteins – IF/R
- Initially binds to cobalamin R in acidic stomach then is cleaved in duodenum and binds to IF
- Attaches to ileal mucosa
- B_{12} malabsorption may result from IF deficiency, achlorhydria or hypochlorhydria, bacterial overgrowth, pancreatic insufficiency, ileal receptor defect, ileal disease, ileal resection

Hormonal regulation:

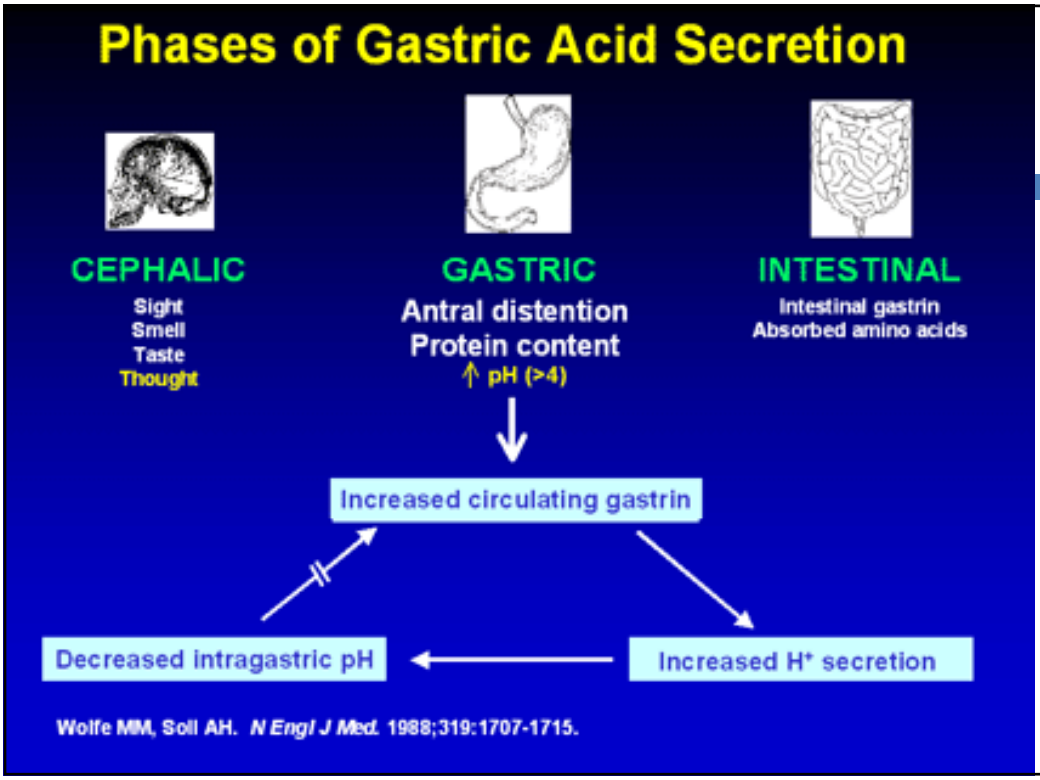
gastrin	distention of stomach, vagus	stomach wall	release gastric secretions
secretin	acid in duonenum	duodenum	release pancreatic chyme
cholecystokinin	fatty acids in duodenum	duodenum	1) slow peristalsis 2) contract gall bladder 3) suppress appetite

Physiology

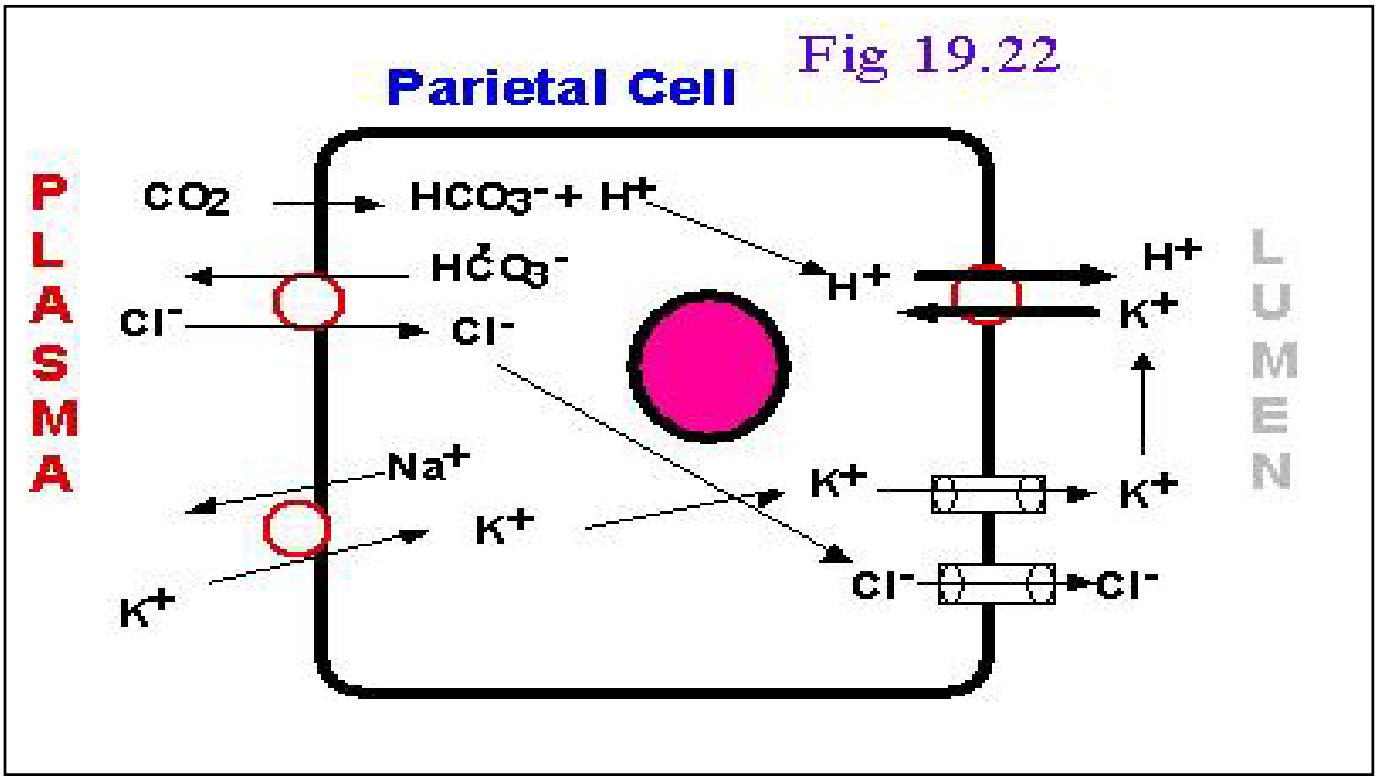
- Gastrin
  - Most important stimulus is a meal
    - amino acids that results from proteolysis
    - Fat and carbohydrates are not stimuli for gastrin secretion
    - Gastric distention that occurs from a meal will stimulate cholinergic neurons thereby releasing gastrin
    - Gastrin will then prompt Parietal cell to secrete HCl
  - Once Gastric distention diminishes, VIP-containing neurons are activated causing stimulation of somatostatin, thus attenuating Gastrin secretion
  - Overall, a lumen pH >3.0 will potentiate gastrin release, whereas a pH <3.0 will inhibit its release

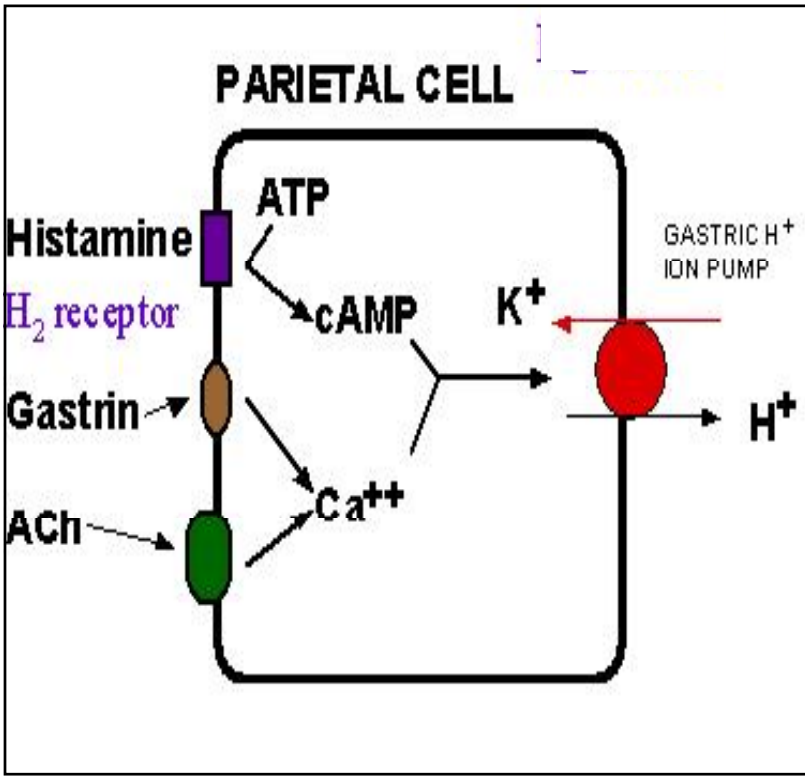
Physiology

- Somatostain
  - Like Gastrin, plays an integral role in gastric physiology
  - Also, used for important therapeutic applications in treatment of digestive diseases
    - Main stimulus is a low or acidic (<3.0)luminal pH
      - Many peptides have shown to release somatostatin
        - Ex. Secretin, Cholecystokinin and gastrin
    - In contrast, stimulation of Vagal nerves along with cholinergic neurons inhibit somatostatin
  - Overall, the most important gastric function of somatostatin is to regulate acid secretion and gastrin release



Gastric Acid Secretion





Histamine

From enterochromafin-like cells (ECL cells) in the gastric mucosa

- produce, store, & release histamine
- activated by ACh, gastrin, & secretagogues

Inhibition of Gastric Secretion

- Important for protection of duodenum
- **Gastric pH < 3 ---> gastric D cells release somatostatin which inhibits gastrin release**
- Acid in duodenum ---> **secretin & CCK---> inhibits gastric secretion and motility**
- Acid, fats, hyper-osmotic solutions in the duodenum ---> release of enterogastrones ---> inhibit gastric motility and secretion
-
- Gastric Inhibitory Peptide (GIP) from duodenum ---> **inhibits parietal cell function**
-

- **Inhibitors of Gastric Secretion**
  - **GIP**
  - **CCK**
  - **Secretin**

Gastric Acid Secretion

- Basolateral membrane of the parietal cell contains specific receptors for the three major stimulants of acid production
  - Histamine
  - Gastrin
  - Acetylcholine
- Each stimulant has its own 2nd messenger system which allows for stimulation of the parietal cell

Gastric Acid Secretion

- Humans normally secrete 2 to 5 mEq/h of HCl in the fasting state, constituting basal acid secretion
  - Both Vagal tone and ambient Histamine secretion are presumed to regulate basal acid secretion
  - Gastrin is not thought to play a role in basal acid secretion
  - Therefore, a Vagotomy or use of H2 blockers (ex. Cimetidine) will decrease basal acid production

Gastric Acid Secretion

- Stimulated acid secretion begins with
  - Cephalic phase
    - Thought, sight or smell of food stimulates acid secretion
    - Mediated by Vagal stimulation
  - Vagal discharge
    - Directs the cholinergic mechanism for stimulation
      - Can be inhibited by Atropine (anticholinergic)
    - Inhibits release of somatostatin
      - Vagal effects inhibit tonic inhibition that is provided by somatostatin

Gastric Acid Secretion

- Gastric Phase
  - Begins when food enters the stomach
    - The following are responsible for stimulation of acid secretion
      - Presence of partially hydrolyzed food constituents
      - Gastric distention
    - Gastrin is the most important mediator of this phase
  - Ends when Antral muscosa is exposed to acid
    - When luminal pH is <2.0 in the antrum, gastrin release stops
    - Somatostatin release is increased
- Entry of digestive products into the intestine begins the intestinal-phase inhibition of gastric acid secretion

Gastric Acid Secretion

- Intestinal Phase
  - Also, releases HCl by way of Gastrin
  - Releases secretin to inhibit Gastrin which ultimately decreases Acid production

Other Factors

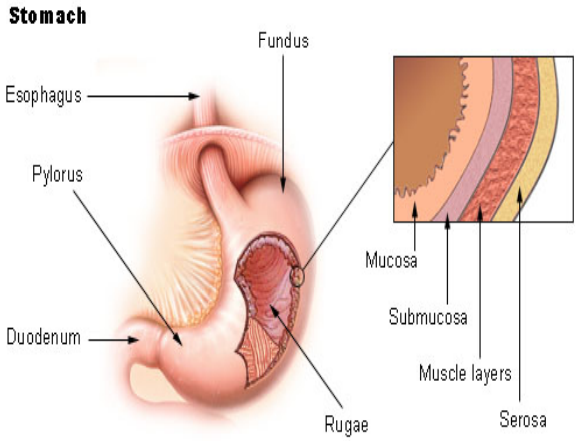
- Pepsin
  - Secreted from gastric chief cells
  - Contributes to the overall coordination of the digestive process
  - Main function is to initiate protein digestion, usually is incomplete
    - Partially hydrolyzed protein by pepsin are important signals for release of
      - Gastrin
      - Cholecystokinin

Other Factors

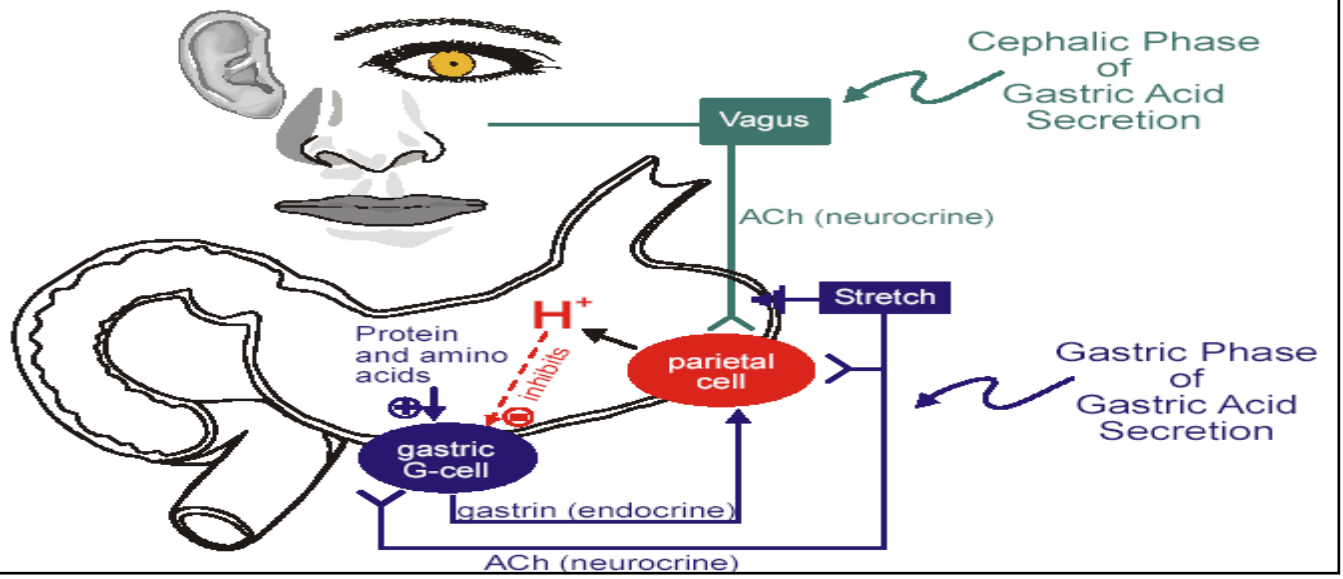
- Intrinsic Factor (IF)
  - Located in the parietal cells (oxyntic gland)
  - Main function is to absorb cobalamin (Vitamin B12) form ileal mucosa and then transported to the liver
  - Secretion of IF is similar to acid secretion
    - stimulated
      - Ach
      - Histamine
      - Gastrin

Other Factors

- Bicarbonate
  - Secreted from the gastric mucosa
  - Theory is that bicarbonate is secreted to maintain a neutral pH at the mucosal surface, even if acidic in lumen
  - Cholinergic agonist, vagal nerve stimulation have been shown to increase gastric bicarbonate production

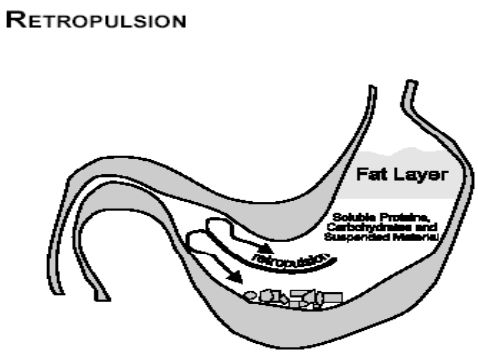


Acid Regulation in the Stomach



Gastric Emptying

- Contraction in the stomach
  - Orad <<<< Caudad (3/minute)
  - Primarily peristaltic
- Solid food is usually forced back into stomach for mixing
- Duodenum contracts much more often but is phasic (pseudosphincter)



INTESTINAL PHYSIOLOGY

Main Functions of Small Intestine

Digestion - various enzymes:

- 1. peptidases – protein digestion
- 2. *sucrase*, maltase and lactase – sugar digestion
- 3. *lipase* – fat digestion

Absorption – performed by villi (small fingerlike projections)

Release of waste to large intestine

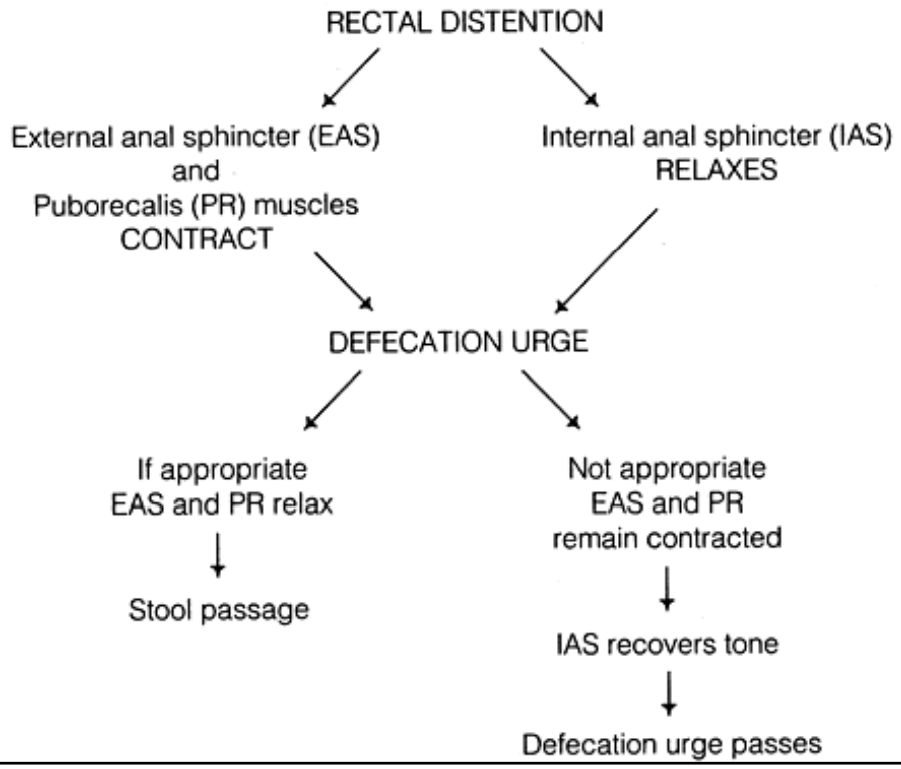
Functions of Large Intestine

- Absorbs water and electrolytes
- Contain intestinal flora (bacteria) – break down some of the molecules not broken down in the small intestine

a. Bacteria use the materials for energy they make certain vitamins like K, thiamine, riboflavin and B12 – absorbed through intestine wall

Defecation

- Presence of food in the stomach:
  - Activates the gastrocolic reflex
  - Initiates peristalsis that forces contents toward the rectum
- Distension of rectal walls caused by feces:
  - Stimulates contraction of the rectal walls
  - Relaxes the internal anal sphincter
- Voluntary signals stimulate relaxation of the external anal sphincter and defecation occurs



Defecation cycle,

- is normally a combination of both voluntary and involuntary processes.
- The defecation cycle is the interval of time between the completion of one bowel movement, and the completion of the following bowel movement.
- At the start of the cycle, the rectum ampulla (anatomically also: *ampulla recti*) acts as a temporary storage facility for the unneeded material.
- As additional fecal material enters the rectum, the rectal walls expand.
- A sufficient increase in fecal material in the rectum causes stretch receptors from the nervous system located in the rectal walls to trigger the contraction of rectal muscles, relaxation of the internal anal sphincter and an initial contraction of the skeletal muscle of the external sphincter.
- The relaxation of the internal anal sphincter causes a signal to be sent to the brain indicating an urge to defecate.

If this urge is not acted upon, the material in the rectum is often returned to the colon by reverse peristalsis where more water is absorbed, thus temporarily reducing pressure and stretching within the rectum.

The additional fecal material is stored in the colon until the next mass 'peristaltic' movement of the transverse and descending colon.
If defecation is delayed for a prolonged period the fecal matter may harden, resulting in constipation.
Once the voluntary signal to defecate is sent back from the brain, the final phase of the cycle begins.
The rectum now contracts and shortens in peristaltic waves, thus forcing fecal material out of the rectum and out through the anal canal.
The internal and external anal sphincters along with the puborectalis muscle allow the feces to be passed by pulling the anus up over the exiting feces in shortening and contracting actions.

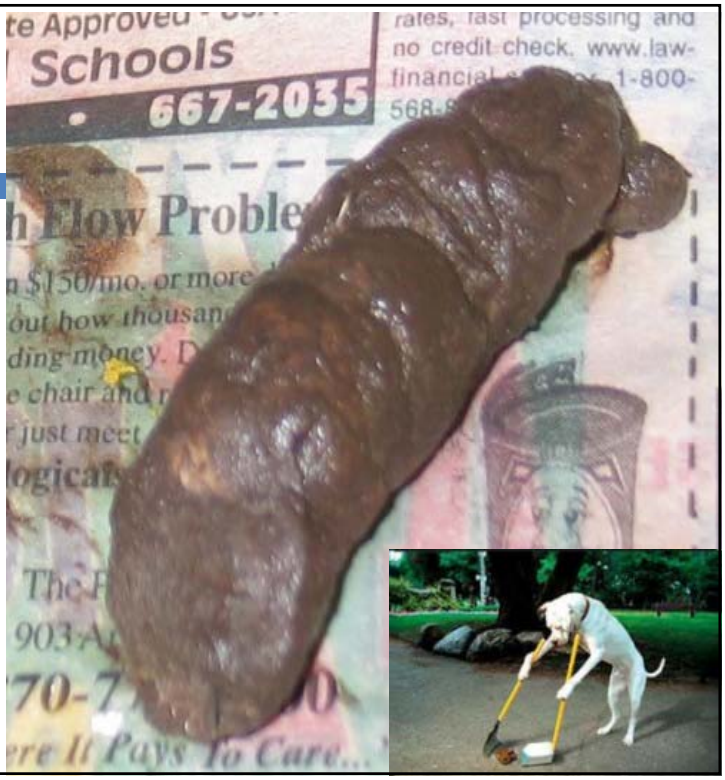
Defecation is normally assisted by taking a deep breath and trying to expel this air against a closed glottis (Valsalva maneuver).
This contraction of expiratory chest muscles, diaphragm, abdominal wall muscles, and pelvic diaphragm exert pressure on the digestive tract.
Ventilation at this point temporarily ceases as the lungs push the chest diaphragm down in order to exert the pressure.

Cardiovascular aspects
During defecation, the thoracic blood pressure rises, and as a reflex response the amount of blood pumped by the heart decreases.
Death has been known to occur in cases where defecation causes the blood pressure to rise enough to cause the rupture of an aneurysm or to dislodge blood clots
Also, in release of the Valsalva maneuver blood pressure falls, this coupled often with standing up quickly to leave the toilet results in a common incidence of blackouts in this situation.

Neurological aspects
•When defecating, the external sphincter muscles relax.
•The anal and urethal sphincter muscles are closely linked, and experiments by Dr. Harrison Weed at the Ohio State University Medical Center have shown that they can only be contracted together, not individually, and that they both show relaxation during urination This explains why defecation is frequently accompanied by urination, and why urination is frequently accompanied by flatulence.
•Defecation may be involuntary or under voluntary control.
•Young children learn voluntary control through the process of toilet training.
•Once trained, loss of control causing fecal incontinence may be caused by physical injury (such as damage to the anal sphincter that may result from an episiotomy), intense fright, excessive pressure placed upon the abdomen, inflammatory bowel disease, impaired water absorption in the colon and psychologicalor neurological factors.
•The loss of voluntary control of defecation is experienced frequently by those undergoing a terminal illness

Feces

- Makeup: water, undigested food, electrolytes, mucous, shed intestinal cells, and bacteria
- 75% water
- Odor – usually a result of bacterial action



LIVER PHYSIOLOGY

- The functions of the liver are so numerous and important that we cannot live without it.
- It produces heparin, prothrombin, and thrombin.
- Its Kupffer's cells phagocytose bacteria and worn-out blood cells.
- It stores excess carbohydrates as glycogen. It stores copper, iron, and vitamins A, D, E, and K.

It stores or transforms poisons into less harmful substances.

It produces bile salts that emulsify or break down fats.

Liver Functions:

- Helps in the break down of carbohydrates
- Maintains blood sugar level
- Breaks down fatty acids – lipoproteins, cholesterol and phospholipids
- Breaks down amino acids
- Stores glycogen, iron and Vitamins A,D, B12
- Breaks down old and damaged RBC
- Removes toxins
- Secretes bile

Hepatocytes' functions include:

•Production of bile
•Processing bloodborne nutrients
•Storage of fat-soluble vitamins
•Detoxification
•Secreted bile flows between hepatocytes toward bile ducts in portal triads

Metabolic function

- **Carbohydrate metabolism**
  - **Gluconeogenesis**
  - **Glycogenolysis and glycogenesis**
- **Hormone metabolism**
- **Lipid Metabolism**
  - **Synthesis of fatty acids, cholesterol, lipoproteins**
  - **Ketogenesis**
- **Drug Metabolism**
- **Protein Metabolism**
  - **Synthesis of plasma proteins**
  - **Urea synthesis**

Storage function

- **Glycogen**
- **All fat-soluble vitamins (A, D, E, K) and some**
- **water soluble vitamins (B12)**
- **Iron**

Protection

Detoxification – converts noxious or insoluble compounds into less toxic or more water soluble forms

Kupffer cells ingest bacteria or other foreign material from blood

Liver Tests:

- ☐ Aminotransferases (AST/ALT)
- ☐ Alkaline Phosphatase
- ☐ Gammaglutamly Transpeptidase (GGTP)
- ☐ Bilirubin
- ☐ Total Protein/Albumin/Globulin
- ☐ Prothrombin Time (INR)

- Aminotransferases
- ☐ **enzymes that leak when liver cells damaged**
- ☐ **AST = aspartate aminotransferase**
- ☐ **ALT = alanine aminotransferase**
- **– ALT = more specific for liver disease**
- ☐ **AST:ALT ratio: >2:1 alcoholic liver disease**
- ☐ **pyridoxine (B6) = coenzyme in synthesis**
- **– B6 deficiency: inhibits ALT>AST**
- ☐ **Alcohol causes mitochondrial injury**
- **– AST: cytosol & mitochondria**

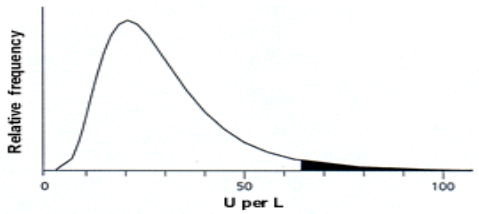
- Alkaline Phosphatase (ALP)
- ☐ **enzyme found in many body tissues**
- ☐ **>80% in liver and bone**
- ☐ **component of cells lining bile ducts**
- ☐ **↑ ALP synthesis by liver in cholestasis**
- ☐ **ALP >3-5X: cholestatic disease**
- ☐ **doesn't differentiate intra/extrahepatic**
- ☐ **t½ = 7d ∴↑ after several days**

Transaminases

- Located in hepatocytes
  - Released after hepatocellular injury
- 2 Forms
  - AST
    - Non-specific to liver: heart, skeletal muscle, blood
  - ALT
    - More specific: elevated in myopathies

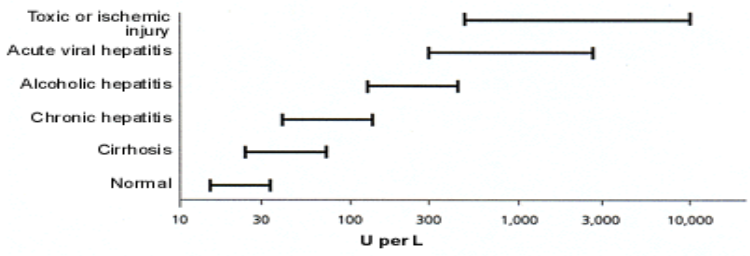
Transaminases

- May not be elevated in chronic liver disease
  - HCV- apoptosis
  - Cirrhosis
- Minimal ALT elevations (<1.5 X normal)
  - Race/Gender
  - Obesity
  - Muscle injury



Transaminases

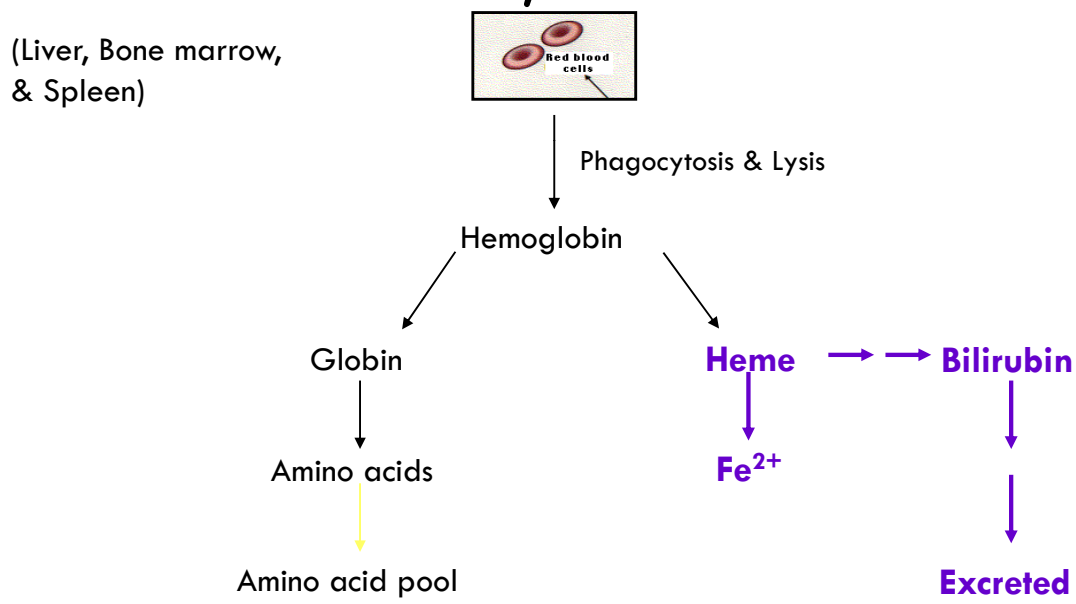
- Mild elevations – more to come
- Marked elevations
  - Acute toxic injury- ie tylenol, ischemia
  - Acute viral disease
  - Alcoholic hepatitis



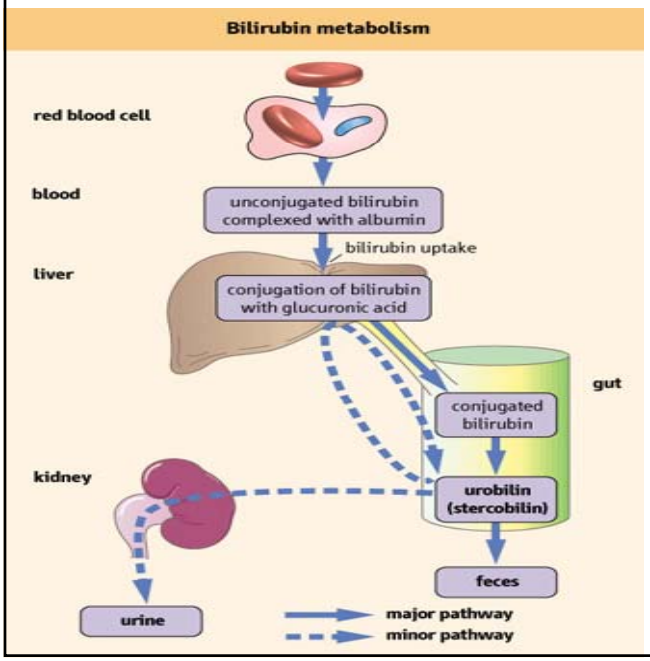
Transaminases

- AST:ALT ratio
  - Elevated in alcoholic disease
    - 2:1
    - If AST > 500 consider other cause
  - No alcohol use suggests cirrhosis

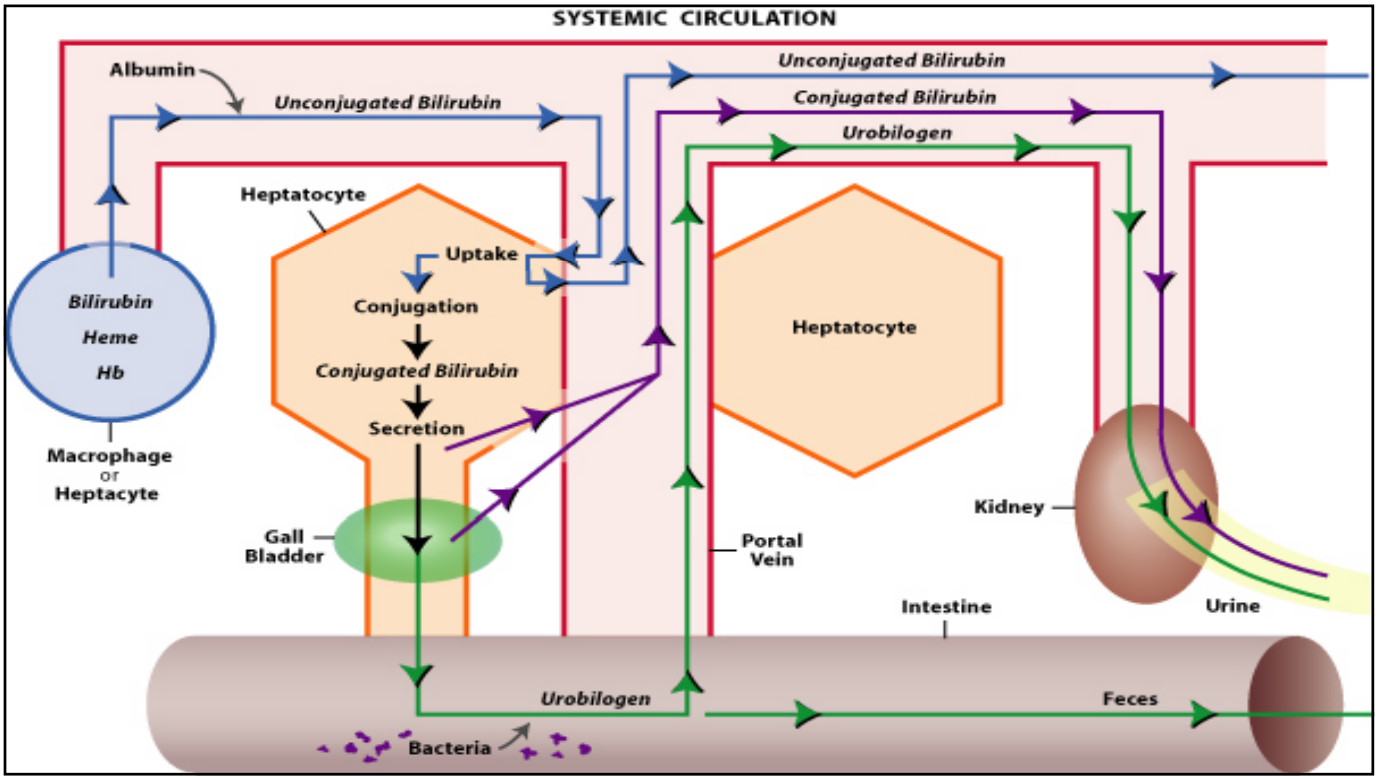
Extravascular Pathway for RBC Destruction

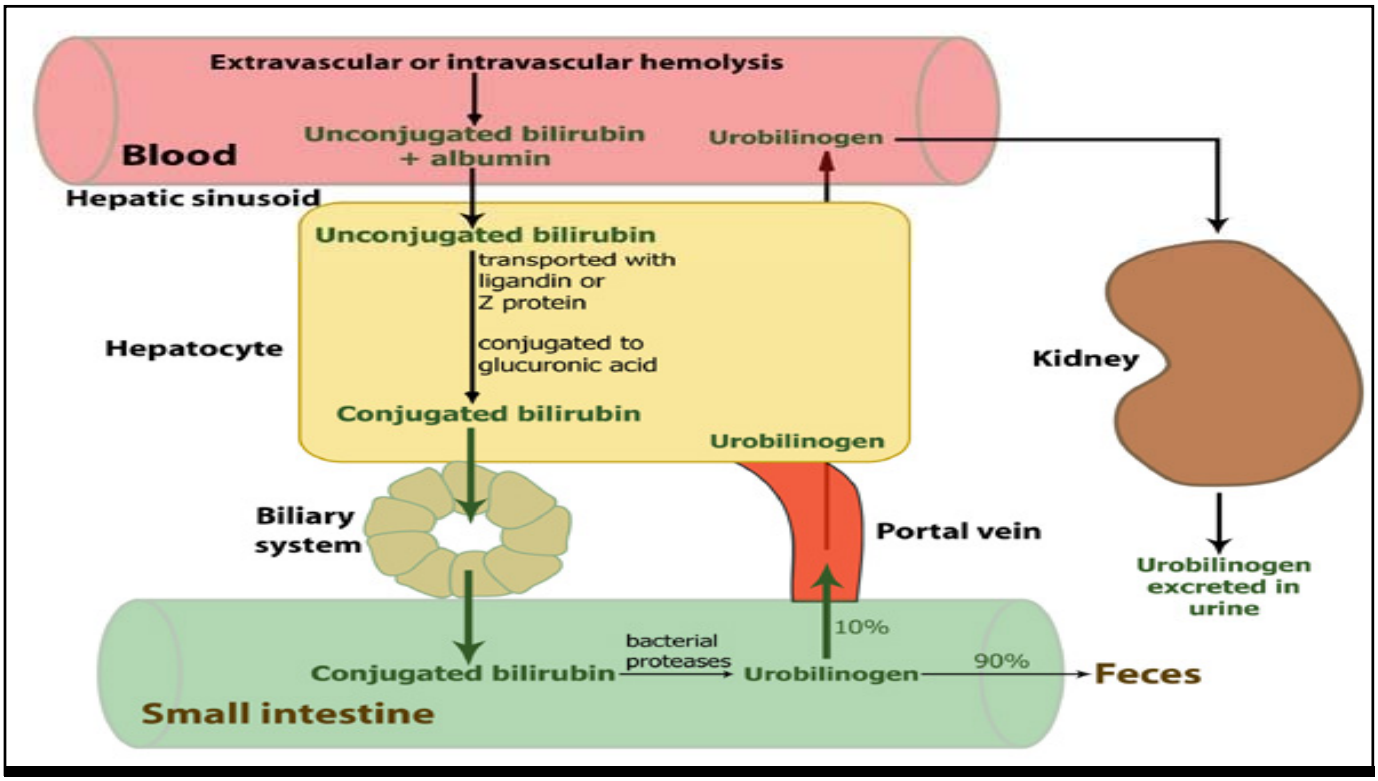


NORMAL BILIRUBIN METABOLISM



- Uptake of bilirubin by the liver is mediated by a carrier protein (receptor)
- Uptake may be competitively inhibited by other organic anions
- On the smooth ER, bilirubin is conjugated with glucoronic acid, xylose, or ribose
- Glucoronic acid is the major conjugate - catalyzed by UDP glucuronyl tranferase
- "Conjugated" bilirubin is water soluble and is secreted by the hepatocytes into the biliary canaliculi
- Converted to stercobilinogen (urobilinogen) (colorless) by bacteria in the gut
- Oxidized to stercobilin which is colored
- Excreted in feces
- Some stercobilin may be re-adsorbed by the gut and re-excreted by either the liver or kidney





The causes of jaundice

Type	Cause	Clinical example	Frequency
Prehepatic	hemolysis	autoimmune abnormal hemoglobin	uncommon depends on region
intrahepatic	infection	hepatitis A, B, C	common/very common
	chemical/drug	acetaminophen alcohol	common common
	genetic errors: bilirubin metabolism	Gilbert's syndrome Crigler–Najjar syndrome Dubin–Johnson syndrome Rotor's syndrome	1 in 20 very rare very rare very rare
	genetic errors: specific proteins	Wilson's disease α_1 antitrypsin	1 in 200 000 1 in 1000 with genotype
	autoimmune	chronic active hepatitis	uncommon/ rare
	neonatal	physiologic	very common
Posthepatic	intrahepatic bile ducts	drugs primary bilary cirrhosis cholangitis	common uncommon common
	extrahepatic bile ducts	gall stones pancreatic tumor cholangiocarcinoma	very common uncommon rare

Differential diagnosis of jaundice

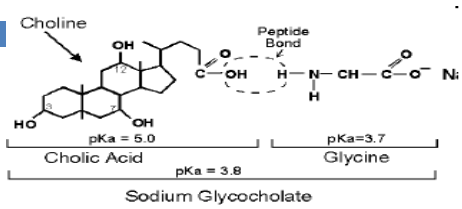
	Prehepatic	Intrahepatic	Posthepatic
conjugated bilirubin	absent	↑	↑
AST or ALT	normal	↑	normal
ALP	normal	normal	↑
urine bilirubin	absent	present	present
urine urobilinogen	present	present	absent

Bile

- Yellowish green liquid
- Make up: bile salts, bile pigments, cholesterol and electrolytes.
- Bile salts – breaks down fat into smaller molecules.

Components of Bile

- 50% Bile Acids (Cholic, chenodeoxycholic, deoxycholic, and lithocholic acid
  - Product of Cholesterol + 7a-Hydroxylase, most is recycled from distal ileum
  - Form micelles- amphipathic
  - pK= approx. 7 if unconjugated
  - conjugated to taurine or glycine- pK goes down, allows them to be soluble in the intestine ☺
- Phospholipids (lecithin)
  - solubilized by bile salts
- Cholesterol
- Bile pigments
  - bilirubin glucuronide



- **Composition of Bile** A yellow-green, alkaline solution containing bile salts, bile pigments, cholesterol, neutral fats, phospholipids, and electrolytes
- Bile salts are cholesterol derivatives that:
  - Emulsify fat
  - Facilitate fat and cholesterol absorption
  - Help solubilize cholesterol
- Enterohepatic circulation recycles bile salts
- The chief bile pigment is bilirubin, a waste product of heme

- Regulation of Bile Release Acidic, fatty chyme causes the duodenum to release:
  - Cholecystokinin(CCK) and secretin into the bloodstream
- Bile salts and secretin transported in blood stimulate the liver to produce bile
- Vagal stimulation causes weak contractions of the gallbladder
- **Cholecystokinin causes:**
  - **The gallbladder to contract**
  - **The hepatopancreatic sphincter to relax**
- As a result, bile enters the duodenum

Regulation of Bile Release

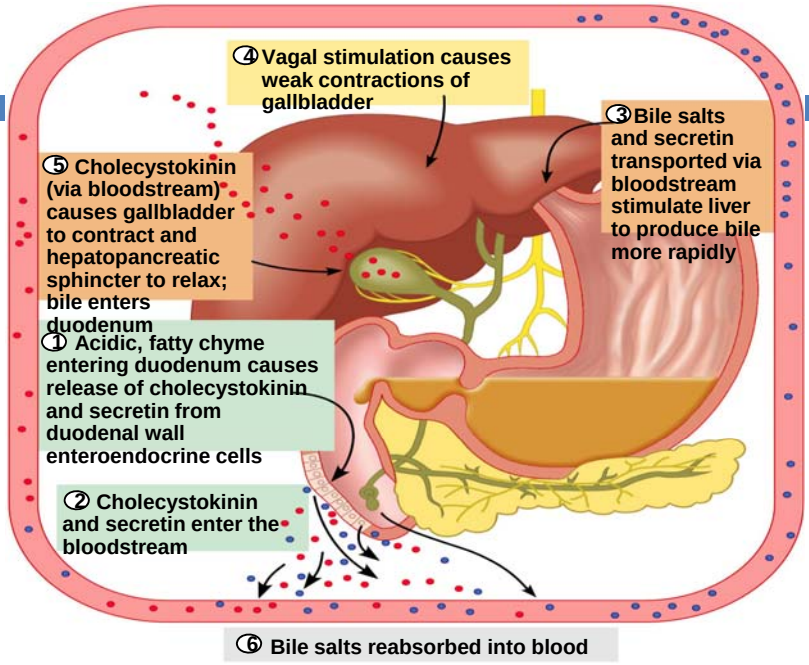


Figure 23.25

BILE

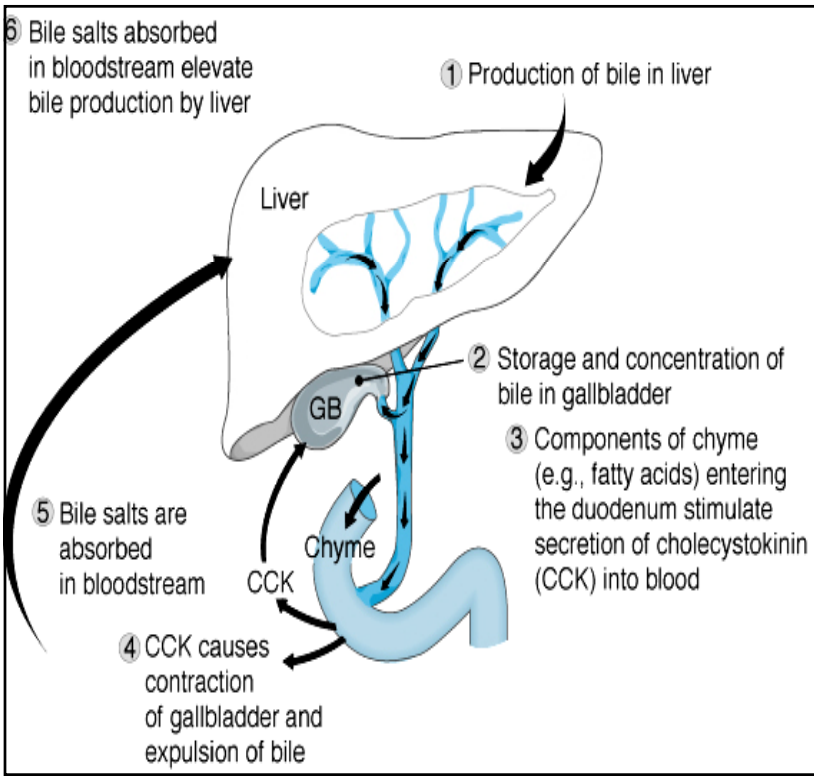
COMPONENTS:

- **BILE SALTS,** (formed in the liver from cholesterol) are the most essential part of bile.
- **BILE PIGMENTS-**The pigment bilirubin (red) and biliverdin (green), derived from hemoglobin, give bile its greenish color because it secretes bile into ducts.
- **CHOLESTEROL**
- **PHOSPHOLIPIDS**

FUNCTIONS OF BILE

1. It breaks down the fats that you eat so that your body can utilize them.
2. Bile is a very powerful antioxidant which helps to remove toxins from the liver.

hepatic artery and **hepatic portal vein**
drain through the
leaky liver sinusoids
⇓
The sinusoids drain into the **central vein**
⇓
Bile flows back through the bile canaliculi
into the bile duct
⇓
stored in the gallbladder
⇓
Cholecystokinin (CCK) is releases bile



Movement of bile

liver

↓

common hepatic duct

↓

gall bladder

↓

cystic duct

↓

bile duct

↓

hepatopancreatic sphincter

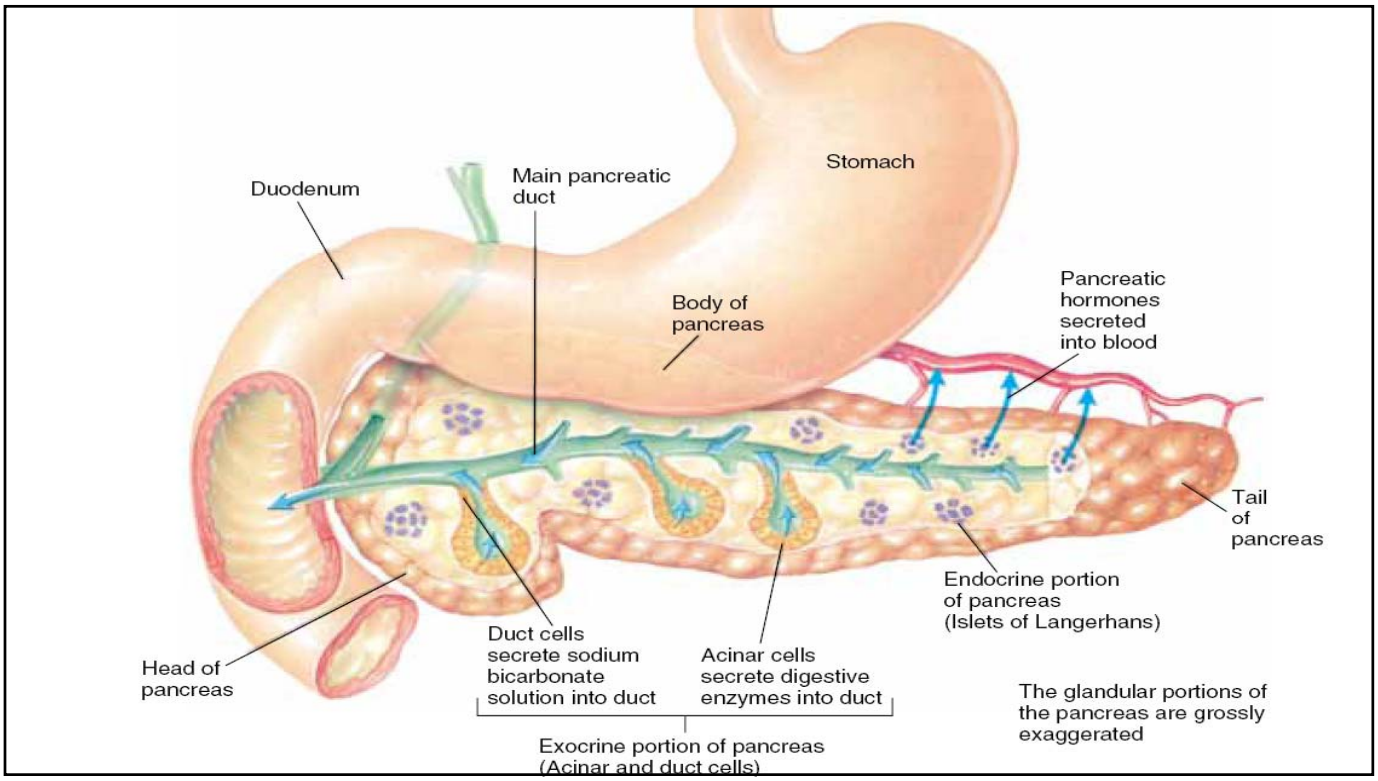
↓

small intestine

Pancreatic juice is composed of two secretory products critical to proper digestion: digestive enzymes and bicarbonate.

The enzymes are synthesized and secreted from the exocrine acinar cells, whereas bicarbonate is secreted from the epithelial cells lining small pancreatic ducts.

PANCREATIC PHYSIOLOGY



- The endocrine cells are the islets of Langerhans:
  - Alpha cells – Glucagon
  - Beta cells – Insulin
  - Both of above regulated by serum blood sugar.
  - Delta cells – Gastrin and other polypeptide hormones

Functions

Most (> 80%) of the cells in the pancreas are involved in the exocrine activity of the organ:

- The production and export of inactive precursors, known collectively as the zymogens, for twenty major digestive enzymes including proteases, lipases, nucleases, and amylase. The pancreas produces more protein per gram of tissue than any other organ.
- The secretion of a bicarbonate-rich alkaline fluid (1200 ml/day in humans) which functions to neutralize the acidic chyme produced in the stomach. The alkalinization is necessary for digestive enzyme activity.

The remainder of the cells are responsible for the production of hormones (predominantly insulin and glucagon) that are released into the blood stream (endocrine function). They are organized in the islets of Langerhans

- **Exocrine function** - Secretes pancreatic juice which breaks down all categories of foodstuff Water solution of enzymes and electrolytes (primarily HCO3-)
  - Neutralizes acid chyme
  - Provides optimal environment for pancreatic enzymes
- **Enzymes are released in inactive form and activated in the duodenum**
  - Examples include
    - Trypsinogen is activated to trypsin
    - Procarboxypeptidase is activated to carboxypeptidase
- **Active enzymes secreted**
  - Amylase, lipases, and nucleases
  - These enzymes require ions or bile for optimal activity
- **The pancreas also has an endocrine function - release of insulin and glucagon**
- Regulation of Pancreatic Secretion Secretin and CCK are released when fatty or acidic chyme enters the duodenum
- CCK and secretin enter the bloodstream
- Upon reaching the pancreas:
  - CCK induces the secretion of enzyme-rich pancreatic juice
  - Secretin causes secretion of bicarbonate-rich pancreatic juice
- Vagal stimulation also causes release of pancreatic juice

Pancreatic Secretions:

- **Hydrelatic**
  - HCO_3^- rich aqueous fluid
  - neutralizes stomach HCl
  - dilutes the chyme
- **Ecbolic**
  - enzyme rich secretion
  - Proteases - endopeptidases
  - **Trypsinogen ---> trypsin**
  - **Chymotrypsinogen --> chymotrypsin**
  - Proelastase --> elastase
  - Proteases - exopeptidases
  - Procarboxypeptidase --> carboxypeptidase
  - Proaminopeptidase --> aminopeptidase
  - **amylase**
  - **Lipases**
  - Ribonuclease
  - Deoxyribonuclease

Protease Activation

- Pancreatic secretion contains trypsinogen and trypsin inhibitor
- Enterokinase in intestine activates trypsin
- Trypsin inhibitor is diluted by chyme

Hormonal Regulation of Pancreatic Secretion

- Secretin

peptide hormone
pancreatic secretion rich in $HCO3^-$

- Cholecystokinin (CCK)

peptide hormone (33 amino acids)
pancreatic secretion rich in enzyme

Pancreatic Secretion:

- **Cephalic Phase**

  Sight, taste, smell of food
  Release of ACh & gastrin in response to vagal stimulation
  Increased pancreatic flow, especially ecbolic

- **Gastric Phase**

  Protein in chyme --> gastrin
  Gastric distention --> ACh from vagus
  Increased pancreatic secretion, esp. ecbolic

- **Intestinal Phase**

  Acid in chyme --> secretin
  hydrelatic secretion
  Long chain fatty acids & amino acids and peptides in chyme
  CCK & vagovagal reflex
  ecbolic secretion

- **Bile from the Liver**

Bile Acids

Primary from cholesterol by addition of OH and COOH
Secondary formed in intestine by resident bacteria
conjugated to taurine or glycine
Bile Flow
Released as CCK causes contraction of gall bladder and relxation of Sphincter of Oddi
CCK (33 amino acid hormone) released in response to fatty acids and lipids in chyme

Pancreatic and Bile Secretions

- Acid in Duodenum activates Secretion of Secretin to initiate HCO_3^- secretion
- AA, Lipids stimulate Gastrin (quick response) and CCK (prolonged response) to initiate pancreatic enzyme secretion.
- CCK also causes GB contraction, Sphincter of Oddi relaxation, and increased Bile Salt excretion by the liver.

Physiology – Exocrine Pancreas

- Secretion of water and electrolytes originates in the centroacinar and intercalated duct cells
- Pancreatic enzymes originate in the acinar cells
- Final product is a colorless, odorless, and isosmotic **alkaline** fluid that contains digestive enzymes (amylase, lipase, and trypsinogen)

Physiology – Exocrine Pancreas

- 500 to 800 ml pancreatic fluid secreted per day
- Alkaline pH results from secreted bicarbonate which serves to neutralize gastric acid and regulate the pH of the intestine
- Enzymes digest carbohydrates, proteins, and fats

Bicarbonate Secretion

- Centroacinar cells and ductular epithelium secrete 20 mmol of bicarbonate per liter in the basal state
- Fluid (pH from 7.6 to 9.0) acts as a vehicle to carry inactive proteolytic enzymes to the duodenal lumen
- Sodium and potassium concentrations are constant and equal those of plasma
- Chloride secretion varies inversely with bicarbonate secretion

Bicarbonate Secretion

- Bicarbonate is formed from carbonic acid by the enzyme carbonic anhydrase
- Major stimulants

  Secretin, Cholecystokinin, Gastrin, Acetylcholine
- Major inhibitors

  Atropine, Somatostatin, Pancreatic polypeptide and Glucagon
- Secretin - released from the duodenal mucosa in response to a duodenal luminal pH < 3

Enzyme Secretion

- Acinar cells secrete isozymes
  - amylases, lipases, and proteases
- Major stimulants
  - Cholecystokinin, Acetylcholine, Secretin, VIP
- Synthesized in the endoplasmic reticulum of the acinar cells and are packaged in the zymogen granules
- Released from the acinar cells into the lumen of the acinus and then transported into the duodenal lumen, where the enzymes are activated.

Enzymes

- Amylase
  - only digestive enzyme secreted by the pancreas in an active form
  - functions optimally at a pH of 7
  - hydrolyzes starch and glycogen to glucose, maltose, maltotriose, and dextrins
- Lipase
  - function optimally at a pH of 7 to 9
  - emulsify and hydrolyze fat in the presence of bile salts

Enzymes of Pancreas

- Proteases
  - essential for protein digestion
  - secreted as proenzymes and require activation for proteolytic activity
  - duodenal enzyme, enterokinase, converts trypsinogen to trypsin
  - Trypsin, in turn, activates chymotrypsin, elastase, carboxypeptidase, and phospholipase
- Within the pancreas, enzyme activation is prevented by an antiproteolytic enzyme secreted by the acinar cells

Insulin

- Synthesized in the B cells of the islets of Langerhans
- 80% of the islet cell mass must be surgically removed before diabetes becomes clinically apparent
- Proinsulin, is transported from the endoplasmic reticulum to the Golgi complex where it is packaged into granules and cleaved into insulin and a residual connecting peptide, or C peptide

Insulin

- Major stimulants
  - Glucose, amino acids, glucagon, GIP, CCK, sulfonylurea compounds, β-Sympathetic fibers
- Major inhibitors
  - somatostatin, amylin, pancreastatin, α-sympathetic fibers

Glucagon

- Secreted by the A cells of the islet
- Glucagon elevates blood glucose levels through the stimulation of glycogenolysis and gluconeogenesis
- Major stimulants
  - Aminoacids, Cholinergic fibers, β-Sympathetic fibers
- Major inhibitors
  - Glucose, insulin, somatostatin, α-sympathetic fibers

Somatostatin

- Secreted by the D cells of the islet
- Inhibits the release of growth hormone
- Inhibits the release of almost all peptide hormones
- Inhibits gastric, pancreatic, and biliary secretion
- Used to treat both endocrine and exocrine disorders

To resume

TABLE 8–2. Summary of Gastrointestinal Hormones

Hormone	Hormone Family	Site of Secretion	Stimuli for Secretion	Actions
Gastrin	Gastrin-CCK	G cells of the stomach	Small peptides and amino acids Distention of the stomach Vagal stimulation (GRP)	↑ Gastric H^+ secretion Stimulates growth of gastric mucosa
Cholecystokinin (CCK)	Gastrin-CCK	I cells of the duodenum and jejunum	Small peptides and amino acids Fatty acids	↑ Pancreatic enzyme secretion ↑ Pancreatic HCO_3^- secretion Stimulates contraction of the gallbladder and relaxation of the sphincter of Oddi Stimulates growth of the exocrine pancreas and gallbladder Inhibits gastric emptying
Secretin	Secretin-glucagon	S cells of the duodenum	H^+ in the duodenum Fatty acids in the duodenum	↑ Pancreatic HCO_3^- secretion ↑ Biliary HCO_3^- secretion ↓ Gastric H^+ secretion Inhibits trophic effect of gastrin on gastric mucosa
Gastric inhibitory peptide (GIP)	Secretin-glucagon	Duodenum and jejunum	Fatty acids Amino acids Oral glucose	↑ Insulin secretion from pancreatic β cells ↓ Gastric H^+ secretion

Dr. Alzoghaibi presentation

TABLE 8–1. Neurotransmitters and Neuromodulators in the Enteric Nervous System

Substance	Source	Actions
Acetylcholine (ACh)	Cholinergic neurons	Contraction of smooth muscle in wall Relaxation of sphincters ↑ Salivary secretion ↑ Gastric secretion ↑ Pancreatic secretion
Norepinephrine (NE)	Adrenergic neurons	Relaxation of smooth muscle in wall Contraction of sphincters ↑ Salivary secretion
Vasoactive intestinal peptide (VIP)	Neurons of mucosa and smooth muscle	Relaxation of smooth muscle ↑ Intestinal secretion ↑ Pancreatic secretion
Gastrin-releasing peptide (GRP) or bombesin	Neurons of gastric mucosa	↑ Gastrin secretion
Enkephalins (opiates)	Neurons of mucosa and smooth muscle	Contraction of smooth muscle ↓ Intestinal secretion
Neuropeptide Y	Neurons of mucosa and smooth muscle	Relaxation of smooth muscle ↓ Intestinal secretion
Substance P	Cosecreted with ACh	Contraction of smooth muscle ↑ Salivary secretion

Dr. Alzoghaibi

Regulation of Gastric Activity

1. Cephalic Phase
2. Gastric Phase
3. Intestinal Phase

1. CephalicPhase

a) Begins with smelling, thinking, taste about food
b) Stimulates the production of gastric juices

c) This is a short lived phase

2. Gastric Phase

a) Begins with arrival of food

b) Stimuli include

(1) Distension of the stomach

(2) Increase in pH of stomach contents

(3) Presence of undigested materials

c) Lasts about 3-4 hours

d) Main action is to release more products from chief cells and parietal cells

(1) Also increased muscle contractions to mix chyme

e) Neural response – stimulation by chemo and stretch receptors coordinate short reflexes and chief and parietal cell releases

f) Hormonal response – gastrin enters the capillaries at the stomach and stimulate chief and parietal cells

3. Intestinal Phase

a) Starts when chyme enters the small intestine

b) Small amounts of liquidy material is squirted into the small intestines

c) Lasts a long time

d) Primary action is to inhibit gastric acid and pepsinogen production, reduction of gastric mixing

e) Hormonal response – stimulation of CCK (cholecystokinin) and gastric inhibitory peptide (GIP)

f) Release of buffers in the small intestine to bring the pH back up

Enzymes of the Small Intestine
(1) Enterokinase – activates proenzymes secreted by the pancreas
(2) Gastrin, cholecystokinin and secretin

Intestinal Hormones

1. Enterocrinin – hormone stimulates the Submucosal glands

2. Secretin – cause an increase in the secretion of bile and buffers
a) Secondarily reduces gastric motility and secretory rates (to duodenum)

3. Cholecystokinin – accelerates the secretion of all digestive enzymes
a) Increase pancreatic enzymes
b) Push pancreatic secretions and bile into duodenum

4. Gastric Inhibitory Peptide
a) Inhibit gastric activity [Glucose dependent]
b) Activates the Submucosal glands
c) Works to make glucose go into the blood and target the fat cells

5. Gastrin – facilitates large amounts of protein enzymes to be released

Small Intestine

- **Mucosa**
- Absorptive cells
- Goblet cells -- mucous
- Enteroendocrine cells -- cholecystokinin (CCK), secretin
- GIP - glucose dependent insulinotropic peptide
- Somatostatin
- Intestinal crypts (Crypts of Lieberkühn)
-
- **Submucosa**
- Brunner's glands in duodenum - alkaline secretion
- Peyer's patches in ileum.
- 5. Surface area increasing structures - plicae circulares, villi, microvilli
- 6. Segmentation and Peristalsis