

Digestive System general review and Application:

Based on the lecture and text material, you should be able to do the following:

- → identify the overall function of the digestive tract
- → describe the major processes that occur in the digestive tract
- → describe the function of each organ and accessory organ of the alimentary canal
- → describe the composition of saliva and explain how salivation is regulated
- → describe the structural modifications of the walls of the stomach and small intestine that enhance the digestive processes in these regions
- → describe the composition of gastric juice, name the cell types responsible for secreting its various components and describe the importance of each component in stomach activity
- → explain how gastric secretion and motility in the stomach are regulated
- → describe the function of the local hormones produced by the small intestine
- → describe the roles of bile and pancreatic juices in the digestive process
- → describe how the entry of bile and pancreatic juice into the small intestine is regulated
- → list the major functions of the large intestine and describe the regulation of defecation
- → list the major enzymes groups involved in chemical digestion, name the foodstuffs on which they act and name the end products of the digestion of protein, fat, carbohydrate and nucleic acid digestion
- → describe the process of absorption of digested foodstuffs that occur in the small intestine

Organs:

- ™ The **alimentary canal** (also called the **gastrointestinal tract**) consists of the mouth, pharynx, esophagus, stomach, small intestine and large intestine.
- ™ The **accessory digestive** organs are the teeth, tongue, salivary glands, liver, gallbladder, and pancreas.

Digestive Processes:

- ™ Ingestion™ Propulsion (peristalsis)™ Mechanical digestion (physically preparing food for chemical digestion)™ Chemical digestion (enzymatic breakdown of food)™ Absorption (into blood or lymph from small intestine)™ Defecation (elimination of waste)

Digestive Activity:

- ™ **A range of mechanical and chemical stimuli provokes digestive activity**
 - ™ Various receptors located in the GI tract respond to several stimuli such as stretching of the wall by food, osmolarity and pH, and presence of substrates.
 - ™ When receptors are stimulated, they:
 - ™ Initiate reflexes that either activate or inhibit glands that secrete digestive juices and/or hormones
 - ™ Mix lumen contents and moves them along by stimulating smooth muscle of GI tract walls
- ™ **Controls of digestive activity are both extrinsic and intrinsic**
 - ™ The entire GI tract is lined with nerve plexuses that result in two reflexes:
 - ™ The **short reflexes** are mediated by the local (enteric) plexuses in response to GI tract stimuli.
 - ™ **Long reflexes** are initiated by stimuli arising within or outside the GI tract. They involve the CNS centers and extrinsic autonomic nerves.

TM The stomach and small intestine also contain hormone-producing cells that reach their target cells through the blood. When stimulated, their contents contribute to secretory or contractile activity.

Digestive Processes occurring in the mouth, pharynx and esophagus

TM Within the mouth, food is chewed, mixed, and moistened with saliva which contains enzymes that aid in the process of chemical digestion

TM Up to 99.5% of saliva is composed of water. It is slightly acidic and its solutes include electrolytes (such as sodium and potassium), salivary amylase – a digestive enzyme, mucin – which hydrates the food, and wastes such as urea.

TM Saliva also contains lysozyme, defensins, and IgA antibodies for protection against microorganisms.

TM The role of saliva is to cleanse the mouth, dissolve food so it can be tasted, moisten food and aid in propulsion of food through the digestive tract, and to begin the chemical breakdown of starchy foods.

TM There are several glands that produce and secrete saliva:

TM The **extrinsic salivary glands** lie outside the oral cavity, but empty their contents within the oral cavity.

TM The three types are the **parotid gland**, the **submandibular gland**, and the **sublingual gland**.

TM The **intrinsic salivary glands** are scattered throughout the oral cavity and their function is to augment the extrinsic salivary glands.

TM The salivary glands are made up of two types of secretory cells:

TM **Serous cells** produce a watery secretion that contains ions and enzymes

TM **Mucous cells** produce mucus, which is stringy and viscous.

TM The parotid gland contains only serous cells, the sublingual glands contain only mucous cells, and the submandibular and intrinsic glands contain both.

TM Intrinsic salivary glands secrete saliva continuously to keep the mouth moist.

- ™ Extrinsic glands are activated by food entering the mouth. The average output of saliva is 1000 – 1500 ml per day!
- ™ Salivation is controlled by the parasympathetic division (PS) of the nervous system.
 - ™ Humans contain receptors in their mouths which when stimulated, send signals to the pons.
 - ™ The PS activates cranial nerves VII (facial) and IX (glossopharyngeal) to increase saliva output.
 - ™ In contrast, the sympathetic division causes release of thick, mucin rich saliva.
 - ™ When strongly stimulated, the blood vessels serving the salivary glands constrict, which ceases release of saliva and causes drymouth.
- ™ Dehydration also inhibits salivation because low blood volume results in reduced filtration pressure at capillaries.

The Teeth

- ™ Teeth are classified according to the shape and function:
 - ™ **Incisors** are for cutting or slicing, **canines** tear and pierce, **premolars** and **molars** are for crushing and grinding.
- ™ Teeth are comprised of a crown and a root
 - ™ The crown is the exposed part that is embedded in the gingiva, or gums. The crown is covered in enamel, which is the hardest substance in the body.
 - ™ The root is the portion embedded in the jawbone.
- ™ Tooth and gum disease results from gradual demineralization of enamel.
 - ™ Metabolic byproducts of plaque produce acids, which dissolve the protective calcium salts on teeth.
 - ™ Enzymes released from the bacteria in the plaque readily digest the remaining materials of the teeth.

TM **Periodontitis** affects up to 95% of the population over the age of 35 and occurs when bacteria are able to invade the bones around the teeth due to demineralization of teeth.

TM Periodontitis increases the risk of heart disease.

Mechanical Processes

TM **Mastication**, or chewing, is the role of the teeth. Mastication begins voluntarily, but stretch reflexes take over when receptors in the cheeks, gums, and tongue are stimulated.

TM **Deglutition** or swallowing involves the coordinated activities of over 22 muscle groups.

TM The buccal phase, the first phase in the mouth, is voluntary.

TM Once food is forced into the pharynx by the voluntary elevation of the tongue, receptors in the pharynx send messages to the pons and medulla to reflexively cause:

TM The tongue to block the mouth

TM The soft palate to rise

TM The epiglottis to close off the glottis

TM Peristalsis to move the food down the esophagus

TM Relaxation of the cardiac sphincter so that food can enter the stomach.

TM Within the stomach, food is mechanically churned and proteins are chemically broken down by salivary amylase.

TM Further chemical breakdown of carbohydrates and lipids does not begin until food reaches the small intestine. Very little is absorbed in the stomach.

Chemical Processes

TM The lining of the stomach is dotted with millions of goblet cells that secrete mucus. The lining also has gastric pits, which lead into gastric glands throughout the stomach. These glands contain a variety of secretory cells that collectively produce gastric juice:

TM **Mucous neck cells** found in the upper regions of the glands produce a different kind of mucus than that of the goblet cells. Its function is not yet fully understood.

- ™ **Parietal cells** are found in the middle region of the glands and secrete hydrochloric acid and intrinsic factor.
 - ™ HCl makes the stomach extremely acidic which is necessary to activate pepsin and kill any bacteria ingested.
 - ™ Intrinsic factor is a glycoprotein required for absorption of Vitamin B12 in the small intestine.
- ™ **Chief cells** produce pepsinogen, the inactive form of the protein-digesting enzyme **pepsin**. They are located in the basal regions of gastric glands.
 - ™ When chief cells are stimulated, HCl encountered in the gland activates the first pepsinogen molecules they release.
 - ™ Once pepsin is present, it also catalyzed the conversion of pepsinogen to pepsin.
 - ™ This positive feedback process is limited only by the amount of pepsinogen present.
 - ™ Chief cells also secrete small amounts of lipase.
- ™ **Enteroendocrine cells** secrete a variety of hormones such as gastrin, histamine, endorphins, serotonin, cholecystokinin, and somatostatin. These all influence several digestive system target organs.
- ™ As explained above, the stomach is exposed to an extremely harsh acidic environment. It protects itself by creating a mucosal barrier.
 - ™ A thick coating of mucus is built up on the stomach wall
 - ™ The cells of the mucosal layer are joined together by tight junctions that prevent the gastric juices from leaking into underlying tissue.
 - ™ Damaged epithelial cells are quickly shed and replaced

Regulation of Gastric Secretion

- ™ Gastric secretion is controlled by both neural and hormonal mechanisms acting through both intrinsic and extrinsic reflexes.
 - ™ The **cephalic phase** prepares the stomach to receive food. The sights, smell, taste, or thought of food triggers it. The receptors involved in these

triggers activate parasympathetic output from the medulla, which increases secretory activity of the gastric glands.

TM Sympathetic innervation decreases these events, and may occur as a result of emotions such as anger, fear or anxiety.

TM The **gastric phase** ensures that gastric secretion and motility continue. Food entering the stomach stimulates mechanoreceptors and chemoreceptors.

TM Mechanoreceptors respond to stomach distension and trigger reflexes, which lead to Ach release.

TM This of course promotes gastric secretion and smooth muscle activity.

TM Chemoreceptors respond to stomach pH and the presence of peptides and/or caffeine.

TM Stimulation leads to the secretion of gastrin from the enteroendocrine cells

TM Food entering the stomach increases the pH of the stomach because the food and saliva have a higher pH than that of normal stomach contents.

TM When gastrin is released, it enters the bloodstream; it stimulates the gastric glands to release more gastric juice.

TM Although it increases the release of pepsinogen, it particularly increases the release of HCl.

TM Since the release of gastrin is triggered by a rise in pH, this is a negative feedback system.

TM As the pH begins to decrease due to the release of more HCl, the release of gastrin will decrease and hence the level of HCl will decrease.

TM Gastrin also causes constriction of the cardiac sphincter, increases the motility of the stomach and relaxes the pyloric sphincter and ileocecal sphincter.

TM When food is present in the stomach, histamine and Ach are released and work with gastrin to increase secretions from gastric glands to mix and churn the food.

- ™ Through the actions of pepsin and acid, the food is now broken down, particularly the proteins.
- ™ There are three sets of reflexes set in motion by chyme in the **intestinal phase**.
- ™ These reflexes are to inhibit gastric secretion and reduce intestinal motility so that the small intestine is not damaged by acid.
 - ™ The first reflex is a short excitatory reflex that releases intestinal gastrin. Its release is stimulated by the presence of chyme in the duodenum and it further promotes digestive activity of the stomach.
 - ™ The second reflex is the enterogastric reflex that is stimulated by the distension of the duodenum and the presence of hydrogen, fats, partially digested proteins and irritating substances via mechano and chemoreceptors. This in turn:
 - ™ Acts via the medulla to inhibit parasympathetic outflow to the stomach.
 - ™ Inhibit intrinsic reflexes in the stomach
 - ™ Activates sympathetic fibers that cause the pyloric sphincter to tighten and prevent further release of chyme into the small intestine.
- ™ The third reflex triggers the release of a series of intestinal hormones including **secretin, gastric inhibitory peptide and cholecystokinin (CCK)**.
- ™ These three inhibit gastric secretion and reduce gastric motility.

Mechanical Processes

Gastric Stretching and Emptying

- ™ The initial response of the stomach to filling is to relax. This is due to:
 - ™ **Receptive relaxation** is a reflex involving the swallowing center of the brainstem and vagus nerve that causes the stomach to relax when food is in the esophagus.

TM **Adaptive relaxation** reflex is activated when the stomach is filling. Stretch receptors on the stomach wall respond, and cause the stomach to dilate.

TM **Plasticity** of the stomach allows it to respond to stretch without greatly increasing its tension and contracting expulsively.

Gastric Contractile Activity

TM In the wall of the stomach are pacemaker cells which slowly depolarize and repolarize at a rate of about 3 per minute (called the basic electrical rhythm or BER).

TM On their own, the depolarization's do not reach threshold and no muscle contraction occurs.

TM When outside stimulus arrives (stretch is the most important of these), threshold is reached, action potentials are fired, and muscle contraction occurs.

TM All of the smooth muscle cells of the stomach are connected via gap junctions; therefore the whole organ contracts.

TM This gives rise to the peristaltic waves which begin near the cardiac sphincter.

TM The waves start out very small, but as they descend over the stomach, they increase and become more vigorous.

TM As the waves reach the pyloric end of the stomach, a small amount of chyme is squeezed out through the pyloric valve.

TM The opening of the valve is very small, so only liquid and small particles will pass through.

TM The wave of the contraction constricts the valve so that only a small amount of chyme will pass through.

TM The rest of the chyme is propelled backward into the stomach where it is mixed further.

TM This back and forth pumping action is the mechanical aspect of gastric digestion.

*As mentioned earlier, as the stomach distends, gastrin is released. Gastrin further stimulates contraction of the smooth muscle. The larger the meal, the greater the activity of the gastric smooth muscle.

Gastric Emptying

- TM As just discussed, only a small amount of chyme is propelled out of the stomach with each peristaltic wave.
- TM Reflexes arising from the duodenum control the actual volume that exits.
 - TM This reflex is triggered by the chyme which enters it.
- TM Recall that the distension of the duodenum, the presence of hydrogen, fatty chyme, partially digested proteins and irritating substances inhibit gastric secretion and motility.
 - TM Therefore, food will only enter the small intestine at the rate that it can be processed.
 - TM The less acid, fat, and protein in the chyme, the faster the chyme will be allowed to enter the small intestine.
 - TM A liquid meal or a meal rich in carbohydrates will pass through the stomach faster than a meal rich in fats and protein.

Digestive processes occurring in the small intestine

- TM The food reaching the small intestine has been altered significantly and now appears as a creamy fluid.
 - TM Carbohydrates and proteins are only partially digested, and no fat digestion has occurred at this point.
 - TM The rest of digestion and nutrient absorption takes place in the small intestine.

Anatomy of the small intestine:

- TM The small intestine extends from the stomach to the large intestine and has three subdivisions; the duodenum, jejunum and ileum.

- ™ The entire structure shows profound modifications for nutrient absorption.
- ™ There are three levels of structural modification which increase surface area:
 - ™ The plicae circulares (circular folds)
 - ™ The villi
 - ™ The microvilli
- ™ The plicae circulares and the villi are modifications of the intestinal wall
- ™ The microvilli represent projections of the plasma membrane of individual cells. They give rise to the brush border and to enhancing surface area available for absorption.
- ™ They also contain the intestinal digestive enzymes that are called the brush border enzymes.
- ™ The epithelium of the small intestine is primarily composed of simple columnar absorptive cells.
- ™ It has many goblet cells that secrete mucus
- ™ It also has enteroendocrine cells that secrete the hormones cholecystokinin, gastric inhibitory peptide, and secretin.
- ™ Between the villi are intestinal crypts or glands that secrete watery mucus that acts as a carrier for the chyme.
- ™ These crypts also contain cells that secrete lysozyme, an antibacterial enzyme.
- ™ Progressing from the duodenum through the ileum, the crypts decrease and goblet cells increase.
- ™ Below the mucosa of the duodenum are also duodenal glands which secrete and alkaline mucus.
- ™ This helps to neutralize the acidic chyme.

- ™ The villi contain a dense capillary bed as well as an enlarged lymphatic capillary called a lacteal.
- ™ These serve to remove absorbed nutrients to other areas of the body.
- ™ Also in the submucosa are aggregations of lymphoid cells called **Peyer's patches**.
- ™ These increase in abundance in the large intestine, which contain large amounts of bacteria that need to be prevented from entering the circulatory system.

Chemical Processes in the Small Intestine

Requirements for optimal intestinal digestive activity

- ™ The chyme entering the small intestine is highly acidic, hypertonic, and still contains pepsin, the powerful protease.
- ™ The walls of the small intestine cannot be protected in the same way as the stomach, as absorption needs to take place here.
- ™ The chyme must be neutralized to protect against the acid and at the same time, deactivate the pepsin.
 - ™ Because chyme is hypertonic, it must also be diluted otherwise it would draw water out of the blood across the intestinal wall.
 - ™ This is why chyme must be released slowly from the stomach. It must be released at a rate that facilitates dilution and neutralization in the small intestine.

Intestinal Juice; Composition and control of production

- ™ This is produced by the mucosa of the small intestine.
- ™ The major stimulation for its production is distension of the intestinal mucosa and irritation by acidic or hypertonic chyme.
 - ™ It consists mainly of water and mucus secreted by the duodenal glands and goblet cells.
 - ™ It has very few enzymes and its job is to dilute the hypertonic chyme and act as a transport medium.

Liver and Gall Bladder

- ™ The liver has many functions, one of which is to produce bile to aid in the digestive process.
 - ™ Bile acts to help neutralize the chyme as it enters the small intestine and is a fat emulsifier.
 - ™ It breaks up fats into tiny particles so that they are more accessible to digestive enzymes.
- ™ The gallbladder is chiefly a storage organ for bile.

Composition of bile

- ™ Bile is an alkaline solution containing a number of components.
 - ™ The important ones for digestion are bile salts, cholesterol and phospholipids.
 - ™ Bile salts act as a fat emulsifier – they break globules of fat entering the small intestine into millions of fatty droplets.
 - ™ This provides a large surface area for the fat digesting enzymes to work on.
 - ™ Bile salts also facilitate fat and cholesterol absorption.
- ™ These salts are conserved:
 - ™ They reabsorbed during digestion in the ileum, returned to the liver by the hepatic portal vein and reused.

Regulation of bile release

- ™ The liver makes bile continuously.
- ™ When there is no food in the small intestine, the hepatopancreatic sphincter (the entrance of the common bile duct and pancreatic duct into the small intestine) is closed and the bile backs up into the gallbladder.
 - ™ When food enters the small intestine, activation of mechano and chemoreceptors leads to parasympathetic stimulation.
 - ™ This mildly stimulates gallbladder contraction

TM This also stimulates the release of cholecystokinin and secretin from the duodenal and enteroendocrine cells.

TM Besides their action on the stomach, these hormones also have effects on the gallbladder and liver.

TM Cholecystokinin stimulates the gallbladder to contract and release its contents.

TM It also allows the hepatopancreatic sphincter to relax and allow the bile to enter the small intestine.

TM Secretin stimulates the liver to increase its rate of producing the watery, bicarbonate rich bile.

The Pancreas

TM The pancreas is an accessory organ which lies right below the stomach.

TM It produces many of the digestive enzymes and also secretes an alkaline fluid that helps neutralize the acid in chyme.

Composition of pancreatic juice

TM Pancreatic juice consists mainly of water, enzymes, and bicarbonate ions.

TM This high pH enables pancreatic fluid to neutralize the acid chyme entering the duodenum and provides an optimal environment for the activity of enzymes.

TM Pancreatic proteases are secreted in an inactive form and activated in the duodenum. This prevents the pancreas from self-digestion.

TM For example, within the duodenum, trypsinogen is activated to trypsin by enterokinase, and intestinal brush border enzyme.

TM Trypsin, a proteolytic enzyme, then activates procarboxypeptidase and chymotrypsinogen.

TM Just like the secretion of bile, parasympathetic nerve stimulation leads to the release of pancreatic juice.

TM Also, secretin leads to the release of the watery, bicarbonate rich component and the cholecystokinin leads to the release of the enzyme rich component of the pancreatic juice.

Mechanical Processes

Motility of the Small Intestine

- TM **Segmentation** is the most common motion of the small intestine, which is the contracting and relaxing of smooth muscle.
 - TM Pacemaker cells in the smooth muscle initiate segmentation, although the duodenum depolarizes more frequently (12 –14 contractions per minute) than the ileum (8 – 9 contractions per minute).
 - TM This allows ample time for complete digestion and absorption as contents move towards the ileocecal valve.
 - TM Long and short reflexes and hormones alter the intensity of segmentation.
 - TM Parasympathetic activity enhances and sympathetic activity decreases segmentation.
- TM **Peristalsis** occurs after most nutrients have been absorbed and is regulated on the basis of which neurons are stimulated.
- TM Peristaltic waves sweep slowly along the duodenum to sweep out debris, bacteria, and meal remnants.
 - TM This is called the **migrating mobility complex** and it's function is to keep bacteria from settling into the small intestine.
- TM The enteric neurons of the GI tract coordinate the mobility patterns.
 - TM Impulses sent proximally by the cholinergic neurons cause contraction and shortening of the muscle layer.
 - TM Impulses sent distally to certain interneurons cause shortening of the longitudinal muscle layer and distension of the intestine, in response to Ach releasing neurons.
 - TM Other impulses sent distally by activated VIP or NO releasing enteric neurons that cause relaxation of the circular muscle.
- TM As a result, as the proximal area constricts and forces chyme along the tract, the lumen of the intestine enlarges to receive it, where it moves toward the ileocecal sphincter.
- TM Most of the time, the ileosphincter valve is constricted and closed.

- ™ Two mechanisms; one neural, the other hormonal cause it relax and allow food residues to enter the cecum.
- ™ Enhanced activity in the stomach initiates the gastroileal reflex that enhances force of segmentation in the ileum.
- ™ Gastrin released by the stomach increases motility of the ileum and relaxes the ileocecal sphincter.
- ™ Once the chyme has passed through, it exerts backpressure that closes the valve's flaps and prevents regurgitation.

Digestive Processes Occurring in the Large Intestine

- ™ The major function of the large intestine is to absorb water from indigestible food residues and eliminate the residue as semisolid feces.

Chemical Processes

- ™ The only chemical processing which occurs in the large intestine is a result of the bacterial flora that resides there.
- ™ These bacteria colonize the colon and ferment some of the remaining carbohydrates that are indigestible by the body.
- ™ They produce irritating acids and a mixture of gases, some of which are quite odorous.
- ™ They also synthesize B complex vitamins and most of the vitamin K which the liver requires to synthesize some blood clotting proteins.

Mechanical Processes

- ™ There are several different types of movement, which occur in the large intestine that can be divided into those associated with propulsion of food through the large intestine to the rectum and those associated with defecation.

Haustra Contractions

- ™ The longitudinal muscles of the large intestine are tonically active and pull the wall of the large intestines into pockets called haustra.
- ™ The smooth muscles within the walls of individual haustra are activated by distension and they move food along to the next haustrum.

TM This is a local reflex that moves the food residue and mixes it which aids in water absorption. Peristalsis occurs at a very slow rate.

Mass Movements (mass peristalsis)

TM Strong, slow moving waves of peristalsis move along the colon three or four times a day.

TM They are triggered by distension of the stomach, therefore they happen right after a meal.

TM Stomach distension also gives rise to the two following gastric reflexes:

TM The gastroileal reflex which opens the ileocecal sphincter

TM The gastrocolic reflex, which forces the contents of the large intestine towards the rectum.

Defecation

TM When feces are forced into the rectum by mass peristalsis, stretching of the rectal wall initiates the defecation reflex.

TM This is a spinal cord mediated parasympathetic reflex that causes the walls of the final segment of the colon and the rectum to contract and the anal sphincter to relax.

TM As feces enter the anal canal, messages reach the brain indicating that defecation is imminent.

TM At this point voluntary control can override the reflex and stop passage of the feces temporarily.

TM If defecation is delayed, the reflex contractions stop and the rectal walls relax until the next wave of mass peristalsis initiates the reflex again.

TM During defecation the muscles of the rectum contract, the anal sphincter relaxes and the movement of the feces may be assisted voluntarily by the contraction of the abdominal muscles against a closed glottis.

TM This is called the Valsalva maneuver. This increases pressure in the abdominal cavity applying pressure on the large intestine and contracting the muscles of the anal canal.

Daily Fluid Balance

TM Over the course of an average day an individual ingests 2L of fluid, 1L of saliva, 2L of gastric juice, 1L of bile, 2L of pancreatic juice, 1L intestinal juice

TM Total fluid ingested **9L** daily

TM **0.1L** is excreted in feces

TM **8L** are reabsorbed by the small intestine

TM **0.9L** are reabsorbed by the large intestine