The Digestive System

Alimentary Canal & Digestive Organs

- Mouth (oral cavity)
- Tongue
- Esophagus
- Liver
- Gallbladder
- Duodenum
- Jejunum
- Ileum
- Small intestine
- Large intestine
- Anus
- Parotid gland
- Sublingual gland
- Submandibular gland
- Salivary glands
- Pharynx
- Stomach
- Pancreas (Spleen)
- Transverse colon
- Descending colon
- Ascending colon
- Cecum
- Sigmoid colon
- Rectum
- Vermiform appendix
- Anal canal

Gastrointestinal Tract Activities

- Ingestion
- Mechanical digestion
  - Chewing (mouth)
  - Churning (stomach)
  - Segmentation (small intestine)
- Chemical digestion
- Propulsion
  - Swallowing (oropharynx)
  - Peristalsis (esophagus, stomach, small intestine, large intestine)
- Absorption
  - Lymph vessel
  - Blood vessel
- Defecation
  - Mainly H₂O
  - Feces
  - Anus
Basic Digestive Concepts

- Digestive activity is provoked by a range of mechanical and chemical stimuli.
  - the **mechanoreceptors** respond to:
    - stretching of the organ by food in the lumen.
  - the **osmoreceptors** respond to:
    - solute concentrations and the pH of the contents.
  - the **chemoreceptors** respond to:
    - substrates and end products of digestion
  - when stimulated, all these above receptors:
    - initiate reflexes that activate or inhibit glands and their secretions (digestive juices or hormones).
    - initiate reflexes that mix lumen contents and move them along the tract via smooth muscle stimulation.

The Peritoneum & Peritoneal Cavity

- **Visceral Peritoneum**: covers the external surface of most digestive organs.
- **Parietal Peritoneum**: lines the body wall within the abdominal-pelvic cavity.
- **Peritoneal Cavity**: the space between visceral and parietal peritoneum.
- **Mesentery**: is a double layer of peritoneum that extends to the digestive organs from the body wall. Provides a route for blood vessels, lymphatics and nerves. It also holds organs in place and provides a storage place for fat. The **greater omentum** and **lesser omentum** are specific ventral mesentery folds.
- **Retroperitoneal organs** are behind the peritoneum layers.
Peritonitis

- Peritonitis is an inflammation of the lining of the abdominal-pelvic cavity.
- most common cause is ruptured appendix.
  - photo is of an appendix being removed by laparoscopic surgery before it ruptured.
Histology of the Alimentary Canal

Mucosa

- **Mucosa** or “mucous membrane”
  - inner-most layer
  - runs the full length of GI tract (mouth to anus).
  - major functions:
    - secretion of mucous
    - secretion of digestive enzymes
    - secretion of hormones
    - absorption of end products of digestion.
    - protection against infectious disease

Mucosa

- typical (not all) mucosa has 3 sublayers:
  - lining of **simple columnar epithelium**:
    - this layer is rich with **goblet cells** (secrete mucin).
      - mucin + water = mucous
      - mucous protects lining from digestive enzymes and eases passage of food.
    - stomach and small intestine also have cells that secrete hormones.
  - **lamina propria**:
    - is loose areolar connective tissue.
    - filled with capillaries and MALT.
  - **muscularis mucosae**:
    - scanty smooth muscle layer
      - contraction affects adjacent surface area (absorption).
Submucosa

• **Submucosa:**
  – just external to the 3 mucosa sub-layers.
  – is mostly dense irregular connective tissue.
  – contains:
    • blood vessels
    • lymphatic vessels
    • nerve fibers
    • elastic fibers
      – helps GI tract to return back to normal shape when food has passed.

Muscularis Externa

• **Muscularis Externa**
  – deep to submucosa (3rd layer from lumen).
  – responsible for **segmentation** and **peristalsis**.
  – most of GI has two parts:
    • **inner circular layer of smooth muscle cells.**
      – several places along the GI track this circular layer thickens and forms sphincters.
    • **outer longitudinal layer of smooth muscle cells.**

Serosa

• **serosa:**
  – the protective outermost layer of the intraperitoneal organs, is the *visceral peritoneum*.
  – is composed of two layers:
    • an inner areolar loose connective tissue layer
    • outer layer of simple squamous epithelium call the *mesothelium*.
  – for the esophagus the serosa is:
    • replaced by an *adventitia layer* which is fibrous connective tissue that binds the esophagus to the surrounding structures.
  – for retroperitoneal organs:
    • the side facing the peritoneal cavity is lined with serosa and the side facing dorsally is line with adventitia.
**Mouth**
- also known as **oral cavity** or **buccal cavity**.
- posteriorly is continuous with **oropharynx**.
- lined with **stratified squamous epithelium**.
  - good for resisting lots of friction from eating, etc..
  - lips and the hard palate have some keratinization to resist the rougher abrasive activities such as eating.
  - produces **defensins**
    - antimicrobial peptides.
    - produced in response to injury.

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**Anatomy of the Oral Cavity**

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**Lips & Cheeks**
- lip muscle is the **orbicularis oris**
- cheek muscle is mostly the **buccinators**.
- both muscles and help keep food in your mouth and assist with talking.
- **red margin** or “**Vermillion Border**”
  - transition from the keratinized stratified squamous epithelium of face to the oral mucous of the lip which is poorly keratinized stratified squamous epithelium.
• median fold that joins the internal aspect of both the upper and lower lip the gums.
• if torn, highly suspect of smothering abuse in infants. (normal in child learning to walk).
The Palate

- **hard palate**
  - anterior 2/3 is maxillae bone
  - posterior 1/3 is palatine bone
  - about 15% have a normal bony outgrowth called a **torus palatinus**
- **soft palate**
  - closes off the nasopharynx during swallowing.
  - has midline **uvula**
  - anchored to tongue by **palatoglossal arches**
  - anchored to oropharynx by **palatopharyngeal arches**
  - **palatine tonsils** are between the arches!

Torus Palatinus & Torus Mandibularis

Tongue

- composed of interlacing bundles of skeletal muscle fibers.
- mixes food with saliva and forms it into a compact mass called a **bolus**.
- fold of mucosa, called the **lingual frenulum**, secures the tongue to the floor.
  - can be very short in newborn: **ankyloglossia** which is a “fused tongue” or “tongue tied”.
    - corrected by snipping the frenulum.
    - can result in some speech problems due to restricted movement.
Salivary Glands

- Extrinsic Salivary Glands
  - sublingual gland
  - submandibular gland
  - parotid gland
    - has long tube called the parotid duct (Stensen duct):
      - opening is opposite the second upper molars.
    - has branches of facial nerve passing through it.
      - high chance of facial muscle paralysis if surgery done on it!!!
    - gland is between skin of cheek and masseter muscle.

- Intrinsic Salivary Glands
  - also called buccal glands, are scattered throughout the oral cavity mucosa.

- all glands secrete saliva (digests starches)
The Salivary Glands

Mumps
- Myxovirus infection of the salivary glands.
  - mostly the Parotid Glands.
- spreads person to person by saliva.
- pain with chewing due to parotid swelling.
- infection can spread to testes in 25%
  - causes sterility
- part of MMR immunization as a child.

Sialolithiasis
- stone formation in the ducts that empty any of the salivary glands.
- painful swelling of gland as saliva can’t exit.
- before surgery, common treatment is to suck lemons to force stone out by pressure from excess saliva formation.
Saliva

- Saliva or “spit” is:
  - about 98% water
  - slightly acidic with pH of about 6.75 to 7.00
  - the remaining 2% contains:
    - electrolytes (sodium, potassium, chloride, etc..)
    - salivary amylase
    - mucin (added to the water is mucous)
    - lysozyme (a bacteriostatic enzyme, slows tooth decay)
    - IgA antibodies
    - some metabolic wastes (urea and uric acid)
    - lingual lipase (a fat-digesting enzyme)
    - defensins (antibiotic and cytokine function)
    - normal flora bacteria

Saliva

- control of salivation:
  - intrinsic glands keep mouth moist by constantly secreting a small amount of saliva.
  - when food enters mouth, the extrinsic salivary glands are activated
  - controlled primarily by parasympathetic ANS.
    - chemoreceptors and mechanoreceptor nerves in mouth send signal to the salivatory nuclei in the pons and medulla.
    - parasympathetic ANS signals are send back along nerve fibers that travel with CN VII and CN IX.
  - thought, smell and sight can trigger salivation:
    - pavlovian effect.
  - Xerostomia is “dry mouth” from poor salivation.

Deciduous & Permanent Teeth
Deciduous & Permanent Teeth

• Enamel
  - hardest substance in the body
  - heavily mineralized with calcium salts.
  - the cells that produce enamel degenerate when the tooth erupts, thus any decay or cracked areas must be filled in artificially by a dentist.

• Periodontal ligament
  - holds tooth in jaw

Teeth

Pharynx

• Histology resembles the oral cavity
  – mucosa is a friction resisting stratified squamous epithelium with scattered mucous producing glands
  – 2 external skeletal muscle layers
    • Longitudinal muscles (inner layer, all elevate pharynx):
      – Stylopharyngeus
      – Palatopharyngeus
      – Salpingopharyngeus
    • Circular muscles (outer layer, all constrict pharynx):
      – Superior Constrictor
      – Middle Constrictor
      – Inferior Constrictor
Esophagus

• 25 cm (10 inch) “mixed” muscle tube.
  – mucosa is a nonkeratinized stratified squamous epithelium.
    ★ changes to a simple columnar epithelium at junction with stomach.
      • This is a common site for acid from the stomach to irritate the esophagus (heartburn) and for cancer to form.
  – mucosa and submucosa form longitudinal folds and esophagus flattens when empty.
  – submucosa’s esophageal glands secrete mucus as food bolus passes by them.
  – muscularis externa is all skeletal muscle in upper 1/3, is mixed in mid third and is all smooth muscle in lower 1/3.

• has 3 constrictions:
  – 1st at level of C6, where it begins
  – 2nd is at crossing of left main stem bronchus
  – 3rd is at T10 where it pierces diaphragm
• has a physiologic sphincter, which is the circular layer of smooth muscle at the gastroesophageal junction.
  – has 2 other names:
    • cardiac sphincter
    • inferior esophageal sphincter.
• It takes about 8 seconds for the food bolus in the mouth to reach the stomach.
Deglutition / Swallowing

1. Upper esophageal sphincter is contracted. During the buccal phase, the tongue presses against the hard palate, forcing the food bolus into the oropharynx where the involuntary phase begins.

Deglutition / Swallowing

2. The uvula and larynx rise to prevent food from entering respiratory passageways. The tongue blocks off the mouth. The upper esophageal sphincter relaxes, allowing food to enter the esophagus.

Deglutition / Swallowing

3. The constrictor muscles of the pharynx contract, forcing food into the esophagus inferiorly. The upper esophageal sphincter contracts (closes) after entry.
Deglutition / Swallowing

4. Food is moved through the esophagus to the stomach by peristalsis.

Anatomy of the Stomach

- Esophagus
- Muscularis externa
  - Longitudinal layer
  - Circular layer
  - Oblique layer
- Serosa
- Body
- Lumen
- Rugae of mucosa
- Lesser curvature
- Greater curvature
- Cardia
- Fundus
- Duodenum
- Pyloric canal
- Pyloric antrum
- Pyloric sphincter (valve) at pylorus
Anatomy of the Stomach

- Adult stomach varies from 15 to 25 cm long.
  - Diameter and volume depend on food volume.
  - Empty stomach has about a 50 ml volume.
  - Mucosa and submucosa collapse inward to form long folds called rugae (means "wrinkle").
- A regular full stomach can hold about 1 gallon!!!
  - Rugae "disappear" out when stomach is full.
  - Digested food at this point is called chyme.
  - The lesser curvature has the lesser omentum running from it to the liver.
  - The greater curvature has the greater omentum draping inferiorly like an apron.
  - Riddled with fat deposits and lymph nodes.

Microscopic Anatomy of the Stomach

- Stomach surface epithelium is simple columnar epithelium which are all goblet cells.
  - Produces a protective two-layer coat of alkaline mucus.
  - Surface layer is viscous mucus that traps lower layer.
  - Deep layer is bicarbonate-rich fluid.
- Millions of gastric pits are the openings to the gastric glands deep in the stomach mucosa.
  - Four types of secretory cells:
    - Mucous Neck Cells
    - Parietal Cells
    - Chief Cells
    - Enteroendocrine Cells
Microscopic Anatomy of the Stomach

- **Mucous Neck Cells:**
  - produces a thin acidic mucus.
- **Parietal Cells:**
  - **Hydrochloric Acid**
  - **Intrinsic Factor**
    - required for Vit. B12 absorption in the small intestine.
- **Chief Cells:**
  - produce **pepsinogen**
    - the inactive form of the protein-digesting enzyme **pepsin**. HCL and pepsin activate it.
- **Enteroendocrine Cells:**
  - histamine, serotonin, somatostatin, gastrin.

Stomach Mucosal Barrier

- protects the stomach from self-digestion.
- 3 factors create the barrier:
  - A thick coating of **bicarbonate-rich mucus** is build up on the stomach wall.
  - The epithelial cells of the mucosa are joined together by **tight junctions** that prevent gastric juice from leaking into the underlying tissue.
  - Damaged epithelial mucosal cells are shed and quickly replaced by division of **undifferentiated stem cells** that reside where the gastric pits join the gastric glands.
    - stomach surface epithelium is completely renewed every 3 to 6 days!!

GI Ulcerations

- **Peptic Ulcer**
  - is erosion in the lining of the stomach or duodenum.
  - commonly caused by an infection with a bacterium called **Helicobacter pylori**.
  - additional factors are stress, acidic diet, caffeine.
  - symptoms: nausea, vomiting, epigastric pain, loss of appetite, weight loss, anemia.
  - 2 types based on location:
    - **Gastric Ulcer**
      - ulcers in the pyloric region of the stomach.
    - **Duodenal Ulcer**
      - ulcers in the first part of the duodenum. (more common type).
Mechanisms of HCl secretion by Parietal Cells

- HCL secretion by Parietal Cell:
  - Multiple substances can initiate HCL formation:
    - Gastrin binding
      - from the "G cells", which are enteroendocrine cells found in the antrum.
    - Acetylcholine binding
      - from parasympathetics.
    - Histamine binding
      - released in the presence of gastrin from the enterochromaffin-like cells
      - Zantac will block this receptor (H2 receptor).

  - the so-called "proton-pump" is the H+K+ ATPase.
  - this pump is blocked by proton-pump inhibitor drugs like omeprazole.

Peristaltic Waves in the Stomach

- The pyloric region of the stomach, allows only liquids and small particles to pass through the barely open pyloric valve after each peristaltic wave reaches it.
  - only about 3 ml or less of chyme enters the duodenum for each peristaltic wave.
  - a full stomach empties in about 4 hours.
  - the stomach has about 3 peristaltic waves per minute.
  - rate controlled by pacemaker cells in the longitudinal smooth muscle layer called interstitial cells of Cajal.
  - these contractions are cyclic slow waves of the stomach, or its basic electrical rhythm (BER).
Vomiting (Emesis)

- induced by:
  - extreme stretching of the stomach / intestine.
  - presence of irritants:
    - bacterial toxins, blood
    - excessive ETOH (alcohol).
    - certain foods: spicy food
    - certain medications (ipecac syrup).
  - all these inducing factors, plus others, send the signal to the **emetic center** of the medulla, which controls the vomiting motor response.
    - diaphragm and abdominal muscles contract
    - cardiac sphincter relaxes, soft palate rises (closes nose).
    - vomiting can then proceed.

Vomiting (Emesis)

- Medical consequences of vomiting:
  - can aspirate vomitus (inhaled into lungs).
    - causes pneumonia
      - most commonly seen in ETOH overdose and passing out
  - dehydration
    - subsequent electrolyte imbalance
      - loss of the potassium and chloride most common.
    - subsequent acid-base imbalance
      - blood becomes more alkaline as you puked the HCl, and that now has to be replaced by what acids were in the blood.

Small Intestine

- starts at the **pyloric sphincter** and ends at the **ileocecal valve**.
- diameter is about 1/2 that of large intestine at about 2.5 to 4 cm.
  - in live person (who has muscle tone) length is about 7 to 13 feet. Cadaver’s is about 20 feet.
- 3 divisions:
  - Duodenum
  - Jejunum
  - Ileum
Duodenum
– means “twelve finger widths long”. 25 cm.
– is mostly retroperitoneal.
  • except for the beginning of the first part, which is connected to the liver by the **hepatoduodenal ligament** of the lesser omentum.
– is divided into 4 parts:
  • Superior (first) part
  • Descending (second) part
    – hepatopancreatic sphincter (**sphincter of Oddi**) located here. Major exit for bile and pancreatic juice.
  • Transverse (third) part
  • Ascending (fourth) part
    – fixed in position by **suspensory ligament of Treitz**, which is a surgical landmark that is attached to right crus of diaphragm.

The Duodenum of the Small Intestine and Related Organs

Jejunum & Ileum

• **Jejunum**
  – second division of the small intestine.
  – about 8 feet long.
  – has **NO Peyer’s patches**.
  – has tall, closely packed **plicae circulares** (circumciliar folds) and longer **vasa recta**.

• **Ileum**
  – third division of the small intestine.
  – about 12 feet long.
  – has Peyer’s patches (mostly distal end).
  – shorter plicae circulares and vasa recta.
**Meckel’s Diverticulum**

– is a **2 inch long out-pouching** of the ileum derived from unobliterated yolk stalk.
  • may be connected to the umbilicus by cord or fistula.
– located about **2 feet** proximal to ileocecal junction.
– occurs in about **2% of the population**.
– may contain **2 types of tissue**:
  • gastric and pancreatic
– symptoms present typically by **age 2**.
– **2 times** more common in boys.
– symptoms mimic acute appendicitis:
  • bleeding, vomiting, fever, constipation, bowel obstruction.

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**Small Intestine Microscopic Anatomy**

– small intestine functions in the **digestion and absorption of nutrients**.
  • **Circular folds** or **plicae circulares** are deep permanent folds of the mucosa and submucosa.
    – nearly 1 cm tall, these folds force chyme to spiral through the lumen, slowing its movement and allowing time for absorption.
  • **Villi** are projections of mucosa about 1 mm high
    – in its core is a capillary bed and lymph capillary (**lacteal**).
  • **Microvilli** or **brush border** of the simple columnar cells.
  • duodenal **Brunner’s glands** secrete an alkaline mucus to neutralize the acidic chyme from the stomach.
– as in the stomach, **slow waves** set the basic electrical rhythm at a frequency of **12 waves/min**.
  • parasympathetics increases smooth muscle contraction.
  • sympathetics decreases smooth muscle contraction.
**Small Intestine Histology**

- epithelium is largely **simple columnar absorptive cells** bound by **tight junctions**.
  - have microvilli on the apical surface of the cells
- mucus-secreting **goblet cells** along whole length.
- some scattered **enteroendocrine cells**
  - mainly secrete secretin and cholecystokinin
- few scattered **intraepithelial T lymphocytes**.
  - able to immediately release cytokines to kill targets.
- between the villi are **intestinal crypts** also known as **crypts of Lieberkühn**.
  - epithelial cells here secrete intestinal juice, a carrier fluid for absorbing nutrients from chyme. **pH of ~7.4 to 7.8**
  - **Paneth cells** secrete protective **defensins & lysozyme**.

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**Structural Modifications of the Small Intestine that Increase its Surface Area from Digestion and Absorption**

![Diagram of the small intestine showing the increase in surface area through villi and crypts.]

- Vein carrying blood to hepatic portal vessel
- Muscle layers
- Circular folds
- Villi
- Lumen

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**Structural Modifications of the Small Intestine that Increase its Surface Area from Digestion and Absorption**

![Diagram highlighting absorptive cells, lacteal, goblet cell, blood capillaries, mucosa, associated lymphoid tissue, intestinal crypt, muscularis mucosae, duodenal gland, microvilli, brush border, villus, enteroendocrine cells, venule, lymphatic vessel, submucosa.]

- Absorptive cells
- Lacteal
- Goblet cell
- Blood capillaries
- Mucosa
  - associated lymphoid tissue
- Intestinal crypt
- Muscularis mucosae
- Duodenal gland
- Microvilli (brush border)
- Vilus
- Enteric endocrine cells
- Venule
- Lymphatic vessel
- Submucosa
Liver

- digestive function is to make **bile** and transport it to the gallbladder, then onward to the duodenum.
- **detoxification**
  - storage of carbohydrate as **glycogen**.
  - storage of lipids as **triglycerides**.
- **protein synthesis:**
  - fibrinogen, prothrombin, albumin, lipoproteins, heparin
- **bile pigments** from the breakdown of hemoglobin.
- storage of vitamins, iron, copper.
- manufactures RBCs.
- contains a **portal triad** at every lobule which includes branches of the **portal vein, hepatic artery, and bile duct**.

Gross Anatomy of the Liver

Bare area has no visceral peritoneum covering it. It touches the diaphragm.
Microscopic Liver Anatomy

- The structural and functional unit of the liver is the liver lobule.
- The liver lobule is roughly hexagonal in shape.
- It is filled with liver cells called hepatocytes.
- Hepatocytes radiate outward from a central vein.
- The central veins merge with other central veins to ultimately empty into the vena cava.
- Between the plates of radiating hepatocytes are enlarged, leaky capillaries, the liver sinusoids.
- Hepatic macrophages (Kupffer Cells) line the sinusoids.
- At each of the 6 corners of the lobule is a portal triad:
  - Hepatic artery, hepatic portal vein, bile duct.
Cirrhosis & Portal Hypertension

- **Cirrhosis** is a progressive chronic inflammation of the liver.
  - usually due to chronic alcoholism or hepatitis.
  - over years, the liver hardens and shrinks, which slows the flow of blood through it.
    - blood plasma leaks to interstitial space called **ascites**.
    - as blood flow slows, the pressure builds and the patient gets **portal hypertension**
    - fortunately some veins anastomose with the veins of the vena cava to route blood flow around the liver.
      - veins of the inferior esophagus
      - hemorroidal veins in the anal canal
      - superficial veins around the umbilicus (caput medusae)
    - these anastomoses tend to rupture and bleed.

Caput Medusae & Ascites

Bile

- a yellow-green, alkaline solution:
  - 65% **bile salts**
    - are amphipathic molecules with hydrophobic and hydrophilic ends that orient around droplets of lipids.
    - enterohepatic circulation absorbs it from small intestine and returns it via bloodstream to the liver.
  - 20% **phospholipids**
  - 10% **bilirubin pigment**
    - waste product of the heme of hemoglobin as worn out RBCs are broken down.
    - bacteria in the small intestine breaks bilirubin down into stercobilin, which give stool its brown color.
  - 4% **cholesterol**

- Bile aids in the intestinal digestion and absorption of lipids by emulsifying and solubilizing them in micelles.
Gallbladder
- thin-walled, pear-shaped sac under liver.
- capacity of 30 to 50 mL.
- 3 parts: fundus, body and neck
  - neck gives rise to the **cystic duct**
    - inside the duct are the **spiral valves of Heister**.
- gallbladder receives bile, concentrates it, stores it and releases it during digestion.
  - when no digestion is occurring, the sphincter of Oddi is closed and the continually formed bile from the liver backs up the spiral valves of Heister and fills the gallbladder, where it is stored until needed.
  - CCK causes bile to be released.

Pancreas
- is almost entirely retroperitoneal.
- has a head, tail and uncinate process
  - if tumors are present in the head, they obstruct bile and pancreatic juice flow out the sphincter of Oddi.
- is both an exocrine gland and endocrine gland (islets of Langerhans).
- has two ducts:
  - **main pancreatic duct** (Wirsung's duct) that runs the length of pancreas and joins bile duct to form the **hepatopancreatic ampulla (ampulla of Vater)**.
  - **accessory pancreatic duct** (Santorini's duct) that drains lower head and uncinate process, empties at the **lesser duodenal papilla** about 2 cm above the ampulla of Vater.

Microscopic Anatomy of the Pancreas

Within the pancreas are the **acini** which are clusters of secretory cells surrounding ducts. **Zymogen** granules stain darkly in these cells and contain the **digestive enzymes**.

Scattered amid the acini are the lighter stained pancreatic **islets of Langerhans**. These endocrine glands release **insulin** and **glucagon**. (see chapter 16)
**Mechanisms Promoting Secretion & Release of Bile and Pancreatic Juice**

1. Chyme entering duodenum causes release of cholecystokinin (CCK) and secretin from duodenal enteroendocrine cells.
2. CCK (red dots) and secretin (yellow dots) enter the bloodstream.
3. CCK induces secretion of enzyme-rich pancreatic juice. Secretin causes secretion of HCO₃⁻-rich pancreatic juice.
4. Bile salts and, to a lesser extent, secretin transported via bloodstream stimulate liver to produce bile more rapidly.
5. CCK (via bloodstream) causes gallbladder to contract and hepatopancreatic sphincter to relax; bile enters duodenum.
6. During cephalic and gastriac phases, vagal nerve stimulation causes weak contractions of gallbladder.

**Pancreatic Juice**
- high volume (1200 to 1500 ml per day)
- Na⁺ and K⁺ concentrations close to that in plasma.
- much higher HCO₃⁻ concentration than plasma.
  - helps to counteract the HCl from the stomach.
- much lower Cl⁻ concentration than plasma.
- **Isotonicity** (regardless of flow rate)
  - at low flow rates (no food), fluid is mostly Na⁺ and K⁺.
  - at high flow rates (meals), fluid is mostly Na⁺ and HCO₃⁻.
- pancreatic lipase, amylase and protease.

**Regulation of Pancreatic Secretion**
- **Secretin**
  - “nature’s antacid” is secreted by the S cells of the duodenum in response to the H⁺ in the duodenum.
  - acts on the pancreatic ductal cells to increase HCO₃⁻ secretion.
- **CCK**
  - is secreted by the I cells of the duodenum in response to small peptides, amino acids, and fatty acids in the duodenum.
  - acts on the pancreatic acinar cells to increase amylase, lipase and protease secretion.
Large Intestine
– extends from the ileocecal junction to the anus and is about 1.5 m (5 feet) long.
– consists of the:
  • cecum
  • appendix
  • ascending, transverse and descending colon
  • sigmoid colon
  • rectum
  • anal canal
– takes the liquid contents of the ileum and converts it into semisolid feces by absorbing water, salts, and electrolytes.
– it also stores and lubricates feces with mucus.

Large Intestine
– ascending & descending colon are retroperitoneal
– transverse & sigmoid colon are intraperitoneal
– ascending and transverse colon are supplied by:
  • superior mesenteric artery
  • vagus nerve
– descending and sigmoid colon are supplied by:
  • inferior mesenteric artery
  • pelvic splanchnic nerves
– Large Intestine is characterized by:
  • Teniae coli: 3 bands of longitudinal smooth muscle.
  • Sacculations or Hastra: produced by the Teniae coli.
  • Epiploic appendages: peritoneum covered sacs of fat attached in rows along the Teniae coli.
Rectal valves allow feces to get stuck on them so you can pass gas (500 ml daily) without also passing the feces!

Hemorrhoids from veins above the pectinate line are non-tender.

Hemorrhoids from veins below the pectinate line are tender. Ouch!

The mucosa of the anal canal is stratified squamous epithelium.

The external anal sphincter is skeletal muscle (voluntary control)

The internal anal sphincter is smooth muscle (involuntary control)

Distension, or stretch, of the rectal walls due to movement of feces into the rectum stimulates stretch receptors there. The receptors transmit signals along afferent fibers to spinal cord neurons.

A spinal reflex is initiated in which parasympathetic motor (efferent) fibers stimulate contraction of the rectal walls and relaxation of the internal anal sphincter.

If it is convenient to defecate, voluntary motor neurons are inhibited, allowing the external anal sphincter to relax so that feces may pass.