Digestive Physiology
Enzymes of Digestion
Salivary Glands

Saliva
- Ox produces up to 200 L/day
- Man 1-2L/day

- Pig and Horse saliva contains some amylase
- Ruminants and carnivores have no salivary amylase

When present salivary amylase starts to break carbohydrates down into simple sugars

Stomach glands and secretions
- Protein digestion begins
  - HCl denatures (unfolds) protein molecules
  - HCl transforms pepsinogen into pepsin that breaks peptides bonds between certain amino acids
- Fat digestion continues
  - gastric lipase splits the triglycerides in milk fat
    - most effective at pH 5 to 6 (infant stomach)
- HCl kills microbes in food
- Mucous cells protect stomach walls from being digested with 1-3mm thick layer of mucous

Other Stomach secretions

Gastrin
- produced by the G-cells
- stimulates HCL secretion

Rennin
- produced by young ruminant animals
- causes milk coagulation

Regulation of Gastric Secretion and Motility
- Cephalic phase: “Stomach Getting Ready”
- Gastric phase: “Stomach Working”
- Intestinal phase: “Stomach Emptying”
Regulation of Gastric Emptying

- Release of chyme is regulated by neural and hormonal reflexes
- Distention & stomach contents increase secretion of gastrin hormone & vagal nerve impulses
  - stimulate contraction of esophageal sphincter and stomach and relaxation of pyloric sphincter
- Enterogastric reflex regulates amount released into intestines
  - distension of duodenum & contents of chyme
  - sensory impulses sent to the medulla inhibit parasympathetic stimulation of the stomach but increase secretion of cholecystokinin and stimulate sympathetic impulses
  - inhibition of gastric emptying

Composition and Functions of Pancreatic Juice

- 1 & 1/2 Quarts/day at pH of 7.1 to 8.2
- Contains water, enzymes & sodium bicarbonate
- Digestive enzymes
  - pancreatic amylase, pancreatic lipase, proteases
    - trypsinogen---activated by enterokinase (a brush border enzyme)
    - chymotrypsinogen----activated by trypsin
    - procarboxypeptidase---activated by trypsin
    - proelastase---activated by trypsin
    - trypsin inhibitor---combines with any Trypsin produced inside pancreas
  - ribonuclease----to digest nucleic acids
  - Deoxyribonuclease

Regulation of Pancreatic Secretions

- Secretin
  - acidity in intestine causes increased sodium bicarbonate release
- GIP
  - fatty acids & sugar causes increased insulin release
- CCK
  - fats and proteins cause increased digestive enzyme release

Regulation of Bile Secretion
Liver Functions--Carbohydrate Metabolism

• Turn proteins into glucose
• Turn triglycerides into glucose
• Turn excess glucose into glycogen & store in the liver
• Turn glycogen back into glucose as needed

Liver Functions--Lipid Metabolism

• Synthesize cholesterol
• Synthesize lipoproteins----HDL and LDL(used to transport fatty acids in bloodstream)
• Stores some fat
• Breaks down some fatty acids

Liver Functions--Protein Metabolism

• Deamination = removes NH2 (amine group) from amino acids so can use what is left as energy source
• Converts resulting toxic ammonia (NH3) into urea for excretion by the kidney
• Synthesizes plasma proteins utilized in the clotting mechanism and immune system
• Convert one amino acid into another

Other Liver Functions

• Detoxifies the blood by removing or altering drugs & hormones(thyroid & estrogen)
• Removes the waste product--bilirubin
• Releases bile salts help digestion by emulsification
• Stores fat soluble vitamins-----A, B12, D, E, K
• Stores iron and copper
• Phagocytizes worn out blood cells & bacteria
• Activates vitamin D (the skin can also do this with 1 hr of sunlight a week)

Summary of Digestive Hormones

• Gastrin
  – stomach, gastric & ileocecal sphincters
• Gastric inhibitory peptide--GIP
  – stomach & pancreas
• Secretin
  – pancreas, liver & stomach
• Cholecystokinin--CCK
  – pancreas, gallbladder, sphincter of Oddi, & stomach

Cells of Intestinal Glands

• Absorptive cell
• Goblet cell
• Enteroendocrine
  – secretin
  – cholecystokinin
  – gastric inhibitory peptide
• Paneth cells
  – secretes lysozyme

**Goblet Cells of GI epithelium**
Unicellular glands that are part of simple columnar epithelium

- submucosal layer has duodenal glands
  – secretes alkaline mucus
- mucosal layer contains intestinal glands = Crypts of Lieberkuhn (deep to surface)
  – secretes intestinal juice
    • 1-2 qt./day----- at pH 7.6
  – brush border enzymes
  – paneth cells secrete lysozyme kills bacteria

**Roles of Intestinal Juice & Brush-Border Enzymes**

- Submucosal layer has duodenal glands
  – secretes alkaline mucus
- Mucosal layer contains intestinal glands = Crypts of Lieberkuhn (deep to surface)
  – secretes intestinal juice
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**Digestion of Carbohydrates**

- Mouth---salivary amylase
- Esophagus & stomach---nothing happens
- Duodenum----pancreatic amylase
- Brush border enzymes (maltase, sucrase & lactose) act on disaccharides
  – produces monosaccharides--fructose, glucose & galactose
  – lactose intolerance (no enzyme; bacteria ferment sugar)--gas & diarrhea

**Lactose Intolerance**

- Mucosal cells of small intestine fail to produce lactase
  – essential for digestion of lactose sugar in milk
  – undigested lactose retains fluid in the feces
  – bacterial fermentation produces gases
- Symptoms
  – diarrhea, gas, bloating & abdominal cramps
- Dietary supplements are helpful
Digestion of Proteins

- **Stomach**
  - HCl denatures or unfolds proteins
  - pepsin turns proteins into peptides

- **Pancreas**
  - digestive enzymes---split peptide bonds between different amino acids
  - brush border enzymes-----aminopeptidase or dipeptidase------split off amino acid at amino end of molecule or split dipeptide

Digestion of Lipids

- **Mouth----lingual lipase**

- **Small intestine**
  - emulsification by bile
  - pancreatic lipase----splits into fatty acids & monoglyceride
  - no enzymes in brush border

Digestion of Nucleic Acids

- **Pancreatic juice contains 2 nucleases**
  - ribonuclease which digests RNA
  - deoxyribonuclease which digests DNA

- **Nucleotides produced are further digested by brush border enzymes (nucleosidease and phosphatase)**
  - pentose, phosphate & nitrogenous bases

- **Absorbed by active transport**

Regulation of Secretion & Motility

- **Enteric reflexes that respond to presence of chyme**
  - increase intestinal motility
  - VIP (vasoactive intestinal polypeptide) stimulates the production of intestinal juice
  - segmentation depends on distention which sends impulses to the enteric plexus & CNS
    - distention produces more vigorous peristalsis
    - 10 cm per second

- **Sympathetic impulses decrease motility**

Mechanical Digestion in Large Intestine

- **Smooth muscle = mechanical digestion**

- **Peristaltic waves (3 to 12 contractions/minute)**
  - hastral churning----relaxed pouches are filled from below by muscular contractions (elevator)
  - gastroilial reflex = when stomach is full, gastrin hormone relaxes ileocecal sphincter so small intestine will empty and make room
  - gastrocolic reflex = when stomach fills, a strong peristaltic wave moves contents of transverse colon into rectum
Chemical Digestion in Large Intestine

- No enzymes are secreted only mucous
- Bacteria ferment
  - undigested carbohydrates into carbon dioxide & methane gas
  - undigested proteins into simpler substances (indoles)----odor
  - turn bilirubin into simpler substances that produce color
- Bacteria produce vitamin K and B in colon

Absorption & Feces Formation in the Large Intestine

- Some electrolytes---Na+ and Cl-
- After 3 to 10 hours, 90% of H2O has been removed from chyme
- Feces are semisolid by time reaches transverse colon
- Feces = dead epithelial cells, undigested food such as cellulose, bacteria (live & dead)

Defecation

- Gastrocolic reflex moves feces into rectum
- Stretch receptors signal sacral spinal cord
- Parasympathetic nerves contract muscles of rectum & relax internal anal sphincter
- External sphincter is voluntarily controlled

Defecation Problems

- Diarrhea = chyme passes too quickly through intestine
  - H2O not reabsorbed
- Constipation--decreased intestinal motility
  - too much water is reabsorbed
  - remedy = fiber, exercise and water

Absorption

- no food is absorbed prior to stomach
- very little is absorbed in stomach; some drugs, alcohol, electrolytes
- most absorption occurs in small intestine of all animals, esp. carnivores and omnivores
- herbivores: large intestine absorption very important as most of the digestion takes place in colon/cecum
- small amounts of water are absorbed in large intestine
- large intestine secretes mucus for lubrication and protection

Proventriculus (forestomach) of ruminant

Unique as it absorbs

- a number of drugs
- salts of sodium and potassium
- carbonates
- chlorides of various substances
- glucose
- short-chain FA (acetic, propionic and butyric)
Neonatal Absorption
macromolecules from colostrum

Absorption of Monosaccharides

- Absorption into epithelial cell
  - glucose & galactose----sodium symporter(active transport)
  - fructose----facilitated diffusion
- Movement out of epithelial cell into bloodstream
  - by facilitated diffusion

Absorption of Amino Acids & Dipeptides

- Absorption into epithelial cell
  - active transport with Na+ or H+ ions (symporters)
- Movement out of epithelial cell into blood
  - Diffusion

Where do all the nutrients/substances that are absorbed go to?
Amino acids and simple sugars enter portal veins → liver

Fats are a little more complicated
Bile salts emulsify fat into smaller droplets
  gastric, lingual and pancreatic lipase degrade
  Triglycerides (TG)

Diglycerides, Monoglycerides, Fatty Acids and Glycerol

- Chylomicrons leave intestinal cells by exocytosis into a lacteal
  - travel in lymphatic system to reach veins near the heart
  - removed from the blood by the liver and fat tissue
Absorption of Electrolytes

- Sources of electrolytes
  - GI secretions & ingested foods and liquids
- Enter epithelial cells by diffusion & secondary active transport
  - sodium & potassium move = Na+/K+ pumps (active transport)
  - chloride, iodide and nitrate = passively follow
  - iron, magnesium & phosphate ions = active transport
- Intestinal Ca+ absorption requires vitamin D & parathyroid hormone

Absorption of Vitamins

- Fat-soluble vitamins
  - travel in micelles & are absorbed by simple diffusion
- Water-soluble vitamins
  - absorbed by diffusion
- B12 combines with intrinsic factor before it is transported into the cells
  - receptor mediated endocytosis

Absorption of Water