Digestion in small intestine

Chemical digestion
Chemical digestion — Pancreatic secretion
Pancreatic juice

• pH 7.8~8.4
• ~1500 ml/day
• Isosmotic
• Components:
  – Pancreatic digestive enzymes: secreted by pancreatic acini
  – Sodium bicarbonate: secreted by small ductules and larger ducts

• Secretion of bicarbonate ions
  – Secreted by the epithelial cells of the ductules and ducts that lead from acini
  – Up to 145mmol/L in pancreatic juice (5 times that in the plasma)
  – Neutralizing acid entering the duodenum from the stomach
Pancreatic digestive enzymes

<table>
<thead>
<tr>
<th>ENZYME</th>
<th>SUBSTRATE</th>
<th>ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trypsin, chymotrypsin, elastase</td>
<td>Proteins</td>
<td>Breaks peptide bonds in proteins to form peptide fragments</td>
</tr>
<tr>
<td>Carboxypeptidase</td>
<td>Proteins</td>
<td>Splits off terminal amino acid from carboxyl end of protein</td>
</tr>
<tr>
<td>Lipase</td>
<td>Fats</td>
<td>Splits off two fatty acids from triacylglycerols, forming free fatty acids and monoglycerides</td>
</tr>
<tr>
<td>Cholesterol esterase Phospholipase</td>
<td>Polysaccharides</td>
<td>Splits polysaccharides into glucose and maltose</td>
</tr>
<tr>
<td>Amylase</td>
<td>Polysaccharides</td>
<td>Splits nucleic acids into free mononucleotides</td>
</tr>
<tr>
<td>Ribonuclease, deoxyribonuclease</td>
<td>Nucleic acids</td>
<td>Splits nucleic acids into free mononucleotides</td>
</tr>
</tbody>
</table>
Starches

Pancreatic amylase

Maltose and 3 to 9 glucose polymers

Pancreatic Lipase

Triglyceride

Monoglyceride and fatty acids
Pancreatic proteinase precursors

Proenzyme
- Trypsinogen
- Chymotrypsinogen
- Procarboxypeptidase
- Proelastase
- Denatured proteins
- Peptides

Active Enzyme
- Trypsin
- Chymotrypsin
- Carboxypeptidase
- Elastase
- Small, large proteins
- Individual amino acids

Processes:
- Enterokinase
- Trypsin
- Chymotrypsin
- Carboxypeptidase,
  Intestinal Aminopeptidase
- Small amounts, di-, tri-peptides
• Trypsin Inhibitor

  – Inhibits the activity of trypsin and thus guards against the possible activation of trypsin and the subsequent autodigestion of the pancreas

Acute pancreatitis

Endoscope inserted into mouth

Endoscope travels through gastro-intestinal tract until reaching point of blockage

Gallstone seen through endoscope
Regulation of pancreatic secretion

- Basic stimuli that cause pancreatic secretion
  - Ach: long reflex and short reflex
  - Cholecystokinin (CCK):
    Secreted by I cells
    Stimulates the acinar cells to secrete large amounts of enzymes
  - Secretin:
    Released by S cells
    Acts primarily on the duct cells to stimulate the secretion of a large volume of solution with a high HCO₃⁻ concentration
Regulation of CCK

Stimulate pancreatic secretion
Inhibit gastric motility
Contract the gallbladder

Regulation of Secretin

Stimulate pancreatic secretion
Inhibit gastric motility
Inhibit HCl secretion in stomach
Regulation of pancreatic secretion

• **Phases of pancreatic secretion**
  – Cephalic Phase: Odor and taste of food — long vagus reflex pathways
  – Gastric Phase: Distension of stomach — long vagus reflex pathways
  – Intestinal Phase: Acid, fats, amino acids, peptides and protein induced secretion of CCK and secretin to stimulate pancreatic secretion.
Bile is produced and secreted by liver cells.
Bile is stored and concentrated in the gall bladder during the interdigestive period. Bile is delivered into the duodenum upon stimulation from CCK.

**Composition of bile**

- $\text{HCO}_3^-$: neutralize the stomach acid
- Bile salts: facial amphipathic
- Lecithin
- Cholesterol
- Bile pigments: metabolite of heme
- Trace metals
- Drug metabolite
Functions of bile

- Bile salts help in the digestion of fat:
  - Emulsifying fat
- Bile salts help in the absorption of:
  - Fatty acid
  - Monoglycerides
  - Cholesterol
  - Fat soluble vitamin A

A molecular model of a bile salt, with cholesterol-derived “core” in yellow.

A space-filling model of a bile salt. The non-polar surface helps emulsify fats, the polar surface promotes water solubility.
Bile salts and phospholipids convert large fat globules into smaller pieces with polar surfaces that inhibit reaggregation, and facilitate the fat digestion.

Emulsified fat globules are small enough that lipase enzymes gain access to degrade triglycerides to monoglycerides and fatty acids, which enter the absorptive cells by simple diffusion or aggregate to form loosely held micelles, which readily break down.
Big Droplets of Fat
Small Droplets of Fat
Miccels
Fatty Acids and Monoglycerides
Chylomicron Assembly
Distribution and Processing

Enterohepatic circulation of bile salts

➢ Up to 95% of the bile salts are “recycled” by reabsorption along the intestine.

➢ Increasing bile salts synthesis & secretion.
Regulation of bile secretion

- **Substances increasing bile production**
  - Bile salts (Enterohepatic circulation of the bile)
  - Secretin: stimulating H₂O and HCO₃⁻ secretion from the duct cells
  - Parasympathetic input (Ach)

- **Substance inhibiting bile production**
  - Somatostatin

- **Substances causing gall bladder contraction**
  - ACh
  - CCK
  - Gastrin
Patients with bile duct cancer most often become symptomatic when the cancer obstructs (blocks) the drainage of bile. Because bile cannot be excreted into the bowel, the bilirubin pigments accumulate in the blood, causing jaundice (yellowing of the skin and the whites of the eyes) in 90% of patients. The jaundice is usually associated with itching of the skin (also called "pruritus"). The body compensates partially and excretes some of this bilirubin via the urine, so patients may have dark (cola colored) urine. Because bile cannot reach the intestine, the patient's stools become white (clay colored).
Cholecystitis

Chemical digestion — Small intestinal juices

- Secreted by:
  - Brunners glands
  - Crypts of Lieberkuhn
- 1~3 L/day
- pH 7.5-8.0
- Isosmotic

- Components
  - $\text{H}_2\text{O}$
  - Electrolytes ($\text{Na}^+$, $\text{K}^+$, $\text{Ca}^{2+}$, $\text{Cl}^-$)
  - Mucus
  - IgA
  - Enterokinase
Small intestinal juices

• Function: Active the trypsin and complete the digestion of peptides.

• Secretion by intestinal glands is mainly due to the local effects of chyme in the intestine and is regulated by both neural and hormonal factors

Physical digestion — Movement of small intestine

• Movement of small intestine during digestion
  
  – Tonic contraction: maintaining a basal state of intestinal smooth muscle contraction
  
  – Segmentation
  
  – Peristalsis
Segmentation

- Consisting of the alternate contraction & relaxation of adjacent bands of circular smooth muscle
- Mixing food and facilitating both digestion & absorption

Peristalsis — Regulated by BER

- Distension by bolus
- Stretch receptors
- Excitatory (Ach) and inhibitory (NANC) plexus neurons
- Csm contracts, Ism relaxes
- Csm relaxes, Ism contracts

Stimulus - Distension
Frequency - BER
Mechanism - local distension of the intestine activates reflex pathways involving excitatory/inhibitory neurons in the plexuses
Movement of small intestine

• Intestinal contractile activity in interdigestive period

  **Migrating Motor Complex (MMC)**
  
  – Strong contraction
  
  – Present in the interdigestive period and disappear when feeding begins
  
  – Sweeping material (undigested food residues, dead mucosal cells, bacteria) into the colon and keeping the small intestine clean.
  
  – Regulated by autonomic nerves and by the release of motilin.

Regulation of intestinal motility

• Autoregulation: Regulated by BER

• Neural Reflexes:
  
  – mainly by ‘short’ reflexes in the intrinsic plexuses which are responsible for peristalsis and segmentation
  
  – also by extrinsic nerves (sympathetic & vagal nerves) which mediate ‘long’ reflexes

• Hormonal controls:
  
  – Gastrin, CCK, motilin, 5-HT (+)
  
  – Secretin, VIP, glucagon (-)
Ileocecal sphincter

Digestion in large intestine

- Digestion in large intestine: Very limited
- Bacteria: Vitamin B, K
Anatomy — large intestine

• Transverse part of the colon
• Descending part of the colon
• Sigmoid colon

Function of large intestine

• The principle functions of the colon:
  – Absorption of water and electrolytes from the chyme to form solid feces.
  – Absorption of Vitamin B, K synthesized by bacteria
  – Storage of fecal matter until it can be expelled
Motility of the colon

• Haustration: facilitate water and electrolytes absorption

Motility of the colon

• Mass movement: propulsive movement

• Peristalsis
Defecation reflex

Absorption in the gastrointestinal tract
Basic principle of absorption

- Almost all absorption of nutrients occurs in the small intestine

- Absorption surface of the small intestinal mucosa

- Total area of 250 m²:
  - Folds: 3-fold
  - Villi: 10-fold
  - Microvilli: 20-fold
Absorption pathways
- Transcellular route
- Paracellular route

Absorption mechanism
- Active transport
- Diffusion
- Solvent drag

Absorption of major nutrients
- $\text{H}_2\text{O} \& \text{Na}^+$
  - $\text{H}_2\text{O}$:
    Diffusion and osmosis
  - $\text{Na}^+$:
    Cotransporter
    Carrier-mediated facilitated diffusion
• Fe$^{2+}$
  Receptor-mediated endocytosis
  Recycle of transferrin and its receptor

• Ca$^{2+}$ : Ca$^{2+}$ pump
Glucose and galactose: Secondary active transport (cotransport with sodium) Fructose: facilitated diffusion

Amino acid: Secondary active transport and facilitated diffuse
Fatty acids and monoglycerides → micelles → epithelial cell → form new triglycerides → transport in lymph duct → circulatory blood

Short and medium chain fatty acids (more watersoluble): Direct absorption into the portal blood

Summary

• Pancreatic secretion (Composition, physiological function and the regulation of pancreatic secretion)
• Biliary secretion (Composition, physiological function and the regulation of the bile)
• Motility of the small intestine.
• Describe the absorption of carbohydrates, proteins and fat.