Digestion & Absorption of Food Nutrients

1. Overview of digestion & absorption of nutrients
2. Functional anatomy of the gastrointestinal (GI) tract
3. Digestion and absorption of macro- & micro-nutrients
4. Digestion & absorption of water
5. Effects of exercise on GI function
6. Exercise & disorders of the GI tract
Lecture 2 Learning Objectives (LO2)

Some of Lecture 2 is a review of BPK 110 material so the LO are given in this context. These LO also highlight any new material that extends beyond these introductory nutrition topics.

LO2-1: To describe and explain the overall structure as well as functions of the organs in gastrointestinal tract (GI Tract) that are involved in digestion and absorption of food. These functions include the types of secretions from the GI tract organs.

LO2-2: To describe and explain the important sphincters as well as types of peristalsis/propulsion in the GI tract that function to aid in the digestion and absorption of food.

LO2-3: To describe and explain the differing sections of the small and large intestines and their functions in digestion and absorption of food.

LO2-4: To describe & explain the metabolic pathways plus the physiological events involved in digestion & absorption of the macro- & micronutrients.

LO2-5: To describe and explain the hormonal control of lipid and protein digestion as well as absorption.

LO2-6: To describe and explain both gastric emptying rate and the effects of exercise on GI tract function.

LO2-7: To describe and explain the absorption of water and water balance with an inclusion of the avenues of secretion and excretion of water.
1. Overview of Digestive & Absorption

- Controlled by the autonomic nervous system: involuntary control

- Digestion hydrolyzes complex molecules into simpler substances for absorption.

- Self-regulating processes within the digestive tract largely control the liquidity, mixing, and transit time of the digestive mixture.

- Starts in mouth, with mechanical & chemical digestion

- Further mechanical & chemical digestion in lower gastrointestinal (GI) tract
2. Functional anatomy of gastrointestinal (GI) tract

- GI tract includes the esophagus, gallbladder, liver, stomach, pancreas, small intestine, large intestine, rectum & anus.

- Has a diffuse network of capillaries that transports absorbed nutrients via hepatic-portal vein to the liver.

- The liver processes the nutrients.

*cardiac = esophageal sphincter

Fig. 3.5 Structure of GI system
### TABLE 3.3 Sphincters in the Digestive Tract, Their Location, and Factors That Influence Them

<table>
<thead>
<tr>
<th>Sphinctor</th>
<th>Location</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Esophageal (upper and lower cardiac sphincter)</td>
<td>Junction between esophagus and stomach; prevents back flow (reflux) of stomach contents into the esophagus</td>
<td>Opens only when esophageal muscles contract</td>
</tr>
<tr>
<td>Pyloric</td>
<td>Junction between stomach and first part of the intestine</td>
<td>Under hormonal and nervous system control; prevents back flow of intestinal contents into stomach</td>
</tr>
<tr>
<td>Oddi</td>
<td>End of common bile duct</td>
<td>When hormone CCK stimulates gallbladder to contract during digestion, this sphincter relaxes to allow bile to flow down the common bile duct and enter the intestinal duodenum</td>
</tr>
<tr>
<td>Ileocecal</td>
<td>Terminus of the small intestine</td>
<td>Opens in the presence of intestinal contents</td>
</tr>
<tr>
<td>Anal (two sphincters)</td>
<td>Terminus of the large intestine</td>
<td>Under voluntary control</td>
</tr>
</tbody>
</table>

Fig. 3.6 Propulsion in GI tract
2. Functional anatomy of gastrointestinal (GI) tract

Fig. 3.7 Structure of the stomach and gastric glands.
- Parietal cells secrete mostly HCl
- Mucous neck cells secrete mucus
- Chief cells produce pepsinogen
2. Functional anatomy of gastrointestinal (GI) tract

Fig. 3.8 Macroscopic structure of small intestine.
- villi & microvilli or brush border
- ↑ surface area to promote absorption
2. Functional anatomy of gastrointestinal (GI) tract

Fig. 3.8 Large Intestine ≡ colon ≡ bowel
- 5 ft long (1.66 m)
- 6 segments of interest
- stores feces, bacteria ferment food residue, H₂O reabsorption
- bacteria synthesize Vit K and biotin that are absorbed
### 2. Functional anatomy of gastrointestinal (GI) tract

**TABLE 3.2 Digestive Secretions and Their Actions**

<table>
<thead>
<tr>
<th>Organ</th>
<th>Target Organ</th>
<th>Secretion</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salivary glands</td>
<td>Mouth</td>
<td>Saliva</td>
<td>Breaks down carbohydrate</td>
</tr>
<tr>
<td>Gastric glands</td>
<td>Stomach</td>
<td>Gastric juice</td>
<td>Mixes with food bolus; hydrochloric acid and enzymes break down proteins</td>
</tr>
<tr>
<td>Pancreas</td>
<td>Small intestine</td>
<td>Pancreatic juice</td>
<td>Bicarbonate neutralizes acidic gastric juices; pancreatic enzymes break down carbohydrates, fats, and proteins</td>
</tr>
<tr>
<td>Liver</td>
<td>Gallbladder</td>
<td>Bile</td>
<td>Bile stored until needed</td>
</tr>
<tr>
<td>Gallbladder</td>
<td>Small intestine</td>
<td>Bile</td>
<td>Bile emulsifies fat to facilitate breakdown by enzymes</td>
</tr>
<tr>
<td>Intestinal glands</td>
<td>Small intestine</td>
<td>Intestinal juice</td>
<td>Intestinal enzymes break down carbohydrates, fat, and protein</td>
</tr>
</tbody>
</table>

Digestive enzymes, proteins found in digestive juices, act on food to degrade it to simpler components. Most enzymes end with −ase (pronounced ace), with the beginning of the word identifying the compounds the enzyme works on. For example, carbohydrase hydrolyzes carbohydrates, lipase hydrolyzes lipids, and protease enzymes hydrolyze proteins. Hydrolysis represents a chemical process where a major reactant splits into two end products, with the addition of a hydrogen atom (H⁺) to one product and a hydroxyl group (OH⁻) to the other.
3. Digestion & absorption of macro- & micro- nutrients

Fig. 3.10 Overview of Digestion
Carbohydrate Digestion & Absorption

- Salivary amylase degrades starch to simpler disaccharides (deactivated in low pH gastric fluid)
- Pancreatic amylase continues carbohydrate hydrolysis in SI to give dextrins (glucose in branched chains) & oligosaccharides.
  - Maltase, Sucrase, Lactase on the brush border complete the final stage of carbohydrate digestion to monosaccharides
  - Glucose & galactose absorbed by Na\(^+\)-dependent carrier mediated transport
  - Fructose absorbed by much slower facilitated diffusion
  - SI epithelial cells secrete monosaccharides to capillaries drain to the hepatic portal vein & to liver
  - Water-insoluble fiber (polysaccharides) & undigested CHO acted on by bacteria in colon
3. Digestion & absorption of macro- & micro- nutrients

Mouth: Lingual Lipase- ‘acid stable’
-acts mainly on short & medium chain saturated fatty acids (FA)
e.g. coconut & palm oils

Stomach: Gastric & Lingual Lipase
-hydrolyze same saturated FA
-high lipid content in stomach stimulates release of GIP and secretin – they slow gastric motility

Small Intestine (SI)
-breakdown of long chain FA
-bile mixes w chyme & emulsifies fat, gives micelles that are absorbed by diffusion
-pancreatic lipase hydrolyzes some TAG to monoglycerides & free FA (FFA)
-same effect of pancreatic lipase on animal & plant fats
-most lipid digestion is in small intestine

Fig. 3.11 Digestion of dietary lipids
3. Digestion & absorption of macro- & micro- nutrients

Digestion & absorption of dietary lipids

**Long chain TAG (>12 C)**
- absorbed into epithelial cells & reform TAG
- transported in lacteals as chylomicrons in lymphatic circulation
- eventually drains from thoracic & r. lymphatic duct to large veins
- action of lipoprotein lipases on capillary walls hydrolyze TAG to give FFA & glycerol for peripheral tissues

**Medium Chain TAG (8-12 C)**
- absorbed into hepatic portal v
- bound to albumin
- processed by liver for energy

**Hepatic Portal Circulation**

**Thoracic Duct**
3. Digestion & absorption of macro- & micro- nutrients

Protein Digestion and Absorption

- Pepsin (precursor pepsinogen from chief cells in stomach) initiates protein digestion in stomach to short chain polypeptides.

Gastrin stimulates secretion of HCl & this:

- Activates pepsin
- Kills pathogenic organisms
- Improves absorption of iron & calcium
- Inactivates hormones of plant and animal origin
- Denatures food proteins, making them more vulnerable to enzyme action

In duodenum low pH inactivates pepsin

- Trypsin (precursor trypsinogen from pancreas) hydrolyzes peptide fragments to di-, tri- and single peptides and aa’s
- Free aa’s absorbed by Na\(^+\)-coupled active transport
- di-, tri- peptides actively absorbed by carrier using H\(^+\) gradient

Very efficient only ~3% ingested protein appears in feces
Amino Acids in the Liver

- amino acids reach the liver via the hepatic portal system,
- Here one of three events occurs:
  - Conversion to glucose (glucogenic amino acids)
  - Conversion to fat (ketogenic amino acids)
  - Direct release into the bloodstream as plasma proteins, such as albumin, or as free amino acids
### 3. Digestion & absorption of macro- & micro-nutrients

#### Hormonal Control of Lipid & Protein Digestion

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Origin</th>
<th>Secretion Stimulus</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastrin</td>
<td>Pyloric areas of stomach and upper duodenum</td>
<td>Food in stomach (protein, caffeine, spices, alcohol); nerve input sphincter; slows gastric emptying</td>
<td>Stimulates flow of stomach enzymes and acid; stimulates action of lower esophageal</td>
</tr>
<tr>
<td>GIP</td>
<td>Duodenum, jejunum</td>
<td>Lipids; proteins</td>
<td>Inhibits secretion of stomach acid and enzymes; slows gastric emptying</td>
</tr>
<tr>
<td>CCK</td>
<td>Duodenum, jejunum</td>
<td>Lipids and proteins in duodenum</td>
<td>Contraction of gallbladder and flow of bile to duodenum; causes secretion of enzyme-rich pancreatic juice and bicarbonate-rich pancreatic fluid; slows gastric emptying</td>
</tr>
<tr>
<td>Secretin</td>
<td>Duodenum, jejunum</td>
<td>Acid chyme; peptones</td>
<td>Secretion of bicarbonate-rich pancreatic fluid and slows gastric emptying</td>
</tr>
</tbody>
</table>
3. Digestion & absorption of macro- & micro- nutrients

Vitamins

- Vitamin absorption occurs mainly by the passive process of diffusion in the jejunum and ileum.
- Vitamin $B_{12}$ employs intrinsic factor (IF) from stomach
- SI absorbs IF by endocytosis
- 90% of fat-soluble vitamins absorbed with dietary lipids.
- Once absorbed, chylomicrons and lipoproteins transport these fat-soluble vitamins to the liver and fatty tissues.
3. Digestion & absorption of macro- & micro- nutrients

Minerals

• Both extrinsic (dietary) and intrinsic (cellular) factors control the eventual fate of ingested minerals.

  - Mineral availability in body depends on its chemical form.
  - Generally body does not absorb minerals very well (% ingested)
    - Heme Fe ~15%, non-heme Fe 2-10%
    - Ca\(^{2+}\) not often > 35% (males > females)
    - Mg 20-30%
    - Zn 14-40%
    - Chromium < 2%

6 Factors affecting mineral absorption:

1) Bioavailability=amount ingested that reaches the systemic circul.
2) Transit time from dietary source and absorption site
3) Quantity of digestive juices
4) pH of intestinal lumen contents
5) Receptor cites in intestinal mucosa & brush border
6) Availability of factors to allow movement to intestinal mucosal cells
Metallic mineral absorption is with specific or general protein carrier. e.g. Fe with transferrin & many mineral combine with albumin

Absorption from across intestinal lining cell walls is via diffusion, facilitated diffusion and/or active transport

Fig. 3.12 Absorption of minerals & their common excretion routes
4. Digestion & absorption of water

**Fig. 3.13** Estimated daily volumes of H$_2$O that enters the small & large intestines as well as the amount absorbed by each section of the GI.

GI absorbs ~9000 mL/day

**Oral intake** 2000 mL

**Secretions** from/into:
- Saliva glands 1500 mL
- Bile 500 mL
- Stomach 2000 mL
- Pancreas 1500 mL
- Small & Large Intestines 1500 mL

% of total excretions or secretions *absorbed*:
- Proximal Small Intestine = 6500mL/9000mL = 72%
- Distal Small Intestine = 1800mL/9000mL = 20%
- Large Intestines 700mL/9000 mL = 8% (Fig 3.13 gives 5.6%)

**Water absorption** - passively by osmosis from SI
5. Effects of Exercise GI on Function

A common measure is Gastric Emptying Rate (GER)

- **GER is widely variable btwn individuals, espec. @ < VO₂MAX**
- ↓GER with: ↓food/fluid solution volume*, ↑temperature, ↑caloric content, ↑meal osmolality & ↑acidity
  * very important since b/c GER ↓’s exponentially w/ food/fluid solut. volume

- Acute & chronic exercise both effect GI function (fxn)
- Acutely for ingested CHO beverages or H₂O:

**Intensity** - light/mod. intensity of 20-60% VO₂MAX = ↑GER vs rest
  
  ≥75% VO₂MAX = ↓GER vs rest

**Mxns?** ↑GER may be due to: i) in mod. intensity exercise.
  ↑abdominal contractions & ↑gastric pressure & ii) ↑rate of transit vs. rest in descending colon with light/mod. intensity exercise

**Mode** – light to moderate intensity running ↑GER vs. cycling

**Duration** – limited information, 1 study showed no Δ vs rest over 2 h exercise at 80% VO₂MAX
Gamma camera scintigraphy w images at intervals 1- 4 h post meal
-most common method/gold standard
-non-invasive, but radiation exposure limits use
-standard meal, with radiolabelled meal Technetium-99m (\(^{99m}\)Tc)
-images used to assess % left in stomach from t=0 h, gives a GER measure

5. Effects of Exercise Gastrointestinal Function

Gastric Emptying Rate (GER)

Szarka & Camiller 2009
Am J Physiol - GI
296:G461-G475
6. Exercise & disorders of the GI tract

- Constipation
- Diarrhea
- Diverticulosis
- Heartburn/reflux
- Irritable Bowel Syndrome
- Gas
- Functional Dyspepsia

- look at these if you are interested, important from a coaching and clinical perspective.
1. Overview of digestion & absorption of nutrients
2. Functional anatomy of the gastrointestinal (GI) tract
3. Digestion and absorption of macro- & micro-nutrients
4. Digestion & absorption of water
5. Effects of exercise on GI function
6. Exercise & disorders of the GI tract