Digestive Physiology

We need food for cellular utilization:
- nutrients as **building blocks** for synthesis
- sugars, etc to break down for **energy**

most food that we eat cannot be directly used by the body
- too large and complex to be absorbed
- chemical composition must be modified to be useable by cells

digestive system functions to altered the chemical and physical composition of food so that it can be absorbed and used by the body; ie
- **physical and chemical digestion**
- **absorption**
- **collect & eliminate nonuseable components**

lumen of GI tract is continuous with outside of body
- food being digested must be isolated from body cells since it’s the same composition as rest of body
- digestion occurs OUTSIDE the internal environment of cells and tissues
- protects internal cells

Movement of Materials

as materials are being processed they are moved through alimentary canal by:
- **swallowing**
  - reflex controlled by medulla
  - pharynx to esophagus

- **peristalsis**
  - sequential smooth muscle contractions in adjacent segments
  - pushes food forward
  - esophagus, stomach, small intestine, large intestine

- **segmentation**
  - alternating contractions and relaxations of adjoining portions of intestine
  - food is moved backward and forward
  - helps to physically break up and mix contents for better digestion & absorption

Digestion

digestion = all food changes that occur in the alimentary canal
need to convert food into a form that can be absorbed and used by body cells

two types of digestion:

**physical digestion**
breaking large pieces down into smaller pieces

**chemical digestion**
breaking large molecules (proteins, fats, starches, etc)
into small molecules (amino acids, fatty acids, sugars, etc)

1. **Mouth**
food entering mouth is physically broken down teeth
mixed with saliva
lubricant
enzyme = **amylase**
→ begins carbohydrate digestion
most (60%) of starch digestion by amylase from saliva occurs in stomach
after swallowing bolus
at end of digestion in mouth food = **bolus**

2. **Stomach**
physical digestion involves muscular contractions to separate and mix
food particles

in stomach bolus is mixed with gastric juices

**gastric juices** low pH ~2
hydrochloric acid
pepsin
→ ideal for breaking proteins into smaller fragments

body must be protected from harsh pH of gastric juices:

a. thick coating of bicarbonate rich mucous
b. tight junctions join epithelial cells to help prevent leakage
c. stomach lining is rapidly replaced
   → renewed every 3-6 days
d. pepsin and HCl are secreted in inactive forms

**vomiting** = medullary reflex:
triggered by irritants in stomach
closing nose and glottis
relaxes cardiac sphincter
spasm of diaphragm

**gastric ulcers:** *Helicobacter pylori*
part of normal flora of stomach
can neutralize stomach acids
excessive growth can irritate stomach lining to produce ulcers
physical digestion is completed in stomach

once digestion in stomach is competed have a white milky liquid = chyme

stomach takes about 2-6 hours to empty after a meal

gastric emptying is controlled by enterogastric reflex:
periodic opening/ closing of pyloric valve
prevents overburdening smaller duodenum

3. Duodenum
all physical digestion has been completed

Completes chemical digestion of food
→ most chemical digestion occurs here

receives digestive juices from pancreas and gall bladder

also produces its own set of enzymes

intestinal and pancreatic juices are alkaline
→ neutralize acidity of chyme:
  enzymes in duodenum work best at alkaline pH

presence of chyme in duodenum triggers:
a. release of bile from liver & gall bladder
b. release of pancreatic secretions
c. release of duodenal secretions

a. Bile
contains no enzymes
contains
  bile salts  → made from cholesterol in liver
  bile pigments  → (bilirubin, biliverdin)
  cholesterol  → normally remains in solution
    may precipitate out as gall stones

bile is a surfactant
→ emulsifies fats into smaller fat droplets to speed their digestion

b. Pancreatic Juices
pancreas is an endocrine gland (insulin, glucagon)
but 98% of its tissues make and secrete digestive juices through ducts to the duodenum
include:
- **bicarbonates** – to neutralize gastric acids
- **proteinases** (esp trypsin and chymotrypsin)
  - breaks proteins into peptides and amino acids
- **lipases** – fats to fatty acids and glycerol
- **amylase** – starches to mono & disaccharides
- **nucleases** – nucleic acids into nucleotides

c. Duodenal Secretions
include:
- **peptidases** – breaks polypeptides into amino acids
- **disaccharidases** – disaccharides into monosaccharides
- **nucleosidases & phosphatases** – break nucleotides into component parts

4. Large Intestine
some digestion occurs here due to bacteria
→ esp in caecum

esp herbivores → large caecum
carnivores → small or no caecum

**Control of Digestive Secretions**

secretions from digestive glands is under nervous and hormonal control
digestion begins as mainly an autonomic nervous reflex
digestion is completed due mainly to hormonal controls

1. **Saliva** (~1500ml/day)
strictly a nervous reflex
reflex is triggered by:
  - mechanical and chemical presence of food in mouth
  - olfactory stimulation
  - visual stimulation
salivation can also be a learned response
→ learned by association: eg. Pavlov’s dog

2. **Gastric Secretions** (~1500ml/day)
secretions occur in three separate phases:
- **cephalic phase**
  - secretions first activated by sight, smell, taste and thoughts of food
- **gastric phase**
continued secretion is triggered by presence of polypeptides in pyloric region of stomach stimulates parietal cells to secrete hormone = **gastrin**

**gastrin** circulates within capillaries of stomach and enhance secretions from gastric glands in stomach wall gastrin is secreted as long as there is food in stomach

**intestinal phase**

chyme is released into duodenum duodenum presence of chyme causes release of **intestinal gastrin** this further stimulates gastric secretions

**Enterogastric Reflex**

slows stomach emptying to once/∼20 seconds signaled by **stretch receptors** in duodenum

speed of reflex varies by

a. types of foods
   - eg. fats - slow; proteins – fast
b. fluidity
   - solids – slower; liquids – quicker
c. age
   - infant – fast; adult – slower

Presence of **fatty chyme** in duodenum (fats float → last to leave stomach) stimulates release of **GIP** (gastric inhibitory peptide) → shuts down gastric secretions

4. **Bile** (∼1000ml/day)
   - when chyme enters duodenum
     → secretes cholecystokinin
     → stimulates peristalsis of gall bladder

5. **Pancreatic Juices** (∼1000ml/day)
   - when chyme enters duodenum it causes the release of:
     - **cholecystokinin**
       → stimulates pancreas to release enzymes
     - **secretin**
       → stimulates pancreas to release bicarbonates

6. **Duodenal Enzymes** (∼2000ml/day)
   - may be another hormone that stimulates release of duodenal enzymes
don’t know now
Absorption

~9-10 liters (2.5 gallons) of food, liquids and GI secretions enter tract/day

~1000 ml reaches the large intestine

150 ml is expelled as feces

~half of that is bacteria from intestines

→ 75 ml wastes/d

absorption occurs throughout digestive tract
~90% occurs in small intestine;
~10% in large intestine and stomach

Stomach
some water
alcohol
a few drugs (eg. aspirin)

Small Intestine
absorb ~90% of materials
absorbs virtually all foodstuffs
absorbs 80% of electrolytes
absorbs most water

Jejunum
all food stuffs
most water
most electrolytes

Ileum
reclaims some additional bile salts

Large Intestine
additional water if body needs it
some Vit K and B’s made by bacteria there

Most nutrient absorption occurs in the small intestine

Small intestine is greatly modified for absorption

1. epithelial cells are joined by tight junctions
   better control of what is absorbed
   substances can’t move between cells
   materials must pass through cells to get to interstitial spaces
   (=transepithelial transport)
2. **surface area** is greatly increased for more efficient absorption of nutrients:

   a. 1” diameter x 10’ long
   \[\text{if smooth tube} = 0.33 \text{ m}^2 (3 \text{ sq ft})\]

   b. but: interior is folded
   \[\text{increases area} \sim 3 \times\]

   c. also: fingerlike projections = **villi**
   \[\text{each} \sim 1\text{mm tall} \]
   \[\text{contain capillary beds & lacteals} \]
   \[\text{increases area another} 10\times\]

   d. also: each epithelial cell of villus has microvilli
   \[\text{up to} 1700/\text{cell} = \text{brush border} \]
   \[\text{increases area another} 20\times\]

   **Total Area = 200m}^2 (1800 \text{ sq ft})**

**Mechanisms of Absorption**

absorption can be an active or passive process

essentially some kind of membrane transport

**In terms of transport processes involved:**

1. most nutrients are absorbed by **active transport**
   eg. glucose
   amino acids
   some minerals

2. some lipids are absorbed by **diffusion** to lacteals
   eg. fats
   fat soluble vitamins

3. water is absorbed by **osmosis**

4. large molecules are absorbed by **pinocytosis**
   eg. a few large fats and proteins passed to lacteals with other fats
In terms of the Absorption of Specific Nutrients:

1. **Carbohydrates**
   - mono → facilitated diffusion → capillaries

2. **Proteins**
   - amino acids → active transport → capillaries
   - each requires a specific carrier
   - eg. genetic diseases
   - whole proteins → endocytosis → capillaries
   - rarely absorbed,
   - but more common in newborns
   - → results in food allergies
   - may also be how IgA are absorbed from mothers milk

3. **Lipids**
   - bile salts are essential for absorption as well as digestion
   - **micelles** = collections of fatty elements clustered together with
     - bile salts
     - polar on outside
     - nonpolar core
   - micelles are much smaller than emulsion droplets
   - → easily diffuse between microvilli to come in contact
     - with cell surface
   - fats, cholesterol, fat soluble vitamins then leave the micelles and
     move through the cell membrane by diffusion into epithelial
     cells of villi
   - once inside epithelial cells:
     - triglycerides are coated with proteins
     - → to produce **chylomicrons**
   - **golgi bodies** process and secrete them
   - most lipids enter **lacteals** in villi
   - a few enter capillary beds
   - **micelles → diffusion → chylomicrons → lacteals**
   - in absence of bile, (eg gall stones), most fat passes to large intestine
once in blood:

fats are hydrolyzed back into free fatty acids that can be used by cells for energy production or converted to fat in adipose tissue

4. Nucleic Acids

nucleotides $\rightarrow$ active transport $\rightarrow$ blood

5. Vitamins

a. water soluble vitamins
   $\rightarrow$ diffusion $\rightarrow$ blood
   except $B_{12}$, very large, charged molecule
   binds to intrinsic factor produced by stomach
   taken in by endocytosis

b. fat soluble
   $\rightarrow$ micelles $\rightarrow$ etc

6. Electrolytes

most are actively absorbed throughout the length of intestine

Fe and Ca++ mainly in duodenum

for most nutrients the amount reaching the intestine is the amount absorbed

But absorption of Fe and Ca is closely tied to body’s need:

Fe

is actively transported into mucosal cells
binds to protein ferritin
stored until needed or lost as cells sloughed off
women have 4x’s more transport proteins than men
in blood Fe binds to protein = transferrin, for transport

Ca

regulated by Vitamin D
acts as a cofactor to facilitate Ca absorption
eg. <Bld Ca $\rightarrow$ >PTH:
   $\rightarrow$ Ca release from bone
   $\rightarrow$ reabsorption of Ca by kidney
   $\rightarrow$ renal activation of Vit D to increase
absorption in intestine

Na\(^+\) is coupled with active absorption of glucose and Amino acids

K\(^+\) moves in by simple diffusion

most anions passively diffuse along a gradient

but Cl\(^-\) is actively transported

7. Water

9 L of water enters small intestine daily
95% is absorbed by small intestine (osmosis) coupled to solute uptake
rest is absorbed by large intestine
of ~ 500 ml of chyme entering large intestine
~150 ml of feces is produced
**Processing of Absorbed Nutrients**

**Liver**

is main organ for metabolic regulation in the body

→ over 200 specific functions

1. **stores** carbohydrates, iron, vitamin A, B12 & D
2. **synthesizes** plasma proteins
3. releases nutrients (eg glucose) to maintain blood levels
4. phagocytes remove old/damaged blood cells and pathogens
5. **detoxify** blood from digestive system
6. is largest **blood reservoir** in body
   receives 25% of cardiac output
7. collects and removes metabolic wastes such as cholesterol, products of RBC destruction, etc
8. secrete bile to aid in digestion (~1pt /day)

**lobule** is functional unit of liver

→ each liver lobe is divided into millions of lobules

- tiny hexagonal cylinders (~2mm x 1mm)

**sinusoid spaces** with small branch of **hepatic vein** extends through middle

**hepatic cells** extend outward from hepatic vein branches

around periphery of each lobule are branches of:

- **hepatic portal vein**
- **hepatic artery**
- **hepatic bile ducts**

→ **arterial blood** brings oxygen to liver cells

→ **venous blood** from hepatic portal vein passes through lobule for “inspection”

within each lobule:

a. phagocytic cells remove toxic compounds and convert them to nontoxic compounds

b. some vitamins and nutrients are removed and stored

c. synthesis of starches, lipids and proteins for storage

d. cholesterol, bile pigments and bile salts are secreted into bile ducts for later use in digestion of fats
**Gall Bladder**
stores and concentrates bile
can hold 30-50 ml of bile
gall stones
jaundice = bile ducts obstructed
body can't get rid of bile
bile is absorbed into blood
causes yellowing of skin

**Pancreas**
composed of 2 kinds of glandular tissue:
exocrine → digestive function
endocrine → secretes hormones
islets = 2% of total mass of pancreas
their secretions pass into circulatory system
secrete insulin and glucagon
Digestive Problems

1. **Choking**
   food in air passages
   usually meats, hot dogs, grapes, carrots, hard candy, popcorn, peanut butter
   may not be able to make a sound
   DON’T hit on back

2. **Vomiting**
   symptom of many diseases
   waves of reverse peristalsis
   if severe may empty duodenum as well
   rest and drink small amounts of fluids
   guard against massive fluid loss

3. **Bulemia**
   self induced vomiting
   may cause damage and infection of esophagus, pharynx, or salivary glands
   erosion of teeth, more dental caries
   esophagus may rupture or tear

4. **Diarrhea**
   frequent loose watery stool
   intestinal contents moving too fast for fluid absorption to occur
   main danger is fluid loss
   also upsets acid/base balance

5. **Constipation**
   caused by:
   lifestyle → inadequate water input
   lack of physical activity
   side effect of medication
   increase in fiber, prunes, laxatives
   → attracts water → softens stool

   Colonic Irrigation
   alternative medical practice
   potentially harmful
   unnecessary
   can rupture the intestine

   frequent use of laxatives and enemas:
   can lead to dependency
   upset body’s fluid balance
mineral oil
can interfere with absorption of fat soluble vitamins

6. Belching
results from swallowed air
carbonated drinks and chewing gums can contribute
occasionally can be a sign of a more serious disorder:
gall bladder pain, colonic distress
eat slowly, chew thoroughly
relax while eating

7. Hiccups
repeated spasms of diaphragm
may be triggered by eating or drinking too fast

8. Gas
normally we expell several 100 ml of gas/day
most is odorless
1% are “volatile” gasses
high carb foods known to produce excess gas

9. Heartburn
cardiac sphincter doesn’t close properly
eat or drink too much
clothing too tight
cure: eat small meals
drink liquids 1 hr before or 1 hr after meal
don’t lie down or bend over
lose weight if overweight
don’t smoke
use antacids but sparingly

10. Ulcers
caused by:
bacterial infection
use of some antiinflammatory drugs
disorders that cause excessive gastric secretions
diet therapy used to be main cure, now antibiotics