Chapter 43 Nutrition & Digestion
BASIC PLAN FOR OBTAINING NUTRIENTS

DIGESTION
SECRETES ENZYMES

ONE WAY

ABSORPTION

GUT IS "OUTSIDE"

MASTICATION

"NON-DIGESTIBLES"
BASIC GUT PLAN

MOUTH/PHARYNX:
MASTICATION
(JAWS, TEETH)

DIGESTION,
INCR. SURFACE AREA

ESOPHAGUS

STOMACH:
HOLDING TANK,
DIGESTION

LARGE INTESTINE/
COLON:
TRASH

SMALL INTESTINE:
DIGESTION,
ABSORPTION OF
WATER, SALTS, GLUCOSE,
FATTY ACIDS

ANUS
First let’s look at jaws and mouthparts
Insects have some of the most elaborate, diverse, and specialized mouthpart adaptations.
Fish can have specialized teeth according to diet, and specialized jaws.

Teeth on pharyngeal jaws vary among species of cichlids and correlate with the type of food eaten.

- Crushes snails
- Eats whole fish
- Grazes on algae

*Figure 43-5b Biological Science, 2/e © 2005 Pearson Prentice Hall, Inc.*
Snakes have jaws that are modified for swallowing food whole.

Snakes also have recurved teeth so that closing the jaw moves food inward.
Unless, of course, the food is too large....
On to mammals...

The jaws and teeth of mammals are modified for eating plant material, other animals, or both.

Beavers eat the inner bark of woody plants.

Wolves can subdue large prey by biting.

Humans can process plant and animal tissues efficiently.
Generalist Dentition Pattern

- Mammalian
- Incisors
- Premolars
- Canine
- Molars
- Carnivore
- Herbivore
Jaw action of carnivores and herbivores is different
Two types of muscles are necessary to transport food from mouth to stomach.

1. **Circular muscles** constrict esophagus behind food

2. Then longitudinal muscles contract, lengthening food mass and pushing it forward
In most mammals, there is a small amount of digestion in the mouth and pharynx, but no absorption of nutrients.

The real work begins at the stomach, continuing to the small and large intestines.
You need to learn this stuff.

The digestive tract:

1. **Mouth**
   - Mechanical and chemical processing
   - (chewing reduces size of food; saliva digests carbohydrates)

2. **Esophagus**
   - Transports food

3. **Stomach**
   - Mechanical and chemical processing (digestion of proteins)

4. **Small intestine**
   - Chemical processing and absorption (digestion of proteins, fats, carbohydrates; absorption of nutrients and water)

5. **Large intestine**
   - Water absorption and feces formation

6. **Rectum**
   - Holds feces

7. **Anus**
   - Feces elimination

Accessory organs:

- **Salivary glands**
  - Secrete enzymes that digest carbohydrates; supply lubricating mucus

- **Liver**
  - Secretes molecules required for digestion of fats

- **Gallbladder**
  - Stores secretions from liver; empties into small intestine

- **Pancreas**
  - Secretes enzymes and other materials into small intestine

Note: “...reduces size of food” should be “increases surface area of food”!
What happens if the sphincter does not work well?

Acid conditions in stomach aid bond breaking. Where does the acid come from?
**Parietal cells**: a type of epithelial cell lining the stomach.

Parietal cells have a membrane spanning proton-ATPase ($\text{H}^+/\text{K}^+\text{ATPase}$).

Protons combine with $\text{Cl}^-$ to make stomach acid, HCl.
Carbonic anhydrase converts $\text{CO}_2 + \text{H}_2\text{O}$ to bicarbonate ion and $\text{H}^+$. Bicarb is exchanged for $\text{Cl}^-$, which diffuses down its gradient across the cell and ultimately combines with the $\text{H}^+$. 

$$\text{NaHCO}_3 = \text{sodium bicarbonate}$$

$$\text{HCO}_3^- = \text{bicarbonate ion}$$

$$\text{H}_2\text{CO}_3 = \text{carbonic acid}$$
Chief cells of the stomach secrete zymogen granules containing pepsinogen, the inactive form of the proteolytic enzyme pepsin.

Acid conditions convert pepsinogen to pepsin.

So, protein degradation to amino acids takes place in low pH conditions.

Guess what the pH preference is for the enzyme pepsin?
Duodenum (D) is the most common location to have ulcerations, and 75% of people with such peptic ulcers have an infection of *Helicobacter pylori*. The bacterium burrows through the mucosa; acid attacks duodenum.

One solution – reduce amount of acid secretion. Prilosec® is a specific inhibitor of the proton pump.
The lumen of the small intestine cannot handle low pH conditions, and the enzymes secreted into the lumen require neutral pH.

So tons of bicarbonate buffer is secreted by the pancreas to neutralize stomach contents.
Note that all these molecules are absorbed at the small intestine.
Sugar transport.

Amylase attacks complex sugars... but not all.
Amylase → secreted in saliva, and by the pancreas → small intestine. Breaks down many carbohydrates.

... but a minor change from starch to cellulose makes the enzyme ineffective.

But cellulase does it!
Sugar transport.

Export enzyme to lumen to break down complex sugars to mono, di- & tri-saccharides

Only M, D & T – S’s can be brought into S.I. epithelial cell.

What is facilitated diffusion ??
What is facilitated diffusion?

A type of passive diffusion (so no ATP used, and not co-transport).

A trans-membrane protein pore makes a channel just for the molecule in question. So that molecule makes it across the membrane more easily than otherwise.
Facilitated transport
protein (solute carrier family 2)

5 modes of moving stuff

Lumen of small intestine
Apical side

Blood
Glucose
Facilitated transport protein

Water channels

Ion channel
Large surface area for absorption.

Note that all macro-molecules must be degraded completely to match transporters.

So glucose can be transported, but not maltose.
There are both blood and lymphatic vessels at the ready to sweep away nutrients transported across the small intestine epithelium.
Protein digestion both stomach and S.I.

Successive degradation to a.a.

(next slide)
Technically proteases attack proteins and peptidases attack peptides, BUT since proteases attack peptide bonds in proteins, terms often used interchangeably.
As with other enzymes, those that degrade proteins are secreted as inactive zymogens so they don’t digest the epithelial cells that synthesize them!
Types of Proteases

Serine proteases: neutral pH, except for trypsin!! (which is a serine protease). Chymotrypsin, elastase also serine proteases. Some carboxypeptidases.

**Carboxyl / aspartyl** proteases: low pH (pepsin)

Thiol proteases with cysteine residues (e.g. Papain): low pH. Some carboxypeptidases.

**Metallo proteases** have metal (e.g. zinc) in the active site: neutral pH
One digestive enzyme used to create others!

Produced by duodenum

A zymogen

Active enzyme --

Cleaves proteins in gut food, but also activates other zymogens!

Produced by pancreas – It represents 32% of pancreas protein content.
# Amino acids and diet

<table>
<thead>
<tr>
<th>Essential</th>
<th>Can Be Synthesized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Histidine$^1$</td>
<td>Alanine</td>
</tr>
<tr>
<td>Leucine</td>
<td>Arginine</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>Aspartic acid</td>
</tr>
<tr>
<td>Lysine</td>
<td>Cysteine</td>
</tr>
<tr>
<td>Methionine</td>
<td>Glutamic acid</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>Glutamine</td>
</tr>
<tr>
<td>Threonine</td>
<td>Glycine</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>Proline</td>
</tr>
<tr>
<td>Valine</td>
<td>Serine</td>
</tr>
<tr>
<td>Tyrosine</td>
<td></td>
</tr>
<tr>
<td>Asparagine</td>
<td></td>
</tr>
<tr>
<td>Selenocysteine</td>
<td></td>
</tr>
</tbody>
</table>

You must eat essential amino acids.

$^1$ Adult humans make enough, kids not.

Leucine, isoleucine & valine > 70% of cell protein.
3. Lipids....
1. Fat globules are not soluble in aqueous solution.

2. Bile salts (next slide) act like detergents (have both a hydrophobic & hydrophilic domain).

3. Emulsified fat → micelles, with much greater surface area, so lipase can attack.

(The drug Orlistat (Xenical) – obesity treatment – inhibits pancreatic lipase: reduce fat digestion.)
LIPIDS

Bile includes:
1. Water Lecithin (a phospholipid)
2. Cholesterol (can turn into lumps in the gall bladder, forming gallstones)
3. Lecithin (a phospholipid)
4. Bile pigments (Bilirubin & Biliverden)
5. Bile salts (e.g., sodium glycocholate & sodium taurocholate)

Bile Salts

- made by liver
- secreted into blood
- stored in gall bladder
Bile “salts” are NOT like NaCl. Rather, these are the salts of a number of steroids, such as cholic acid, taurocholic acid and deoxycholic acid.

Cholic acid
LIPIDS

Note: gall bladders are not found in all animals: they are present in many vertebrates, and most mammals (but not horses or rats).

Human liver produces about a quart of bile/day.

Since bile increases the absorption of fats, it also enhances the absorption of fat-soluble vitamins: A, D, E, K.

To try at home:

Bile from slaughtered animals can be mixed with soap. Applied to fabric a few hours before washing is quite effective at removing tough stains.
The Large Intestine

- TRASH COMPACTER
- ABSORB VITAMIN K FROM BACTERIAL FERMENTATION (ANAEROBIC)
- RECOVER SODIUM

Fermentation the only way to digest complex sugars present in plants.

Adaptation for more herbivory = more symbiotic bacteria.
Ruminants are really good herbivores:

OK, how does it really work, and how did we get here from there?
The evolution of herbivory

Generalist Gut

Herbivory specialization

Rabbit (coprophagy)
COPROPHAGY IN RABBITS

GRASS

STOMACH

CECUM

FERM #1

FERM #2

FECAL PELLETS

FERM #2: bacteria digest complex CHO's.

CP's = CECAL PELLETS
Ruminants = Most Advanced Herbivores

Hippos
Sloths
Larger Marsupials
Bovids
Cervids
Giraffe
Camels

Move all fermentation up to stomach:
Large, Partitioned
How the Ruminant Stomach Works

Reticulum: Food Storage ~15% of BW

Rumen: Fermentation Chamber
- Cellulose Digestion
- Yt K

Mouth/Mastication

Reticulum (Most)

Rumen

Regurgitate

Omasum

Abomasum

Cecum

True Stomach: HCl, Pepsin

Water Removal

Regurgitate
Because of regurgitation, some HCl shows up in mouth. The average cow will produce about 50 gallons of saliva/day to neutralize the acid!

Anaerobic fermentation is slow, but allows ruminants to survive on low-grade plant material (grasses). Works if you have a small surface area/volume ratio.

Rumination co-evolves with the major radiation of grasses in the tertiary.
Ions/salts you ingest that are used in biochemical reactions

- Calcium
- Chlorine
- Copper
- Iodine
- Iron
- Magnesium
- Manganese
- Molybdenum
- Phosphorus
- Potassium
- Selenium
- Sodium
- Zinc

Used as enzyme cofactors, ion/osmo regulation, nervous system ion gradients, structural elements.
Vitamins are small quantity “nutrients”.

<table>
<thead>
<tr>
<th>A vitamins</th>
<th>C vitamins</th>
<th>Used as enzyme cofactors, growth regulators.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retinol</td>
<td>Ascorbic Acid</td>
<td>Some vitamins are really hormones (Vitamin D), but historically mislabeled.</td>
</tr>
<tr>
<td>Retinal</td>
<td></td>
<td>A, D, E, K lipid soluble.</td>
</tr>
<tr>
<td>Carotenoids</td>
<td></td>
<td>B, C water soluble &amp; so not stored.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B vitamins</th>
<th>D vitamins</th>
<th>K vitamins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thiamine</td>
<td>Cholecalciferol</td>
<td>K &amp; biotin synthesized by gut flora</td>
</tr>
<tr>
<td>Riboflavin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Niacin</td>
<td>Tocopherols</td>
<td></td>
</tr>
<tr>
<td>Niacinimide</td>
<td>Tocotrienols</td>
<td></td>
</tr>
<tr>
<td>Pantothenic acid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyridoxine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biotin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Folic acid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyanocobalamin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydroxycobalamin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methylcobalamin</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>E vitamins</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Phylloquiine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Menaquinone</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Digestion homeostasis: maintaining blood sugar levels...
43.16 blood sugar homeostasis.

A double feedback loop creates a much more stable level.
Diet influences on health

- Obesity, genetic predisposition can lead to diabetes
- Cholesterol deposition in blood vessels -- increased by certain kinds of dietary fat and genetic predisposition
- Many others we won’t talk about
The Type II Diabetes Mellitus Epidemic

Type II diabetes:

1. Pancreas does not produce enough insulin
2. Liver, other cells become resistant to (ignore) insulin

(Type I = juvenile diabetes or early onset diabetes; typically the pancreas does not produce any insulin)
Incidence of type II diabetes mellitus among Pima Indians

Figure 43-18a Biological Science, 2/e
© 2005 Pearson Prentice Hall, Inc.
Type II diabetes mellitus is more prevalent in obese people.
Cholesterol-occluded blood vessel:

- Cholesterol deposit
- Wall of artery
- Blood

Figure 43-19 Biological Science, 2/e
© 2005 Pearson Prentice Hall, Inc.