BIOLOGY 164: ORGANISMAL PHYSIOLOGY
ANIMAL NUTRITION
SPRING 2004

The primary function of the gastrointestinal tract:

How do organisms adapt for maximizing the usefulness of feeding?
adaptations for feeding

herbivores

carnivores

What is the GI tract?

What does the mammalian GI tract include?

What are the major functions of the GI tract?
1) motility --

2) secretion --

3) digestion/absorption --

4) immune tissue --

What factors control GI function?
1) hormones

2) autonomic nervous system
   a) parasympathetic nervous system

   b) sympathetic nervous system

3) enteric nervous system

GI motility:

smooth muscle

skeletal muscle

What are the types of motility in the GI tract?
1) rhythmic segmentation

2) peristalsis

3) tonic contraction

What is digestion?

What is absorption?

What is secretion?

How does blood flow in the GI tract?

What processes/organs are involved in the movement of food through the GI tract from the mouth to the anus?
I. Mastication

II. Deglutition

III. Salivary glands

IV. Esophagus

V. Stomach

What are the secretions of the stomach cells?

What causes ulcers?

VI. Pancreas
endocrine pancreas

exocrine pancreas

What types of digestive enzymes are secreted by the exocrine pancreas?
Proteolytic enzymes

Amylolytic enzymes

Lipolytic enzymes

Nucleolytic enzymes

What are the major functions of pancreatic juice?

VII. Liver and gallbladder (biliary system)

digestive function of the liver

enterohepatic circulation

What are the functions of bile salts?
1) emulsify dietary fats

2) solubilize lipid soluble compounds

What are the functions of the gallbladder?

VIII. Small intestine

major function of the intestines

What are the functions of intestinal motility?

How is intestinal motility controlled?
1) Intrinsic nerves

2) Extrinsic nerves

What are intestinal cells and what do they do?
1) enterocytes

2) secretory cells

3) crypt cells

DIGESTION AND ABSORPTION
What happens with digestion?
Carbohydrates

Proteins

Fats

Nucleic acids (DNA, RNA)

What are the five major digestive secretions of the GI tract?
1) saliva

2) gastric juice

3) pancreatic juice

4) bile

5) intestinal juice

Where does absorption of nutrients occur (besides the small intestine)?
1) under the tongue

2) from the stomach

3) from the large intestine.

A. How are carbohydrates digested and absorbed?
in the mouth –

in the stomach –

in the small intestine –

brush border membrane enzymes

absorption of monosaccharides

What happens if there are non-digestible solids (fiber) in the food?

B. How are fats digested and absorbed?
in the stomach --

in the small intestine –

to cells --

into cells --

inside cells --

out of cells --

final destination --

C. How are proteins digested and absorbed?
in the stomach –

in the intestine –

brush border membrane enzymes

into cells

D. How is water absorbed?

IX. Large intestine – cecum, colon, rectum, anus

The function of the large intestine

How is defecation initiated?

Mass movements

What digestion and absorption can occur in the large intestine?

What causes intestinal flatus (colonic gas)?

What is the defecation reflex?

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DR. GOODMAN'S NOTES

This handout refers to material covered in Chapter 50 of Life: The Science of Biology Volume III: Plants and Animals, by W.K. Purves, D. Sadava, G.H. Orians, and H.C. Heller, 6th edition, 2001. Read and study pages 886 – 893. All of Chapter 50 should be read.

Your Learning Objectives for this Section are:

1) Using examples from several different types of organisms, describe how the GI tract is designed for its primary function.
2) Compare and contrast GI tract function under parasympathetic and sympathetic nervous system control. Why are these functional differences helpful to the organism?
3) Be able to give the details of how the GI tract digests and absorbs one of the following nutrient categories (carbohydrates, proteins, and fats). Be sure to include what happens in each organ of the GI tract and what happens to allow the breakdown products to both enter an intestinal epithelial (absorptive) cell and leave the cell.
4) Outline the basic function of each of the organs in the mammalian GI tract.
5) Analyze what would happen to an individual who lacked pancreatic enzymes and why.
6) Analyze what would happen to an individual who had their gallbladder removed and why.
7) Explain how the defecation reflex is initiated and how two different sphincters are involved.

Introduction:

The **primary function** of the gastrointestinal tract is to convert nutrients, water, and electrolytes into chemical forms usable by the organism.

How do organisms adapt for maximizing the usefulness of feeding?

Various **adaptations for feeding** have occurred including anatomical, physiological, and biochemical changes. Anatomical adaptations are: the elephant's trunk, the giraffe's neck, special mouthparts for grinding, cutting, etc., specially designed teeth, etc. **Herbivores** have evolved to be able to digest and use vegetation. **Carnivores** have evolved to be able to detect, catch, kill, rip apart, and ingest their prey.

What is the GI tract?

The inside of the GI tract (where the food/feces are) is by definition **outside the body**. The GI tracts of most animals are **tubes with a mouth and an anus**. Food can be **broken apart** by teeth, mandibles, or gizzards and then **stored** in stomachs or crops and then **digested and absorbed** in the midgut or small

intestine passing into the hindgut or large intestine and then the **feces** passing through the rectum on the way to exit by **defecation**. In most cases, the GI tract has evolved **LARGE surface areas** for the absorption of the breakdown products of food.

What does the mammalian GI tract include?
oropharynx →esophagus →stomach →small intestine →large intestine →anus

and its accessory organs: salivary glands, liver and gallbladder (biliary system), pancreas

What are the major functions of the GI tract?
4) **motility** -- for movement down the tube and for mixing with digestive juices
5) **secretion** -- water, salts, enzymes, hormones, and mucus (these are digestive, regulatory, and protective juices)
6) **digestion/absorption** -- breakdown of proteins, carbohydrates, and fats into forms that can be absorbed from the small intestine into the blood
7) since the GI tract is **outside the body,** foreign invaders need to be repelled by special **immune tissue**

What factors control GI function?
3) True **hormones** (secreted into blood) help to control the function of the GI tract. These include secretin, gastrin, and cholecystokinin (CCK) that regulate the functions of numerous organs throughout the GI tract.
4) There are extrinsic nerves from the **autonomic nervous system** that affect the GI tract.
   a) The parasympathetic nervous system regulates secretomotor function (secretion and motility) – **REMEMBER REST AND DIGEST!**
   b) sympathetic – mostly antagonistic to normal GI function (no secretion/motility) – **REMEMBER FIGHT OR FLIGHT!**
5) There are intrinsic nerves in the GI tract from the **enteric nervous system** that affect function.
   a) One level is found between the circular and longitudinal muscles in the walls of the GI tract and regulates motility, tone, and rhythm.
   b) One level is found between the circular muscle and the submucosal layer in the walls of the GI tract and regulates secretion.

GI motility: The purpose of GI motility is for **propulsive activity** down the tube and breaking apart the food to help **mix** it with digestive secretions.

There is **smooth muscle** making up most of the walls of the GI tract except at the top and bottom where striated skeletal muscle is found (so that only the very **top and bottom** can be under <u>voluntary</u> control).

What are the types of motility in the GI tract?

4) **rhythmic segmentation** -- of circular muscle is used for **mixing** and propulsion (like squeezing a sausage between the fingers periodically in different places)
5) **peristalsis** – coordinated waves of contraction between circular and longitudinal muscles that is preceded by relaxation of the section ahead for **propulsion** (like milking a sausage skin to remove the meat)
6) **tonic contraction** -- contracted most of the time (like the **sphincters** that usually are closed to inhibit the passage of foodstuffs from one section to another)

What is digestion? – The **chemical breakdown** (hydrolysis) of carbohydrates, proteins, fats into compounds **usable** by the intestinal cells using motility and the enzymes in the digestive juices and cell membranes.

What is absorption? – The **uptake** of water, electrolytes, and the final breakdown products of the nutrients through the GI tract wall and into the bloodstream. These compounds need to be able to move **into** the **epithelial cells** and then to **cross** the cells and finally to **leave** the cells in order to enter the bloodstream.

What is secretion? – There are two primary functions for the secretions of the GI tract: 1) the secretion of the **digestive enzymes, salts, and water** helps to facilitate digestion and absorption and 2) the secretion of **mucus** helps to coat the inside walls of the GI tract for lubrication and protection.

How does blood flow in the GI tract?

There are **parallel circuits** of blood that go to each organ individually and can be individually regulated by the body by constricting or dilating the blood vessels. There are **series circuits** that take the venous blood from the GI tract organs (stomach, pancreas, intestines) via the portal vein directly to the liver resulting that the liver is first exposed to all absorbed substances.

What processes/organs are involved in the movement of food through the GI tract from the mouth to the anus?

I. Mastication (chewing) – Mastication has both **voluntary and involuntary** components and stimulates taste buds, lubricates, reduces particle size, and mixes the food with the saliva.

II. Deglutition (swallowing) – Deglutition has both **voluntary and involuntary** components and involves the **swallowing reflex** that initiates the first peristaltic wave going down the esophagus.

III. Salivary glands – Salivary glands found under the tongue secrete water, mucus, ions and the digestive enzyme **α-amylase**, in order to hydrate food, make food easier to slide, and begin to break down starch.

IV. Esophagus – The esophagus is a 2-foot long **smooth muscle** tube that serves as a **conduit** for food from the mouth to the stomach and has peristaltic waves and secretion of mucus.

V. Stomach – The stomach is designed to **store food** and begin to process it prior to allowing the chyme (glob of food) **slow entry into the small intestine**.

What are the secretions of the stomach cells?
Gastric juice in the stomach contains hydrochloric acid (HCl), the enzyme pepsinogen, **mucus**, various ions, and the protein intrinsic factor. Some stomach cells produce both **HCl** (stomach acid) and **intrinsic factor** (binding protein that allows later absorption of vitamin B-12). Other stomach cells secrete **pepsinogen** that will become the enzyme (pepsin) and begin to break down proteins in the stomach. Other stomach cells secrete the hormone **gastrin** into the **blood**.

REVIEW OF THE STOMACH RESPONSE TO A MEAL:
At the start of the meal, there is increased secretion of gastric juice.
Shortly after the food enters the stomach, there are vigorous contractions for mixing and propulsion.
After the meal about 2 h later, there is a decline in secretion.
There is only limited breakdown of starch by salivary amylase or simple fats by lingual lipase or protein by pepsin while food is in the stomach.
When the chyme is ready, the stomach empties its contents slowly into the small intestine.

What causes ulcers?
The stomach wall is **resistant to digestion** by HCl and pepsin because it is covered by a thin layer of **alkaline (basic) mucus**, its epithelial cells are joined by **tight junctions** to prevent acid leak, and damaged epithelial **cells are replaced quickly.**
Both gastric and duodenal ulcers have been linked to the infection of the individual with the organism ***Helicobacter pylori.***
Thus, the **treatment of choice for ulcers now** is 2 weeks of combination antibiotic therapy + 4-8 weeks with an acid-reducing drug (until the stomach wall recovers).

VI. Pancreas
The **endocrine** pancreas secretes the hormones insulin, glucagon, and somatostatin (islets of Langerhans).
The **exocrine** pancreas secretes **pancreatic juice** (chloride, bicarbonate, sodium, potassium with particularly **high bicarbonate** (very basic) and numerous **digestive enzymes**).

What types of digestive enzymes are secreted by the exocrine pancreas?

Proteolytic enzymes – break down proteins
Amylolytic enzymes – break down starches (i.e., α-amylase)
Lipolytic enzymes – break down fats (i.e., lipase)
Nucleolytic enzymes – break down RNA and DNA (i.e., RNAase and DNAase)

Most pancreatic enzymes are secreted as **zymogens** (inactive molecules) and are activated when enterokinase changes trypsinogen into trypsin and many enzymes are activated by trypsin. **This is important because otherwise the pancreas might digest itself (acute pancreatitis).**

What are the major functions of pancreatic juice?

The **bicarbonate** in pancreatic juice neutralizes the acid from the stomach in the chyme to facilitate digestion and absorption **(pancreatic enzymes need a pH of 6.0 – 8.0).**

Despite the presence and normal activity of both the salivary and gastric enzymes, there would be **significant maldigestion and malabsorption** in the absence of pancreatic enzymes (cystic fibrosis patients have this problem).

REVIEW OF PANCREATIC RESPONSE TO A MEAL:

Get pancreatic secretion of enzymes by smell, taste, chewing, swallowing (thinking about food)
Get pancreatic secretion of enzymes when food enters the stomach
Get pancreatic secretion of enzymes when chyme enters the upper part of small intestine (70-80% response)

VII. Liver and gallbladder (biliary system)

The primary **digestive function** of the liver is the **secretion of bile.**

The **hepatic (liver) bile** is an aqueous solution of organic and inorganic compounds with salts particularly bicarbonate secreted by the liver cells.

The **enterohepatic circulation** of blood flowing from the intestine directly to the liver facilitates the secretion and the recycling of bile salts so that they do not need to be remade constantly.

What are the functions of bile salts?

2) Bile salts help **emulsify dietary fats** into smaller droplets that can more easily be acted upon by the digestive enzymes.

2) Bile salts **solubilize lipid soluble** compounds (including the fat soluble vitamins) into **mixed micelles** so that they can more easily get to the intestinal epithelial cells to be **absorbed by diffusion**.

The **gallbladder bile** is the hepatic bile after it has been stored (and modified) in the gallbladder.

What are the functions of the gallbladder?

1) The gallbladder **concentrates the bile** by absorbing sodium, chloride, bicarbonate, and water out of the bile. The gallbladder bile is more acid than hepatic bile.
2) The gallbladder then **delivers** the bile to the upper part of the small intestine **at appropriate times** to begin digesting fats**.**

VIII. Small intestine

The **major function** of the intestines is to facilitate the digestion and absorption of nutrients and water.

What are the functions of intestinal motility?

The motility in the intestine helps to **mix** the chyme with the secretions (intestinal and pancreatic juices). The motility helps to stir the chyme so that it comes in contact with the large **digestive/absorptive surface area.** The motility helps to **move** the chyme **down** the GI tract. The motility helps to promote lymph flow by **"milking"** the lymph vessels.

How is intestinal motility controlled?

3) **Intrinsic nerves** of the enteric nervous system coordinate intestinal motility.
4) **Extrinsic nerves** (the parasympathetic vagus nerve is excitatory and sympathetic nerves are generally inhibitory) help to modulate the motility.

What are intestinal cells and what do they do?

4) **enterocytes (intestinal epithelial cells)** -- These cells are the **digestive and absorptive** units of the body!
5) **secretory cells** – The goblet cells secrete **mucus;** endocrine cells secrete the hormones **secretin** or **cholecystokinin** into the blood.
6) **crypt cells** – produce **mucus and water** and act as **stem cells** to replace the dead epithelial cells (during the turnover cycle the brush border membrane enzymes are released from the dead cells to act on the chyme)

Intestinal cells **secrete water and electrolytes** (2-3 L daily) to maintain the fluidity of chyme – this is rapidly reabsorbed later in the intestine.

DIGESTION AND ABSORPTION

What happens with digestion?

Carbohydrates are broken down into monosaccharides.
Proteins are broken down into di- and tripeptides and some individual amino acids.
Fats are broken down into monoglycerides and free fatty acids.
Nucleic acids (DNA, RNA) are broken down into purines, pyrimidines, and sugars.

The **catalysts** (make it happen faster) for complete digestion of these nutrients are the **digestive enzymes**.

What are the five major digestive secretions of the GI tract?

6) **saliva** in the oral cavity (mouth)
7) **gastric juice** in the stomach
8) **pancreatic juice** in the duodenum (upper small intestine)
9) **bile** (from liver and/or gallbladder) in the duodenum (upper small intestine)
10) **intestinal juice** in the small intestine

Where does absorption of nutrients occur (besides the small intestine)?

1) Very lipid soluble compounds like nitroglycerine can be absorbed **under the tongue.**
2) Other lipid soluble compounds like ethanol, aspirin, and bile acids can be absorbed **from the stomach.**
3) Some of the nutrients and water that were not already absorbed in the small intestine can be absorbed **from the large intestine.**

A. How are carbohydrates digested and absorbed?

in the mouth – salivary α-amylase (3-5% digestion)

in the stomach – when **salivary α-amylase** is still active **(30-40% digestion)**

in the small intestine – **pancreatic α-amylase to oligosaccharides** (few sugars) like maltose
THEN **oligosaccharides to monosaccharides** (single sugars) by **brush border membrane enzymes** like sucrase, lactase, and maltase
then absorption of monosaccharides across the enterocytes using **transport proteins**

What happens if there are non-digestible solids (fiber) in the food?
Fiber stays in the lumen and binds water:
low fiber diet – mouth to anus transit time for food takes 3 days
high fiber diet – mouth to anus transit time for food is < 20, 30 h

But fiber binds calcium, iron, magnesium, zinc, bile salts, and lipids (cholesterol) and causes them to be excreted in the feces so a **mineral supplement** may be needed on a high fiber diet. In addition, people with high cholesterol are encouraged to eat lots of fiber.

D. How are fats digested and absorbed?

in the stomach – small amounts of simple fats with **lingual lipase** from the salivary glands and **gastric lipase** from gastric glands

in the small intestine – essentially all fat digestion occurs in small intestine

fats are emulsified by **agitation** and the presence of **bile salts**

digested by pancreatic lipase in small intestine

THEN **solubilized** into mixed micelles with bile acids for delivery to the cell

diffuse into cells through the lipid bilayer

in cells may be resynthesized from components to form **chylomicrons** with protein coats

released from the cells

then taken up by the **lymph** vessels

E. How are proteins digested and absorbed?

in the stomach – pepsin (10-30% digestion)

in the intestine – proteolytic enzymes of pancreas breakdown to **small peptides** (2-6 amino acids – 70%) and **individual amino acids** (30%)

THEN some oligopeptides (few amino acids) further broken down by **brush border membrane enzymes** to single amino acids, nucleoproteins are broken down by **DNAase and RNAase**

THEN absorbed by intestinal epithelial cells using **transport proteins**

D. How is water absorbed?

Eight liters of water reach the small intestine daily (80% is reabsorbed). Water transport in the intestine occurs **BY OSMOSIS** depending upon the **location** in the intestine (leakiness of the walls varies from beginning to end), the rate of **active transport**, and the **osmolarity** of the chyme in the intestinal lumen.

IX. Large intestine – cecum, colon, rectum, anus

The function of the large intestine is for **drying and storage** of the chyme before excretion.

How is defecation initiated?

Mass movements usually occur after breakfast and a few other times of the day and **CAN initiate defecation.**

When **fecal material enters the rectum**, rectal distension **may initiate defecation reflex** (at an appropriate time)**.**

What digestion and absorption can occur in the large intestine?

water (1.5 L) enters the large intestine every day and 90% is absorbed

salts can also be absorbed

food residues can be further **digested by the bacteria in the colon** – some carbohydrate digestion of fiber and mucus and then absorbed by diffusion;

some lipid digestion by microbes; some bile salt digestion to more lipid soluble forms so that they can be recycled through the liver.

bacteria in the colon also synthesize Vitamin K for the body.

What causes intestinal flatus (colonic gas)?

1) swallowed **air** in the GI tract
2) **carbon dioxide** made from water and bicarbonate combining in the lumen
3) volatile **metabolites** from the bacteria including hydrogen, methane, carbon dioxide.
4) **diffusion of gas from blood to lumen**

What is the defecation reflex?

The **rectum** is usually empty. If it is distended at a convenient time by feces or an increase in pressure (**Valsalva maneuver** – straining), the defecation reflex is initiated. The **internal anal sphincter** relaxes and the **external anal sphincter** transiently constricts, when both are relaxed, defecation can occur.

THE END OF DIGESTION!