Biology 120
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Chapter 41
Animal Nutrition and Digestion (The Digestive System)

SUBJECTS:

I. Nutrition and Essential Nutrients
II. Digestion and Types of Digestive Systems
III. The Human Digestive System
IV. Types of Feeders
V. Adaptations of the Digestive System

Notes

In the early days of life on Earth (2 billion years ago) organisms were microscopic, lived in the ocean, and obtained the nutrients needed to live by absorbing them directly from the ocean. Many modern organisms still feed this way. Yeast and fungi, for example, feed by secreting digestive enzymes onto the substrate on which they live, and then absorb the broken down digestion products. (ie- fungi growing on wood secrete enzymes called cellulase enzymes that break down cellulose into individual glucose units. The glucose is then absorbed directly through the fungal membrane, and used for energy.)

As organisms became multicellular and bigger, and moved on to land, it was necessary to develop special organ systems designed to take food inside and digest it internally. Some primitive organisms like the Cnidarians (jellyfish, hydras etc.) have an internal digestive compartment with a single hole leading to it (Figure 41.7). Food is taken in, digestive enzymes (that break down the food) are secreted into the compartment, some of the digestion products (individual sugars from broken down polysaccharides, amino acids from broken down proteins etc.) are absorbed by the tissue lining the compartment, and anything that can't be digested is sent back out through the same hole. More advanced organisms have two holes, one (the **mouth**) for taking food inside, and another (the **anus**) for sending the things that can't be digested back outside (Figure 41.8). The long tube that connects the mouth to the anus is referred to as the **alimentary canal**, the **gastrointestinal system,** or the **digestive tract**. Various compartments along this tube store the food while digestive enzymes are added to it, and special glands produce these enzymes.

I Nutrition and Essential Nutrients

Humans and other organisms need to ingest materials to carry out metabolic processes. Most of the larger biological molecules (proteins and polysaccharides) are too large to be absorbed in the alimentary canal, and too big to cross the membrane of the alimentary canal. Therefore, they are broken down first. Proteins broken down into amino acids which can cross the membrane, polysaccharides (ie-starch) are broken down into glucose, which can cross the membrane etc. Vitamins and minerals, which are cofactors (prosthetic groups) for many enzymes can also cross the membrane. Of the 20 amino acids, humans can only make 12 of them. The other 8 are

referred to as '**essential amino acids'** because we can't make them, and we must get them from food.

A list of necessary vitamins and minerals, which we must get from food is given in Tables 41.1 and 41.2. Note that most of the vitamins are water soluble, but some are called 'fat-soluble vitamins.' This means that these vitamins are absorbed and stored in fat. This is important because it is possible to take (or eat) too much of these vitamins. If you eat too much of a water soluble vitamin, it will simply be released back out in the urine. Vitamin B2 (Riboflavin) is a good example of this. If you take a vitamin pill, and then notice that your urine is bright yellow, it's because the excess riboflavin is coming back out.

Vitamin A (Retinol) is an example of a fat-soluble vitamin that you can take too much of. The excess vitamin A will be retained in body fat, and give you a headache or dizziness. An extreme lack of Vitamin A, by contrast, can lead to vision problems or even blindness. This is the case in some impoverished countries where people receive insufficient Vitamin A in their diets. A lack or excess of several other vitamins can also cause problems. **Vitamin B9 (Folic Acid)** is another example. If a pregnant woman has too much or too little folic acid during her pregnancy, the baby may be born with birth defects. As a result, doctors often keep close track of a woman's folic acid levels during pregnancy.

Minerals are also important (Table 41.2). Iron is essential for proper red blood cell formation, and a lack of iron in the diet can lead to **iron-deficiency anemia** (lack of red blood cells, tiredness and weakness). By contrast, most North American diets include too much sodium. Sodium is found mostly in table salt that is added to food. Sea salt (a mixture of sodium chloride and potassium chloride) is a healthier alternative.

II Digestion and Types of Digestive Systems

Some examples of digestive systems are shown in Figure 41.8. The **alimentary canal** consists of a long tube leading from the mouth to the anus. Food is moved down this tube through a process called **peristalsis**, where the tube is squeezed by smooth muscles, pushing the food down the tube. (You may have heard of a type of pump, seen in hospitals, called a 'peristaltic pump' which uses the same principle.) Along the way down the alimentary canal, several compartments and glands are seen. Different organisms will have different compartments along the way, including:

1. **Mouth:** A hole where food is taken inside. The process of taking food inside is called **ingestion**.
2. **Pharynx**: muscular organ that helps the mouth to draw food inside.
3. **Salivary Glands:** add saliva to the food to prevent it from abrading (scratching up) the digestive tract. Saliva is a viscous liquid full of polysaccharides and (in some cases) enzymes. In humans, for example, saliva contains **amylase enzymes** that begin breaking down starch from the time the food is ingested.
4. **Teeth:** to grind food up into smaller pieces that can be more easily broken down by digestive enzymes. (Not all organisms have teeth.)
5. **Gizzard:** Animals that don't have teeth (worms and birds for example) have a muscle-lined compartment where gravel (small rocks) is kept. The gravel is obtained from the

ground. When food enters the gizzard, it contracts, and grinds up the food, the way teeth do.

6. **Crop:** A compartment that some animals have where liquid is added to food before it proceeds.
7. **Rumen:** A compartment that contains **symbiotic bacteria** and **protozoa** that can break down cellulose. The presence of these symbiotic organisms allows certain animals (ie-cows) and insects (ie-termites) to eat cellulose (grass and wood). Once the cellulose has been broken down into glucose, the food (and sometimes some of the symbiotic microbes) then passes into a second stomach where regular digestion takes place. Animals that have a rumen are called **ruminants**.
8. **Stomach:** a compartment where digestive enzymes are added, often under acidic conditions, which then proceed to break down proteins and lipids.
9. **Small Intestine:** long tube, often with a surface area that has been expanded by folding and the presence of **villi** (finger-like projections) where the broken down food is absorbed.
10. **Large Intestine:** large amounts of water are added to the food to help the enzymes break it down. This water is reclaimed in the large intestine.
11. **Rectum:** a compartment for storing feces (the waste products that can't be broken down by digestion) before it is expelled out through the anus.
12. **Anus**: A hole leading outside the alimentary canal, where food waste products that can't be digested are expelled.

III The Human Digestive System

A schematic diagram of the human digestive system is shown in Figure 41.9. The top part, including the mouth, pharynx, salivary glands and esophagus is sometimes called the upper digestive tract, to distinguish it from the other organs (the lower digestive tract). From top to bottom it includes:

1. **The mouth, tongue, teeth and salivary glands:** The teeth grind up the food into smaller pieces that are more easily broken down by digestive enzymes. (Digestive enzymes attach to the surface layer of food, and a collection of smaller pieces has a larger surface area than one large piece.) The food bites are repositioned for the teeth to grind up by the tongue. Salivary glands secrete a viscous liquid (saliva) into the mouth to help emulsify the food, and also protect the esophagus and mouth from being abraded (scratched) by rough food particles. Saliva also contains **amylase enzymes** that begin breaking down starch. (You learned this in Lab 4.) The mouth is also lined will lose cells called **buccal cells** that come off easily. Eventually the food is balled up into a mass of chewed food and saliva called a **bolus**, and swallowed.
2. **Pharynx:** Muscular top of the esophagus that helps propel a food bolus down the esophagus.
3. **Esophageal Sphincter:** a ring of muscle that closes off the top of the esophagus, preventing food from coming back up.
4. **Epiglottis:** a flap of cartilage and skin that covers the **trachea** (tube leading to lungs), preventing us from inhaling things we eat and drink.
5. **Esophagus:** muscular tube leading from the pharynx to the stomach. Food is pushed down the esophagus using **peristalsis**.

6. **Cardiac Sphincter:** Ring of muscle tissue that pinches the esophagus closed just above the stomach, preventing stomach acid from going up into the esophagus.
7. **Stomach:** Mucus lined, acidic compartment where food is mixed with an enzyme called **pepsin,** which breaks down proteins. Mucus is a viscous liquid containing polysaccharides and proteins that lines the stomach (as well as some other parts of the body). In this case, the mucus prevents the stomach from acid and pepsin. Pepsin is produced in an inactive, polymer form (called **pepsinogen**) by stomach cells called **chief cells**. Pepsinogen is then activated when it is cut up into monomers of pepsin by already active molecules of pepsin. Cells called **parietal cells** produce large amounts of **hydrochloric acid**, bringing the pH of the stomach down to about pH 2, which is the optimum pH for pepsin. The mixture of pepsin and HCl is called **gastric juice**. ('Gastric' is another word for stomach.)
8. **Pyloric Sphincter:** Ring of muscle that pinches the bottom of the stomach closed, thus controlling what enters the small intestine.
9. **Duodenum:** The part of the small intestine that joins to the bottom of the stomach.
10. **Liver, Gall Bladder and Bile Salts:** Bile salts emulsify fats, aiding in their digestion (you proved this in Lab 2). Bile salts are produced by the liver, stored in the gall bladder, and secreted into the duodenum to assist with the breakdown and absorption of fats in the small intestine.
11. **Pancreas:** produces other digestive enzymes, including more amylases (that break down starch), lipases (that break down emulsified fats) and proteases (that break down protein) which are also added in the duodenum, and allow digestion to continue along the length of the small intestine. The pancreas also produces **bicarbonate**, a basic buffer solution, that neutralizes the stomach acid and makes the pH of the intestine basic. Enzymes that are active in the intestine have a high optimum pH or around pH 8.
12. **Small intestine**: The job of the small intestine is to absorb the broken down food products. Thus, the larger its surface area, the more it can absorb. It is folded many times to increase its surface area (a common method of increasing the surface area of an active exchange membrane), and also has **villi** on it. Villi are small, finger-like projections from the epithelial cells lining the intestine, which increase its surface area even more. The small intestine is also quite long (about 10m). The part of the small intestine that makes contact with the stomach is called the duodenum, which is relatively short. The longer part is arbitrarily divided in two, with the first part (on the left side of your abdomen) called the **jejunum**, and the second part (right hand side) called the **ileum**. As the food passes through the small intestine it is mixed with water and enzymes, and broken down. The broken down components then pass through the intestinal epithelium to a network of veins (carrying blood) that empty into a larger vein called the **hepatic portal vein**. The hepatic portal vein leads to the **liver**. The nutrient rich blood is then filtered by the liver to remove toxins before proceeding to the main blood stream. Much of the glucose from the digested food is also stored in the liver as glycogen.
13. **Large Intestine:** Large amounts of water are added to food as it passes through the small intestine in order to aid in digestion. This water is recovered in the large intestine. The large intestine is sometimes referred to as the **colon**.

The Swallow Reflex: When you swallow a bolus of food, the **epiglottis** automatically closes to cover your **trachea**, preventing food and drink from going into the lungs. (This also means you can't breath while you are swallowing.) As food passes the epiglottis, the esophageal sphincter opens to allow it to enter the esophagus.

Digestion of Food in the Stomach: The stomach is lined with small holes called **gastric glands**. Gastric glands are lined with three types of cells: **parietal cells**, which secrete hydrochloric acid, **chief cells** which produce an inactive, polymerized enzyme called pepsinogen, and **mucous cells**, which secrete mucous. Pepsinogen is the inactive precursor of the protease pepsin. Pepsinogen enters the stomach and is activated when it is cut up into individual pepsin monomers by some active pepsin monomers that are already in the stomach. Pepsin is a protease that has an optimum pH of 2.0. Secretion of HCl by the parietal cells makes the stomach environment acidic enough for pepsin to work. The combination of pepsin and acid is called gastric juice. The mixture of food, acid and pepsin is called **chyme**. Mucous cells secrete mucous to coat the lining of the stomach, so that it won't be burned by the acid or broken down by the pepsin. When food leaves the stomach (via the pyloric sphincter) the acid is neutralized by bicarbonate buffer in the duodenum.

Acid Reflux ('heartburn'): The cardiac sphincter closes the upper part of the stomach to prevent gastric juice from 'refluxing' up into the esophagus and burning it. The cardiac sphincter is only supposed to open when food is coming down the esophagus. However, if you eat too much, the stomach may become so full that the cardiac sphincter is unable to close properly, causing acid reflux, or 'heartburn.' Also, if you eat before you are about to lie down to go to sleep, food is attempting to go down the esophagus while it is horizontal, and parallel to the stomach. This makes it easier for gastric juices to reflux back into the esophagus, again causing heartburn. This is why it's important not to eat too much, and not to eat before going to bed.

Coffee and Stomach Acid: Parietal cells are stimulated by caffeine to produce more acid. Caffeine is a major component of coffee and tea. Thus, drinking coffee after a meal actually helps you digest food. Drinking coffee in the absence of food, however, may lead to excess production of stomach acid, and heartburn.

IV Types of Feeders

Animals are often classified by what they eat:

1. **Carnivores:** Animals that eat only other animals. (Usually live animals that they must kill. Example: Lions, brown bears, hawks.)
2. **Herbivores:** Animals that eat only plants. (Example: cows, caribou, ruminant animals.)
3. **Omnivores:** Animals that will eat both plants and animals, including animals that were already dead. (Examples: humans, pigs, dogs, black bears.)
4. **Detritivores:** Animals that eat (and therefore recycle) decomposing materials. Usually dead plant material. (Examples: worms, potato bugs, dung beetles.)

Animals are also classified by how they feed (see Figure 41.6):

1. **Filter Feeders:** Live in the water and 'strain' the water through special filtering structures to obtain food particles or small life forms. (Examples: clams, baleen whales.)

2. **Substrate Feeders:** Eat the material that they live on. (Example: a caterpillar eating the leaves that it lives on.)
3. **Fluid Feeders:** Usually insects, get their nutrition entirely from fluids. These fluids are usually sucked out of other life forms. (Examples: Mosquitos, bees.)
4. **Bulk Feeders:** Eat a large amount of material (a 'meal'), and then digest it before they are hungry again. (Examples: Humans, bears, snakes, rodents etc.)

V: Adaptations of the Digestive System

Different types of animals have developed different features that determine what they are able to eat. Here we will focus on one of those features: the teeth.

Dental Adaptations (Teeth):

There are three types of teeth

1. **Incisors:** usually in the front of the mouth, used for biting pieces of food off of a larger mass of food.
2. **Canines:** Canine teeth are also called 'fangs.' They are long, pointed, and sharp; and are very effective at killing other animals. They are usually located near the front of the mouth.
3. **Molars:** Molars are flat teeth, used for grinding. They are usually located near the back of the mouth, and are effective at grinding up larger pieces of food that have been bitten off by the incisors.

These three types of teeth are arranged differently in Carnivores, Herbivores and Omnivores (see Figure 41.16).

A. **Carnivores:** have sharp incisors (for killing prey animals) and very long, sharp canine teeth. Molars are reduced or absent.
B. **Herbivores:** have sharp incisors, for biting leaves off of trees and shrubs, and extensive molars, but canine teeth are either greatly reduced, or absent altogether.
C. **Omnivores:** have teeth that are 'in between' those of a carnivore and an herbivore. Incisors are still sharp, but canine teeth are reduced slightly (look at your own teeth in the mirror. Note that you still have 'fangs' like a wolf, but they are much smaller). Molars are still present, but not as rough as those of an herbivore, and therefore not as good at grinding up plant matter.

PRACTICE QUESTIONS:

Short Answer Questions:

1. What do you call the long tube that connects the mouth to the anus in the digestive system?
2. What do you call a muscular compartment that contains gravel (small rocks) that is used to grind up food by animals that don't have teeth (ie-birds).
3. What do you call the row of thin filaments in a whale's mouth that it uses to filter feed?
4. What do you call an organism that eats what it lives on top of? (ie-a caterpillar eating a leaf)

5. What do you call an organism that swallows a large portion of food all at once, and then waits for it to be digested before eating again? (ie-humans)
6. What is the name of the ring of muscle tissue that closes off the top of the stomach, preventing acid from going up into the esophagus.
7. What do you call a ball of food that you swallow after chewing it up?
8. Name for the flexible tube (lined with striated muscle at the top and smooth muscle lower down) that connects the mouth to the stomach?
9. Name for the rigid, cartilage-lined tube connecting the throat to the lungs.
10. Name for a method of moving things through a tube that relies on squeezing the tube (ie-moving food down the esophagus, or through the intestines)?
11. Name for the organ that stores bile salts used to emulsify fats prior to their digestion.
12. List one fat-soluble vitamin, that you have to be careful not to take too much of.
13. List one fat-soluble vitamin that is lacking in some diets, with the lack of this vitamin sometimes leading to blindness.
14. List one water-soluble vitamin which can result in birth defects if a pregnant woman has too much or too little of it.
15. Ruminant animals are capable of digesting cellulose because they have two stomachs. The first stomach contains symbiotic bacteria and protozoa that can break down cellulose. There the cellulose is broken down into glucose before it enters the second stomach which is a regular stomach. What is the first stomach, containing the symbiotic bacteria and protozoa called?
16. Which human organ is responsible for detoxifying toxic chemicals that are sometimes found in food? (This same organ is responsible for storing the iron needed by red blood cells.)
17. Name the three parts that comprise the small intestine in their correct order, starting from where it connects to the stomach (3 points).
18. Name the part of the small intestine that makes contact with the stomach.
19. Name the organ that <u>produces</u> bile (as opposed to storing it).
20. What is the purpose of bile salts?
21. What do you call an animal that eats only other animals?
22. What do you call an animal that eats only plants?
23. What do you call an animal that eats anything (plants and animals)?
24. What do you call an animal that eats only rotting vegetation and/or excrement?

Essay Questions:

1. **Explain the different forms of teeth, and how different dental adaptations are used by carnivores, herbivores and omnivores. (20 points)**
2. Explain how a cow is able to digest cellulose. (10 points)
3. Explain why and how coffee can be bad for your stomach. (10 points)
4. Explain how proteins are broken down into amino acids during digestion. (10 points)
5. **Explain what 'heartburn' is, and what causes it. (10 points)**
6. Explain how acid in the stomach, and the release of pepsin into the stomach does not destroy the tissue lining the stomach. (10 points)
7. Explain what happens to prevent foods you eat and liquids you drink from getting into your stomach. (5 points)
8. Explain what happens during the swallow reflex. (5 points)

9. Explain what villi are, and what their function is. (5 points)

DEFINITION QUESTIONS: Define what is meant by the following terms.

1. Acid Reflux (5 points).
2. Esophagus.
3. Trachea.
4. Gall Bladder.
5. Pepsin.
6. Villi.
7. Rumen.
8. Ruminant.
9. Cardiac Sphincter.
10. Pyloric Sphincter.
11. Parietal cell.
12. Chief cell.

Extended Matching Inventory: Match the term to the definition.

A. Alimentary Canal
B. Bile Salts
C. Bolus
D. Cardiac Sphincter
E. Chief cells
F. Chyme
G. Crop
H. Epiglottis
I. Esophageal Sphincter
J. Esophagus
K. Feces
L. Gall Bladder
M. Gizzard
N. Hepatic Portal
O. Ileum
P. Jejunum
Q. Parietal cells
R. Pepsin
S. Pepsinogen
T. Peristalsis
U. Pyloric Sphincter
V. Saliva
W. Salivary Glands
X. Stomach
Y. Trachea
Z. Villi

1. Name for a muscle-lined compartment where gravel is stored, and used by animals that don't have teeth to grind up food.
2. Name of the vein that transports nutrient rich blood from the small intestine to the liver.
3. Name for small, finger-like projections that increase the surface area of the epithelium lining the small intestine.
4. Name for the waste product produced during digestion (components of food that can't be digested, and are released through the anus).
5. Name for the first part of the small intestine.
6. Name for the second part of the small intestine.
7. Name for a type of movement where things are moved through a tube by squeezing the tube (ie-moving food down the esophagus).
8. Name for food mixed with gastric juice in the stomach.
9. Ball of food that goes down your esophagus after you've chewed it up.
10. Name for the inactive precursor (polymer) of Pepsin.
11. Name for the part of the intestine that joins to the stomach.
12. Name for cells that secrete HCl (hydrochloric acid) into the stomach.
13. Ring of muscle that closes the top of the esophagus.

14. Rigid tube leading to the lungs.
15. Name of the enzyme that breaks down proteins in the stomach, and has a very low optimum pH.
16. A flap of cartilage that closes when you swallow, preventing food or water from going down the trachea to the lungs.
17. Ring of muscle that closes the top of the stomach, preventing acid from going up the esophagus.
18. Organ where bile salts are stored.
19. Cells that secrete Pepsinogen into the stomach.
20. Ring of muscle that closes the bottom of the stomach, and regulates the passage of food into the Duodenum.
21. Tube leading from the mouth to the stomach.
22. Biological compounds made in the liver, and used to emulsify fats and lipids prior to digestion.
23. Viscous liquid that is secreted into the mouth, that protects the mouth and esophagus from being abraded (scratched) by food.
24. Organs that secrete amylase enzymes (that break down starch) into food.
25. Compartment in the digestive system where protease enzymes that have an extremely low optimum pH are added to food.
26. Name for a compartment near the front of the digestive system of some animals, where moisture is added to food.
27. Name for the long tube that connects the mouth to the anus.