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Carbohydrates and Lipids in Human Health

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by Chris Willems

Objectives

Adolescent students are fascinated by their bodies. Educators can leverage student engagement by selecting topics that capitalize on innate student interest.

Topics anchored around diet, nutrition, digestion, and evolution have been crafted into this curriculum unit. This unit is intended to be part of a high school biology course. It may also be used with anatomy and physiology, forensics, health, epidemiology, and biotechnology courses.

This unit will be taught in the first quarter of the biology course when introducing carbohydrates, lipids, nucleic acids and proteins. I believe student interest in the topic will rise if I incorporate human anatomy in the topic of biological chemistry.

An engaging high school science curriculum should address diet, nutrition and digestion in a highly visual and meaningful manner. In this unit I will connect diet and nutrition with an understanding of the major biological molecules by examining the chemical composition of the food we eat. Evolution is illustrated by examples of anatomy and biochemistry of different animals that have specialized methods to consume a variety of foods.

It is my intention to show that the interactions among biomolecules and living systems can be phenomenally fascinating. If students are captivated by a topic, they are much more likely to dedicate the time and energy to master the concepts of that topic.

Food and energy: "You are what you eat"

Our food is primarily made of carbohydrates, proteins, fats, minerals, vitamins and water. We need to regularly ingest food to sustain ourselves.

Living things do not follow the pattern of decay seen in the rest of the natural world. Unlike nonliving things (such as rocks), living things *maintain* themselves. They *build* new cells, tissues and organs in the process of development. Once mature, organisms can *sustain* existing biological structures by cellular division. This process, also called mitosis, allows cells to use molecules such as water, amino acids (building blocks of proteins), carbohydrates and lipids to create new cells. This process requires the transfer of energy among chemical bonds.

Our cells are regularly being replaced and recycled and this requires a regular influx of energy and matter. We obtain energy in the form of food calories; new matter in the form of the molecules contained in our food.

Not all molecules are digestible by all animals. These unneeded molecules may be eaten along with more desirable molecules. This is part of the reason why animals must have a caudal opening (anus) in their digestive system.

A balanced diet for humans includes several servings of breads, cereals, fruits and vegetables every day. Also essential are smaller servings of milk, dairy, meat and eggs. Fats, oils and sweets should make up a very small portion of a balanced diet.

Human beings eat several hundred pounds of food a year. From this food we obtain all the molecules we need so our bodies can operate, grow and replace the cells lost to wear, old age, or damage.

Animals, such as humans, have evolved intricate strategies of intercellular communication. Feedback, feed–forward, and inhibition allow us to maintain steady–state, or homeostasis.

We get hungry because we want to eat. This seemingly simple cause and effect is the result of the empty stomach secreting the peptide hormone ghrelin into the bloodstream. When this hormone is received by hypothalamus, it stimulates the release of growth hormones, which makes us want to eat. After eating to satiation, the release of the peptide hormone leptin causes the hypothalamus to inhibit hunger sensations. Leptin is released by a variety of tissues including adipose (fat cells), stomach, bone, pituitary, and the liver [1].

Metabolism

The word metabolism comes from the Greek root "change" and involves the building up or breaking down of molecules to be used by the body. These molecules will be used for cell growth, fuel and other processes. If the process involves breaking down molecules into simpler ones, usually to release energy, it is called catabolic. If building up complex molecules, for structures or energy storage, it is called anabolic.

Developed and less active bodies do not need as many energy calories as developing and active bodies. Developing bodies are adding cells at a rapid rate, and this requires an infusion of both new material (molecules) and energy. Active bodies, likewise, need more calories to sustain the energetic demands of more motion.

Proteins

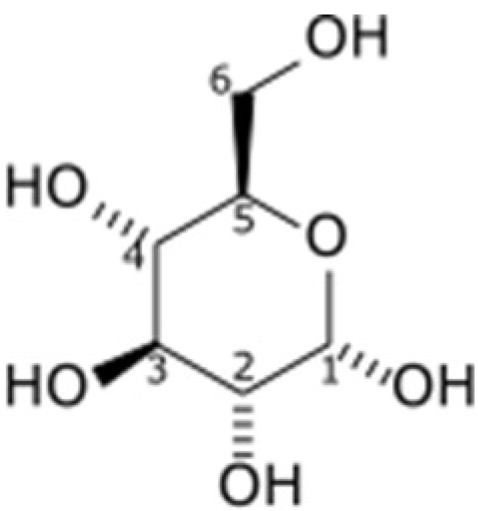
Proteins are molecules made of nitrogen, carbon, oxygen and hydrogen and sometimes sulfur. These molecules are found in animal tissue such as meat (including fish), eggs, cheese and legumes, and many other plant foods.

Proteins are large molecules assembled from smaller units called amino acids and serve many important roles in living things. Amino acids are linked by covalent bonds called peptide bonds. Proteins can serve as enzymes, hormones as well as the building blocks of complex physical features. Proteins comprise teeth, bone, muscle, tendon, cartilage, skin – most of what makes up an organism.

As enzymes, proteins facilitate chemical reactions that would not otherwise happen in the short time, or lower temperatures required by living things. As hormones (such as the previously mentioned appetite inhibitor leptin) they are protein messengers that deliver information around the body.

Carbohydrates

Figure 1: Glucose molecule



Carbohydrates are made of hydrogen, oxygen, and carbon that combine to form monosaccharides. These simple sugars are made of five (pentose) or six (hexose) carbon rings. Additional hydrogen and oxygen atoms allow these rings to form disaccharides ("two sugars") such as sucrose and lactose or polysaccharides ("many sugars") such as starch.

Sugars are essential to living things. They provide a way to store chemical energy to operate living things. They are also the structural backbone to the information storage molecules DNA and RNA, as well as many of the other essential molecules in living things. Sugars are transported through the blood stream in the form of the simple sugar glucose. They have 4 calories of energy per gram.

Figure 1 shows glucose, a 6 carbon sugar. Glucose is manufactured from carbon dioxide and water by plants during photosynthesis. The element carbon plays a central role in the features of living things, primarily because it can make four chemical bonds. The chemical formula for the glucose molecule is $C_6H_{12}O_6$. The formula indicates the presence of 6 carbon atoms, 12 hydrogen atoms and 6 oxygen atoms. In figure 1, carbon atoms are located at each of the corners of loci 1 through 6 (they are implied by the ring structure). At each site you will note that it is bonding with other carbons, oxygen, and/or hydrogen atoms.

These glucose molecules bond with each other in a condensation reaction. A condensation chemical reaction involves the formation of a water molecule when one glucose molecule releases a hydrogen and the other releases an oxygen and a hydrogen. These extra hydrogens and the oxygen combine to make water ($H_2 0$).

To help students understand this process in the classroom, physical modeling activities that can be employed to make this less abstract. If molecular modeling kits are available, individual glucose molecules can be constructed and brought next to each other. With the removal of one hydrogen and one oxygen and hydrogen from the adjacent molecule, a condensation reaction can be modeled. Then, the two molecules can be joined to represent the growing carbohydrate polymer chain. If modeling kits are not available, toothpicks (to represent bonds) and different colored jelly beans (to represent different atoms) can be substituted in model making. (Save these models for a later activity that will involve their disassembly.)

Plants use starch to store chemical energy in the form of a polymer of glucose molecules. These chains can be up to 600 units long.

Animals use glycogen to store glucose. We will later see that it is stored in muscles and the liver. This molecule is more compact and stable than glucose.

The energy contained within the bonds of glucose is converted within the mitochondria of cells in to a more accessible form of chemical energy, adenosine triphosphate (ATP). The cells can readily access the chemical energy contained in the ATP and use it to do the work required by living things.

Cellular respiration is illustrated in this simplified chemical reaction.

glucose + 6 O_2 6 CO_2 + 6 H_2O

This reaction occurs in both the cytoplasm and in the mitochondria. Glucose is transformed into a three carbon sugar, and then in the mitochondria it loses hydrogens. The electrons on these hydrogens are used to create ATP, the energy molecule cells need to do their work. "Waste" products from this reaction are carbon dioxide and water.

Lipids

Like carbohydrates, lipids (fats, oils and waxes) are also made of hydrogen, oxygen, and carbon combined into molecules called fatty acids. These fatty acids are linked to glycerol molecules.

Unlike carbohydrates, lipids do not readily combine with water. Some fats are solid (body fat), some are liquid (oils on our skin). These chemical properties are a result of the specific fatty acid they contain.

Fats are triglyceride molecules. They have three fatty acid molecules bonded to a glycerol molecule and are typically solid at room temperature. Fats are very energy dense molecules: they have nine calories per gram.

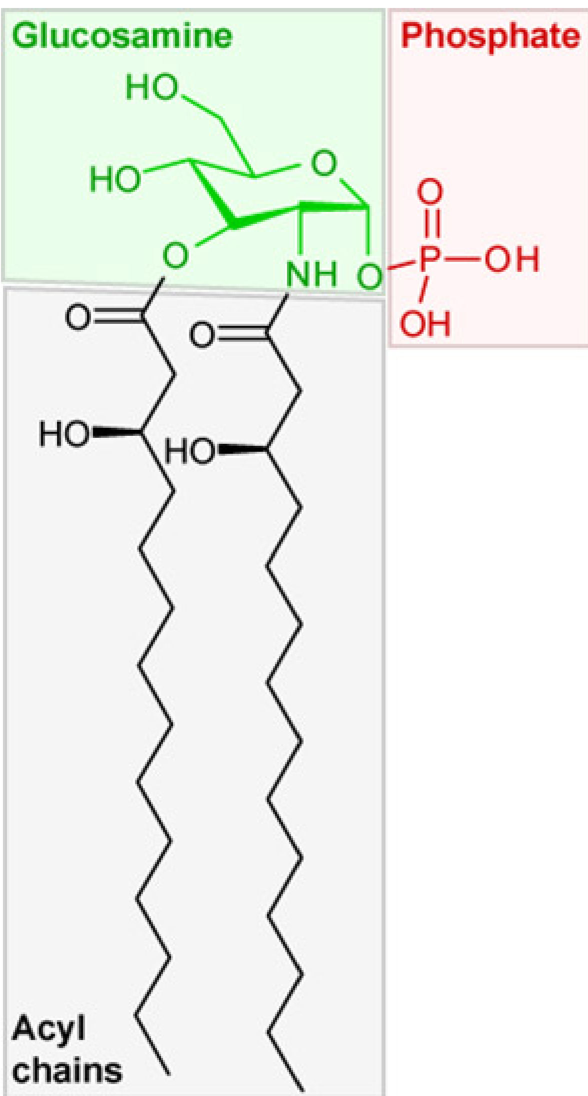
Oils (a kind of fat) are liquid at room temperature and can be made from living things, typically plant material. Fossil fuel oil refers to oils that had been made by plants millions of years ago and were buried.

Waxes are fatty acids linked to alcohol molecules and have a low melting point. They are synthesized by both plants and animals.

Butter is a combination of butterfat, proteins and water. It is solid at room temperature and below because the fatty acid chains are closely packed and the strands are weakly attracted to each other.

Margarine is made from hydrogenated vegetable or animal fat with skim milk. Hydrogenation involves the addition of hydrogen to the oil in order to straighten out the fatty acid chain and make it solid at room temperature

Figure 2: Phospholipid



Lipids, such as the phospolipid in figure 2, are essential for the assembly of cell membranes since they are generally not water soluble. Cell membranes allow for the separation of cells as well as spaces within a cell, which allow for chemical reactions. If all the water soluble elements within a cell could freely mix the complex work of living things could not properly occur. It would be chemical chaos within the cell.

In figure 2 the structure of the phospholipid molecule is very important to the function of the molecule. As with the other lipids we have surveyed, this phospholipid has a long actyl "tail". This is segment of the molecule is repelled by water (hydrophobic) and the glucosamine and phospate "head" of the molecule has an affinity for water.

When these molecules self assemble into a membrane – either as a cell membrane or an organelle membrane, they arrange themselves into a two molecule thick sheet. In this arrangement the acyl "tails" point inward, toward each other, and the glucosamine and phospate "heads" point outward.

Digestion

Digestion involves the chemical and physical breakdown of food into smaller molecules. This needs to happen if the molecules are to pass through the intestine wall and be transported by the bloodstream to locations in the body where they are needed.

Enzymes

Enzymes are proteins that facilitate chemical reactions. They make life processes possible by speeding up chemical reactions and lowering the temperature at which the reactions can occur. The high temperatures required by non–facilitated chemical reactions would destroy living tissue. Vitamins can be thought of as co–enzymes that assist enzymes with metabolic processes.

Enzyme–facilitated chemical reactions include such actions as molecule construction, energy transfer, and digestion. Food encounters enzymes first in the mouth, and then in numerous places along the digestive tract.

The action of salivary amylase begins carbohydrate digestion in the mouth. Amylase ("amly" is Latin for starch) is an enzyme that breaks down starch (a polysaccharide sugar) into the double sugar maltose (two linked glucose molecules). The human body cannot absorb the disaccharide sucrose, but it can absorb the simple sugars glucose and fructose.

In the classroom, the following activity can be used to simulate the action of salivary amylase. Groups of students can be asked to volunteer to chew unsweetened bread or crackers, cheese, nuts, or other similar foods for two minutes, and notice how it tastes. Ask students not to swallow (this is difficult) and then keep the bolus (chewed food) in their mouths for an additional thirty seconds. Have students make note of the new taste, then they may swallow.

The action of salivary amylase in breaking the carbohydrates into sugars in the mouth can be observed by the sweeter taste of the starch (bread or crackers) after the two minutes of chewing. Encourage students to discuss their results with each other.

As with the molecular modeling suggested for building carbohydrates, a classroom activity around disassembling the model will show how the starch is disassembled by salivary amylase. Again, students can discuss and then demonstrate their understanding by diagramming the chemical reaction that is occurring.

A laboratory to support enzyme understanding can be done using commonly available enzymes such as lactaid. Lactaid is taken by people who are unable to digest the milk sugar lactose. The laboratory work begins by having students understand the basic functions of enzymes, and then more specifically that lactase cleaves lactose into glucose and galactose. Students then practice measuring glucose with glucose test strips, also available at drugstores. These strips give a range of glucose values that is sufficient for the purpose of this laboratory. Once students are comfortable with the measuring protocol, provide students with enzyme, cow milk, unsweetened soy milk and unsweetened rice milk. Have students measure the glucose levels in the samples both before and after they treat the samples with lactaid and then discuss why glucose was not detected in the soy and rice milk samples. If glucose IS detected in these samples, discuss why this might have happened, and if possible, redo the experiment.

The next step in this laboratory would be to change some other variables. Students should be free to suggest changes based on what they have learned about enzyme action. Reasonable changes would be to change the pH of the cow milk, heat up or cool down the reaction, or vary the amount of enzyme or substrate. Students should have an opportunity to share their plans and results with the class, as well as write about the results of their laboratory work.

Enzymes that break down proteins are called proteolytic enzymes. "Lysis" is from the Greek and means "to separate" and in this case the protein chains of amino acids are being separated.

Enzymes that break down fats are called lipases and act in concert with bile salts from the liver. A molecule that has the ending "ase" indicates an enzyme; hence lipase is a molecule that breaks down lipids.

The Mouth

The mouth is where intial processing of food begins. The tongue, teeth and salivary glands each play essential roles in digestion.

The tongue is essential for juvenile mammals as it allows them to create negative pressure for suckling. In mature mammals, it allows the food to be manipulated between the teeth for thorough mastication. The tongue also contains the taste buds on its surface [2] .

The tongue "stirs" the food to ensure thorough mastication. The tongue can move food all around to be sure the food is thoroughly chewed. The tongue helps form food into a mass called a bolus for swallowing. It then moves the bolus to the back of the mouth for swallowing.

Saliva, a watery mucous, moistens food to make it easier to swallow. Saliva also cleans the mouth and teeth. Saliva contain the enzymes salivary amylase and lysozyme. We have observed the action of amylase. Lysozyme lyses (breaks apart) some cells, including bacteria.

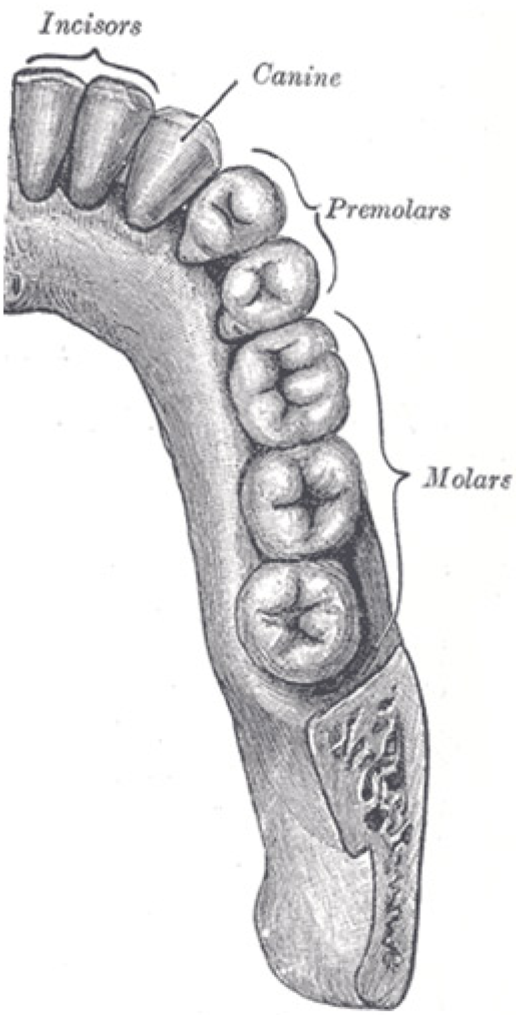
Teeth

Teeth have a three layer structure. Enamel makes up the outer layer and is the hardest tissue of the body, owing to the presence of the mineral hydroxylapatite. The middle layer is dentine and analgous to bone. The lower portion of the tooth, the root, is covered in cementum that allows it to attach to the sockets in the jaw bones [3].

Baby teeth (milk or deciduous teeth) break through at 6 months. Babies get about 20 teeth that last about 10 years. Most adults will develop about 32 teeth [4].

Teeth (figure 3) are responsible for biting, slicing, tearing, chopping and grinding food. The objective is to create smaller pieces to swallow. This process aids digestion by creating a greater surface area for digestive enzymes to work. It is not necessary to thoroughly chew your food, but it makes it easier for your digestive system to process your food. Of course, chewing and paying attention to the food in the mouth will reduce the incidence of choking.

Figure 3: Teeth types



The incisors slice chunks of food.

Canines rip and tear food.

Pre–molars and molars are responsible for chewing and grinding food to a pulp.

Lips, cheeks and tongue work together to push the mass of food (called a bolus) back toward the molars.

The evolution of mammals has created many different "eaters". If you peer (carefully) inside a domestic cat's (a carnivore) mouth, you will see many sharp teeth. These animals do not chew their food. In contrast, the mouth of a deer (an herbivore) has some incisors at the front of the mouth, but the rest of the mouth is full of grinding molars. Humans have both sharp and grinding teeth because they are omnivores.

A classroom activity to help students understand the evolution of mammals is to make observations of different skulls. This can be done by purchasing skull casts, borrowing skulls, or visiting natural history museums such as the Peabody Museum of Natural History in New Haven or the American Museum of Natural History.

Smell, sight, and even the thought of food causes salivary glands to activate. Salivary glands are located at the back of the mouth, under the tongue, on the face, and under the sides of the lower jaw. These are connected to the mouth by tubes called "ducts".

The largest is the parotid gland, which is near the cheek bones. The submandibular salivary gland has a duct that opens at the base of the tongue. The sublingual gland is on floor of mouth, under the tongue (figure 4).

Dogs and cats have no amylase in their saliva. Their natural diet contains almost no carbohydrates [4] .

Human have six to eight times the level of salivary amylase than chimpanzees. This is most likely a result of our different diets. Relative to humans, chimps eat very little starch and much more fruit [5] .

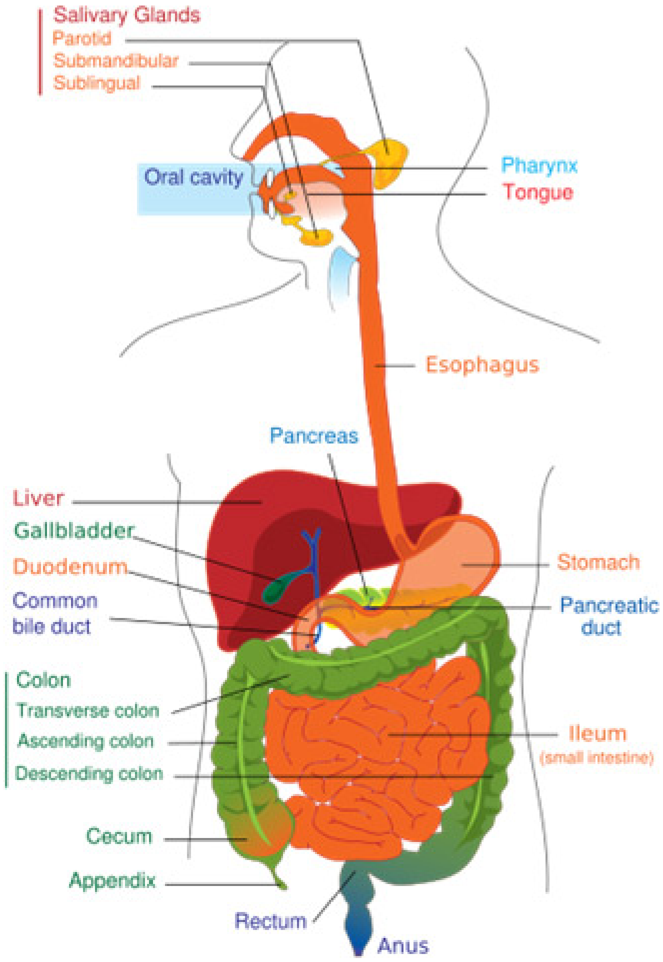
The Digestive system

The digestive system can be thought of as a long tube, called the digestive tract or gut, that begins in mouth (figure 4). This opening then becomes the pharynx, esophagus, stomach, small and large intestine and the undigested material exits through the anus. This is a 20 to 40 hour process.

As food travels through the digestive system, it is broken down into smaller molecules. The body uses these molecules for generating energy or building structures.

Esophagus

Figure 4: The Digestive System



The pharynx is the structure that connects the mouth to the esophagus. The term esophagus comes from the Greek "entrance for eating". Once the tongue presses the food to the throat and it is swallowed, the food takes about 10 seconds to reach the stomach via the esophagus. The rest of the digestive process is involuntary.

The top of the pharynx opens to the back of the nose (the nasopharynx). The soft palate blocks the opening to the nose, keeping food from being forced upward. The epiglottis is a cartilaginous flap that temporarily blocks the larynx. The vocal cords also close to prevent food from entering the trachea and lungs. The trachea is commonly called the windpipe and leads to the lungs. When attempting to simultaneously eat and talk, choking can result. This is a result of food going down the trachea when the epiglottis is open.

The esophagus is composed of layers of smooth (involuntary) and striated (voluntary) muscle tissue. Waves of muscle contraction and relaxation move the food bolus along. These alternating waves, called peristalsis, continue throughout the digestive system. Peristalsis can be thought of like squeezing a tube of toothpaste. A classroom activity to simulate peristalsis is squeezing a tennis ball through pantyhose. In our seminar we found this to be most effective if segments of pantyhose were cut to the approximate length of a human esophagus. Students are then challenged to move the "bolus" in ten seconds from one end to another!

Cows and other ruminants are said to have four "stomachs". It appears that the first three of these chambers have evolved as outpockets of the esophagus. When food enters these chambers it is acted upon by microbes. As the material is regurgitated and swallowed, it can again be acted upon by the microbes. This process allows ruminants access to the energy contained in cellulose molecules. This energy source is not available to other mammals who do not have this extended digestion time and the appropriate flora and enzymes. P. 46 Rogers.

Stomach

The stomach is is a "J shaped" organ located up behind the left hand side of ribcage. When empty, it is about size of a fist; it can hold up to four liters (the size of a boxing glove) when full. It is lined with folds called rugae. These folds flatten out and disappear as the stomach fills with food.

Gastric acid is produced in epithelial cells and gastric pits in the stomach wall. The gastric glands of the stomach also produce hydrochloric acid that denatures proteins and further softens food while also killing bacteria and viruses. The stomach itself does not dissolve from the action of the hydrochloric acid because it is lined with a lipid–rich mucous that resists the corrosive acid. The cells that line the stomach are replaced frequently, every 3 or 4 days.

Mucous is a slippery glycoprotein, a molecule containing sugar units and protein that retains water. It also resists the proteolytic enzymes of the digestive system while facilitating the movement of food through the digestive system.

The stomach generates about 1.5 liters of gastric juice per day. Gastric juice is watery mucous, digestive enzymes and acid. Zymogenic cells in the stomach release pepsinogen, which is an inactive form of the protelytic enzyme pepsin. Pepsinogen is activated by stomach acid to become pepsin. Pepsin initates the breakdown of protein by breaking polypeptides (proteins) down into peptides (strings of amino acids). When amino acids are dissolved in acidic solutions, they disassociate because one end is positive (the nitrogen terminal, H_3N^+), one is negative (the carboxyl terminal is COO^-). Water molecules are also polar, so some amino acids are attracted to the negative and positive ends of water.

Three concentric sets of muscles make up the stomach wall. Three times per minute the stomach vigorously squeezes and tightens around a creamy liquid of food, mucous, and enzymes called chyme. As the stomach mixes and works the chyme, water quickly passes to the small intestine. Few food nutrients are absorbed in stomach.

Starchy meals pass through the stomach in about an hour. Lipid meals (meats, cheese, fried food) stay in stomach for three or more hours. When the chyme is soupy enough, peristaltic waves take the digesting food to the end of the stomach. At the distal end, the muscles around the pyloric sphinctor muscles relax, and chyme is released in peristaltic waves into the small intestine.

In the stomach, the proteolytic enzyme pepsin cleaves between these amino acids.

Phenylanine and Alanine

Phenylanine and Leucine

Phenylanine and Methionine

Tyrosine and Alanine

Tyrosine and Leucine

Tyrosine and Methionine

Tryptophan and Alanine

Tryptophan and Leucine

Tryptophan and Methionine

A classroom activity can be used to illustrate this enzymatic cleaving. Dr. Stewart shared a paper digestion activity he created. To build upon his activity, I add decorative scissors with cuts such as "Pinkering", "Flash", "Colonial", "Victorian", "Arabian", and "Double Bubble" to indicate different enzymes acting on different substrates. Additional teaching strategies involve using lactase enzyme on various "milks" such as soy, rice and cow. Also suggested is a laboratory integrating "Beano" enzyme to a variety of foods and recording the effectiveness of the enzyme [6] .

Harmful bacteria or viruses can cause an upset stomach. Heartburn and indigestion can be caused by eating too quickly.

Small Intestine

Called "small" because at 1.5 inches, it's about half as wide as the large intestine. It is folded and rolled up in an area just below your rib cage in the middle of your body. At twenty feet, the small intestine is the longest and most important part of the digestive system.

The small intestine is where most of our digestion occurs. The inner lining is ridged, folded, and studded with millions of little projections called villi and microvilli. If the small intestine were flattened out, it would have an area of almost 3000 square feet! This represents an area ten times greater than the area of your skin and is about as big as a basketball court!

It takes a while to absorb food through the gut wall. The small intestine has increased the surface area by increasing its length. The small intestine fits because it is curled up and folded over itself.

The small intestine allows small molecules to pass through the wall, but we eat big molecules. A metaphor for this organ is a chain gang – which makes little rocks out of bigger rocks.

Protein molecules need to be disassembled into single amino acid or di– or tripeptide in order to be absorbed. Pancreatic proteases break polypeptides into peptides (amino acid chains). Peptidases take these chains down to individual amino acids. Proteases trypsin and chymotrypsin reduce proteins to their constituent amino acids.

Carbohydrate enzymes that are active in breaking down these large molecules in the small intestine include maltase. These enzymes act on maltose to reduce them to the monosaccharide glucose.

Students can be engaged in this activity by using the decorative scissors as an analogue for the protease trypsin to cleave the peptides arginine and leucine at the carboxyl (right) end. The same can be done with a different pattern cut to indicate the action of protease chymotrypsin for tyrosine and tryptophan.

Fatty acids and monoglycerides (after pancreatic enzyme digestion) are passed to lacteal (lymph) capillary and sent to the circulatory system and eventually the liver.

Villi have many capillaries to facilitate transport of digested proteins and sugars into the bloodstream. Lacteals are tubes in the villi that allow fats to be transported to the blood. Villi bend and wave to keep blood flowing through the capillaries and into the bloodstream. Ateries and veins are located just under the base of the villi.

The lining of small intestine make intestinal juice that includes enzymes to digest proteins, carbohydrates, and fats. Mucous is also produced, and as with the mouth, esophagus and stomach, it coats and protects the lining of small intestine.

The first section of the small intestine is called the duodenum. The duodenum is about a foot long and shaped like a letter "C". The liver and pancreas have ducts that join together and have a common opening to the duodenum.

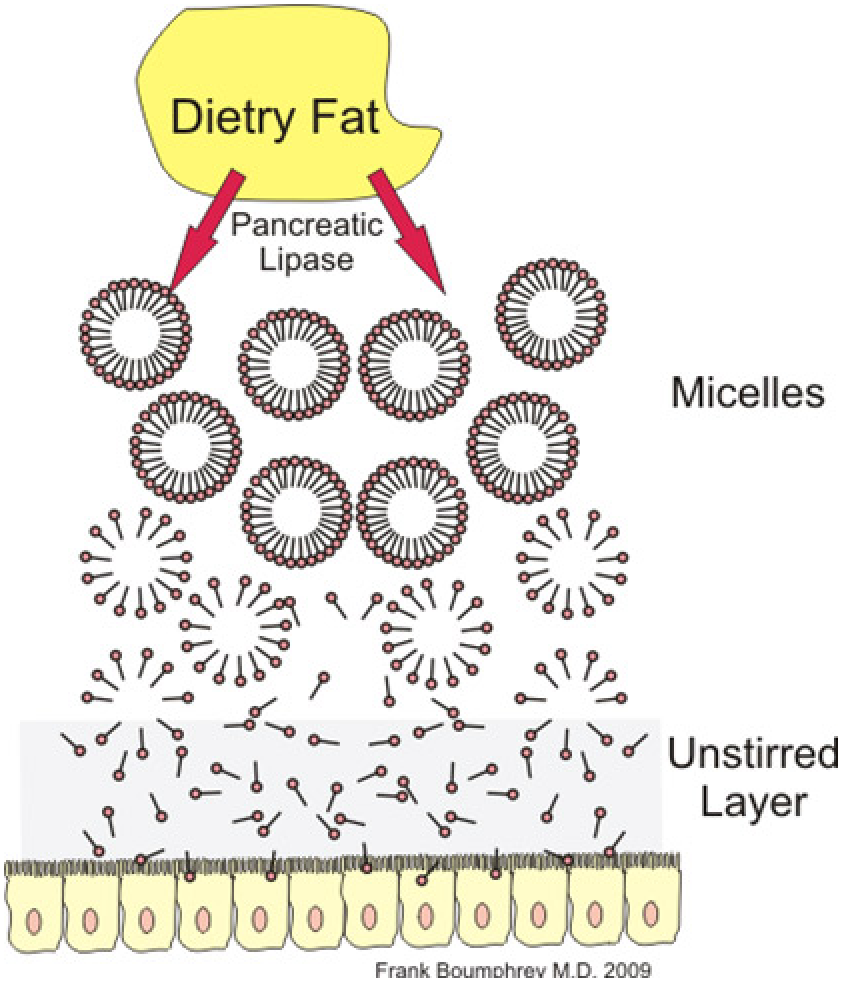
The second section of the small intestine is called the jejunum and is about 6.5 feet long. Most digestion happens in these two sections.

The third and final section of the small intestine is called the ileum. By the end of the small intestine, water and waste are all that remain to enter the large intestine.

The Problem of Getting Fat into Suspension

Long chain fats (triglycerides) are insoluble in water, yet fats must be dissolved in water in order for them to leave the intestine and enter the absorptive cells. Lipases serve to reduce the length of these molecules and make them more soluble.

Figure 5: Fat absorption



Lipases work with bile salts to form micellar solutions of fat (figure 5).

Pancreatic lipase breaks triglicerides down into free fatty acids and monoglycerides (fatty acid + glycerol).

Figure 5 illustrates the cleaving of fatty acid chains from the triglyceride fat molecules. As these fats are reduced to monoglycerides, they reach the unstirred layer.

The unstirred layer is a mucous covering through which the lipids must pass in order to reach the cells that line the intestine.

The bile salts disassociate from the lipids, and diffuse back into the lumen of the small intestine. The monoglycerides are brought to a cellular structure called the endoplasmic reticulum, and enzyme acyltransferase synthesizes the monoglycerides back into triglycerides. The fats are then packed into membrane–bound structures by the golgi apparatus and enter the lymphatic system via the lacteal ducts and travel to the liver for storage until needed for metabolism.

Altheriosclerosis (coating and hardening of the arteries) occurs if too much cholesterol is allowed to enter the blood stream. When this happens, white blood cells are recruited, inflammation and plaques form and is then coated with calcium. Result can be a heart attack. If the plaque is located in the head, an ischemic stroke can occur.

Familial *hypercholesterolemia* is a defect in the low density lipoprotein receptor. In this disease, cholesterol blood level increases to three times higher than normal. The homozygous (two identical gene copies) condition of this disease results in a heart attacks at age 5!

High density lipoproteins help clear cholesterol from body by bringing cholesterol back to the liver for disposal. HDL also delivers cholesterol to steroid hormone producing locations, such as the ovaries, testes, and adrenal glands.

Pancreas

The pancreas is about 6" long, looks like a flat pink fish behind the stomach. Pancreatic juice is composed of fifteen digestive enzymes (including trypsin, chymotrypsin, lipase, amylase, and proteases) and a bicarbonate buffer for neutralizing stomach acid. These enzymes enter the duodenum through the pancreatic ducts. The pancreas also secretes the hormones insulin and glucagon into the blood stream for energy use and growth.

Insulin is a 51 amino acid hormone synthesized by specialized pancreatic cells called islet cells. Insulin is released when glucose levels in the blood rise as a result of eating. Likewise, when blood glucose levels decline, glucagon stimulates the liver to release glucose into the blood.

Insulin works by stimulating liver, muscle and fat cells to take up glucose. Insulin does this by binding to receptors on the surface of these cells. This causes these cells to activate glucose transporters, which results in the storage of glucose in the cell.

The Liver

The liver is the largest organ in body, weighing up to four pounds. It is located next to stomach on the right hand side of body, just below the rib cage. The liver receives and stores glucose as glucagon and converts it back to glucose when the body needs it. It stores vitamins and iron, filters blood, and processes toxic wastes. The liver makes bile, which is a substance we addressed when breaking down fat into smaller units that digest more easily.

This complicated outpocketing of digestive system performs hundreds of different chemical reactions. The blood that flows into the liver has glucose, fatty acids and amino acids dissolved in it.

Liver cells process glucose into glycogen for storage. If there is too much glucose available, the liver stores it as fat. The liver breaks down fatty acids for energy, or stores them as fat. Liver makes lipoproteins that transport fats to and from body cells. The liver also breaks down excess amino acids for energy and converts their nitrogen into waste urea.

Proteins and sugar go directly to the liver. As we have seen, fat enters the lymphatic system that can bypass the liver to direct the fat into the bloodstream if needed.

Homeostasis is maintained by the liver by processing a large volume of blood and controlling its chemical composition. It oversees the metabolism of carbohydrates, fats and proteins from food and also stores minerals and vitamins. It also destroys worn out red blood cells and recycles the iron (heme groups) contained within.

Hepatocytes (liver cells) make up to 1 liter of bile per day. Hepatocytes are organized into sesame seed–sized lobules in the liver.

The liver is an important site of vitamin storage. Stellate cells store up to 2 years' supply of vitamin A. Liver also stores fat soluble D, E, and K vitamins. It also stores the water soluable B_{12}.

The liver gets 20% of its blood from a hepatic artery. The rest of the blood supply is oxygen–poor but nutrient rich blood carried from the small intestine in the portal vein.

The manufactured bile is stored in the gallbladder, which can be thought of as a small muscular bag. The bile emulsifies fat which allows the enzyme lipase a bigger surface area for chemical action. Bile salts are used in fat digestion in the duodenum.

The liver makes most of the proteins for blood plasma such as fibrinogen that is essential for blood clotting. It also manufactures albumen that maintains the water balance in the blood.

Appendix

The appendix is a structure that extends off the ascending (beginning) of the large intestine (colon). It may be used in digestion in some animals. It is a non–functional (vestigal) structure in modern humans. It must be removed if it becomes infected. It may have helped our survival in the past as a reservoir for beneficial bacteria lost to bouts of colon–voiding diarrhea.

Large Intestine

The large intestine receives watery, undigested material from the small intestine. The primary role of the large intestine is to remove water, sodium and chloride ions. The large intestine helps the body avoid dehydration while converting watery waste into solid feces.

The large intestine is about 6 feet long and about three inches wide. It has a smooth lining, with no villi as found in the small intestine. The small intestine joins the large intestine at a region named the caecum.

The large intestine goes up the right side (ascending), then across (transverse), then down and back (descending) to connect with the rectum. The rectum is a straight, five inch long tube that goes to anus.

Digested material passes through the large intestine over a five to thirty–six hour period. Remaining water, minerals and vitamins are absorbed here by specialized cells. Here bacteria (gut flora) break down undigested waste, make vitamins such as B complex and vitamin K, and generate gas such as odorless hydrogen, methane and carbon dioxide. They also generate odiferous hydrogen sulfide. The colon also helps the immune system by producing antibodies against pathogens.

Feces are water, undigested food, dead body cells from lining of gut. Dead bacteria can make up to 50% of the weight of feces.

Concluding Comments

This unit provides an overview of some of the significant events that occur in the digestive system. It provides a sequential guideline for helping students understand biochemistry of digestion by using the human digestive system as the model. This approach is engaging for students as they have direct, personal experience with some aspects of their digestive anatomy. Biochemistry is complicated, but the use of examples and hands on concrete activities as described in this teaching plan will help students delve more deeply into this fascinating topic.

Notes

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[1] Roberts, Dr. Alice *The Complete Human Body* , New York, DK Publishing, 2010, 363.

[2] Rogers, Kara, *The Digestive System* , New York, Brittanica Educational Publishing, 2011. 31

[3] Stewart, Dr. William. YNHTI seminar on digestion May 15, 2012

[4] Rogers, Kara, *The Digestive System* , New York, Brittanica Educational Publishing, 2011. 28–30

[5] *American Scientist* . March–April 2010.

[6] Stewart, Dr. William. YNHTI seminar on digestion May 15, 2012

Figure 1 of glucose

http://en.wikipedia.org/wiki/File:D–glucose_wpmp.png

Figure 2 of lipid

http://wikimediafoundation.org/wiki/File:Lipid_X.png

Figure 3 of digestive system

http://upload.wikimedia.org/wikipedia/commons/c/c5/Digestive_system_diagram_edit.svg

Figure 4 of teeth

http://en.wikipedia.org/wiki/File:Gray997.png

Figure 5 of fat absorption

http://wikimediafoundation.org/wiki/File:Micelle_fat_absorption.png

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Raunig, V., L. Bullerwell, and W. Hagar. "Enzymes and the what and how of digestion. *Science Scope* 17. No 8 (1994): 37–40.

Reading list for students

Roberts, Alice, Dr., *The Complete Human Body: The Definitive Visual Guide* . New York, DK Publishing, 2010.

Rogers, Kara, *The Digestive System* . New York, Brittanica Educational Publishing, 2011

Simon, Seymour, *Guts: Our Digestive System* . New York, Harper Collins, 2005

Implementing District Standards

This unit engages students in the processes of scientific inquiry by encouraging them to describe and explain natural phenomena – in this case what happens in our bodies.

With the enzyme investigations, students can delve more deeply into the functioning of these proteins, and learn what conditions are optimal for their effectiveness.

Students will formulate a testable hypothesis with logical connections to the study of the digestive system. They will then design and conduct different experiments to answer these questions. Students will also assess the reliability of data generated, share their findings and critically review with fellow students and their teacher.

Finally, students will make clear conclusions and explanations based on their data and reflect on the experimental design. In doing so, they will be applying standards around scientific numeracy.

This unit engages students in the process of scientific literacy by providing motivation to research various media, read and write about the functioning of their digestive system.

Connecticut science content standard 9.5 "Due to its unique chemical structure, carbon forms many organic and inorganic compounds" is explicitly addressed in the work around carbohydrates, lipids and proteins in this unit.

Connecticut science content standard 10.1 "Fundamental life processes depend on the physical structure and the chemical activities of the cell" is addressed at several points – including the functioning of salivary glands in the mouth, epithelial cells of the stomach and small intestine, as well as the cells of the pancreas and liver.

Connecticut science performance D 29 "Describe the general role of enzymes in metabolic cell processes" is the focus of the major wet lab of this curriculum unit, as well as all along the digestive pathway outlined in this unit.