LECTURE 14: DIGESTIVE SYSTEM, METABOLISM, NUTRITION

Alimentary Canal (**Figure 14.1**)

From the root word "aliment" = nourish, the *alimentary canal* is the tube through which food travels when ingested. A common synonym for the alimentary canal is the *gastrointestinal tract* or *GI tract*. Attached to the alimentary canal are *accessory organs* of digestion.

The organs of the alimentary canal are the *mouth, pharynx, esophagus, stomach, small intestine*, and the *large intestine*, which terminates in the *anus*.

The accessory organs of the alimentary canal are the *teeth, salivary glands, pancreas, liver* and *gall bladder*.

Let's Masticate: (**Figure 14.9**) The chewing of food, or *mastication*, takes place in the mouth or *oral cavity*. The grinding of food is accomplished by the teeth.
In the adult, the upper and lower teeth both include a set of *central incisors*, *lateral incisors*, *canine teeth*, two sets of *premolars*, and three sets of *molars*, for a total of 32 teeth. In the baby teeth or *deciduous* teeth, there are only two molars, and no premolars. The visible portion of the tooth is composed of the hardest substance in the body, *enamel*.

(**Figure 14.2**) During mastication, food is continually mixed by the tongue. The tongue is covered with *papillae*, which contain taste buds, and is secured to the floor of the mouth by the *lingual frenulum*. In addition to mixing and tasting food, the tongue initiates the action of swallowing (=*deglutition*). During swallowing, the food will pass under the anterior hard palate and the posterior soft palate, from which hangs a finger-like projection called the *uvula*. Also attached to the soft palate, lateral to the uvula, are two masses of lymphatic tissue, the *palatine tonsils*.

(**Figure 14.1 again**) Emptying into the oral cavity are three pairs of *salivary glands*. The secretion of these glands – saliva – is composed of mucus, which helps bind food together into a mass called a *bolus*, and a clear fluid containing the enzyme *salivary amylase*, which begins the process of starch digestion. Saliva also contains *lysozyme* and certain antibodies, which combat bacteria.

Parasympathetic reflexes accelerate saliva production whenever food is introduced into the mouth. The same reflex can be provoked by a non-food item (rubber band, tooth pick, pebble, sugar free gum, etc.) when introduced into the mouth. In fact, salivation can be triggered without introducing anything into the mouth at all.

The Russian scientist Ivan Pavlov won the Nobel Prize in physiology and medicine in 1904 for his work in digestive physiology. One line of investigation pursued by Pavlov involved the stimulation of salivation in dogs. In his early work, Pavlov measured the amount and type of saliva produced when certain types of food were introduced into a dog's mouth. He noticed that salivation began well before the introduction of food into the dog's mouth; it began as soon as the dog was able to see and smell the food. In fact, the sight of the food bowl, even if the bowl were empty, would often cause salivation.

Pavlov reasoned that the neurological circuitry to cause salivation in response to tasting, smelling or seeing food was already "hard-wired"; it did not require any *conditioning*. Therefore, salivation in response to such a direct food stimulus was called an *unconditioned reflex*. Salivation upon seeing a particular bowl could not have been hard-wired; it could only provoke salivation after the bowl was associated over and over again with the arrival of food; this association was conditioned. Therefore, salivation in response to the sight of a particular bowl was considered to be a *conditioned reflex*. Probably Pavlov's most famous experiments involved ringing a bell prior to feeding. After enough repetition, the dogs would begin to salivate as soon as the bell was rung. A conditioned salivary reflex to the bell had been established. In later years, Pavlov demonstrated conditioned reflexes involving stomach secretions and other aspects of digestive physiology. Today, it is considered "obvious" that conditioned reflexes and other psychological factors can profoundly influence digestion.

Once food is swallowed, it enters the pharynx, where two layers of skeletal muscles, one arranged in a circular manner and one arranged in a longitudinal manner, initiate the food-propelling motion called *peristalsis*.(**Figure 14.12**)

Esophagus: After the pharynx, a bolus of food enters the esophagus.

The four tissue layers of the esophagus are essentially the same throughout the remainder of the alimentary canal. The innermost layer is a *mucosa*. Superficial to this is a connective tissue *submucosa*, which is rich in blood and lymphatic vessels.

The next layer is the *muscularis externa*. Like the pharynx, the muscularis externa contains muscles arranged in a circular and a longitudinal manner, to continue the action of peristalsis. Unlike the pharynx, these are smooth muscles, not skeletal.

There is a rich network of motor and sensory nerves located mostly in the submucosa and muscularis externa of the alimentary canal. In fact, there are almost as many neurons in the alimentary canal as there are in the spinal cord. If all of the sympathetic and parasympathetic nerves to the alimentary canal are cut, the nerve network within the alimentary canal will still maintain peristalsis and secretion to a sufficient degree for the digestion of food. For this reason, some anatomists refer to the alimentary nerve network as the *enteric* nervous system – a third division of the autonomic nervous system.

This doesn't mean that the sympathetics and parasympathetics have no role in digestive physiology – they do. A digestive system without sympathetics and parasympathetics would be like a car without accelerator and brake pedals. This wouldn't do. The reality of the road is change. Traffic speeds up; traffic slows down. The road is flat for a while, then it goes uphill or downhill. A car without accelerator or brake pedals would not allow for adaptation. The sympathetics and parasympathetics are the brake and accelerator for the digestive system.

(**Figure 14.5**) The fourth and outermost layer is a fluid-secreting serous layer called the *visceral peritoneum*. The *parietal peritoneum* lines the abdominal and pelvic cavities. In addition to the lubricating function of the peritoneum, various folds and cords of peritoneum act as the internal organ version of ligaments, holding the abdominal contents in place.

A bolus of food travels in the esophagus, through an opening or *hiatus* in the diaphragm, and into the stomach. When the diaphragm is damaged or not functioning correctly, a portion of the stomach may protrude upward; a condition called *hiatal* hernia. This is characterized by a bloated feeling after meals, plus frequent acid reflux into the esophagus. Because diaphragm dysfunction can cause chest pain and dyspnea, and since a person with acid reflux is often nauseous, attacks of hiatal hernia are often mistaken for myocardial infarction.

Stomach (**Figure 14.4**): The stomach lies in the upper left quadrant of the abdomen. A bolus of food enters the stomach through the *cardioesophageal sphincter*. Food is mechanically digested in the stomach through a churning action. The submucosal layer contains numerous glands. which empty into the lumen of the stomach. Some of the secretions of these glands include *intrinsic factor*, which aids in the absorption of vitamin B12, hydrochloric acid, and protein-digesting enzymes.

The mucosa of the stomach secretes a thick mucus lining, to prevent the stomach from essentially digesting itself. When this protection fails, the result is a peptic ulcer. These ulcers can occur anywhere from the lower esophagus to the upper small intestines. Aggravating factors include emotional stress, irritation of the sympathetic or parasympathetic nerves to the stomach, allergies, smoking, alcohol consumption, and frequent use of aspirin or ibuprofen. A recently identified risk factor is infection by the bacterium *Helicobacter pylori*.

Severe gastric ulcers can be life threatening if enough blood vessels are eroded to cause severe bleeding (bleeding ulcer). Another life threatening situation is when the ulcer goes all the way through the stomach wall, allowing gastric juices to damage the peritoneum and the pancreas (perforated ulcer).

After being digested in the stomach, food resembles a heavy cream called *chyme*. Chyme leaves the stomach through the *pyloric sphincter*, which connects to the small intestines.

Small Intestines (**Figure 14.6**): The first portion of the small intestines is the *duodenum*. Digestive enzymes which help break down carbohydrates, proteins and fats enter the duodenum from the *pancreas*. The pancreas is located in the upper abdomen, with its head in the left upper quadrant, and its tail in the right upper quadrant.

Fat digestion is further aided by *bile*, which is produced in the *liver* and stored in the *gall bladder* (located in the upper right quadrant of the abdomen). Bile enters the duodenum from the gall bladder.

In addition to bile and the pancreatic enzymes, the small intestine produces enzymes of its own, which further break down carbohydrates and proteins.

(**Figure 14.7**) As food travels through the rest of the small intestine, most of the nutrients are absorbed from it by fingerlike projections of the mucosal layer called *villi*. Each villus contains a rich capillary bed and a lymphatic capillary called a *lacteal*. The individual cells lining the mucosa of the villi have their own projections called *microvilli*. Nutrients are absorbed through the microvilli of the mucosal cells, and are transported to the capillaries and the lacteal. Before this absorption takes place, proteins have been broken down into amino acids, starches and complex sugars have been broken down into monosaccharides, and fats have been broken down into glycerol and fatty acids.

Towards the end of the small intestines there is a great deal of lymphatic tissue in the submucosal layer, called *Peyer's patches*. The remnants of digested food leaves the small intestines in the lower right quadrant of the abdomen through the *ileocecal valve*.

Large Intestines (**Figure 14.8**): The first segment of the large intestine is called the *cecum*, which contains a small projection rich in lymphatic tissue, called the *appendix*.

From here, the indigestible food residue – now called *feces* - travels upward through the portion of the large intestines called the *ascending colon*. Feces is rich in

bacteria, and therefore quite toxic to the body. The only absorption that takes place in thecolon is the absorption of water.

There is a turn in the colon just under the liver – the *hepatic flexure*. From here, the *transverse colon* travels across the upper abdomen to a point just under the spleen, where it makes another turn – the *splenic flexure*. From here, the *descending colon* leads to the final segment – the *sigmoid colon*, leading to the *rectum*, and finally to the *anus*, through which feces is expelled from the body, in the process called *defecation*.

If the passage of feces through the colon is too rapid, very little water will be absorbed, causing diarrhea. If the colon is sluggish, too much water will be absorbed, and the dry, hard feces will be difficult to expel, causing constipation.

METABOLISM

Metabolism: All of the chemical reactions within the body of a living organism.

Anabolism: All metabolic reactions in which molecules are combined to make larger (and more complex) molecules.

Catabolism (**14.6**): All metabolic reactions in which molecules are broken down into smaller (and simpler) molecules. Generally speaking, catabolic reactions involve the capture of energy in the form most usable in the body – ATP. A major example of a catabolic reaction is *cellular respiration*, in which glucose is broken down to carbon dioxide and water through oxidation. This process creates ATP, and therefore usable energy for the cell.

The Hepatic Detour (**Figure 11.14**): When nutrients are absorbed into the capillaries and lacteals of the villi of the small intestines, and water is absorbed from the colon, they do not immediately enter the general circulation. They are conveyed to the *hepatic portal vein*, which enters the liver. The nutrient-rich blood moves through the liver slowly, while nutrients are processed. After this, the *hepatic veins* return the blood to the general circulation via the inferior vena cava.

Glucose Metabolism in the Liver (**Figure 14.20**): When blood glucose levels are high (hyperglycemia), the liver stores some of it as glycogen. This process is *glycogenesis*. If blood glucose levels are especially high, the liver will convert some of it to fat, which is then stored in the adipose tissues. When blood glucose levels are low (hypoglycemia), glycogen is broken down to glucose, which is then released to the circulation. This process is called *glycogenolysis*. When glucose is scarce, it can be synthesized from fats or proteins = *gluconeogenesis*.

Fat Metabolism in the Liver: The liver uses some of the fats absorbed from the small intestines for energy production. Some of the fat is converted into *cholesterol*. This lipid is utilized in some of the endocrine glands to produce steroid hormones, it is converted to vitamin D in the skin, and it is used in the construction and repair of the plasma membranes of the body's cells. It should be noted that only 15% of the body's cholesterol supply comes directly from the diet; 85% is synthesized from other lipids in the liver. After cholesterol has served its purpose, it is catabolized in the liver to *bile salts*, which are the major constituent of bile.

Fats and cholesterol do not dissolve in blood, therefore, the liver binds them with proteins. *Lipoproteins* are soluble in the blood. *Low-density lipoproteins* (*LDLs*) transport lipids to the body cells. *High-density lipoproteins* (*HDLs*) transport lipids from the body cells for breakdown

by the liver. If LDLs accumulate in the circulation, they are often deposited in the artery walls = atherosclerosis.

Protein Metabolism In the Liver: There are certain amino acids that the body cannot synthesize; they must be obtained from proteins in the diet. They are called *essential amino acids*. From these, the liver synthesizes all of the other amino acids used in metabolism; these are called the *non-essential amino acids*. To be clear, a non-essential amino acid is **not** non-essential in terms of metabolism. It is non-essential in terms of the diet; it is not an essential nutrient.

In addition to non-essential amino acids, the liver also produces blood proteins, such as albumin and clotting proteins.

Blood Cleansing In the Liver: A large number of bacteria are present in the blood entering the liver through the hepatic portal vein. These bacteria are removed by a myriad of phagocytic white blood cells arrayed in the liver. This is a very efficient process; 99% of the bacteria entering through the hepatic portal vein are captured and destroyed before the blood leaves the liver and joins the systemic circulation.

The bacteria in the intestines also produce a great deal of ammonia, and this is absorbed by the blood. Ammonia is tremendously toxic to the human body. The liver converts ammonia to urea, which can then be safely excreted by the kidneys.

Nutrient Storage: The liver is a reservoir for certain nutrients, including iron, and vitamins A, D, and B12.

Fast Burn or Slow Burn: In addition to ATP, cellular respiration produces heat. Measuring the amount of heat released from a person is a measure of the speed at which their over-all metabolism is proceeding. The standard measurement of this is *basal metabolic rate* (*BMR*), which is the amount of heat (measured in kilocalories, or *kcal*) released per hour by the body of a person at complete rest.

Body Temperature (**Figure 14.21**): At rest, body temperature is determined by BMR. BMR is influenced by many factors, including age, gender, and emotional state. The single most important factor in determining BMR is the level of thyroid hormones, particularly thyroxine.

When a person is in a hot environment, a number of responses will be generated by the hypothalamus to prevent overheating. In particular, the blood vessels of the skin will dilate, and the sweat glands will become more active. (Why?) In a cold environment, the blood vessels of the skin will constrict, and the sweat glands will become less active. Also, shivering begins. If the exposure to cold goes on too long, the skin can be severely damaged. (Why?)

Vitamins and Controversy: *Vitamins* are nutrients required in smaller amounts than the major nutrients (water, carbohydrates, proteins and lipids), but they are essential. Most vitamins assist enzymes in their work of promoting (catalyzing) the chemical reactions of

metabolism. These are sometimes called "coenzymes".

Due to the fundamental nature of these coenzymes in metabolism, a single vitamin can be important to many different aspects of physiology in many different types of cells. For this reason, differences in individual constitution, activity levels, illness, injury and many other factors can alter a person's vitamin requirements. In some cases, this has led to controversy. The levels of the major vitamins required to prevent overt deficiency diseases in otherwise healthy adults are established, but some researchers have questioned whether or not these recommended daily allowances (RDAs) are adequate to maintain optimal health for every person in every situation.

Vitamin C is an interesting case in point. Also known as *ascorbic acid*, vitamin C has a number of functions in metabolism. Extreme vitamin C deficiency is common in people deprived access to fresh fruit and green, leafy vegetables. This extreme deficiency leads to a disease called *scurvy* – once the bane of sailors on long voyages, until the British navy discovered that issuing a daily allowance of limes to their sailors prevented the disease. (This is the basis of one nick-name for English people – "limeys".)

One of the most well-established functions of vitamin C is to assist in the production of a non-essential amino acid – *hydroxyproline*. This amino acid is a building block of the protein *collagen*. In light of this information, why would some people claim to use vitamin C to treat bleeding gums? Arthritis? Sprains and strains? Easy bruising? Slow healing of wounds? Could such claims lead to controversy?

Another function of vitamin C is to facilitate the absorption of iron from the digestive tract. How could this function lead to claims that vitamin C is a good "tonic" for people suffering from fatigue?

Vitamin C is found in large concentrations in the adrenal glands, and is apparently essential for the production of some of the adrenal hormones, particularly the glucocorticoids. Hunting cultures often were able to stave off scurvy during the winter months by eating the adrenal glands of the animals they hunted. Can you treat stress with vitamin C?

Vitamin C plays an important but poorly-understood role in normalizing the immune system. In fact, frequent infection is a sign of scurvy. Is vitamin C a cure for colds? Cancer? Allergies?

Under certain circumstances, oxygen, usually present in the body as O2, forms the caustic molecule O3. This is sometimes known as *peroxide* or *superoxide*, and is one of a category of caustic chemicals known as *free radicals*. Free radicals can cause cellular damage, and can even disrupt the structure of DNA. Vitamin C is known to speed up the catabolism of O3 to O2. Is vitamin C a treatment for aging?

A number of animals are able to synthesize their own vitamin C. Based on studies of how much vitamin C these animals produce for each kilogram of body weight, the American biochemist Linus Pauling calculated that adult humans require up to 9,000 mg of vitamin C per day for optimum health. The RDA for vitamin C is much lower – 60-70 mg per day for the average adult. Is one of these answers wrong? Is there some way they can both be right?

A *megadose* of a vitamin is considered to be anything exceeding 10x the RDA;

Pauling's recommendations are well into the megadose range. Yet, vitamin C has few known deleterious effects, even at megadosages. Signs of vitamin C "overdose" are primarily digestive upset (especially diarrhea) and burning on urination. The only documented situation in which vitamin C supplementation is clearly dangerous is when it is combined with the use of aspirin. This combination is a risk factor for peptic ulcer.

Minerals are also essential for a variety of structural purposes, (such as the use of *calcium* in building bones and teeth) and in the creation of the proper electrolytic environments for the body cells to work properly (such as the role of *sodium* and *potassium* in creating the action potential of the nerve cell or muscle cell). Some minerals are needed in very small amounts, and are known as *trace* minerals.

One example of a trace mineral is chromium, which is utilized by the body in micrograms, not milligrams. Chromium helps to form one of the active sites on one of the enzymes involved with glucose metabolism. For this reason, some nutritionists refer to chromium as "glucose tolerance factor", and recommend it for people with diabetes mellitus or hypoglycemia.