

Animal Nutrition

Chapter 41

Nutrition

- For any animal, a nutritionally adequate diet is essential for **homeostasis**, a steady-state balance in body functions.
- A balanced diet provides fuel for cellular work and the materials needed to construct organic molecules.
- A nutritionally adequate diet satisfies three needs:
 1. **Fuel** (chemical energy) for all the cellular work of the body;
 2. **Organic raw materials** animals use in biosynthesis (carbon skeletons to make many of their own molecules)
 3. **Essential nutrients**, substances that the animals cannot make for itself from any raw material and therefore must obtain in food in prefabricated form.

Fuel

- Homeostatic mechanisms manage an animal's fuel
 - The flow of food energy into and out of an animal can be viewed as an “**energy budget**”
 - The production of **ATP** accounts for the largest fraction of the energy budget of most animals.

Adenosine Triphosphate (ATP)

- ATP powers basal or resting metabolism, as well as activity, and temperature regulation (in endothermic animals).
- Nearly all ATP is derived from oxidation of organic fuel molecules in cellular respiration
 - Carbohydrates
 - Proteins
 - Fats

Fuel: Carbs, Fats, Proteins

- The monomers of carbohydrates, fats, and proteins can be used as fuel, although priority is usually given to carbohydrates and fats.
- Protein is generally burned only as a last resort.

Fuel

- Fats are especially rich in energy, liberating about twice the energy liberated from an equal amount of carbohydrate or protein during oxidation.
- When an animal takes in more calories than it needs to produce ATP, the excess can be used for **biosynthesis** (Growth, Storage and Reproduction).

Control of Blood Sugar

- In humans, the liver and muscle cells store energy as **glycogen**, a polymer made up of many glucose units.
- **Glucose** is a major fuel molecule for cells, and its metabolism, regulated by hormones is an important aspect of homeostasis.
- If glycogen stores are full and caloric intake still exceeds caloric expenditure, the excess is usually stored as fat.
- The human body regulates the use and storage of **glucose**, a major cellular fuel.
 - When glucose levels rise above a set point, the pancreas secretes insulin into the blood.
 - Insulin enhances the transport of glucose into body cells and stimulates the liver and muscle cells to store glucose as glycogen, dropping blood glucose levels.
 - When glucose levels drop below a set point, the pancreas secretes **glucagon** into the blood.
 - Glucagon promotes the breakdown of glycogen and the release of glucose into the blood, increasing the blood glucose levels.

Energy Storage

- When fewer calories are taken in than are expended, fuel is taken out of storage depots and oxidized.
- The human body generally expends liver glycogen first, and then draws on muscle glycogen and fat.
- Most healthy people - even if they are not obese - have enough stored fat to sustain them through several weeks of starvation.
 - The average human's energy needs can be fueled by the oxidation of only 0.3 kg (0.66 lbs.) of fat per day.
 - Severe problems occur if the energy budget remains out of balance for long periods.

Undernourishment

- If the diet of a person or other animal is chronically deficient in calories, **undernourishment** results.
- The stores of glycogen and fat are used up, the body begins breaking down its own proteins for fuel, muscles begin to decrease in size, and the brain can become protein deficient.
 - Protein burning is usually a last resort
- If energy intake remains less than energy expenditure, **death** will eventually result, and even if a seriously undernourished person survives, some damage may be irreversible.
- Because a diet of single staple such as rice or corn can often provide sufficient calories, undernourishment is generally common only where drought, war, or some other crisis has severely disrupted the food supply.

Overnourishment

- **Overnourishment**, or obesity, the result from excessive food intake, is a common problem in the United States and other affluent nations.
- The human body tends to store any excess fat molecules obtained from food instead of using them for fuel.
- In contrast, when we eat an excess of carbohydrates, the body tends to increase its rate of carbohydrate oxidation.
- While fat hoarding can be a liability today, it probably provided a fitness advantage for our hunting/gathering ancestors, enabling individuals with genes promoting the storage of high-energy molecules during feasts to survive the eventual famines.

Human Weight

- Despite its propensity to store fat, the human body seems to impose limits on weight gain (or loss).
- Some people remain at a more-or-less constant weight no matter how much they eat.
 - Suggests a strong genetic component to weight
- Most dieters return to their former weight soon after they stop dieting.

Leptin

- In mammals, a hormone called **leptin**, produced by adipose cells, is a key player in a complex feedback mechanism regulating fat storage and use.
 - A high leptin level cues the brain to depress appetite and to increase energy-consuming muscular activity and body-heat production.
 - Conversely, loss of body fat decreases leptin levels in the blood, signaling the brain to increase appetite and weight gain.
- These feedback mechanisms regulate body weight around a fairly rigid set point *in some individuals* and over a relatively wide range in others.
 - Researchers have identified some of the genes involved in fat homeostasis and several chemical signals that underlie the brain's regulatory role.
 - Some of the signals and signal antagonists are under development as potential medications for obesity.

Fabricating Organic Molecules

- In addition to fuel for ATP production, an animal's diet must supply all the raw materials for biosynthesis.
 - Essential nutrients
 - Carbon skeletons: organic precursors
- Given a source of organic carbon (such as sugar) and a source of organic nitrogen (usually in amino acids from the digestion of proteins), animals can fabricate a great variety of organic molecules
 - **Carbohydrates**
 - **Proteins**
 - **Lipids**

Essential Nutrients

- Besides fuel and carbon
- skeletons, an animal's diet must also supply **essential nutrients**.
- These are materials that must be obtained in preassembled form because the animal's cells cannot make them from any raw material.
- Some materials are essential for all animals, but others are needed only by certain species.
 - For example, ascorbic acid (vitamin C) is an essential nutrient for humans and other primates, guinea pigs, and some birds and snakes, but not for most other animals.

Malnourishment

- An animal whose diet is missing one or more essential nutrients is said to be **malnourished** (not equivalent to being undernourished)
- For example, many herbivores living where soils and plants are deficient in phosphorus eat bones to obtain this essential nutrient.
- Malnutrition is much more common than undernourishment in human populations, and it is even possible for an overnourished individual to be malnourished.
 - by Living on Taco Bell Burritos and Coca Cola, for example

Amino Acids

- Animals require 20 different amino acids to make proteins.
- Most animals can synthesize half of these if their diet includes organic nitrogen.
- We cannot synthesize **Essential Amino Acids**, which must be obtained from food in prefabricated form.
 - The same amino acids are essential for most animals.
 - Eight amino acids are essential in the adult human with a ninth, **histidine**, essential for infants.
 - **Protein Deficiency**
- A diet that provides insufficient amounts of one or more essential amino acids causes a form of malnutrition known as **protein deficiency**.
 - This is the most common type of malnutrition among humans.

Essential Fatty Acids

- While animals can synthesize most of the fatty acids they need, they cannot synthesize essential fatty acids.
- These are certain unsaturated fatty acids, including **linoleic acids** required by humans.
- Most diets furnish ample quantities of essential fatty acids, and thus deficiencies are rare.

Vitamins

- **Vitamins** are organic molecules required in the diet in quantities that are quite small compared with the relatively large quantities of essential amino acids and fatty acids animals need.
- While vitamins are required in tiny amounts - from about 0.01 mg to 100 mg per day - depending on the vitamin, vitamin deficiency (or overdose in some cases) can cause serious problems.
- So far 13 vitamins essential to humans have been identified.
 - These can be grouped into
 - **water-soluble vitamins**
 - **fat-soluble vitamins**

Minerals

- Minerals are simple inorganic nutrients, usually required in small amounts - from less than 1 mg to about 2,500 mg per day.
- Mineral requirements vary with animal species.
- Humans and other vertebrates require relatively large quantities of **calcium** and **phosphorus** for the construction and maintenance of bone among other uses.
- **Iron** is a component of the cytochromes that function in cellular respiration and of hemoglobin, the oxygen binding protein of red blood cells.
- While **sodium**, **potassium**, and **chloride** have a major influence on the osmotic balance between cells and the interstitial fluids, excess consumption of salt (**sodium chloride**) is harmful.
 - The average U.S. citizen eats enough salt to provide about 20 times the required amount of sodium.
 - Excess consumption of salt or several other minerals can upset homeostatic balance and cause toxic side effects.
 - For example, too much sodium is associated with high blood pressure, and excess iron causes liver damage.

Food Processing

- The four main stages of food processing
 - **Ingestion**
 - **Digestion**
 - **Absorption**
 - **Elimination**

Ingestion

- **Ingestion**, the act of eating, is only the first stage of food processing.
 - Food is “packaged” in bulk form and contains very complex arrays of molecules, including large polymers and various substances that may be difficult to process or may even be toxic.
 - Animals cannot use macromolecules like proteins, fats, and carbohydrates in the form of starch or other polysaccharides.
 - First, polymers are too large to pass through membranes and enter the cells of the animal.
 - Second, the macromolecules that make up an animal are not identical to those of its food.
 - In building their macromolecules, however, all organisms use common monomers.
 - For example, soybeans, fruit flies, and humans all assemble their proteins from the same 20 amino acids.

Digestion

- **Digestion**, the second stage of food processing, is the process of breaking food down into molecules small enough for the body to absorb.
- Digestion cleaves macromolecules into their component monomers, which the animal then uses to make its own molecules or as fuel for ATP production.
 - Polysaccharides and disaccharides are split into simple sugars.
 - Fats are digested to glycerol and fatty acids.
 - Proteins are broken down into amino acids.
 - Nucleic acids are cleaved into nucleotides.

- Digestion reverses the process that a cell uses to link together monomers to form macromolecules.
 - Rather than removing a molecule of water for each new covalent bond formed, digestion breaks bonds with the addition of water via enzymatic hydrolysis.
- A variety of hydrolytic enzymes catalyze the digestion of each of the classes of macromolecules found in food.
- Chemical digestion is usually preceded by mechanical fragmentation of the food, by chewing, for instance.
- Breaking food into smaller pieces increases the surface area exposed to digestive juices containing hydrolytic enzymes.

Absorption

- After the food is digested, the animal's cells take up small molecules such as amino acids and simple sugars from the digestive compartment, a process called **absorption**.

Elimination

- During **elimination**, undigested material passes out of the digestive compartment.

Digestion in Protists

- Heterotrophic protists engulf their food by **phagocytosis** and digest their meals in food vacuoles.
- Newly formed vacuoles are carried around the cell until they fuse with lysosomes, which are organelles containing hydrolytic enzymes.
- Later, the vacuole fuses with an anal pore and its contents are eliminated.

Digestion in Animals

- In most animals, at least some hydrolysis occurs by **extracellular digestion**, the breakdown of food outside cells.
- Extracellular digestion occurs within compartments that are continuous with the outside of the animal's body.
- This enables organisms to devour much larger prey than can be ingested by phagocytosis and digested intracellularly.

Gastrovascular Cavity

- Many animals with simple body plans, such as cnidarians and flatworms, have digestive sacs with single openings, called gastrovascular cavities.
- For example, a hydra captures its prey with nematocysts and stuffs the prey through the mouth into the gastrovascular cavity.
- The prey is then partially digested by enzymes secreted by gastrodermal cells.
- These cells absorb food particles and most of the actual hydrolysis of macromolecules occur intracellularly.
- Undigested materials are eliminated through the mouth.

Alimentary Canal

- In contrast to cnidarians and flatworms, most animals have **complete digestive tracts** or **alimentary canals** with a mouth, digestive tube, and an anus.
- Because food moves in one direction, the tube can be organized into special regions that carry out digestion and nutrient absorption in a stepwise fashion.
- Food ingested through the mouth and pharynx passes through an esophagus that leads to a crop, gizzard, or stomach, depending on the species.
 - Crops and stomachs usually serve as food storage organs, although some digestion occurs there too.
 - Gizzards grind and fragment food.
- In the intestine, digestive enzymes hydrolyze the food molecules, and nutrients are absorbed across the lining of the tube into the blood.
- Undigested wastes are eliminated through the anus.
- This system enables organisms to ingest additional food before earlier meals are completely digested.

Mammalian Digestive System

- The mammalian digestive system consists of the alimentary canal and various accessory glands that secrete digestive juices into the canal through ducts.
- **Peristalsis**, rhythmic waves of contraction by smooth muscles in the walls of the canal, push food along.
- **Sphincters**, muscular ring-like valves, regulate the passage of material between specialized chambers of the canal.
- The accessory glands include the **salivary glands**, the **pancreas**, the **liver**, and the **gallbladder**.

Oral Cavity

- Both physical and chemical digestion of food begins in the mouth.
- During chewing, teeth of various shapes cut, smash, and grind food, making it easier to swallow and increasing its surface area.

- The presence of food in the oral cavity triggers a nervous reflex that causes the salivary glands to deliver saliva through ducts to the oral cavity.

Saliva

- Saliva contains a slippery glycoprotein called **mucin**, which protects the soft lining of the mouth from abrasion and lubricates the food for easier swallowing.
- Saliva also contains buffers that help prevent tooth decay by neutralizing acid in the mouth.
- Antibacterial agents in saliva kill many bacteria that enter the mouth with food.
- Chemical digestion of carbohydrates, a main source of chemical energy, begins in the oral cavity.
- Saliva contains **salivary amylase**, an enzyme that hydrolyzes starch and glycogen into smaller polysaccharides and the disaccharide maltose.

Swallowing

- The tongue tastes food, manipulates it during chewing, and helps shape the food into a ball called a **bolus**.
- During swallowing, the tongue pushes a bolus back into the oral cavity and into the **pharynx**.
- The pharynx, also called the throat, is a junction that opens to both the **esophagus** and the trachea (windpipe).
- When we swallow, the top of the windpipe moves up such that its opening, the glottis, is blocked by a cartilaginous flap, the **epiglottis**.
- This mechanism normally ensures that a bolus will be guided into the entrance of the esophagus and not directed down the windpipe.

Stomach

- The stomach stores food and performs preliminary digestion
- The stomach is located in the upper abdominal cavity, just below the diaphragm.
- With accordion-like folds and a very elastic wall, the stomach can stretch to accommodate about 2 L of food and fluid, storing an entire meal.
- The stomach also secretes a digestive fluid called **gastric juice** and mixes this secretion with the food by the churning action of the smooth muscles in the stomach wall.
- Gastric juice is secreted by the epithelium lining numerous deep pits in the stomach wall.
- With a high concentration of hydrochloric acid, the pH of the gastric juice is about 2 - acidic enough to digest iron nails.
 - This acid disrupts the extracellular matrix that binds cells together.
 - It kills most bacteria that are swallowed with food.
- Also present in gastric juice is **pepsin**, an enzyme that begins the hydrolysis of proteins.
 - Pepsin, which works well in strongly acidic environments, breaks peptide bonds adjacent to specific amino acids, producing smaller polypeptides.
- As a result of mixing and enzyme action, what begins in the stomach as a recently swallowed meal becomes a nutrient-rich broth known as acid **chyme**.

- Most of the time the stomach is closed off at either end.
- The opening from the esophagus to the stomach, the **cardiac orifice**, normally dilates only when a bolus driven by peristalsis arrives.
 - The occasional backflow of acid chyme from the stomach into the lower esophagus causes heartburn.
- At the opening from the stomach to the small intestine is the **pyloric sphincter**, which helps regulate the passage of chyme into the intestine.
- A squirt at a time, it takes about 2 to 6 hours after a meal for the stomach to empty.

Small Intestine

- The small intestine is the major organ of digestion and absorption
- With a length of over 6 m in humans, the small intestine is the longest section of the alimentary canal.
- Most of the enzymatic hydrolysis of food macromolecules and most of the absorption of nutrients into the blood occurs in the small intestine.
- In the first 25 cm or so of the small intestine, the **duodenum**, acid chyme from the stomach mixes with digestive juices from the pancreas, liver, gall bladder, and gland cells of the intestinal wall.
- The **pancreas** produces several hydrolytic enzymes and an alkaline solution rich in bicarbonate which buffers the acidity of the chyme from the stomach.
- The **liver** performs a wide variety of important functions in the body, including the production of bile.
- Bile is stored in the **gallbladder** until needed.
 - It contains bile salts which act as detergents that aid in the digestion and absorption of fats.
 - Bile also contains pigments that are by-products of red blood cell destruction in the liver.
 - These bile pigments are eliminated from the body with the feces.

Digestion of Carbohydrates

- Specific enzymes from the pancreas and the duodenal wall have specific roles in digesting macromolecules.
- The digestion of **starch** and **glycogen**, begins by **salivary amylase** in the oral cavity, continues in the small intestine.
- Pancreatic amylases hydrolyze starch, glycogen, and smaller polysaccharides into disaccharides.
- A family of disaccharidases hydrolyze each disaccharide into monomers.
 - Maltase splits maltose into two glucose molecules.
 - Sucrase splits sucrose, a sugar found in milk, into glucose and fructose.
- These enzymes are built into the membranes and extracellular matrix of the intestinal epithelium which is also the site of sugar absorption.

Digestion of Proteins

- **Digestion of proteins** in the small intestine completes the process begun by pepsin.
- Several enzymes in the duodenum dismantle polypeptides into their amino acids or into small peptides that in turn are attacked by other enzymes.
 - **Trypsin** and **chymotrypsin** attack peptide bonds adjacent to specific amino acids, breaking larger polypeptides into shorter chains.
 - **Dipeptidase**, attached to the intestinal lining, split smaller chains.
 - **Carboxypeptidases** and **aminopeptidase** split off one amino acid from the carboxyl or amino end of a peptide, respectively.

Digestion of Fat

- Nearly all the fat in a meal reaches the small intestine undigested.
- Normally fat molecules are insoluble in water, but bile salts, secreted by the gallbladder into the duodenum, coat tiny fats droplets and keep them from coalescing, a process known as **emulsification**.
- The large surface area of these small droplets is exposed to **lipase**, an enzyme that hydrolyzes fat molecules into glycerol, fatty acids, and glycerides.

Duodeun,

- **Most digestion occurs in the duodenum.**
- The other two sections of the small intestine, the jejunum and ileum, function mainly in the absorption of nutrients and water.
- To enter the body, nutrients in the lumen must pass the lining of the digestive tract.
- The small intestine has a huge surface area, about 300 m², roughly the size of a tennis court.
- The enormous surface of the small intestine is an adaptation that greatly increases the rate of nutrient absorption.

Intestinal Wall

- Large circular folds in the lining bear fingerlike projections called **villi**, and each epithelial cell of a villus has many microscopic appendages called **microvilli** that are exposed to the intestinal lumen.
- Penetrating the core of each villus is a net of microscopic blood vessels (capillaries) and a single vessel of the lymphatic system called a lacteal.

Colon (Large Intestine)

- Reclaiming water is a major function of the large intestine
- The large intestine, or colon, is connected to the small intestine at a T-shaped junction where a sphincter controls the movement of materials.
- One arm of the T is a pouch called the **cecum**.
- A major function of the colon is to recover water that has entered the alimentary canal as the solvent to various digestive juices.
 - About 7 L of fluid are secreted into the lumen of the digestive tract of a person each day.
 - Over 90% of the water is reabsorbed, most in the small intestine, the rest in the colon.
- Digestive wastes, the feces, become more solid as they are moved along the colon by peristalsis.
- Movement in the colon is sluggish, requiring 12 to 24 hours for material to travel the length of the organ.
- Living in the large intestine is a rich flora of mostly harmless bacteria.
 - One of the most common inhabitants of the human colon is *Escherichia coli*, a favorite research organism.
- As a byproduct of their metabolism, many colon bacteria generate gases, including **methane** and **hydrogen sulfide**.
- Some bacteria produce vitamins, including biotin, folic acid, vitamin K, and several B vitamins, which supplement our dietary intake of vitamins.
- Feces contain masses of bacteria and undigested materials including cellulose.
- Although cellulose fibers have no caloric value to humans, their presence in the diet helps move food along the digestive tract.
- The feces may also contain excess salts that are excreted into the lumen of the colon.

Rectum

- The terminal portion of the colon is called the **rectum**, where feces are stored until they can be eliminated.
- Between the rectum and the anus are two sphincters, one involuntary and one voluntary.