Section A: Nutritional Requirements

1. Animals are heterotrophs that require food for fuel, carbon skeletons, and essential nutrients: *an overview*

2. Homeostatic mechanisms manage an animal’s fuel

3. An animal’s diet must supply essential nutrients and carbon skeletons for biosynthesis
Introduction

• As a group, animals exhibit a great variety of nutritional adaptations.
  • For example, the snowshoe hare of the northern forests, obtains all their nutrients from plants alone.
  • Hares and rabbits have a large intestinal pouch housing prokaryotes and protists that digest cellulose.
  • 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.
1. Animals are heterotrophs that require food for fuel, carbon skeletons, and essential nutrients: *an overview*

- A nutritionally adequate diet satisfies three needs:
  - fuel (chemical energy) for all the cellular work of the body;
  - the organic raw materials animals use in biosynthesis (carbon skeletons to make many of their own molecules);
  - essential nutrients, substances that the animals cannot make for itself from *any* raw material and therefore must obtain in food in prefabricated form.
2. Homeostatic mechanisms manage an animal’s fuel

• The flow of food energy into and out of an animal can be viewed as a “budget,” with the production of ATP accounting for the largest fraction by far of the energy budget of most animals.

• ATP powers basal or resting metabolism, as well as activity, and, in endothermic animals, temperature regulation.
• Nearly all ATP is derived from oxidation of organic fuel molecules - carbohydrates, proteins, and fats - in cellular respiration.

• The monomers of any of these substances can be used as fuel, though priority is usually given to carbohydrates and fats.

• 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.
  • This biosynthesis can be used to grow in size or for reproduction, or can be stored in energy depots.
  • 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 hormone action, 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.

(1) When glucose levels rise above a set point, (2) the pancreas secretes insulin into the blood.

(3) 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.

(4) When glucose levels drop below a set point, (5) the pancreas secretes glucagon into the blood.

(6) Glucagon promotes the breakdown of glycogen and the release of glucose into the blood, increasing the blood glucose levels.
The pancreas uses the hormones insulin and glucagon to signal distant cells to take up or release glucose to regulate levels on the blood.
• 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 of fat per day.
• Severe problems occur if the energy budget remain out of balance for long periods.

  • 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.

  • 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.

• Another cause of undernourishment is anorexia nervosa, an eating disorder associated with a compulsive aversion to body fat.
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.
• 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.
  • Most dieters return to their former weight soon after they stop dieting.
• 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.
• Obesity may be beneficial in certain species.
  
  • Small seabirds called petrels fly long distances to find food, which is rich in lipids.
  
  • By bringing lipid rich food to their chicks, the parents minimize the weight of food that they must carry.
  
  • However, because these foods are low in protein, young petrels have to consume more calories than they burn in metabolism - and consequently they become obese.
  
  • In some petrel species, chicks at the end of the growth period weigh much more their parents and are too heavy to fly and they need to starve for several days to fly.
  
  • The fat reserves do help growing chicks to survive periods when parents are unable to find food.
3. An animal’s diet must supply essential nutrients and carbon skeletons for biosynthesis

• In addition to fuel for ATP production, an animal’s diet must supply all the raw materials for biosynthesis.
  • This requires organic precursors (carbon skeletons) from its food.
  • 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, and lipids.
• 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.
• An animal whose diet is missing one or more essential nutrients is said to be **malnourished**.

• 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.
• Animals require 20 amino acids to make proteins.
• Most animals can synthesize half of these if their diet includes organic nitrogen.
• **Essential amino acids** must be obtained from food in prefabricated form.
  • Eight amino acids are essential in the adult human with a ninth, histidine, essential for infants.
  • The same amino acids are essential for most animals.
• 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.

• The victims are usually children, who, if they survive infancy, are likely to be retarded in physical and perhaps mental development.
• The proteins in animals products, such as meat, eggs, and cheese, are “complete,” which means that they provide all the essential amino acids in their proper proportion.

• Most plant proteins are “incomplete,” being deficient in one or more essential amino acid.
  • For example, corn is deficient in the amino acid lysine.
  • Individuals who are forced by economic necessity or other circumstances to obtain nearly all their calories from corn would show symptoms of protein deficiency.
  • This is true from any diet limited to a single plant source, including rice, wheat, or potatoes.
Protein deficiency from a vegetarian diet can be avoided by eating a combination of plant foods that complement each other to supply all essential amino acids.

For example, beans supply the lysine that is missing in corn, and corn provides the methionine which is deficient in beans.
• Because the body cannot easily store amino acids, a diet with all essential amino acids must be eaten each day, otherwise protein synthesis is retarded.

• Some animals have special adaptations that get them through periods where their bodies demand extraordinary amounts of protein.

  • For example, penguins use their muscle proteins as a source of amino acids to make new proteins during molting.
• 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** 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 and fat-soluble vitamins, with extremely diverse physiological functions.
<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Major Dietary Sources</th>
<th>Some Major Functions in the Body</th>
<th>Possible Symptoms of Deficiency or Extreme Excess</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water-Soluble Vitamins</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin B₁ (thiamine)</td>
<td>Pork, legumes, peanuts, whole grains</td>
<td>Coenzyme used in removing CO₂ from organic compounds</td>
<td>Beriberi (nerve disorders, emaciation, anemia)</td>
</tr>
<tr>
<td>Vitamin B₂ (riboflavin)</td>
<td>Dairy products, meats, enriched grains, vegetables</td>
<td>Component of coenzymes FAD and FMN</td>
<td>Skin lesions such as cracks at corners of mouth</td>
</tr>
<tr>
<td>Niacin</td>
<td>Nuts, meats, grains</td>
<td>Component of coenzymes NAD⁺ and NADP⁺</td>
<td>Skin and gastrointestinal lesions, nervous disorders Flushing of face and hands, liver damage</td>
</tr>
<tr>
<td>Vitamin B₆ (pyridoxine)</td>
<td>Meats, vegetables, whole grains</td>
<td>Coenzyme used in amino acid metabolism</td>
<td>Irritability, convulsions, muscular twitching, anemia Unstable gait, numb feet, poor coordination</td>
</tr>
<tr>
<td>Pantothenic acid</td>
<td>Most foods: meats, dairy products, whole grains, etc.</td>
<td>Component of coenzyme A</td>
<td>Fatigue, numbness, tingling of hands and feet</td>
</tr>
<tr>
<td>Folic acid (folacin)</td>
<td>Green vegetables, oranges, nuts, legumes, whole grains (also made by colon bacteria)</td>
<td>Coenzyme in nucleic acid and amino acid metabolism</td>
<td>Anemia, gastrointestinal problems May mask deficiency of vitamin B₁₂</td>
</tr>
<tr>
<td>Vitamin B₁₂</td>
<td>Meats, eggs, dairy products</td>
<td>Coenzyme in nucleic acid metabolism; needed for maturation of red blood cells</td>
<td>Anemia, nervous system disorders</td>
</tr>
<tr>
<td>Biotin</td>
<td>Legumes, other vegetables, meats</td>
<td>Coenzyme in synthesis of fat, glycogen, and amino acids</td>
<td>Scaly skin inflammation, neuromuscular disorders</td>
</tr>
<tr>
<td>Vitamin C (ascorbic acid)</td>
<td>Fruits and vegetables, especially citrus fruits, broccoli, cabbage, tomatoes, green peppers</td>
<td>Used in collagen synthesis (e.g., for bone, cartilage, gums); antioxidant; aids in detoxification; improves iron absorption</td>
<td>Scurvy (degeneration of skin, teeth, blood vessels), weakness, delayed wound healing, impaired immunity Gastrointestinal upset</td>
</tr>
<tr>
<td>Vitamin</td>
<td>Major Dietary Sources</td>
<td>Some Major Functions in the Body</td>
<td>Possible Symptoms of Deficiency or Extreme Excess</td>
</tr>
<tr>
<td>------------------------</td>
<td>------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Fat-Soluble Vitamins</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin A (retinol)</td>
<td>Provitamin A (beta-carotene) in deep green and orange</td>
<td>Component of visual pigments; needed for maintenance of epithelial tissues; antioxidant; helps</td>
<td>Vision problems; dry, scaling skin</td>
</tr>
<tr>
<td></td>
<td>vegetables and fruits; retinol in dairy products</td>
<td>prevent damage to lipids of cell membranes</td>
<td>Headache, irritability, vomiting, hair loss, blurred vision, liver and bone damage</td>
</tr>
<tr>
<td>Vitamin D</td>
<td>Dairy products, egg yolk (also made in human skin in</td>
<td>Aids in absorption and use of calcium and phosphorus; promotes bone growth</td>
<td>Rickets (bone deformities) in children, bone softening in adults</td>
</tr>
<tr>
<td></td>
<td>presence of sunlight)</td>
<td></td>
<td>Brain, cardiovascular, and kidney damage</td>
</tr>
<tr>
<td>Vitamin E (tocopherol)</td>
<td>Vegetable oils, nuts, seeds</td>
<td>Antioxidant; helps prevent damage to lipids of cell membranes</td>
<td>None well documented in humans; possibly anemia</td>
</tr>
<tr>
<td>Vitamin K (phyloquinone)</td>
<td>Green vegetables, tea (also made by colon bacteria)</td>
<td>Important in blood clotting</td>
<td>Defective blood clotting</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Liver damage and anemia</td>
</tr>
</tbody>
</table>
The subject of vitamin dosage has aroused heated scientific and popular debate.

Some believe that it is sufficient to meet recommended daily allowances (RDAs), the nutrient intakes proposed by nutritionists to maintain health.

Others argue that RDAs are set too low for some vitamins, and a fraction of these people believe, probably mistakenly, that massive doses of vitamins confer health benefits.

While research is ongoing, all that can be said with any certainty is that people who eat a balanced diet are not likely to develop symptoms of vitamin deficiency.
• **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.
<table>
<thead>
<tr>
<th>Mineral</th>
<th>Major Dietary Sources</th>
<th>Some Major Functions in the Body</th>
<th>Possible Symptoms of Deficiency*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium (Ca)</td>
<td>Dairy products, dark green vegetables, legumes</td>
<td>Bone and tooth formation, blood clotting, nerve and muscle function</td>
<td>Retarded growth, possibly loss of bone mass</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>Dairy products, meats, grains</td>
<td>Bone and tooth formation, acid-base balance, nucleotide synthesis</td>
<td>Weakness, loss of minerals from bone, calcium loss</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>Proteins from many sources</td>
<td>Component of certain amino acids</td>
<td>Symptoms of protein deficiency</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>Meats, dairy products, many fruits and vegetables, grains</td>
<td>Acid-base balance, water balance, nerve function</td>
<td>Muscular weakness, paralysis, nausea, heart failure</td>
</tr>
<tr>
<td>Chlorine (Cl)</td>
<td>Table salt</td>
<td>Acid-base balance, formation of gastric juice, nerve function, osmotic balance</td>
<td>Muscle cramps, reduced appetite</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>Table salt</td>
<td>Acid-base balance, water balance, nerve function</td>
<td>Muscle cramps, reduced appetite</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>Whole grains, green leafy vegetables</td>
<td>Cofactor; ATP bioenergetics</td>
<td>Nervous system disturbances</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>Meats, eggs, legumes, whole grains, green leafy vegetables</td>
<td>Component of hemoglobin and of electron-carriers in energy metabolism; enzyme cofactor</td>
<td>Iron-deficiency anemia, weakness, impaired immunity</td>
</tr>
<tr>
<td>Fluorine (F)</td>
<td>Drinking water, tea, seafood</td>
<td>Maintenance of tooth (and probably bone) structure</td>
<td>Higher frequency of tooth decay</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>Meats, seafood, grains</td>
<td>Component of certain digestive enzymes and other proteins</td>
<td>Growth failure, scaly skin inflammation, reproductive failure, impaired immunity</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>Seafood, nuts, legumes, organ meats</td>
<td>Enzyme cofactor in iron metabolism, melanin synthesis, electron transport</td>
<td>Anemia, bone and cardiovascular changes</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>Nuts, grains, vegetables, fruits, tea</td>
<td>Enzyme cofactor</td>
<td>Abnormal bone and cartilage</td>
</tr>
<tr>
<td>Iodine (I)</td>
<td>Seafood, dairy products, iodized salt</td>
<td>Component of thyroid hormones</td>
<td>Goiter (enlarged thyroid)</td>
</tr>
<tr>
<td>Cobalt (Co)</td>
<td>Meats and dairy products</td>
<td>Component of vitamin B₁₂</td>
<td>None, except as B₁₂ deficiency</td>
</tr>
<tr>
<td>Selenium (Se)</td>
<td>Seafood, meats, whole grains</td>
<td>Enzyme cofactor; antioxidant functioning in close association with vitamin E</td>
<td>Muscle pain, possibly heart muscle deterioration</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>Brewer’s yeast, liver, seafood, meats, some vegetables</td>
<td>Involved in glucose and energy metabolism</td>
<td>Impaired glucose metabolism</td>
</tr>
<tr>
<td>Molybdenum (Mo)</td>
<td>Legumes, grains, some vegetables</td>
<td>Enzyme cofactor</td>
<td>Disorder in excretion of nitrogen-containing compounds</td>
</tr>
</tbody>
</table>

*All of these minerals are also harmful when consumed in excess.
• 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.