Chapter 41:
Animal Nutrition

1. Overview of Animal Nutrition
2. Digestive Organs
3. Digestive Adaptations
1. Overview of Animal Nutrition
The Need to Feed

Feeding satisfies 3 requirements:

1 – chemical energy to fuel cellular processes
2 – organic building blocks for macromolecules
3 – essential nutrients the animal cannot make for itself

Animals feed in 3 general ways:

- **Carnivores** – eat food derived from other animals
- **Herbivores** – eat food derived from plants
- **Omnivores** – eat food derived from both plants & animals
Essential Nutrients

Essential nutrients must come from the diet and are of 4 types:

- essential amino acids
- essential fatty acids
- vitamins
- minerals

Phospholipid and Prostaglandin Synthesis

(molecules in red with an *asterisk are essential)
Essential Amino Acids

Animals require 20 amino acids to build proteins, roughly half of which are essential and must be obtained in the diet.

- most animal protein sources contain all essential amino acids (for humans) and thus are sources of **complete** protein
- most plant protein sources lack one or more essential amino acids and thus are **incomplete** protein sources

*R group is different for each amino acid
Vegan diets must combine plant foods to get complete protein in a given meal.

- e.g., rice & beans, nut butter & bread

A few plant protein sources provide complete protein

- e.g., soy, quinoa, garbanzo beans (chick peas)

9 essential AAs for humans:

- isoleucine
- leucine
- lysine
- methionine
- phenylalanine
- threonine
- tryptophan
- valine
- histidine (infants only)
Essential Fatty Acids

Animals can synthesize most of the fatty acids they need, however, several such as linoleic acid are essential and must be obtained in the diet.

Most essential fatty acids are unsaturated (i.e., have 1 or more double bonds).
Vitamins

Vitamins are organic molecules required in the diet in minute amounts.

• there are 13 vitamins which are classified as “water soluble” or “fat soluble”
## Table 41.1 Vitamin Requirements of Humans

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Major Dietary Sources</th>
<th>Major Functions in the Body</th>
<th>Symptoms of Deficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water-Soluble Vitamins</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B₁ (thiamine)</td>
<td>Pork, legumes, peanuts, whole grains</td>
<td>Coenzyme used in removing CO₂ from organic compounds</td>
<td>Beriberi (tingling, poor coordination, reduced heart function)</td>
</tr>
<tr>
<td>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>B₃ (niacin)</td>
<td>Nuts, meats, grains</td>
<td>Component of coenzymes NAD⁺ and NADP⁺</td>
<td>Skin and gastrointestinal lesions, delusions, confusion</td>
</tr>
<tr>
<td>B₅ (pantothenic acid)</td>
<td>Meats, dairy products, whole grains</td>
<td>Component of coenzyme A</td>
<td>Fatigue, numbness, tingling of hands and feet</td>
</tr>
<tr>
<td>B₆ (pyridoxine)</td>
<td>Meats, vegetables, whole grains</td>
<td>Coenzyme used in amino acid metabolism</td>
<td>Irritability, convulsions, muscular twitching, anemia</td>
</tr>
<tr>
<td>B₇ (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>B₉ (folic acid)</td>
<td>Green vegetables, oranges, nuts, legumes, whole grains</td>
<td>Coenzyme in nucleic acid and amino acid metabolism</td>
<td>Anemia, birth defects</td>
</tr>
<tr>
<td>B₁₂ (cobalamin)</td>
<td>Meats, eggs, dairy products</td>
<td>Production of nucleic acids and red blood cells</td>
<td>Anemia, numbness, loss of balance</td>
</tr>
<tr>
<td>C (ascorbic acid)</td>
<td>Citrus fruits, broccoli, tomatoes</td>
<td>Used in collagen synthesis; antioxidant</td>
<td>Scurvy (degeneration of skin and teeth), delayed wound healing</td>
</tr>
<tr>
<td><strong>Fat-Soluble Vitamins</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A (retinol)</td>
<td>Dark green and orange vegetables and fruits, dairy products</td>
<td>Component of visual pigments; maintenance of epithelial tissues</td>
<td>Blindness, skin disorders, impaired immunity</td>
</tr>
<tr>
<td>A</td>
<td>Dairy products, egg yolk</td>
<td>Aids in absorption and use of calcium and phosphorus</td>
<td>Rickets (bone deformities) in children, bone softening in adults</td>
</tr>
<tr>
<td>E (tocopherol)</td>
<td>Vegetable oils, nuts, seeds</td>
<td>Antioxidant; helps prevent damage to cell membranes</td>
<td>Nervous system degeneration</td>
</tr>
<tr>
<td>K (phyllquinone)</td>
<td>Green vegetables, tea; also made by colon bacteria</td>
<td>Important in blood clotting</td>
<td>Defective blood clotting</td>
</tr>
</tbody>
</table>
Minerals

Vitamins are simple inorganic nutrients, most of which are required in small amounts.
<table>
<thead>
<tr>
<th>Mineral</th>
<th>Major Dietary Sources</th>
<th>Major Functions in the Body</th>
<th>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>Impaired growth, 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>Impaired growth, fatigue, swelling</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>Enzyme 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; 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 structure</td>
<td>Higher frequency of tooth decay</td>
</tr>
<tr>
<td>Iodine (I)</td>
<td>Seafood, iodized salt</td>
<td>Component of thyroid hormones</td>
<td>Goiter (enlarged thyroid gland)</td>
</tr>
</tbody>
</table>

*Additional minerals required in trace amounts include cobalt (Co), copper (Cu), manganese (Mn), molybdenum (Mo), selenium (Se), and zinc (Zn). All of these minerals, as well as those in the table, can be harmful in excess.*
Dietary Deficiencies

An individual suffers from malnutrition when the diet is deficient in essential nutrients (essential amino acids, fatty acids, vitamin and/or minerals) which can cause disease, deformities and death.

Undernourished individuals do not consume enough calories which leads to:

1. using up carbohydrate (glycogen), then fat stores
2. breaking down one’s own proteins – loss of muscle mass, protein deficiency in the brain
3. irreversible damage and/or death
The Main Stages of Food Processing

Digestion occurs at 2 levels:

- **mechanical digestion** (e.g., chewing) breaks up food to increase its surface area
- **chemical digestion** requires enzymes to catalyze the hydrolysis of polymers into monomers

Absorption is the uptake of nutrients into cells and **elimination** is the passage of undigested material from the body.
The Ingestion of Food

**Suspension Feeders** – filter food particles from a watery environment

**Substrate Feeders** – live in or on food source

**Fluid Feeders** – suck liquid nutrients from host

**Bulk Feeders** – eat large pieces of food
A few animals digest material *intracellularly* in lysosomes (e.g., sponges), however most animals carry out *extracellular* digestion in a digestive compartment continuous with the outside of the animal’s body.
Most animals have a digestive tube with 2 openings – a mouth & anus – and thus have a complete digestive tract or alimentary canal.

- Ingestion, digestion, absorption and elimination occur sequentially in specialized compartments of the digestive tube
2. Digestive Organs
The Mammalian Digestive System

Alimentary Canal – oral cavity, pharynx, esophagus, stomach, small & large intestines

- passage of food material controlled by muscular sphincters

Accessory Organs – salivary glands, liver, gall bladder & pancreas
The Oral Cavity, Pharynx & Esophagus

Mechanical & chemical digestion begins in the mouth as food is chewed.

(a) Trachea open (breathing)

(b) Esophagus open (swallowing)

- chewed food is mixed with saliva which contains amylase to chemically digest starch & mucus to lubricate the food bolus as it is swallowed through the pharynx and into the esophagus.
Digestion in the Stomach

Mechanical & chemical digestion continue in the stomach:

- coordinated muscular contractions churn food to continue mechanical digestion
- pepsin, mucus & HCl (gastric juice) are added to begin the digestion of proteins
- the resulting mixture called chyme will eventually pass through the pyloric sphincter to the small intestine
Chemical Digestion in the Mouth & Stomach

**ORAL CAVITY, PHARYNX, ESOPHAGUS**

**CARBOHYDRATE DIGESTION**

- **Polysaccharides** (starch, glycogen) → **Salivary amylase** → **Smaller polysaccharides**
- **Disaccharides** (sucrose, lactose) → **Maltose**

**STOMACH**

**CARBOHYDRATE DIGESTION**

- **Smaller polysaccharides** → **Maltose**
- **Disaccharides** (sucrose, lactose)

**PROTEIN DIGESTION**

- **Proteins** → **Pepsin** → **Small polypeptides**
Pancreatic juice containing bicarbonate (to neutralize stomach acid) and various digestive enzymes is released into the duodenum to complete the majority of chemical digestion.
SMALL INTESTINE (enzymes from pancreas)

**CARBOHYDRATE DIGESTION**
- Smaller polysaccharides
  - Disaccharides (sucrose, lactose, maltose)
  - Pancreatic amylases
  - Disaccharides

**PROTEIN DIGESTION**
- Small polypeptides
  - Pancreatic trypsins and chymotrypsins
  - Smaller polypeptides
  - Pancreatic carboxypeptidase
  - Small peptides
  - Amino acids

**NUCLEIC ACID DIGESTION**
- DNA, RNA
  - Pancreatic nucleases
  - Nucleotides

**FAT DIGESTION**
- Fat (triglycerides)
  - Pancreatic lipase
  - Glycerol, fatty acids, monoglycerides

**Chemical Digestion in the Small Intestine**
SMALL INTESTINE (enzymes from intestinal epithelium)

**CARBOHYDRATE DIGESTION**
- Disaccharides (sucrose, lactose, maltose)
  - Disaccharidases
  - Monosaccharides

**PROTEIN DIGESTION**
- Small peptides
  - Dipeptidases, carboxypeptidase, and aminopeptidase
  - Amino acids

**NUCLEIC ACID DIGESTION**
- Nucleotides
  - Nucleotidases
  - Nucleosidases and phosphatases
  - Nitrogenous bases, sugars, phosphates
The Role of Bile in Digestion

Bile is produced in the liver, stored in the gall bladder and released into the duodenum to aid in the digestion of fats (i.e., triglycerides to fatty acids).

- Fats (lipids) are hydrophobic and insoluble in water
- Bile emulsifies fats – disperses them into smaller droplets – to increase the collective droplet surface area to allow lipases to more efficiently encounter and digest fats
Absorption in the Small Intestine

Digestion is more or less completed in the **duodenum** and most absorption occurs along in the **jejunum** and **ileum**

- folds, villi & microvilli dramatically increase the surface area for absorption in the small intestine
The Absorption of Fats

- Epithelial cells lining the small intestine absorb fatty acids and monoglycerides through the apical surface which are reformed into triglycerides within the cell.

- Triglycerides are combined with other lipids and special proteins to form soluble aggregates called chylomicrons.

- Chylomicrons are transported across the basal surface into lymphatic lacteals in the center of each villus and carried to the liver via the lymphatic system.
Blood Transport from Small Intestine to Liver

- All non-lipid nutrients are transported across the intestinal epithelium to capillaries in each villus and to the liver via the hepatic portal vein.

- Blood-borne nutrients and toxins are processed in liver sinuses before the blood enters the vena cava to the rest of the body.
Processing in the Large Intestine

The large intestine consists of the **cecum, colon & rectum:**

- the cecum aids in the fermentation of plant material and is connected to the appendix which has a role in immunity
- the colon is full of beneficial bacteria that aid in digestion and nutrient production
- the colon reabsorbs water to minimize water loss and to compact feces which is stored in the rectum before elimination
Summary of Digestion & Absorption

- Mouth
- Esophagus
- Stomach
- Small intestine
- Large intestine
- Rectum
- Liver
- Veins to heart
- Hepatic portal vein
- Lymphatic system

- Secretions from salivary glands
- Secretions from gastric glands
- Secretions from liver
- Secretions from pancreas

- Absorbed food (except lipids)
- Absorbed water

Lipids
3. Digestive Adaptations
Dental Adaptations

- a big part of the success of mammals is the evolution of specialized teeth tailored to the diet of the animal
Gut Structure Correlates with Diet

The digestive tracts of animals are variations on an ancestral plan that evolved to be more complex and specialized for processing a variety of food sources.
Stomach & Intestinal Adaptations

- Carnivores tend to have large, expandable stomachs and relatively small large intestines.
- Herbivores tend to have longer large intestines and a large cecum to handle more difficult to digest plant material.
Mutualistic Adaptations of Herbivores

Many herbivores have complex digestive systems that depend on mutualistic microbes to help digest cellulose and other plant materials in compartments that serve as fermentation chambers.

- ruminants have the most advanced herbivorous digestive systems
The Role of Feedback Mechanisms

- The hormones gastrin, secretin & cholecystokinin (CCK) have important roles in regulating the release of digestive substances.
Secretion of insulin by beta cells of the pancreas

Transport of glucose into body cells and storage of glucose as glycogen

Blood glucose level rises (such as after eating).

NORMAL BLOOD GLUCOSE (70–110 mg glucose/100 mL)

Blood glucose level falls (such as after fasting).

Secretion of glucagon by alpha cells of the pancreas

Blood glucose level rises.

Breakdown of glycogen and release of glucose into blood

Blood glucose level falls.

• **insulin** & glucagon produced in the pancreas work together in reciprocal ways to maintain blood glucose homeostasis
Regulation of Appetite

- **ghrelin** produced in multiple digestive organs stimulates appetite when the stomach is empty
- **leptin** produced in adipocytes suppresses appetite and regulates levels of stored fat
- **insulin** from the pancreas & **peptide YY (PYY)** produced in the small & large intestines after meals also suppress appetite