An Introduction to Animal Structure and Function

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Functional Anatomy: An Overview

Animal form and function reflect biology's major themes

- **Natural selection** provides a mechanism for long-term adaptation, organism also have the capacity to adjust to environmental change over the short term by physiological responses:
- All animal activities require fuel in the form of chemical energy: **bioenergetics** – how organisms obtain, process and use their energy resources.
- The correlation of structure and function: **functional anatomy** = anatomy + physiology.

Function correlates with structure in the tissues of animals

- In multi-cellular organisms, cells with common structure and function group into **tissue**s, which may be held together by **extracellular matrix**.
- Combinations of various tissues make up functional units called **organ**s, and groups of organs work together form organ **system**.

- **Epithelial tissue**s, sheets of tight packed cells, cover the outside of the body, or line organs and cavities within the body.
  - Functions of epithelium:
    1. Protection: as barrier against mechanical injury, microorganism invasion and fluid loss: **tight junction**
       - The cells at the base of the barrier are attached to a **basement membrane**, a dense mat of extracellular matrix: filtering wastes in the kidney, or providing routes of migration for cells during development.

2. Absorb or secret chemical solutions: **glandular epithelia**
    - To lubricate or moist the lumen of the digestive and respiratory tracts: **mucous membrane**
    - To release digestive enzymes or absorb nutrients in intestine:
- Classification of epithelium:
  - **Simple, stratified,** or **pseudostratified**
  - **Cuboidal**, **columnar**, or **squamous**

- **Connective Tissue (CNT)**
  - Characteristics of Connective Tissues:
    - A sparse population of cells scattered through an extracellular matrix.
    - The matrix consists of a web of fibers secreted by the cells of the CNT.
  - Functions of Connective Tissues: binding and supporting other tissues
  - Classification of connective tissues
    1. **Collagenous fiber**s are made of **collagen**, the most abundant protein in the animal kingdom.
    2. **Elastic fiber**s made of **elastin** provide a rubbery quality.
    3. **Reticular fiber**s composed of collagen and continuous with collagenous fibers form a tightly woven fabric that joins CNT to adjacent tissues.
  - The major types of CNT in vertebrates are **loose connective tissue**, **adipose tissue**, **fibrous connective tissue**, **cartilage**, **bone**, and **blood**.
    1. **Loose connective tissue**:
       - The most widespread connective tissue in the vertebrate body.
       - Two major types of cells in loose CNT: **fibroblast**s and **macrophage**s.
    2. **Adipose tissue**:
       - Adipose tissue pads and insulates the body and stores fuel molecules.
       - The amount of fat we store when we are babies determines in part the number of fat cells in our connective tissues.

3. **Fibrous connective tissue**:
   - Large numbers of collagenous fibers: dense
   - In tendons and in ligaments:
4. **Cartilage**:
   - An abundance of collagenous fibers embedded in a rubbery matrix made of chondroitin sulfate are secreted by **chondrocytes**.
   - The skeletons of sharks and rays are made of cartilage. Other vertebrates have cartilaginous skeletons during the embryo stage, but most of the cartilage is replaced by bone as the embryo matures.
5. **Bone**: a mineralized connective tissue.
   - Bone-forming cells, **osteoblast**s, deposit a matrix of collagen, and also release calcium, magnesium, and phosphate ions, which combine and harden within the matrix into the mineral hydroxyapatite.
   - **Haversian system**s in mammalian bone have concentric layers of matrix, which are deposited around a central canal containing blood vessels and nerves. **Osteocyte**s, trapped osteoblasts, are located in **lacunae**, spaces surrounded by the hard matrix.
   - In long bones, only the outer region is hard compact bone built from Haversian systems. The interior is a spongy tissue honeycombed with spaces filled with **bone marrow**: Blood cells are manufactured in red bone marrow located near the ends of long bones.
6. **Blood**: The matrix is **plasma**, consisting of water, salts, and a variety of dissolved proteins.
   - **Erythrocyte**s, **leukocyte**s and **platelet**s.

- **Nervous tissue**
  - **Neuron (nerve cell)** including cell body, **dendrite** and **axon** is the functional unit of nervous tissue.

- Dendrites transmit **nerve impulse**s from their tips toward cell body. Axons transmit impulses toward another neuron or toward an effector.

- **Muscle Tissue**
  - **Muscle tissue** is composed of long cells, **muscle fiber**s that are capable of contracting when stimulated by nerve impulses.
    - Contractile proteins **actin** and **myosin** in the cytoplasm of muscle fibers.
  - In the vertebrate body, there are three types of muscle tissue:
    - **Skeletal muscle** (**striated muscle**) attached to bones by tendons is responsible for voluntary movements of the body.
      - Adults have a fixed number of muscle cells: weight lifting and other methods of building muscle do not increase the number of cells but simply enlarge those already present.
    - **Cardiac muscle** is striated, but branched: the cells are joined by **intercalated disc**s, which relay signals from cell to cell during a heartbeat.
    - **Smooth muscle**, lacks striations, is found in the walls of the digestive tract, bladder, arteries, and other internal organs.
      - Smooth muscles are responsible for involuntary body activities.
      - Smooth muscles contract more slowly than skeletal muscles but can remain contracted longer.

<u>The organ systems of an animal are interdependent</u>

- Many of the organs of vertebrates are suspended by **mesenteries**, sheets of connective tissue in body cavities.

- Each organ system consists of several organs and has specific functions, but the efforts of all systems must be coordinated for the animal to survive.

Body plans and the external environment

- The body plan or design of an animal (size, shape, and feature) results from a pattern of development programmed by the genome, itself the product of millions of years of evolution due to natural selection.

Physical laws constrain animal form

- Physical requirements constrain what natural selection can “invent”, including the size of single cells.
- Hydrodynamics: convergent evolution of tuna, shark, and dolphin.

Body size and shape affect interactions with the environment

- An animal's size and shape have a direct effect on how the animal exchanges energy and materials with its surroundings.
  - A large cell has less surface area relative to its volume than a smaller cell of the same shape: This is one reason nearly all cells are microscopic.
  - Most animals have extensively folded or branched internal surfaces specialized for exchange with the environment, and the circulatory system shuttles materials among all the exchange surfaces within the animal.

Regulating the internal environment

Mechanisms of homeostasis moderate changes in the internal environment

- **Interstitial fluid**, the internal environment of vertebrates, fills the space between cells, exchanges nutrients and wastes with blood in capillaries.
- **Homeostasis** means "steady state: Actually, the internal environment of an animal always fluctuates slightly, when the external environment changes. Homeostasis is a dynamic state.

Homeostasis depends on feedback circuits

- Any homeostatic control system has three functional components:
  - The **receptor** detects a change in some variable of the animal's internal environment. The **control center** processes information it receives from the receptor and directs an appropriate response by the **effector**.
- **Negative feedback**: Most homeostatic mechanisms in animals
  - For example, body temperature regulation: A thermostat in the brain monitors - production of sweat - heat produced by metabolism.
- **Positive feedback**:
  - For example, labor: the pressure of the baby's head - uterine contractions.
- **Regulated change** is essential to normal body functions:
  - For example, raising body temperature after infection:

Introduction to the bioenergetics of animals

Animals are heterotrophs that harvest chemical energy from the food they eat

- One of the defining features of life is the exchange of energy with the environment:
  - As **heterotroph**s, animals obtain chemical energy in food, which is digested by enzymatic hydrolysis. Energy-containing molecules absorbed by the cells can generate **ATP** by the **catabolic processes** of **cellular respiration** and **fermentation**.
  - An animal constantly exchanges energy with its environment as cellular work generates heat:
- Animals must manage their energy resources not only for homeostasis, but for everything else they do. Chemical energy remaining in cells can be used in biosynthesis to construct their own macromolecules.

Metabolic rate provides clues to an animal's bioenergetic "strategy"

- **Metabolic rate**: The total amount of energy an animal uses in a unit of time.
  - Energy is measured in **calories** (cal) or **kilocalories (kcal).**
  - Metabolic rate can be measured by monitoring an animal's heat loss per unit of time, or be determined by the amount of oxygen consumed by an animal's cellular respiration.
- The bodies of **endotherm** are warmed by heat generated by metabolism, and their body temperature must be maintained at a certain level to sustain life. **Ectotherms** absorb most of their body heat from the external environment.
  - The energy an endotherm requires to sustain minimal life functions is generally higher than that of an ectotherm.
  - Endothermy is a high-energy strategy that permits intense, long-duration activity over a wide range of environmental temperatures.

Metabolic rate per gram is inversely related to body size among similar animals

- Physiologists have determined that the amount of energy it takes to maintain each gram of body weight is inversely related to body size.
  - The higher metabolic rate of a smaller animal's body proportionately demands a greater rate of delivery of oxygen to the tissues. The smaller mammal also has a higher breathing rate, blood volume, and heart rate.
- One hypothesis for endotherms: The smaller the animal, the greater the energy cost of maintaining a stable body temperature
  - Surface area to volume ratio: The smaller an animal, the greater its surface area to volume ratio, and thus the greater the loss of heat to, or gain of heat from the surroundings.

Animal adjust their metabolic rates as conditions change

- **Basal metabolic rate** (**BMR**): The metabolic rate of an **endotherm** at rest, with an empty stomach, and experiencing no stress.
- **Standard metabolic rate** (**SMR**): The metabolic rate of a resting, tasting, nonstressed **ectotherm** at a specific temperature.
  - Metabolic rates are highest during intense physical exercise, with maximal rates about five to ten times greater than the BMR or SMR.
- Many factors can influence an animal's metabolic rate, including its age, sex, size, body temperature, the temperature of its surroundings, the quality and quantity of its food, its activity level, amount of available oxygen, hormonal balance, and the time of day.

Energy budgets reveal how animals use energy and materials

- For most animals, the majority of food is devoted to the production of ATP (for BMR or SMR, activity, and temperature control), and relatively little goes to growth or reproduction.