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Chapter 41 Animal Form & Function

I. Form, Function, and Adaptation

A. Animals differ in their anatomy (form) and physiology (function) and are adapted for the conditions in which they live.

B. Natural selection is the process that produces adaptations.

1. Natural selection occurs when individuals that carry certain alleles leave more offspring than do individuals with different alleles of the same gene.
    a. The frequency of selected alleles increases from one generation to the next, which results in evolution.
    b. Evolution also occurs through genetic drift, migration, and mutation.
2. Natural selection is the only process that, over time, increases the ability of the organism to survive and reproduce.

C. Trade-Offs

1. Trade-offs, an inescapable compromise between traits, may be the most important type of constraint on adaptation.
2. Trade-offs often involve expenditures of time or energy.
    a. Example: The amount of time and energy that mothers devote to egg production
    b. Hypotheses
        (1) If more eggs are produced, each egg will be smaller and have less nutrient-rich yolk.
        (2) Larger eggs develop into larger, stronger offspring.
        (3) Larger offspring survive better than smaller ones.
    c. Experiment (Sinervo et al.) in which egg size and number were manipulated surgically in side-blotched lizards.
        (1) Treatment 1: Yolks were removed from young eggs, which resulted in large clutches of small eggs.
        (2) Treatment 2: All but a few eggs were destroyed, which resulted in small clutches of large eggs.
        (3) Control females: Their eggs were left alone.
    d. Results and conclusions
        (1) As egg size increases, egg number decreases.
        (2) A female lizard cannot produce large clutches of large eggs.
        (3) A trade-off occurs between egg size and number.
    e. Do larger offspring survive better?
        (1) 1668 hatchling lizards were marked, released, and recaptured a month later.
        (2) Result: Larger offspring were recaptured more frequently.
        (3) Conclusion: Offspring size is correlated with offspring success.
3. Organisms cannot be perfectly adapted to all aspects of their environment.
    a. Desert animals that sweat to cool off are in danger of dehydration.
    b. Osprey's beak is highly adapted for tearing meat, not for building nests.
4. All adaptations are compromises, constrained by genetic and historical factors.
    a. Adaptations are *not* short-term, reversible responses to environmental fluctuations; those changes are called acclimatizations.
    b. Adaptations occur due to changes in allele frequencies.

II. Tissues, Organs, and Systems: How Does Structure Correlate with Function?

A. The function of an anatomical feature often correlates to its size, shape, or composition.

B. Levels of Organization in Animal Anatomy

1. Correlations between structure and function exist at the level of molecules and organelles.
    a. Protein shape correlates to whether the protein is an enzyme or performs a structural role.

b. Rough ER has ribosomes and a large membrane surface area, which correlates to its function in protein synthesis and processing.

2. Structure/function correlations also exist at the level of tissues, organs, and organ systems.

C. Tissues: Groups of Cells with the Same Structure and Function

1. Connective tissue consists of cells arranged in an extracellular matrix.
   a. Loose connective tissue functions in cushioning organs, and is composed of fibrous proteins in a soft matrix.
   b. Cartilage and bone
      (1) Function—supporting the body and binding tissues or organs together
      (2) Structure—fibrous proteins enclosed in a firm, hard matrix
   c. Blood
      (1) Function—transport of gases, nutrients, and wastes to and from all cells in the body
      (2) Structure—cells suspended in a liquid matrix
2. Nervous Tissue
   a. Function—deliver electrical signals to other cells
   b. Structure—long projections that contact other cells and deliver signals by means of electrical impulses and chemical secretions
3. Muscle
   a. Function—movement
   b. Structure—long muscle-fiber cells move when they hydrolyze ATP
4. Epithelial tissue covers the outside of the body, lines the surfaces of organs, and forms glands.
   a. Function—barrier and protective layer
   b. Structure—layers of tightly-packed cells that have many membrane proteins to regulate the exchange of molecules
      (1) Epithelial tissue has polarity.
         (*a*) The apical side faces away from other tissues, or faces the environment.
         (*b*) The basolateral surface faces the interior of the animal and is connected to other tissues.
      (2) Examples of this polarity as they relate to function
         (*a*) Small intestine: Epithelial cells line the interior (the lumen) of the small intestine, have folded apical membranes that contain proteins specialized to uptake digested nutrients.
         (*b*) Trachea: The apical side of these epithelial cells secretes mucus and is covered with cilia to sweep away dust and pathogens.
         (*c*) The apical surfaces of glandular epithelial cells secrete substances onto the apical surfaces of organ epithelia.
      (3) Epithelial cells have short life spans because they are exposed to the environment and damaged; new epithelial cells are constantly manufactured via mitosis to replace the dying cells.

D. Organs and Systems

1. Organs are structures with a specialized function; they consist of several tissues. Example: Small intestine
2. Systems are groups of tissues and organs that work together. Example: Digestive system
3. Organ structure correlates to function, and system components work together in an integrated fashion.
   a. Esophagus transports food from mouth to stomach—long muscular tube.
   b. Liver and pancreas are secretory, and their cells contain abundant endoplasmic reticulum.
   c. The digestive system is one long tube divided into sections with different functions.
4. Each component in the body is integrated with other parts, and each level of organization is integrated with other levels; therefore, the organism as a whole is greater than the sum of its parts.

III. How Does Body Size Affect Animal Physiology?

A. The body size of an animal affects many aspects of its functions and behavior.
   1. Larger bodies require more food, produce more waste, reproduce more slowly, take longer to mature, and live longer.
   2. Smaller bodies lose heat and water faster, and so are more susceptible to cold and dehydration.

B. Surface Area/Volume Relationships
   1. How do changes in surface area and volume affect cell form and function?
      a. The rate at which molecules and ions diffuse in and out of a cell depends on the cell's surface area.
      b. The rate at which nutrients are used and waste products produced depends on the volume of the cell.
      c. As a cell gets larger, its volume increases much faster than its surface area.
         (1) Surface area increases as a function of the square of the cell's linear dimension.
         (2) Volume increases as a function of the cube of the cell's linear dimension.
   2. Comparing mice and elephants
      a. Metabolic rate, the overall rate of energy consumption by an individual, is most often measured based on oxygen consumption.
      b. To compare metabolic rate in different species, metabolic rate is divided by overall mass.
         (1) Metabolic rate divided by mass is reported in units of mL O_2/gram/hour.
         (2) Because metabolic rate depends on activity level, basal metabolic rate (BMR—at rest with an empty stomach, in the absence of temperature or water stress) is measured.
      c. Do larger or smaller organisms have higher metabolic rates?
         (1) Elephants are 200,000 times larger than mice, but their BMR is 1/12 that of the mouse.
         (2) Hypothesis: As the size of an organism increases, its BMR must decrease.
            (*a*) Metabolism depends on the exchange of materials across surfaces.
            (*b*) As size increases, volume increases much faster than surface area.
            (*c*) The available surface area will fail to keep up with metabolic rate, unless BMR slows.
      d. Surface area-to-volume issues influence the development of an organism during its lifetime.
         (1) Hatchlings weigh a few milligrams, but adults grow to 50 kg or more; a total size increase of one millionfold.
         (2) Salmon exchange gases across their gills, skin, and yolk sacs.
         (3) Do young salmon breathe through their gills or skin?
            (*a*) Fish were inserted into a device that placed their head in a different compartment from their body.
            (*b*) One oxygen electrode measured oxygen uptake by their gills, and another measured oxygen uptake by their skin.
            (*c*) Newly hatched larvae take up O_2 mostly through their skin; but during growth, skin surface area decreases in relation to volume, so fish develop gills as the primary respiratory structure for life.
   3. Adaptations that increase the surface area
      a. Gills consist of sheetlike structures called lamellae whose cells are flattened.
         (1) Gills have a huge amount of surface area relative to their volume.
         (2) Diffusion of gases from water to blood occurs rapidly enough to keep up with growth.
      b. The lining of the small intestine has extensive folded surfaces called villi.
      c. The circulatory system is highly branched, with capillaries as the smallest elements.

C. Do all aspects of an animal's body increase in size proportionately?
   1. Allometry occurs when changes in body size are accompanied by disproportionate changes in anatomical structures or physiological processes.
      a. Example: The skeletal mass increases much faster than overall body mass.
      b. Galileo was the first to describe allometry; he observed that bones of large animals are disproportionately thicker than those of smaller animals.
      c. Isometric quantities are those that change at the same rate.

2. Allometry as a response to surface area/volume relationships
    a. Area and volume analysis explains why the relationship between mammalian skeletal size and body mass is allometric.
        (1) Volume is the body mass that the skeleton must support.
        (2) Area is the cross-sectional area of the bones that support the mass.
            (*a*) Strength and weight of bones is a function of their cross-sectional area.
            (*b*) As mass increases, the amount of bone required for support has to increase disproportionately.
    b. Example: Elephants can't jump, because landing from a height of a few meters would likely cause multiple leg fractures.
3. Allometry as adaptation
    a. Structures that display allometry may be interpreted as adaptations to a lifestyle or environment.
    b. Example: Dogs have larger hearts than do cats of the same size.
        (1) Cats stalk prey and capture it with a short sprint.
        (2) Dogs run prey down during long-distance chases.
        (3) Hypothesis: The larger hearts of dogs are an adaptation that increases blood flow to muscles, making sustained chases possible.

IV. Homeostasis

A. Animal physiology can be analyzed in the context of homeostasis.
1. Homeostasis is the maintenance of relatively constant chemical and physical conditions for some quantity such as temperature, pH, or nutrient levels.
    a. Conformational homeostasis occurs in animals that must conform to their surroundings.
    b. Regulatory homeostasis requires a physiological mechanism that adjusts the internal state to keep it near a specific value.
2. Many of the structures and processes in animals can be interpreted as mechanisms for achieving homeostasis.
3. The role of the epithelium in maintaining homeostasis
    a. Epithelium exists at the interface between the internal and external environment; membrane proteins on the surfaces of epithelial cells regulate the transport of ions, water, nutrients, and wastes.
    b. Epithelium plays a critical role in achieving homeostasis by controlling the exchange of materials across surfaces.
4. Why is achieving homeostasis important?
    a. Enzymes, which are critical to all processes in living cells, function normally only in a narrow range of physical and chemical conditions.
    b. Changes in pH and the chemical environment can dramatically alter enzyme structure and function.
    c. Temperature can dramatically alter enzyme structure and function.
        (1) Changes in temperature affect membrane permeability and rates of diffusion.
        (2) Freezing of water in cells causes tissue damage as water expands upon conversion to ice.

B. Regulation and Feedback
1. Regulatory systems monitor internal conditions and return them to set points.
    a. Set points are normal, or target values for a controlled variable.
2. Each homeostatic system has three main components:
    a. Sensor—a structure that senses some aspect of the external or internal environment.
    b. Integrator—a component of the nervous system that
        (1) Evaluates incoming sensory information.
        (2) "Decides" if a response is required to achieve homeostasis.
    c. Effector—any structure that helps restore the desired internal condition.
3. Homeostatic systems are based on negative feedbacks.
    a. Negative feedback occurs when effectors reduce or oppose a change in internal conditions.
    b. Example: A rise in blood pH triggers effectors that reduce that rise in pH to normalize it.

V. How Do Animals Regulate Body Temperature?

A. Thermoregulation: Achieving Homeostasis of Body Temperature
1. Receptors all over the body constantly monitor mammalian body temperature.
   a. Sensory receptors in the anterior hypothalamus monitor blood temperature.
2. Temperature information gathered by these receptors is transmitted to an integrator in the brain.
3. If temperature falls too low, cells in the posterior hypothalamus initiate signals that induce shivering or fluffing of fur and feathers.
4. If temperature gets too high, cells in the anterior hypothalamus initiate signals that induce shade-seeking behavior and evaporative cooling through sweating or panting.

B. Gaining and Losing Heat
1. Animals fall into two general categories based on how they gain heat.
   a. Endotherms produce heat in their own tissues.
   b. Ectotherms rely on heat gained from the environment.
   c. Homeotherms keep their body temperature constant.
   d. Heterotherms allow their body temperature to rise or fall depending on environmental conditions.
   e. An animal's source of heat and the degree to which its body temperature varies can be graphed.
      (1) Humans and birds are endothermic homeotherms that produce their own heat and maintain it at a specific temperature.
      (2) Mosquito larvae are ectothermic heterotherms whose body temperatures vary greatly.
      (3) Small mammals in cold climates lose heat; therefore they lower their metabolic rate and their body temperatures drop—a condition called torpor, or if sustained, called hibernation.
      (4) Naked mole rats live in underground tunnels and allow their body temperatures to rise and fall to match the burrow temperatures.
      (5) Bumblebees shiver on cold mornings to raise their body temperature.
2. Sources of body heat
   a. Muscle activity, including shivering, produces heat in many ectotherms and most endotherms.
   b. Normal cell metabolism also produces heat; endotherms have greater mitochondrial density in their cells.
   c. Specialized heat-generating tissues occur in some animals.
      (1) Adipose tissue is a connective tissue made up of fat-storing cells.
      (2) Many mammals have brown adipose tissue that has a high density of mitochondria and stored fats.
         (*a*) Oxidation of fats in these tissues produces no ATP; heat is released instead.
         (*b*) Brown adipose tissue produces 10 times more heat than other tissues.
      (3) Small animals and infants of large species commonly have brown adipose tissue.
         (*a*) Human infants have brown adipose tissue in the neck and chest.
         (*b*) Small size means larger surface-to-volume ratio and more rapid loss of heat.
         (*c*) Hypothesis: Brown adipose tissue is an adaptation for small endotherms to achieve homeostasis with respect to temperature.
3. Exchanging heat with the environment
   a. All animals constantly exchange heat with their environment.
      (1) Heat flows from regions of higher temperature to regions of lower temperature.
      (2) An individual gains heat from a warmer environment and loses heat to a cooler environment.
   b. Animals exchange heat with the environment in one of four ways:
      (1) Conduction—the direct transfer of heat between two physical bodies in contact with each other
      (2) Convection—the transfer of heat due to air or water moving over the body surface
         (*a*) Convection effectively increases the rate of heat exchange by conduction.
         (*b*) Air or water in direct contact with the body surface is constantly replaced.
         (*c*) The rate of heat transfer increases with increasing speed of air or water flow.
         (*d*) Convection maintains a large temperature gradient for conduction.
      (3) Radiation—the transfer of heat between two bodies that are not in direct contact

(*a*) The major source of radiant heat is the Sun.
(*b*) All objects radiate heat as a function of their temperature.
(4) Evaporation—heat loss through the phase change when liquid water becomes a gas
(*a*) Only heat loss occurs by evaporation, not heat gain.
(*b*) A lot of energy is required to heat water to the point of evaporation, due to hydrogen bonding in liquid water.
(*c*) Water is an efficient coolant on a hot day, but getting wet can be deadly on a cold day.

4. Conserving heat
   a. Air is a poor conductor of heat, which makes it a good insulator.
      (1) Endothermic animals trap air under feathers and under fur.
      (2) Feathers and fur reduce heat loss by conduction.
   b. Aquatic environments
      (1) Little heat loss occurs by evaporation.
      (2) Little radiation occurs because water transmits radiation poorly.
      (3) Water is an extremely effective conductor.
         (*a*) Metabolic heat is rapidly lost, especially through surfaces like gills, which have a high surface-to-volume ratio.
         (*b*) Most aquatic invertebrates and fish have a body temperature that matches that of the water they inhabit.
   c. Endotherms in aquatic habitats
      (1) Otters retain heat with dense, water-repellent fur that retains air next to the skin.
      (*2*) Seals and whales are insulated by fatty blubber.
      (3) Countercurrent heat exchanger—minimizes heat loss through tongues of some aquatic mammals.
         (*a*) Arteries and veins in gray whale tongues are arranged antiparallel to one another.
         (*b*) Heat from arteries transfers directly into veins returning to the body center.
         (*c*) Loss of heat, which would occur when arterial blood arrives at body extremities, is reduced.
         (*d*) Countercurrent heat exchangers are also found in flippers of whales and dolphins, and legs of the arctic fox.

C. Ectothermy versus Endothermy
1. Homeostatic systems are interpreted as adaptations that arose by natural selection.
   a. Structure relates to function in temperature homeostasis.
      (1) Brown adipose tissue has abundant mitochondria for generating heat.
      (2) Arrangement of arteries and veins facilitates countercurrent heat exchange.
   b. Surface area/volume relationships are critical.
      (1) Heat is gained and lost across surfaces.
      (2) Small objects lose heat faster than larger ones.
         (*a*) Small endotherms must expend a lot of energy to stay warm.
         (*b*) Energy requirements limit the size of endotherms to none smaller than a shrew.
      (3) Ectotherms of millimeter or centimeter size are common.
2. Endothermy and ectothermy are examples of trade-offs in adaptation.
   a. Advantages of endothermy
      (1) Enzymes are maintained at constant temperature at all times.
      (2) Mammals and birds can remain active in winter and at night.
      (3) Their high metabolic rate enables them to sustain high levels of aerobic activity, such as running or flying.
   b. Disadvantages of endothermy
      (1) Large quantities of energy-rich food must be consumed.
      (2) Energy used to produce heat is unavailable for growth, reproduction, and other processes.
   c. Advantages of ectothermy
      (1) Can survive on much less food

(2) Can use a greater proportion of energy to support reproduction

d. Disadvantages of ectothermy
   (1) Temperature-dependent chemical reactions slow down as body temperature drops.
   (2) Muscular activity is slowed, making them more vulnerable to predation in the cold.
   (3) They are less successful at inhabiting cold environments.