Animal form and function

IF3211 Domain Specific Computation

School of Electrical Engineering and Informatics ITB

Content

- The Internal Environment of Animals
- Animal Nutrition
- Circulation and Gas Exchange
- The Immune System

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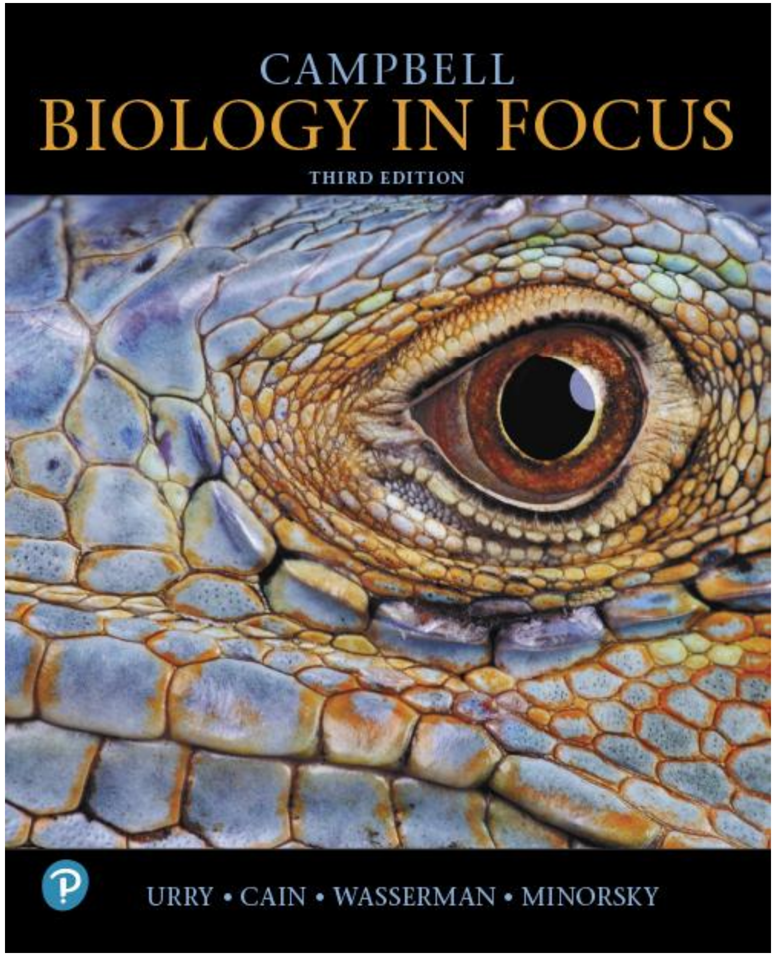


Chapter 32

The Internal Environment of Animals: Organization and Regulation

Lecture Presentations by

Kathleen Fitzpatrick and Nicole Tunbridge,

Simon Fraser University

Overview: Diverse Forms, Common Challenges

- **Anatomy** is the study of the biological form of an organism
- **Physiology** is the study of the biological functions an organism performs
- Form and function are closely correlated

Concept 32.1: Animal Form and Function Are Correlated at All Levels of Organization

- Cells form a working animal body through emergent properties that arise from levels of structural and functional organization
- Cells are organized into
    - **Tissues**, groups of cells with similar appearance and common function
    - **Organs**, different types of tissues further organized into functional units
    - **Organ systems**, groups of organs that work together

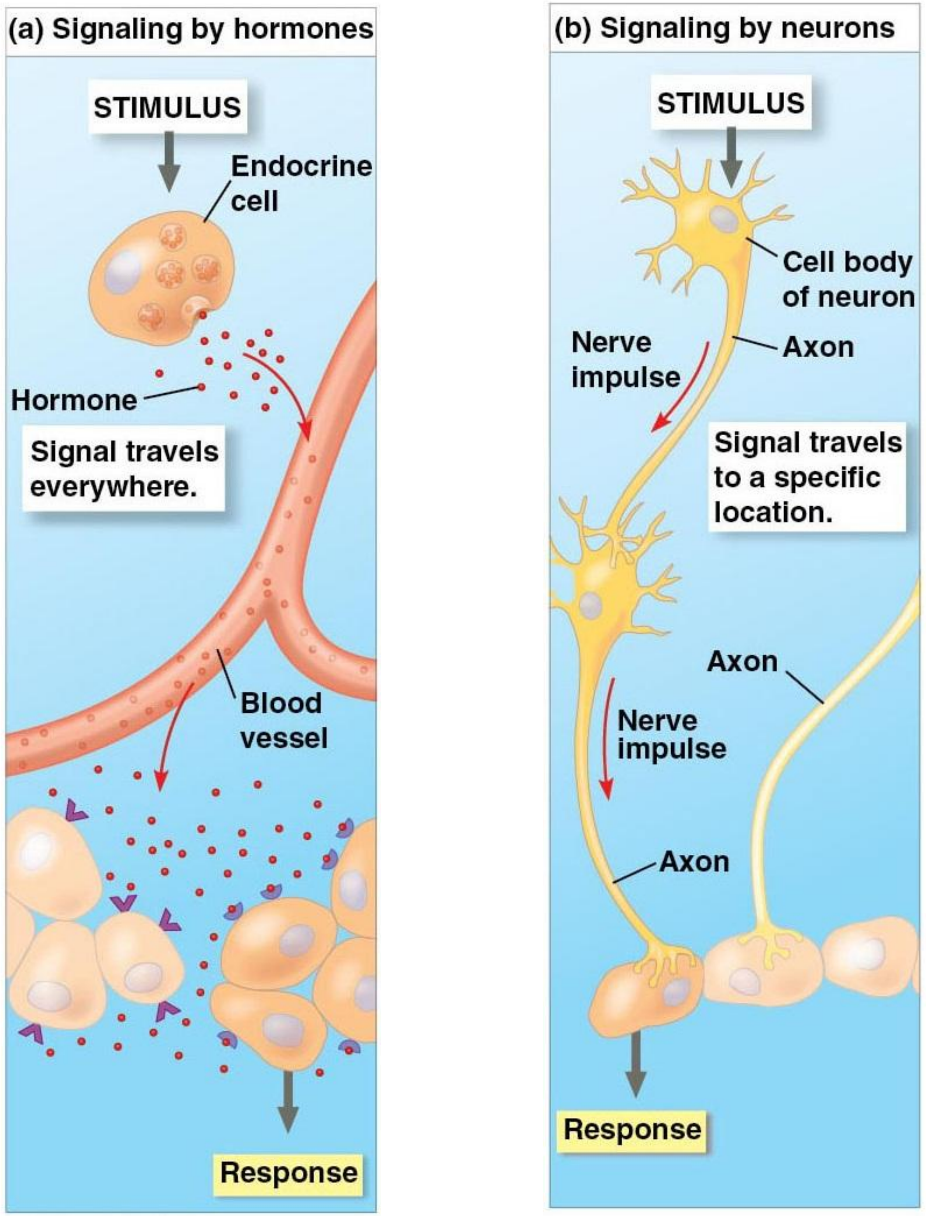
Concept 32.1: Animal Form and Function Are Correlated at All Levels of Organization

- The specialized, complex organ systems of animals are built from a limited set of cell and tissue types
- Animal tissues can be grouped into four categories
  - Epithelial
  - Connective
  - Muscle
  - Nervous

An Overview of Coordination and Control (1 of 3)

- Animals have two major systems for coordinating and controlling responses to stimuli
- In the **endocrine system**, signaling molecules released into the bloodstream by endocrine cells reach all locations in the body
- In the **nervous system**, neurons transmit signals along dedicated routes, connecting specific locations in the body

Signaling in the Endocrine and Nervous Systems

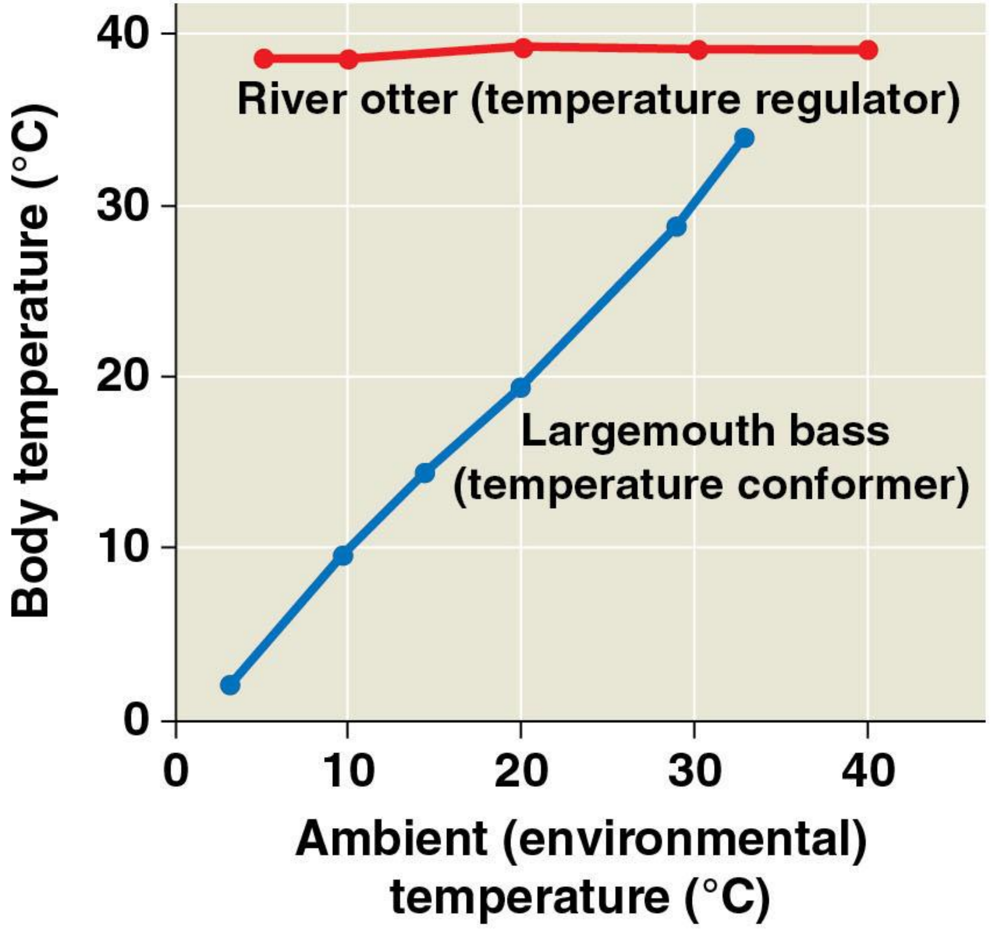


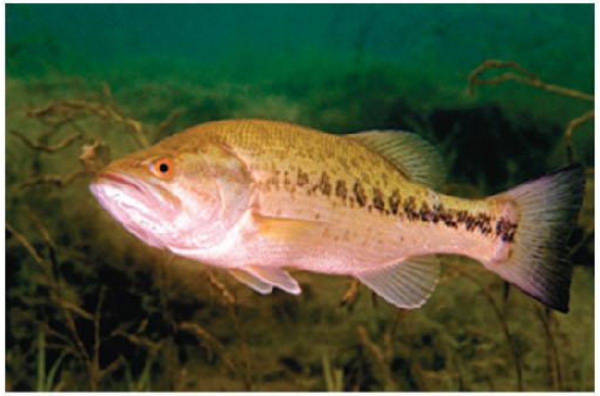
Regulating and Conforming

- An animal that is a **regulator** for an environmental variable uses internal mechanisms to control internal change despite external fluctuation in that variable
- An animal that is a **conformer** for an environmental variable allows its internal condition to change in accordance with external changes in that variable

Figure 32.10

Regulating and Conforming





Homeostasis

- **Homeostasis** is the maintenance of a “steady state” or internal balance by an organism regardless of external environment
- In humans, body temperature, blood p H, and glucose concentration are each maintained at a constant level
- Regulation of room temperature by a thermostat is analogous to homeostasis
- Animals achieve homeostasis by maintaining a variable at or near a particular value, or **set point**
- Fluctuations above or below the set point serve as a **stimulus** that is detected by a **sensor** and triggers a **response**
- The response returns the variable to the set point

Endothermy and Ectothermy

- **Endothermic** animals generate heat by metabolism; birds and mammals are endotherms
- **Ectothermic** animals gain heat from external sources; ectotherms include most invertebrates, fishes, amphibians, and nonavian reptiles

Figure 32.12

Endothermy and Ectothermy

(a) King penguins (*Aptenodytes patagonicus*), endotherms

(b) Florida red-bellied turtles (*Pseudomys nelsoni*), ectotherms

Balancing Heat Loss and Gain

- Organisms exchange heat by four physical processes
  - Radiation
  - Evaporation
  - Convection
  - Conduction
- Heat is always transferred from an object of higher temperature to one of lower temperature

Osmoregulatory Challenges and Mechanisms

- Organisms that are **osmoconformers**, consisting of some marine animals, are isoosmotic with their surroundings and do not regulate their osmolarity
- Organisms that are **osmoregulators** expend energy to control water uptake and loss in a hyperosmotic or hypoosmotic environment

Nitrogenous Wastes

- The type and quantity of an animal's waste products may have a large impact on osmoregulation
- Among the most significant wastes are nitrogenous breakdown products of proteins and nucleic acids
- Some animals convert toxic **ammonia** (NH_3) to less toxic compounds prior to excretion

Excretory Processes

- Many animal species produce a fluid waste by refining a **filtrate** derived from body fluids
- Key functions of most excretory systems
  - **Filtration**: Filtering of body fluids
  - **Reabsorption**: Reclaiming valuable solutes
  - **Secretion**: Adding nonessential solutes and wastes from the body fluids to the filtrate
  - Excretion: Releasing processed filtrate containing nitrogenous wastes from the body

Invertebrates

- Flatworms have excretory systems called protonephridia, networks of tubules connected to external openings
- The smallest branches of the network are capped by a cellular unit called a flame bulb
- The dilute urine produced is emptied into the external environment

Vertebrates

- In vertebrates and some other chordates, the **kidney** functions in both osmoregulation and excretion
- The kidney consists of tubules arranged in an organized array and closely associated with a network of capillaries
- The excretory system includes ducts and other structures that carry urine from the tubules out of the body

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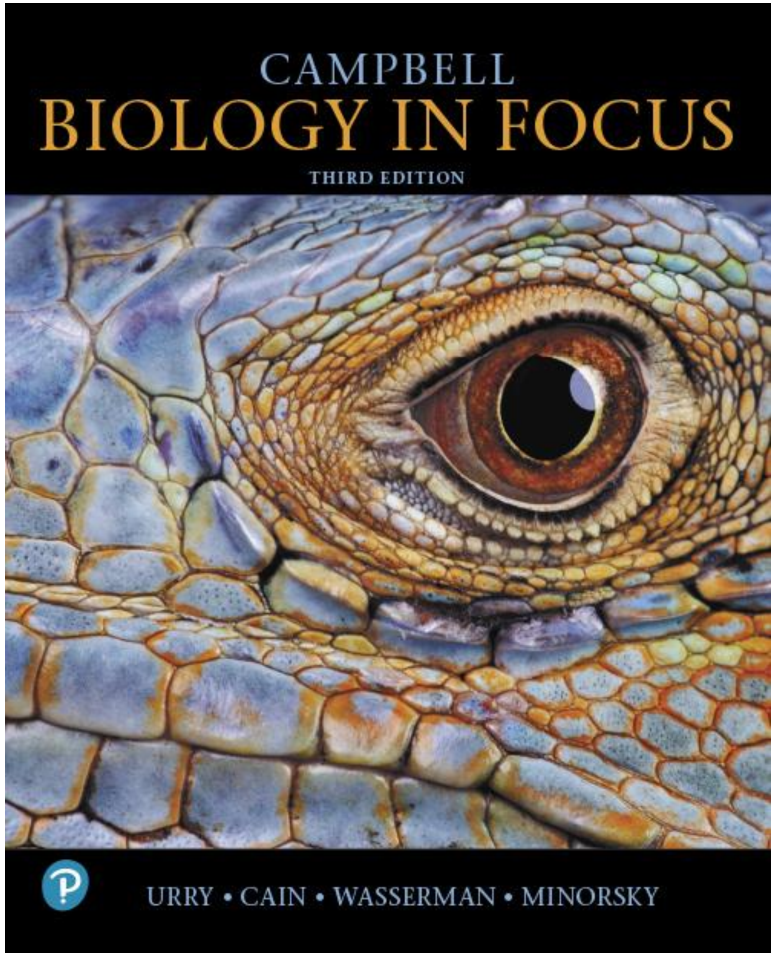

Chapter 33

Animal Nutrition

Lecture Presentations by
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Pearson

Overview: The Need to Feed

- Food is taken in, taken apart, and taken up in the process of animal **nutrition**
- In general, animals fall into three categories
  - **Herbivores** eat mainly plants and algae
  - **Carnivores** eat other animals
  - **Omnivores** regularly consume animals as well as plants or algae
- Most animals are also opportunistic feeders

Concept 33.1: An Animal's Diet Must Supply Chemical Energy, Organic Building Blocks, and Essential Nutrients

- An animal's diet provides
  - Chemical energy, which is converted into ATP that powers cellular processes
  - Organic building blocks, such as organic carbon and organic nitrogen, which synthesize a variety of organic molecules
  - **Essential nutrients**, which are required by cells and must be obtained from dietary sources

Essential Nutrients

- Essential nutrients must be obtained from an animal's diet
- There are four classes of essential nutrients
  - Essential amino acids
  - Essential fatty acids
  - Vitamins
  - Minerals

Essential Amino Acids and Fatty Acids

- In animals, fatty acids are converted into a variety of cellular components, such as membrane phospholipids, signaling molecules, and storage fats
- **Essential fatty acids** cannot be synthesized by animals but can be synthesized by plants
- Animals typically obtain ample quantities of essential fatty acids from their diets

Vitamins

- **Vitamins** are organic molecules required in the diet in small amounts
- Thirteen vitamins are essential for humans
- Vitamins are grouped into two categories: fat-soluble and water-soluble

Minerals

- **Minerals** are simple inorganic nutrients, usually required in small amounts
- Ingesting large amounts of some minerals can impair health

Deficiencies in Essential Nutrients

- Deficiencies in essential nutrients can cause deformities, disease, and death
- Animals may consume salt or other minerals to obtain missing nutrients

Undernourishment

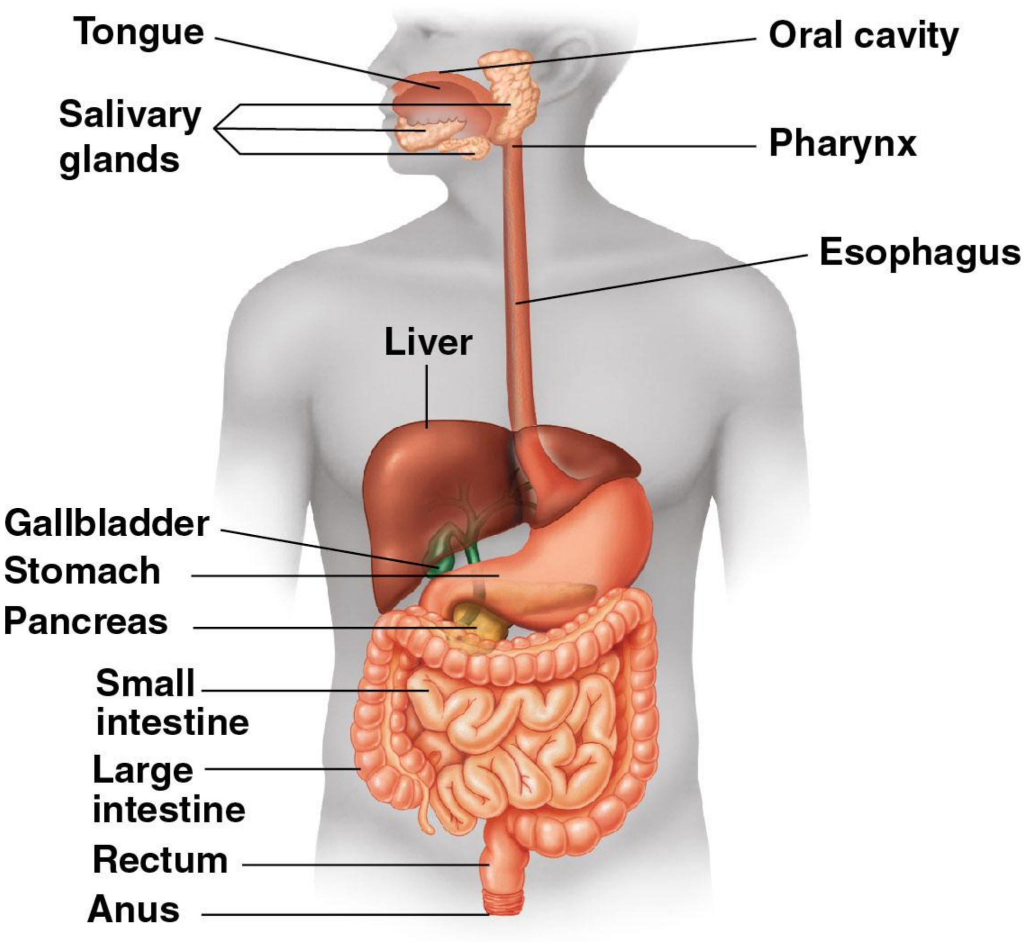
- Malnutrition can arise when a diet does not provide enough chemical energy
- An undernourished individual will
    - Use up stored fat and carbohydrates
    - Break down its own proteins
    - Lose muscle mass
    - Suffer protein deficiency of the brain
    - Die or suffer irreversible damage

Concept 33.2: Food Processing Involves Ingestion, Digestion, Absorption, and Elimination

- Food processing can be divided into four distinct stages:
  - Ingestion
  - Digestion
  - Absorption
  - Elimination

Figure 33.7

The Human Digestive System

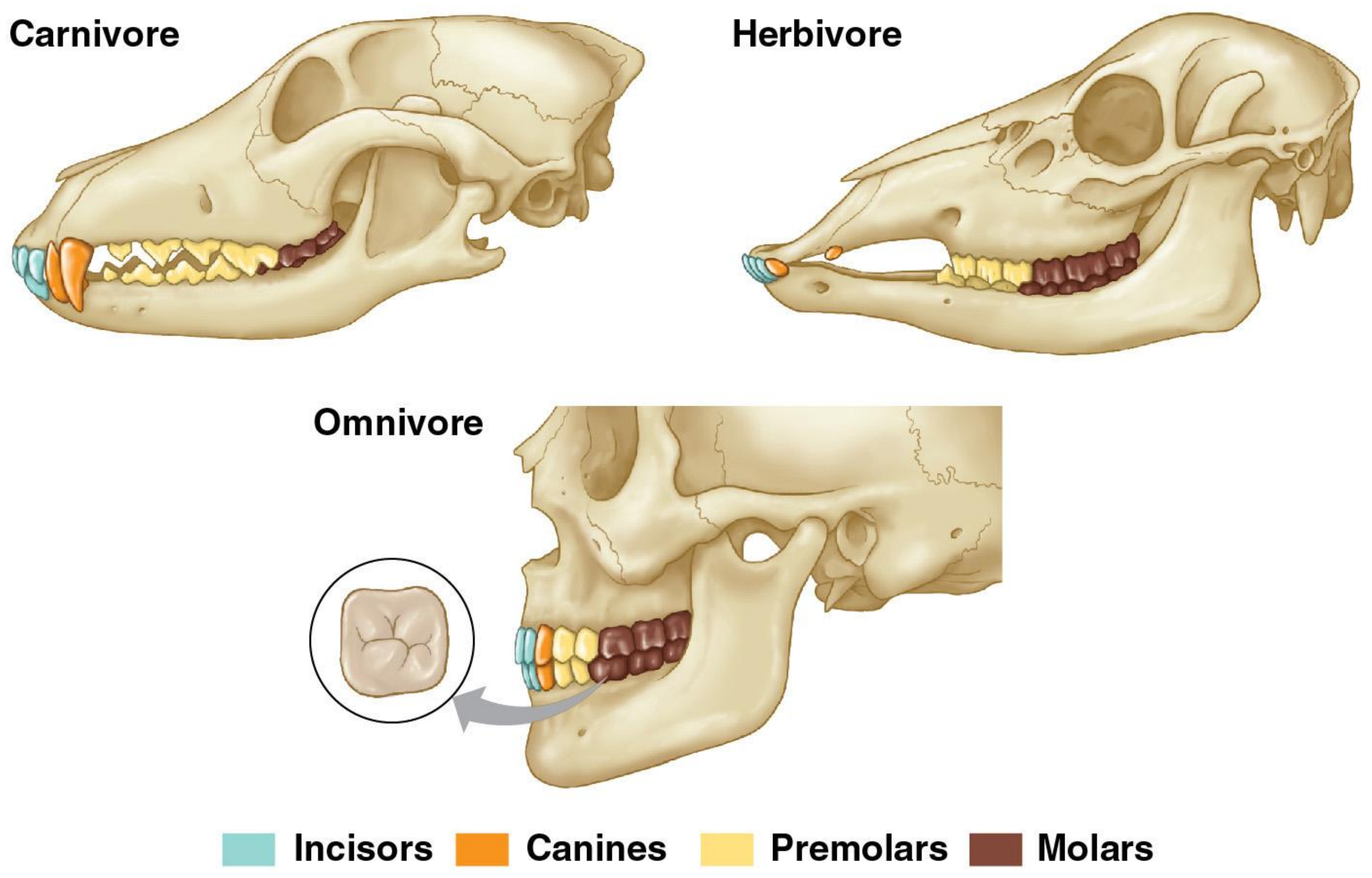


Dental Adaptations

- Dentition, an animal's assortment of teeth, is one example of structural variation reflecting diet
- The success of mammals is due in part to their dentition, which is specialized for different diets
- Nonmammalian vertebrates have less specialized teeth, though exceptions exist
    - For example, the teeth of poisonous snakes are modified as fangs that can inject venom

Figure 33.12

Dentition and Diet



Stomach and Intestinal Adaptations

- Many carnivores have large, expandable stomachs
- Adaptation is apparent in the length of the digestive system in different vertebrates
- Herbivores and omnivores generally have longer alimentary canals than carnivores, reflecting the longer time needed to digest vegetation

Mutualistic Adaptations in Herbivores

- Many vertebrates host mutualistic bacteria and protists in fermentation chambers of their alimentary canals
- These microorganisms can digest cellulose to simple sugars and other compounds
- The most elaborate adaptations for herbivorous diets have evolved in **ruminants**, the cud-chewing animals that include deer, sheep, and cattle

Regulation of Digestion

- Each step in the digestive system is activated as needed
- The enteric division of the nervous system helps to regulate the digestive process
- The endocrine system also regulates digestion through the release and transport of hormones

Energy Allocation

- The flow and transformation of energy in an animal—its **bioenergetics**—determine nutritional needs
- An animal's energy use per unit of time is called its **metabolic rate**
- Metabolic rate can be determined by monitoring an animal's rate of heat loss, the amount O_2 consumed of the amount of CO_2 produced ,

Regulation of Energy Storage

- When an animal takes in more energy than is needed for metabolism and activity, excess energy is stored
- In humans, the liver and muscle cells are used first; energy is stored as glycogen
- When glycogen depots are full, additional excess energy is stored as fat in adipose cells
- When fewer calories are taken in than expended, the body expends liver glycogen, muscle glycogen, and then fat

Glucose Homeostasis

- **Insulin** and **glucagon** together maintain glucose levels
- Insulin levels rise after a carbohydrate-rich meal, and glucose entering the liver through the hepatic portal vein is used to synthesize glycogen
- When glucose concentration is low in the hepatic portal vein, glucagon stimulates the liver to break down glycogen and release glucose into the blood
- Insulin and glucagon are produced in the pancreas in beta cells and alpha cells, respectively

Diabetes Mellitus

- **Diabetes mellitus** is a disease caused by a deficiency of insulin or a decreased response to insulin in target tissues
- Cells are unable to take up glucose to meet their metabolic needs
- Fat becomes the main substrate for cellular respiration

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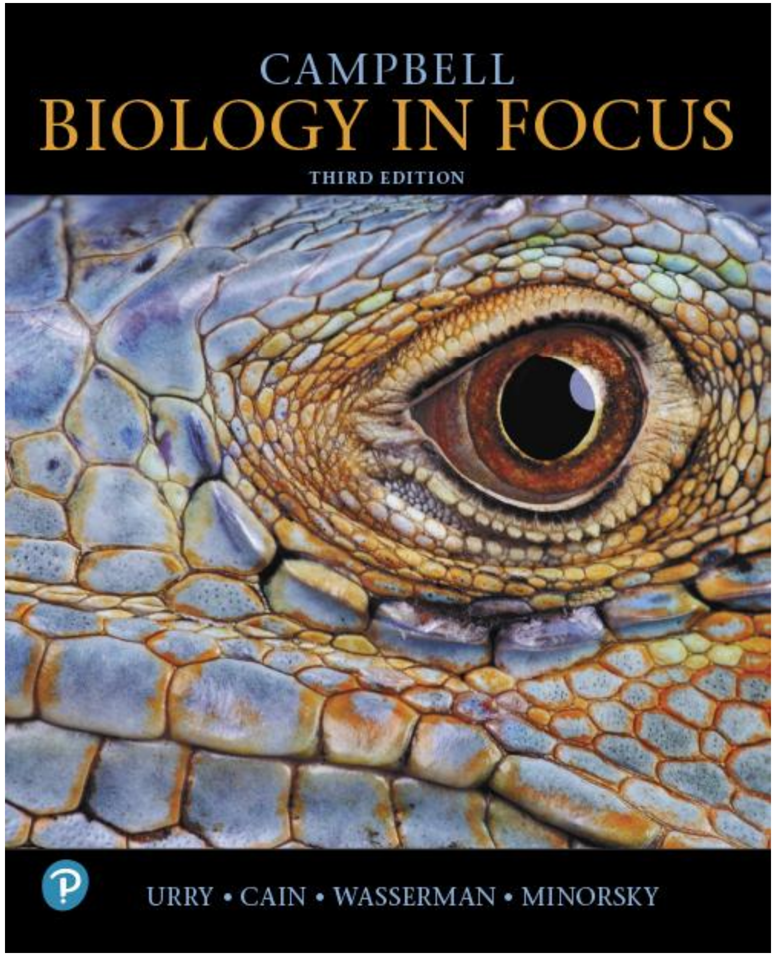

Chapter 34

Circulation and Gas Exchange

Lecture Presentations by
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Concept 34.1: Circulatory Systems Link Exchange Surfaces with Cells Throughout the Body

- Small molecules such as O_2 and CO_2 move between cells and their immediate surroundings by **diffusion**
- Diffusion time is proportional to the square of the distance travelled
- Diffusion is only efficient over small distances

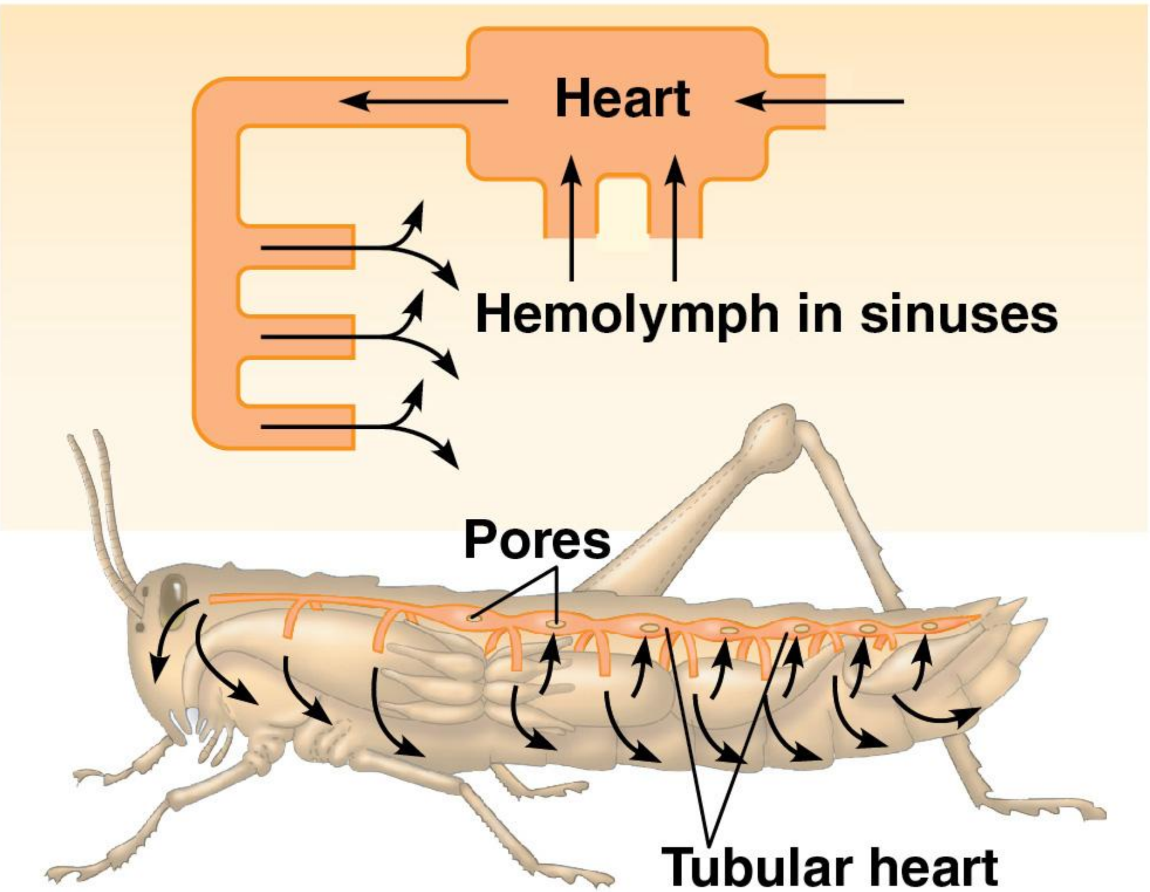
Open and Closed Circulatory Systems

- Circulatory systems are either open or closed
- In arthropods and some molluscs, circulatory fluid bathes the organs directly in an **open circulatory system**
- The circulatory fluid, called **hemolymph**, is also the interstitial fluid that bathes body cells

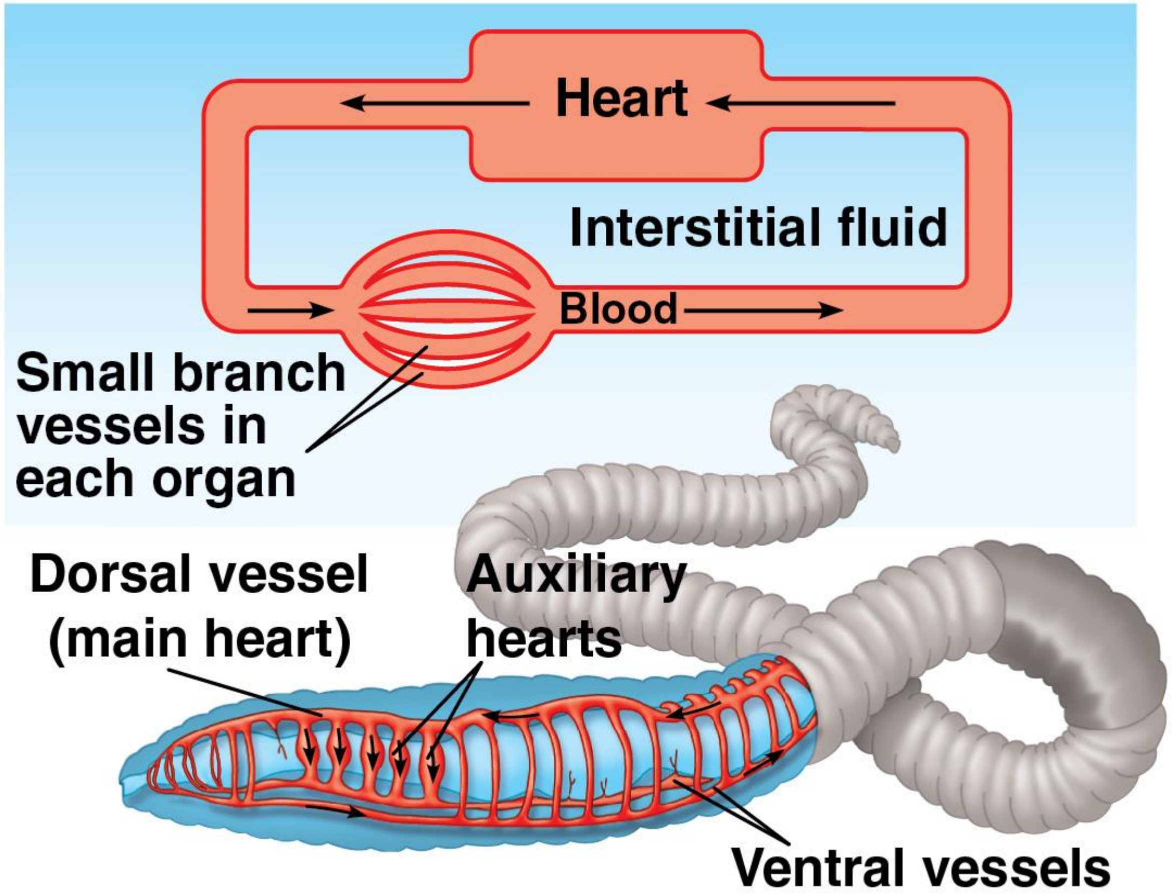
- In **closed circulatory systems** the circulatory fluid called **blood** is confined to vessels and is distinct from interstitial fluid
- Chemical exchange occurs between blood and interstitial fluid and between interstitial fluid and body cells

Open and Closed Circulatory Systems

(a) An open circulatory system



(b) A closed circulatory system



Organization of Vertebrate Circulatory Systems

- Vertebrates have a closed circulatory system called the **cardiovascular system**
- The three main types of blood vessels are arteries, veins, and capillaries
- Blood flow is one-way in these vessels

Single Circulation

- Sharks, rays, and bony fishes have single circulation with a two-chambered heart
- In **single circulation**, blood leaving the heart passes through two capillary beds before returning
- As the animal swims, contraction and relaxation of muscles help accelerate the pace of circulation

Double Circulation

- Amphibians, reptiles, and mammals have **double circulation**
- Having both pumps within a heart simplifies coordination of the pumping cycle
- Oxygen-poor and oxygen-rich blood is pumped separately from the right and left sides of the heart
- Gas exchange takes place in the lungs in reptiles and mammals (pulmonary circuit) and both the lungs and skin in amphibians (pulmocutaneous circuit)

Mammalian Circulation

- Blood begins its flow with the right ventricle pumping blood to the lungs via the pulmonary arteries
- The blood loads O_2 and unloads CO_2 in the capillary beds of the lungs
- Oxygen-rich blood from the lungs enters the heart at the left atrium via the pulmonary veins and is pumped through the aorta to the body tissues by the left ventricle

The Mammalian Heart: A Closer Look

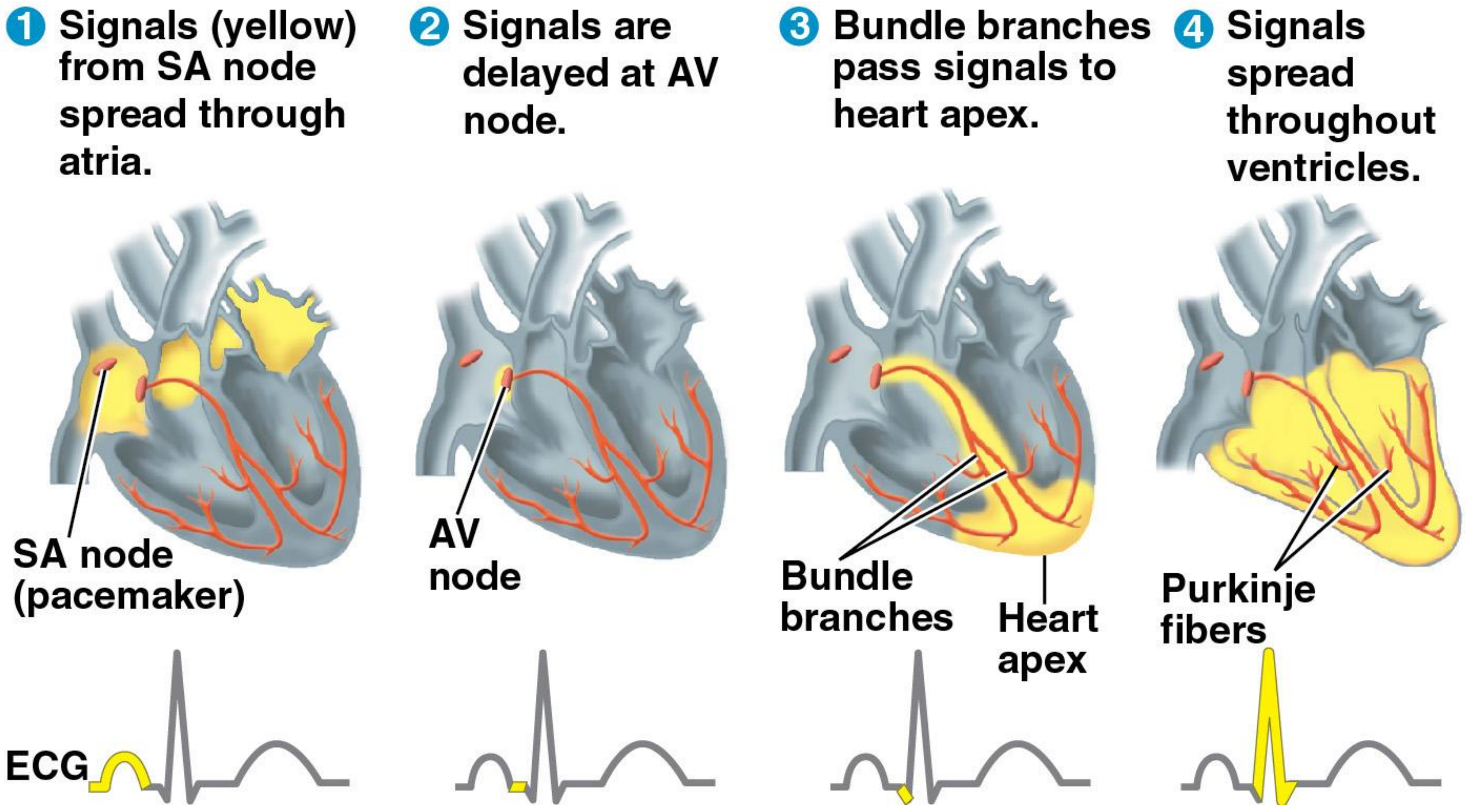
- The contraction phase for each chamber is called **systole**
- The relaxation phase for each chamber is called **diastole**
- The “lub-dup” sound of a heart beat is caused by the recoil of blood against the A V valves (lub) then against the semilunar (dup) valves
- Backflow of blood through a defective valve causes a heart murmur

Maintaining the Heart's Rhythmic Beat

- Some cardiac muscle cells are autorhythmic, meaning they contract without any signal from the nervous system
- The **sinoatrial** (**SA**) **node**, or pacemaker, sets the rate and timing at which all other cardiac muscle cells contract
- The SA node produces electrical impulses that spread rapidly through the heart and can be recorded as an **electrocardiogram** (**ECG** or **EKG**)

Figure 34.8

The Control of Heart Rhythm



Blood Vessel Structure and Function

- A vessel’s cavity is called the central lumen
- The epithelial layer that lines blood vessels is called the **endothelium**
- The endothelium is smooth and minimizes resistance to blood flow

Blood Flow Velocity

- Blood vessel diameter influences blood flow
- Velocity of blood flow is slowest in the capillary beds, as a result of the high resistance and large total cross-sectional area
- Blood flow in capillaries is necessarily slow for exchange of materials
- Blood flow speeds up as it enters venules and veins that have smaller total cross-sectional areas

Changes in Blood Pressure During the Cardiac Cycle

- Arterial blood pressure is highest when a heart ventricle contracts, during ventricular systole
- **Pulse** is the rhythmic bulging of artery walls with each heartbeat
- During diastole, the elastic walls of the arteries snap back
- Arteries remain pressurized throughout the cardiac cycle, so blood flows continuously to arterioles and capillaries

Capillary Function

- Blood flows through only 5–10% of the body’s capillaries at a time
- Each tissue has many capillaries, so every body part is supplied with blood at all times
- Capillaries in major organs are usually filled to capacity
- Blood supply varies in many other sites

Blood Composition and Function

- Vertebrate blood is a connective tissue consisting of cells suspended in a liquid matrix called **plasma**
- The cellular elements occupy about 45% of the volume of blood

Plasma

- Among the solutes in plasma are inorganic salts in the form of dissolved ions, which are an essential component of blood
- Some of these buffer and/or maintain the osmotic balance of blood
- Others affect the composition of interstitial fluid, where many ions affect muscle and nerve activity
- These plasma electrolytes are kept within narrow concentration ranges

Blood Clotting

- Injury to a blood vessel initiates a chain of events that seals the break to avoid blood loss
- Coagulation is the formation of a solid clot from liquid blood
- Blood clotting occurs when a series of events converts inactive fibrinogen to fibrin, which forms the framework of a clot
- A blood clot formed within a blood vessel is called a **thrombus** and can block blood flow

Cardiovascular Disease

- Cardiovascular diseases are disorders of the heart and the blood vessels
- Cardiovascular diseases kill more than 750,000 people in the United States each year

Atherosclerosis, Heart Attacks, and Stroke

- Damage or infection can roughen the lining of arteries and lead to **atherosclerosis**, the hardening of arteries by accumulation of fatty deposits
- Cholesterol is a key player in the development of atherosclerosis
- Damage to the arterial lining results in inflammation
- A fatty deposit called a plaque grows and the artery walls become thick and stiff
- If the plaque ruptures, a thrombus can form in the artery, potentially triggering a heart attack or stroke

Risk Factors and Treatment of Cardiovascular Disease

- **Low-density lipoprotein** (**LDL**) delivers cholesterol to cells for membrane production
- **High-density lipoprotein** (**HDL**) scavenges excess cholesterol for return to the liver
- Risk for heart disease increases with a high LDL to HDL ratio
- The LDL/HDL ratio is strongly influenced by lifestyle

- **Hypertension** (high blood pressure) contributes to the risk of heart attack and stroke
- Hypertension can be reduced by dietary changes, exercise, medication, or some combination of these

Concept 34.5: Gas Exchange Occurs Across Specialized Respiratory Surfaces

- **Gas exchange** is the uptake of molecular O_2 from the environment and the discharge of CO_2 to the environment

Respiratory Media

- O_2 is plentiful in air, and breathing air is relatively easy
- In a given volume, there is less O_2 available in water than in air
- Obtaining O_2 from water requires greater energy expenditure than air breathing
- Aquatic animals have a variety of adaptations to improve efficiency in gas exchange

Respiratory Surfaces

- Gas exchange across respiratory surfaces takes place by diffusion
- Respiratory surfaces tend to be thin and are always moist
- The respiratory organ is also branched or folded enlarging the available surface area for gas exchange
- Respiratory surfaces vary by animal and can include gills, tracheae, and lungs

Tracheal Systems in Insects

- The **tracheal system** of insects consists of a network of air tubes that branch throughout the body
- The tracheal system can transport O_2 and CO_2 without the participation of the animal's open circulatory system
- Larger insects must ventilate their tracheal system to meet O_2 demands

Lungs

- **Lungs** are an infolding of the body surface, usually divided into numerous pockets
- The circulatory system (open and closed) transports gases between the lungs and the rest of the body
- The use of lungs for gas exchange varies among vertebrates that lack gills

How a Mammal Breathes

- Mammals ventilate their lungs by **negative pressure breathing**, which pulls air into the lungs
- Lung volume increases as the rib muscles and **diaphragm** contract
- The **tidal volume** is the volume of air inhaled with each breath

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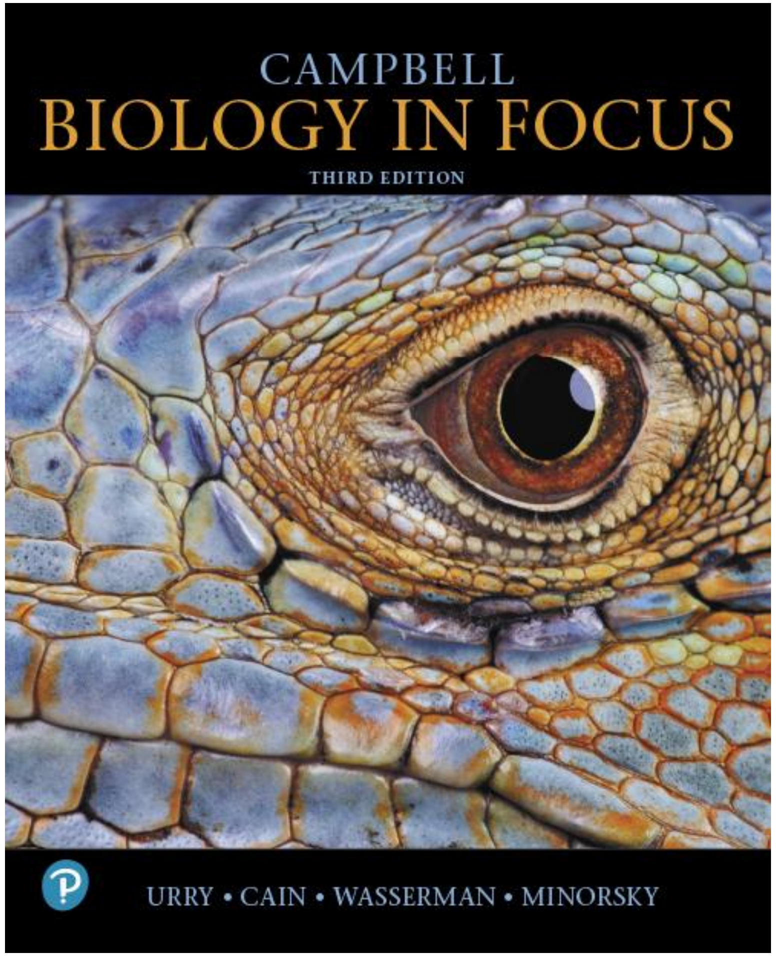

Chapter 35

The Immune System

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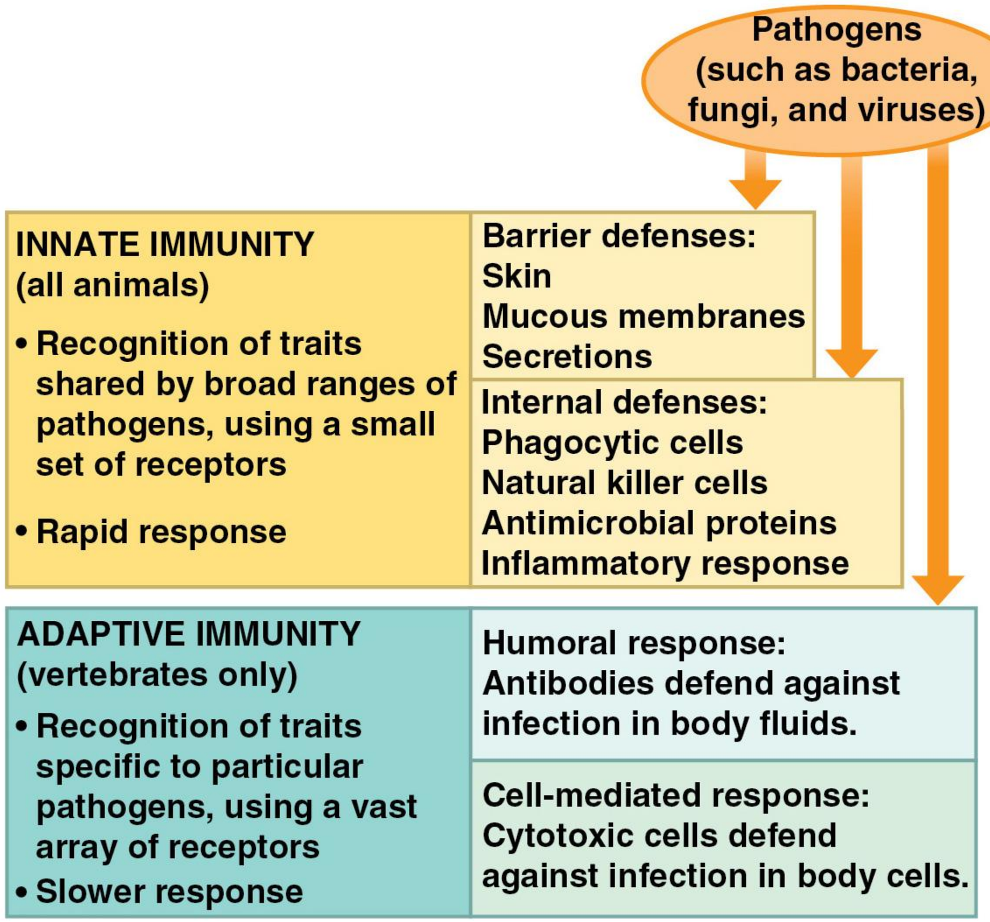
Overview: Recognition and Response

- The internal environment of an animal is a nearly ideal habitat for **pathogens**, agents that cause disease
- The **immune system** enables an animal to avoid or limit many infections
- All animals have **innate immunity**, a defense that is active immediately upon infection
- Vertebrates also have **adaptive immunity**

Figure 35.2

Overview of Animal Immunity



Innate Immunity of Vertebrates

- The immune system of mammals is the best understood of the vertebrates
- Innate defenses include barrier defenses, phagocytosis, and antimicrobial peptides
- Additional defenses are unique to vertebrates: natural killer cells, interferons, and the inflammatory response

Barrier Defenses

- Barrier defenses include the skin and mucous membranes that line the digestive, respiratory, urinary, and reproductive tracts
- Mucus traps pathogens and other particles
- Many body secretions, including saliva, mucus, and tears, are hostile to many pathogens
- The low pH of skin and the digestive system prevents growth of many bacteria

Cellular Innate Defenses

- Pathogens entering the mammalian body are subject to phagocytosis
- Phagocytic cells recognize groups of pathogens by **Toll-like receptors (TLRs)**
- Each mammalian TLR binds to fragments of molecules characteristic to a set of pathogens

Innate Defense: Proteins and Peptides

- In mammals, pathogen recognition triggers release of peptides and proteins that attack pathogens or impede their reproduction
- **Cytokines** are small peptides that act as signaling molecules in innate defense
- **Interferons** are cytokines only produced in vertebrates, interfering with viruses and helping activate macrophages
- The **complement system** consists of about 30 proteins that are activated by substances on pathogen surfaces
- Activation can lead to lysis of invading cells

Inflammatory Response

- The **inflammatory response**, such as pain and swelling, is brought about by molecules released upon injury of infection
- Activated macrophages release **cytokines**, signaling molecules that recruit neutrophils to the site of injury or infection
- Mast cells release **histamine**, which triggers blood vessels to dilate and become more permeable

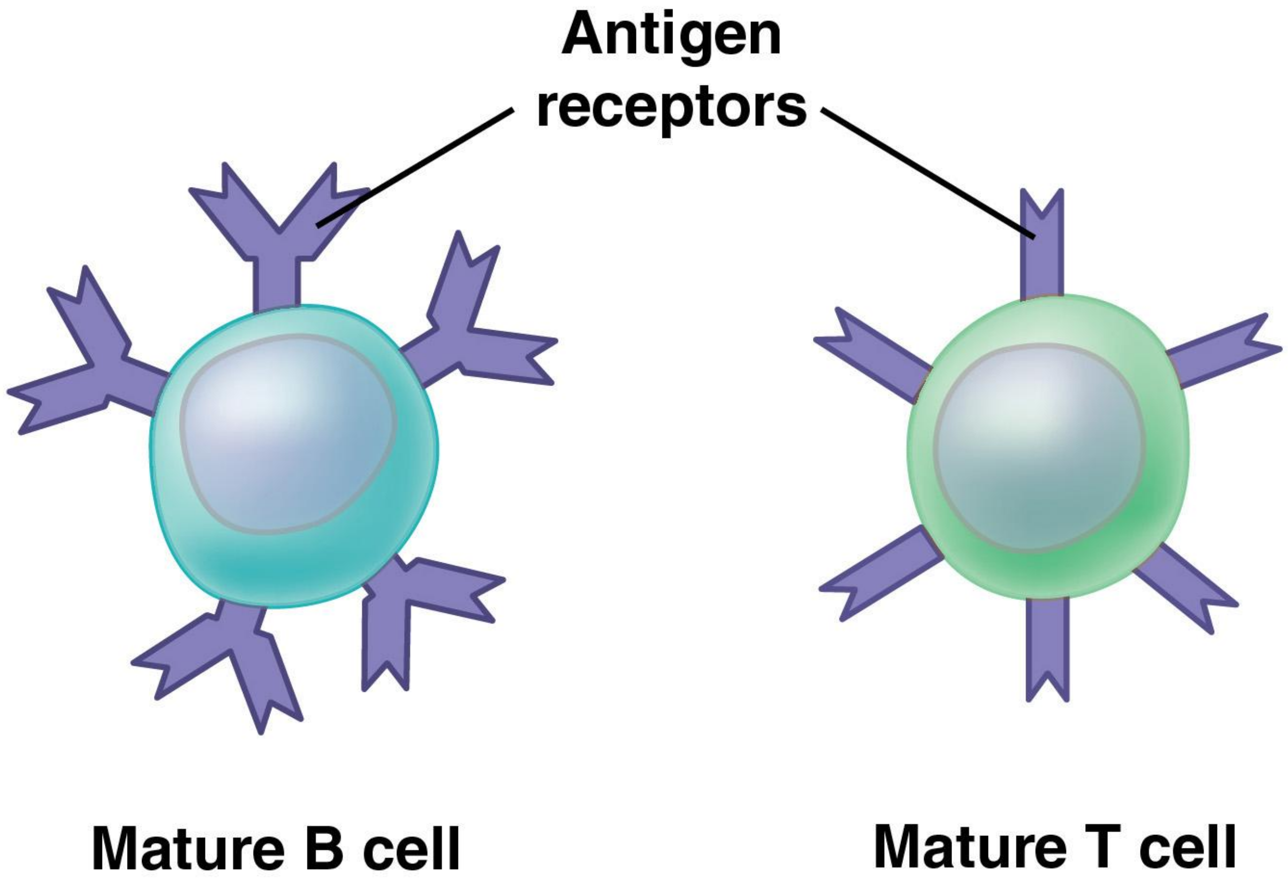
Evasion of Innate Immunity by Pathogens

- Adaptations have evolved in some pathogens that enable them to avoid destruction by phagocytic cells
- The outer capsule of some bacteria interferes with molecular recognition
- Tuberculosis (TB) resists breakdown within lysosomes after being engulfed by a host cell
- Many viral genomes encode proteins that generally suppress host cell protein synthesis or specifically suppress the synthesis of defense proteins such as interferons

Concept 35.2: In Adaptive Immunity, Receptors Provide Pathogen-Specific Recognition

- The adaptive response relies on two types of **lymphocytes**, or white blood cells
- Lymphocytes that mature in the **thymus** above the heart are called **T cells**, and those that mature in bone marrow are called **B cells**

Figure 35: Lymphocytes



Antigen Recognition by B Cells and Antibodies

- Binding of a B cell antigen receptor to an antigen is an early step in B cell activation
- This gives rise to cells that secrete a soluble form of the protein called an **antibody** or **immunoglobulin (Ig)**
- Secreted antibodies are similar to B cell receptors but lack a membrane anchor
- The antibodies provide a direct defense against pathogens in body fluids

B Cell and T Cell Development

- The adaptive immune system has four major characteristics
  - Large repertoire of lymphocytes and receptors
  - Self-tolerance; lack of reactivity against an animal’s own molecules
  - Proliferation of B and T cells after activation
  - Immunological memory

Origin of Self-Tolerance

- Antigen receptors are generated by random rearrangement of DNA
- As lymphocytes mature in bone marrow or the thymus, they are tested for self-reactivity
- Some B and T cells with receptors specific for the body's own molecules are destroyed by apoptosis, or programmed cell death
- The remainder are rendered nonfunctional

Immunological Memory

- Immunological memory is responsible for long-term protection against diseases, due to a prior infection
- The first exposure to a specific antigen represents the **primary immune response**
- During this time, selected B and T cells give rise to their effector forms
- In the **secondary immune response**, memory cells facilitate a faster, stronger, and longer response to the same antigen
- Immunological memory can span many decades

Concept 35.3: Adaptive Immunity Defends Against Infection of Body Fluids and Body Cells

- B and T lymphocytes produce a humoral immune response and a cell-mediated immune response
- In the **humoral immune response**, antibodies help neutralize or eliminate toxins and pathogens in the blood and lymph
- In the **cell-mediated immune response**, specialized T cells destroy infected host cells

Summary of the Humoral and Cell-Mediated Immune Responses

- Both the humoral and cell-mediated responses can include primary and secondary immune responses
- Memory cells enable the secondary response

Immunization

- The protection provided by a second immune response provides the basis for immunization
- Immunization uses of antigens artificially introduced into the body to generate an adaptive immune response and memory cell formation
- Vaccines used today may be made from
  - Inactivated bacterial toxins
  - Killed or weakened pathogens
  - Bacterial or viral proteins, or the mRNA or DNA encoding these proteins

Active and Passive Immunity

- Active immunity occurs when a pathogen infection or immunization prompts an immune response
- Passive immunity occurs when antibodies are passed from one animal to another
- For example, antibodies in the blood of a pregnant female pass to the fetus
- Antibodies are passed from mother to offspring in breast milk

Antibodies as Tools

- Polyclonal antibodies, produced following exposure to an antigen, are products of many different clones of plasma cells, each specific for a different epitope
- **Monoclonal antibodies** are prepared from a single clone of B cells grown in culture
- Monoclonal antibodies have provided the basis for many recent advances in medical diagnosis and treatment
- In one example, a single drop of blood is used to identify every virus that a person has encountered

Immune Rejection

- Cells transferred from one person to another can be destroyed (rejected) by the recipient's immune defenses
- To minimize rejection, physicians use donor tissue that matches the MHC molecules of the recipient as closely as possible
- Recipients also take medicines that suppress their immune responses

Allergies

- Allergies are exaggerated (hypersensitive) responses to antigens called **allergens**
- In localized allergies such as hay fever, plasma cells secrete antibodies specific for antigens on the surface of pollen grains
- This triggers immune cells in connective tissue to release histamine and other inflammatory chemicals
- Antihistamines block receptors for histamine and diminish allergy symptoms

Autoimmune Diseases

- In individuals with **autoimmune diseases**, the immune system targets certain molecules of the body
- Autoimmune diseases include systemic lupus erythematosus, type 1 diabetes, multiple sclerosis, and rheumatoid arthritis
- Genes, heredity, and environment all influence susceptibility to autoimmune disorders

Immune System Avoidance

- Mechanisms to thwart immune responses have evolved in pathogens
- A pathogen may alter how it appears to the immune system by changing the epitopes it expresses
- Such changes are called antigenic variation
- This mechanism is seen in the parasite that causes sleeping sickness and in the influenza virus

Cancer and Immunity

- The frequency of certain cancers increases when adaptive immunity is impaired
- 15–20% of all human cancers involve viruses
- The immune system can act as a defense against viruses that cause cancer and against cancer cells that harbor viruses
- In 2006, a vaccine was released that acts against human papillomavirus (HPV), a virus associated with cervical cancer

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Computing Tools

Computing-related Tasks

Modeling Homeostasis and Feedback Control

- Simulation of physiological feedback systems using computational modeling.

Immune Response Simulation

- Agent-based and cellular automata models for simulating immune system dynamics.

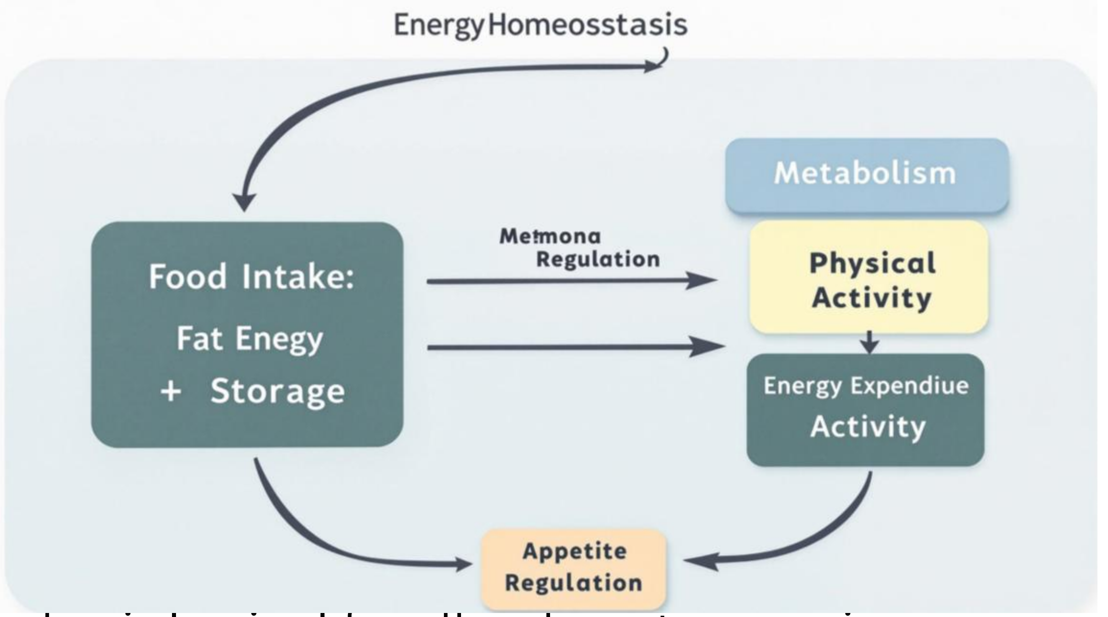
Metabolic Rate and Body Mass

- Regression analysis and scaling laws in biological systems.

Modeling Homeostasis and Feedback Control

Pattaranit Ratchada and van den Berg Hugo Antonius 2008, "Mathematical models of energy homeostasis", J. R. Soc. Interface.5:1119–1135

http://doi.org/10.1098/rsif.2008.0216

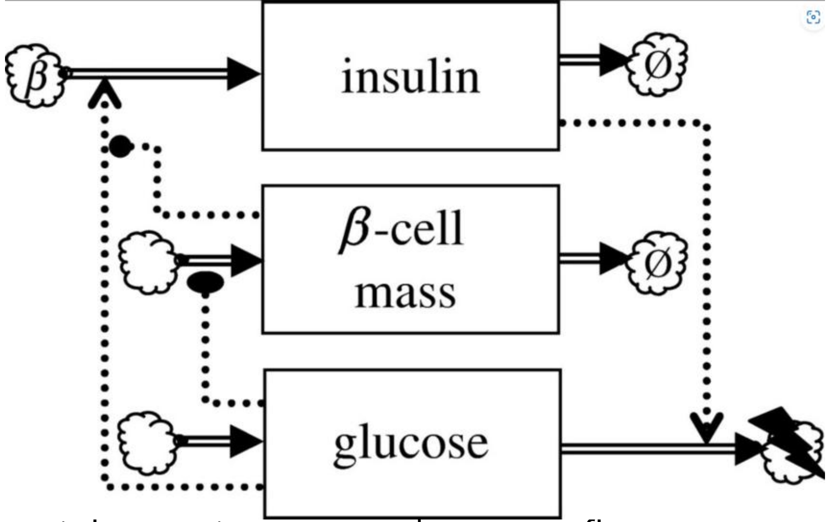


- Simulation of physiological feedback systems using computational modeling.
- It proposes a mathematical and computational model that describes how
  - Energy homeostasis is the balance between energy intake, storage, and expenditure.
  - Regulated by hormones (e.g., insulin, leptin) and feedback loops.
  - Disruption leads to metabolic diseases (obesity, diabetes).

Modeling Homeostasis and Feedback Control

Pattaranit Ratchada and van den Berg Hugo Antonius 2008, "Mathematical models of energy homeostasis", J. R. Soc. Interface.5:1119–1135

http://doi.org/10.1098/rsif.2008.0216



- Compartmental models use differential equations to track energy flow between body compartments.
- Control theory models represent feedback regulation (e.g., how the brain adjusts appetite and metabolism).
- Example equation: $$\frac{dE}{dt} = I(t) - E_{out}(t)$$ where E is stored energy, $I(t)$ is intake, and $E_{out}(t)$ is expenditure.
- Application of the model
  - Models predict weight change dynamics and the effects of interventions.
  - Explain why weight loss slows over time and how feedback can fail.
  - Computational modeling aids in designing treatments for obesity and diabetes.

Immune Response Simulation

Folcik, V. A., An, G., & Orosz, C. G. (2007). "The Basic Immune Simulator: An agent-based model to study the interactions between innate and adaptive immunity." Theoretical Biology and Medical Modelling, 4, 39. https://tbiomed.biomedcentral.com/articles/10.1186/1742-4682-4-39

- The immune system is a complex network of cells and molecules that defend against pathogens.
- Traditional models struggle with the system’s spatial and stochastic nature.
- The Basic Immune Simulator (BIS) uses agent-based modeling: each immune cell is an autonomous agent with its own rules.

Immune Response Simulation

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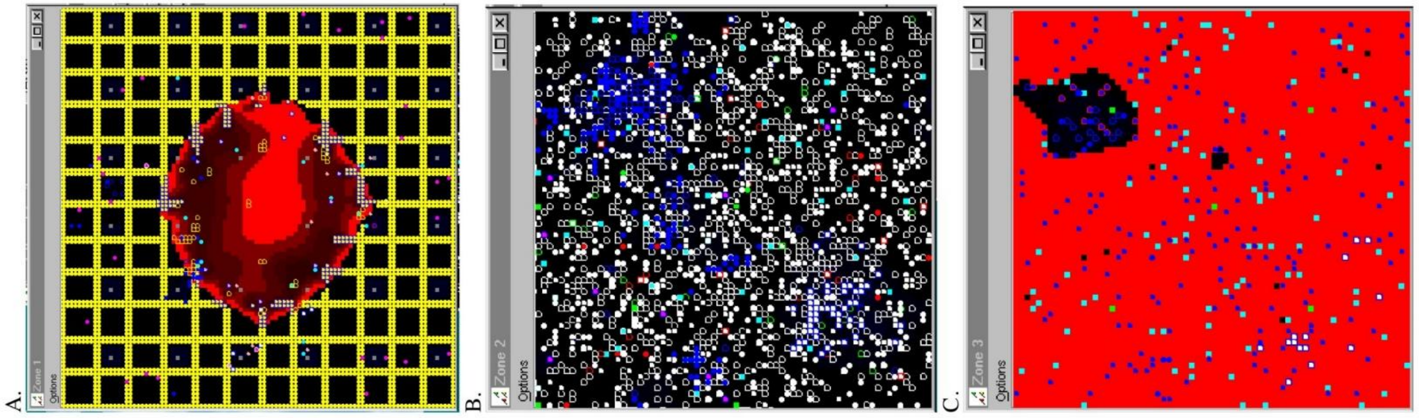
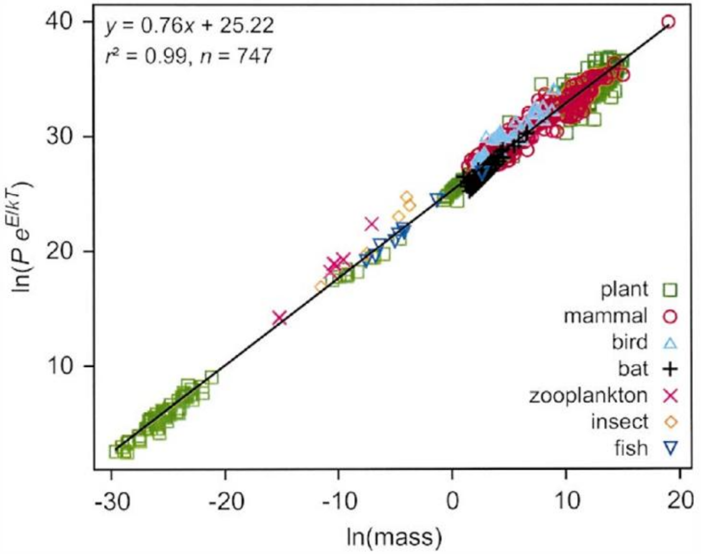
- BIS simulates both innate and adaptive immunity.
- Agents include pathogens, innate immune cells (macrophages, dendritic cells), and adaptive immune cells (T and B cells).
- The model tracks detection, response, activation, and memory formation.
- Agents move, interact, and change state based on probabilistic rules in a spatial grid.
- Application
    - BIS can simulate real immune responses and test "what-if" scenarios (e.g., immune deficiencies, pathogen mutations).
    - Useful for research, hypothesis testing, and education.
    - Demonstrates the power of agent-based models in capturing emergent behavior in biological systems.



Metabolic Rate and Body Mass

"West, G. B., Brown, J. H., & Enquist, B. J. (1997). "A general model for the origin of allometric scaling laws in biology. Science, 276(5309), 122-126. https://research-management.mq.edu.au/ws/portalfiles/portal/62174764/Publisher+version+%28open+access%29.pdf



- Many biological traits (metabolic rate, heart rate, lifespan) scale with body mass in predictable ways.
- Metabolic rate B scales as B≈$B_o M^{3/4}$ across diverse species.
- Why does this "three-quarter power law" appear so universally?
- West, Brown, and Enquist (1997) explain scaling laws using the geometry of resource distribution networks.

Metabolic Rate and Body Mass

"West, G. B., Brown, J. H., & Enquist, B. J. (1997). "A general model for the origin of allometric scaling laws in biology. Science, 276(5309), 122-126. https://research-management.mq.edu.au/ws/portalfiles/portal/62174764/Publisher+version+%28open+access%29.pdf

- Key assumptions:
  - Networks are fractal-like and space-filling.
  - Terminal units (e.g., capillaries) are size-invariant.
  - Networks are optimized for minimal energy cost.
- The WBE model uses mathematical and computational tools: geometry, network theory, and optimization.
- Demonstrates the power of domain-specific computation in biology.
- Applications: understanding organism design, predicting ecological patterns, informing medical research.