Body Defense Mechanisms

OUTLINE:

- The Body’s Defense System
- Three Lines of Defense
- Distinguishing Self from Nonself
- Antibody-Mediated Responses and Cell-Mediated Responses
- Steps of the Adaptive Immune Response
- Active and Passive Immunity
- Monoclonal Antibodies
- Problems of the Immune System
The Body’s Defense System

- The body generally defends you against anything that it does not recognize as being part of or belonging inside you

  - Common targets of the defense system include

    - Pathogens
      - Disease-causing bacteria, viruses, prions, protozoans, fungi, parasitic worms
    - Cancer cells
      - Once normal body cells whose genetic changes cause unregulated cell division
Three Lines of Defense

Three strategies for defending against foreign organisms and molecules or cancer cells

1. Physical and chemical surface barriers
   - Nonspecific
   - Keep foreign organisms or molecules out

2. Internal cellular and chemical defenses
   - Nonspecific
   - Attack any foreign organism or molecule that has gotten past the surface barriers

3. Immune response
   - Specific
   - Destroy specific targets and remember them
Figure 13.1 The body’s three lines of defense against pathogens.

First line of defense: Nonspecific physical and chemical surface barriers

Second line of defense: Nonspecific internal cellular and chemical defense

Third line of defense: Immune response
First Line of Defense: Physical and Chemical Barriers

- Physical barriers
  - Skin
    - Nearly impenetrable
    - Waterproof
    - Resistant to most toxins and enzymes of invading organisms
  - Mucous membranes
    - Line the respiratory and digestive tracts
    - Sticky mucus traps microbes
First Line of Defense: Physical and Chemical Barriers

- Chemical barriers
  - Sweat and oil glands of the skin
    - Produce chemicals that slow or prevent growth of bacteria
  - Lining of the stomach
    - Produces hydrochloric acid and protein-digesting enzymes that destroy pathogens
First Line of Defense: Physical and Chemical Barriers

- Chemical barriers (cont’d)
  - Urine
    - Slows bacterial growth with acidity
    - Washes microbes from urethra
  - Saliva and tears
    - Contain lysozyme, an enzyme that kills bacteria
Figure 13.2 The body’s first line of defense.

**Tears**
- Wash away irritating substances and microbes
- Lysozyme kills many bacteria

**Saliva**
- Washes microbes from the teeth and mucous membranes of the mouth

**Skin**
- Provides a physical barrier to the entrance of microbes
- Acidic pH discourages the growth of organisms
- Sweat and oil gland secretions kill many bacteria

**Respiratory tract**
- Mucus traps organisms
- Cilia sweep away trapped organisms

**Stomach**
- Acid kills organisms

**Large intestine**
- Normal bacterial inhabitants keep invaders in check

**Urinary bladder**
- Urine washes microbes from urethra
Defensive Cells and Natural Killer Cells

- Phagocytes (WBCs) that engulf pathogens
  - Neutrophils: arrive first
  - Macrophages: develop from monocytes that leave the circulatory system
  - Eosinophils: attack pathogens that are too large for phagocytosis, such as parasitic worms

- Natural killer (NK) cells
  - Also a type of WBC
  - Search out abnormal cells, including cancer cells, and kill them
Figure 13.3 A *macrophage ingesting a bacterium.*
Figure 13.4 *Natural killer, or NK, cell.*
Interferons and Complement System

- Interferons: slow viral reproduction
  - Small proteins secreted by a cell infected by a virus
    - Attract macrophages and natural killer cells that destroy infected cells
    - Stimulate neighboring cells to make proteins that prevent the viruses from replicating
Complement system: assists other defensive mechanisms

- Group of proteins that enhances both nonspecific and specific defense mechanisms
- Destroy pathogens, enhance phagocytosis, stimulate inflammation
**Figure 13.5** Complement has a direct destructive effect on pathogens.

- **Step 1:** Activated complement proteins form holes in the cell wall and membrane of the bacterium.
- **Step 2:** The bacterium can no longer maintain a constant internal environment. Water enters the cell.
- **Step 3:** The bacterium bursts.

**Intact bacterium**

**Pores in membrane caused by complement**

**Bacterium bursting**
Inflammation

- Destroys invaders and helps repair and restore damaged tissue
  - Four signs
    - Redness
    - Heat
    - Swelling
    - Pain
Inflammation

- **Redness**
  - Mast cells release histamine, which causes blood vessels to dilate
  - Blood flow to the area increases, delivering defensive cells and removing dead cells and toxins

- **Heat**
  - Temperature rises as a result of increased blood flow
  - Speeds healing and activities of defensive cells
Inflammation

- **Swelling**
  - Histamine causes capillaries to become leaky and fluid seeps into tissues
    - Fluid brings clotting factors, oxygen, and nutrients

- **Pain**
  - Can be caused by
    - Excess fluid
    - Bacterial toxins
    - Prostaglandins
The inflammatory Response

The inflammatory response is a nonspecific internal response to injury or localized infection. This tutorial illustrates how different components of the immune system act to limit the spread of the infection and repair the wound.

Press "PLAY" to begin Animation.
Figure 13.6 *The inflammatory response.*

**Blood vessels widen**
- **Redness:** Blood flow carries defensive cells and chemicals to damaged tissue and removes toxins.
- **Heat:** Increases the metabolic rate of cells in the injured area to speed healing.

**Capillaries become more permeable**
- **Swelling:** Fluid containing defensive chemicals, blood-clotting factors, oxygen, nutrients, and defensive cells seeps into the injured area.
- **Pain:** Movement is hampered, allowing the injured area to heal.

**Additional processes**
- **Complement destroys bacteria.**
- **Phagocytes engulf bacteria.**
- **Clot formation prevents loss of blood.**
Fever

- An abnormally high body temperature
- Caused by pyrogens
  - Chemicals that reset the brain’s thermostat to a higher temperature
- A mild or moderate fever helps fight bacterial infection
- A very high fever (over 105°F or 40.6°C) is dangerous
Table 13.1 The Second Line of Defense

<table>
<thead>
<tr>
<th>Defense</th>
<th>Example</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defensive cells</td>
<td>Phagocytic cells, such as neutrophils and macrophages</td>
<td>Engulf invading organisms</td>
</tr>
<tr>
<td></td>
<td>Eosinophils</td>
<td>Kill parasites</td>
</tr>
<tr>
<td></td>
<td>Natural killer cells</td>
<td>Kill many invading organisms and cancer cells</td>
</tr>
<tr>
<td>Defensive proteins</td>
<td>Interferons</td>
<td>Slow the spread of viruses in the body</td>
</tr>
<tr>
<td></td>
<td>Complement system</td>
<td>Stimulates histamine release; promotes phagocytosis;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>kills bacteria; enhances inflammation</td>
</tr>
<tr>
<td>Inflammation</td>
<td>Widening of blood vessels and increased capillary permeability, leading to redness, heat, swelling, and pain</td>
<td>Brings in defensive cells and speeds healing</td>
</tr>
<tr>
<td>Fever</td>
<td>Abnormally high body temperature</td>
<td>Slows the growth of bacteria; speeds up body defenses</td>
</tr>
</tbody>
</table>
Third Line of Defense: Adaptive Immune System

- Has specific responses and memory
  - Organs of the lymphatic system are important components
  - Defined by its function: recognize and destroy specific pathogens or foreign molecules
Third Line of Defense: Adaptive Immune System

- Adaptive immune response
  - The body’s specific defenses
  - Important characteristics
    - Specificity: directed at a specific pathogen
    - Memory: remembers the pathogen and attacks it so quickly that illness does not result upon second exposure
Distinguishing Self from Nonself

- Major histocompatibility complex (MHC) markers
  - Molecules found on our own cells that label cells as “self”
  - Used by the immune system to distinguish cells of your body from foreign invaders

- Antigens
  - Nonself substance or organism that triggers an immune response
  - Usually large molecules, such as proteins, polysaccharides, or nucleic acids
  - Often found on surface of invader
Figure 13.8 All nucleated cells in the body have molecular MHC markers on their surface that label them as self.

A self (MHC) marker labels the body’s cells as self or “friend.”

An antigen is a molecule, often on the surface of a pathogen, that the immune system recognizes as a specific “foe.”
Distinguishing Self from Nonself

- Lymphocytes
  - WBCs
    - Responsible for the specificity and memory of the adaptive immune response
  - B lymphocytes (B cells): form and mature in bone marrow
  - T lymphocytes (T cells): form in bone marrow and mature in thymus gland
    - Recognize MHC self markers
Distinguishing Self from Nonself

- Programmed to recognize one particular type of antigen
- Specificity results from each cell developing its own particular receptors on its surface
- When an antigen fits into receptors, then the body targets that particular antigen
- Divide repeatedly, forming two cell lines
  - Effector cells: short-lived cells that attack the invader
  - Memory cells: long-lived cells that remember the invader and mount a quick response when it is next encountered
Antibody-Mediated Responses and Cell-Mediated Responses

- Antibody-mediated immune responses
  - Defend against antigens that are free in body fluids, including toxins or extracellular pathogens
  - Effector B cells (plasma cells) use antibodies (Y-shaped proteins) to neutralize the antigen

- Cell-mediated immune responses
  - Protect against cancer cells and body cells that have become infected with viruses or other pathogens
  - Cytotoxic T cells cause cancer cells and infected body cells to burst
Figure 13.9 An overview of the adaptive immune response.

1. Threat: Antigen is engulfed.
2. Detection: Macrophage presents antigen to helper T cells to identify invader.
3. Alert: Helper T cell activates memory helper T cell.
4. Alarm: Naive B cell and cytotoxic T cell are activated.
5. Building specific defenses: Naive B cell becomes effector helper T cell, which becomes memory B cell.
7. Continued surveillance: Antibodies target pathogens or toxins outside cells.
8. Continued surveillance: Memory cells remain and provide a quick response to the antigen in a future encounter.
# Table 13.2 Cells Involved in the Adaptive Immune Response

<table>
<thead>
<tr>
<th>Cell</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Macrophage, dendritic cell, or B cell</strong></td>
<td>An antigen-presenting cell</td>
</tr>
<tr>
<td></td>
<td>• Engulfs and digests pathogen or invader</td>
</tr>
<tr>
<td></td>
<td>• Places a piece of digested antigen on its plasma membrane</td>
</tr>
<tr>
<td></td>
<td>• Presents the antigen to a helper T cell</td>
</tr>
<tr>
<td></td>
<td>• Activates the helper T cell</td>
</tr>
<tr>
<td><strong>T Cells</strong></td>
<td></td>
</tr>
<tr>
<td>Helper T cell</td>
<td>The “on” switch for both lines of immune response</td>
</tr>
<tr>
<td></td>
<td>• After activation by macrophage, the helper T cell divides,</td>
</tr>
<tr>
<td></td>
<td>forming effector helper T cells and memory helper T cells</td>
</tr>
<tr>
<td></td>
<td>• Helper T cells activate B cells and T cells</td>
</tr>
<tr>
<td>Cytotoxic T cell (effector T cell)</td>
<td>Responsible for cell-mediated immune responses</td>
</tr>
<tr>
<td></td>
<td>• When activated by helper T cells, the cytotoxic T cell divides to form</td>
</tr>
<tr>
<td></td>
<td>effector cytotoxic T cells and memory cytotoxic T cells</td>
</tr>
<tr>
<td></td>
<td>• Destroys cellular targets, such as infected body cells, bacteria, and</td>
</tr>
<tr>
<td></td>
<td>cancer cells</td>
</tr>
<tr>
<td>Suppressor T cell</td>
<td>The “off” switch for both lines of immune responses</td>
</tr>
<tr>
<td></td>
<td>• Suppresses the activity of the B cells and T cells after the foreign</td>
</tr>
<tr>
<td></td>
<td>cell or molecule has been successfully destroyed</td>
</tr>
<tr>
<td><strong>B Cells</strong></td>
<td>Involved in antibody-mediated responses</td>
</tr>
<tr>
<td></td>
<td>• When activated by helper T cells, the B cell divides to form</td>
</tr>
<tr>
<td></td>
<td>plasma cells and memory cells</td>
</tr>
<tr>
<td><strong>Plasma Cell</strong></td>
<td>Effector in antibody-mediated response</td>
</tr>
<tr>
<td></td>
<td>• Secretes antibodies specific to extracellular antigens, such as</td>
</tr>
<tr>
<td></td>
<td>toxins, bacteria, and free viruses</td>
</tr>
<tr>
<td><strong>Memory Cells</strong></td>
<td>Responsible for memory of immune system</td>
</tr>
<tr>
<td></td>
<td>• Generated by B cells or any type of T cell during an immune response</td>
</tr>
<tr>
<td></td>
<td>• Enable quick and efficient response on subsequent exposures of the</td>
</tr>
<tr>
<td></td>
<td>antigen</td>
</tr>
<tr>
<td></td>
<td>• May live for years</td>
</tr>
</tbody>
</table>
Steps of the Adaptive Immune Response

1. Threat
   - Foreign organism or molecule (an antigen) enters the body

2. Detection
   - Macrophage detects foreign organism or molecule and engulfs it

3. Alert
   - Macrophages present antigens to helper T cells
     - Macrophages are antigen-presenting cells
     - Helper T cells are the main switch for the adaptive immune response
Figure 13.10 A macrophage.

**Step 1: Threat**
An invader enters the body.

**Step 2: Detection**
- A macrophage encounters, engulfs, and digests the invader (antigen; e.g., a bacterium).
- The macrophage places a piece of the invader (antigen) on its surface with the self (MHC) marker.

**Step 3: Alert**
The macrophage presents the antigen to a helper T cell and secretes a chemical that activates the helper T cell.
Steps of the Adaptive Immune Response

4. Alarm

- Helper T cells activate appropriate B cells and T cells to destroy the specific antigen

- When activated, these cells divide to form clones of cells designed to eliminate the specific antigen from the body

  - Clonal selection is critical to the adaptive immune response
Steps of the Adaptive Immune Response

5. Building specific defenses

- B cells form plasma cells that secrete antibodies into the bloodstream that bind to antigens
- T cells form cytotoxic T cells that attack
Figure 13.11 *Clonal selection.*

There is a tremendous variety of B cells. Each B cell has receptors for a different antigen on its surface.

This B cell has receptors specific for this particular antigen.

The antigen binds to the B cell with appropriate receptors.

The selected B cell divides, producing a clone of cells all bearing receptors specific for that particular antigen.

Plasma cells produce antibodies specific for this particular antigen.

Memory cells remain to bring about a quick response to that antigen in the future.
6. Defense: the antibody-mediated response

- Antibodies specific to the antigen eliminate the antigen
  - Precipitation
  - Lysis (bursting)
  - Attraction of phagocytes
  - Neutralization

- An effector cytotoxic T cell releases perforins, which cause holes to form in cells with the particular antigen
**Figure 13.12 Antibody-mediated immune response.**

**Step 4: Alarm**
The helper T cell stimulates the B cell to begin dividing.

**Step 5: Building specific defenses**
The B cell divides and forms plasma cells and memory cells.

**Step 6: Defense**
Plasma cells secrete antibodies specific for that antigen.

**Step 7: Continued surveillance**
Memory B cells remain and mount a quick response if the invader is encountered again.
Figure 13.13 An antibody.

- Antigen on surface of a bacterial cell
- Antigen on surface of a virus particle
- Site on antibody that binds specifically with the viral antigen
- The site on antibody that binds specifically with the bacterial antigen
Steps of the Adaptive Immune Response

- Immunoglobulins
  - Five classes of antibodies, each with a special role to play in protecting against invaders
    - IgG
    - IgM
    - IgE
    - IgA
    - IgD
# Table 13.4 Classes of Antibodies

<table>
<thead>
<tr>
<th>Class</th>
<th>Structure</th>
<th>Location</th>
<th>Characteristics</th>
<th>Protective Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>IgG</td>
<td>Monomer</td>
<td>Blood, lymph, and intestines</td>
<td>Most abundant of all antibodies in body; involved in primary and secondary immune responses; can pass through placenta from mother to fetus and provides passive immune protection to fetus and newborn</td>
<td>Enhances phagocytosis; neutralizes toxins; triggers complement system</td>
</tr>
<tr>
<td>IgA</td>
<td>Dimer or monomer</td>
<td>Present in tears, saliva, and mucus as well in secretions of gastrointestinal system and excretory systems; present in breast milk</td>
<td>Levels decrease during stress, raising susceptibility to infection</td>
<td>Prevents pathogens from attaching to epithelial cells of surface lining</td>
</tr>
<tr>
<td>IgM</td>
<td>Pentamer</td>
<td>Attached to a B cell, where it acts as a receptor for antigens; free in blood and lymph</td>
<td>First Ig class released by plasma cell during primary response</td>
<td>Powerful agglutinating agent (10 antigen-binding sites); activates complement</td>
</tr>
<tr>
<td>IgD</td>
<td>Monomer</td>
<td>Surface of many B cells; blood and lymph</td>
<td>Life span of about 3 days</td>
<td>Thought to be involved in recognition of antigen and in activating B cells</td>
</tr>
<tr>
<td>IgE</td>
<td>Monomer</td>
<td>Secreted by plasma cells in skin, mucous membranes of gastrointestinal and respiratory systems</td>
<td>Binds to surface of mast cells and basophils</td>
<td>Involved in allergic reactions by triggering release of histamine and other chemicals from mast cells or basophils</td>
</tr>
</tbody>
</table>
Figure 13.14 Cell-mediated immune response.

- **Step 4: Alarm**
The helper T cell stimulates a naive or memory cytotoxic T cell to begin dividing.

- **Step 5: Building specific defenses**
The cytotoxic T cell divides and forms effector cytotoxic T cells and memory cytotoxic T cells.

- **Step 6: Defense**
Effector cytotoxic cells cause the target cell to burst and die. In this case, the target cell is a cell infected with a virus that triggered the response.

- **Step 7: Continued surveillance**
Memory cytotoxic T cells remain and mount a quick response if the invader is encountered again.
Steps of the Adaptive Immune Response

7. Continued surveillance

- Immunological memory allows for a more rapid response on subsequent exposure to the antigen
  - Primary response
    - Occurs during body’s first encounter with a particular antigen
    - Antibody concentration rises slowly
  - Secondary response
    - Occurs during subsequent encounter with that antigen
    - Strong and swift due to the large number of memory cells programmed to respond to that particular antigen
Figure 13.15 The primary and secondary immune responses.
Steps of the Adaptive Immune Response

8. Withdrawal of forces

- Suppressor T cells turn off the immune response when the antigen no longer poses a threat
Steps of the Adaptive Immune Response

Antibody- and Cell-Mediated Immunity

How does the body combat infection? The immune system is a complex network of cells and proteins whose most important job is finding invading microbes and destroying them. In this tutorial, we will examine the specific defense strategies of the immune system, which include both antibody- and cell-mediated responses. Press "PLAY" to begin Animation.
### Table 13.3 Steps in the Adaptive Immune Response

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>1: Threat</td>
<td>Foreign cell or molecule enters the body.</td>
</tr>
<tr>
<td>2: Detection</td>
<td>- Macrophage detects foreign cell or molecule and engulfs it.</td>
</tr>
</tbody>
</table>
| 3: Alert | - Macrophage puts antigen from the pathogen on its surface and finds the helper T cell with correct receptors for that antigen.  
- Macrophage presents antigen to the helper T cell.  
- Macrophage alerts the helper T cell that there is an invader that “looks like” the antigen.  
- Macrophage activates the helper T cell. |
| 4: Alarm | Helper T cell activates both lines of defense to fight that specific antigen. |
| 5: Building specific defenses (clonal selection) | - Antibody-mediated defense—B cells are activated and divide to form plasma cells that secrete antibodies specific to the antigen.  
- Cell-mediated defense—T cells divide to form cytotoxic T cells that attack cells with the specific antigen. |
| 6: Defense | - Antibody-mediated defense—antibodies specific to the antigen eliminate the antigen.  
- Cell-mediated defense—cytotoxic T cells cause cells with the antigen to burst. |
| 7: Continued surveillance | Memory cells formed when helper T cells, cytotoxic T cells, and B cells were activated remain to provide swift response if the antigen is detected again. |
| 8: Withdrawal of forces | Once the antigen has been destroyed, suppressor T cells shut down the immune response to that antigen. |

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Active and Passive Immunity

- **Active immunity**
  - The body produces memory B cells and T cells following exposure to an antigen
    - Occurs naturally when a person gets an infection
    - Can also occur through vaccination
      - Introduction of a harmless form of an antigen into the body to stimulate immune responses
  - Long-lived because memory cells are produced
Active and Passive Immunity

- Passive immunity
  - Results when a person receives antibodies that were produced by another person or animal
  - Short-lived because the recipient’s body was not stimulated to produce memory cells
Monoclonal Antibodies

- A group of identical antibodies that bind to one specific antigen
- Used in research, clinical diagnosis, and disease treatment
Problems of the Immune System

- Autoimmune disorders
  - Occur when the immune system fails to distinguish between self and nonself and attacks tissues or organs of the body
- Classification
  - Organ-specific
    - Usually caused by problematic T cells
    - Example: Hashimoto’s thyroiditis
  - Non-organ-specific
    - Usually caused by problematic B cells
    - Example: systemic lupus erythematosus
Problems of the Immune System

- Allergies
  - Overreaction by the immune system to an antigen
  - The antigen is usually harmless and is called an allergen
  - Example: hay fever (allergic rhinitis)
Figure 13.16 Common causes of allergies.

Pollen grains

Dust mite
Allergies

- Steps in an allergic reaction
  - During the first exposure:
    - Allergens cause plasma cells to release class IgE antibodies
    - IgE antibodies bind to mast cells or basophils
  - On subsequent exposures:
    - Allergen combines with IgE attached to mast cells and causes release of histamine
    - Histamine causes redness, swelling, itching, and other symptoms of an allergic response
Figure 13.17 Steps in an allergic reaction.

First exposure

Step 1: The invader (allergen) enters the body.

Step 2: Plasma cells produce large amounts of class IgE antibodies against the allergen.

Step 3: IgE antibodies attach to mast cells, which are found in body tissues.

Subsequent (secondary) response

Step 4: More of the same allergen invades the body.

Step 5: The allergen combines with IgE attached to mast cells. Histamine and other chemicals are released from mast cell granules.

Step 6: Histamine causes blood vessels to widen and become leaky. Fluid enters the tissue, causing swelling.

- Histamine stimulates release of large amounts of mucus.
Allergies

- Anaphylactic shock
  - Extreme allergic reaction that can be fatal
  - Can cause pooling of blood in capillaries, which makes breathing difficult
- Common triggers
  - Insect stings
  - Medications (penicillin)
  - Foods (shellfish, peanuts)
Allergies

- Allergens can be identified by injecting small amounts of suspected antigens and monitoring skin response.

Treatments

- Antihistamines
  - Block the effects of histamine

- Allergy shots
  - Inject increasing amounts of a known allergen in an effort to desensitize the person to the offending allergen.
You Should Now Be Able To:

- Describe the three lines of defense
- Understand how the body distinguishes self from nonself
- Know the antibody-mediated responses and cell-mediated responses
- Know the steps of the adaptive immune response
- Understand active and passive immunity
- Describe monoclonal antibodies
- Know the major problems of the immune system
  - Autoimmune disorders
  - Allergies