Chapter 43: The Immune System

Our students consider this chapter to be a particularly challenging and important one. Expect to work your way slowly through the first three concepts. Take particular care with Concepts 43.2 and 43.3. It is rewarding, however, in Concept 43.4 to put your new knowledge to work and truly understand the devastation caused by the destruction of helper T cells by HIV.

Overview: The immune responses of animals can be divided into innate immunity and acquired immunity. As an overview, complete this figure indicating the divisions of both innate and acquired immunity.

Concept 43.1: In innate immunity, recognition and response rely on shared traits of pathogens

1. We first encountered phagocytosis in Concept 7.5, but it plays an important role in the immune systems of both invertebrates and vertebrates. Review the process by briefly explaining the six steps to ingestion and destruction of a microbe by a phagocytic cell.

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2. Explain the role of the Toll receptor in producing antimicrobial peptides.

Signal transduction from the Toll receptor to the cell nucleus leads to synthesis of a set of antimicrobial peptides active against fungi.

3. List the three innate defenses vertebrates share with invertebrates and the two defenses unique to vertebrates.

Both share the innate defenses of barrier defenses, phagocytosis and antimicrobial peptides. Vertebrates alone have natural killer cells, inflammatory response and interferons.

4. In the chart below, list five examples of barrier defenses and how they work.

<table>
<thead>
<tr>
<th>Barrier Defense</th>
<th>How the Barrier Repels Pathogens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mucous membranes</td>
<td>Mucus, a viscous fluid, enhances defenses by trapping microbes and other particles.</td>
</tr>
<tr>
<td>Saliva, tears</td>
<td>Destroys various exposed epithelia, providing a washing action that also inhibits colonization by fungi and bacteria.</td>
</tr>
<tr>
<td>Stomach acid</td>
<td>Kills most of the microbes in food and water before they can enter the intestines.</td>
</tr>
<tr>
<td>Secretions from oil and sweat gland</td>
<td>Give human skin a pH ranging from 3 to 5, acidic enough to prevent the growth of many bacteria.</td>
</tr>
<tr>
<td>Skin</td>
<td>Blocks entry of many pathogens.</td>
</tr>
</tbody>
</table>

5. Explain how Toll-like receptors are used in cellular innate defenses, using TLR3 and TLR4 as examples.

Each mammalian Toll-like receptor binds to fragments of molecules characteristic of a set of pathogens, like TLR3 and TLR4.

6. In the chart below, explain the role of the four phagocytic cells.

<table>
<thead>
<tr>
<th>Phagocytic Cell Type</th>
<th>Role in Innate Defense</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutrophils</td>
<td>Circulate in the blood. Engulf and destroy infecting pathogens.</td>
</tr>
<tr>
<td>Macrophages</td>
<td>Some migrate through the body, others reside permanently in organs and tissues.</td>
</tr>
<tr>
<td>Eosinophils</td>
<td>Populate tissues, like skin. Engulf pathogens.</td>
</tr>
<tr>
<td>Dendritic cells</td>
<td>Often found beneath mucosal surfaces.</td>
</tr>
</tbody>
</table>
7. In the figure below, trace the flow of lymph in four stages. For each stage, explain the role of the lymphatic system in innate defense.

8. Explain the role of the following two antimicrobial compounds.

- **Interferon** - Proteins that provide innate defense by interfering with viral infections.

- **Complement** - Activation results in a cascade of biochemical reactions that can lead to lysis of invading cells.

9. Use the figure below to explain the three steps of an **inflammatory response**.

1. At the injury site, mast cells release histamines and macrophages secrete cytokines. These signalling molecules cause nearby capillaries to dilate.

2. Capillaries widen and become more permeable, allowing fluid containing antimicrobial peptides to enter the tissues. Signals released by immune cells attract neutrophils.

3. Neutrophils digest pathogens and cell debris at the site, and the tissue heals.
10. What role do natural killer cells play in the immune system?
   Play a major role in the rejection of tumors and cells infected by viruses.

11. It might seem like pathogens have little hope of mounting an infection, but do not forget that pathogens are constantly evolving ways to circumvent our immune system. As examples, how do the pathogens that cause pneumonia and tuberculosis avoid our immune responses?
   Pneumonia: an outer capsule covers the surface of the bacterium making molecular recognition difficult.
   Tuberculosis: grows and reproduces.

Concept 43.2 In acquired immunity, lymphocyte receptors provide pathogen-specific recognition

12. From the first four paragraphs of this concept, summarize where T cells and B cells develop, and give an overview of their functions. (Note that they are a type of white blood cell known as a lymphocyte.)
   Like all blood cells, lymphocytes originate from the cells in the bone marrow. Lymphocytes have cell-surface antigen receptors for foreign molecules.

13. What is immunological memory, and why is it important?
   Is responsible for the long term protection that a prior infection or vaccination provides against many diseases, such as chickenpox.

14. Explain how cytokines help coordinate the innate and acquired immune responses.
   Cytokines promote blood flow to the site of injury or infection.

15. The following brief questions will serve as a primer for immune system recognition.
   a. What is an antigen?
      A substance that elicits an immune response by binding to receptors of B cells, antibodies or of T cells.
   b. What is the relationship between an antigen receptor, an antibody, and an immunoglobulin?
      An antigen receptor is a general term for a surface protein, located on B cells and T cells, that binds to antigens, initiating adaptive immune response.
   c. How is an epitope related to an antigen? (Look at Figure 43.10.)
      An epitope is the accessible portion of an antigen that binds to an antigen receptor.
16. In the figure of a B cell below, label the antigen-binding sites, light and heavy chains, variable and constant regions, transmembrane region, and disulfide bridges.

17. What forms the specific antigen-binding site? (Be sure to note that each B cell produces only one type of antigen receptor. For any one cell, all antigen receptors or antibodies produced are identical.)

18. In the figure of a T cell below, label the antigen-binding site, alpha and beta chain, variable and constant regions, transmembrane region, and disulfide bridge.

19. T cells also display only one type of antigen receptor on the surface of the cell. Compare and contrast a T cell with a B cell.
20. *B-cell receptors* recognize and bind to antigens whether they are free antigens (like a secreted toxin) or on the surface of a pathogen. Explain the role of the *major histocompatibility complex (MHC)* to *T-cell receptor* binding.

\[
\text{T cells bind only to fragments of antigens that are displayed on the surface of host cells.}
\]

21. Explain how an infected host cell uses the MHC molecule to display an antigen.

\[
\text{Inside the host cell, enzymes in the cell cleave the antigen into smaller peptides.}
\]

22. Explain the differences between Class I and Class II MHC molecules, noting type of cells that display the molecule, types of diseases involved with each molecule, and what type of T cell recognizes the MHC molecules.

<table>
<thead>
<tr>
<th>MHC Class</th>
<th>Displayed by?</th>
<th>Diseases associated with (cancer, viral or bacterial)?</th>
<th>Recognized by which T cells?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I MHC</td>
<td>any body cell</td>
<td>cancer</td>
<td>cytotoxic T cells</td>
</tr>
<tr>
<td>Class II MHC</td>
<td>dendritic cells</td>
<td>viral</td>
<td>helper T cells</td>
</tr>
</tbody>
</table>

23. Using Figure 43.12 as a guide, label completely the figure below.

24. List three properties of the *acquired immune system*.

1. Self-tolerance
2. Immunological memory allows for a more rapid response to an antigen previously encountered
3. Cell proliferation triggered by activation greatly increases the number of B and T cells specific for an antigen.
25. One of the early problems in immunology was trying to understand how an organism with a limited number of genes (for humans, about 20,500) could produce a million different B-cell protein receptors and 10 million different T-cell protein receptors! The answer resulted in a Nobel Prize and a startling exception to the notion that all cells have exactly the same DNA. Use the figure below to label and explain the four steps involved in producing genetically unique B-cell receptors.

26. Explain how the body develops self-tolerance in the immune system.

27. Define the following terms.

**Effector cells** - short lived cells that take effect immediately against the antigen and any pathogens producing that antigen.

**Memory cells** - long lived cells that can give rise to effector cells if the same antigen is encountered later in the animal's life.

**Clonal selection** - the proliferation of a lymphocyte into a clone of cells in response to binding to an antigen.
28. Using the blue text in the margin of Figure 43.14, explain the four key events to clonal selection.

1. Antigens bind to the antigen receptors
2. The selected B cell proliferates
3. Forming a clone of identical cells
4. Some daughter cells develop into long lived memory cells or plasma cells

29. Graphs similar to the one below have been seen on several AP Biology exams. It depicts the primary and secondary immune response. The first arrow shows exposure to antigen A. The second arrow shows exposure to antigen A again, and also antigen B. Label this graph and then use it to explain the difference between a primary and secondary immune response.

Primary response peaks about 10-17 days after the initial exposure. Secondary immune response occurs next.
Concept 43.3 Acquired immunity defends against infection of body cells and fluids

30. Explain fully the function of the two divisions of acquired immunity.

**Humoral immune response** — antibodies help neutralize or eliminate toxins and pathogens in the blood and lymph.

**Cell-mediated immune response** — in this response, specialized T cells destroy infected host cells.

31. *Helper T cells* play a critical role in activation of both T cells and B cells. In full detail, label and explain the three steps involved using Figure 43.17. This is an important step!

32. Explain the role of *dendritic cells* and *macrophages* in starting a primary and secondary immune response.

Phagocytosis enables macrophages and dendritic cells to present antigens to and stimulate helper T cells.

33. *Cytotoxic T cells* are the effector cells in cell-mediated immunity.

34. What must occur for a *cytotoxic T cell* to become activated?

Require signaling molecules from helper T cells as well as interaction with a cell that presents an antigen.
35. Completely label the diagram below. Then carefully explain the three primary steps that occur as a cytotoxic T cell destroys a target cell.

36. How is B-cell antigen presentation unique?

   The B cell presents only the antigen to which it specifically binds.

37. Completely label the diagram below. Then carefully explain the three primary steps that occur in **B cell activation**.

38. What is the difference between plasma cells and memory cells produced from the activation of B cells?

   Plasma cells and memory cells are different because plasma cells are antibody secreting.
39. Explain how **monoclonal antibodies** are used in home pregnancy kits.

   Are used to detect HCG.

40. Why is the antibody response to a microbial infection **polyclonal**?

   A polyclonal response is one where many different clones of plasma cells form.

41. Explain these three ways antibodies can dispose of antigens.

   **Viral neutralization** — neutralize virus by blocking its ability to bind to a host cell.

   **Opsonization** — promotes phagocytosis.

   **Activation of complement** — activates the complement system.

42. Using examples, explain the difference between **active and passive immunity**.

   **Active immunity** refers to long term defenses that arise when a pathogen infects the body. **Passive immunity** refers to short term immunity conferred by the transfer of antibodies.

43. Describe how **immunizations** can serve as an example of active immunity.

   Active immunity can develop through the introduction of antigens into the body by immunization.

44. Why is immune rejection an example of a healthy immune system?

   An immune rejection is expected from a healthy immune system in response to foreign tissue.

45. Briefly describe the following features of immune rejection.

   a. Explain how antibodies against blood types are present.
      
      Certain bacteria normally present in the body have epitopes very similar to the A and B carbohydrates.

   b. What is the role of MHC in tissue and organ transplants?
      
      MHC molecules stimulate the immune response that leads to rejection.

   c. Why are bone marrow transplants medically unique?
      
      Treatment effectively obliterates the recipient's immune system, leaving little chance of graft rejection.
Concept 43.4 Disruptions in immune system function can elicit or exacerbate disease

46. What are allergies?

Allergies are exaggerated (hypersensitive) responses to certain antigens called allergens.

47. Label Figure 43.23 and then use it to explain a typical allergic response.

48. Explain what happens if a person experiences anaphylactic shock.

Anaphylactic shock is a whole body, life threatening reaction that can occur within seconds of exposure to an allergen.

49. Autoimmune diseases occur when the immune system turns against particular molecules of the body. Describe the cause and symptoms of the following autoimmune diseases.

- **Lupus** - cause skin rashes, fever, arthritis and kidney disfunction.
- **Rheumatoid arthritis** - damage and painful inflammation of the cartilage and bone of joints.
- **Type 1 diabetes mellitus** - targets of autoimmune cytotoxic T cells.
- **Multiple sclerosis** - muscle paralysis through a disruption in neuron function.
50. Explain how immunodeficiency diseases are different from autoimmune diseases.

Diseases that are those in the response of the immune system is defective or absent, such as SCID or AIDS. AIDs, such as rheumatoid arthritis or lupus, can occur while the immune system is active.

51. Just as our immune system has evolved to thwart pathogens, pathogens have evolved to thwart our immune system. Describe the following pathogen strategies.

- **Antigenic variation** — a pathogen alters how it appears to the immune system.
- **Latency** — after infecting a host, some viruses enter a largely inactive state called latency.
- **Attack on the immune system: HIV** — the pathogen that causes AIDS, escapes and attacks the adaptive immune response.

52. Explain how the high mutation rate in surface antigen genes in HIV has hampered development of a vaccine for AIDS. (You might take note that HIV—human immunodeficiency virus—is the virus that causes the disease AIDS—acquired immunodeficiency syndrome. These acronyms are often used incorrectly.)

HIV persists because of antigenic variation.

**Testing Your Knowledge: Self-Quiz Answers**

Now you should be ready to test your knowledge. Place your answers here:

1. _______ 2. _______ 3. _______ 4. _______ 5. _______ 6. _______ 7. _______