MATH AND SCIENCE @ WORK

AP* BIOLOGY Educator Edition

MICROGRAVITY EFFECTS ON HUMAN PHYSIOLOGY: IMMUNE SYSTEM

Instructional Objectives

Students will

- review the structure and function of the immune system and its response to infection;
- examine the effects of microgravity on the suppression of the immune system; and
- evaluate implications of discovering how to control T-cell responses and how it could affect cancer tumor treatments.

Degree of Difficulty

For the average AP Biology student, this problem is at a moderate difficulty level.

Class Time Required

This problem requires 70-85 minutes to be completed over two class periods.

First Class Period: 40-45 minutes

- Introduction (10-15 minutes)

  To engage students and introduce the topic of the immune system in space, discuss the following two articles from Science Daily.

  - *Immune System Compromised During Spaceflight, Study Finds* http://www.sciencedaily.com/releases/2010/05/100514094842.htm
  - *Scientist-Astronaut Sends T-Cells Into Space* http://www.sciencedaily.com/releases/2006/08/060830215111.htm

  After reviewing the articles, discuss the immune system on Earth.

- Student Work Time (30 minutes)
  - Complete question A and B in class.

Student Research (to be completed as homework)

- Complete question C as a research assignment.

Grade Level
10-12

Key Topic
Immune Response

Degree of Difficulty
Moderate

Teacher Prep Time
10 minutes

Class Time Required
70-85 minutes (completed over two class periods)

AP Course Topics
Molecules and Cells:
- Cells

Organisms and Populations:
- Structure and Function of Plants and Animals

NSES Science Standards
- Unifying Concepts and Processes
- Life Science
- Science in Personal and Social Perspectives
- History and Nature of Science

*AP is a trademark owned by the College Board, which was not involved in the production of, and does not endorse, this product.

Second Class Period: 30-40 minutes

- Discuss research assignment in groups and then work together to complete question D. Groups may present answers to the class for a deeper understanding. (20-30 minutes)
- Post Discussion (10 minutes)

Background

This problem is part of a series of problems that apply Math and Science @ Work in NASA's scientific laboratories.

From the beginning of the human space flight era, NASA has been mindful of the need to monitor the health and well-being of its astronauts. Keeping astronauts healthy in space, while researching the effects of microgravity on the human body, became a key priority. The Immunology Laboratory at the NASA Johnson Space Center investigates the effects of spaceflight on various aspects of human physiology. One of the primary areas of research conducted by the Immunology Laboratory is the effect of spaceflight on the human immune system.

The human immune system is a complicated network of different cell types (granulocytes, lymphocytes, monocytes, etc.), that reside in various tissues throughout the body. Immune cells primarily reside in the blood and lymph nodes, and migrate to any tissue where disease or injury may occur. Research suggests that immune system suppression occurs during spaceflight; however, the magnitude and specific nature of the suppression are unknown. Should the immune system remain compromised for the duration of an exploration-class space mission (such as to the Moon or Mars), this would result in greater crew risk for contracting illnesses. NASA researchers are currently conducting studies on Earth and onboard the International Space Station (ISS) to investigate potential countermeasures (or interventions) for immune system suppression during future human space exploration missions.

Figure 1: Astronaut Shannon Lucid receives an immunization from Cosmonaut Yury Usachev in-flight as part of a NASA-Mir experiment designed to examine the effects of long-duration spaceflight on the humoral (antibody producing) arm of the immune system.

AP Course Topics

Molecules and Cells

- Cells
  - Prokaryotic and eukaryotic cells

Organisms and Populations

- Structure and Function of Plants and Animals
  - Structural, physiological and behavioral adaptations
  - Response to the environment

NSES Science Standards

Unifying Concepts and Processes

- Systems, order and organization
- Form and function

Life Science

- The cell

Science in Personal and Social Perspectives

- Personal and community health

History and Nature of Science

- Science as a human endeavor

Problem and Solution Key (One Approach)

Our complex immune system consists essentially of disease-fighting cells that can travel throughout the body. It is a highly regulated system that has multiple cell types that use chemical signals (cytokines) to communicate and respond. Research suggests that our immune system functions different in space than on Earth. NASA scientists are working to determine which parts of the immune response are affected by microgravity.

A. The immune system protects organisms from infection using a series of layered defenses against invading pathogens. The first line of defense consists of surface barriers that prevent pathogens from entering the body.

I. Identify one mechanical, one chemical, and one biological surface barrier and explain how each one protects the body from invading pathogens.

- *Mechanical:*
  - *Skin – provides sealed barrier over large surface of the body*
  - *Lungs – coughing and sneezing mechanically eject pathogens and other irritants from the respiratory tract*
  - *Tears and/or urine – mechanically expel pathogens through flushing action*
  - *Mucus secretions – trap and entangle microorganisms*
- *Chemical:*
  - *Skin and/or respiratory tract – secrete antimicrobial peptides and enzymes*
  - *Saliva, tears, and/or breast milk – contain antibacterial enzymes*
  - *Stomach – gastric acid and proteases protect against ingested pathogens*

- *Biological:*
  - *Genitourinary and/or gastrointestinal tracts- commensal flora serve as biological barriers by competing with pathogenic bacteria for food and space and, in some cases, by changing the conditions in their environment (such as pH or available iron).*

II. Identify at least two of the four types of leukocytes (white blood cells) that are activated as part of the innate immune response and discuss the role of each.

There are two main populations of leukocytes that are involved in the innate immune response: granulocytes and monocytes. Granulocytes may be further subdivided into neutrophils, basophils, and eosinophils. Monocytes mature into macrophages upon activation at a site of tissue inflammation.

- *Neutrophils are agile, short-lived leukocytes, and part of the inflammatory response. They see a microbe, engulf it, kill it with superoxide or hydrogen peroxide, and then digest it. When they die, pus is formed. They are typically seen in shallow cuts/scratches.*
- *Basophils are leukocytes that appear in specific kinds of inflammatory reactions. They contain an anticoagulant, heparin (which prevents blood from clotting too quickly), and the vasodilator, histamine (which promotes blood flow to tissues). Like eosinophils, basophils play a role in both parasitic infections and allergies.*
- *Eosinophils are leukocytes that provide defense against specific kinds of infections including multicellular parasites and viral infections.*
- *Monocytes are heavy-duty macrophages that break apart invading pathogens and present smaller pieces to T cells. They are typically seen in deep puncture wounds.*

III. Two of the most important cells found in the adaptive immune response are B cells and T cells. Describe the origin and specific functions of B cells and T cells in the human immune system.

B cells are made in the bone marrow then migrate to the spleen. They send out antibodies which are proteins that latch onto pathogens or other problem-causing invaders, flagging them to be destroyed.

T cells begin as stem cells in bone marrow and mature in the thymus. They are soldiers of the system, physically attacking and destroying pathogens. With cytokines, immune cells can communicate, recruit other cell types, become activated, and affect pathogen removal. T cells may be further divided by which types of cytokines they produce.

B. NASA scientists believe that astronauts may experience certain factors during spaceflight that can cause suppression of the immune system. These factors include physiological stress, isolation, fatigue caused by heavy in-flight work, demanding exercise schedules, disruptions in sleep patterns and circadian rhythms, and radiation exposure.

I. Identify the three major hormones involved in the ‘fight or flight’ response that can be activated as a result of physiological or psychological stress.

Epinephrine, norepinephrine, cortisol

II. Evaluate how chronic stress and sustained 'fight or flight' responses over time would have a negative impact on the human immune system.

When the 'fight or flight' response is activated, all non-urgent bodily functions (including the immune response) are slowed down. Under chronic stress, the immune system can be lowered enough that the body becomes more vulnerable than usual to bacterial or viral infections.

C. Discuss two observed effects on T-cell function during spaceflight seen in astronauts or in cell culture simulations of microgravity.

- *T-cell function and cytokine production profiles are altered in astronauts during spaceflight.*
- *Some of the steps necessary for the T cell's activation (intracellular signaling, required for cell activation) are inhibited (in-vitro observation).*
- *T cells aren't able to move efficiently (in-vitro observation).*
- *T cells aren't able to signal each other effectively, as cytokine production (occurring after T-cell activation) is greatly reduced during spaceflight (in-vitro observation).*

D. Gaining an understanding of how spaceflight affects an astronaut's immune system would enable scientists to develop countermeasures to correct or alleviate this problem. Potential countermeasures might include medicines, improved diet, altered work schedules, and radiation shielding. This same research could potentially provide countermeasures for diseases on Earth resulting from reduced immune function.

Based on spaceflight research of the immune system, evaluate the impact of T-cell response control and the effects that it could have on cancer patients.

Astronauts may be at increased cancer risk if NK cells do not function normally to eliminate cancer cells. In cancer patients, the ability to control T cells would allow a sustained activation of the immune response in order to vigorously and aggressively attack tumors in an effort to kill them. This could ultimately eliminate or reduce the need for radiation and chemotherapy treatments, which can be ineffective and produce debilitating side effects.

Scoring Guide

Suggested 10 points total to be given.

Question		Distribution of points
A	*4 points*	1 point for correctly identifying and explaining one mechanical, one chemical, and one biological barrier 1 point for correctly explaining origin and function of B cells and T cells 1 point for each type of leukocyte correctly identified with role in the innate immune response explained (2 points maximum)
B	*3 points*	2 points for correctly listing the three hormones 1 point for correctly stating that chronic stress would slow down immune response, thus increasing susceptibility to pathogens
C	*1 point*	1 point for correctly listing two effects of microgravity on T-cell function
D	*2 points*	2 points for correctly stating that you could maximize T-cell attack on cancer cells

Contributors

This problem was developed by the Human Research Program Education and Outreach (HRPEO) team with the help of NASA subject matter experts and high school AP Biology instructors.

NASA Experts

Brian Crucian, Ph.D. – Immunology Lab, NASA Johnson Space Center, Houston, TX

Mayra Nelman – Immunology Lab, NASA Johnson Space Center, Houston, TX

AP Biology Instructor

Teresa Fisher – Manvel High School, Alvin Independent School District, TX