MATH AND SCIENCE @ WORK

AP* BIOLOGY Educator Edition

MICROGRAVITY EFFECTS ON HUMAN PHYSIOLOGY: SKELETAL SYSTEM

Instructional Objectives

Students will

- recall materials, procedures, and results of required AP Biology lab 1: Diffusion and Osmosis;
- understand feedback mechanisms and how homeostasis is maintained; and
- evaluate the physiological impact of bone density loss to various human systems.

Degree of Difficulty

For the average AP Biology student, this problem will be at a moderate level of difficulty.

Class Time Required

This problem requires 60-85 minutes.

- Introduction: 10-15 minutes
- Student Work Time: 30-45 minutes
- Post Discussion: 20-25 minutes

Preparatory Resources

The following resources can be used to gain a better understanding of risks to the skeletal system associated with spaceflight.

- *Appendix A: Microgravity Effects on Human Bone* lists some of the knowns and unknowns that have come from NASA research on the skeletal system and microgravity.
- *Appendix B: Countermeasures that May Prevent Bone Loss* provides a published list of possible countermeasures used to prevent bone loss in space. Some of the advantages and disadvantages of each countermeasure are listed.
- The video, *How Space Exploration Affects Astronauts' Bones* (2:16), may be used before or after reading the background section to engage students about this topic. Download or stream it from: http://www.nasa.gov/multimedia/videogallery/index.html?media_id=14387949

Grade Level
10-12

Key Topic
Feedback Mechanisms, Application of Lab 1

Degree of Difficulty
Moderate

Teacher Prep Time
30 minutes

Class Time Required
60-85 minutes

Technology
Movie player and projector (optional)

AP Course Topics
Molecules and Cells:
- Cells

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

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

- This website details the physiological risks of spaceflight as well as countermeasures that are currently being used and being studied: http://bioastroroadmap.nasa.gov/User/discipline.jsp

Background

This problem is part of a series of problems that apply Math and Science @ Work in NASA's Space Shuttle Mission Control Center.

Since its conception in 1981, NASA has used the space shuttle for human transport, the construction of the International Space Station (ISS), and to research the effects of space on the human body. One of the keys to the success of the Space Shuttle Program is the Space Shuttle Mission Control Center (MCC). The Space Shuttle MCC at NASA Johnson Space Center uses some of the most sophisticated technology and communication equipment in the world to monitor and control the space shuttle flights.

Within the Space Shuttle MCC, teams of highly qualified engineers, scientists, doctors, and technicians, known as flight controllers, monitor the systems and activities aboard the space shuttle. They work together as a powerful team, spending many hours performing critical simulations as they prepare to support preflight, ascent, flight, and re-entry of the space shuttle and the crew. The flight controllers provide the knowledge and expertise needed to support normal operations and any unexpected events.

Figure 1: NASA Surgeon Dr. Jeff Jones (right) and suit technician Bill Welch (left) assist Astronaut Andrew J. (Drew) Feustel as he dons a Mark III advanced space suit.

One of the flight control positions in the Space Shuttle MCC is the Surgeon. This medical doctor, trained in clinical and aerospace medicine, monitors and maintains the astronauts' health during all phases of a given mission, including pre-flight, on-orbit, and post-flight rehabilitation. A Surgeon may be assigned up to a year prior to a mission and will work closely with the crew to optimize their health and physical readiness during training. The Surgeon also provides medical training to crews in areas such as space physiology, toxicology, medical diagnostics, and procedures that might be required on-orbit (such as administering IV's, suturing, and removing foreign bodies from an eye). During a mission, the Surgeon monitors the astronauts' sleep-rest cycles, and monitors environmental parameters, provides crew health consultations, determines readiness for spacewalks, and tracks metabolic rates during spacewalks. Post-flight, the Surgeon evaluates the medical and physiological aspects of returning to the gravity of Earth and guides the subsequent physical exercise and recovery plan.

Note: Refer to Appendix A and B before moving on to the problem.

AP Course Topics

Molecules and Cells

- Cells
  - Membranes

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

Science as Inquiry

- Abilities necessary to do scientific inquiry

Life Science

- The cell

Science in Personal and Social Perspectives

- Personal and community health
- Natural and human-induced hazards

History and Nature of Science

- Science as a human endeavor

Problem and Solution Key (One Approach)

Shifting from an environment with gravity to a microgravity environment causes changes in an astronaut's body. One area of concern for the astronauts' health is the loss of bone density. On Earth, a person's bone density peaks around the age of 30. After the age of 35, the bone density decreases on average by < 1% each year. However, on average, an astronauts' bone density at those same sites decreases by 1 to 2% per month while living in space, even though astronauts exercise and are otherwise healthy individuals. Therefore, astronauts on a 14-day space shuttle mission could lose as much as 0.5-1% bone density at specific sites. This weakening of the astronauts' bones is in a way similar to osteoporosis, a condition in which bones have lost minerals (especially calcium) making them weaker, more brittle, and susceptible to fractures.

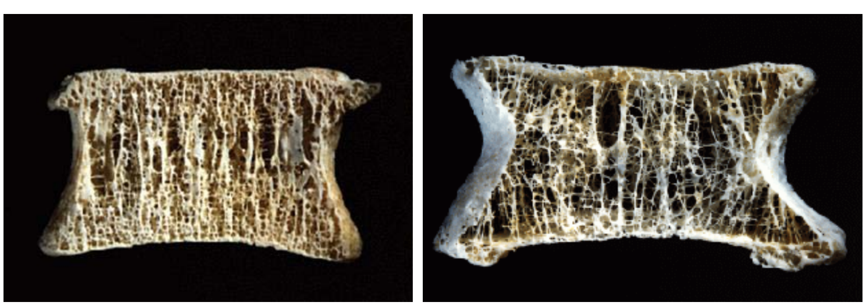

Figure 2: Normal bone compared to osteoporotic bone.
(Source: Mosekilde, L. Z rheumatol 2000; 59: Suppl 1:1-9)

A. Bones are a reservoir for calcium. Osteoclasts are bone cells that break down the bone density by removing calcium from the bone. This calcium will eventually be excreted in the urine. Hormones and other stimuli cause reabsorption and release of calcium ions into and out of the blood. Which cellular movement process will allow the calcium ions to move from the bone into the blood stream? Explain how this could happen.

   One way that calcium ions can be moved from bone cells into the blood is by active transport. The plasma membrane calcium ATPase is a transport protein powered by the hydrolysis of ATP to remove a calcium ion. For each ATP that is hydrolyzed, one calcium ion is removed.

   Another way that calcium ions can be removed from bone cells and into the blood is by the sodium-calcium pump. The sodium-calcium exchanger uses active transport to move calcium ions across the cell membrane via a membrane protein that can transport the calcium ions. This process moves calcium ions at a faster rate than using the calcium ATPase.

B. Homeostasis is the ability to maintain balance or equilibrium in the body. The maintenance of blood Ca^{2+} is maintained by a negative feedback mechanism. Describe the meaning of a negative feedback mechanism in regulating the calcium levels by explaining how the osteoclast activity is affected by hormones.

   Negative feedback refers to a process by which the end product of a reaction inhibits the propagation of that reaction, either directly or indirectly. When calcium levels decline, the parathyroid gland releases PTH which indirectly stimulates osteoclasts to destroy the bone matrix and release calcium ions by increasing the production of 1, 25-dihydroxy vitamin D3 in the kidneys. Once calcium reaches the normal level, the release of PTH stops. When calcium increases above the normal levels, calcitonin is released by the thyroid gland which uppresses bone degradation. Osteoclasts are inhibited from breaking down the bone allowing osteoblasts to form bone resulting in the calcium levels going back to normal.

C. Comparing the bone density loss in an astronaut during a 10-day space shuttle mission versus an astronaut on a 6-month mission on the ISS, would the Surgeon be more concerned about the astronaut on the space shuttle mission or on the ISS? Describe some countermeasures that could be used to rectify this issue.

   The Surgeon will be more concerned for the ISS astronaut because of the bone density loss for the space shuttle astronaut is less than 1%, but the ISS astronaut could experience a 6-12% bone density loss. Because bones with higher bone density are stronger than bones with lower bone density, countermeasures to build or maintain bone include resistive exercises, loading forces on bones during treadmill exercise, nutrition enrichment, and pharmaceutical agents.

Scoring Guide

Suggested 8 points total to be given.

There is one additional point possible; however, students should not receive more than 8 total points for the question, or more than the allotted points per question.

Question		Distribution of points
A	*2 points*	1 point for naming one of the cellular movement processes 1 point for correct explanation of movement process
B	*3 points*	1 point for correctly defining negative feedback mechanism 1 point for the reason why osteoclasts are destroying bone matrix 1 point for reason why osteoclasts stop destroying bone matrix
C	*3 points*	1 point for identifying the ISS astronaut 1 point for each reasonable countermeasure mentioned (2 points maximum) **1 additional point for explaining the reasons why Surgeons would be more concerned for the ISS astronaut in terms of bone loss*

Contributors

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

NASA Experts

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AP Biology Instructors

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Appendix A

Microgravity Effects on Human Bone

Known

Fractures from Bone Loss
Bone loss on extended missions in space could result in fractures in space or on Mars.

Bone Turnover
On Earth old, damaged bone is constantly being removed and replaced with new bone. Both of these functions are adversely affected in space resulting in net bone loss.

Variation in Body Areas
Astronauts may lose bone at different rates in different parts of the body. Some have lost up to 20% bone density in the hip.

Bone Loss Data
Astronauts typically lose bone at the rate of 1 to 1.5% per month in space but only at specific sites of the skeleton.

Types of Bone

Trabecular Bone: located in bone marrow cavity (vertebrae, ribs, ends of long bones).	**Cortical Bone:** found in the shaft of long bones and forms the outer shell around bone marrow compartment.
20% of total skeletal mass.	80% of total skeletal mass.

Bone Turnover Rates on Earth per Year

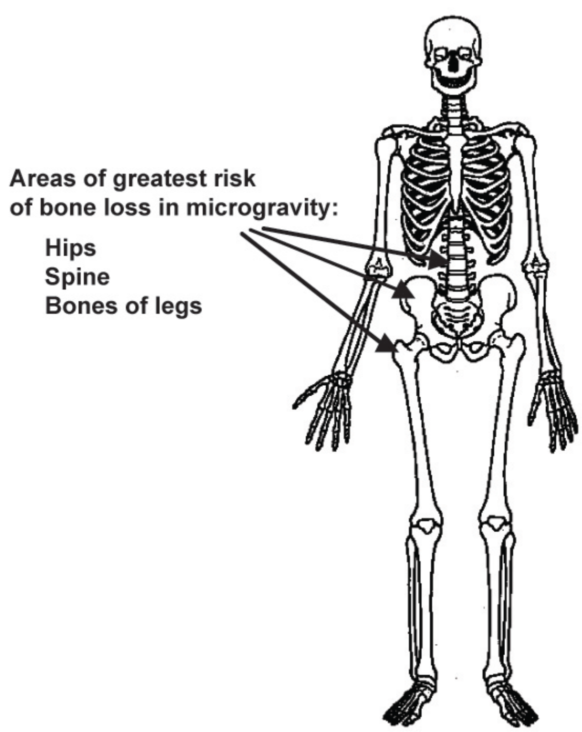
Entire Skeleton	10%
Cortical Bone	3%
Trabecular Bone	25%

Unknown

Type of Human Bone Loss
It is not known the degree to which trabecular bone microstructure is affected in space.

Individual Variables
It is not known what factors influence bone loss in space and to what degree. Gender? Genetics? Amount of exercise done in space? Body chemistry?

Permanent or Long Term Bone Loss
Bone loss could result in some level of permanent changes after returning from missions greater than 100 days with unknown effects on long-term disability.



Appendix B

Countermeasures That May Prevent Bone Loss

It is not known which countermeasures are the best methods to prevent bone loss in space.

Possible Countermeasures	Possible Drawbacks
Exercise Some exercise in space does appear to maintain or increase bone mineral density.	Vigorous exercise in space may not counteract bone loss in trabecular bone compartments.
Medications A medication that helps osteoporosis sufferers maintain bone density might reduce bone loss in space.	It is not known if all medications that works on Earth will work the same in space.
Centrifuge Rides on a short-radius centrifuge in orbit may prevent bone loss. (A bedlike device that rotates at 23 rpm to produce 1 g on the astonaut's feet.)	A centrifuge is a potentially expensive and resource intensive technological addition to a spacecraft.