MATH AND SCIENCE @ WORK

AP* BIOLOGY Student Edition

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MICROGRAVITY EFFECTS ON HUMAN PHYSIOLOGY: SKELETAL SYSTEM

Background

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.

Problem

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.

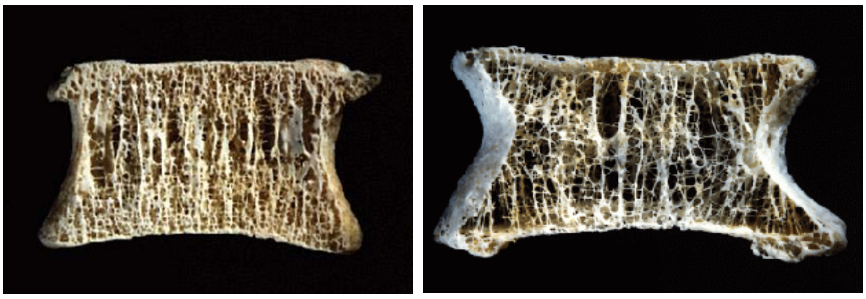


Figure 2: Normal bone compared to osteoporotic bone.
(Source: Mosekilde, L. Z rheumatol 2000; 59: Suppl 1:1-9)

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 happens.

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.

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.

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

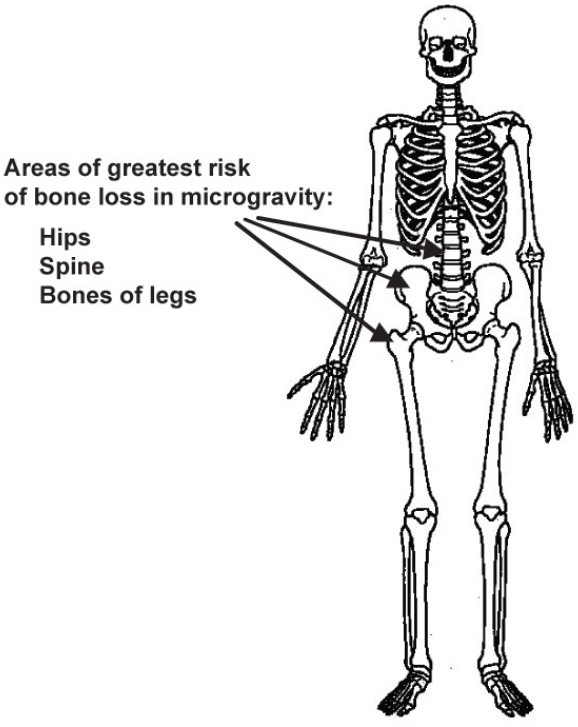
Entire Skeleton	10%
Cortical Bone	3%
Trabecular Bone	25%

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.