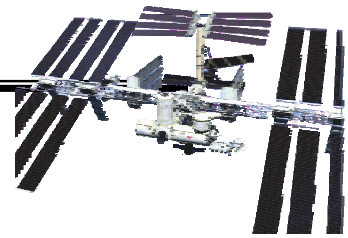
The Skeleton



Inner Space in Outer Space:
A Virtual Astronaut Teacher's Guide

Introduction

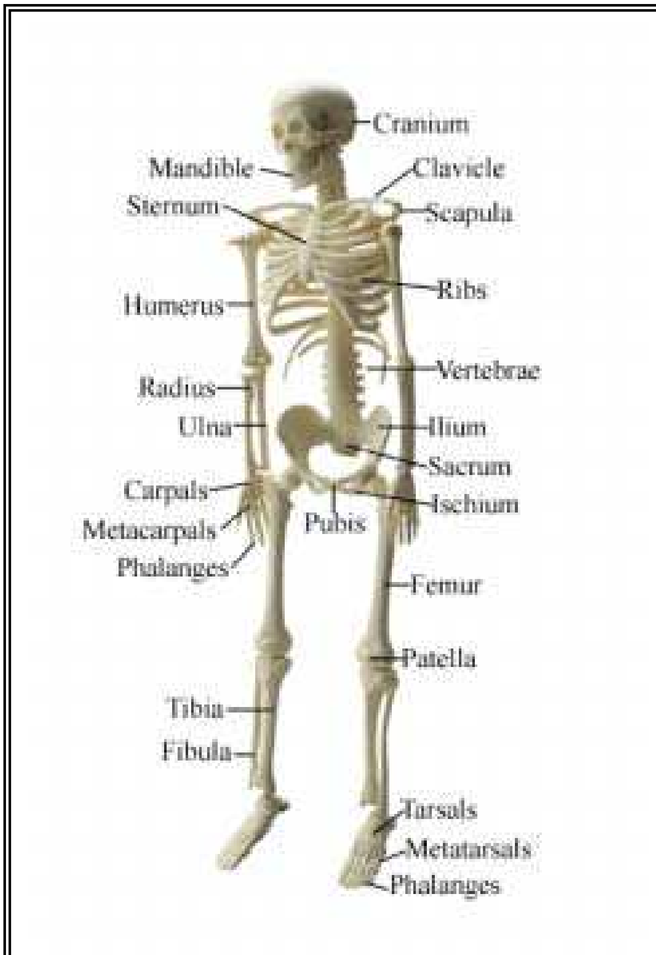
Think about the human body. Now compare it to the body of animals you have seen. Do you notice anything different? The human body is the only one that supports an upright, or *bipedal*, form of locomotion. Over millions of years, the bones of the skeleton have developed in a way that allows us to walk upright on two legs and function against the pull of the Earth's gravity.

What happens, then, when we leave this source of gravity? Once on orbit, astronauts live in **microgravity**: the force of gravity is much, much weaker (virtually zero), and the body no longer needs to counteract it. As a result, the body adapts to its new microgravity surroundings. The changes to bone in particular hold consequences for astronauts once they return to Earth.

Before we can understand how and why bone changes in microgravity, we need an understanding of how bone works on Earth.

Bone on Earth

The 206 bones in the human body come in many sizes and shapes. One of the largest bones of the body, the femur, can be over a foot long, while some of the smallest bones in the body—the pisiform bone in the wrist, or the stapes in the inner ear—are no bigger than a pea.



What do your bones do for you? The first answer that you might come up with is "Bones support my body"—and you would be correct. The skeletal system provides the framework for the human body—and much more. We rely on our bones for many things:

- <u>Support and protection</u>: Bones are an essential component of the body's support system. The skeleton anchors soft tissues like organs, muscles, ligaments, and tendons. It also supports the weight of these tissues. It is easy to visualize the skeleton as the concrete support structure of a building. Just like the concrete of a building protects its inhabitants from the outside elements, the skeleton also protects some of our most vital organs. The thick bones of the skull, for instance, protect the brain. Without this protection, the internal organs would be in danger of injury from slight bumps and falls.

- Storage: The skeleton houses several sources of nutrition and energy. Bone contains **yellow marrow**, where the body stores a reserve of fat cells. These fat cells can be utilized when the body needs a supply of energy. In addition to fat, bones also store essential ions, like calcium, phosphate, hydrogen, potassium, and magnesium. These minerals are used in many systems of the body for a wide range of processes.

- Cell Production: The skeleton is also responsible for the production of blood cells. The soft spongy tissue inside bone called **red marrow** manufactures **red blood cells**, which transport oxygen throughout the body, and **platelets**, which help the clotting process.

- Movement: The skeleton also plays an important role in our ability to walk, jump, sit, stand, and run. In order to create movement, our muscles operate a system of levers—our bones. Without these levers, the muscles will not move.

The structure of bone gives it the strength to protect and support our bodies and the flexibility to absorb the forces generated by some types of movement. The combination of strength and flexibility comes from the **composite** structure of bone. This means that it has both an organic component and an inorganic component. The organic component is composed mainly of **collagen**, long chains of protein that intertwine in flexible, elastic fibers. Collagen is also so strong that a single fiber only one millimeter in diameter can support the weight of a 10-*kilogram* load. **Hydroxyapatite,** the inorganic component, is a calcium-rich mineral that stiffens and strengthens the collagen. Together, the interwoven organic and inorganic components of bone create a sturdy yet flexible skeletal structure able to support the body, absorb the shock of movement, counteract the pull of gravity, and allow us to move.

Bone is a dynamic material; it is constantly changing throughout our lives. The **remodeling** process replaces old bone with healthy new material and also helps heal fractures and breaks. The remodeling process involves three types of cells: osteoblasts, osteocytes, and osteoclasts. **Osteoblasts** form new bone. These cells synthesize and deposit bone material. **Osteocytes**, which are actually mature osteoblasts, maintain mature bone tissue. The third type of bone cell, **osteoclasts**, **resorb** or "eats" older bone tissue. As the calcium in mature bone ages, osteoclasts begin to resorb it, leaving a tiny tunnel. About three weeks later, when they are finished with their meal, the osteoclasts disappear, and osteoblasts enter the tunnel. The osteoblasts redeposit new calcium, leaving the bone healthy and strong. The osteoblasts mature into osteocytes and become embedded in the bone. The bone continues to age and the remodeling process starts again.

The key to the remodeling process is that osteoblasts and osteoclasts work at an equal rate. Osteoblasts lay down the same amount of new bone as the osteoclasts resorb. If the body were to absorb too much calcium from bones (if osteoclasts work faster than osteoblasts), the skeleton would become thin and weak. Consequently, a healthy body never loses more calcium than will be replaced, and the bones maintain a constant strength. As we are about to see, however, exposure to microgravity changes this balance.

Bone in Space

Bone begins to change after an astronaut has lived in microgravity for only a few days. Microgravity reduces the amount of weight that bones must support to almost zero. At the same time, many bones that aid in movement are no longer used as much as they are on Earth. For example, microgravity allows astronauts to "float" effortlessly in one position, so they do not have to use the bones in their legs, hips, or back to sit or stand. When a bone is not used, a biomechanical trigger causes calcium normally stored in the bones to be broken down and released into the bloodstream. This decrease in bone mass density is called **osteoporosis**. Osteoporosis leaves bone weak and less able to support the body's weight and movement upon return to Earth, placing the astronaut at a higher risk of fracture.

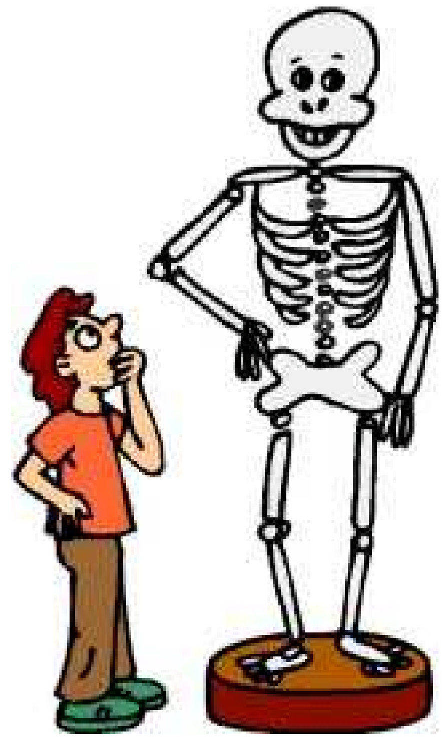
Bone loss begins within the first few days in space. Some astronauts who spent months aboard the Russian space station *Mir* lost as much as 20% of their bone mass. The most severe loss occurs between the second and fifth months in space, although the process continues throughout the entire time spent in microgravity. The exact mechanism that causes the loss of calcium in microgravity is unknown. Many scientists believe that microgravity causes osteoclasts to resorb bone much faster than osteoblasts lay down new bone. The exact trigger for this change has not been found.

Astronauts do not feel the effects of bone loss while they are in space, but they are affected upon their return to Earth. When the force of gravity returns, the skeleton may no longer be strong enough to support the body's weight or counteract gravity. This leaves astronauts at a much higher risk of bone break or fracture.

Microgravity-induced osteoporosis is a serious matter, so doctors and scientists are researching ways to limit or prevent bone loss in astronauts. Throughout the history of space flight, astronauts have always done special exercises to keep their muscles and bones strong. In addition, flight surgeons make sure that astronauts receive dietary and vitamin supplements that give them added protection against bone loss. In the future, it is possible that new types of exercises, diets, or even medication may prevent bone mineral loss—in astronauts and in people on Earth.

Activity #1: Bag of Bones

Objective
Following this activity, the student will be able to
- Identify the effects of decreased bone mass (osteoporosis)
- Describe why healthy bones are important in space and on Earth

National Science Standards


Unifying Concepts and Processes in Science
- Evidence, models, and explanation
- Change, constancy, and measurement

Form and function

Science as Inquiry
- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Life Science
- Structure and function in living systems
- Diversity and adaptations of organisms

Science in Perspective
- Personal health

History and Nature of Science
- Nature of science

National Mathematics Standards
- Mathematics as problem solving
- Mathematics as reasoning
- Mathematical connections
- Computation and estimation

Materials Needed
- Corn puff cereal (approx. 4.5 oz. per group)
- Ziplock snack bags (6 5/8 inch x 3 ¼ inch) - 5 per group (larger bags hold too much cereal to count in a reasonable amount of time)
- Permanent markers for labeling bags
- Heavy books (one per group)
- Student Activity Guide (one per student)
- Broom and dustpan (for clean-up)

Time Required
This activity may be spread out over a two- or three-day period. You may wish to use the first day for discussion and baggie preparation, and the second and third days for experimentation, data collection, and discussion.

Procedure

1. Begin with a discussion of osteoporosis. Ask students if they know anyone—grandparents, for example—who suffers from osteoporosis. Do they know what osteoporosis is? Do they know what causes it?
2. Explain to students that astronauts experience a particular kind of osteoporosis. Describe the effects of microgravity on bone.
3. Tell the students that they are going to investigate bone loss and the effects that it may have. To do this, they will use baggies and cereal to make their own "bones." Explain that each baggie will represent a bone, and the cereal inside the bone will represent the calcium and cells that make the bone strong. Removing cereal from some of the bags will simulate a bone that has lost some of its mass.
4. Distribute cereal, snack bags, and worksheets to students. In order to expedite the experiment, students should work in groups of four; the group can work on Bag 1 together, and then each student is responsible for one additional bag.
5. Students should follow the directions on the worksheet. Note about cereal smashing: some of the cereal has natural holes in it. Explain to students that they should examine the cereal *before* smashing it, so that they have a reference point when counting unaffected pieces after the smashing step. In addition, *one* student should be responsible for smashing *all* of the bags, so that the amount of force will be the same on each bag.
   Discuss what students should look for when they are counting "affected" pieces of cereal. Pieces that have dust (from other smashed pieces) or only a tiny flake taken off should not be counted as "affected."
6. After the students have completed the activity, bring the group back together. Ask each group to share their results with the class. Discuss the results and the follow-up questions.
7. If some groups' results did not come out as expected (i.e., density did not drop), discuss the possible reasons for this. Answers may include miscounting, uneven force applied when smashing bags, etc. Can students think of another way to test their hypotheses?

Extensions

1. Have students graph the data from their investigations to explore the relationship between bone density and amount of damage.
2. Compare group outcomes to demonstrate that results always vary—and are often unexpected. Emphasize that science is often indefinite, but always involves *systematic* study.
3. Investigate other risk factors for osteoporosis, including health, ethnicity, age, etc. Explore ways in which students can change their lifestyles now so that they may avoid osteoporosis in the future.

Assessment

Student worksheets and classroom discussion may be used for assessment.

Bag of Bones

Osteoporosis is a loss of bone mass. It makes bones weak and fragile, which can make it very easy to fracture or break a bone. Low bone mass can be a problem throughout a person's life, but it may not be until late in life that full-blown osteoporosis develops. In fact, many people do not realize that they have osteoporosis until one of their bones fractures after a minor slip or fall.

Osteoporosis is a big problem in the world today. In the United States alone, two million men and eight million women have osteoporosis, and another eighteen million men and women are at risk for this disease. It is not limited to one group of people, either. As many as 50% of Caucasian and Asian women are at the highest risk. More than ten percent of Hispanic and African-American women also run the risk of osteoporosis.

Astronauts who spend more than a week in space also suffer from a form of osteorporosis. This type, called **disuse osteoporosis**, occurs when astronauts do not use their bones in space in the same way that they do on Earth. For example, the bones used in standing and walking on Earth are not used nearly as much in space, because astronauts spend much of their days "floating" and propelling themselves with their arms. By the end of their mission, astronauts lose bone mass in their legs and hips, which leaves them at risk for fracutures and breaks when they return to Earth's gravity. Although astronauts eventually regain most of their bone mass, they may not fully recover. It is important, both for future astronauts and for our health here on Earth, that researchers learn all that they can about why osteoporosis occurs, and how we can prevent it.

Using every-day bags and cereal to represent bone, and a heavy textbook to represent an unexpected force (like a bump or a fall), you will see how low bone mass affects bone, and why it is important that astronauts and people on Earth do everything they can to prevent osteoporosis.

Get Ready

- 5 snack bags
- Corn puff cereal
- A very heavy book (like a dictionary)
- A broom and dustpan (for clean-up)
- Permanent marker
- Pen or pencil

Think about it

- Why is it important to have strong, healthy bones?

- What will happen if your bones become weak?

Formulate your hypothesis

What do you think will happen to a bone (in this case, represented by your baggie and cereal) if force is suddenly applied to it? Will the results change if the bone is progressively weakened?

Collect the data and test your hypothesis

1. Using a permanent marker, label the bags 1-5.

2. Bag 1 will represent a healthy bone on Earth. To build a "bone" you will use pieces of cereal to represent individual units of bone mass. Fill the bag with enough cereal so that the bag is very full and there is very little air in it, but not so full that you cannot close it. Keep track of how many pieces of cereal you put into the bag, and record this on your worksheet as **Normal Bone Density.** Close the bag, and make sure it is closed *tightly*—otherwise you may wind up with a very big mess!

3. To represent a bone that has lost mass as a result of spaceflight or aging, you now need to fill each bag with less cereal, or bone mass, than is in Bag 1.
   Bag 1: 0% bone loss (normal bone)
   Bag 2: 90% of original bone remains; 10% original bone lost
   Bag 3: 80% of original bone remains; 20% original bone lost
   Bag 4: 65% of original bone remains; 35% original bone lost
   Bag 5: 50% of original bone remains; 50% original bone lost

To calculate the amount of cereal you need in Bag 2, you will need to calculate 90% of **Normal Bone Density**. Fill Bag 2 with this amount. This represents a loss of 10% of the bone mass.

4. Use a similar method to calculate 80%, 65%, and 50% of the Normal Bone Density, and fill Bags 3, 4, and 5 with these amounts. Record the amount of bone left in each bag on your worksheet.

5. Now you are ready to see what effects a sudden force may have on weakened bones. Place Bag 1 on a hard surface. Then, quickly and carefully, but forcefully, smash the heavy book onto the bag. Again using the same amount of force, smash the remaining bags.

6. What happened to your bones? Count the number of *unaffected* cereal pieces left in each bag, and record this on your worksheet.

7. How much of the bone was unaffected? To calculate this, use the formula below and record your values on your worksheet.

$$\left[\text{\# unaffected remaining in the bag} \div \text{original density of the bag}\right] \times 100$$

8. How much of the bone was affected? To calculate this, subtract the Unaffected Bone value from 100%. Record your values on your worksheet.

Bag of Bones Worksheet

Normal Bone Density=__________ pieces of cereal in Bag 1
Density of Bone 2 = 90% of Bag 1 = ________ pieces of cereal
Density of Bone 3 = 80% of Bag 1 = ________ pieces of cereal
Density of Bone 4 = 65% of Bag 1 = ________ pieces of cereal
Density of Bone 5 = 50% of Bag 1 = ________ pieces of cereal

Before the Experiment			After the Experiment		
Bag	Bone Loss Represented	Density (# of cereal pieces in bag)	# of unaffected pieces	% of bone unaffected	% of bone affected
1	0%				
2	10%				
3	20%				
4	35%				
5	50%				

Analyze the results

What happened as the amount of cereal decreased?

Now imagine that your baggie bone is actually a real bone. If a real bone were built like your baggie bone, what would happen if a sudden force (like a bump or fall) were applied to the bone?

Do your findings support your hypothesis? Why or why not?

How do you think we can prevent bone loss?