BioEd℠

THE SCIENCE OF MUSCLES AND BONES

Bone Structure: Hollow vs. Solid

by
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RESOURCES
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BCM
Baylor College of Medicine

ISBN-13: 978-1-888997-82-8

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Teacher Resources from the Center for Educational Outreach at Baylor College of Medicine. The mark "BioEd" is a service mark of Baylor College of Medicine.

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ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of Bobby R. Alford, M.D., Laurence R. Young, Sc.D., Ronald J. White, Ph.D., and William A. Thomson, Ph.D., as well as the contributions of the following reviewers: Cassius B. Bordelon, Jr., Ph.D., Greg Byrne, Ph.D., Paula Cutler, Maithili Daphtary, Ph.D., Michael Grusak, Ph.D., Kathy Major, Grant Schaffner, Ph.D., and Carola Wright, Ph.D. Preparation of this guide would not have been possible without the invaluable assistance of the following field test teachers: Cheryl Anderson, Dorothy Arceneaux, Cathy Bucchino, Veronica Curry, Sharon Fontaine, Lollie Garay, Delores Hall, Marilyn Manning, Demetria Rutherford and Kim Walker.

This work was supported by National Space Biomedical Research Institute through NASA NCC 9-58.

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TEAMING WITH BENEFITS

by Jeffrey P. Sutton, M.D., Ph.D., Director, National Space Biomedical Research Institute (NSBRI)

Dr. Jeffrey P. Sutton

Space is a challenging environment for the human body. With long-duration missions, the physical and psychological stresses and risks to astronauts are significant. Finding answers to these health concerns is at the heart of the National Space Biomedical Research Institute's program. In turn, the Institute's research is helping to enhance medical care on Earth.

The NSBRI, a unique partnership between NASA and the academic and industrial communities, is advancing biomedical research with the goal of ensuring a safe and productive long-term human presence in space. By developing new approaches and countermeasures to prevent, minimize and reverse critical risks to health, the Institute plays an essential, enabling role for NASA. The NSBRI bridges the research, technological and clinical expertise of the biomedical community with the scientific, engineering and operational expertise of NASA.

With nearly 60 science, technology and education projects, the NSBRI engages investigators at leading institutions across the nation to conduct goal-directed, peer-reviewed research in a team approach. Key working relationships have been established with end users, including astronauts and flight surgeons at Johnson Space Center, NASA scientists and engineers, other federal agencies, industry and international partners. The value of these collaborations and revolutionary research advances that result from them is enormous and unprecedented, with substantial benefits for both the space program and the American people.

Through our strategic plan, the NSBRI takes a leadership role in countermeasure development and space life sciences education. The results-oriented research and development program is integrated and implemented using focused teams, with scientific and management directives that are innovative and dynamic. An active Board of Directors, External Advisory Council, Board of Scientific Counselors, User Panel, Industry Forum and academic Consortium help guide the Institute in achieving its goals and objectives.

It will become necessary to perform more investigations in the unique environment of space. The vision of using extended exposure to microgravity as a laboratory for discovery and exploration builds upon the legacy of NASA and our quest to push the frontier of human understanding about nature and ourselves.

The NSBRI is maturing in an era of unparalleled scientific and technological advancement and opportunity. We are excited by the challenges confronting us, and by our collective ability to enhance human health and well-being in space, and on Earth. ◆

NSBRI RESEARCH AREAS

CARDIOVASCULAR PROBLEMS

The amount of blood in the body is reduced when astronauts are in microgravity. The heart grows smaller and weaker, which makes astronauts feel dizzy and weak when they return to Earth. Heart failure and diabetes, experienced by many people on Earth, lead to similar problems.

HUMAN FACTORS AND PERFORMANCE

Many factors can impact an astronaut's ability to work well in space or on the lunar surface. NSBRI is studying ways to improve daily living and keep crewmembers healthy, productive and safe during exploration missions. Efforts focus on reducing performance errors, improving nutrition, examining ways to improve sleep and scheduling of work shifts, and studying how specific types of lighting in the craft and habitat can improve alertness and performance.

MUSCLE AND BONE LOSS

When muscles and bones do not have to work against gravity, they weaken and begin to waste away. Special exercises and other strategies to help astronauts' bones and muscles stay strong in space also may help older and bedridden people, who experience similar problems on Earth, as well as people whose work requires intense physical exertion, like firefighters and construction workers.

NEUROBEHAVIORAL AND STRESS FACTORS

To ensure astronaut readiness for spaceflight, preflight prevention programs are being developed to avoid as many risks as possible to individual and group behavioral health during flight and post flight. People on Earth can benefit from relevant assessment tests, monitoring and intervention.

RADIATION EFFECTS AND CANCER

Exploration missions will expose astronauts to greater levels and more varied types of radiation. Radiation exposure can lead to many health problems, including acute effects such as nausea, vomiting, fatigue, skin injury and changes to white blood cell counts and the immune system. Longer-term effects include damage to the eyes, gastrointestinal system, lungs and central nervous system, and increased cancer risk. Learning how to keep astronauts safe from radiation may improve cancer treatments for people on Earth.

SENSORIMOTOR AND BALANCE ISSUES

During their first days in space, astronauts can become dizzy and nauseous. Eventually they adjust, but once they return to Earth, they have a hard time walking and standing upright. Finding ways to counteract these effects could benefit millions of Americans with balance disorders.

SMART MEDICAL SYSTEMS AND TECHNOLOGY

Since astronauts on long-duration missions will not be able to return quickly to Earth, new methods of remote medical diagnosis and treatment are necessary. These systems must be small, low-power, noninvasive and versatile. Portable medical care systems that monitor, diagnose and treat major illness and trauma during flight will have immediate benefits to medical care on Earth.

For current, in-depth information on NSBRI's cutting-edge research and innovative technologies, visit www.nsbri.org.

OVERVIEW

Students investigate and compare the weight-bearing capacity of solid and hollow cylinders, make inferences about bone structure and observe the interior of cleaned long bones of chickens.

ACTIVITY

Bone Structure: Hollow vs. Solid

Bones are living tissues that contain blood vessels and nerve cells within a structure composed of collagen (a flexible fibrous material) and minerals (mainly calcium and phosphate). Without calcium (in the form of calcium salts), bone would be flexible and soft, and without collagen fibers, bone would be brittle. The collagen fibers and calcium salts together make bone almost as strong as steel, but much lighter. Unlike steel, bone can repair itself when broken with the help of bone-forming cells (osteoblasts) and bone digesting cells (osteoclasts). The prefix "osteo" means bone.

To provide support and still be easy to move, bones must be both strong and lightweight. These features are most important for the long bones in arms, legs and wings.

Each human long bone is composed of a shaft (diaphysis) with two flared ends (epiphyses). The diaphysis resembles a hollow cylinder. It is made of hard compact bone that is resistant to bending. The inner cavity of the diaphysis contains yellow marrow that stores fat. The epiphysis is a thin shell of compact bone filled with a lattice or sponge-like structure that is surrounded by red marrow (which makes red blood cells).

SCIENCE, HEALTH & MATH SKILLS

GRADES 5–8

- Predicting
- Observing
- Comparing
- Weighing
- Gathering data
- Recording data

CONCEPT

- Long bones are made of hollow tubes, which give strength with minimal weight.

TIME

10 minutes for set-up; one or two sessions of 45–60 minutes for activity

MATERIALS

- Heavy-weight balance or bathroom scale
- Poultry scissors or small saw

Each group will need:

- 2 bathroom-sized paper cups
- 6–10 heavy, stackable weight units (bricks, cans, reams of paper or books)
- 1/3 cup dried beans
- 1 long bone from a chicken leg or thigh that has been cooked and cleaned (see Setup)
- Magnifiers
- Sheet of corrugated cardboard
- Copy of student sheets

SETUP & MANAGEMENT

If you wish, you can use the long bones prepared for the activity, "The Human Skeleton." Otherwise, before class, cook enough chicken legs or thighs to provide one long bone to each group, or have students bring leftover cooked chicken bones from home. Remove all meat from the bones (additional boiling may be necessary) and soak them in a 1:10 bleach/water solution for five minutes.

Calcium

The mineral calcium gives bones their hardness. People between 11 and 24 years of age need 1,200 milligrams of calcium (three or more servings of calcium-rich foods) each day. Sources of calcium include low-fat dairy products, sardines, green leafy vegetables and nuts.

Losing Calcium?

Chalk is brittle and snaps apart easily. A chicken bone will not snap in half the same way. Although a chicken bone has calcium salts like chalk, the bone also has collagen fibers that make it stronger.

When we remove calcium salts from bone, it becomes flexible and cannot maintain its shape to provide support.

Baby Bones

Babies' bones are very soft and are made of cartilage. Over time, cartilage is broken down and replaced with bone.

Safety Issues

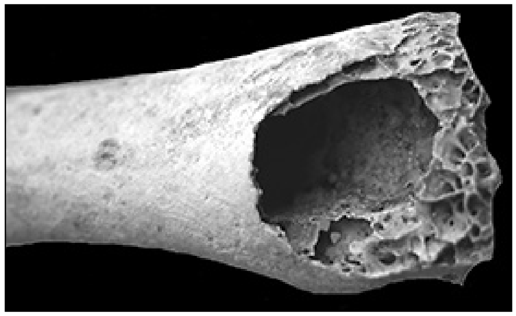
Please read "Setup & Management," and follow all school district and school laboratory safety procedures. It always is a good idea to have students wash hands before and after any lab activity.

Bone Recycles!

A group of special cells constantly breaks down and rebuilds bones throughout life. This process is important because it allows bone to repair damage and to respond to changes in its environment, including changes in physical activity.

Animals Without Bone Marrow

Manatees and their relatives live and feed in water. Their rib and leg bones lack marrow cavities, making their skeletons dense and relatively heavy. Water, however, helps support the weight of their bodies.



Hollow areas inside bird bones, like the ulna shown above, lighten the skeleton's weight.

Place all materials in a central location. Have students work in groups of 2–4.

PROCEDURE

1. Point to your arm or leg and ask students to think about characteristics that might be important for large arm or leg bones. Stimulate their thinking by asking questions such as, *What type of work does my arm/leg do? Does it matter how much the bones in my arm/leg weigh? Does it matter if my arm/leg bones are very strong?* Based on students' answers, make a list of desirable characteristics of long bones.
2. Tell students they will be conducting an investigation that will provide clues about the structure of long bones in humans and other vertebrates. Specifically, they will be comparing the relative abilities of solid and hollow cylinders to support external weights. Ask, *Is a hollow cylinder or a solid cylinder able to support more weight, relative to its own weight?*
3. Have each group's Materials Manager and a helper collect two paper cups, beans, cardboard and a set of weights. Using the "Weighing 'In'" sheet as a guide, have students compare the weights that can be supported by a hollow cylinder (empty cup) and a solid cylinder (cup filled with dried beans). Each group should conclude its explorations by calculating the ratio of weight supported to cylinder weight for each kind of cylinder.
4. Initiate a class discussion of students' results by asking, *Which cylinder was heaviest?* (solid), and *Which cylinder held the most weight?* (solid). *Did either cylinder hold more weight than you expected? Which cylinder had a higher ratio of weight supported?* (hollow). *Did you expect this result?*
5. Ask students to think about which type of cylinder (hollow or solid) might make a better bone. Pass out the "Hollow or Solid?" student sheet. Have students record their predictions about the structure of long bones (hollow or solid).
6. Have the Materials Managers pick up one or more bones for their groups. Have students observe the outsides of the bones with and without a magnifier, and draw an exterior view of a bone in the space provided on their sheets.
7. Using a small saw, hammer or poultry scissors, cut or break open the bone(s) for each group. Students will observe that the bones have hard walls and a central space filled with a soft substance (marrow). Ask students to compare the structure of the bone to the hollow and solid cylinders. Ask, *Which cylinder does the bone most resemble?* Help students to conclude that the relatively hollow design of real bones allows them to be light, but still strong enough to do their jobs. Relate students' conclusions to the list of valuable characteristics of bones made earlier.

EXTENSIONS

• The thighbone (femur) is the longest bone in the body. Its shaft is round in cross section. The main shinbone (tibia) is the second longest bone in the body. Its shaft is triangular in cross section. Challenge students to investigate the relative strengths of different-shaped columns. Have students use note cards to create columns with different shapes in cross section (round, square, triangular, etc.). Ask them to consider the total amount of material necessary to build each kind of column as they reach their conclusions about relative strength.

• To observe how calcium contributes to the hardness of bones, have students soak cleaned chicken bones in vinegar for about one week. Vinegar, a weak acid, will leach calcium out of the bones, which then will become weaker and softer. ◆

ACTIVITY

WEIGHING "IN"

Use stackable weight units to investigate the support strength of hollow and solid cylinders. You will need 2 paper cups, dried beans, a piece of cardboard, a balance, and a set of stackable weight units (cans, bricks, etc.).

1. Fill one paper cup to the top with beans. This will be your solid cylinder. The other (empty) cup will be your hollow cylinder.
2. Use a balance to weigh each cylinder and one stackable-weight unit. Record the weights in the table on the right.
3. Predict how many units (bricks, books or cans) each cylinder will support. Record your predictions in the table below.
4. Place your hollow cylinder on the floor and cover it with a piece of cardboard, so that the cardboard is centered over the cylinder. Place the weight units on top of the cardboard, one at a time. Balance the weights carefully so that your experiment does not topple over. See how many units of weight the cylinder will hold before it is crushed. Record this number below.
5. Repeat Step 4 using the solid cylinder instead of the hollow cylinder.
6. Determine the ratio of weight supported by each cylinder. Divide the total number of weight units supported by the cylinder, by the weight of that cylinder. Record your answers below.

Solid cylinder (with beans)	gm
Hollow cylinder	gm
One stackable-weight unit	gm

	Hollow Cylinder	Solid Cynlinder
PREDICTION: Number of units each cylinder will support		
Number of units supported by each cylinder		
Total weight of units each cylinder supported		
Weight of cylinder		
Number of units supported divided by weight of cylinder		

7. Which cylinder was heavier?

____

8. Which cylinder is able to support more weight, relative to its own weight?

____

ACTIVITY

HOLLOW OR SOLID?

1. Based on what you know, do you predict that real bones are solid or hollow?

2. Give a reason for your prediction.

3. Obtain a cooked, cleaned chicken leg bone. Follow the instructions underneath the boxes below.

Observe and draw the outside of the bone.

Your teacher will break open the bone. Draw what you see inside the broken end.

4. Are most real bones solid or hollow?

5. What might be some advantages of this structure?