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Making Some Bones About It

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ISSUES IN-DEPTH

Making some bones about it

Bone is the Rodney Dangerfield of organ systems. It gets no respect. We hang our organs on it, we bend it, we weigh it down, and we ask it to perform throughout our lifetime without praise. While most people regard bone as a static entity in our body, this is a serious misconception and one that should be corrected early because bone health is a concern for people of all ages—not just the elderly. While bone tissue is primarily for protection and structural support, it is among the most important of tissues in our body because bones have significant metabolic features. This article will address some of the features of bone, its cell types, the metabolic role that this important tissue has in our body, and ways we can help students to better understand bone and why it is important to their overall health—both now and in the future.

Bone basics

Bone tissue forms our skeleton and enables us to produce varied motions, including gross motor tasks like walking and running, as well as fine motor skills like talking and moving our fingers. Bones also protect vital organs such as the brain, liver, spleen, and heart. Bones contribute to the development of blood and have a complex hormonal role to play. With considerable range in size, they can be as large as the *femur* (the prominent thigh bone) or as small and delicate as the *incus*, located in our middle ear. After studying bone tissue for a little while, students would not be mistaken to believe that bone is the “coolest” of all tissues in the body and is worthy of their time and attention.

Bone components

Bone *matrix* is even more fantastic than Keanu Reeves could imagine. The matrix is a dense material occupied by calcium and potassium salts. These salts form a crystalline structure. Collagen fibers are interspersed in the matrix to provide framework on which these crystals can form. The collagen material is very flexible and incredibly strong when subjected to tensile (pulling) forces. Matrix is the cement that confers strong resistance to compression; it is inflexible and very brittle. Consequently, the matrix is analogous to steel-reinforced concrete. But, unlike concrete, the matrix is not a static entity—it is constantly being remodeled. There are cells that continuously degrade the matrix, placing



calcium in the bloodstream, while there are other cells laying down new matrix simultaneously.

The matrix contains several cell types: *osteoblasts*, *osteocytes*, and *osteoclasts*—they are bone builders, bone monitors, or bone destroyers.

- Osteoblasts are cells that are responsible for laying down the matrix. They make and release proteins into the matrix to promote the deposition of calcium salts into bone tissue. This process is known as *osteogenesis* and is the primary way bone is “built.”
- Osteocytes are the most abundant of cell types in bone. Osteocytes occupy a lake-like space called a *lacuna*, which is surrounded by the matrix. The lacuna holds only one osteocyte and, because it is surrounded by the matrix, it uses narrow passageways to communicate with other cells that are a great distance away. These narrow passageways, called *canaliculi*, radiate through the matrix to allow nutrients to reach the osteocyte. While it does not receive blood flow directly, the osteocyte receives hormones, nutrients, and gases from a distant capillary. The osteocyte functions as a bone monitor, releasing chemicals and signaling other cells about the quality

of the mineral content in the matrix. Secondly, the osteocyte participates in the repair of damaged bone tissue, so it can also be considered an ancillary bone builder. If a bone is compromised or broken, the broken lacuna releases an osteocyte that transforms into another cell type to promote bone growth and repair.

- The osteoclast is a cell that is derived from our immune system and is responsible for secreting materials into the matrix that liberate calcium into our bloodstream. In other words, the osteoclast breaks down bone tissue. Unlike the osteoblast, with only one nucleus, the osteoclast is a huge cell containing 50 or more nuclei. It is like a giant Death Star following around the osteoblasts, degrading the matrix (imagine the conflict when Darth Vader meets Keanu Reeves' Neo).

Together, these three cell types control the growth and maintenance of bone tissue. If the work of the osteoblast exceeds that of the osteoclast (construction > deconstruction), then there is a relative net gain in the mass of bone tissue. When the osteoclasts work at a rate greater than the osteoblasts (deconstruction > construction), then there is a net bone loss. Growing and developing middle school students should be experiencing a net gain of bone mass, while teachers are hopefully experiencing an even distribution of workload between osteoblasts and osteoclasts in order to maintain their bone mass.

Bone tissue is covered by a fibrous layer called the *periosteum*. This outer membrane is rich in blood flow and nerve supply. It isolates the bone tissue from surrounding extracellular environments and other organ systems. Literally, it is the skin of your bones. The periosteum is continuous with a specialized form of cartilage where bones meet other bones, i.e., joints.

Bone construction and deconstruction

The organic and mineral composition of bone is always going through a process of building up and tearing down. We call these events *remodeling*. Bone remodeling is underway throughout the entire life of an individual, although some bones remodel more quickly than others. The bones of the femur, for example, may be completely remodeled in six months while some of the bone in the skull may take 10 years to completely remodel. One-fifth of a young adult's bone mass is remodeled every year. In a very real sense, our bones are continuously replaced.

Bone remodeling also occurs in response to physical stress. When we are born, our bones are extremely smooth because we haven't had a long history of mov-

ing; but, as we develop and mature, bones develop ridges, grooves, and protuberances as a consequence of the muscles pulling against bone. The greater the forces placed on bones, the more pronounced these bumps and ridges become. This remodeling in accordance to the loads placed upon it is known as *Wolff's Law*. Regular exercise is an important component to the development of bone tissue in young people and continues to be important in adult or fully matured bone. After prolonged exposure to weightlessness, as experienced by astronauts, there is a degenerative change to bone in which bone mass is lost, bone architecture is changed, and mineral deposits within bone are altered. While most of us will not go into space, the lesson here is that without normal stress on the bone, its quality is compromised with potentially serious effects on overall health. It has been shown that just a few weeks of bed rest or exposure to space flight will result in a loss of one-third of bone mass. This finding has significant implications for today's youth who adapt sedentary lifestyles and avoid exercise.

Bone shapes and sizes

Bones come in a remarkably diverse array of shapes and sizes. The *pisiform* bone of the wrist is about the size of a small pea, but without it we would not have the wrist flexibility we enjoy. The bones of the skull are flat with jagged edges, but when linked together form a relatively smooth and uniform surface. The bones of the arms and legs tend to be long and thin, in contrast to the kneecap, which is rounded and flatter. It is remarkable that bones differentiate so commonly in humans and yet with a little training, one could easily identify a leg bone and indicate if it is male, female, young, old, and in certain instances, its ethnicity. As uniform as bones are between humans, they share structure and function with other mammals in a remarkable continuity of genetic manifestation.

Bones must respond to forces but cannot be compromised by weight. In our distant past, the bones of the human body needed to be light enough to outrun predators, but strong enough to withstand an assault if caught. There are four general classifications of bone shape. The *long bones* have a shaft; are generally denser around the periphery; are usually very light; and are found in the arms, legs, fingers, and toes. *Short bones* are generally cube-shaped, and include the wrist and ankle. Short bones also include a subclass of bones called *sesamoid* bones. Sesamoid bones are unique in that they are often misunderstood by the general public. An example of a short bone, sesamoid-type, is the kneecap. Most people believe that the kneecap is for the

protection of the knee joint when, in fact, this sesamoid bone allows an improved mechanical advantage of the quadriceps muscle to extend the lower leg. We could not kick a ball or jump in the air without this important bone—the kneecap in particular speaks to the diversity of bone tissue.

Flat bones are bones that are thin, flattened, and often curved. The bones of the ribs and the skull are examples of flat bones. The bones of the skull are joined together through the union of jagged edges called *sutures* while the bones of the rib articulate with the irregular bones of the spinal column. Other examples of irregular bones are the bones of the hip and the three bones of the middle ear (the *incus*, *stapes*, and *malleus*). So, if your students can step back and imagine the huge diversity in structure and function of bone tissue, they can pat themselves on the irregular bone of the lower shoulder girdle (the scapula)!

Bones as supply sources

Our bones also serve as a vast reservoir for minerals. Locked in the matrix are calcium, potassium, magnesium, manganese, and other elements that can be released to the bloodstream in times of dietary privation. This is why we can tolerate a variety of nutritional assaults on our body and still, over the long run, maintain a high degree of health. Furthermore, much of the structural integrity of bone is found at its peripheral margins. This leaves the center of some bones (the bone marrow) with the ability to harbor cells that make blood and store fat.

Bone health

Nutritional and hormonal factors contribute significantly to bone health. Because of the constant remodeling of bone tissue in which calcium salts are lost to the blood, there must be a continuous influx of new calcium from dietary sources. Lesser amounts of minerals like iron, fluoride, manganese, and magnesium are also essential. One would think that as osteoclasts take the calcium *out* of bone and render it to the bloodstream that osteoblasts would take this calcium from the bloodstream and simply put it back *into* the bone being formed. This is not the case, however. The calcium lost as a consequence of osteoclastic activity is removed from the body through normal urinary processes. Consequently, in order for the osteoblast to build bone, exogenous calcium sources must be available in the diet.

A startling fact about bones is that more than half of adult bone calcium is acquired during adolescence. However, elevated calcium in the diet is not a

guarantee that calcium will be taken up by the bone tissue. In order to facilitate calcium placed in the matrix, vitamin D must be either synthesized through our skin and exposure to sunlight or taken up as vitamin D₃ in some of our food products, like milk. Vitamin D is activated by parathyroid hormone to increase calcium absorption from the intestinal tract. Quite frankly, eating large amounts of calcium alone will ensure nothing but lots of calcium in your feces. It is vitamin D that enables the transport of calcium across the intestinal wall and into your bloodstream for potential uptake by the osteoblasts. As calcium increases in the blood, parathyroid hormone is inhibited, thus regulating how much calcium can be absorbed. Adequate levels of vitamin C are required by enzymes related to osteoblast development. One doesn't have to see *Mutiny on the Bounty* to recognize scurvy is a condition characterized by a loss of bone mass and strength. The British ruled the seas in large part through their recognition of this important vitamin-to-bone relationship. They would bring limes on board their ships to prevent scurvy and were given daily rations of this vitamin C-rich food, thus enabling longer ocean voyages. The term "limey" for people of British descent persists from this practice.

People who rely on nutritional supplements for their calcium have to know what they are taking so they know when to take it for maximum absorption. The concepts of *bioavailability* and *solubility* are important here; one must know that when it comes to calcium, bioavailability and solubility are not equivalent. In truth, almost all calcium supplements have the same bioavailability if they are taken with food (meaning, at a meal). Calcium carbonate and calcium citrate are the two most common calcium supplements on the market (although there are others). Calcium carbonate requires stomach acid to break down the calcium so that it can be absorbed into the bloodstream; calcium citrate is far more soluble. However, when taken with food, their bioavailability is nearly equal. Another misconception is that the calcium supplement will be 100% absorbed if it is 100% soluble—absorption is dependent on many additional factors and can be inhibited by high sodium levels, low magnesium, low vitamin D, low vitamin C, high phytic acid (found in whole grains) levels, use of tobacco, coffee consumption, and certain diseases. The lesson to be learned here is that any calcium supplement should be taken with meals and needs to be a part of a comprehensive plan for bone health, not the sole component of the plan.

Bone health and disorders

Society is too quick to embrace the notion that as people age, their bones automatically become thinner and weaker. This syndrome, known as *osteopenia*, can be avoided. It is not unreasonable to expect your body to continue maintaining bone mass throughout the rest of your life, if you have adequate nutrition and exercise. Most of us, however, see a reduction in bone mass beginning at age 30. This is a consequence of disuse and sedentary lifestyle that doesn't have to happen. Typically, after the age of 30, women lose approximately 8% of their skeletal mass every decade and men deteriorate at the rate of 3% per decade. As indicated earlier, this bone loss is not uniform throughout all of our bones, but seems to be most prominent at the vertebrae (resulting in a loss of height as we get older).

Osteoporosis is the reduction in bone mass that results in a compromise to normal functioning of the body; it is caused by osteoclastic (breakdown) activity exceeding osteoblastic (building) activity to the extent that normal physiological functions and mobility are compromised. Osteoporosis leads to fragile bones that could fracture or fail under loads that younger individuals could easily tolerate. We often think of Grandma falling down and breaking her hip, when in fact the normal sequence is that Grandma placed a load on her femur and hip bones resulting in a fracture that then caused her to fall—it is generally *not* the fall itself that caused the break. She fell because her bones were broken under normal use. This manifestation of osteoporosis results in significant behavioral changes in the elderly including loss of mobility, dietary changes, changes in psychological disposition, and a cascade of events that profoundly affect their lives. This bone syndrome also represents billions of dollars annually in reduced work productivity and increased health-care costs.

Historically, osteoporosis was thought to exist mostly in the postmenopausal female. This is because estrogen has a protective effect on bone tissue. When the ovaries are compromised, the estrogen-producing capacity of women falls precipitously and therefore osteoclastic activity becomes elevated and is attendant with increased bone loss. For some women, hormone replacement therapy is a good choice for maintaining bone health. More recently, young people, both men and women, are showing evidence of osteoporosis. The teenage girl who participates in gymnastics and has a rigid and confining dietary regimen is at risk for osteoporosis. Increasingly, young Hispanic men and women, especially those showing evidence of diabetes, are at increased risk for osteoporosis. Clearly, bone health is an issue for all; osteoporosis is not a disorder

confined to the aging female, but is a multifaceted disorder that affects many age groups, operates across economic and socioeconomic lines, and can appear in both genders.

Osteomalacia, which translates into “soft bones,” is the umbrella term for a number of disorders in which bones are inadequately mineralized. In these conditions, osteoblastic activity may be normal, but complete mineralization of the matrix is lacking and therefore bones are softened and weakened. The clinical manifestation (symptom) of this disorder is pain when weight is placed on the affected bones, although that can also be a symptom of other bone disorders as well.

At the beginning of the 20th century, a syndrome analogous to osteomalacia—rickets—was common in children. Rickets is more severe than osteomalacia because malformation of bones during childhood and adolescence is not easily corrected. In children with rickets, bone is incompletely mineralized and the long bones tend to bend as loads are placed upon them. The result is legs that are bowed way out, shoulders that are slumped, and bones that are inappropriately thickened. Both osteomalacia and rickets are often caused by inadequate amounts of vitamin D or calcium in someone's diet. Recognition of the etiology of these disorders resulted in significant changes in our society. At the early part of the 20th century, children would go to work in factories early in the morning before sunrise and would not leave until evening, long after sunset. This was especially true in the northeast portion of the United States. Consequently, exposure to sunlight and its ability to produce vitamin D in our body was limited. Child labor laws were enacted in part because of the high incidence of rickets and osteomalacia, resulting in eight-hour workdays for children and daylight saving time so children could have exposure to sunlight. More recently, in the 1930s, it was recognized that high-calcium dietary sources could be enriched with vitamin D, which is why milk today is routinely fortified with vitamin D.

Osteosarcoma is malignant cancer of the bone tissue and is a rather common type of cancer; it may either develop in the bone or originate from any other tissue, like muscle or liver, and settle in the bone tissue. Osteosarcoma is of particular interest for young people. It primarily affects individuals between the ages of 10 and 30 and it is the sixth leading cancer in children under the age of 15. Nearly 50% of osteosarcomas affect bones around the knee; osteosarcoma is one of the primary causes of limb amputation not due to accident or injury.

Rattling skeletons with your students

Our main goal with this particular article is to raise your awareness of bone science and health so that you can integrate more in-depth study of the skeletal system into your curriculum. The skeletal system—like most body systems we cover in science class—is often studied in isolation from other systems; we hope that you will take the knowledge presented here and employ a more connected approach to studying bone and its relationships to the endocrine system, the digestive system, and to diet and exercise as well. While there are many resources that deal with the bones, we found these three to be exemplary:

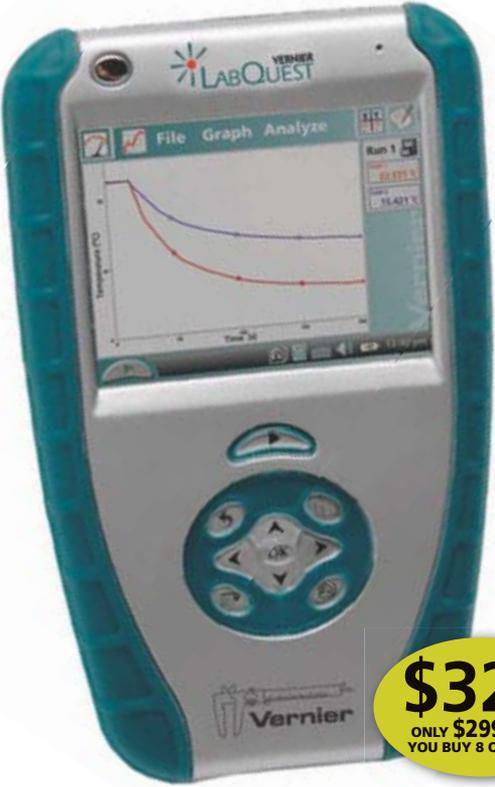
- The Discovery Channel Broken Bones lesson is great for grades 6 through 8 and guides students through processes of maintaining healthy bones and mending broken bones. <http://school.discoveryeducation.com/lessonplans/programs/brokenbones>
- National Institutes of Health website has a comprehensive unit called Looking Good, Feeling Good: From the Inside Out and it is correlated

to multiple middle-level standards. <http://science.education.nih.gov/supplements/nih6/Bone/guide/implementing.htm>

- The Dairy Council of California’s website has middle school-specific lessons and resources with fact sheets, activities, and more. www.dairycouncil-of-ca.org/Educators/ClassroomPrograms/Programs/EYOBoneHealth.aspx

We hope you find these useful with your students—good luck, but don’t “break a leg!”

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