How Stress Affects Bones

In this section, we are going to discuss how bones react to stress. We'll cover four topics: bone formation and growth, compact bone architecture, bone remodeling, and finally, what happens to bone when it cannot respond to changes in stress.

Bones have many roles to play in the body—one of these roles is to serve as an organic warehouse for calcium. Calcium is the most abundant element in your body, because it's used at some level by every cell in your body. So calcium is an ion in high demand by 100 trillion cells. Bones store and release calcium to meet the body's demands. Let's talk a little bit about this warehouse of calcium, starting with how it is built.

Bones begin to form during fetal development. However, prenatal bone is primarily cartilage, flexible tissue that contains no nerves or blood vessels. As bone tissues develop, ossification, also called osteogenesis, occurs. This may be intramembranous ossification or endochondral ossification. Intra-membranous ossification only occurs in a few places and, as the name implies, these bones form between membrane sheets. These sheets give rise to flat bones, such as the cranial bones and the clavicles. The second and more common type of bone formation is called endochondral ossification.

Endochondral ossification uses the fetal cartilage skeleton as a model to form the bone skeleton. In other words, the bone forms while the cartilage it is replacing is broken down. The bone begins to form at ossification centers. As more cells grow and secrete the calcium matrix--or area between bone cells--the ossified area expands until the whole bone is formed. In effect, the bones replace the cartilage.

Certain cells are responsible for secreting, maintaining, and dissolving the hard bone matrix. Let's discuss these cells next.

Three cell types are involved in bone formation, growth, and maintenance. These cells are osteoblasts, osteoclasts and osteocytes. The osteoblasts are the cells that lay down the new bone matrix. “Blast” means to form something. Osteoblasts are called “bone germinators” because new bone is deposited from their secretions. The growth can either make the bone longer or thicker. Making the bone thicker is called appositional bone growth. The osteoblasts migrate to areas that need a thicker bone matrix or bone tissue repaired. So osteoblasts are found on the outer or inner bone perimeters, where they can be most mobile.

Osteoclast, on the other hand, literally means, “bone breaker.” The function of the osteoclasts is to destroy the bone matrix. They do this by secreting powerful enzymes that break it down into its various components. Osteoclasts serve an important function by releasing calcium into circulation so the other tissues, like muscles and nerves, can use it. Osteoblasts and osteoclasts perform opposite functions and originate in different ways. Osteoblasts are true bone cells because they come from and form bone tissue. Osteoclasts are actually a specialized type of white blood cell. All blood cells are formed in the bone marrow. These white blood cells just stay put and work to dissolve bone matrix.

How do these cells know when to adjust your bone density or free calcium for other tissues to use? And why do certain activities contribute to bone density, while others do not? In the next section we will talk about how these two cells coordinate their functions so that new bone matrix is formed when and where it is needed. We will also learn why activities such as weightlifting and high impact aerobics add bone density, while a non-impact activity like swimming does not.

Your bones experience all types of stress. For instance, taking the stairs will increase stress on your bones, while riding the elevator doesn't. Breaking a leg is caused by a stress greater than your bone can handle; then you have to stay off it for up to six weeks. That downtime significantly reduces normal stress on the bone, necessary to maintain its density, causing it to lose some thickness. Stress increases bone mass. Lack of stress will cause you to lose bone mass. How do your bones know if they're being stressed or not? Well, they know because of a third type of cell, called the osteocyte.

Think of the osteocytes as the more mature, sedate version of the osteoblasts. Osteocytes can't migrate around like osteoblasts because they are found in small pits surrounded by the bone matrix they have secreted. Small passageways connect the cells together. These little canals are called canaliculi and their function is to allow the cells to communicate with each other, get and receive nutrients, and relay waste products. As a result, the osteocytes can closely monitor the types of stresses that are being placed on the bones. The small pit in which they reside to maintain the existing bone matrix is called a lacuna. So you can think of osteocytes as “stress sensors” making sure that the osteoblasts and osteoclasts don't get out of synch and drastically change your bone structure. In order to withstand stresses exerted on bone, these cells interact to form a specific bone architecture. Let's look at that next.

You have two types of bone, compact and spongy. Since this topic focuses on bone remodeling in response to stress, and remodeling only occurs in compact bone, our talk will only include compact bone architecture.

Compact bone is considered dense and superficial. But when you look at it under a microscope what you see are small holes throughout the bone. These holes are access ports for nerves and blood vessels. Remember, that is where blood is formed. In addition to these access ports, compact bone has a specific architecture, which allows it to withstand high stresses. This architectural phenomenon is called the osteon.

The osteon is the functional unit of compact bone. In order to withstand stress, the osteon is formed by the osteocytes to be tiny weight-bearing pillars. Think of a lighthouse. It is wider at the base for stability and tapers as it goes higher. The osteon is surrounded by layers called lamellae. Through a cross-section of the osteon, these lamellae look like rings in a tree trunk. But when you closely, they aren't just bone crystal. You will see collagen fibers integrated with the bone matrix. These organic protein fibers are important because they help give the bone some flexibility so that it can withstand even greater stresses. The trick is that they are oriented in opposite directions in each layer. So the first layer may have them going to the right while the second layer will have them oriented towards the left, then right and left again. This criss-cross orientation allows the compact bone to withstand torsion stresses. You could call the osteon design a “twister-resister.”

Although compact bone is dense and with the alternating lamellar design of the osteons it can withstand high stresses and bear heavy weights, it has a disadvantage. This disadvantage is that compact bone can only withstand those forces coming from a limited number of directions. Let's take the tibia for example. If a person is doing squat lifts, which involves stress exerted on the bone in a vertical direction, the tibia can withstand over 2.5 times the weight of the individual. But if the bone gets hit from a perpendicular direction (or at right angles to the long axis of the bone), it will snap. So bone can only compensate for stress in a limited number of directions.

Now let's move on to our third topic, how your body adjusts your skeleton to changes in mechanical stress. This is called bone remodeling.

Bone remodeling is the process of adding calcium, also known as deposition, to bone or releasing calcium, also called resorption, from bone into circulation. This is achieved by coordinating the activities of the osteoblasts and osteoclasts. These two cell types form little remodeling units. These remodeling units are made of adjacent osteoblasts and osteoclasts that form small packets. The remodeling units are managed and directed in their activities by the osteocytes, the stress-sensing cells. Remodeling occurs in compact bone only and can occur on the outside or in the compact bone lining the marrow cavity.

Remodeling is actually a response to two sets of signals. One set is a negative feedback loop for calcium regulation in the blood. The other is the response to mechanical and gravitational forces. One of the interesting facts about remodeling is that it occurs continuously, meaning that remodeling does not depend on your level of activity. Your cells always need calcium. So the osteoclasts are always releasing it into circulation. In contrast, the osteoclast activity is counterbalanced by the osteoblasts so that you do not lose calcium to the point of having trouble functioning normally. However, if your activity level increases, so does the rate of remodeling. And while your bone mass remains constant overall commensurate with your age, remodeling can occur unevenly. For example, the distal portion of your femur, located near your knee, will be replaced after six months, while it takes years before the shaft will be fully replaced.

In order for remodeling to occur, your bones need adequate amounts of calcium, phosphate, vitamins D, C, and A, and protein. But to instigate substantial changes, there has to be a corresponding change in your level of activity. For instance, let's say you decide to begin weight training or conditioning training. As you lift weights and put mechanical stress on your bones, they thicken. They are responding to increasing mechanical stress by laying down new bone matrix.

In contrast to this is lost bone mass. The example most people are familiar with is a broken bone. While the bone is immobilized in the cast, osteoblasts are migrating to the wound site and laying down new matrix. But it's also losing bone matrix at the same time because there is no stress being put on it. However, once you start stressing the bone again, it will add density just as quickly as it came off.

An interesting case of bone loss occurs in astronauts. An astronaut can only stay in the Space Station for a limited number of months, because the reduced gravity environment doesn't put any pressure on her bones. In addition, with no gravity to help direct bone growth, her bone density would decrease to the point that it would no longer support her frame once back on Earth.

So, let's return to the example of weight training. You start strength training every day. Just how do the mechanical forces you experience cause a change in the cells' activities? It is a combination of three factors. First, increased activity means more calcium is needed for other tissues. So hormones adjust the activity of the osteoclasts. The hormone that stimulates osteoclasts is calcitonin. But, at the same time that osteoclasts are releasing calcium from your skeleton, the mechanical stress from weight training sends the message that you need more calcium so that you don't compromise the bones' density. In response to this message, another hormone called parathyroid hormone stimulates osteoblast activity, storing more calcium in the bones. So, the stress you put on your bones determines where remodeling will occur. In places with high stress, more calcium will be deposited and less taken away, while places with little stress are better candidates for resorption of calcium into circulation.

How does stress change bone density? One way involves the properties of the bone crystals, which are made from ions. All ions have electric charges. So when stress is exerted on the bone, tiny electrical fields are generated. These fields help the osteoblasts migrate to the site of stress to start laying down new matrix. In other words, the osteoblasts respond to electrical signals.

So what happens if these signals are not working properly and bones cannot respond adequately to stress? A homeostatic imbalance occurs. For example, if the bones don't get the calcium deposits they need, the body develops a condition called osteomalacia, also called “soft bones.” In children this condition is called Rickets. The bones don't get enough calcium to harden correctly, causing pain when weight is put on them.

Another homeostatic imbalance is a condition called osteoporosis. Whereas in osteomalacia the bones become soft, in osteoporosis the bones become very brittle. Osteoporosis involves a decrease in the activity of osteoblasts. So bone matrix is not deposited, but the osteoclasts function normally and keep right on dissolving the bone matrix.

Well, let's review what we have covered in this tough topic section. We have discussed intramembranous and endochondral ossification and the cell types involved in bone formation. We discussed the importance and control of bone remodeling. Finally we ended the discussion with examples of bone conditions resulting from homeostatic imbalances.