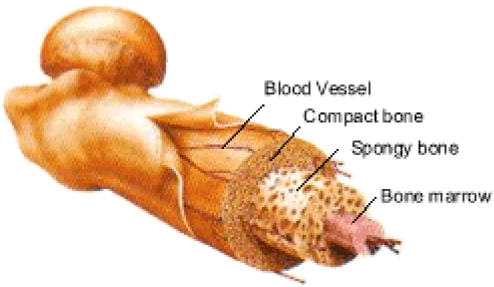
The Mechanics of Bone Tissue Part II



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Abstract

The following article is a continuation of the series on bone mechanics. Once again it is placed in a questions and answers format.

What are the specific forces that Bone Must Cope With, and How Is It Designed To Cope?

Today, I intend on introducing you to four specific forces that each of your bones must face. This section will be referred to in almost every single article dealing with the skeletal system, which follows. Here is what I want you to know:

1. Four specific forces, which occur on the skeletal system
2. When these stressors are manifested
3. How Bone Tissue is Constructed To Accommodate Each Specific Situation

1. Compression

When a system is " squeezed " it can be referred to as a compression stressor(36). Two bones being pressed tighter together is the greatest example of such a case. For example, your femur articulates with your tibia. When you stand, the condyles of those bones compressed against each other. This stress is greater when under a load of resistance.

The most dealt with compression area is the vertebral column. This column is composed of individual bones called vertebrae. They form joints, in a similar manner as a chain of links would. It is for this reason that the “back bone” is often referred to as the “posterior chain.” With great freedom comes great responsibility, and such is the case with your vertebral column. Several movements can take place within its parameters, including flexion(bending forward), extension, side bending, rotation(21), etc. etc.

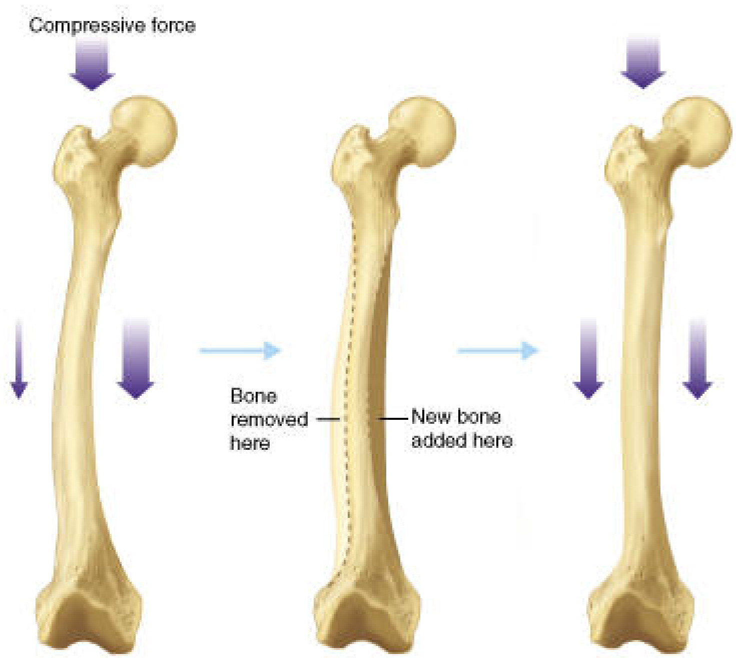
Vertebrae are stacked one on top of each other. Specifically, one body of one vertebrae, lies on top of the body inferior to it. Thus, as you sit in an erect position(at least that is preferable), each vertebrae bears the weight of the vertebrae superior to it. Actually, the effects are additive, meaning the lumbar region(lower back), must bare much more weight then the cervical(neck). Pressure is doubled when the area is halved.

Therefore the body is designed with the lumbar region containing much wider vertebrae then their cranial (closer to the skull cap) counterparts(59). Further, in order to absorb much of the shock, their lies a cushion of cartilage, known as the annulus fibrosis(intervertebral disks) between each adjacent vertebrae.

When the body is properly aligned, it is interesting to note that it is designed to use compression as a tool to actually “ stabilize “ itself. However, when alignment is faltered, compression can and will have deleterious effects (detrimental / injurious)(22).

In order to analyze the vertebrae, you must be familiar with the compression forces born between two adjacent neighboring bones. You see, the body is not the only aspect that articulates. In reality, there are four processes, which protrude laterally on these bones called articular processes. Two inferior articular processes of the superior(on top) vertebrae, articulate with the two superior processes of the inferior bone. When the vertebrae are pulled into a state of flexion, all the weight is born by the adjacent bodies. However, when in full extension, compression is born by both the bodies and the articular processes. Therefore you minimize stress. As we will see in a future issue, which analyzes this area in extreme detail, countless factors can affect this relationship. Your goal as an athlete is to minimize stress, or in many cases use it to your advantage. Other factors which you will learn about concern intervertebral hydration rates. Meaning many of your actions can dehydrate the annulus fibrosis. Meaning that compressive forces will exude that much greater stress on the parties involved.

How Does The Body Cope With Compression?



Several factors must be taken into consideration. However the main players are

A. Bone Mineral Content – this refers to the total amount of mineral within one specified bone(4, 9, 17).

B. Bone Mineral Density – How much mineral content can be found within a region of bone. According to Dr. Barron in his study of mineral density, 80-90 percent of cortical bone is calcified, where as that figure is only in the 20-25 percent range for trabecular(spongy) bone(4). As a consequence we would therefore expect more fracture rates in regions of the body, composed primarily of the latter (59). According to Dr. Highet in the Journal of Sports medicine, the limbs(appendicular skeleton), are higher in percentage of dense cortical then are the bones of the frame, that is-the axial skeleton(25). It is for this reason, that those who have aged, or not properly conditioned their bone while weight training can easily fracture the spinal column, leading to such disorders as kyphosis
(35, 20, 40)(hunch back).Interestingly enough, female athletes are at a major risk of this, if they do not pay extra special care to several specific factors(27).

C. Specified Cortical Strength – Think carrot. That may sound strange, but it sets up the perfect analogy for understanding this aspect of bone tissue. If you take a carrot, and bend it, you notice that the highest amount of stress occurs on the outer edges of the root as it is being stretched, and bent(compressed) at the same time. On the inside, the pressures cancel each other out (36). Therefore when you hear the root snap, it is due to the outside aspects this particular system failing, and not the inner regions (or no where near). Weight on your bones, normally occurs " off center(36). " Meaning, the same effect is occurring. Thus, as wolfs law states, shape is related to function (59). Therefore you can deduce that the outside of the bone would contain a higher amount of cortical tissue. This is exactly what we find (25).

D. Specified Trabecular Strength – Trabecular(spongy bone) strength can be thought of as being akin to structural beams. In other words, where stress is great, spongy tissue on the inside of a bone is greatest. Just as you would place more support on the side of the building which bares the brunt of the structure. Once again, a flawless design (19). The rest of the bone does not need as much support, and instead is hollow, and filled with marrow.

As an athlete, you will therefore want to emphasize activities, which enhance bone mineral content, and increase cortical width and calcification(18, 20, 19, 30, 31). Shortly, we will not only analyze this from a training standpoint, but also nutritionally. Further, we must consider every detrimental aspect, which can subtract from the desired effects.

2. Tension

Any type of " pulling " force, qualifies as a form of tension. Two main pulling forces act on bones. The first is based on what is called the " musculotendon unit. " This comprises the joining of a tendon into a particular bony region. Thus, the musculotendon unit distally for the biceps brachii is on the lateral bone of the forearm, that is-the radius. As a muscle contracts its force is transferred via this attachment point, and it is during this time where the aspect of insertion is pulled. All forces have four unique characteristics. I will not go into heavy depth on calculating them today, but I will in the future. The main aspects I am concerned with today are magnitude and point of application. The former refers to the amount of force applied, the latter refers to where the force is applied to. Thus, the level at which the biceps contract, and its line of pull effect the stress level on the bone. Though the insertion point cannot be changed, the line of pull can (24). Keep that in mind, as it has significant application for those attempting to enhance speed and strength. Ligaments also exert a pulling force on the bone.

The second main form of tension is opposite that of compression. Simply put, it is the stretching aspect that occurs when you bend a carrot. The femur provides an excellent illustration of why this is the case. It must bare all the weight superior too it, and it is placed at an angel, which allows us to walk fully upright.

How Does The Body Cope With Tension?

For the compression / tension relationship, it once again has a greater density of cortical bone on its periphery. However, the musculo-tendon relationship is different. You see, if the bone does not cope, your muscles can literally pull the tendon right off your bone! Not a pretty picture eh? Bone however is designed to grow where tension is greatest (59). Thus, the junction between bone and tendon will be a rather large protrusion as is on the medial and lateral epicondyles of the humerus. As you palpate this area, you will now have a greater appreciation for the importance of high density bone, where it's needed most! There are times however when a muscle can increase in strength faster then bone can handle it, and this is where injuries occur. One of the main areas is during a growth spurt, or during a bulk. However, several precautions can be taken, just like in any training regiment to " maximize " bone density, and completely avoid this (covered in part three).

3. Torsion

Supination is the process by which you twist your forearm so as to turn your palm superiorly (facing upwards). Twisting dumbbell curls take advantage of this motion by beginning with the palm turned downwards. As one turns their wrist, the weight is actually resisting in the opposite direction, thus the forearm bones are being twisted in opposite directions at once. This is what is known as " torsion. " When Marshal Faulk stops and spins the opposite direction, he has stressed his tibia(lower leg) by exposing it to this force.

How Does The Body Cope With Torsion?

If you recall from article one, cortical bone is actually composed of layers or circular rings of bone called lamellae. Collagen is what gives a bone its strength. Once again, God has composed an amazing plan to cope with such stressors. Each layer runs in the exact opposite direction throughout an entire haversian system! This means that bone can take an extreme amount of stress and keep coming for more (36).

4. Shearing Stress

When two bones slide past each other, the result, or rather the process is known as shearing(22). For example, if an athlete bounces on a preacher curl, his forearm will slide downwards while the humerus remains in place. In football, when an player clips an opponent, their shin bone will slide forward while the thigh remains steady.

How Does The Body Cope?

Similar to tension, in regards to tendon insertions, the bony formations where ligaments attach must be extremely strong. If this is the case, then sliding will be minimized.

Inventory List of Bones Mechanical Properties

To Recap, bone tissue's mechanical properties can be divided into three specific areas.

1. Elasticity – Like a rubber band, bone is displaced. The capability to return to its original shape is known as elasticity. This will be further discussed when addressing a concept known as the " stress – strain relationship. "

2. Strength – This tissue's level of strength can be characterized as its ability to fight fractures caused by any of the above four main levels of stress. To give direct measurements, a healthy bone has half the strength of steal in resisting compression, and when compared to withstanding tension it is fully as strong as steel! Think about that next time you are under the rack!

3. Fatigue Resistance – Stress fractures are a common term these days (22). Essentially it refers to the process by which an athlete fractures a bone by repeatedly using it on similar activities. A bones ability to sustain activities for long periods of time is known as fatigue resistance.

Each of the above factors is of vital importance, and can be manipulated (9).

You speak of Machinery, What Specific Machines Are Formed By Bones?

Such a question merits extreme insight. Therefore my intensions are to *introduce* you to various machines today, and dedicate whole articles on more in depth functions of these concepts, and how to manipulate them for maximum speed and strength in a future addition of Hyperplasia.

In order to grasp this concept, I need to first explain what purposes, are served by machinery.

Note: Not all of these are served by one individual construction. However, each is able to fill one or more of the following criteria

1. They have the ability to alter the direction that the force is applied. In other words they can take a force that is directed one way, and cause it to be transferred in another direction (11). A machine may for example take a force that is directed posteriorly, and change the line of pull so that the force is transmitted anteriorly.

2. A Machine may have the ability to stabilize two weights.

3. Of extreme importance is to provide the mechanism, whereby the force you apply(i.e. muscular contraction) can be manipulated to actually move a greater resistance, then the force which was applied. This is a “ mechanical advantage. “

4. To provide an advantage in movement. This means that a machine can move load X, further then applied Force A did.

5. Finally a machine can provide an advantage in speed applicability. That is-the ability to move a load faster then the applied force moved.

Bones in the human body are designed to form three specific machines. These include the following.

A. The Lever System – This particular system consists of a fulcrum, also known as an axis, and a lever which rotates around it. The axis is always perpendicular to the plane, which the level moves. To illustrate this look at your elbow joint, which is formed by the humerus, radius and ulna. This is known as a hinge joint (21, 25). Now straighten the elbow joint and place it at your side so that your palm faces forward. The axis runs side to side from the medial aspect of the elbow to the lateral aspect. The movement of the lever however brings the forearm closer to the arm(flexion), or moves it further away from the arm(extension). As you can see this is perpendicular, or forms a 90 degree angle with the axis. In a lever system, the general positive force is muscle contraction. This can stabilize a load, or cause movement as described. There are actually three lever systems, which will be detailed latter. I will however describe a simple mechanical advantage currently. Think of a hammer pulling the head of a nail out of a board. The point of application is the end of the hammer on the nail. The axis, is an imaginary line running through the point of rotation and is perpendicular to the action. The lever(handle) on the hammer allows the user(you) to apply force further away from the point of application. Recall from earlier in the article, that two keys to determining stress on an object are the point of application, and the degree of force. In order to determine how large the force is, you simply multiply the force applied (as in a muscular contraction), Xs the force arm distance. Therefore applying force higher up on the hammer handle, enhances the magnitude of the force at the point of application.

Most levers in the body however provide advantages in speed, and range of motion, such as the ankle joint. In this movement, the axis is the ankle joint. The applied positive or motive force is the posterior calf muscles, and the point of application is the ball of the foot when performing plantar flexion (standing calf raises).

The main bones, which serve as levers are “long bones.” Long bones are just that, longer then they are wide. Your thigh bone is a perfect example. The joints formed are the basic fulcrums. However, many positions, which we will analyze in the future, allow the entire body to work as a lever system.

B. Wheel and Axle Machines **-** Such machines provide maximum range of motion, and also tremendous abilities to enhance speed production. They can also be used to increase the magnitude of torque. The most basic wheel and axle machine to illustrate my point is a can opener. You clip the blade into the can. Following this you twist the can opener handle, which causes the blade to rotate around the can eventually freeing the contents for your next meal. There are several points to make here. One, if you recall, the measurement or length of the force arm(i.e. the handle of the hammer) is proportional to the magnitude of the torque produced. The same applies here. However, in a wheel and axle system, the radius of the wheel, is the force arm. The radius is simple to calculate. It is the length or distance of the point in the middle of a circle, to its perimeter (or half the diameter).

In a wheel and axle system, the axle is the aspect, which is of a smaller diameter. Thus, on the can opener, the resistance, which is being overcome, is at the actual point on the can, which is being cut through or opened. The small blade doing the cutting is the axle. The mechanical advantage is provided by the wheel (handle) on the can opener because it has a larger radius then the axle, allows a lesser force on the wheel to be transmitted to a greater force at the point of application.

That is one arrangement. However, you should also realize that roles could be reversed. If the wheel is the larger diameter aspect of this machine, we know that if a force is applied to the wheel it will have a larger torque (force through rotation), then will the axle, had you applied the force directly to it instead.

Another key point however is that range of motion, and speed are increased on an object with a smaller force arm. Roles are reversed Therefore, if you were to apply direct force to an axle on a machine, you would actually turn the wheel faster, then if you had applied that force directly to the wheel. Thus

a. Analyze the force applied. In the case of the human body, this is muscular contraction. If that force is applied to a greater sized force arm, then the magnitude of the muscle torque is increased.

b. If you decrease the radius, then you increase the speed and increase your advantage in range of motion.

An excellent example in the body, which takes advantage of speed and range of motion, can be seen through shoulder actions. Lets analyze this. The shoulder joint is formed by the head of the humerus, inserting into the scapula. This is called a ball and socket joint (25). And it allows the humerus to rotate. Perform the following action. **1.** Bend your forearm. **2.** Now cock it back as if you were going to throw a ball. **3.** If you keep the humerus in this plane, but rotate it forward, your forearm will move downwards (similar to throwing actions). The rotation occurs on the humerus. If you analyze the forearms movement however, you will notice that it rotated in a circular motion, such that you could calculate its radius (the forearm was the wheel as it was larger in diameter then the humeral rotation). The rotator cuff muscles, and deltoids however applied their force to the smaller radius. That is-the humerus or upper arm bone. This allowed for maximum speed build up, and range of motion. But a disadvantage in the magnitude of force production. It is more favorable to be able to utilize speed and ROM in this movement however(think of a pitcher). Therefore the machines in your body are specialized for the tasks they must perform.

C. Pulley System – Out of all the machines housed in our bodies, I have always been most intrigued with the pulley system arrangement. Most people allow their lives to slip away, never realizing the complex being that they truly are. Columbia Concise Encyclopedia defines such a machine as follows:

" A machine consisting of a wheel over which a rope, belt, chain, or cable runs.

A grooved pulley wheel like that used for ropes is called a sheave. A single sheave mounted in a block and fixed in place changes the direction of force exerted on the rope passing over it(11)." Columbia Concise 2003

Thus, a pulley system can change the direction of a force. Think of the last time that you bit the dust. What protected your knee? It was your patella correct (knee cap)? The patella not only provides protection, but also acts as the wheel in your knee joints pulley system. You see, your femur has two condyles, and these articulate with the condyles on your tibia. The patella is placed in between the condyles. Finally, the tendon of the quadriceps femoris forms within this bone. Any bone, which a tendon forms within, is known as a " sesmoid " bone (21). When you extend your knees, the quadriceps contract, but the muscles do so by pulling toward their center or gaster. The pulley system in place here is the tendon (rope) with a tensile strength of steel, and the sesmoid bone which it passes over. As the quads contract, the pulley causes the force to be redirected so that the legs move in the opposite direction, which is of course the action of extension. Furthermore, the pulley system increases the magnitude of torque applied through the knee joint (28, 52).

Can You Provide a Brief List of Bone Categories + Functions?

Yes I can. And it will be quite easy now that we have laid out the specific machinery found within the body.

Long Bones – As described earlier these are longer then they are wide. Meaning the shaft encompasses the majority of the tissue housed. The humerus, femur, forearm bones, leg bones etc. are examples. Wolfs law states that shape is related to function (59). Such is the case here. Bones with a longitudinal emphasis are used as levers. The upper extremity bones are lighter, as they are used for a greater range of motion, and actions such a manipulation of objects, and speed (a boxer throwing a knock out punch). The femur and tibia are much thicker as they bare the body's weight. The fibula does not bare the weight of the body as it does not form a joint with the femur and is therefore much smaller. However, due to muscle attachments it is extremely bumpy, especially in the competitive athlete (32).

Short Bones – As the name implies, these are thick chunks of bone, which can primarily be found in the feet and hands. What do you notice about both of these areas? They have extreme movement correct. Indeed, the many joints, which can be formed between short bones, allow for a high range of motion. Further more short bones are used for elasticity and adaptability. When you walk the feet must bare extreme amounts of weight, and conform to endless varieties of terrain. The arrangement of this tissue in the region allows the feet to almost mold to these surfaces, and absorb shock. This is why your feet have " arches. " Arches, which can be manipulated to increase speed and storage of potential energy.

Flat Bones – Your skull houses one of the most vital components of your central nervous system. The brain. This area is composed of flat bones, which like a helmet or any type of armor form protective barriers for their precious contents. The scapula is also a flat bone (your shoulder blades), and protects several structures in the back region.

Irregular Bones – Tissue molded in the body that does not conform to the above shapes is known as irregular bone. Your spinal cord is protected by these very bones. The vertebrae have a shape which allows them to protect the CNS, provide canals (foramen) for nerves to exit, have flat bodies and other processes for joint formation, are designed for extreme forms of movement, and yet can bare extreme amounts of weight(i.e. the lumbar region houses interlocking articular processes, which allow an athlete to form the vital strong arch). Additionally they have processes such as the spinous processes (the back bone you can see posteriorly) and transverse processes which allow muscles to attach, and cause localized rotations. Indeed, these are hand crafted for extreme situations and a high array of environments.

Conclusion

The skeletal system is extremely complex, so then how does one manipulate this for enhanced athletic performance? That is covered in part three of this series.

Yours In Sport

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