Biomechanics
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Lecture - 53
Properties of Bones

Vanakkam. Welcome to this video on biomechanics. We have been looking at mechanics of biological materials. Specifically, we were looking at bones. First we looked at the types of tissues and the classification of tissues based on material properties. Then we looked at bones and the microstructure of bone and the types of bone, and the types of cells within the bone.

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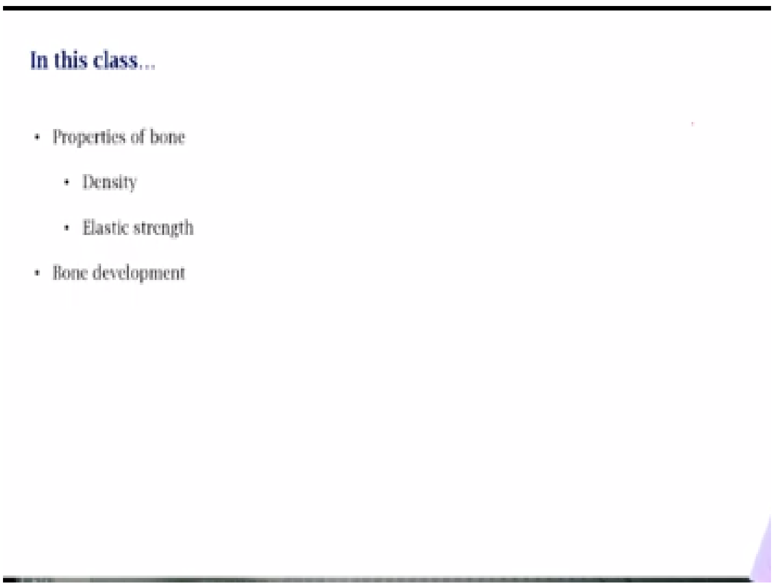

In this video, we will be looking at the mechanical properties of bones. Specifically, we will be looking at density and elastic strength and development of bones.

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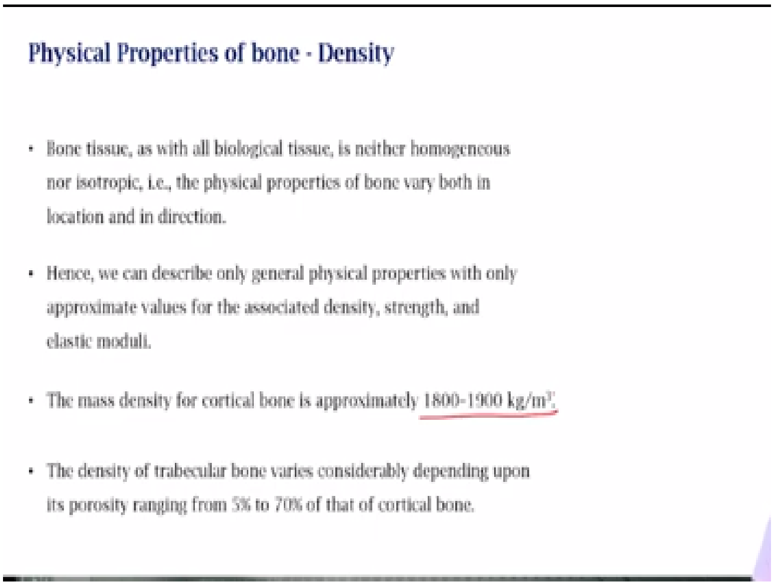

Important to note that bone tissue like any other biological tissue is not homogeneous. Of course, when we discussed long bones, we discussed compact bones and cancellous bones, spongy bones and strong cortical bones, we discussed. That means obviously, it is not homogeneous, that it is not a single material.

So I cannot choose sample from a space and then assume that the property remains the same throughout that material. Bone is also not isotropic in its material properties. That is the properties or the material properties of the bone changes depending on the direction, depending on the dimension from which you measure.

So in one dimension, the property is something the same property when you measure even in the same location from a different dimension will be something else. So that is it is a strongly non isotropic or anisotropic material. So that means when we discuss material properties, we only discussed general physical properties with some approximate values for density, strength and elastic modeling.

These are some approximate values for some specific bones that were tested or sampled. So for the cortical bone, the density is approximately 1800 to 1900 kilogram per meter cube, about two times the density of water, little less.

That is quite dense, right? The density of the cancellous bone or the trabecular bone changes substantially depending on the porosity, that is ranging from 5% to 70% of the cortical bone, from 5% to 70% of the cortical bone. That means it can be really light or really less dense or it can be almost as dense as the cortical bone. So that is a function of the amount of holes that are present in the network structure.

That is a function of the amount of porosity that is present. It turns out that the stronger the bone, the lesser will be the amount of pores or the amount of porosity, right? So as people age, the porosity increases. And of course, this is different between men and women. Women, for example, are in particular prone to a disease that is in which the porosity is pathologically high or in which there is a lot of holes, there are a lot of gaps.

Of course, this disease is called osteoporosis, right? A case in which the porosity is high. So the amount of porosity of this determines the strength of the bone and that varies considerably within the body for an individual and this also varies across individuals as a function of age and general state of health.

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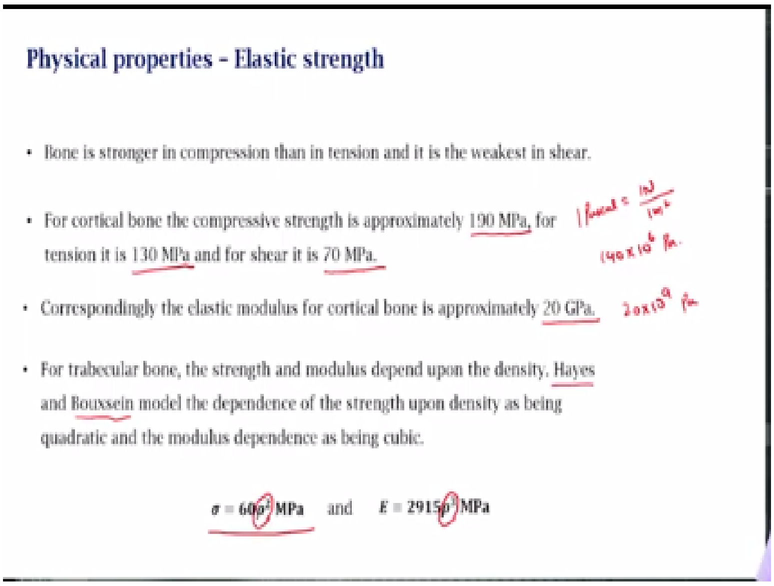

Important to note that the bone is strong in compression when compared with tension. So if you push a bone, it is strong. So it can take compressive loads when compared with tensile loads. But the load that it cannot take much is shear. It cannot take shear. Shear is the greatest danger to bones. A lot of fractures happen due to shear. Because shear is its major weakness.

It can take a lot of compression, but it cannot take a lot of shear. For cortical bone compressive strength is around 190 MPa. What is a Pascal? 1 Pascal is 1 Newton of load in 1 meter square area. 1 meter square area is very large area in that if you just apply 1 Newton load that is called 1 Pascal. 190 MPa means, mega means 190 into 10 to the power 6 Pascals is the strength that or the compressive strength that this bone has without damaging.

So it can take so much compressive stress without damaging itself. In tension it can take about 130 MPa, but for shear it is almost 1/3 of the strength that it has in compressive direction. So that means, it shear strength is very weak, much weaker than the compressive strength. The elastic modulus for the cortical bone is about 20 GPa. So that is 20 into 10 to the power 9 Pascals, right?

Something that you will have to remind yourself, kilo is 10 power 3, mega is 10 power 6, giga is 10 power 9 and so on and so forth. For the cancellous bone, the strength of the bone and the modulus depend upon the density, right? So porosity starts to play a role, the more porous it is, the less denser it is. And it turns out that its strength is a function of the density or porosity, right?

There are models that have attempted to find out or relate the density and the strength, right? One such model is the Hayes Bouxsein model which relates the strength upon the density as being quadratic; so this is a, and the modulus as being cubic. So that is the elastic modulus is a function of rho cube and the strength is a function of rho square.

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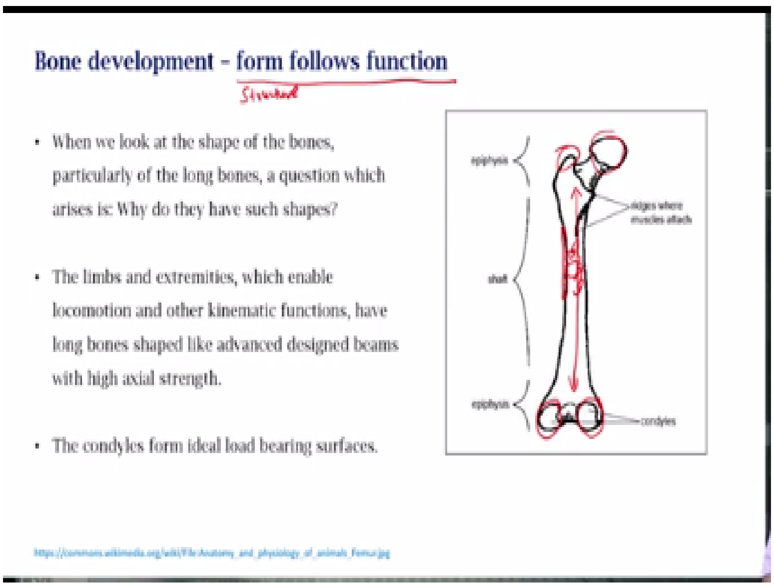

When we look at bones, a question that comes to our mind is, why are the shape like this? Why are they looking like this and not like something else, right? In particular, when you look at long hollow bones like the femur, for example, why are they looking like this, right? They have many functions. In this case, the form follows function.

Remember, in the beginning of the course, we discussed that in biomechanics, we will be discussing the structure function relationships. In this case the structure, form means structure is it not? In this case, the structure is dictated by the function that it is required to perform. So what is the function of the femur?

Well, to be able to participate in the most crucial function, which is locomotion or walking, it is contributing to the kinematics, locomotion, walking. So there is a necessity to have advanced designs like beams with high axial strength, so it can take a lot of strength in this direction. So it can take a lot of stress or a lot of load in this direction. And these regions right, the condyles where it is connecting to other bones are the major load bearing surfaces.

These are going to be really strong that they are going to take load from the top and then going to pass it on to the next lower segment, right? So these are the ideal load bearing segments. So they have more than one function obviously. They are in, they are participating in kinematics or locomotion walking and they are also participating in kinetics or dynamics or passing on the load from one part of the body to another part of the body.

So they have many functions and these functions are what determine the structure, right? Later in one of the videos we will be discussing why are long bones hollow, right? There it will become more interesting, it will become crucial to discuss why is for example the femur hollow? Because if it was not hollow, what would be the dynamics that you would have to pay?

That what would be the cost, metabolic cost or the expense that you will have to incur to move a fully solid bone for example. That is a curious question. For example, if you take this femur, there is going to be some thickness here, which is the cortical, or the compact bone and then in the middle, you are going to have cancellous, hollow or trabecular bone, right?

If it is solid, that is going to be it is going to be heavier, but it is going to come with a lot of other costs involved, dynamics involved, something that we will see in a future class.

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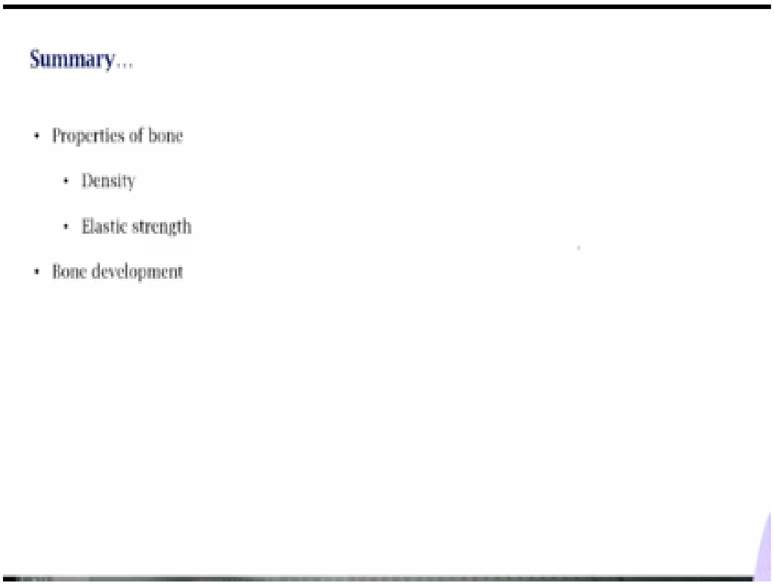

So in this video, we looked at material or mechanical properties of bones, which are approximate values, and we saw that the bone is strongest in compression and weakest in shear right, weakest in shear. Many of the fractures happen due to shear or improper shear loading and the elastic strength. And we saw that the relationship between density and strength and modulus are quadratic and cubic in nature, as we saw in one of the previous slides.

We also discussed why are bones shaped like this or why are they having specific dimensions and shapes like this, because they have specific functions of kinematics and kinetics. They have specific functions of participating in motion, which is kinematics and kinetics, which is passing on the load from the top to the next lower segment, right? So these are the various properties of the bone.

And after discussing all this, we come to the conclusion that the structure of the bone is determined by the function that it is required to perform. So a specific bone is structured in a specific way because it is used to perform a specific function, right? With this, we come to the end of this video.