Introduction to Biomaterials

Prof. Bikramjit Basu

Prof. Kantesh Balani

Department of Materials and Metallurgical Engineering

Indian Institute of Technology, Kanpur

Module No. # 01

Lecture No. # 39

Understanding Design Concepts of Orthopedic-Implants

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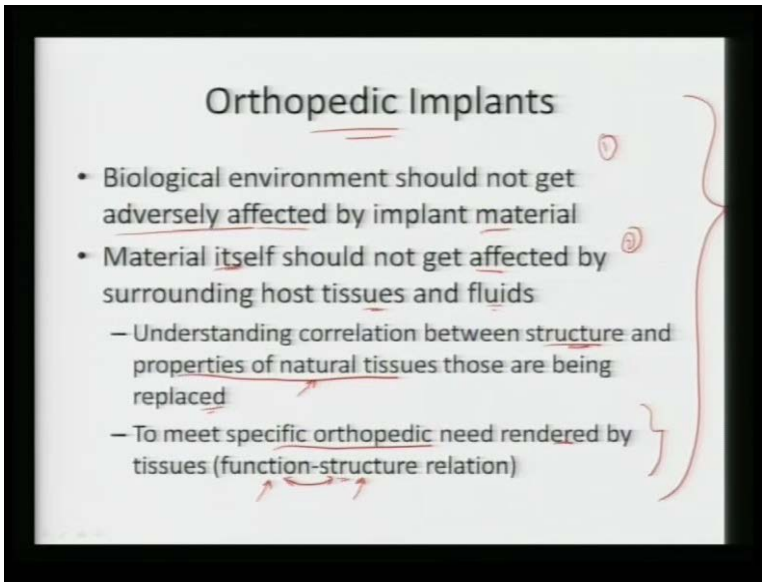

In this lecture we learn about understanding the designing concepts of orthopedic implants. So, ideally, orthopedic implants, once they are inserted into the body we need to have, we need to basically evaluate certain concerns. First thing is the biological environment should not get adversely affected by the implant materials, that is the first criteria, if you are using a orthopedic implant into the body, it should not affect, adversely affect, the implant material though it will be affecting in a manner that it will try to assist the overall functionality of the system, but it should not, it should not adversely affect the overall harmony of this particular biological environment. At the same time once a particular implant is being inserted into the body the material itself should not degrade, it itself should not get affected by the surrounding host tissues and

the fluids which are encompassing it. So, the material has to satisfy two criteria: it should not affect the biological environment and secondly, it should not get affected by the biological environment adversely- so, both the conditions have to be satisfied by the orthopedic implant. And once we have learnt about the material and the overall biological environment, so, then only it will give us a nice feeling about how we can utilize a particular material artificially and take over the functionality of the damaged or the un-functional system.

So, understanding the correlation what is happening between the structure and the properties of the natural tissue is very, very essential, because only once we understand what is the overall functionality or the properties of the natural tissue then only we should be able to, then only we will be able to replace them and assist them with replacing with certain synthetic or artificial material. So, in continuity the specific orthopedic need which is rendered by the tissue has to be replaced by an artificial implant, artificial orthopedic implant. So, in total it becomes essential to see the correlation between what is the function of the tissue and how it is being affected by the structure. So, overall structure of the tissue and its functionality has to be replaced exactly by the artificial orthopedic implant. So, that gives the overall feel of this orthopedic implants- the first thing is it should not get adversely affect the biological environment, secondly, it itself should not get degraded or affected by the surrounding host tissues and fluids.

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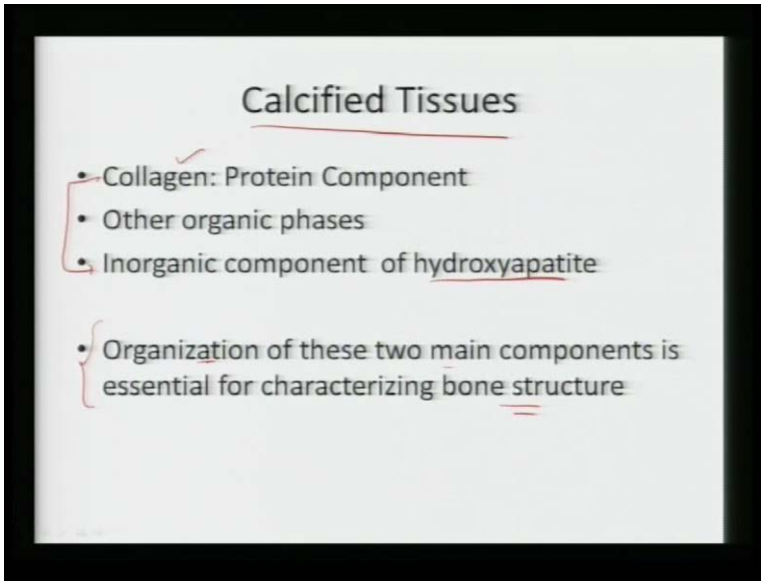

So, the calcified tissues which are present in the body- first of all, collagen is the protein component and there are certain other organic phases, but one of the main components of this calcified tissues are collagen and inorganic compound, which is made up of hydroxyapatite. So, organization of these two main components is essential for characterizing any bone structure, because only the way, the hydroxyapatite and collagen, how they are twined, how they are coiled together to render the overall bone structure, that basically tells us that organization of these two components is very, very critical and how the functionality is being rendered by the composition of these 2, the protein and the apatite. So, now, it becomes essential to understand what is happening at the, what is happening from molecular level to the micro level, and how these entities are basically related, or how they are being structured to give the final properties of the bone.

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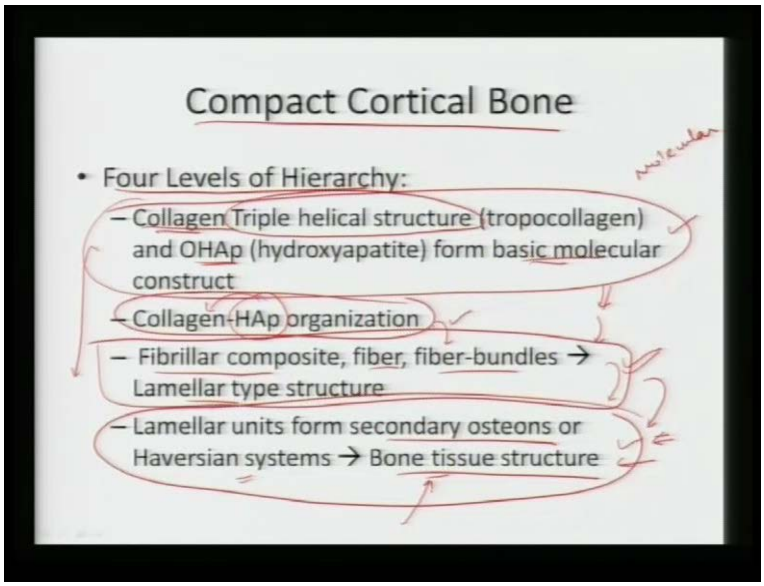

So, in the compact cortical bone there are 4 levels of hierarchy, 4 levels which are starting from molecular to the macro to the macro scale. So, at the molecular level we can see that the collagen and hydroxyapatite, collagen and hydroxyapatite, they form the basic molecular construct. So, we have collagen triple helical structure which is called tropocollagen and then, we have oxy hydroxyapatite which is also called HAP, which form the basic molecular construct then, we have intertwining of collagen and hydroxyapatite. So, we get second level of structure which is collagen and HAP, and this HAP is present both in the inter and the intra regions, fibril regions of the collagen. And later on, it goes to forming certain fibrillar composites, fibers or fiber bundles, which

shows kind of lamellar type of a structure. And these lamellar types of structure eventually go into forming certain secondary osteons or haversian system, which is the properties of overall bone tissue structure.

So, we can see there are 4 levels: molecular level; we have collagen and hydroxyapatite,; then we have organization of collagen and HAP; then it goes on to forming some fibrillar composites, which forms some sort of a lamella; and this lamella units is going to form a haversian system. So, we can see in totality this one represents the overall bone tissue whereas, the basic unit is construct of a certain molecules of hydroxyapatite and collagen. So, we can see how this particular structure is evolving from molecular level when we have only hydroxyapatite and collagen, goes on to forming the organization in certain manner, goes on to forming certain fibers or fibrillar structure or lamellar types structure, and all these lamella units going to form a osteons or the haversian system, which is representative of the bone tissue structure.

We can see at the third stage itself we can somehow estimate the properties of this particular composite, because we are finding the arrangement of HAP and collagen has certain lamellas, so, we can go on to forming the local elastic properties of the, this particular structure, lamellars structure, but it gets even more complicated because the way the lamella units are forming in to haversian system it becomes very, very complicated, but still it is again possible to evaluate the macro or the mechanical properties of this particular structure which represents the bone tissue.

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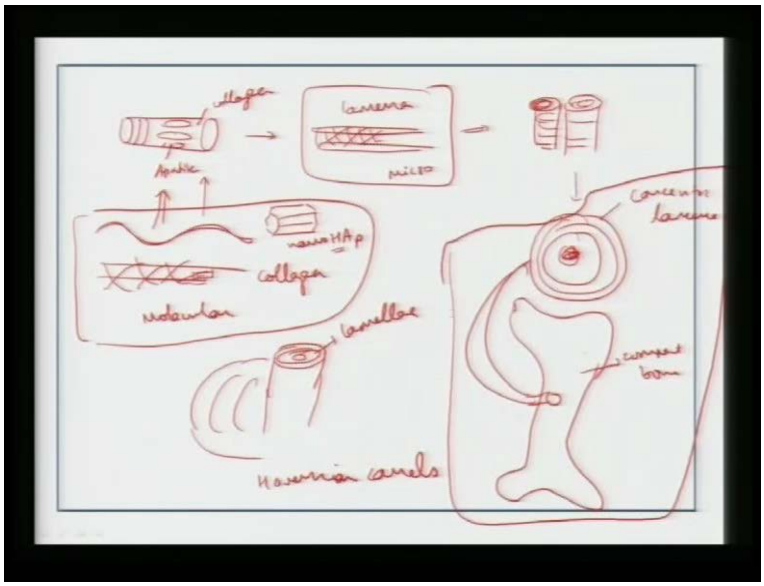

So, we can see that initially, we generally can start with the overall apatite. So, we have a particular apatite formulation in certain regions. So, we can see the apatite crystals which are somehow related and then, they basically, this collagen fiber and the structure of these apatite crystals, these are nothing but apatite crystals, it is nothing but the collagen. So, particular (( )) of it gives rise to, we have certain collagen molecules which are nothing but the formation of certain peptides and amino acids and proteins. And then, we have overall lamellar kind of construct, which basically evolves. And then, we have apatite crystals which are embedded into this particular collagen. So, we have certain apatite, goes on to forming certain apatite on to this particular amino acid acidic structure of the collagenous protein. And if after that we get certain fibers which are nothing but the collagen fiber, so, we can see certain fibers which basically come out of it, and this particular fiber, they start forming some concentric lamina. So, at molecular level we can see collagen plus some crystals of apatite which are nothing but the hexagonal type of structure- so, these are kind of nanocrystals of hydroxyapatite.

And then, it forms certain arrangement to form some fibril kind of a structure and then, this is nothing but, this is more of a micro level kind of structure which is construct, which has been developed after the collagen and HAP they have combined or intertwined. Finally, it goes on to forming osteons which are nothing, which are nothing but the arrangement of all these fibrils- so, they go on to forming fibrils out here. And eventually, it forms haversian canals, these are nothing but concentric lamina- so,

concentric laminas go on to forming certain haversian canal. And all these are basically present in the compact bones.

So, we can see the overall bone structure is something like this, and we can see the compact bone then, it has all these systems which are composed of this haversian canal system. So, we can see that generally the bone which composed mainly, which has certain lamellas. In a 3dimensional construct we can see the all these laminas are somehow incorporated both as circular as well as all this kind of cylindrical systems which are nothing but, this is nothing but, it is a lamella and go on to forming the haversian canals. The overall structure has already been defined in one of the earlier constructs. So, we can see that we have molecular structure which is composed of collagen and nano-hydroxyapatite; a particular arrangement gives rise to the fibrils of apatite and collagen, and these go on to forming a concentrate lamella- and how this collagen and HAP basically can combine will I will show it little later- but once we have formed a concentric lamella it goes on to form certain concentric lamina or a plane type lamina which forms the osteons or the haversian canals for this bone structure. So, we can see how the hierarchy is developing, starting from molecular level to the final macro level which is nothing but the bone.

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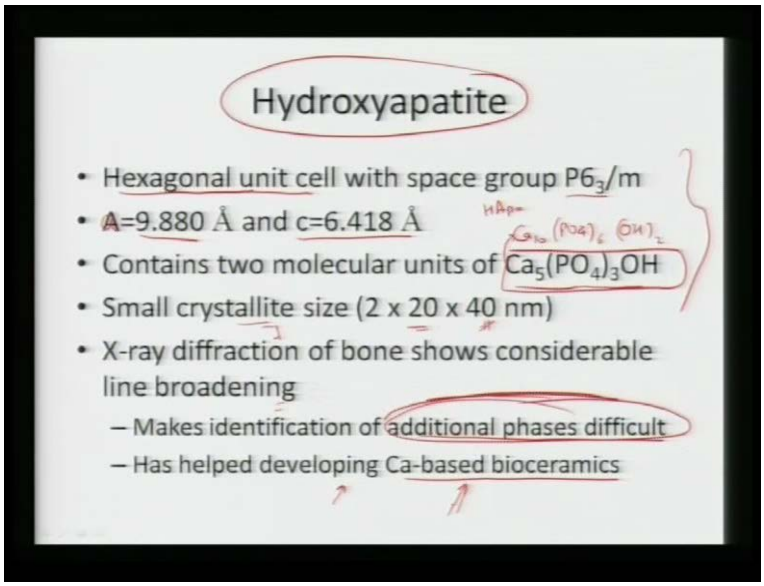

So, hydroxyapatite is nothing but a hexagonal unit cell with a space group of P 63 by m, and again it has a latice parameter of a, small a, of 9.880 angstrom and c of 6.418

angstrom. So, it contains two molecular units of Ca5 PO4 3 OH twice, and so, eventually it goes on to forming Ca10 PO4 6 OH twice- this is the formula for the hydroxyapatite. And since it contains two units of this smaller units, it goes on to forming Ca10 PO4 whole 6 OH twice. And that is a small crystallite size, so it can get really embedded on to the collagen to form certain fibrillose structure. And again, the x-ray diffraction of the bone, it shows considerable line broadening because it has a very limited crystallite (( )), so it makes the identification of additional phases very, very difficult. In the presence of this nano crystals there is always some line broadening associated with the x-ray diffraction. But again because of presence of this calcium based ceramic it has high development of certain calcium based bioceramics, because the original, or the bio structure of this particular bone is very, very similar to that of calcium based ceramics. So, eventually, we can see, we can go on to developing certain synthetic bioceramics which are based on calcium. So, eventually, what this calcium will do, it will assist the precipitation of apatite on its surface. So, we have hydroxyapatite, synthetic hydroxyapatite, it will assist formation of osteoblast type cells on to its surface.

So, we can see hydroxyapatite, the overall crystal structure is hexagonal type, P 63 by m, it has a smaller letters parameter of a, 9.880 and c to the longer (( )) 6.418 angstrom. It contains 2 molecular units of Ca5 PO4 3 OH. And again, because of the small crystallites generally we observe very broadening of the x-ray diffraction and very limited, this peak height is very, very small, so it makes the identification of certain other phases very, very difficult. And also, it makes it difficult to understand how this hydroxyapatite is now bonded with the collagen, because it is very, very still, it is matter of divide, how this particular hydroxyapatite is now bonded with the collagen. But, now, the presence of calcium, this, hydroxyapatite, it has now made development of certain bioceramics to replace the bone as, to work as a bone implant very, very feasible.

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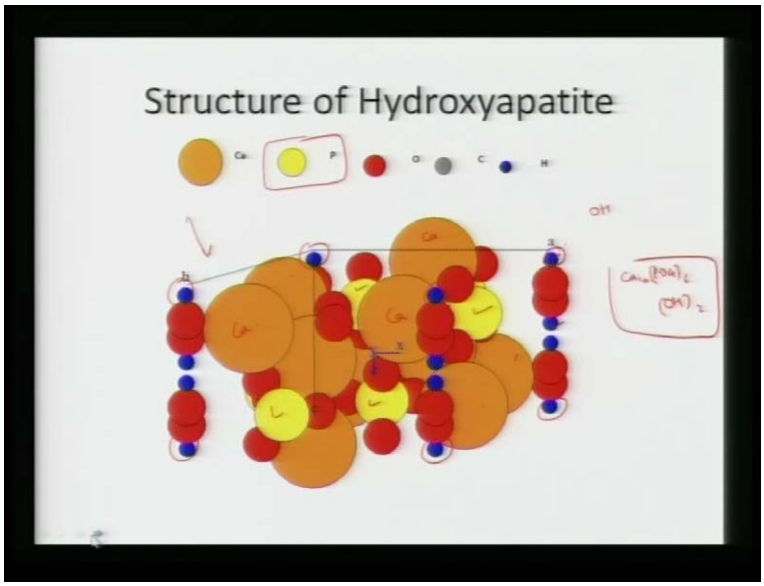

So, we can see the structure of hydroxyapatite, it is again P 63 by m, we can see all the calcium, the calcium atoms which are sitting as such; we have Ca10, so we have 10 molecules, 10 atoms of calcium; and Ca10 PO4 6, so, we have 6 atoms of P which are sitting out as yellow atoms then, we have oxygen which is again sitting at certain locations and H- so, H is basically present as OH twice. So, we can see that there are certain units which are, they are contribute only one fourth in all the locations, so, we have 1 2, so, basically, there are OH twice is present, so we have Ca10 Pa4 6 OH twice. So, these are one eight, which are being basically being included one eighth, one eighth, one eighth , one eighth and again one eighth, and again, others are (( )) by one fourth. So, we can see there are, this is the overall structure is now being present as a hydroxyapatite.

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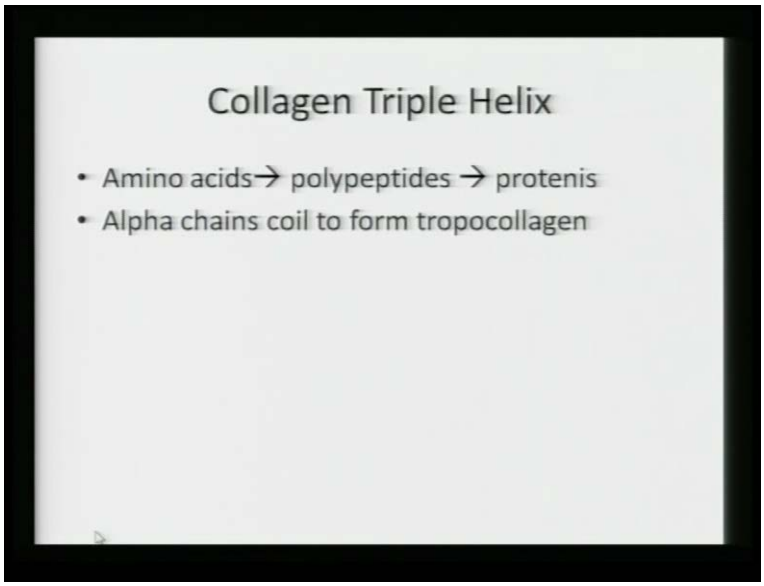

Further, the presence of collagen triple helix can also be explained, explained now, that we have amino acids which go on to forming polypeptides or proteins, and we have alpha chains which coil to form tropocollagen.

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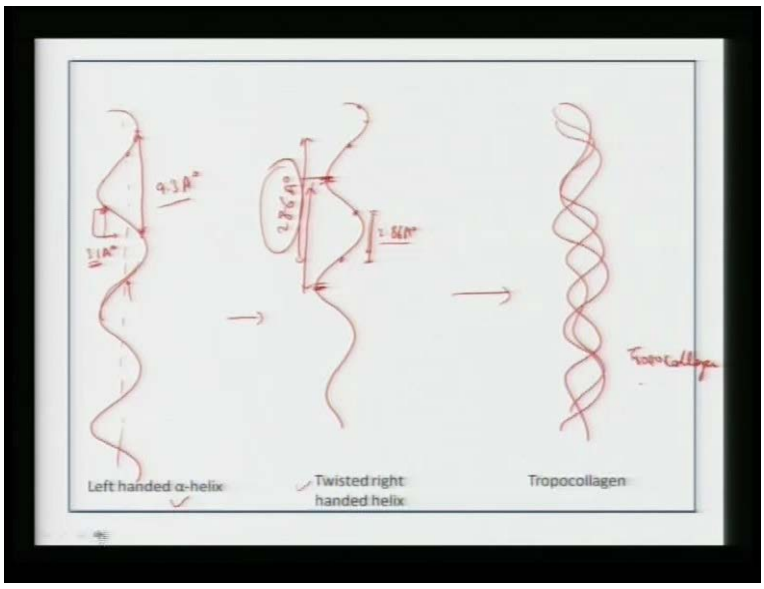

So, we can see in alpha helix, so, we can see in alpha helix we have left handed alpha helix, so, it goes on to forming certain alpha helix, and we have all the peptides, which are basically sitting here. So, we have 3 units which basically go on to forming the overall length of, repeating of length of 9.3 angstrom, the distance between 2 to such,

basically, peptides is around 3.1 angstrom. And again, we can see that these go on to, these, basically, they get untwisted to right handed alpha helix structure, to right handed helix structure, so this thing is now, basically, the basic chain if you take we have symmetry along the central axis, but now these basically, this itself is now, basically, deformed to make it a right hand, right handed helix.

So, opening of it basically, now, opens of this particular chain, and the distance between those 2 is around 2.86 angstrom, and the overall repeating part goes on to 10 such, 10 such super coils will make it 28.6 angstrom. So, initially, we had 3 units of 3.1 angstrom to make it 9.3, but in this case it basically opens to reduce the distance between the vertical distance, it is used to 2.86 angstrom whereas, 10 units now go on to forming 1 repeating unit- so, we have repeating from here to here comes to around 28.6 angstroms. And again, the 3 of these particular helix structures, they go on to forming a coil and then, it forms a tropocollagen fiber. So, we can we have to start from the alpha helix structure, which is left handed alpha helix, with the nearest, with the distance, verticals of around 3.1 angstrom. And 3 units, they form the pitch which is nothing but 9.3 angstroms. Whereas, after uncoiling it the twisted right handed helix, it has now a distance nearest, nearly distance of 2.86 angstrom, and the overall repeating pitch basically comes to 28.6 angstrom, and 3 of such structures they combine to form tropocollagen.

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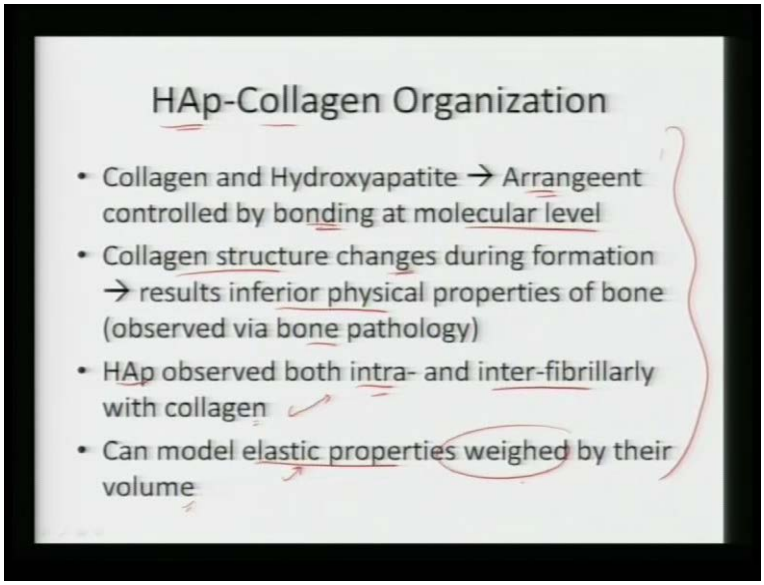

And again, once the HAP and collagen are present, so, the HAP, collagen organization, that basically is controlled by some sort of a bonding at the molecular level. But still it is of under debate that how this particular bond, hydroxyapatite, is now being bonded with collagen to give out such a structure where hydroxyapatite is present both in the intra and the inter fibril structures or zones. So, we can see collagen and hydroxyapatite, there is some sort of arrangement which is now controlled by the bonding at the molecular level. It is also been observed in bone, via bone pathology that the collagen structure changes during its formation. So, it can also result in certain inferior physical properties later on. So, the particular structure is not really exactly consistent, had it be, had certain sort of a controlled bonding with the HAP, it will, it should be able to repeat itself no matter what, but that is not so.

So, there is something which is very, very tricky which is happening at the molecular level and that is dictating the overall bonding between hydroxyapatite and the collagen. And HAP is observed both in the intra as well as inter fibrillary region with the collagen. And again, their arrangement, now, basically, can decide, from that particular model we can basically decide how we can estimate the elastic properties which are now being weighed by their volume. So, certain volume of hydroxyapatite and certain volume of collagen can give us certain mechanical properties. So, we can see that hydroxyapatite and collagen, they are bonded in certain manner, there is some still, there is not much of understanding of how this bonding is occurring, how this arrangement has been occurring between the two. And again, the way the hydroxyapatite is now being present in the collagen, that can dictate the overall volume, and from the overall volume we can also find what is the elastic property which can arise out of this particular arrangement.

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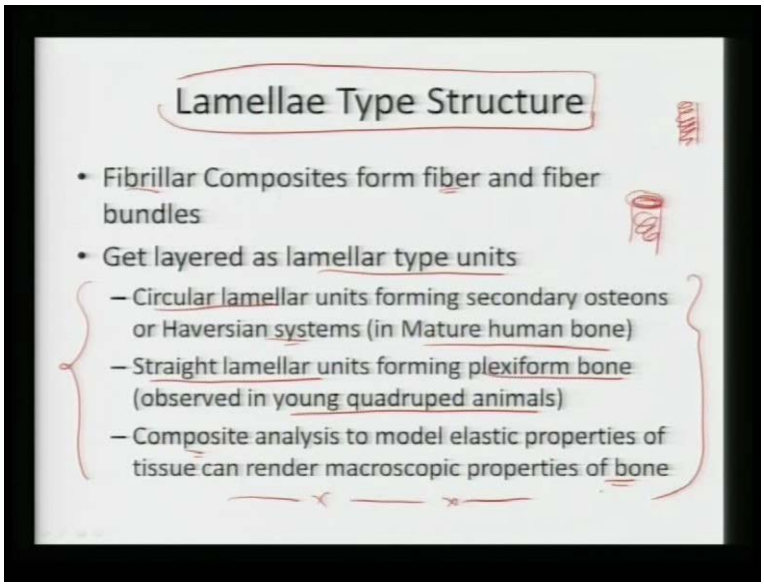

So, once this particular arrangement is formed, the lamellae type structure is formed, so, that is formed the by the fibrillar composites. So, fibers, they go on to forming fiber and fiber bundles. So, we have certain fibers which are basically, which are basically being, and these fiber bundles they go on to forming a certain lamellae type units; it can be circular lamellar as we see, that, those present in the haversian system; so, we have certain fibrous lamellae type of, circular lamella type units which are, which basically form osteons or haversian system- and that happens in the mature human bone. Whereas, there can be also formation of straight lamellae units which forms some sort of plexiform bone, and which is predominant basically in the young quadruped animals like, cats or bigger cats or rabbits type of animals.

And now, this particular structure is enough to predict the overall macro properties which are present for the bone. So, initially in the previous case we had particular arrangement of bone and HAPs (( )) from the volume percent we can estimate the overall mechanical properties, but once we have lamellae type of a structure, in this lamellar type of structure, we can identify what is the overall composition. But this particular system very, very complex because of presence of certain porosity, the overall construct of this particular lamellae, how they are arranged by the, weather as a circular or as a planar or a plexiform type of a bone, presence of any veins, which basically supply nutrients to the blood, any blood vessels to carry the oxygen. So, these makes, these makes the bone very, very complicated. And this composite, the analysis of this

particular composite to estimate its elastic property because much more complicated than the previous case. So, we have more of a haversian type of system, lamellae system, and that is now being formed from the construct of fibrillar composites which were earlier fibers, so, this fibers go on to forming lamellas, and this lamellas go on to forming haversian systems or osteons So, that is, now, we can see there are four levels of hierarchy which is present in this particular construct of bone.

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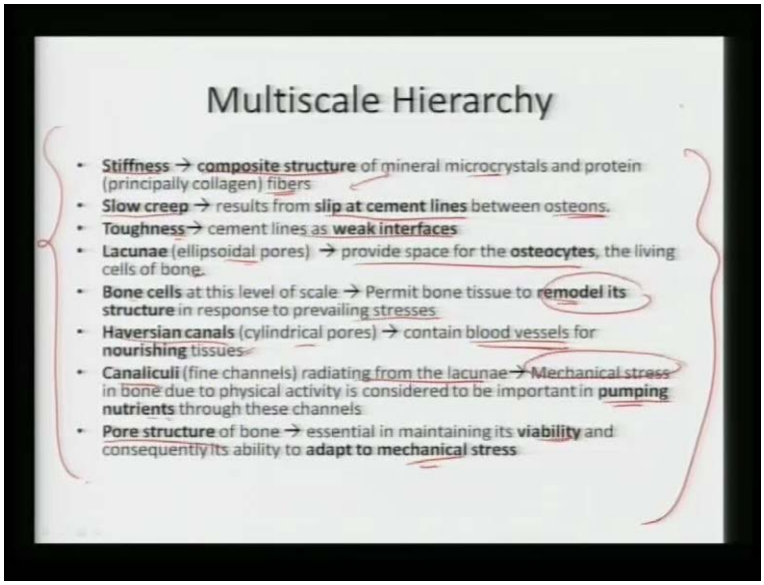

But this multi scale hierarchy is very, very essential because there are many, many properties which arise in bone. So, we can see the stiffness part, and the stiffness arise from the composite structure because we have collagen, we have micro crystals of hydroxyapatite, and this collagen fibers they go on to forming a certain construct, and that gives much more compliance, or much more stiffness, this apatite or the crystallite (( )), they can provide much more stiffness to the bone. We can obtain slower creep because the slip at the cement lines, which is present between the osteons, so, between the osteons we have certain region which is more like a cement type of a, cement lines type of a structure, so slipping at those areas can give us slow creep. Again, cement lines, they also work as weak interfaces, so, upon any impact they can absorb the shock, they can absorb the energy to give out much more toughness. Presence of certain pores which are called lacunae, they also provide space for osteocytes, or the living cells of the bone, and these osteocytes are essential for the survival of the bone.

Again, bone cells at this level of scale they basically permit remodeling, and remodeling is very, very necessary in order to undertake certain stresses. So, bone cells, bone cells at this level of scale they allow remodeling the structure which is in response to the stresses borne by the bone. And again, these are osteons or the haversian canals, these also called cylindrical pores- they contain blood vessels and blood vessels are necessary for nourishing the tissues. And there are very fine channels which are called canaliculi and they radiate from the lacunae. And again, it also assists in pumping the nutrients, by, because of mechanical stresses via some physical activity, we need to keep the bone nourishing, so, we have to pump certain nutrients, and those nutrients are passed through these canaliculi, or the fine channels. And again, the pore structure of the bone also helps maintaining the viability and adaptability to mechanical stresses.

So, we can see each and every kind of feature, or the structure has certain functionality; that stiffness arising from the composite structure; slow creeper and as in because of cement lines; cement lines also assist toughening the material; then we have ellipsoid pores, they allow the space for osteocytes, or the living of the bone; and the bone cell then, they permit the remodeling; again, we have haversian canal canals or cylindrical pores which allow the carriage of the blood vessels; and blood vessels they carry nutrients for themselves; then, we have fine channels again, they are required for pumping the nutrients; and the pores structure is very essential to adapt to the stresses and enhance the viability of the bone. So, we can see the multi scale hierarchy is arising from the basic construct of collision and the apatite. And how these are going on, how they go on to construct various complex systems, whether it be lacunae, bone cells, haversian canals, or canaliculi. So, basically all the arrangement of all is very, very essential in terms of dictating the all multi functionality of the bone.

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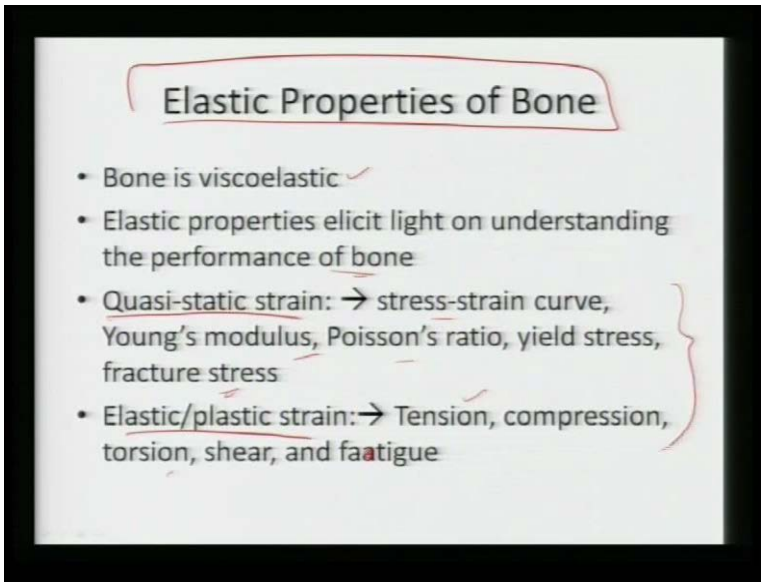

So, it becomes essential to see what is happening in the bone, or what are the elastic properties of the bone. Though bone is basically in a, viscoelastic, it has certain response with respect to time, but the elastic property itself can elicit in terms of understanding the performance of bone itself, so it becomes essential that we understand how the elastic properties are now being dictated. We can have quasi static strain to understand stress strain curve, young's modulus, Poisson's ratio, yield stress, fracture stress.So, that will basically allows to understand what is the response of a bone once a stress is being applied, what will be its stiffness, how much will it contract, what is the overall strength which it can bear, at what stress it will basically fracture. We can also apply certain elastic plastic strain to understand the tension, compression, torsion, shear and fatigue behavior of the bone. And this is also essential because bone undergoes variety of stresses, while we are jogging we are undergoing impact, while we turn our foot we also undergo torsion, there can be again shear depending on how we are running.

And all this compression is very, very essential because we are (( )) , we keep jumping, if we are hanging from somewhere, bone undergoes tension. So, the variety of stresses, those, basically, dominate the lifetime of the bone. And because it is essential to understand them to an entirety, so, we can now model the bone and we can see how the stress response, or the how the remodeling of bone will occur when we supply it with an artificial implant material. So, if you are inserting an artificial implant material into the

body, so, how the bone around it will reconstruct itself, that is also very, very essential in terms of dictating the functionality of the implant material.

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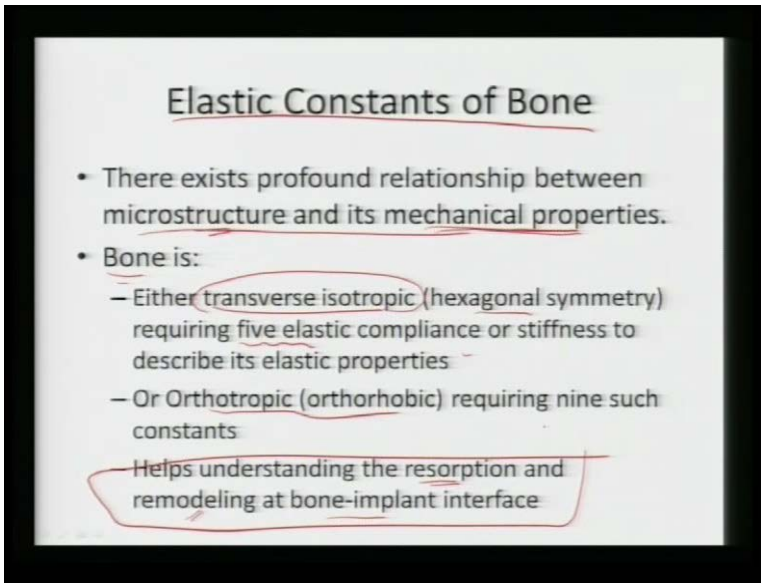

So, it becomes essential also to identify what are the elastic constants of the bone because it has been observed that there is a very strong relationship between the microstructure of the bone and its arising mechanical property; so, that is that makes it very, very critical that we somehow basically be able to engineer the overall microstructure, which is existent in the bone and then, identify its mechanical property; and then, be able to design artificial implant material which can mimic its microstructure and also mimic its functionality in terms of mechanical property, in terms of its behavior, in terms of its corrosion resistance, in terms of its stress bearing or structural applications. So, bone is basically considered either transverse isotropic because of its hexagonal symmetric, and further it requires 5 elastic compliances or stiffness to describe its elastic properties. Or it also considered as orthotropic- orthotropic requiring 9 such constants. So, basically, now, this helps understanding the overall resorption in the remodeling at the bone-implant interface.

So, we can see if we are able to identify the overall elastic properties, we can understand how the bone resorption will occur, or how the bone remodeling will occur at the bone implant interface. So, first critical thing is the microstructure has certain dependence on the resulting mechanical properties. And bone we can consider either as transverse

isotropic because of hexagonal symmetric, or it is also considered orthotropic requiring then 9 components of elastic compliance or stiffness.

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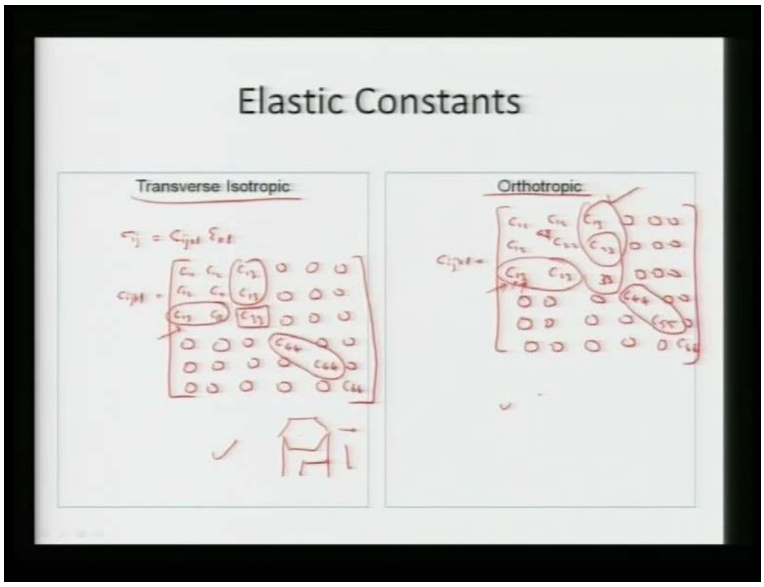

So, considering it to be transverse isotopic we have the overall dependence of stress with strains sigma ij equal to the stiffness tenser, which is of order 4. So, in this particular case we have to define C ijkl, this is nothing but the compliance matrix, and that will be resulting, because of transfer isotropic, we can assume that properties along 1 2, and 1 2 1 2 1, they are nothing but the same; so the response at the other 2 regions, because of its hexagonal symmetry, we can assume it will be C11 C12 C13; so, 1 and 2, it is the same, so, we also get then C13. So, 1 and 2, basically, are now being same; and then, we get C44 again, C44, 0.

So, that is how the dependence we can get, that we have this particular terms which basically are nothing but the same. So, C23 and 13, they become the same sort of response of the stress in the third direction, gives the same reason either in 1 or 2. So, we can see that particular part either (( )) out here. And when the bone is considered orthotropic it means there is no dependence as such- so, we require in totality, we require 9 such compliance term or the stiffness terms. So, in this case we have Cijkl, it becomes, there is no dependence, or it becomes C 1 C12 C13 0 0 0 and C12 C22, so, there is, we can see there is no dependence between them, C 23 0 0 0 C13 C23 C33 0 0 0- so, we can see dependence between them is now eliminated in this particular case, so, again, we can

see is no dependence out here, sorry, out here, snd there is no dependence on the other side as well. So, this is, if we apply certain strain in one direction, it will also results certain, it will also have certain dependence like, it will also alter the strain, the compliance in the third direction.

So, stress in 1 (No Audio from 30:34 to 30:42), strain 3 is basically affected, which is similar to strain in 2 and getting, stress in 2 and strain in 3, but the that is not arising when the system is orthotropic in nature. So, we can see there can be certain dependence because of the transverse isotropic or because of its hexagonal symmetry. So, we can see this side and this side basically is now symmetric whereas, it is not so in the third direction- but in this orthotropic case we do not see any similarity either along 1 or 2.

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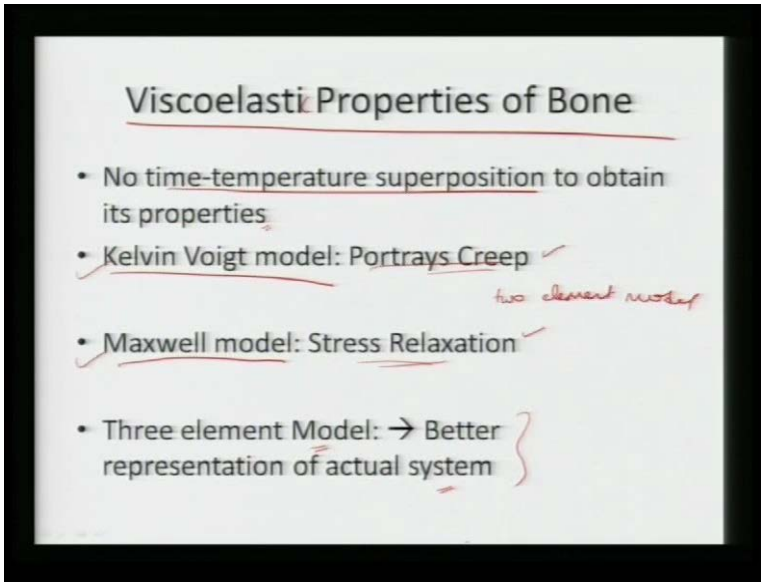

So, again, the time, the visco, since the bone is viscoelastic in nature, the viscoelastic properties of bone, there is no time-temperature super position to obtain its properties. So, generally the time temperature superposition is done either by enhancing the temperature or by enhancing the time we can get the similar performance, but that is not so in the case of bone. And again, there are certain model which define, which define the viscoelastic properties of bone. So, there is one Kelvin voigt model which can be portrays creep very easily, or this Maxwell model which can render the stress relaxation point. And these both are only two element models. But because owing to the complexity we require three element model for better representing the actual system. So, we can see

that in the Kelvin voigt model and the Maxwell model we only have two terms, which are arising from the stiffness and the capacitance, or the resistance and the capacitance type, which can portrays creep. And Maxwell model, it can represents stress relaxation. But we require three or a better model to represent the actual system of the bone.

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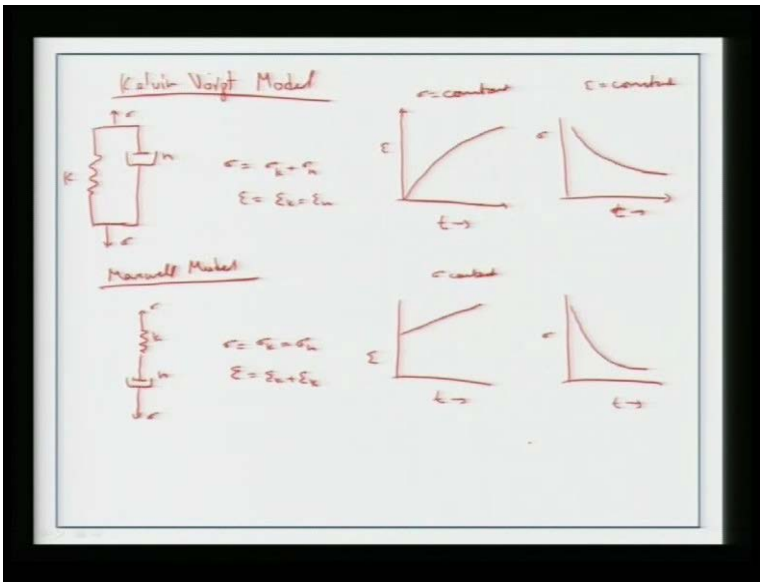

Just to give you feel of the Kelvin voigt model, so, the Kelvin voigt model, we have the system where we have resistance and we apply stress along this side, so we have it like this, and then, so, we have capacitance, we have resistance of k, capacitance of n then, we are applying stress in the other direction. So, in this case we can see the sigma is arising, the stress is arising, it is now being shared between the component k and the component n whereas, the strain is similar in the both the cases. So, if we see overall response when sigma is constant, we will see that the strain gradually increases, so, when sigma is equal to constant with time strain gradually increases. Whereas, once we keep the epsilon is equal to constant we have more of a stress relaxation is occurring. So, when we have strain constant we can see that stress relaxation which is happening out here. In case of Maxwell model we have structure which is more like this, we have the resistance and capacitance in series- in the previous case Kelvin voigt model we have, we had this resistance and the capacitance in parallel whereas, in this case we have everything in series, so, we have k and n. So, in this case if we you apply stress, which is equal to sigma k equal to sigma n, it is the overall strain is now being shared between the

two. So, in this case if we have a sigma constant, we can see this strain as linearly increasing, or again the stress part it also is gradually decreasing.

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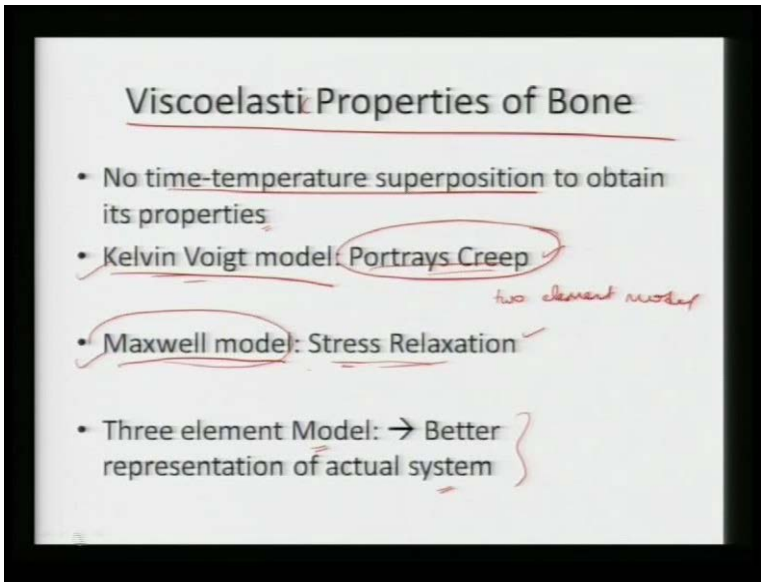

So, we can see from the previous case, the Kelvin voigt model, it can portrays the creep, its constant stress, what is the overall strain which is happening in the Maxwell model, how the stress is now relaxing itself.

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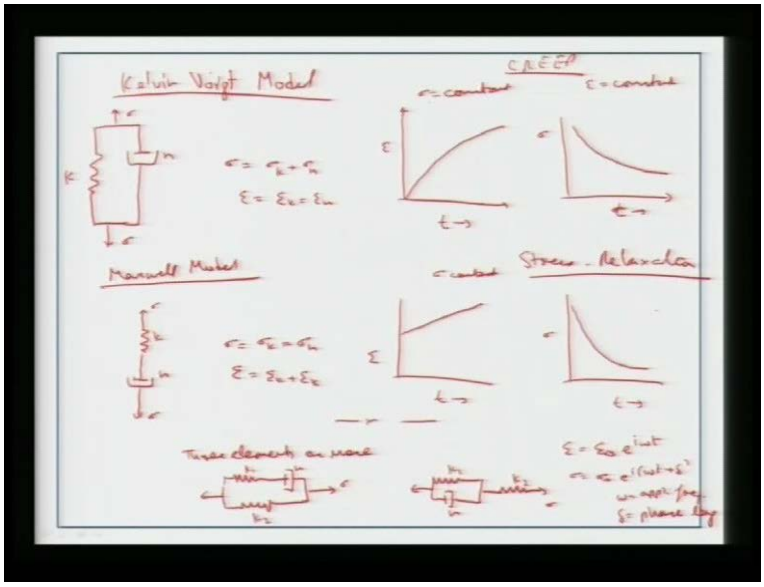

So, we can see the stress relaxation part here and the creep part from here. When sigma is constant the strain is basically increasing. So, we can see the creep part from here

whereas, the stress relaxation parts from here. But, again, these are not sufficient to elicit what is happening at the bone level, so we require three elements or more to construct. So, again, we can have construct of something like this, we can have the resistance and capacitance and then, resistance in parallel, so, series of k1, k2 and n and then, we applying stress, or it can also be, we can have this particular construct as well, again, resistance in series to apply the stress.

So, but again we need to have dependence, which is more like e power i omega t, or sigma equal to sigma naught e power i omega t plus delta, where omega is applied frequency and to delta is the phase lag which is occurring between the stress and the strain. So, we can see this type of a structure is essential, or may be more complicated structure is required, more complicated arrangement is required to mimic the overall stress strain behavior of the bone.

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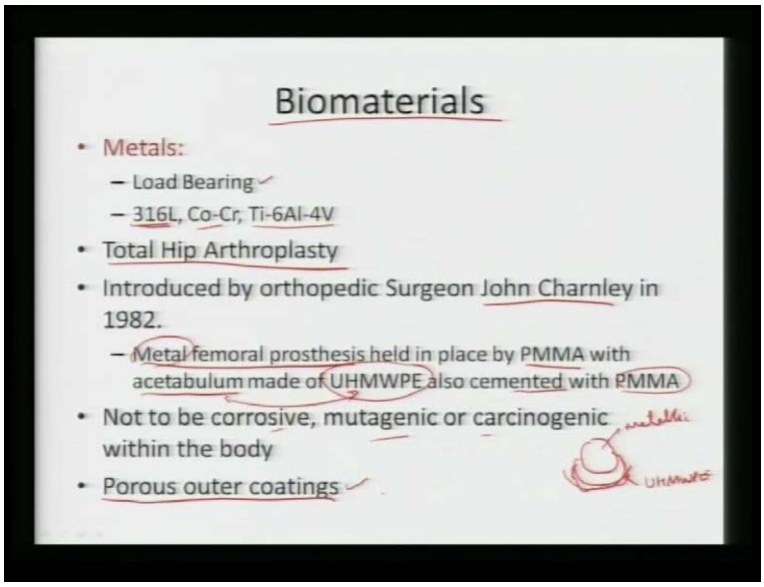

And going on to the materials, we can see that biomaterials are, they can be basically classified into three broad categories of metals, ceramics and polymers. So, in case of metals these are nothing but the load bearing entities, so if we want an entity to bear a load, or act as structural material, we need to incorporate metals; and we can see we have certain elements like 316L stainless steel, cobalt chromium alloys and titanium 6 aluminum 4 vanadium. And for any structure to bear the load at least to have very high strength as well as high impact resistance, and these metals are invariable used in the

total hip arthroplasty. And it was, particular construct was developed by an English orthopedic surgeon, John Charnley in 1982. What he has done is he has taken the metal femoral prosthesis and he has cemented it by poly methyl acrylate with the acetabulum, which is now made up of ultra high molecular weight polyethylene also cemented with the PMMA. So, we can see that our femoral prosthesis and the acetabulum, they both have now joined by PMMA, and the material is now being differed like, metal in conjunction with PMMA, which is now fixed by PMMA and now, is fixed in the UHMWPE, which is ultra high molecular polyethylene, which is making the acetabulum.

So, we have the acetabulum cup and we have the acetabulum, and the hip, and the femoral ball which is now being sitting out here, so we can see that this metallic entity is now in contact with the ultrahigh molecular weight polyethylene- so, now, this particular construct it has shown very dramatic improvement in terms of its longevity. But again, there are certain (( )) which are associated with metals, but though they are load bearing, they need not be corrosive or mutagenic or carcinogenic. Because the basic problem with the metals is they get, they tend to become highly corrosive once they come in contact with certain fluids, and they tend to realize metallic ions which can become even carcinogenic. So, what is happened recently that they are now being protected by certain ceramic layers, so, they have certain porous outer coating and this outer coatings are nothing but, made up of certain ceramics such as hydroxyapatite and then, it allows the bone to grow on to itself and act as a site biocompatible layer- and the pours basically assist them ingrowth of cells into the porosity and anchor them on to itself.

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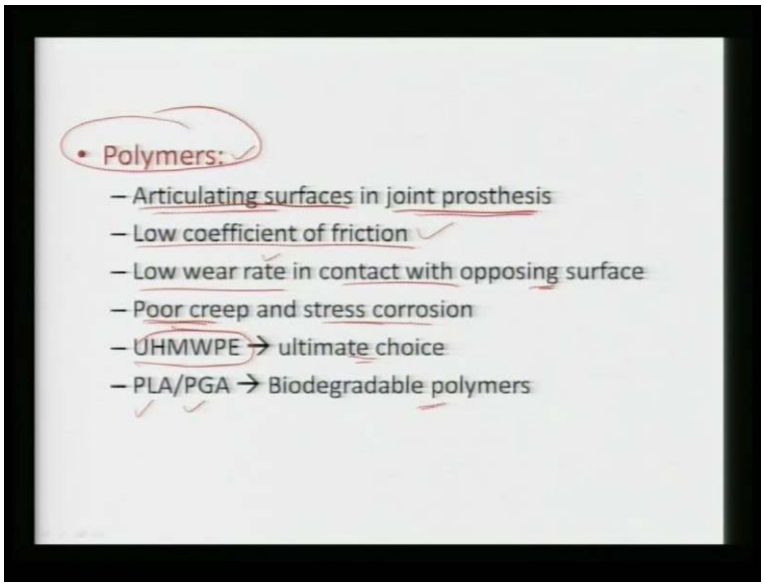

So, basically, metals have been utilized as load bearing entity whereas, polymers they are very good in, they very good, these are very nicely at the articulating surfaces basically, at the joint prosthesis. It happens because they are highly complaint in nature, they can twist, they can basically change their shape once any force is acting on them, so, they can accommodate release of the stress. They need to have very low coefficient of friction so that they can survive longevity and they can ease out the friction which is happening between the adjoining articulating surfaces. They also need to have low wear rate in contact with the opposing surfaces. At the same time they need to have very high strength as well as good corrosion resistance. But they tend to show very poor creep, because they have very poor strength, low melting points so they show very poor creep, resistance and they show very low resistance with the stress corrosion. So, there is a basic problem with the polymers, but eventually ultrahigh molecular polyethylene has become as emerges as the ultimate choice. Also there are certain degradable polymers such as polylactic acid and polyglycolic acid- those are also have emerged as a bio degradable polymer. In case where we require a local, or a very short term strengthening for certain things such as sutures, so, we can, if we try to heal, or particularly seal particular location or a cut and eventually that PLA or PGA dissolves with time and it allows the new layer of skin to grow at that particular location.

So, we can see polymers for orthopedic applications, they are very, very good, basically, serving at the articulating surfaces in the joint processors; they posses low coefficient of

friction; they have lower wear rate, they require low wear rate in contact with the opposing surface. But the problem with them is they have generally have poor creep resistance and poor stress corrosion resistance, but eventually ultrahigh molecular polyethylene as emerged as a ultimate choice of the for the acetabulum and then, it improves the, enhancing the life of the orthopedic implant.

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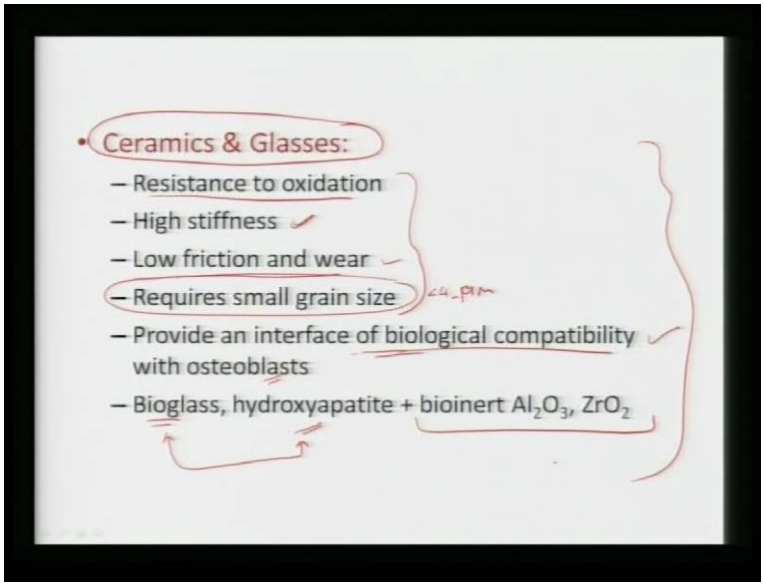

Additionally, certain ceramics and glasses have also coming into the picture. Basically, because of that two main features; first things is there is certain good mechanical properties and chemical properties, they have resistance to oxidation, they posses very high stiffness, they have low coefficient of friction, and they also has very good wear resistance. And also there is, one limitation being imposed here is they require very small grain size to the order of 4 to less than 4 micrometer specifically, for aluminum oxide with certain purity. The additional advantage with ceramics is they can provide an interface of biological compatibility with osteoblast. So, this is the basic feature of this ceramic, which can provide much enhanced cytocompatibility with the real life tissues.

So, first of all they have low resistance oxidation, they have high resistance oxidation, they posses very high stiffness, they have low friction and wear and also, they provide an interface which is very compatible to the osteoblast- so, that makes it a very applicable material. So, eventually there are certain materials which have been developed, certain ceramics and glasses such as biogases, hydroxyapatite, which has emerged as a bioactive

materials, and they allow the precipitation of apatite on to their surface and then, they can allow the natural bone to replace and take its place. Also, there are certain bioinert materials such as aluminum oxide or zirconium which can also allow the growth of cells on to their surface without any reactions. So, we can see on one hand where we require metals for load bearing applications, polymers are good at the joint applications whereas, ceramics and glasses, they can serve as active agents in terms of assisting the cell growth and proliferation.

So, we can see there are different combinations of metals, polymers and ceramics, which are essential in terms of undertaking three different functionalities. So, ceramics and glasses, they are highly utilized for providing an interface with biological entities such as osteoblast, and they can render their growth, growth on to any surface, onto their surface, and they can also be applied as coatings onto the metals. So, for a metallic implant and if you want to have interfacing with the real life cells and tissues, we can apply a porous coating of ceramics so cells can really adhere themselves, they can interlock themselves with the pores and they can start growing because of their good biological compatibility with the ceramics and glasses.

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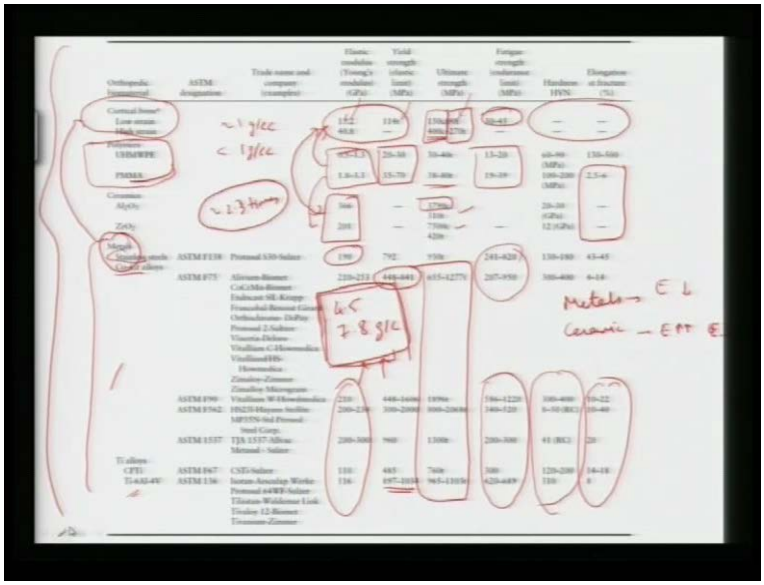

So, we can see there are certain traits, certain properties of this particular biomaterials, starting from the cortical bone to depending on the type of stream which is being applied, we can get the elastic modules between 7-30 or 40 gigapascal. And again, it can be

different in tension and in compression. So, elastic modulus is out here, but the yield strength is approximately 114 megapascal. Ultimate strength, depending on whether it is compression or tension, we can see the compression the values are much higher than that of a tensions. So, we can see the tension values are 270 megapascal where it goes to 400 megapascal under compression. Fatigue strength are to the order of 30-45.And also, the density are, also, the densities are much more comparable to that of polymers, to the order of around 1 grams per cc whereas, polymers, they generally have densities less than 1 gram per cc or so. So we can see polymers, first candidates, they have again elastic modulus which are very, very low in comparison to that of a cortical bone.

So, we need to somehow utilize these polymers for some joint applications, but we need to somehow reinforce them with either metals or ceramics to improve their elastic modules. Their yields and also is very, very poor, compression's ultimate strength is also very, very poor, but fatigue strength is approximately similar to that of cortical bone. Coming to the ceramics, they have very high elastic modules, once the elastic modules is very, very high they can impart stress shielding to the bone, so the bone will undergo modeling and will start (( ))- so, that is not really good. Again, the ultimate strength is very, very high, it can go on to couple of times, maybe one or two magnitude higher than that of a cortical bone, so from 150 it can go to 3790, 3.7 gigapascals, which is very, very high- so, that is not only good for replacing the bone.

So, we require it to again reinforce with certain material, or to induce much more porosity, if you are inducing the porosity, then it can basically reduce the elastic modulus to a dramatic, dramatically low extent- and that can now become comparable to that of a cortical bone. There are certain metals which also have been utilized very recently to replace, to serve as a bioimplant material- so, stainless steel, cobalt chromium alloys and titanium 6Al4v alloys. Again, their modulus is pretty high, elastic modulus going to approximately 200 gigapascal whereas, that of a cortical bone is around 15-40 gigapascal. Yield strength again, its very, very high at 448-841- it can go up to over 1000 for the commercial, for the titanium 6 alumina 4 vanadium alloys. This strength again, it is, similar order as that of a, it is much higher than that of cortical bone, approximately twice, thrice, that of a cortical bone. Again, the strength is pretty high, fatigue strength, because these are nothing but metals, so they tend to high, very high fatigue strength.

They can sustain very huge damages into them. Their hardness is again much higher than that of a polymer or of a cortical bone. But the elongation in fracture is again much lower than that of, than that of a polymer. And ceramics, they possess the least value of elongation because they are highly brittle in nature. So, for metals, they have very high e, very high young's modulus, but their elongation at fracture is lower than that of a polymer; ceramics, they have very high modulus, elastic modulus is very, very high, their compression strength is also very, very good, but they lack in the elongation, the elongation is very, very poor. So, elongation is to the order of 2 point, elongation is very, very poor for the ceramics and whereas, metals, they perform very good because they can sustain very high damages. And the cortical bone, there are certain numbers which are not available now. So, but again in terms of density we can say ceramics, their densities is to the order of 2-3 times that of a bone. Whereas, metals, they are pretty heavy, they go from say 4.5 to around 7.8 grams per cc, so they are approximately couple of times, 4 to 10 times much denser than a cortical bone.

So, again, we need to introduce certain porosity into it, or to provide certain structure which is much more complaint and apply a certain coating around it so the, so it can really, it can really interface with the cells or the surrounding tissues. So, we can see metals, they are highly tough, they have very high elastic modulus which can lead to the stress yielding of the bone. So, we need, so, generally, these metals are now coated with porous ceramics; and porous ceramic, they generally have a density to the order of 2-3 times than that of cortical bone. So, porous ceramics can really serve as a similar material as that of a cortical bone.

So, you get toughening by metals and we get compatibility by coating this ceramic on to this metal, and now it can represent that of a, represent a natural cell or a tissue or similar to that of a osteoblast and then, bone can start really growing on to it by incurring and by finding the biocompatibility around it. Again, polymers, ploymers also, they show a very good promising, they are also promising candidate materials, and they use, utilized basically in the regions where we have joints- so, it can take care of much more complaints at the joints and it can enhance the overall functionality, or reduce the friction at those joints. So, we can see this is the overall paradigm of different materials starting from the natural cortical bone, polymer, ceramics and metals, and how they are basically linked to render a particular functionality.

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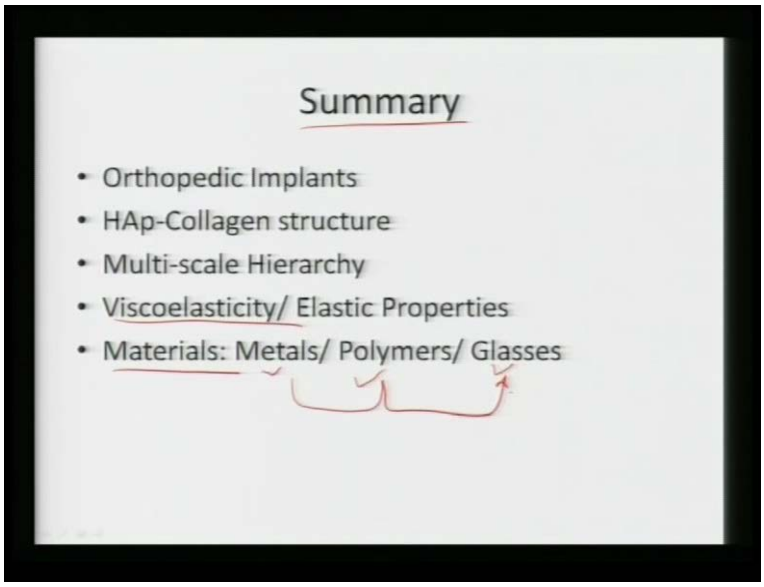

So, in summary, orthopedic implants are the ones which do not introduce any sort of an adverse effect either to the biological environment or at the same time do not get affected themselves once they are inserted into the biological environment. And there is some sort of a interplay between hydroxyapatite and collagen, how they go on to forming molecular chains, and how they go on to form a fibrils then, on to lamella and then, haversian systems to form the overall hierarchical structure of the bone and get multi functionality in the bone. So, the multi-scale hierarchy starting from the cement lines, or those canaliculi, or those haversian systems to supply the nutrients, at the same time remodel themselves when any stress is applied to them becomes very, very essential. So, multi-scale hierarchy is one of the very critical components. And then, it goes on to finding the viscoelasticity or elastic properties in the bone by applying Kelvin voigt model or Maxwell model, or more than two or three element model in order to estimate what is the overall property which can arise from this particular structure.

And also, the overall bone structure is, can, we need certain elastic constants to estimate the elastic properties, it can go on to basically understanding either the, taking them either as transverse isotropic or also taking them as to be autotrophic in nature in order to estimate the elastic property- so, depending on that we also require certain stiffness or compliance values for perfectly estimating its response. And there are certain classes of materials starting from metals, polymers, or glasses, it can even be composites. And we can also see there is a difference in terms of the functionality starting from polymers

basically, serving as a complaint material, or metals serving as a structural material, or ceramic which is much more of a biocompatible material, or, interface, which can interface with the biological cell to render the overall engineering of artificial implant material, and serve, make it serve as a replacement for the bone. So, basically, I will end my lecture here. Thank you.