Oral Biology
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Lecture - 22
Biomimetics - Part 2

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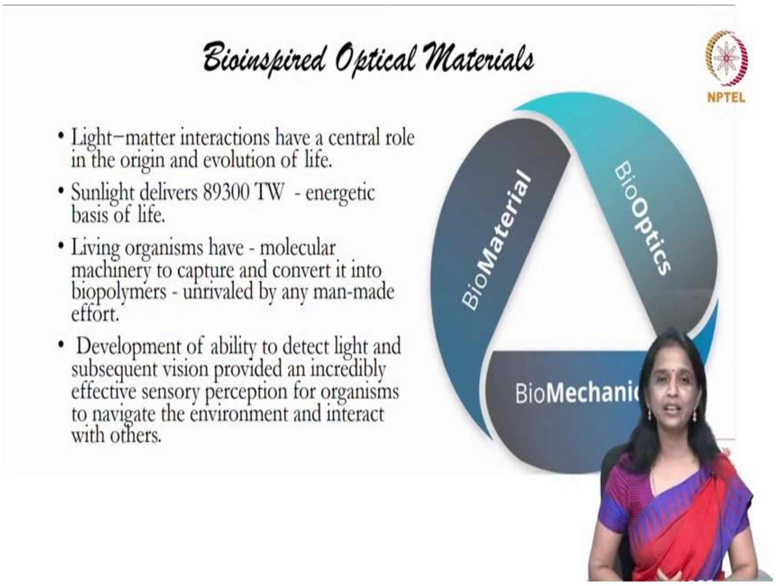

We move on to a very important area of Biomimetics that is Bioinspired Optical Materials. Where are we if we do not use our vision? The most important sense organ we know that the moment we open our eyes we have a colorful world in front of us and how many of the living beings are deprived of relishing this beautiful nature in front of us.

So, to address that defect in disease states which are targeting the optical tissues there have been attempts to replacing it with bio inspired optical materials not only for replacement it also helps in handling many other requirements, which actually the ophthalmologists really want.

So, having said that the field of bio material inspired optical material involves biomaterial, bio-optics and biomechanics because it is a continuing sequential course of events which actually define the bio inspired optical materials. So, as we go on to read bio inspired optical materials we know that the sun is actually the major light source and the tissues especially our sense organs actually perceive the light source through very intricately kept light receptors inside the eye. So, that perception the ability to perceive light and then to signal that light and then to perceive it back and to receive and to reflect all that is to be again reflected as a Biomimetic material. So, that is what the bioinspired optical materials try to do.

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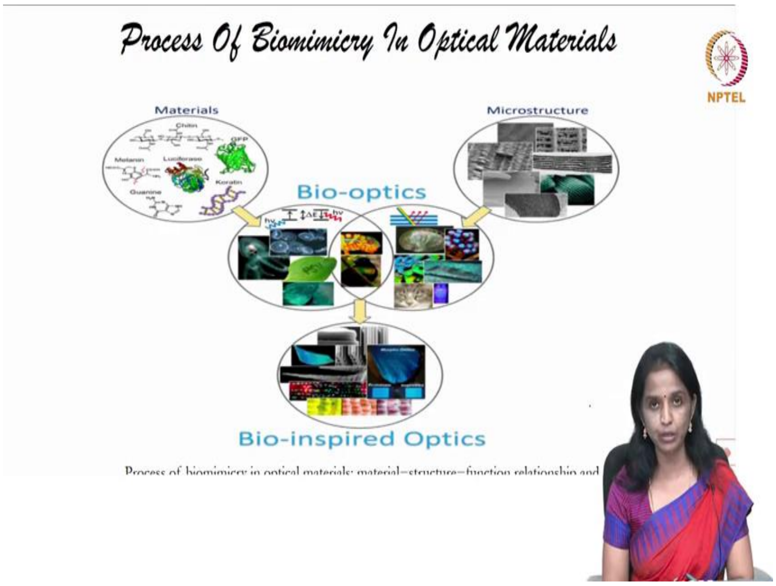

But once you see this that we knew we understand that it has to be a very smaller structure of a micro dimensional structure which has to be having a very nice biomaterial quick enough to grasp the light energy, absorb the light energy and then derive the signals and perceive the signals and then send it to higher centers or perceive and then reflect it back.

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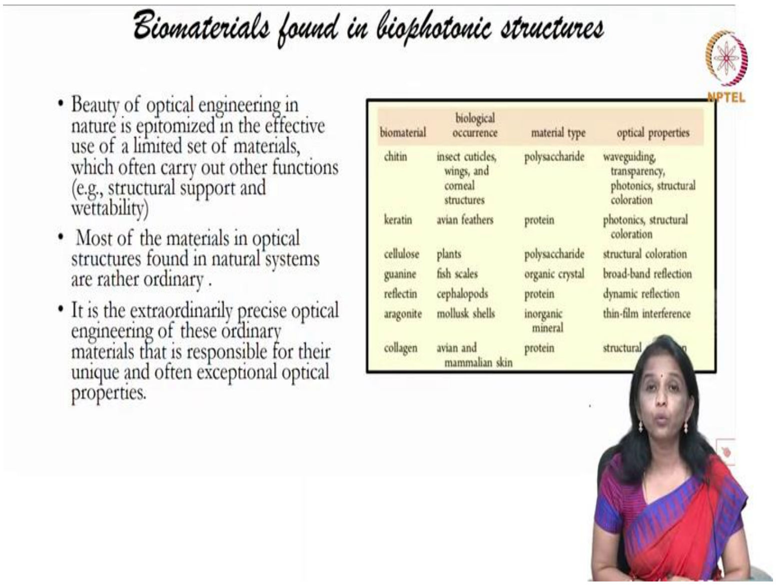

So, which are the biomaterials which are involved in biophotonic structures or bio inspired optical systems? So, if you see this particular list of biomaterials over here they are all very simple. You can see them the chitin, keratin, cellulose, guanine, aragonite, reflectin and collagen are all very simple basic bio materials which are very much available.

having known that we have been told that these are the biomaterials which are involved in optical or biophotonic structures, but it just does not stop with a piece of collagen. How do we convert that into a biophotonic system that is the challenge. due to this it is not about the biomaterials mainly it is about how that is being organized in a particular structure and that is how actually that makes the difference by in biophotonic structures.

the arrangement or the organization of that particular biomaterials into a very intricate complex structure can only do this biophotonic property or only which can present a biophotonic property. So, it is a very challenging field, but very prospective field in healthcare device making especially.

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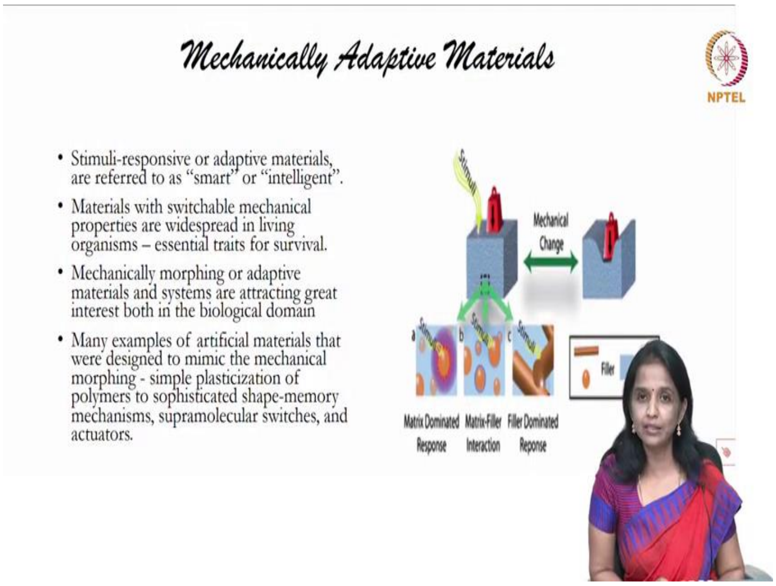

And now the next one is our most important mechanically adaptive materials. As the word says when there is a physical stimuli or a mechanical stimuli if the material is able to adapt ability to adapt will give you a upper edge or a better survival edge applies to anything. So, your ability to adapt makes you more survivable or more capable to survive in any kind of challenging environments the same applies to material science also.

So, if there is a physical stimuli or a mechanical stimuli the material, which is actually taking up that physical and mechanical stimuli is able to adapt and change its shape and structure good enough to survive that kind of stimulus or an insult or any challenging atmosphere. In that way it is going to really help in the process of biomaterial science and in creation of biomedical devices. So, this is especially of great use in creating supra molecular switches and then it is also helpful in shape memory mechanisms and actuators.

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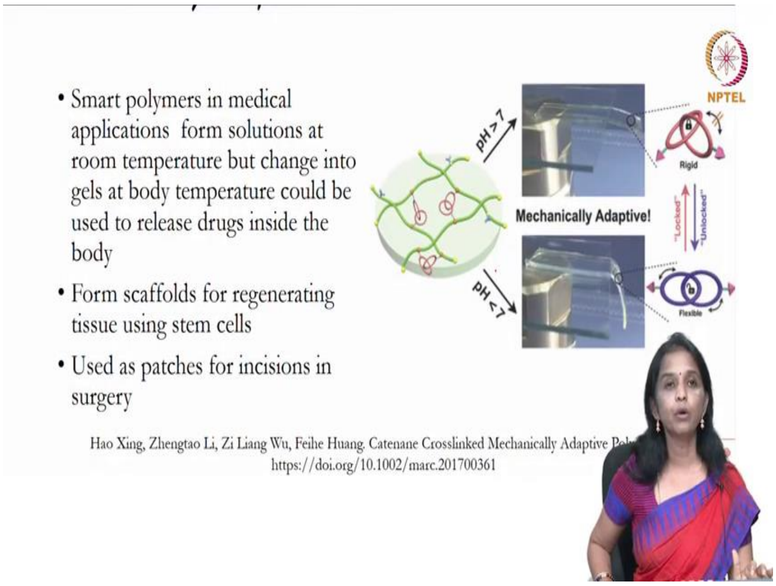

So, as we move on the most important part of mechanically adaptive materials is actually derived from polymers smart polymers which are very important and which forms the basis of your mechanically adaptive mechanisms. How are they used? They are mainly used for forming scaffolds for regenerating tissues using stem cells and they are also used as patches in surgery.

So, as already said so these are areas where there will be constant state of biophysical flux or changes happening. So, in those areas if the material is able to adapt and survive with any kind of stimulus that is happening then the outcomes would be as expected or as desired.

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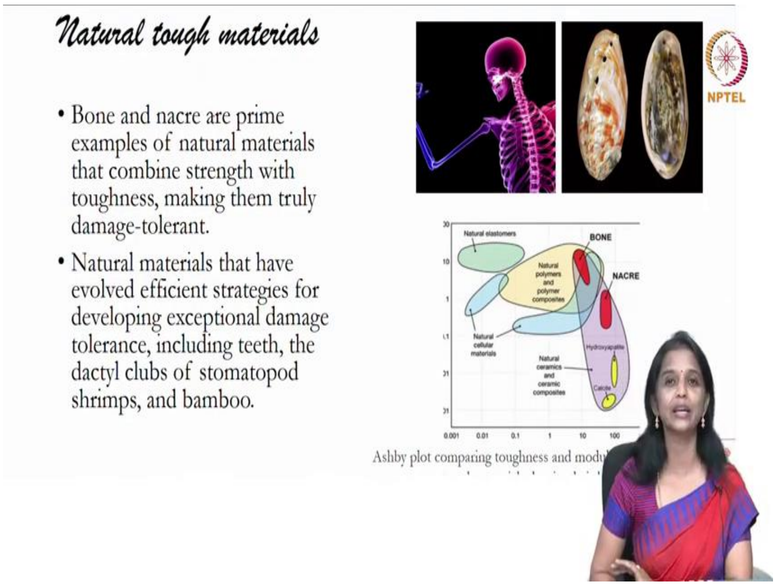

And then we move on to a very interesting area we know that we are actually made of a skeletal framework and that is why now I am able to sit erect. So, this human body is able to sit erect in this way because of an inner hard framework and that inner hard framework is called as bony skeleton and if that skeleton or framework was not there I would just be a mass of tissue or a ball of tissue together.

So, this structural definition would not be there if the bony skeleton is absent. So, bone is such a beautiful tissue which actually is revered in the field of healthcare industry because this is actually what forms a very important substrate of the morphological structure.

As mentioned there are other similar structures which are as good naturally derived hard structures or to put across to in simpler words living tissues which are as or good enough or hard are your bone and then there is another tissue, which is mean in hard enough which is secreted by the nature itself or a living beings is your nacre. So, these two are very important and these are exceptionally strong enough to withstand any kind of physical stimuli.

So, that makes it really helpful and in addition to your bone we have teeth and dactyl clubs of stomatopod shrimps and bamboo. These are all examples of extraordinarily tough natural derived materials. So, this beautiful plot over here which actually goes into comparing the toughness and the modulus tells that bone and nacre forms the most toughest structures as far as natural materials are concerned. We have other natural materials all below them. So, they are very very tough and having high strength and high modulus.

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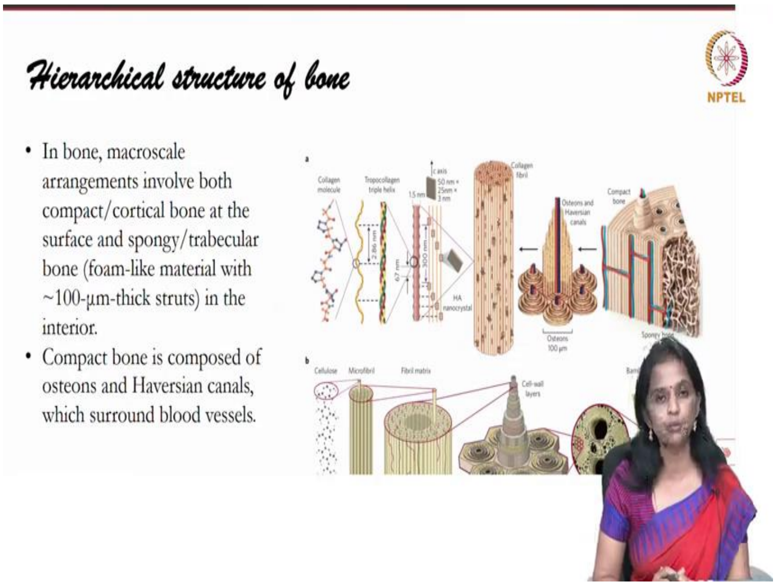

And this is one important thing which you have to understand why is bone tough. And we know that there is a huge requirement for bone graft or bone replacement materials because we know that the incidence of trauma and the incidence of bone related diseases are very high there is a constant need for replacement materials.

As we understand that there is a huge demand for bone replacement materials we have to go and see what is bone really made of. As we understand the architecture of bone we can try to mimic the same outside in vitro and then place the same inside in vivo. So, the most important thing which has to be understood as we go through the bony architecture is that it is actually made of an outer compact bone and then we have the inner trabecular bone. So, these are very important.

So, the inner trabecular bone is called a spongy bone which is actually got lot of spaces in between, compact bone does not have space and it is tightly sealed.

So, this Harversian system is a tube like structure with perpendicular Volkmann canals and over the system we have leaf like structures lamellas being wound up around. So, this is called as the lamellar bone. So, the compact bone would be lamellated like this you can see the projection here. So, there is a central canal; the central canal or the Haversian canal has the blood vessels which are very important to supply nutrition to the bone and then we have the lamellated bony structures.

The center part has your cancellous bone. So, this cancellous bone has the bone marrow. So, it has to have lot of spaces and that is why it is spongy in nature. So, where was this similar to or which structure is similar to our bone natural bone it is very similar to the bamboo tissue. So, when we try to mimic this kind of hard structures if we can derive exactly intricate structure like this it would be stronger as bone.

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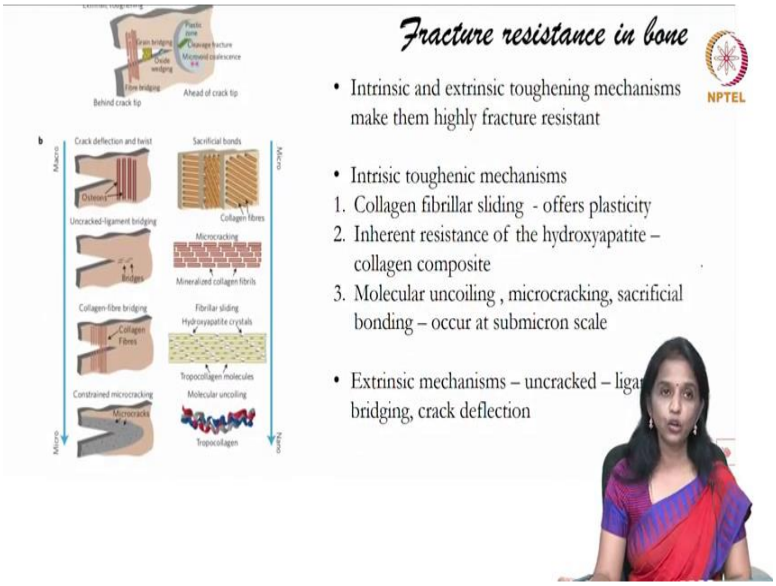

And not only that the other points which has to be mimicked from bone for better graft system is that because of this intricate architecture which was already said there are other intrinsic and extrinsic toughening mechanisms which makes bone very resistant to fracture.

We definitely undergo fracture with very high impact forces, but normal forces bone actually is resistant. So, how does that resistance happen? It is because of the intrinsic and extrinsic toughening mechanisms. So, that intrinsic toughening mechanisms happens with collagen fibrillar sliding, inherent resistance of the hydroxyapatite which is the most important inorganic ion.

And then we have the molecular uncoiling, micro cracking, sacrificial bonding which all occur at a sub micron level. So, all these are actually placed in very beautifully sandwiched process and then we can see that there is micro cracking, there is fibrillar sliding. All these are possible by that hierarchical arrangement of organic and inorganic ions in perfectly sandwiched manner.

And additionally we have extrinsic mechanisms like ligament bridging and crack deflection. As we keep reading ligament bridging and crack deflection we should understand that the bones are actually attached to the muscular structures by the tough ligament structures.

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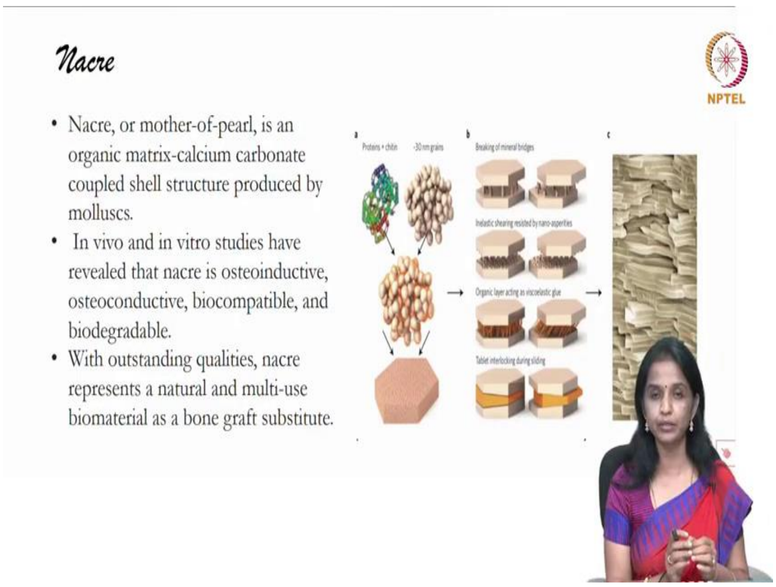

And then we have to read about Nacre because Nacre is again a very inspiring hard tissue which can be which can be try to replicate for bone graft like structures. So, if the basis of how the nacre forms is that we have to understand that it is actually a organic matrix, compost organic matrix and then we have the inorganic calcium carbonate coupled structure. So, we have a protein and then we have the inorganic structure together coming to make the most tough hardest structure here.

And this in vivo and in vitro has been tested and has been found to be osteoinductive meaning that it can actually induce bone formation. So, what are we reading about? We are reading about nacre, but this nacre is good enough to induce bone formation in vivo and it is also found to be osteoconductive.

So, it can actually conduct and create new bone formation. It can initiate new bone formation and it can actually conduct and create a newer bone formation and additionally it is biocompatible and biodegradable as well. So, all these important characteristics which are very classically the ideal requirements of a graft material is present in nacre and there are numerous studies trying to replicate this beautiful naturally available tough material.

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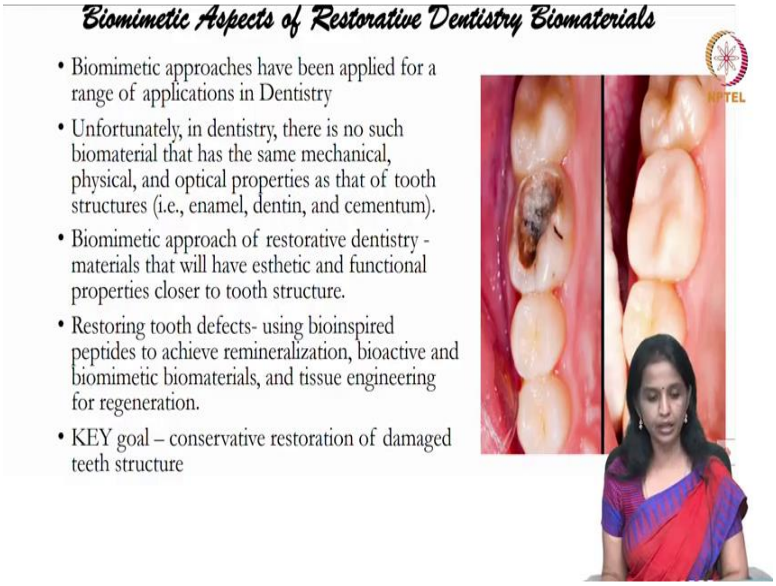

And now we move on to a very important part of biomaterial science. How are we doing Biomimetics in dentistry? So, biomimetics in the field of dentistry is very important. So, we have been talking about general topics till now. What we need to understand is restorative dentistry is field where we need very tough material good enough to mimic the naturally tough teeth structure and good enough to replace.

Unfortunately, till date we do not have a material which can actually give us the exact strength which the enamel, dentine and cementum can offer. We have very advanced materials, but still they cannot match the naturally available structures. But what happens is there is a very very strong need of all these materials because dental caries is a disease which is the most prevalent disease of mankind and because this is more common we can see that unique tooth structure which is the hardest part of the body is getting broken down because of microbial acidic attack.

So, as it gets damaged we need to restore it back to bring back the function; the most important function for survival of mankind that is mastication. Because only when mastication is proper that the survival is possible by aiding in proper food intake and digestion. So, we can see that this teeth which was badly broken down is being restored into its earlier morphology.

So, a complete replacement was of what was there already is what restorative dentistry is all about. So, what we need here is to achieve remineralization, the material has to be bioactive and the material has to be proper replacement. So, the important goal here is conservative restoration of damaged teeth structure. Whatever is left out is so precious that has to be retained and whatever is been lost has to be replaced.

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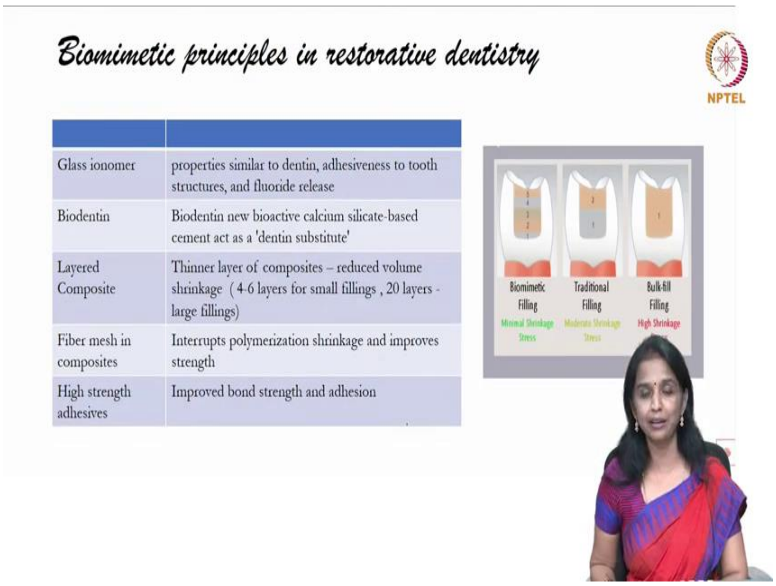

So, that has to be done and can be done with biomaterials and this biomaterials still have a long way to go to match exactly what nature has offered to us in the form of enamel, dentine and cementum. So, what do we do? What are the biomimetic principles principally existing? Having reading about biomimetics here it is very important to know what are the biomimetic principles in restorative dentistry.

So, the first and well-known among this is glass ionomer which has got very similar properties to dentine and has got adhesive property to tooth structure and it also gives out fluoride release. So, this is very crucial especially in case of deeper dental caries where we need a antimicrobial agent not allowing the bacterial adhesion happening again and bacterial colonization happening again.

So, fluoride release is of great importance, additionally those fluorides are the ones which would actually help in remineralization as well. And then we know Biodentin is a very famous frequently used word which is containing calcium silica based cement and this is also been used as a dentin substitute.

And another approach of doing biomimetic approaches in restorative restoring your teeth back is by using very thin layers of filling materials this is especially applied with a polymer composite. So, composites have become the norm in restorative dentistry. Earlier it was amalgam and nowadays composites have completely changed the picture of endodontic restorative dentistry and where we apply composites in layers.

But biomimetic approach what is being advocated is the thinner the layer the better the strength which actually is a biomimetic approach of going in very small hierarchical approaches or very small hierarchical growths. So, this is very important. Additionally, if you can actually keep a fiber mesh among that poly polymer composites that would again aid-in reducing the polymer shrinkage.

So, what are we trying to do? We are again getting inspired by nature where we are supporting a scaffold we are giving strengthening the substance by giving a scaffold there and we also have high strength adhesives with improved bond strength and adhesive property. All are inspired by nature and we are just trying to mimic and redo what the nature has done and replace what has been lost.

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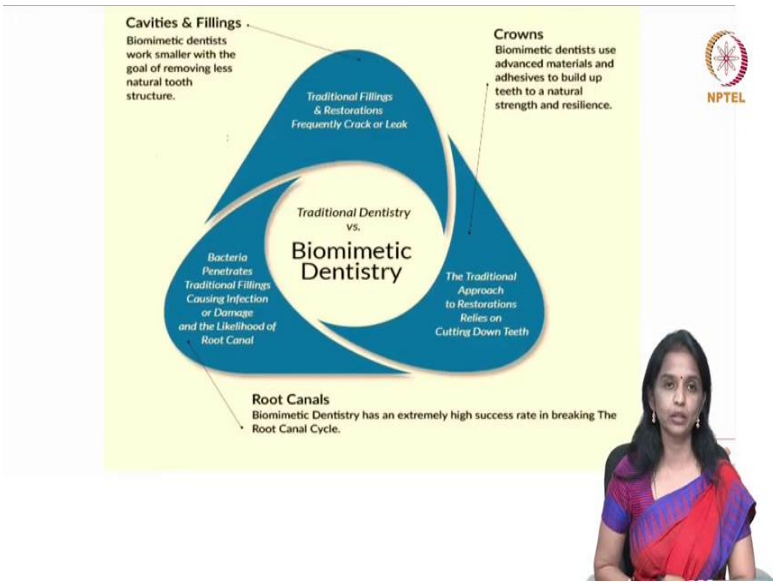

So, in this way this is again a very important schematic picture. So, we can see that what are the requirements of Biomimetic Dentistry. We definitely do lot of restorative work in form of cavities and I mean in the form of fillings and then there is full replacement of the entire crowns and then there is endodontic management of the root canal clearance.

So, all that can be approached with a biomimetic approach trying to be as close to nature and not trying to be on the other end of the spectra being artificial. As we go close to the nature not disturbing its architecture and its micro environment the results are going to be more fruitful and going to be more positive.

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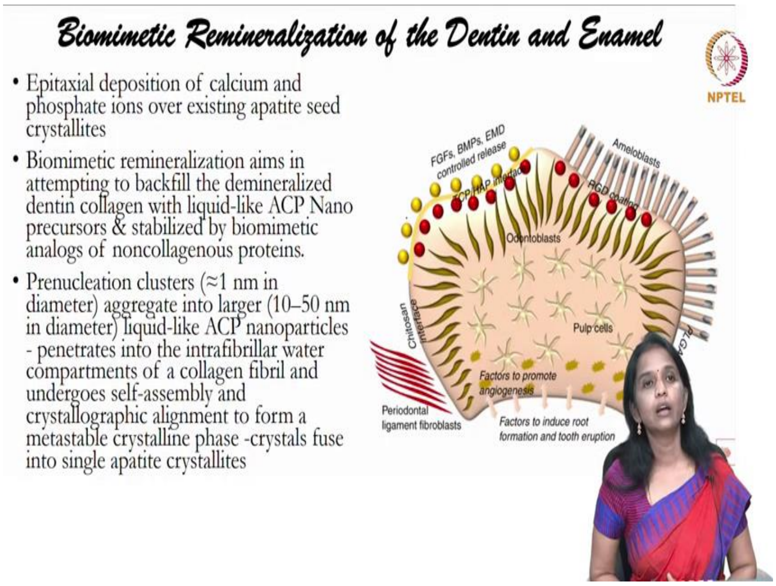

And the most important here is Remineralization approaches. Remineralization approaches in dentin and enamel are very important because the approaches which are being tried are very crucial to bring back anything which is lost or which is trying to strengthen what is being lost. So, having said that the biomimetic approaches use a epitaxial type of deposition.

So, this is exactly in sync with what nature has already done. So, biomimetic remineralization uses epitaxial deposition which means that there is a nucleating agent and over which the inorganic ions gets attached and then it grows on to become a larger harder tissue.

So, you need a nucleating agent or a seed agent that is actually the triggering agent and over which there will be remineralization. So, when this particular statement is being told, when are we when we are going to do it on an artificial basis? How are we going to supply these nucleating agents?

So, these nucleating agents are nanoscale. So, that we already know that nano has advanced so beautifully and we have to just create nano scale nucleating agents. So, these nanoscale nucleating agents will act as seed molecules to attract inorganic ions and then the hard tissue keeps growing.

So, in addition not only the seed agents we also need a protein assembly that is very crucial both in dentin and in enamel also. So, if you we can create a protein scaffold over which there is an epitaxial deposition also, then the phenomenon of remineralization of dentin and enamel would really be very superior and excellent in characteristics.

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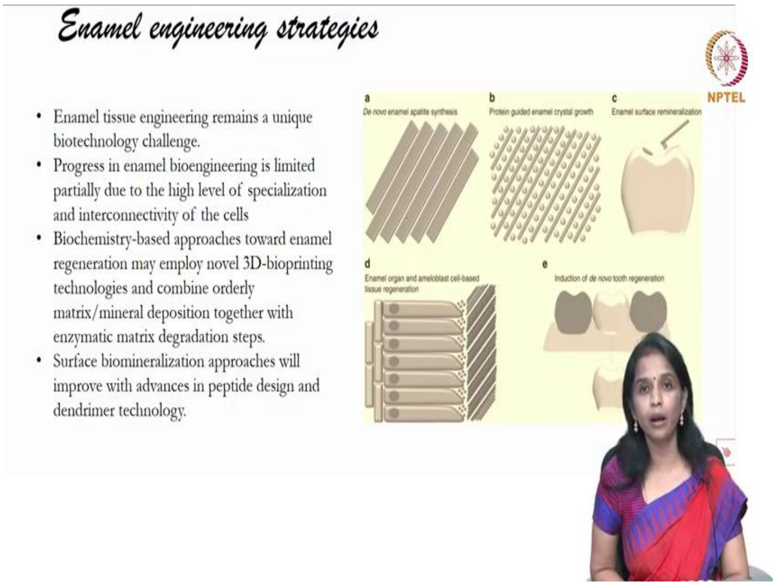

And to be more specific about Enamel engineering strategies; enamel engineering strategies are more sought after because enamel is always looked upon as the most desirable hard tissue which is to be engineered always. Because enamel is more stronger than bone and it is most frequently sought after biomimetic material and there has been numerous attempts to exactly recreate enamel.

Recreating enamel has been the dream of many research labs all over the globe and there are few approaches here. So, the first one is a De novo enamel apatite synthesize synthesis. So, you just create the apatite and then from the start and then you can also see that there is a protein guided enamel crystal growth.

This is actually comparatively given us a better approach because we create a protein scaffold or framework over which the crystals are seeded and that gives a more specified outcome. Additionally, we also try to create a surface remineralization approach and then we also have enamel origin that is the cell enamel cell that is ameloblast cell based tissue regenerative approaches.

But, that kind of approach is very challenging because ameloblasts are very very sensitive type of cells. And additionally, there is induction of tooth, new tooth regeneration; that is tooth engineering approaches which means that in vivo there will be the teeth itself is grown and we have the enamel in that. So, again all these are in the process of research and there is huge scope of research in this particular enamel engineering strategies.

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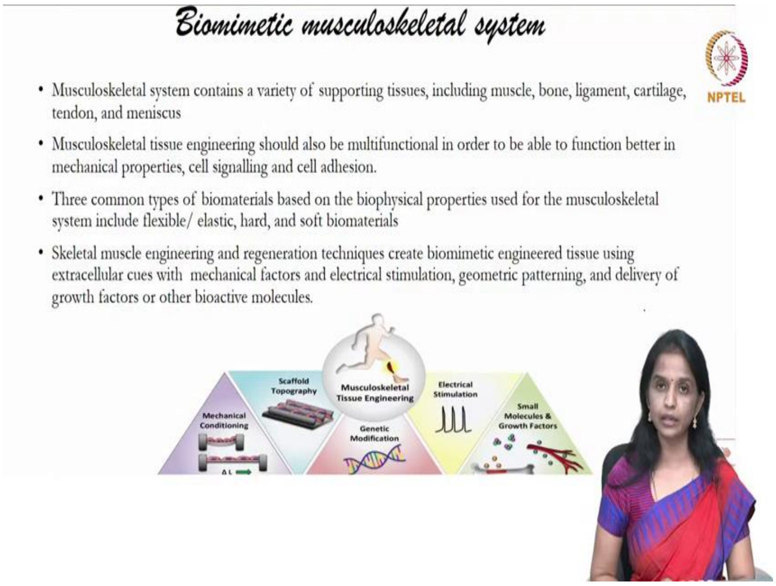

Next we move on to another interesting area that is musculoskeletal system. This musculoskeletal system is more challenging than or equally challenging musculoskeletal system is equally challenging as your recreation of enamel because here we are actually seeing a sandwich of a soft tissue and a hard tissue area.

So, when we have a combination of soft tissue and a hard tissue to be recreated it becomes more challenging because it cannot be a single material, there has to be materials of different characteristics coming together to replace the soft tissue and to replace the hard tissue.

And please do remember that at the interface between the hard and the soft tissue the material should have intermediate characteristics. So, it is challenging and not only that we know that musculoskeletal system the muscle has to contract and has to have electrical stimulus or signal conducting abilities also.

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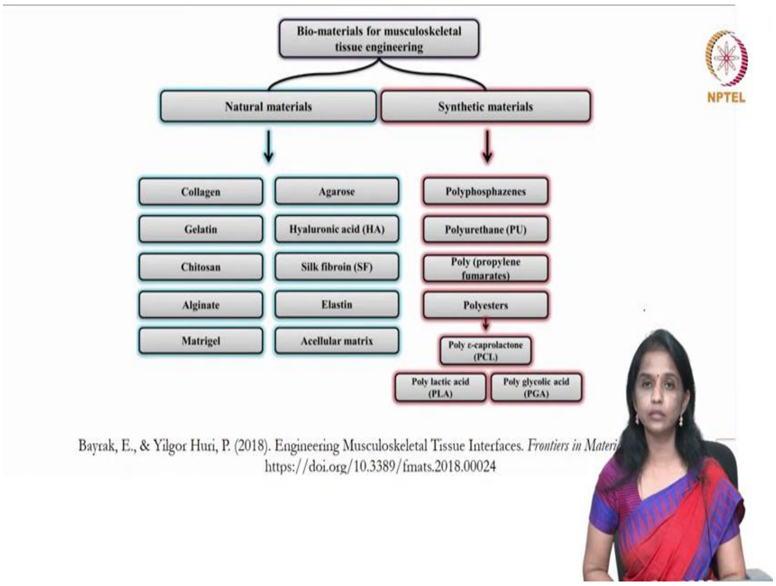

Again, we look into series of materials, which have been used and tested for musculoskeletal regenerative strategies, but what we need to understand is though again these biomaterials listed out here look very simple it is about the architectural design which you are able to achieve with the materials which are suggested here.

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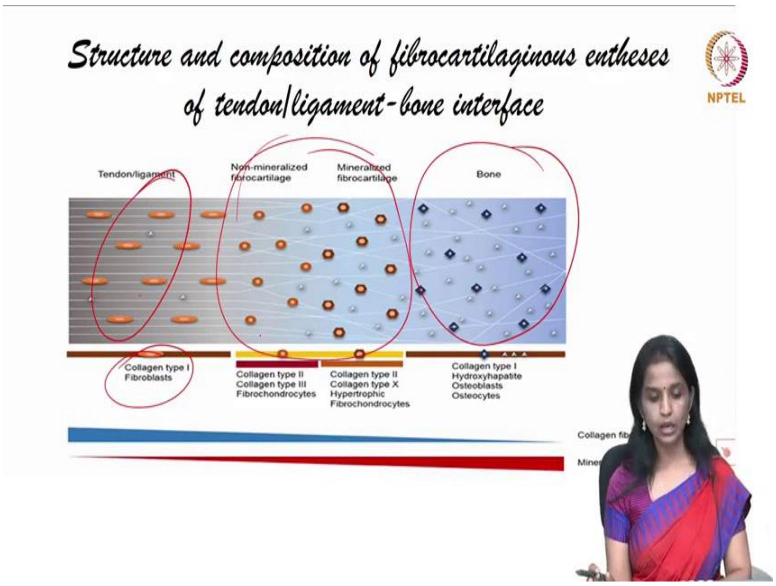

As already mentioned we have the tendon or the ligament which is actually the soft tissue which is the collagen type I fibroblast and then we have the intermediate region which actually forms the cartilage and then we have the very strong bone. So, there is a soft tissue, there is bone, intermediate you have a firmer structure. So, there is soft, firm and hard on one side. So, when we bring all these three together the derived materials or the materials which is required to replace such a structure is very challenging.

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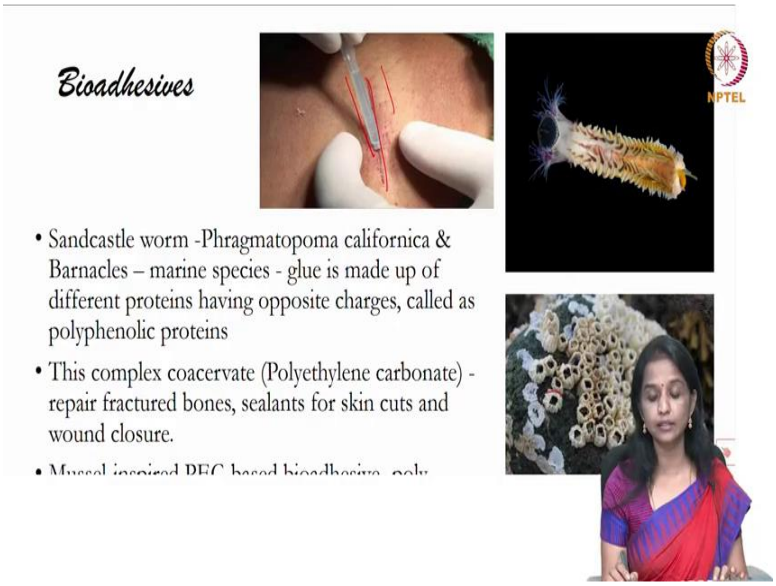

So, that is why musculoskeletal regeneration is still under lot of research and there is lot of scope in musculoskeletal regeneration as such. And then we move on to a very interesting area again bioadhesives. As the word in indicates and as the picture over here depicts there is an incision and the surgeon actually is trying to place a glue like substance to seal the incisions together.

So, these adhesives are actually derived from naturally available worm like structures specifically marine species, we have the sandcastle worm and the barnacles. All of us would have seen such barnacles near the seashore, the big rocks over the seashore has such structures stuck onto it.

Next time when you see them try removing it; it would be so hard impregnated onto the hard rocky areas. So, that is the capacity of the bio adhesive which is nature made. So, when we are trying to recreate that particular beautiful nature structure we have to just try to replicate what was there in that particular structure we have the barnacles and the sandcastle worms here. So, when that was studied it was found that it was nothing but polyethylene carbonate which is the predominant compound which was involved in having that adhesive capacity.

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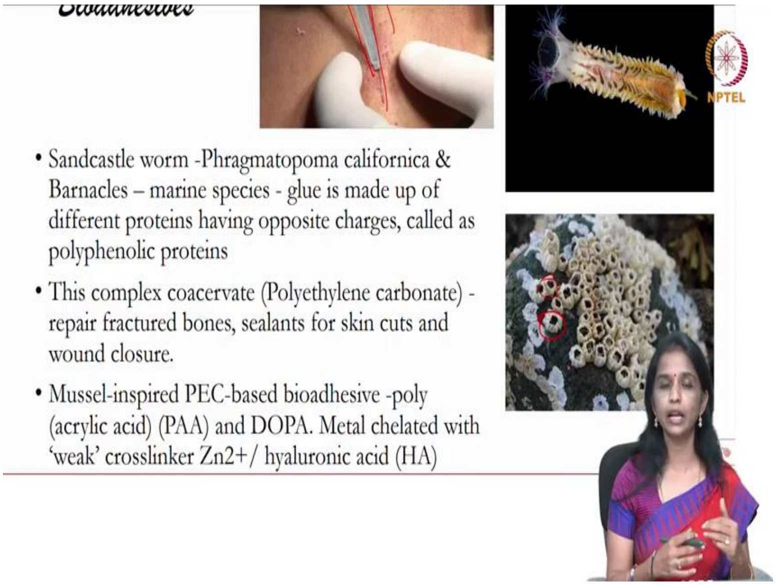

In addition to polyethylene carbonate later there were other modifications which have been attempted and by adding your poly acrylic acid and then by adding DOPA again. Additionally there have been studies which has attempted to add on with zinc and then hyaluronic acid as well to make more different combinations and newer formulations.

By doing this there is again a range of products which actually claim one better than the other. Again all these are derived from these very small structures present all over us all surrounding us and all that we need to is just observe nature and then reproduce them and recreate them.

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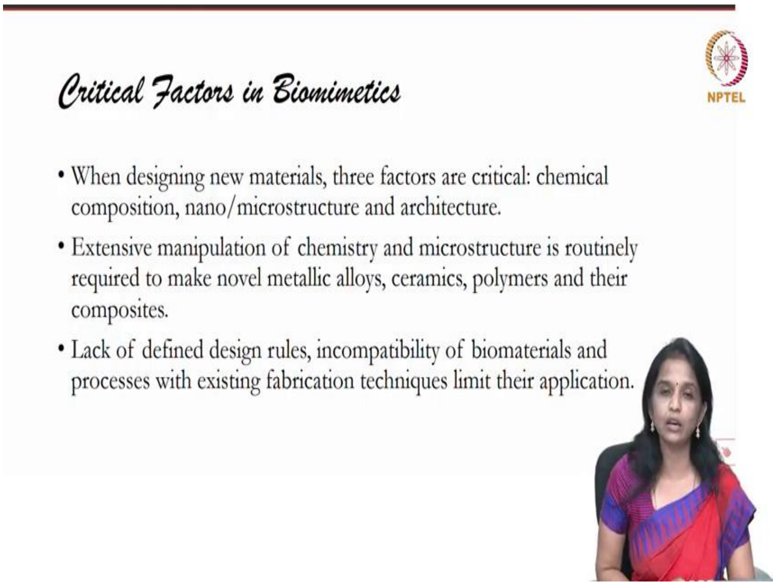

So, the critical factors having said lot about Biomimetics, it will offer lot of promises as I had listed you quite many applications. But what we need to understand is there are still critical factors in biomimetics; nature is above us and we are just part of it. So, when we try to create that or we try to mimic that particular existence itself there are certain challenges.

So, when designing newer materials the most important critical is the chemical composition, the microstructure and the architecture. Creating everything one by one alone is not enough there has to be a micro environment and there has to be biophysical cues and so many things.

So, putting together is not easy. that is why we are evolving with newer materials every day and we have numerous research works being published very frequently. But, what we need to understand is putting all these three together are very critical, but we have come a long way and there have been really impressive materials inspired by nature. So, again there are other challenges like we do not have a proper design rules.

For example, please do remember recreating cell based enamel remineralization that itself is a very big challenge because ameloblast may not grow into the direction which is actually expected and which is easily happening in the tooth structure cannot happen in vitro that easily.

So, all that there is a very important lack of design process and biomaterial formulations are not that what to say well-defined or they need lot of standardization and most of them if we go to a very high end or a very harder structures they may be incompatible to the body and existing fabrication techniques have their own challenges as well. So, these are the critical factors which are limitations in biomimetics, but I am sure there is a lot biomimetic approaches have to offer.

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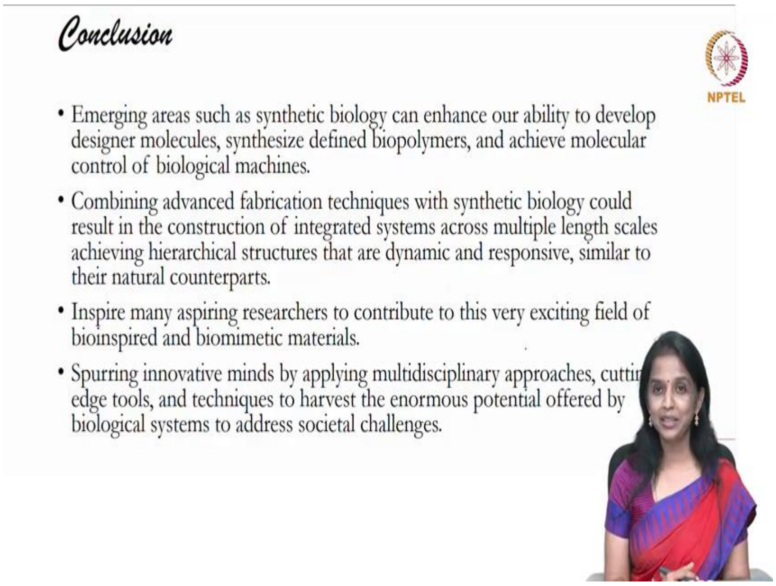

So, having with all that in mind, all that we need to know about biomimetics is that nature is a treasured, trove of information. So, we can be inspired by nature and we can keep on creating just a glimpse at nature any part of it any natural structure has huge tons of information just waiting for you to open up, observe and recreate. And best wishes for recreating and becoming the creator yourself.

Thank you.