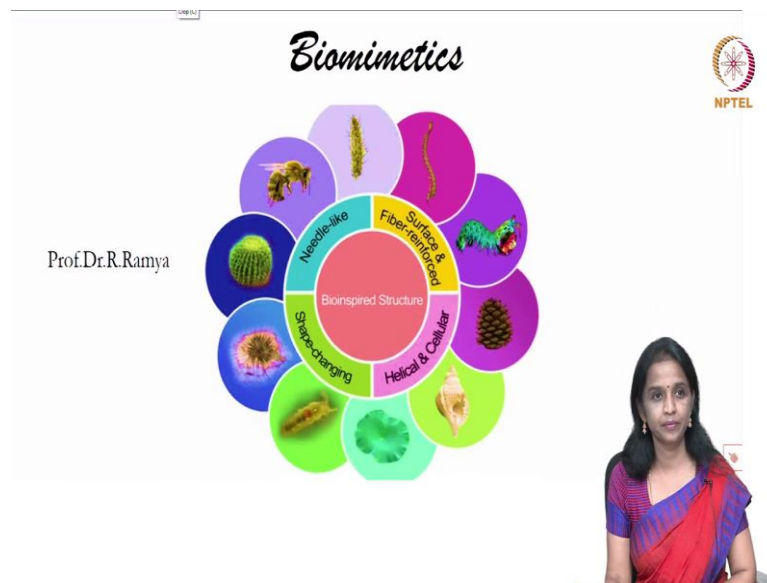


Oral Biology
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Lecture - 21
Biomimetics - Part 1


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Today, we have a very interesting lecture on Biomimetics. The word biomimetics itself sounds really amazing or inspiring and now we go on to study this beautiful subject of biomimetics.

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Lecture outline




<ul style="list-style-type: none">• Overview• What is Biomimetics• Why Biomimetics• Biomimetic approaches• Self assembly -DNA Origami• Biosensing• Tissue engineering	<ul style="list-style-type: none">• Bioinspired Optics• Natural tough materials• Biomimetic remineralization• Bioadhesives• Critical factors• Conclusion
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So, this lecture would give this is a lecture outline and we have a quick look of what biomimetics are.


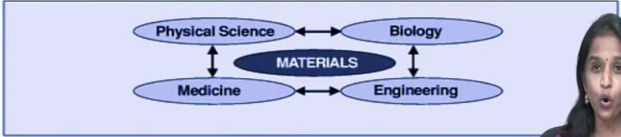
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Overview



Bioinspired Materials Application of biological design rules and principles to materials design	Materials - Enabled Biology <ul style="list-style-type: none">• Tissue engineering• Prosthesis• Drug delivery• Sensors and diagnostics• Battlefield medicine• Performance enhancement	Bioderived Materials Biological routes to new materials
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Required Infrastructure



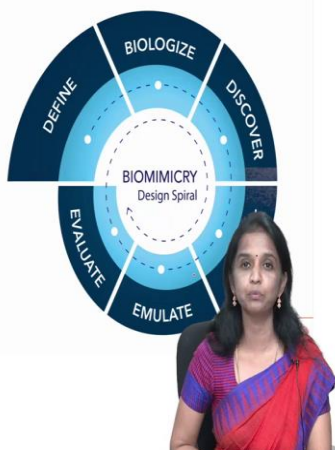
So, the overview of biomimetics is that we would quickly do about what bioinspired materials are and what are bioderived materials. And again this beautiful topic on the discipline of biomimetics is actually an interdisciplinary field which involves physical sciences, biological sciences put together medicine and engineering field as well.

So, that makes this particular topic a very interesting topic which actually touches upon both medicine and engineering together and what is biometrics all about.

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What is it

- **Innovations inspired by nature**
- **Bioinspiration** - learning nature's design principles in building highly complex and sophisticated structures
- **Biomimetics** - study of multi-disciplinary mechanisms and biologically produced materials to design novel products to mimic nature.



The diagram is a circular 'Design Spiral' for biomimicry. It consists of five segments arranged in a circle: DISCOVER (top right), BIOLOGIZE (top), EMULATE (bottom right), EVALUATE (bottom left), and DEFINE (left). The center of the spiral is labeled 'BIOMIMICRY Design Spiral'. The diagram is overlaid on a video frame of a woman in a red and blue sari.

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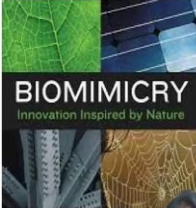
So, this biometrics is put in a simple word it is innovations inspired by nature. I do not think there is anything beautiful to say about this more than this particular statement. So, nature has already innovated for us it is our duty to just absorb observe absorb and then emulate and then just keep mimicking what is already there in front of you and create newer things or just derive things.

So, that is all about biomimetics and this is a very beautifully given schematic. So, just understand what is there in nature and then try to emulate what is there and then evaluate what is exactly all about the nature has to offer to you. So, when you get inspired by nature you are just learning the nature's design when you are trying to exactly mimic and replicate what you really want that is biomimetics why and how biomimetics.

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Why & How

- Evolution of varied life forms over 3.8 billion
- Treasure trove of biological insights
- Even a simple observation in nature can lead to a bioinspired material



The most important thing as already mentioned; it is an innovation inspired by nature and we all know that as far as our knowledge is concerned we approximate that the evolution has begun over 3.8 billion years. So, so much of work has already gone earlier and it is our duty to just observe and then mimic what is already there done and made and executed.

So, it is a treasure trove of biological insights even a simple observation in nature can lead to a bioinspired material just open your eyes and then observe nature or just glimpse just have a look at it have a sneak peek on it and nature has. So, much of information to give to you; in other words, it is a treasure trove and all that you need to do is just keep observing and then relishing and then reproducing what is already there.

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Why

- Nature's "solution manual" is quite exhaustive
- Bioinspiration is a virtually limitless source of ideas and it has "something for everyone" - Prof. Whitesides
- Area has 14 000+ papers published since 2010, the field is still considered to be young and offers enormous potential
- Bioinspired materials and strategies have certainly opened new venues in fabrication of optical devices, sensors, and materials.

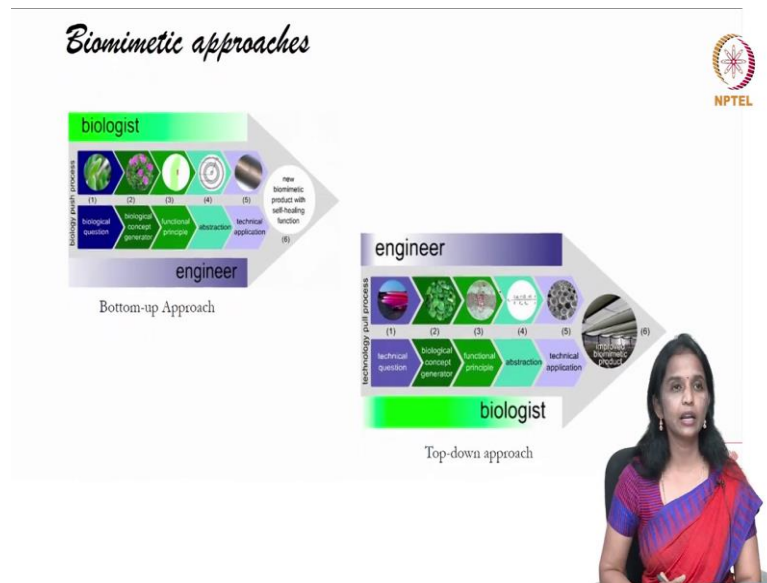
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This is another beautiful schematic diagram over there and the statements are so beautifully given and drafted. So, it says nature is already a solution manual it is very exhaustive all that you need to do is just flip through a few pages and then create your own the creator has done all and all that you need to do is just pick up and then get inspired by them.

So, bio inspiration is a virtually limitless source of ideas and it has something for everyone and that is very very important it has something for everyone and it is; so, exhaustive and available for all.

So, having said that the most important point here is from a past one two decades the number of papers on biometrics are really huge, but still there is lots to be done and there is enormous potential for newer insights and newer strategies to be drawn from this biomimetic thought process. So, bioinspired materials have really opened up and we have numerous applications which we will be discussing optical devices, sensors and materials. So, we actually inspire and then we try to mimic and then produce a novel design.

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So, biomimetic approaches can be bottom up or it can be top down approach. So, there is that is always there in biomaterial fabrication either it is a bottom up approach or a top down approach.

If it is going to be a bottom up approach, it is going to be a background starting from the biologist and then the engineer takes it up and then brings out a new biomimetic product whereas, if it is going to be a top down approach the engineer takes a question a technical question start analyzing it and then he goes comes down to deeper aspects or the baseline aspects and then he derives the product which he really wants to. So, that is the two approaches.

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Biomimetic approaches

Mechanism-driven
Engineering Problem → Biology → Biological Solution → Engineering Solution

Organism-driven (focused)
Biology → Biological Solution → Engineering Problem → Engineering Solution

Organism-driven (integrative)
Biology ↔ Biological Solutions ↔ Engineering Problems ↔ Engineering Solutions

Problem-Driven Biologically Inspired Design Process
The pattern of problem-driven follows a progression of steps starting with the technical problem to be solved. The individual steps comprise:
•Step 1: problem definition
•Step 2: reframing of the problem
•Step 3: search for biological solutions
•Step 4: definition of the biological solution
•Step 5: principle extraction
•Step 6: principle application

Solution-Based Biologically Inspired Design Process
The pattern of solution-based also follows a sequence of steps but contrary to the problem-driven, the starting point here is a particular biological solution. The individual steps comprise:
•Step 1: identification of the biological solution
•Step 2: definition of the biological solution
•Step 3: principle extraction
•Step 4: reframing of the problem
•Step 5: problem search
•Step 6: problem definition
•Step 7: principle application

And then further, we have more in depth explanation of what biomimetic approaches are. So, there is something called as problem driven approach and there is something called as solution based approach. So, these are how the biomimetic approaches are handled.

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Self-assembly

- Self-assembly is the process by which an organized structure spontaneously forms from individual components, as a result of specific, local interactions among the components.
- Molecules, such as peptides, proteins, DNA, lipids, organic molecules, and hybridization of metal ions and organic molecules have been used as self-assembly building blocks.

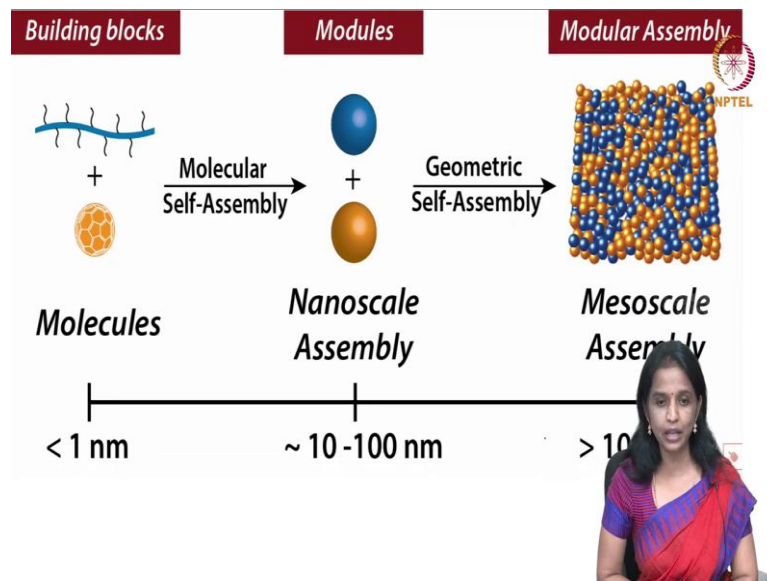
Soluble peptides → Self-assembly and structural transitions → Functional hierarchical materials

So, as we see here the self assembly is actually the beginning of what biomimetics is all about and how biomimetics can be done and used for innovations and used in multiple approaches. So, having said that self assembly as the word says it all self assembly is where there are some molecules which have the potential to form newer compounds by

assembling on its own. So, it is have it is got the capability to form newer molecules or newer structures with smaller units.

So, the best example for this self assembly is they are enormous in nature and the best ones are your peptides the proteins, DNA, lipids, organic molecules and hybridization of metallic ions.

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So, having said that how do we go about using this concept of self assembly? So, the concept of self assembly moves from molecules to nanoscale and then to mesoscale. So, it just goes on and then building to form a larger structure.

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DNA origami

- DNA origami - folding DNA into a desired shape.
- Watson-Crick base pairing is highly predictable and specific – allows precise engineering of nanostructures.
- DNA Interactions DNA -pairing of nucleotide (nt) bases, adenine (A) & thymine (T) and cytosine (C) & guanine (G).
- Molecular conformation of DNA - typical B-type DNA - right-handed double helix diameter of ~ 2 nm and ~ 3.4 nm per helical turn. The measured twist - $\sim 34.6^\circ$ per base pair (bp).
- Convenient synthesis of DNA oligonucleotides (oligos)



So, the best one in this particular self assembly is doing your DNA origami. DNA origami as the word is so beautifully described; origami we all know it is a method to take any structure into a desired shape. And this DNA origami specifically when you have the prefix DNA over there in front of origami all that we need to know is the structure is being made with DNA as the model. So, we are just trying to mimic DNA and we are trying to derive a structure which is similar to DNA.

So, why are we using or why are we inspired by DNA? That is because after Watson and Crick, decoded the DNA structure there has been enormous studies making so much of use from that particular Watson and Crick model and that model makes it so simple. So, why is it so simple? The scientist did a very fantastic job of bringing out the structure and this particular structure has the ability to be reproducible and not only reproducible can be multiplied many number of times.

So, there can be exact replication and then there can be multiplication. So, that is the basis of DNA and that is the basis of any formulation as such. So, how does DNA help in this; we all know that DNA is made of nucleotides and the pairing happens with a definite sequence and that definite sequence does not change at all.

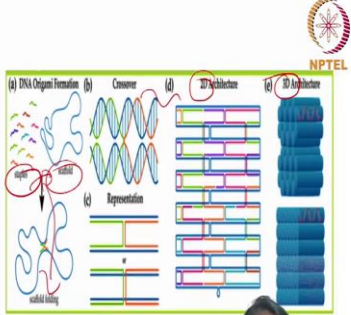
So, this definite or specificity is what is actually making DNA origami a most sought after technique for biomimetics and not only that this DNA molecular conformation actually helps in a most important way in addition to the nucleotides. The molecular

conformation of DNA is also very helpful and it is also having a specific sequence. So, that is being exploited to create multiple number of products.

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DNA origami

- DNA has become one of the most extensively used molecular building blocks for engineering self-assembling materials.
- DNA origami uses hundreds of short oligonucleotides - staple strands - scaffold strand - designer nanoscale architectures.
- Applications - electronics, nanophotonics, reaction networks, human healthcare diagnostics and therapeutics



Babatunde, B.; Arias, D.S.; Cagan, J.; Taylor, R.E. Generating DNA Origami Nanostructures through Shape. *ACS Nano* 2012, 6, 2950. <https://doi.org/10.1021/nn2031107>

So, all you can see that the DNA origami is used for self assembly engineering self assembly molecules. So, this picture actually helps in a beautiful way there are two strands which can be derived the staple strand which actually goes into forming the scaffold strand and then this goes on to forming a bigger molecule.


So, all these are helped and then we derive more intricate twisting and pleating and that goes into formation of a 2D structure and further twisting and turning in a particular specific sequence results in a 3D architecture element whichever we need to such intrinsic specific creation of a self assembled molecule can help in many many applications, because we know that the sequence is going to be very specific and it is going to be repetitive and it can be multiplied in many number of ways.

With that concept this DNA origami is a typical example of biomimetics and has got numerous applications in electronics, nanophotonics, reaction networks human healthcare diagnostics and therapeutics. You can see the wide ranges there right from engineering to medicine DNA origami helps us in all applications.

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Biosensing

- Detection of biomolecules using an analytical device (i.e., biosensor) that combines a biological component with a physicochemical detector.
- Advancing biosensing nanotechnologies with hybrid nanostructures detect even in chemically “noisy” bioenvironments as they are highly sensitive



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And then we move on to a very very interesting or most sought after term in recent times that is biosensing. Biosensing, we are all very very what to say passionate about that particular term the passionate craving for this particular biosensing comes because of that desire to have point of care diagnostics right in your arm so that you can actually diagnose and help yourself or the healthcare worker is quick enough to diagnose any particular pathology or any particular disease states.

So, this is actually a most required area which has numerous scope in the field of medicine and not only in the field of medicine there are many many applications for biosensing more critically it is of great help in healthcare. So, when we talk about biosensing, all that we need to know is a biosensor has a sensory component or the sensing component that is a biological component and then there is a detector and that goes into detecting and then identifying what is exactly there.

the most important and interesting part of biosensing is the more accurate it is or the more specific it is to even detect a very small molecule of interest biosensors will be of greater help. So, biosensing has grown really well in the past two decades and we have so much of improvements and advancements in the field of biosensing, where we have point of care diagnostics in our hand.

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Biosensing

Current Biomolecular Detection Approaches Such As Immunoassays, Traditional Biosensors, and Nanobiosensors of Nanostructured Reporters and Functional Transduction Shells

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So, traditional immunoassays involved a lot of procedure whereas, your point of care diagnostics is all there in the hands of the specialist or sometimes even in the hands of a Layman who can help themselves.

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Nanoengineered building blocks and their integration into nanobiosensors

• Centre - Surface architecture of the transduction shell and its design principles

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So, this particular schematic diagram helps in letting us know what exactly these biosensors are. So, this centrally placed diagram here clearly illustrates that there is a nano structured reporter molecule which is actually the transduction shell. So, this

transduction shell helps in actually having very clear bio recognize recognition units and surface passivated layers. So, this is actually of very great interest.


So, as nanotechnology keeps progressing to a great level the molecules at the center part or which is the key molecule becomes involved and involved and then it becomes more advanced and it becomes more specific the more the specific the point of care diagnostic the more reliable it is and that is when we keep doing or trying newer molecules. So, here we have the list of targets which we are constantly working on and we are constantly looking for to create newer devices.

So, this is there the craving is there in almost all fields of medicine and in fields of engineering as well.

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Tissue Engineering

- Tissue engineering is the construction of bioartificial tissues *in vitro* as well as the *in vivo*
- Mimicking cell microenvironment has emerged as a key determinant in tissue engineering
- Extracellular matrix (ECM) - three-dimensional (3D) biochemical and biophysical cues that trigger and regulate critical cell behaviors.
- Improved control of cell behaviors in 3D has advanced the fields of tissue regeneration, in vitro tissue models, large-scale cell differentiation, immunotherapy, and gene therapy.



Now, again there is another interesting field in biomimetics where the biomimetic aspect is so strong that we just want to replicate what nature has already created. So, that has made this a wonderful world of tissue engineering where we try to create organs or we try to just replicate what nature has already done few thousand years ago.

So, tissue engineering is all about creating bio artificial tissues in vitro or even in vivo. So, here in tissue engineering we all know about the basics the tissue engineering needs the cells the scaffold and the micro environment. Here the more challenging aspect of tissue engineering earlier was about the scaffold, but now the scaffolds have really

advanced really well and now the more key element which is of great interest is your extracellular matrix.

Because it is that extracellular matrix which actually has a definitive role in achieving what we really want by creating that bio artificial tissue or bio artificial organ because the basis or the foundation or the matrix is actually created by that extracellular environment. So, if you can actually control the cell behavior by placing this or by controlling the extracellular environment then you can tune the behaviour so well and it is that cell behavior which is very critical.

So, cell behaviour does not rely on the cell alone it is very much dependent on the extracellular environment also. So, as we keep controlling the extracellular environment in a perfect way then the effects on the cell behavior would be really better controlled and the outcomes would be really very specific and more desirable. So, that is why mimicking the micro cell environment is very important.

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Key components of the cell microenvironment.

- Neighboring cells, soluble factors, the ECM, and biophysical fields (e.g., stress and strain, electrical, and thermal fields).
- ECM serves as a structural support for cells to reside within but also provides diverse biochemical and biophysical cues for regulating cell behaviors.

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So, here this micro cell environment is actually made of neighbouring cells, the factors that are very important and then we have the physical fields which they are subjected to; putting together all these, then we have a very strong control over the micro environment and this are very important to defining the bio artificial structure which you are going to create too, because they would be applying a lot of biochemical aspects bio mechanical

aspects to the cell and that behaviour is actually perceived and the organ can be made to function as though in a natural environment.

So, that is what is actually being done and being improvised upon over the past few years.

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Design considerations for engineering the 3D cell microenvironment.

- The design considerations can be generally divided into two classes
- Biochemical (e.g., cell adhesion ligands, soluble factor immobilization, and chemical functional groups)
- Biophysical design considerations (e.g., structural features, mechanical properties, degradability, and electrical conductivity).

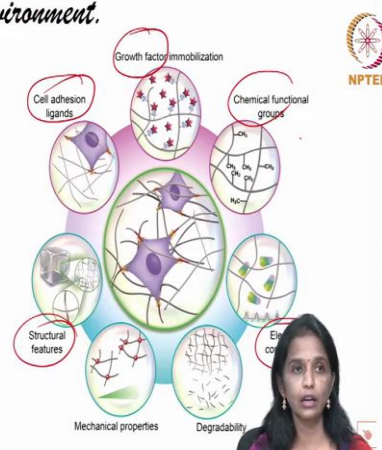
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earlier we had two dimensional then the last few years we have about three dimensional micro environment. Three dimensional micro environment again involved a lot of aspects which involves a growth center, a growth factors, cell adhesion ligands, structural features, electrical conductivity, chemical functional groups and then we have mechanical properties and degradability.


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microenvironment.

- The design considerations can be generally divided into two classes
- Biochemical (e.g., cell adhesion ligands, soluble factor immobilization, and chemical functional groups)
- Biophysical design considerations (e.g., structural features, mechanical properties, degradability, and electrical conductivity).



The diagram illustrates various design considerations for a microenvironment. It features a central cell with several surrounding circular callouts: 'Growth factor immobilization' (showing a cell with red stars), 'Chemical functional groups' (showing a cell with chemical structures like -OH, -NH₂, -COOH, -CH₃, and -H₂C), 'Cell adhesion ligands' (showing a cell with red dots), 'Structural features' (showing a cell with a grid), 'Mechanical properties' (showing a cell with a spring), 'Degradability' (showing a cell with a grid), and 'Electrical conductivity' (showing a cell with a circuit). The NPTEL logo is in the top right corner.



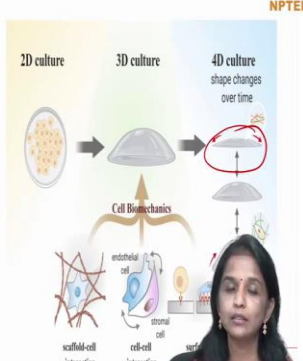
A woman in a red and blue sari is speaking, positioned in front of the slide.

All these factors were actually defining the 3D micro environment.


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4D cell microenvironment

- 4D control uses tunable materials, resulting in tissue constructs to remodel
- Applications
 - (1) Promotion of tissue regeneration
 - (2) Construction of functional in vitro tissue models for pathophysiological studies and drug testing
 - (3) Enhancement of large scale cell differentiation
 - (4) Implementation of immunotherapy
 - (5) Enablement of gene therapy.



The diagram shows the progression from 2D culture to 3D culture to 4D culture. 2D culture is shown as a flat layer of cells. 3D culture is shown as a dome-shaped cell cluster. 4D culture is shown as a cell cluster that changes shape over time, indicated by a red circle and an arrow. Below the cultures, 'Cell Biomechanics' is illustrated with 'scaffold-cell interaction' and 'cell-cell interaction'. The NPTEL logo is in the top right corner.



A woman in a red and blue sari is speaking, positioned in front of the slide.

And now, the world has moved on to 4D micro environment. So, what is the difference between a 3D and a 4D culture, it is just simple difference which you have to remember. There is an alteration in the physical stimuli which is actually given through the cell micro environment. So, that is the major difference between a 3D and a 4D culture.

So, the physical biophysical cues on the 3D culture system makes the entire artificial organ more tuneable in the sense the more it can be tuned and it can be as close to the

natural tissue the outcomes of that particular organ whatever is desired can be easily brought into. So, physically tuneable characteristics is that statement which actually makes 3D and 4D culture different.