Bioinspired Functionally Graded Composite Assembled Using Cellulose Nanocrystals and Genetically Engineered Proteins with Controlled Biomineralization

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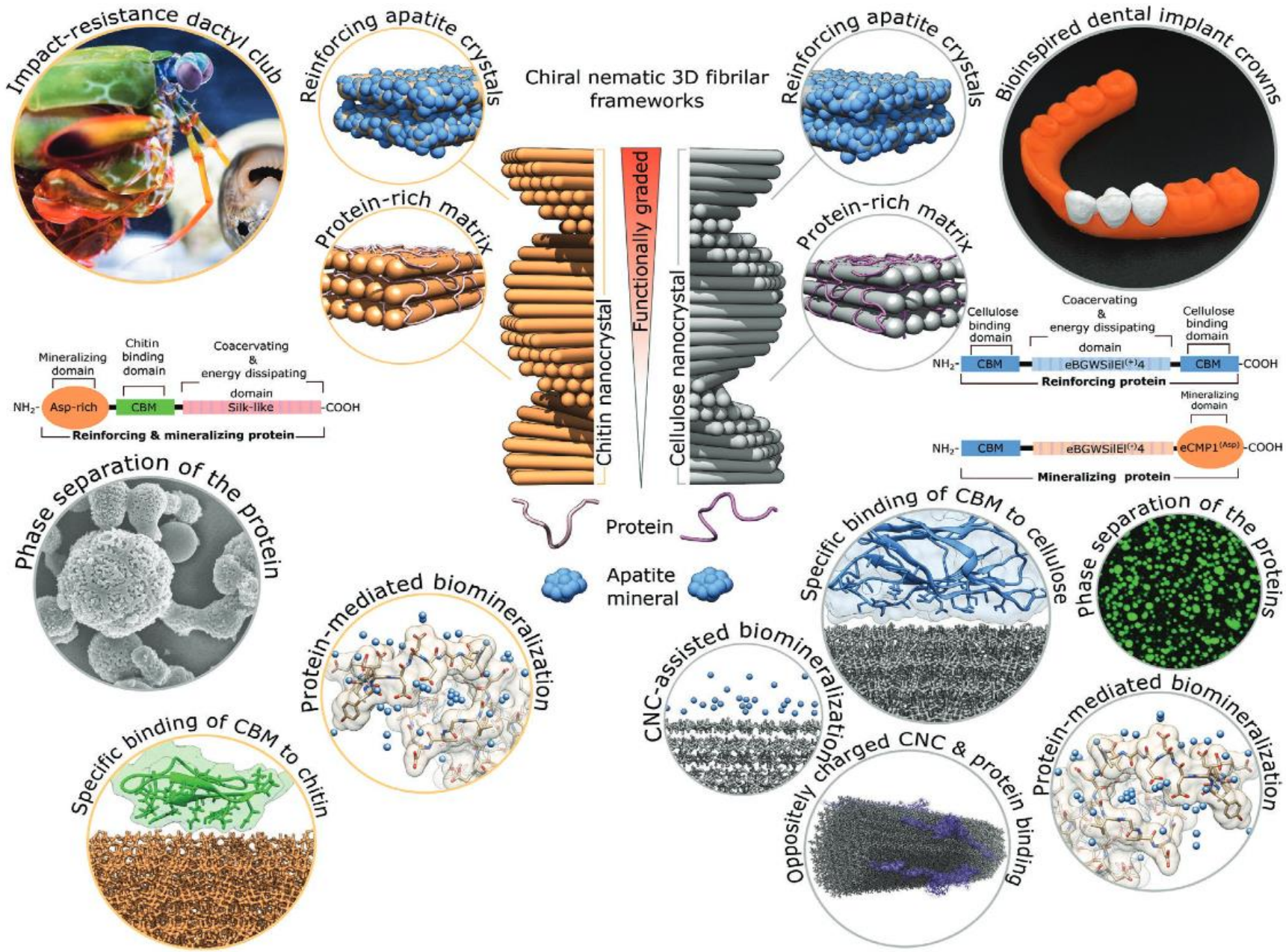
Introduction

- Many biological materials, such as peacock mantis shrimps' (*Odontodactylus scyllarus*) clubs, comprise of a durable and strong structure
- The club structure is a multiphase composite including interior and exterior parts
- The interior region consists of three components:
  - fibrillar chitin
  - a protein-rich matrix
  - amorphous calcium phosphate and calcium carbonate
- Exterior region consists of the same components in different organizations and forms

Fischer, G. n.d. Peacock mantis shrimp. https://www.shutterstock.com/fi/image-photo/peacock-harlequin-painted-clown-mantis-shrimp-1380713624


Impact-resistance dactyl club
Reinforcing apatite crystals
Chiral nematic 3D fibrilar frameworks
Reinforcing apatite crystals
Bioinspired dental implant crowns
Protein-rich matrix
Chitin nanocrystal
Functionally graded
Cellulose nanocrystal
Protein-rich matrix
Mineralizing domain
Chitin binding domain
Coacervating & energy dissipating domain
NH2- Asp-rich CBM Silk-like -COOH
Reinforcing & mineralizing protein
Cellulose binding domain
Coacervating & energy dissipating domain
Cellulose binding domain
NH2- CBM eBGWSilEl(+)4 CBM -COOH
Reinforcing protein
Mineralizing domain
NH2- CBM eBGWSilEl(+)4 eCMP1(Asp) -COOH
Mineralizing protein
Phase separation of the protein
Protein
Apatite mineral
Specific binding of CBM to cellulose
Phase separation of the proteins
Protein-mediated biomineralization
CNC-assisted biomineralization
Protein-mediated biomineralization
Specific binding of CBM to chitin
Oppositely charged CNC & protein binding

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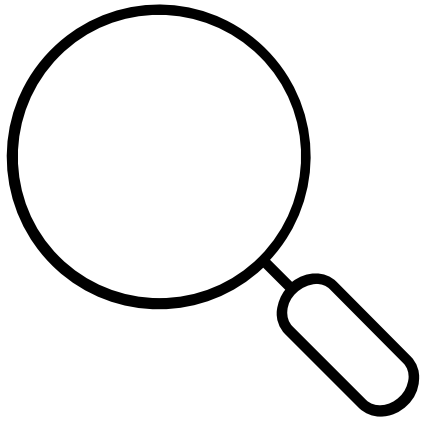
Aim of the Research

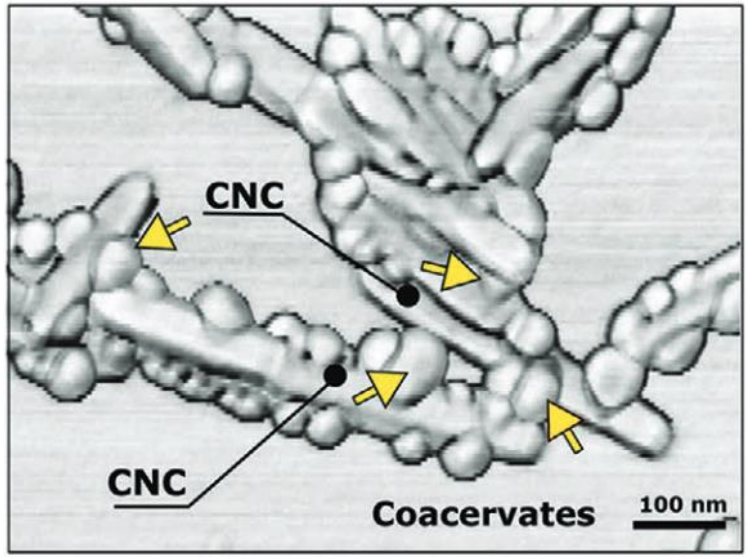


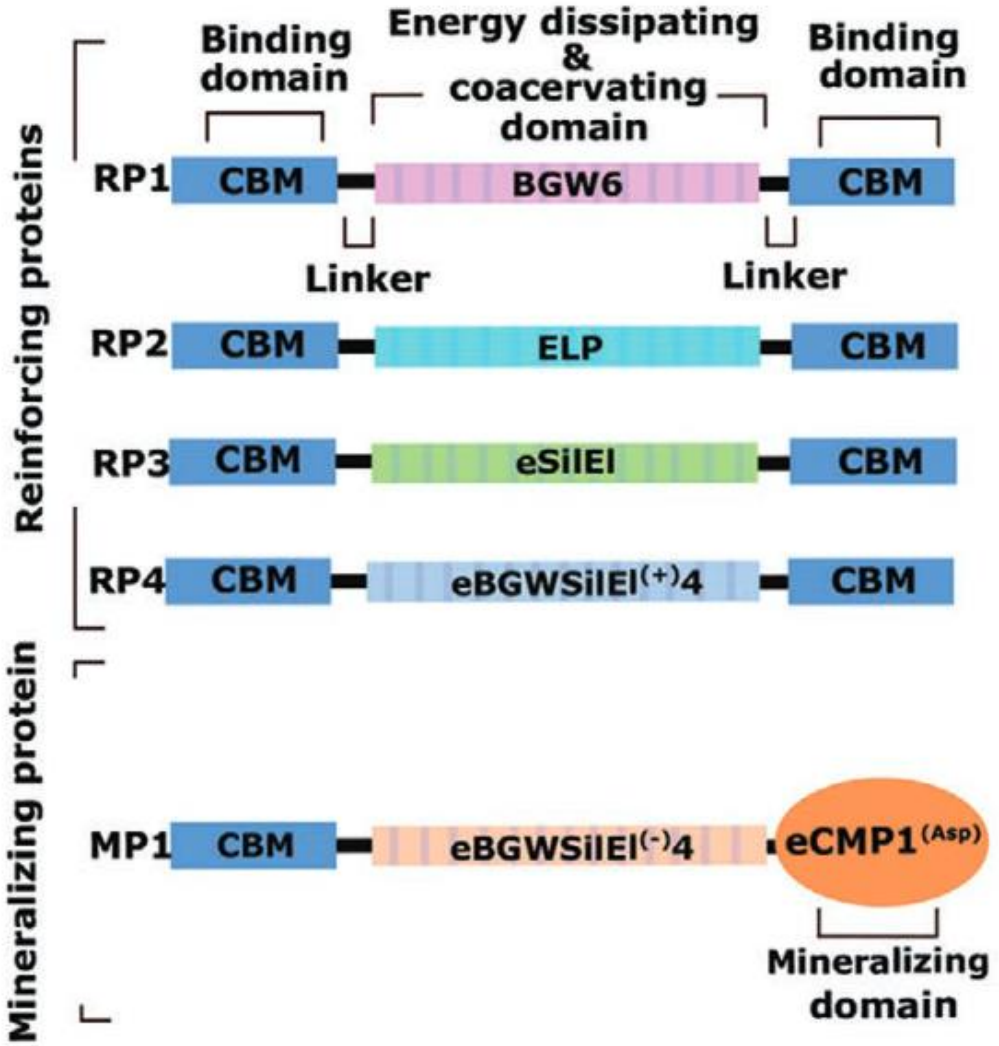
- The article aimed to design and manufacture a biocomposite that mimics the unique structure of the shrimp' clubs utilizing synthetic biology
- The composite was used to fabricate a dental implant
- To achieve the goal, multiple methods were performed:
  - Building-Block component selection
  - Nanocomposite assembly (CNC)
  - Nanocomposite assembly (MP1)
  - Design and fabrication of a dental implant crown

Building Blocks

- Cellulose nanocrystal (CNC)

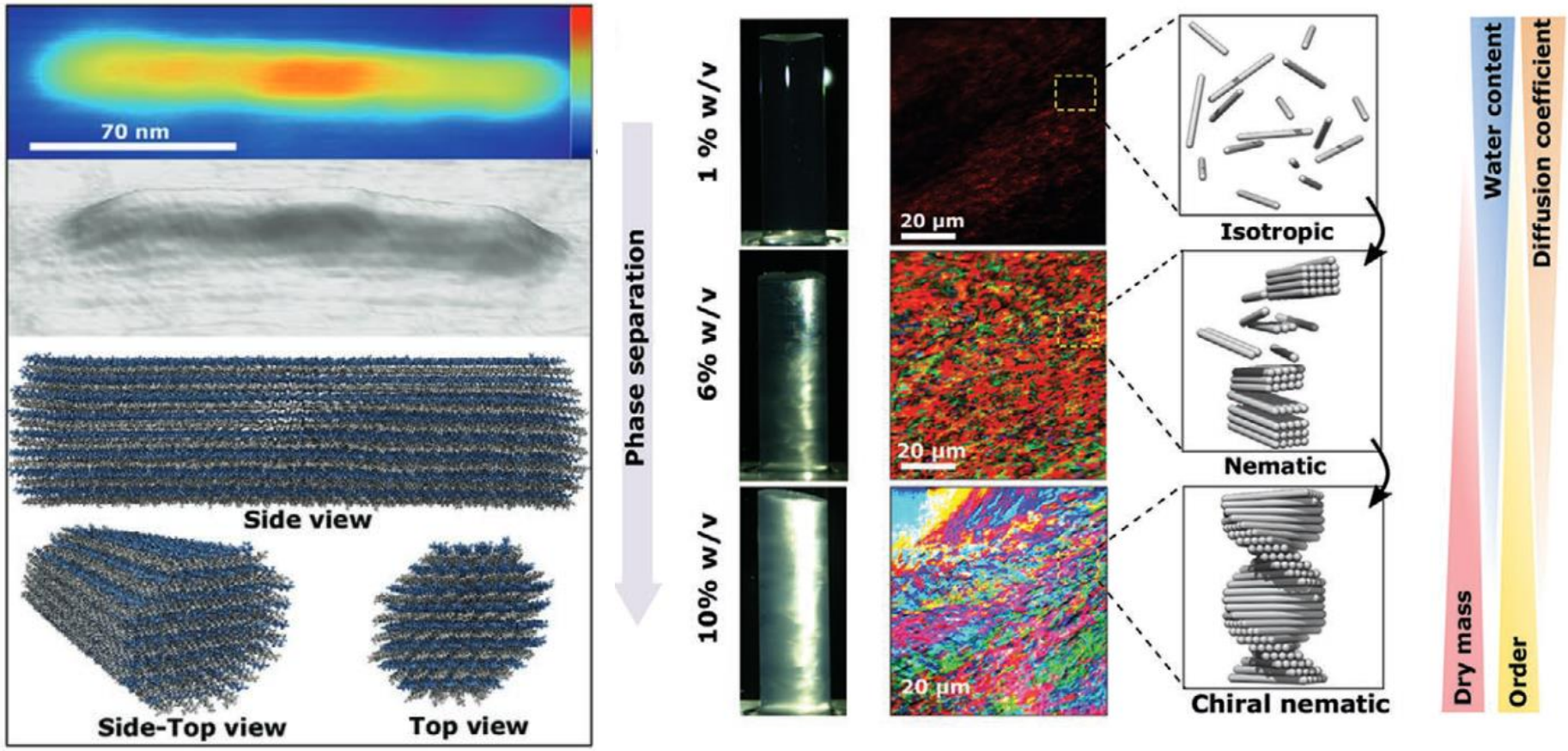
  -> Colloidal rods
- Reinforcing proteins (RP1-4)
- Mineralizing protein (MP1)

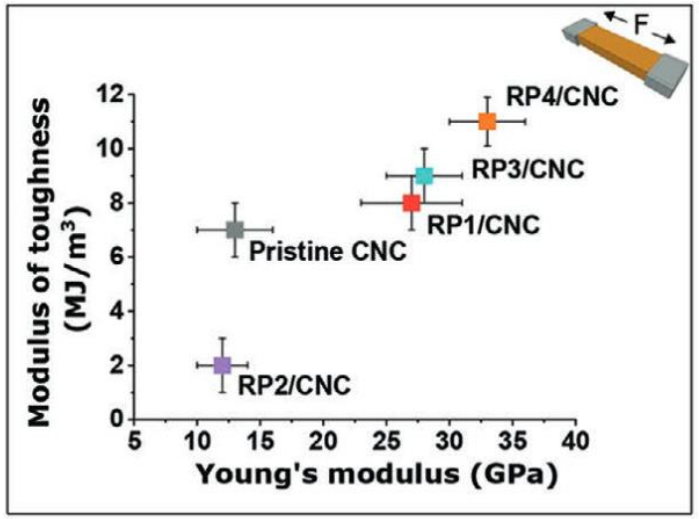


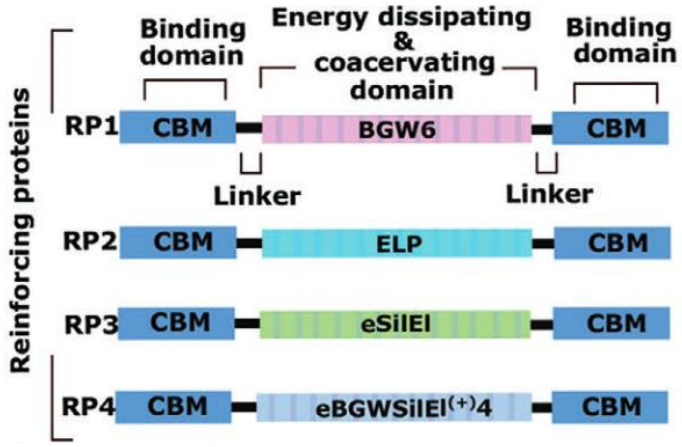


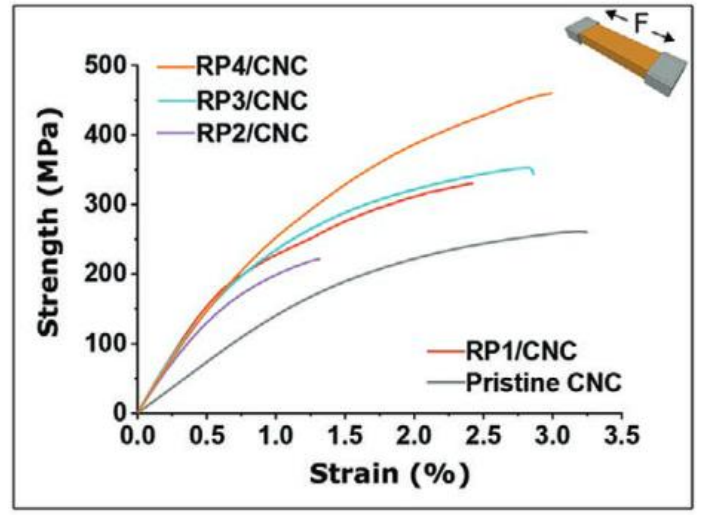
Cellulose nanocrystal (CNC)

- CNC has impressive mechanical properties
- It is the "structural backbone" of the composite
- Self-assembly into a left-handed chiral nematic liquid crystal
- Compatible with carbohydrate binding domain (CBD)-containing proteins









Reinforcing proteins (RP1-4)

- Cellulose binding module (CBM)
- RP4 had the highest performance

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Mineralizing protein (MP1)

- Biomineralization of apatite by CMP-1

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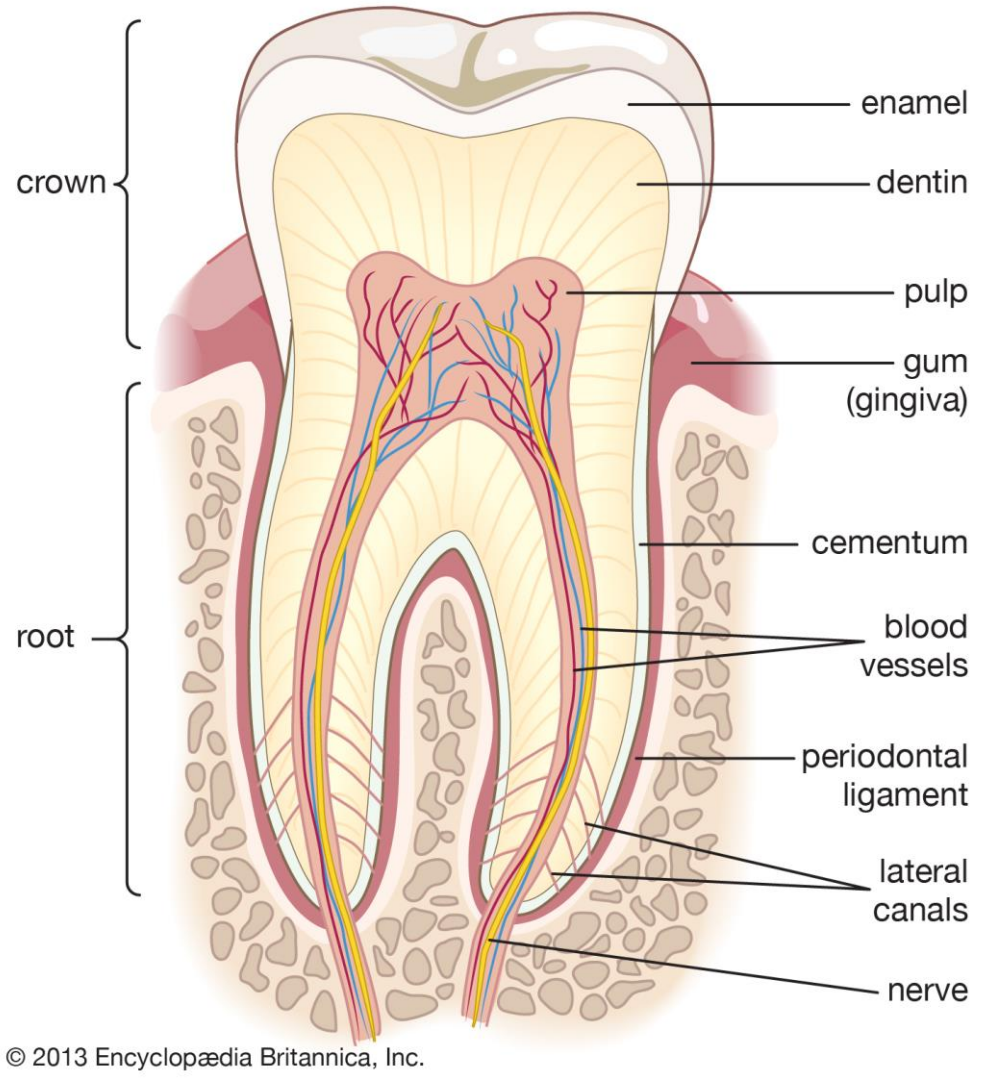


Two types of structure required

- Like the club or human tooth, the composite consists of two parts
- The softer and more flexible interior, which is covered by a harder exterior
- This composition allows the material to withstand hard impacts, while keeping the structure intact

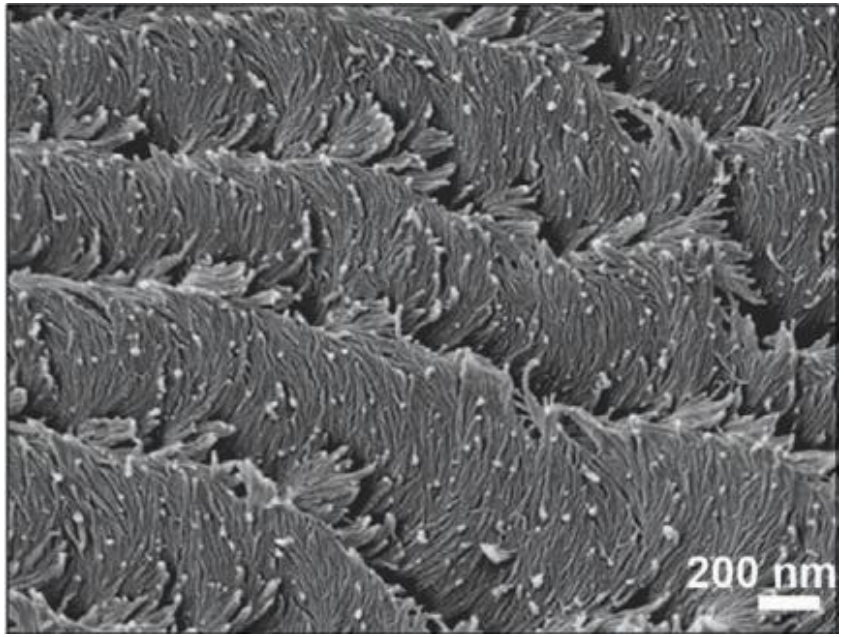
Interior Region

- Nanocomposite assembly of the interior region of the crown

  - Consists of CNC and RP4 protein composite

- The interior region need to be impact resistant

  - High stiffness, strength, and modulus of toughness



SEM image of fractured cross-section after three-point flexural bending testing

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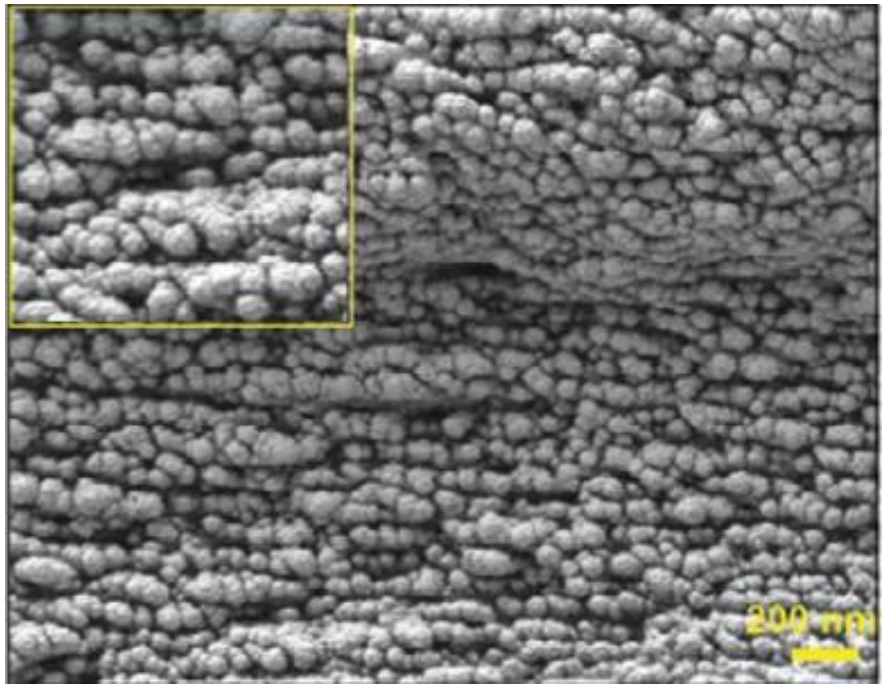
Exterior Region

- Nanocomposite assembly of the exterior region of the crown
  - Consists of CNC, RP4, and MP1
  - Apatite crystallization
- The exterior region need to be highly mineralized, stiff, and hard



SEM image of fractured cross-section after three-point flexural bending testing

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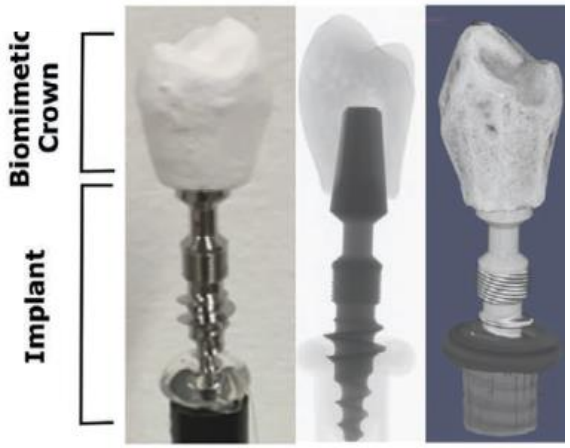
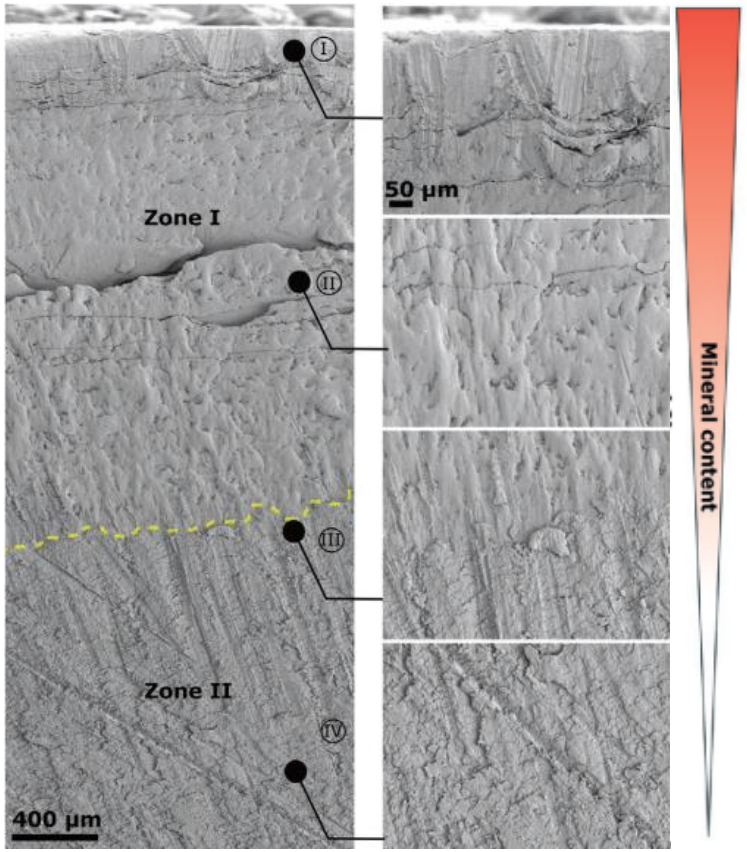
Bioinspired Dental Implant

- A synthetic tooth was built as a proof of concept
- It was a success
  - Similar properties compared to natural tooth
  - No cytotoxicity was found





SEM images of the cross-section cut of the dental implant

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The Importance of the Research

- Pioneering study in the field of material technology
  - Potential for future applications
- Reflects the future of research and the growing importance of synthetic biology
- Published recently but already cited

Sources

1. Pezhman Mohammadi et al. **Bioinspired Functionally Graded Composite Assembled Using Cellulose Nanocrystals and Genetically Engineered Proteins with Controlled Biomineralization**. Adv.Mater.2021, 33, 2102658

Questions?