Advancing Therapeutic Outcomes Through Bioinspired Biomaterials

What Are Biomaterials?

Biomaterials can be used as implants, scaffolds, or in other ways for therapeutic use or diagnostic purposes.

Biomaterials are specially designed to interact with biological systems.

From Materials to Healthcare

Materials: Synthetic materials, biological materials, metals, or alloys

Engineering: Imparting desirable properties through innovative design

Use in healthcare/human–machine interface/brain–computer interface

Biomimicry: Nature Provides Design Templates for Solving Engineering Challenges

Hierarchy of microstructures (tissue level to the cell level) results in desirable properties such as strength, toughness, and fracture resistance.

Nature's Design Examples

- Spider silk (toughness and tensile strength)
- Lotus leaves (water resistance)
- Shark skin (hydrodynamic properties)
- Gecko skin (antimicrobial and adhesive properties)
- Aragonite tiles in mother of pearl (toughness and energy)
- Butterfly gyroid nanostructures (color)

Understanding Microstructures Requires Imaging Tools

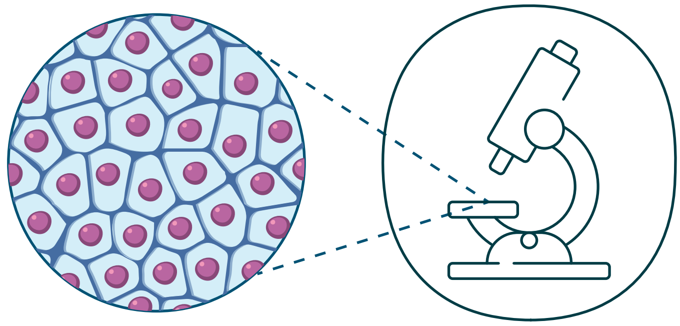
Bridge the macro-world structural features with the ultrafine nanoscale features

Facilitate hierarchical design of biomaterials

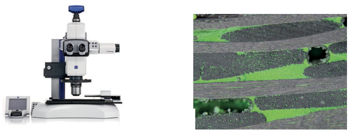
ZEISS-Integrated Microscopy for Biomaterial Design

ZEISS provides integrated microscopy solutions for visualizing complex natural hierarchies from the outer shell to molecular interface.

Multi-scale, multi-modal, and *in situ* microscopic characterization helps link microstructures with properties, processes, and material performance.

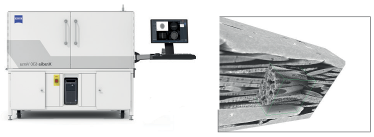


The Complete Imaging Portfolio



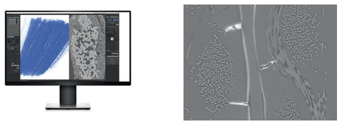
Stereo light microscopy (LM)
3D visualization of large-scale morphology

1 µm

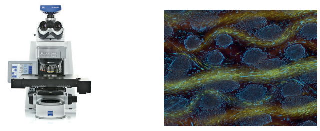


Sub-micron X-ray microscopy (XRM)
3D X-ray imaging of internal microstructure

700 nm

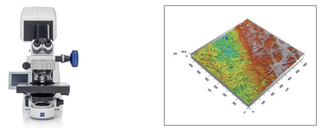


AI-based image reconstruction



Widefield LM
Imaging of large 2D areas, fluorescence imaging of cells and tissues

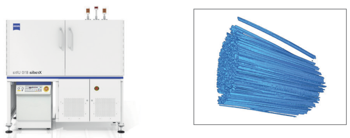
250 nm



Confocal LM
3D imaging of cells, tissues, and polymers

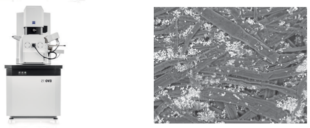
Polarized LM
Analysis of crystalline, fibrous, and polymer textures

200 nm



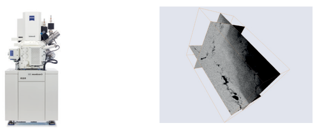
Nanoscale XRM
Nanoscale 3D imaging

< 50 nm



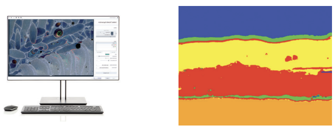
Conventional scanning electron microscopy (SEM)
Exploring surface morphology or particle shape

< 2 nm

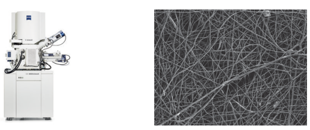


Focused ion beam SEM
Nanoscale imaging, sample preparation, and material analysis

< 1 nm

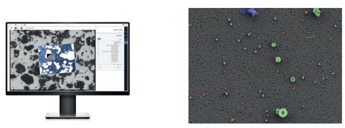


AI-based image segmentation



Field-emission SEM
High-resolution surface imaging

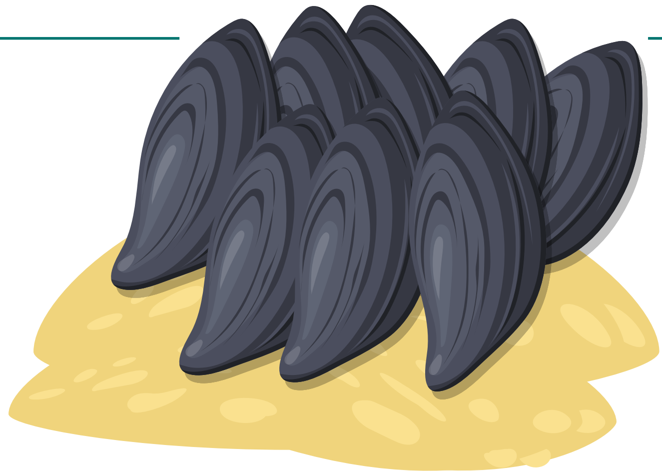
< 1 nm

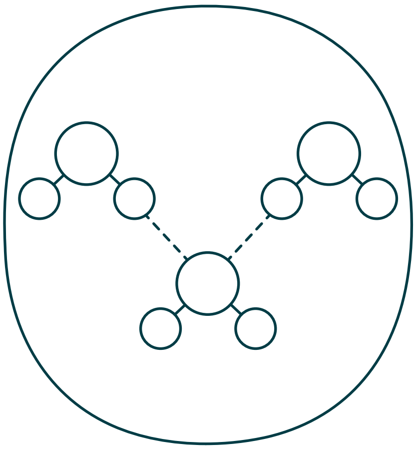


Multi-modal, correlative software

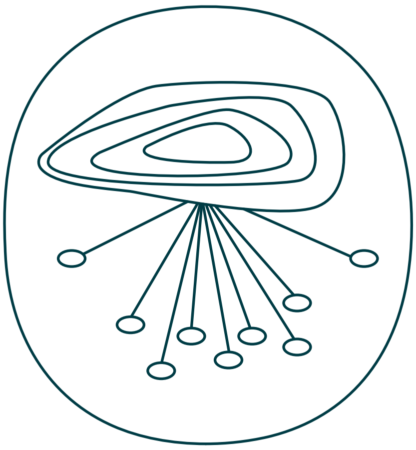
Understanding Mussel Adhesion

From tissue level to cell level, various molecular forces determine how molecules interact and affect adhesion and self-healing: hydrophobic interactions, hydrogen bonding, metal coordination, cation–π forces, and anion–π forces.



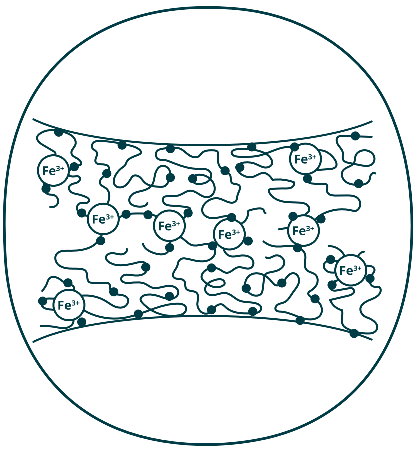


These intermolecular and surface forces can be measured using force-measurement tools like atomic force microscopes, surface force apparatus, and optical tweezers.



Mussels Stick to Wet Surfaces

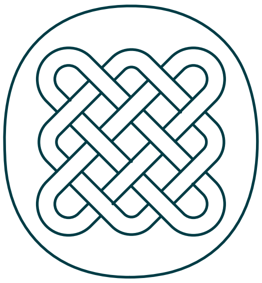
Mussels adhere to virtually any surface in wet, turbulent environments through specialized proteins. The forces involved include polymer–metal ion complexation, cation– and anion–π interactions, and hydrogen bonding and hydrophobic interactions.



How It Works

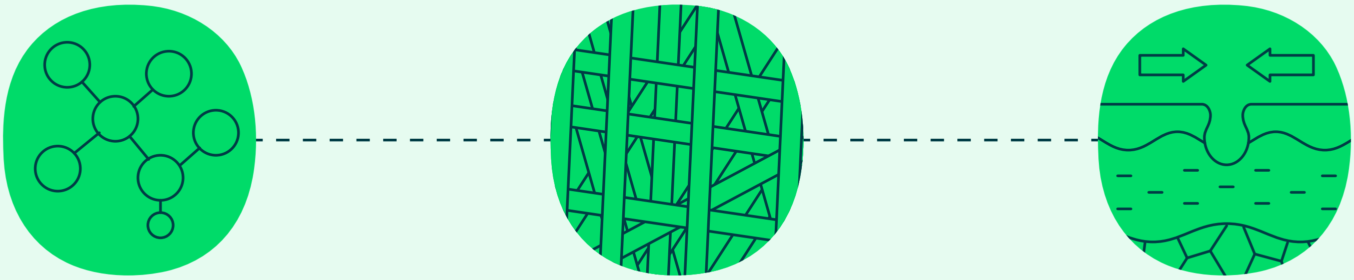
Mussel foot protein-1 combined with Fe^{3+} ions create tunable adhesion. Force tools detect reversible binding changes when ions are introduced. ZEISS imaging tracks protein secretion and plaque formation, leading to development of adhesives with adjustable bonding strength.

From Natural Adhesion to Advanced Materials



Mussels produce adhesive proteins that can self-assemble and form strong, durable cross-linked networks.

ZEISS microscopy integrated with force-measurement tools quantifies intermolecular forces—the effect of aromatic groups, hydrated cations, and cation–π and anion–π interactions—leading to the development of coacervate adhesives with self-healing properties.



Applications in Nature-Inspired Biomaterials

ZEISS systems support development of self-healing hydrogels and lubricating surfaces, coacervate adhesives, coatings for wearable and biomedical devices, hydrogels for wearable electronics, temperature- and ion-responsive polymers, and bioinspired flexible electronics and sensors.

ZEISS-integrated microscopy systems accelerate nature-inspired biomaterial design by revealing the multiscale microstructures responsible for desirable mechanical and functional properties.

From Observation to Innovation

- **Decode hierarchical structures from macro to molecular scale**
- **Quantify structure–property relationships with correlative imaging**
- **Support development of self-healing, adaptive biomaterials**

Further Resources

Wiley Event: Register for free to watch the recording of:
Designing Bioinspired Soft Materials and Interfaces via Tunable Noncovalent Interactions

Wiley Publications:

Localized Ionic Reinforcement of Double Network Granular Hydrogels

A Pseudo-*Mytilus Edulis* Foot Protein-Based Hydrogel Adhesive with Osteo-Vascular-Immune Coupling Effects for Osteoporotic Bone-Implant Integration

Multifunctional Mussel-Inspired Hydrogels and Films Formed via Catechol-VO_2 Nanoparticle Coordination

For more information and to find the right system for your needs, please visit:

ZEISS Microscopy