Next Generation Biomaterials

BioEng 458 - Lecture 1

Biomaterials anyone?

Definition -

materials that interact with biological systems

Goal -

improve health, treat diseases, enhance quality of life.

Very broad field!

Goals for BioEng-458

Understand basic principles of biomaterials design

Learn about the **innovative** developments in biomaterials

Discover unexpected **intersections** across Bioengineering disciplines

Imagine **creative** solutions to problems in human health

Do **fun** science anchored in real world applications

Course organization

Lectures: Fri. 15.00 to 17.00 in BS170

no recording

Exercise sessions: Wed. 12.00-14.00 in BS160

mostly with TAs

Your instructors

Prof. Li Tang

- BS Peking University, Chemistry
- PhD University of Illinois, Urbana Champaign, Material Sciences
- Postdoc at MIT, Koch Institute for Integrative Cancer Research
- Now Associate Prof. at EPFL, Institute for BioEngineering

Immunoengineering, immunotherapy, mechanobiology, biomaterials

Your instructors

Prof. Alex Persat

- BS Ecole Polytechnique
- PhD Stanford U., Mechanical Engineering
- Postdoc at Princeton U., Molecular Biology
- Now Associate Prof. at EPFL, Global Health Institute

Mechanobiology applied to Microbiology and Infection Biology

Teaching assistants

Alice Pellegrino

PhD student in the Persat lab, MSc in Life Science Engineering, EPFL

Dea Müller

PhD student in the Persat lab, MSc in Biology, ETHZ

Jose Vasquez

PhD student in the Deplancke lab

Course schedule and topics

Date	Class	Content/Activity	Teacher(s)
Feb. 21	L1	Introduction	Alex
Feb. 28	L2	**Nanobiomaterials**	Li
Mar. 7	L3	**Organoid technology**	Prof. Matthias Lutolf
Mar. 14	L4	**Synthetic Biology meets Biomaterials**	Alex
Mar. 21	L5	**Biomaterials for tissue engineering**	Li
Mar. 28	L6	**Living biomaterials**	Alex
Apr. 4	L7	**Smart biomaterials for biosensing**	Prof. Nako Nakatsuka
Apr. 11	L8	**Microrobotics for medicine**	Prof. Simone Schürle
Apr. 18 & 25		Easter	Easter Bunny
May 2	L9	**Engineered hydrogels for mechanobiology**	Prof. Eileen Gentleman
May 9	L10	**Biomaterials for cell & gene therapy**	Li
May 16	L11	**Workshop to prepare report/presentation**	Alex, Li, TAs
May 23	L12	Final presentation I	You
May 30	L13	Final presentation II	You again

Evaluation

Final exam

60% of your grade

Group project

40% of your grade

Group projects

1. Self-assemble into groups of 5
2. We will propose topics and ideas for projects in the form of a challenge
3. Learn about the fundamentals and latest developments
   - Write a 1p. pre-proposal
   - Write a research proposal/report
   - Present project in one of the last two lectures

++ Continuous support during the semester during exercise sessions

++ TA support (one TA assigned per group)

Project schedule

Date	Content/Activity
Feb. 19	none
Feb. 26	**Group project: topic introduction**
March 5	**Group project: groups and topics finalized**
March 12-19-26	Group project
April 2-9	**Group project - help with 1-page outline**
April 11	**1-page outline due**
May 7-14-21	Group project (report due May 22)

Questions?

Introduction to Biomaterials

BioEng458 - Lecture 1

Biomaterials: basic principles

biomaterial = biological material?

Biomaterials
what are they?

Materials engineered to interact with biological systems

Two classes:

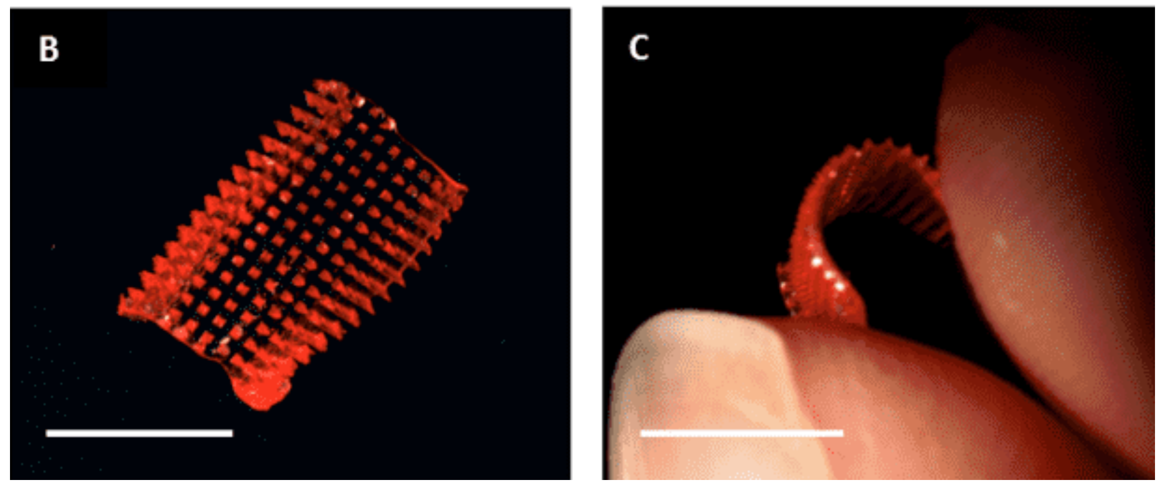
- Natural (collagen, silk) **-> biological materials**
- Synthetic (metals, polymers)

Applications of biomaterials

materials at many scales

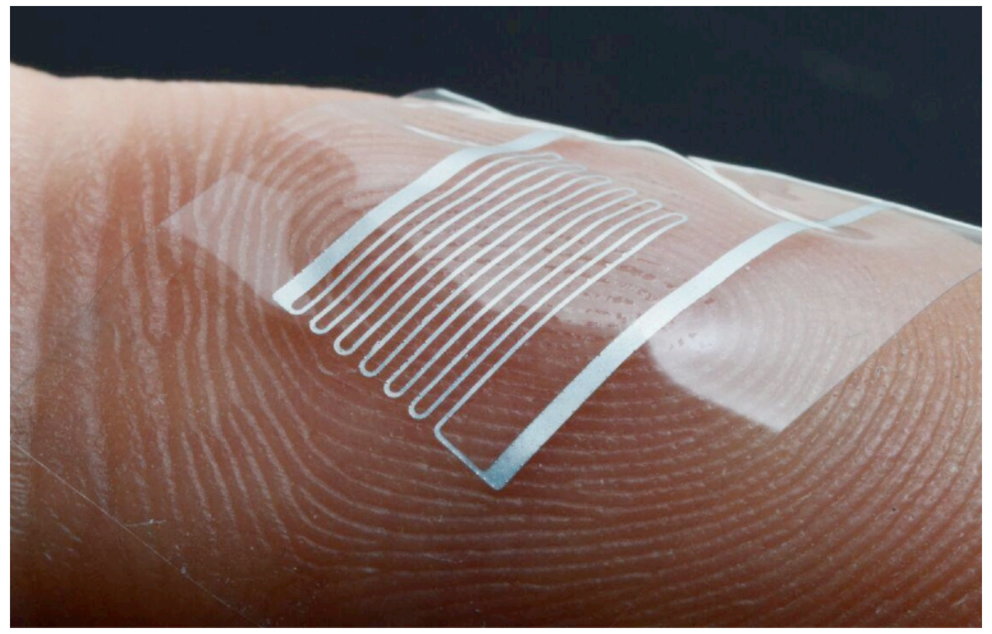
Drug delivery systems

Nanoparticles, hydrogels



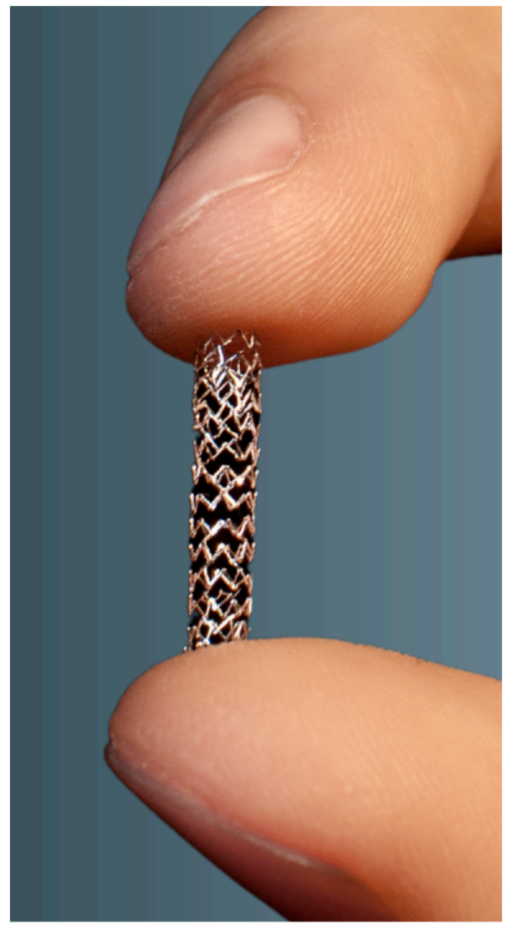
Wearable, diagnostics

Flexible electronics



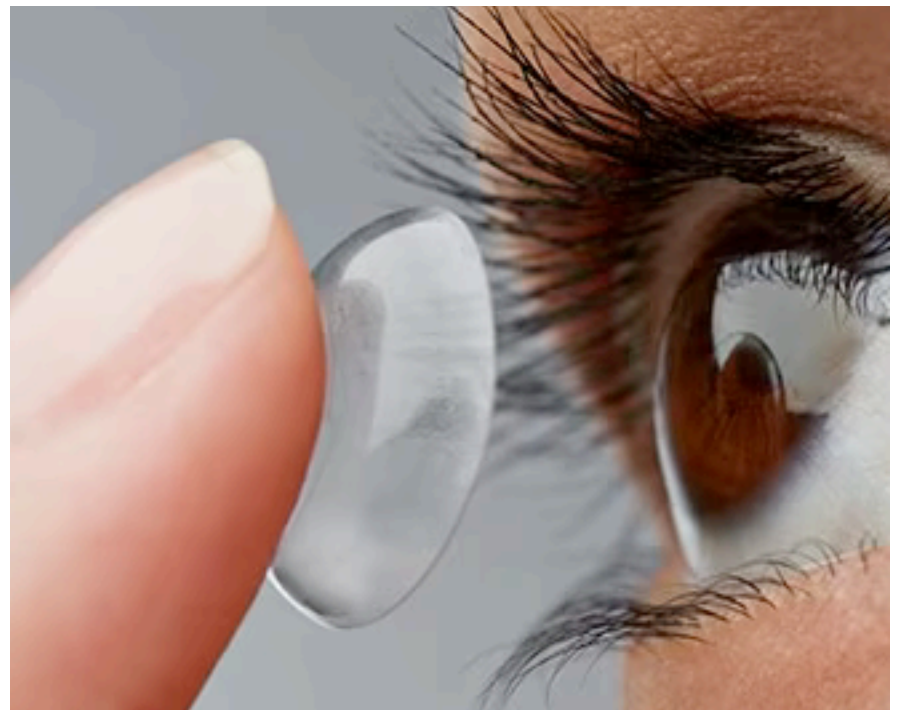
Stents and heart valves

Nitinol, Polymers, Stainless steel



Contact lens

Polymers



Dental filling and prosthetics

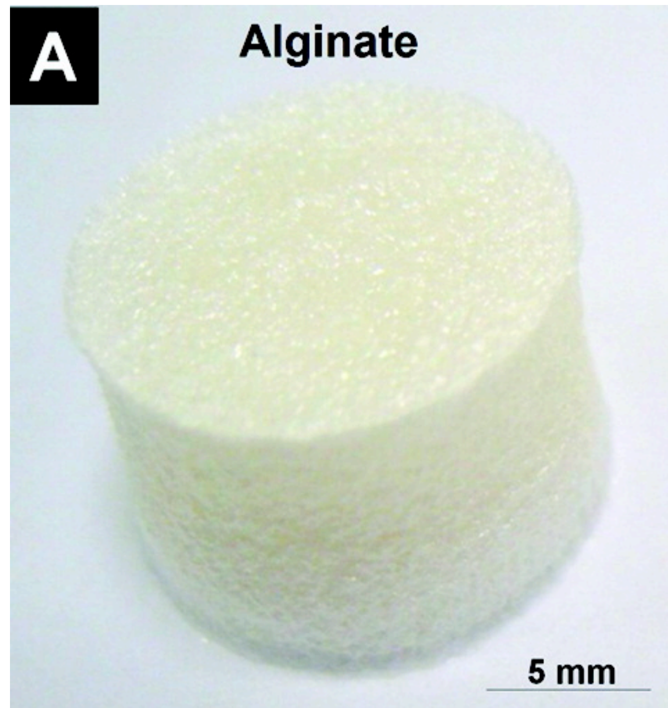
Ceramic, metal

Artificial hips/knees

Titanium, Cobalt-Chrome alloys

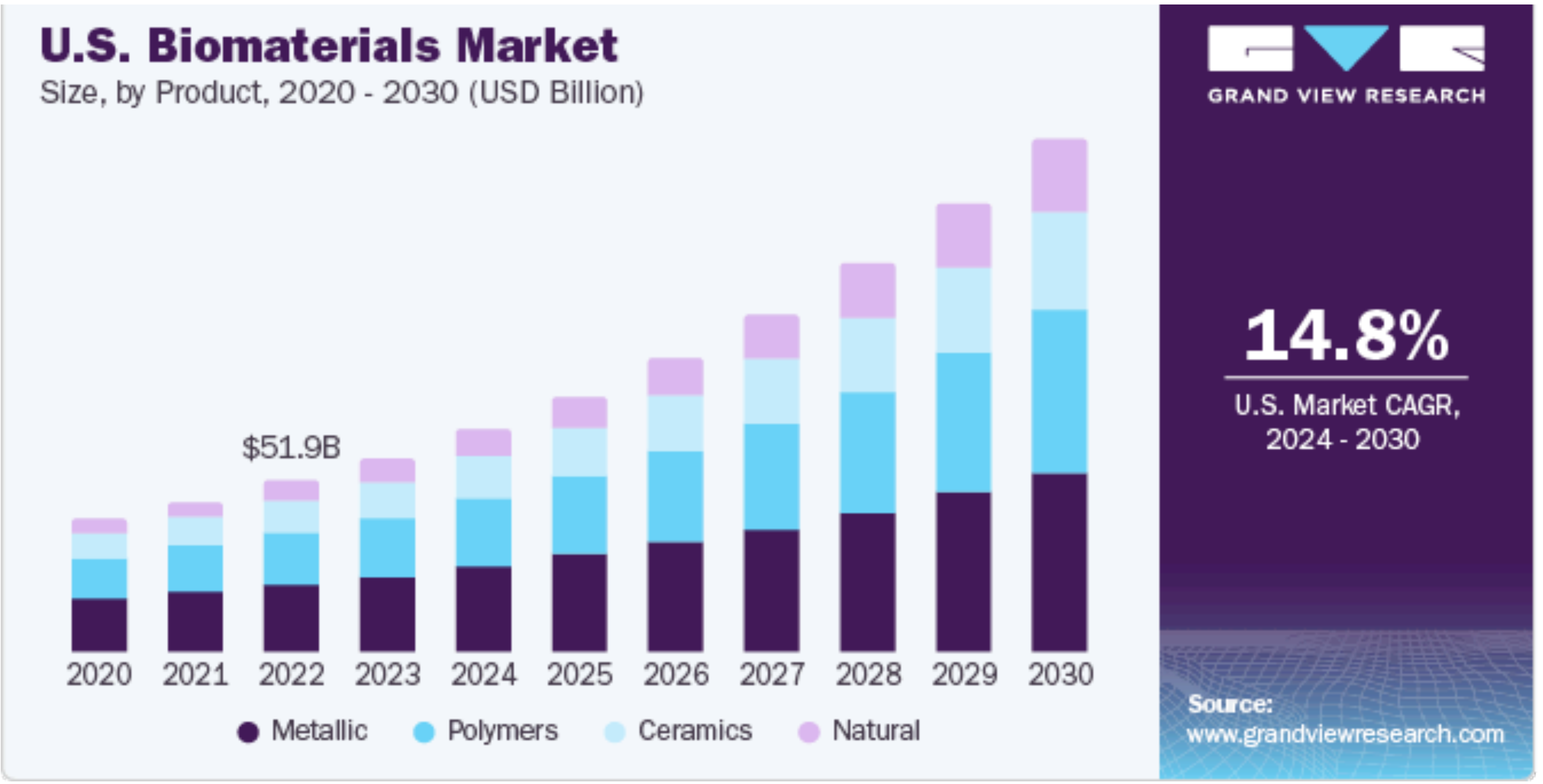
Tissue scaffolds

Hydrogels



The business side of Biomaterials

Global biomaterials market is valued at ~$178+ billion



Key Sectors in growth:

- Orthopedics & Implants.
- Regenerative Medicine.
- Drug Delivery & Diagnostics.

Industry Players:

- Big Biotech & MedTech: Medtronic, Johnson & Johnson, Stryker.
- Startups & Innovation: 3D bioprinting firms, bioengineered tissue companies.

Challenges & Opportunities:

- Regulatory Hurdles: FDA & EMA approval processes.
- Sustainability & Biodegradability: Push for greener biomaterials.
- Cost vs. Accessibility: Balancing high-tech solutions with affordability.

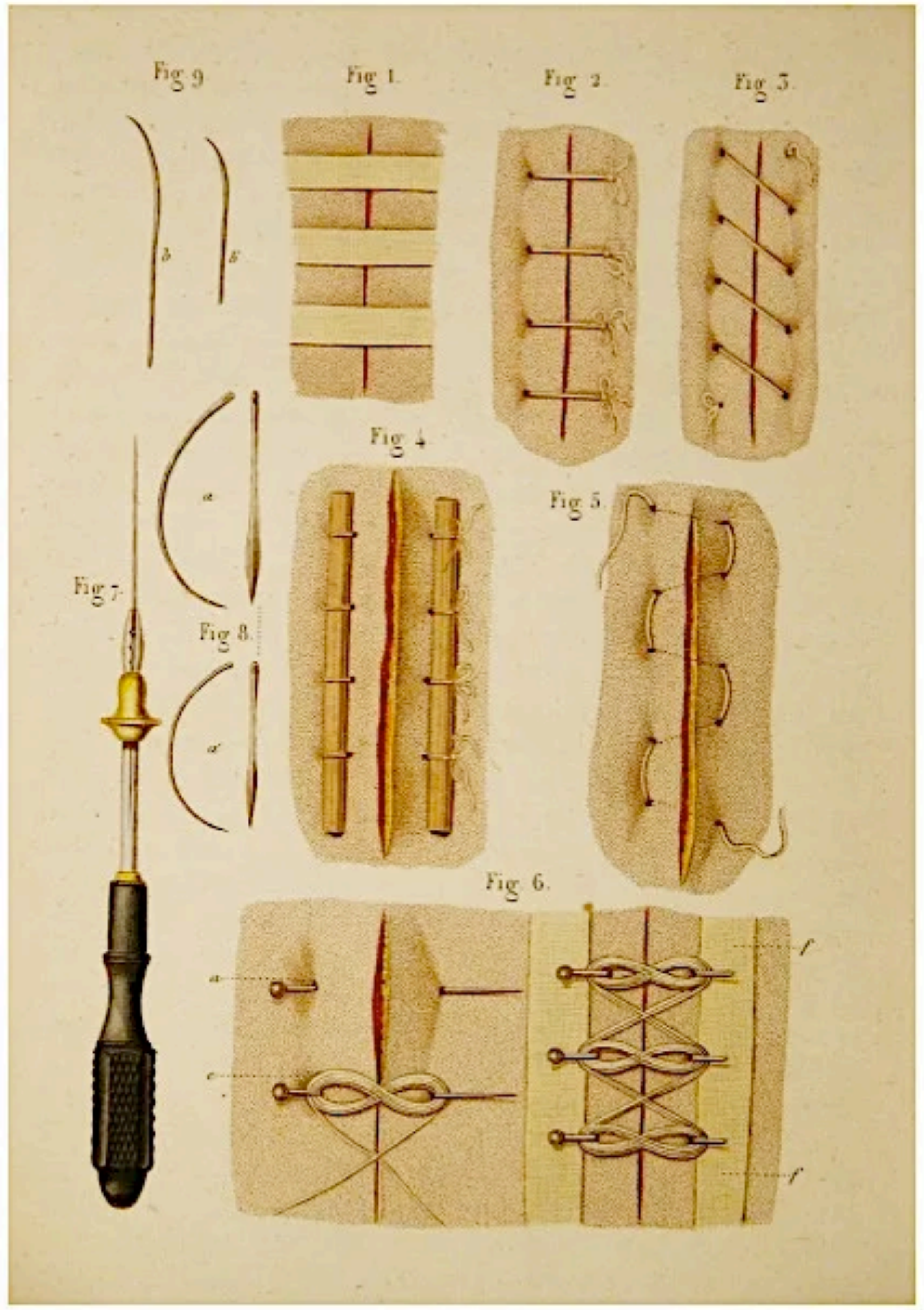
A brief history of Biomaterials

- Ancient Egyptians used linen for sutures
- Etruscans and Romans used gold for dental fillings (200 A.D.)

Early 20th century:

- Titanium for implants
- Biocompatible polymers (PMMA for contact lens)

Ambroise Paré catgut sutures



Material types

Metals: Titanium, Stainless Steel, Cobalt-Chrome

Polymers: Biodegradable (PLGA, PCL) vs. Non-biodegradable (PMMA, Silicone)

Ceramics: Hydroxyapatite, Bioactive Glass.

Composites: Combination of different material classes.

Material choice depends on application

Biomaterials: design considerations

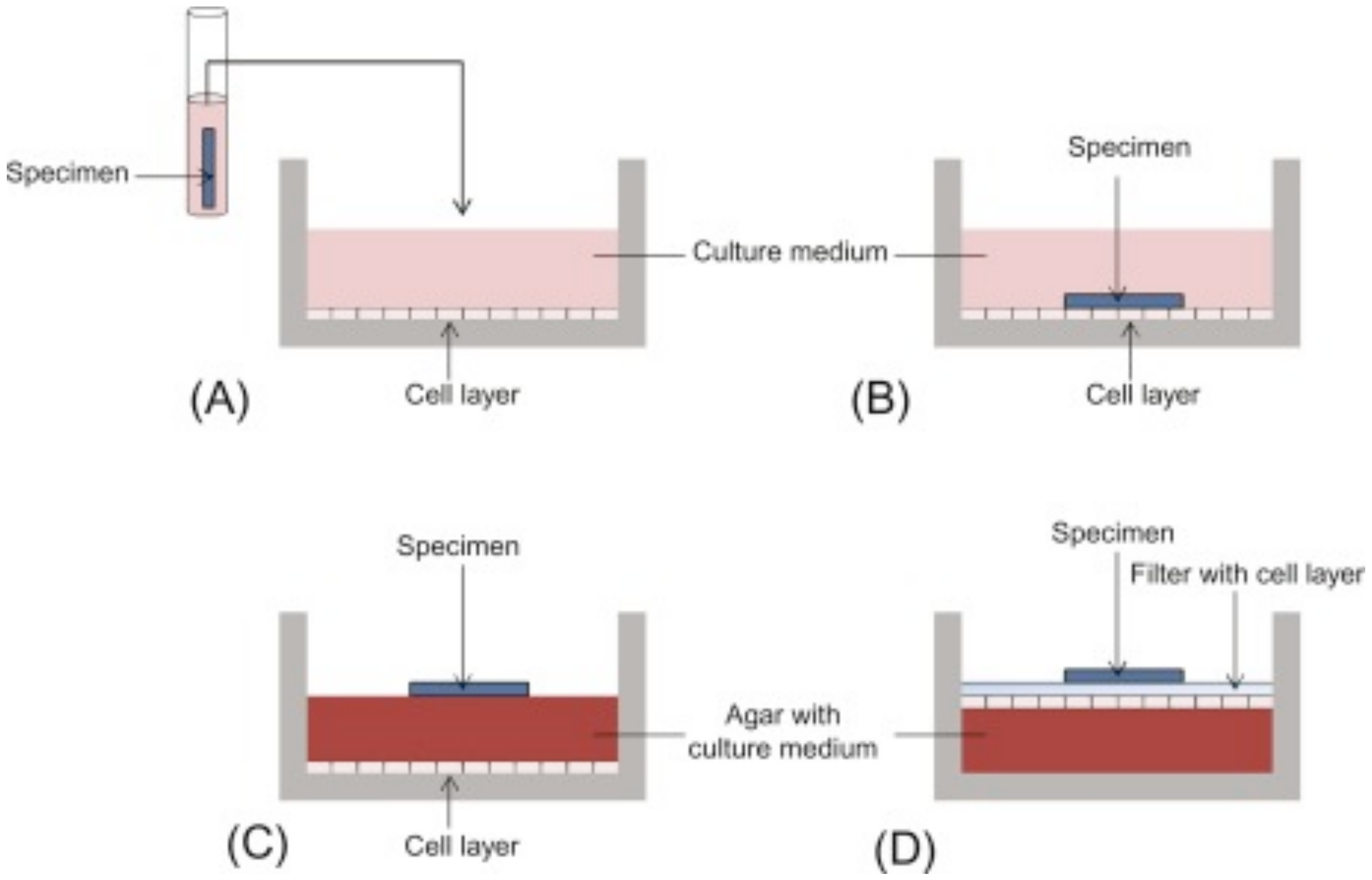
key properties (non-exhaustive)

- Biocompatibility
- Mechanical Properties
- Degradability and Stability
- Surface Properties
- Sterilization and Safety

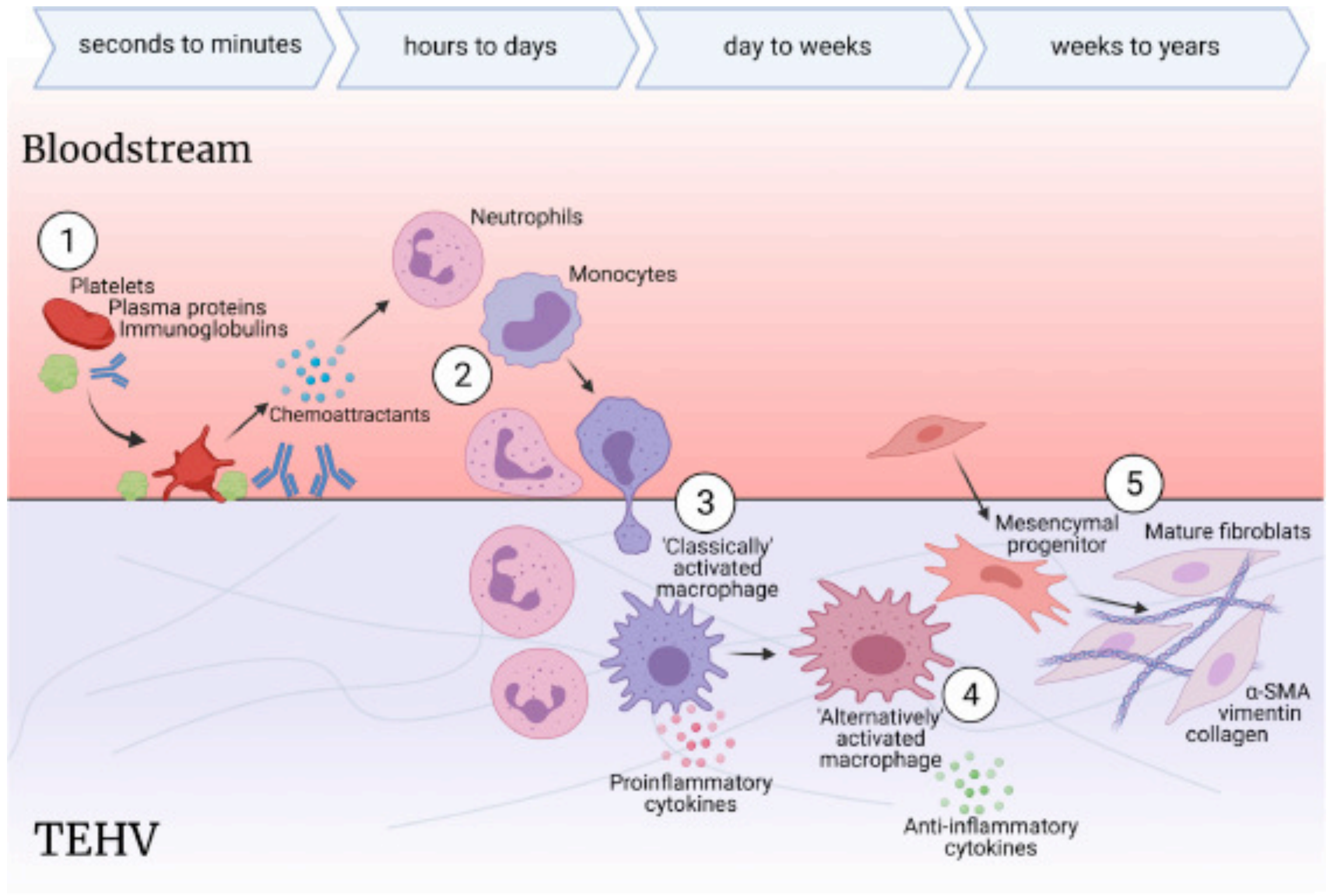
Biocompatibility

Material is not harmful

Cytotoxicity: does the material kill cells?



Immunogenicity: does the material induce an immune response?



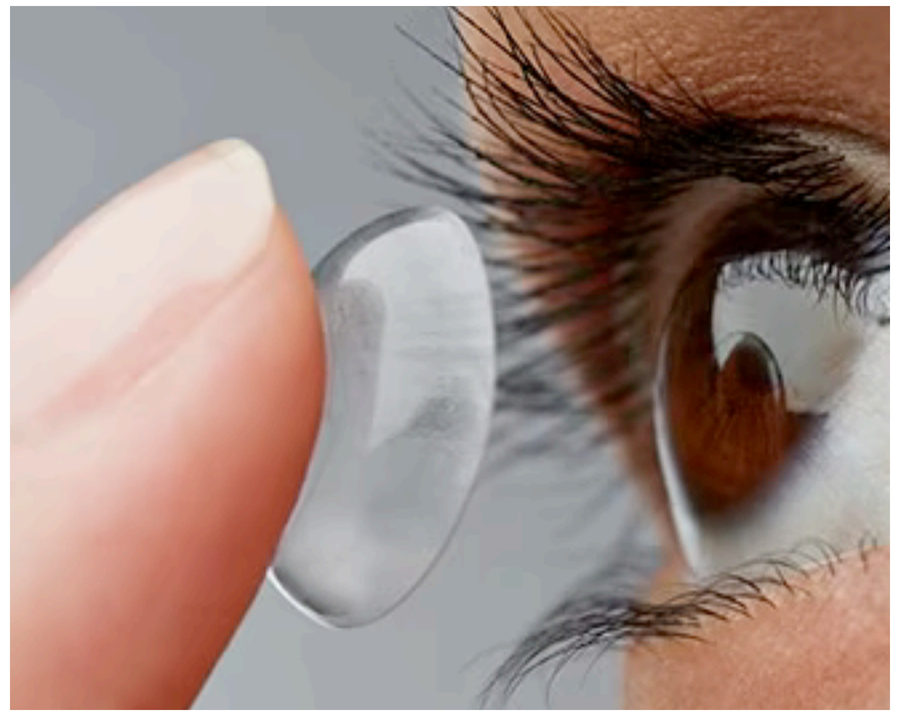
Biodegradability and Stability

Should biomaterials stay or go?

Permanent biomaterials

bone implants, dental filling

Reduce environmental impact



Biodegradable biomaterials

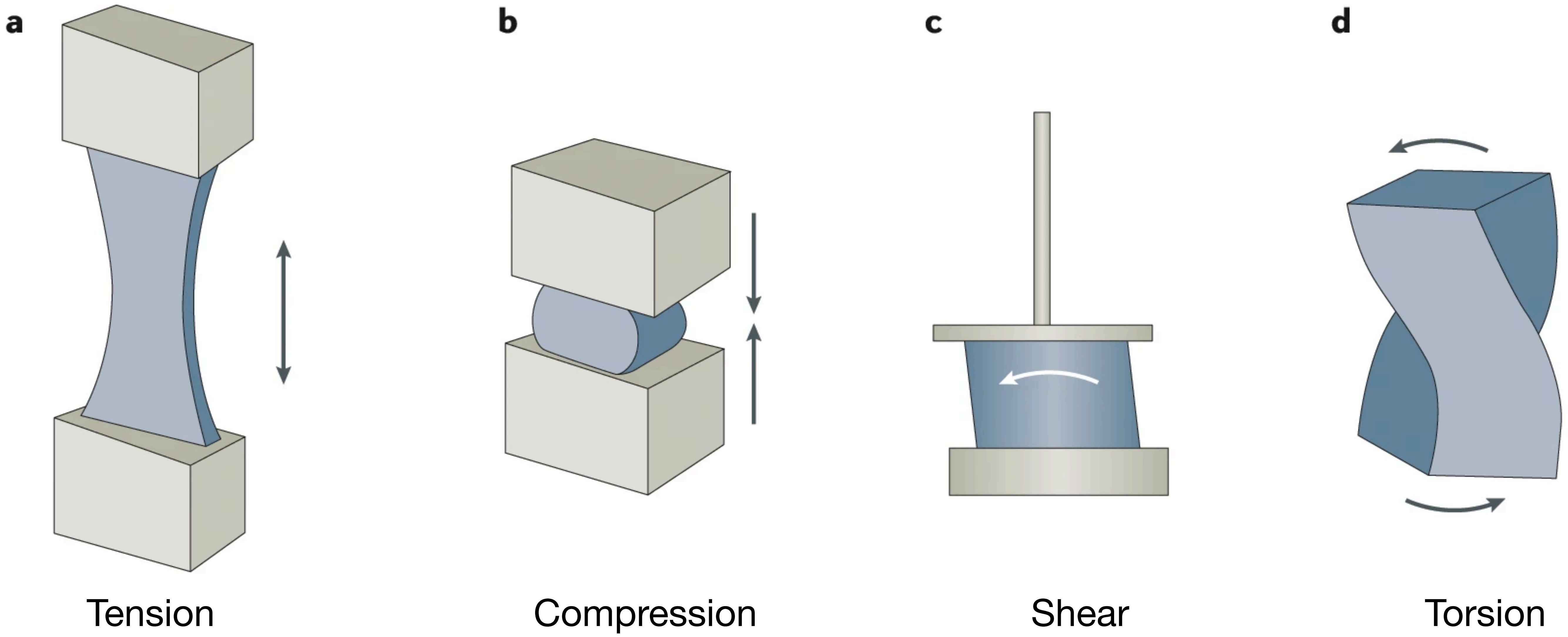
drug carriers, absorbable stitches

Select material types based on environment (pH, temperature, immunogenicity)

Mechanics

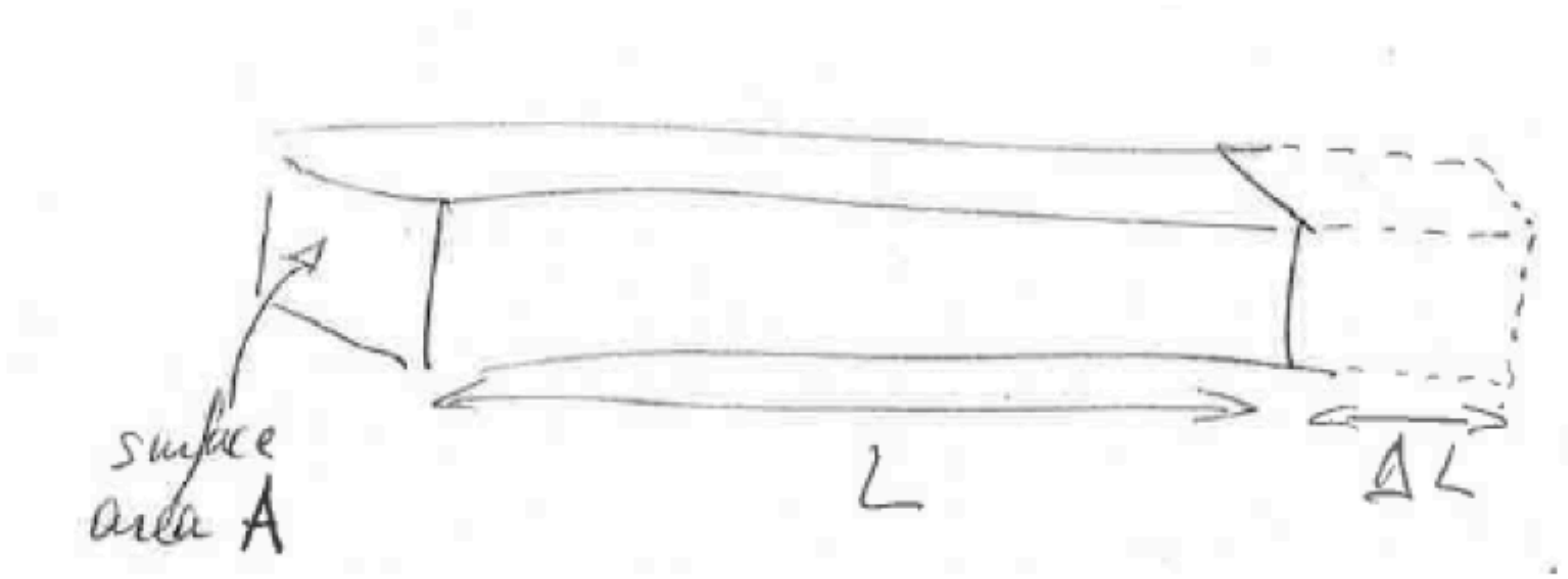
How do biomaterials behave under force? 😬

- Tensile strength
- Compressive strength
- Elastic modulus
- Fracture toughness



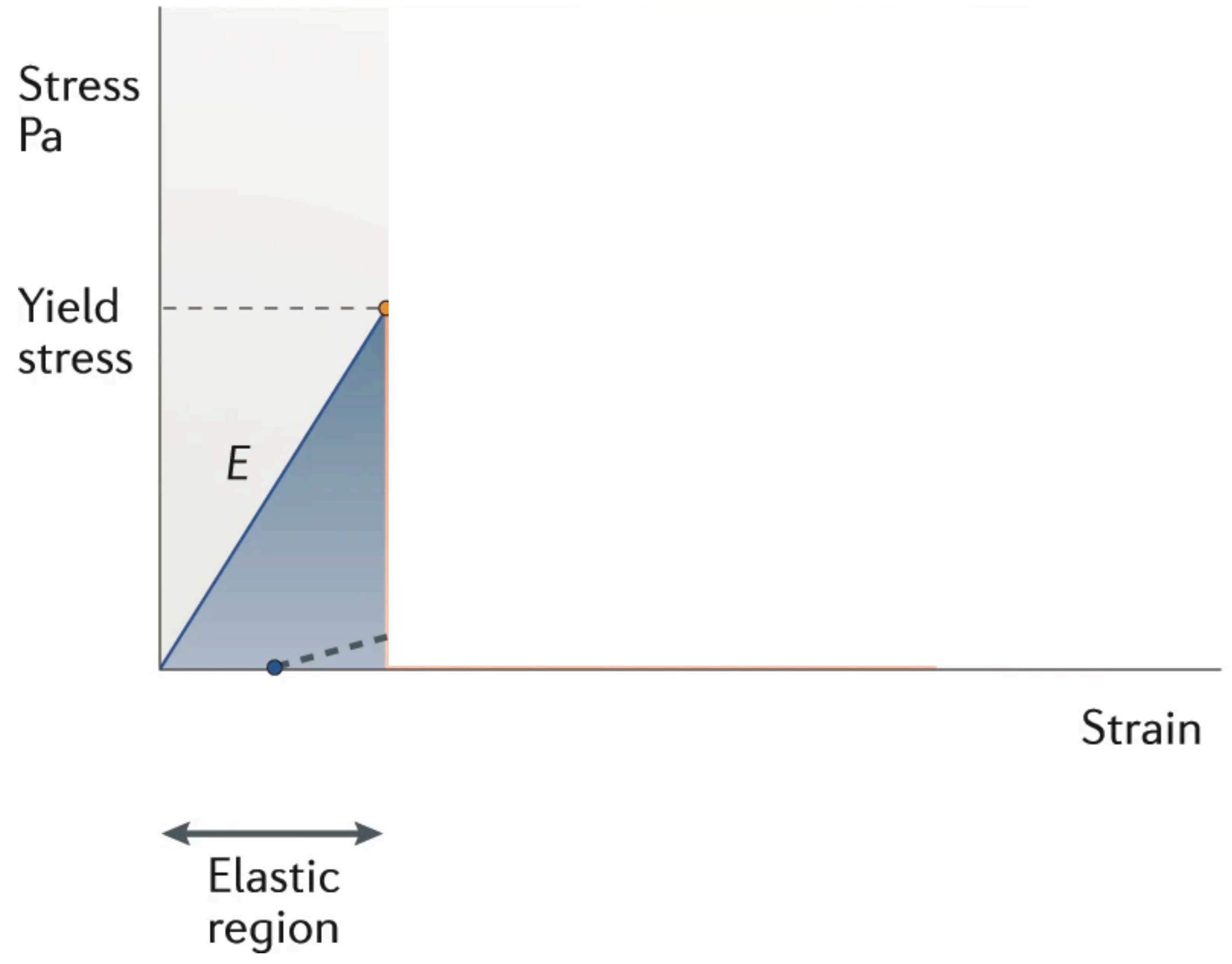
Elastic modulus

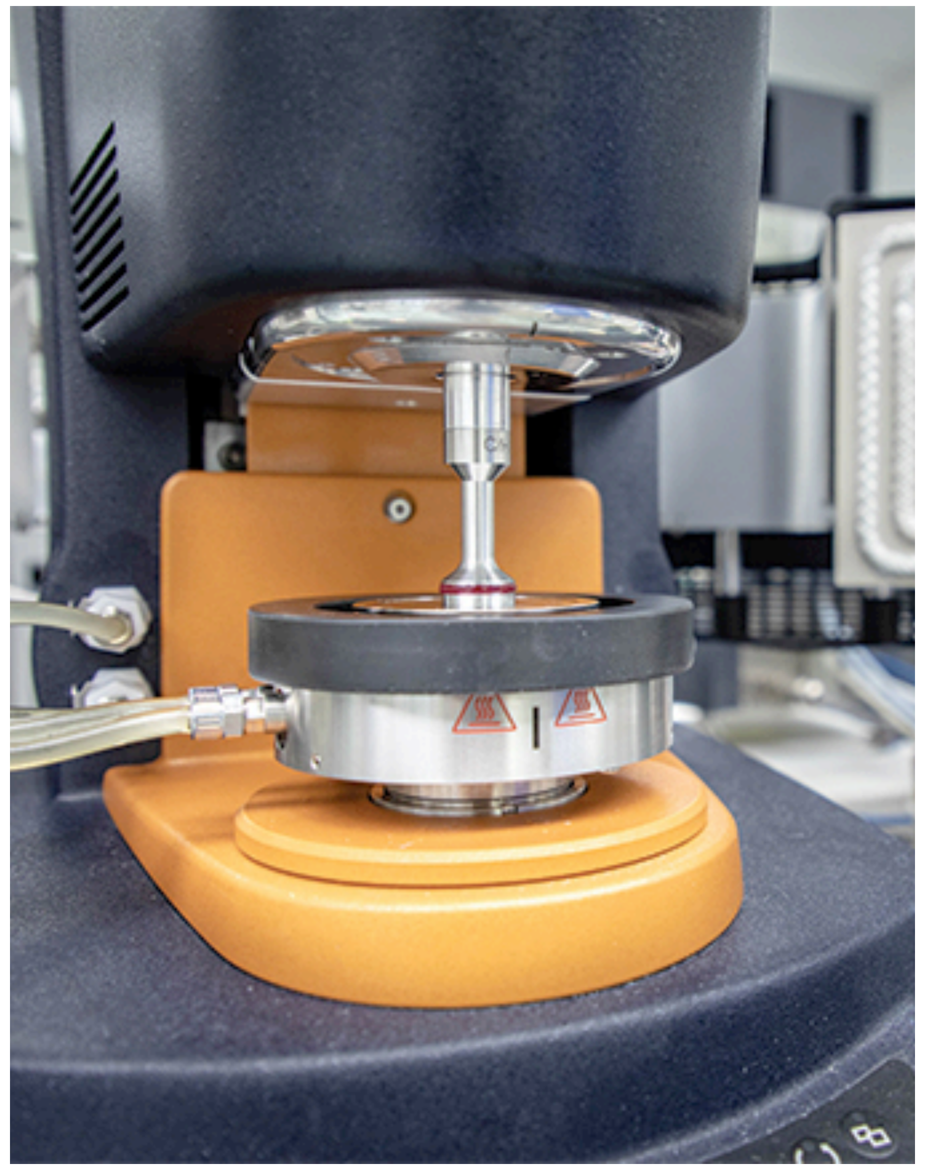
or Young’s modulus, quantifies the stiffness of a material



Strain $$\epsilon = \frac{\Delta L}{L}$$

Stress $$\boxed{\frac{F}{A} = E\frac{\Delta L}{L}}$$

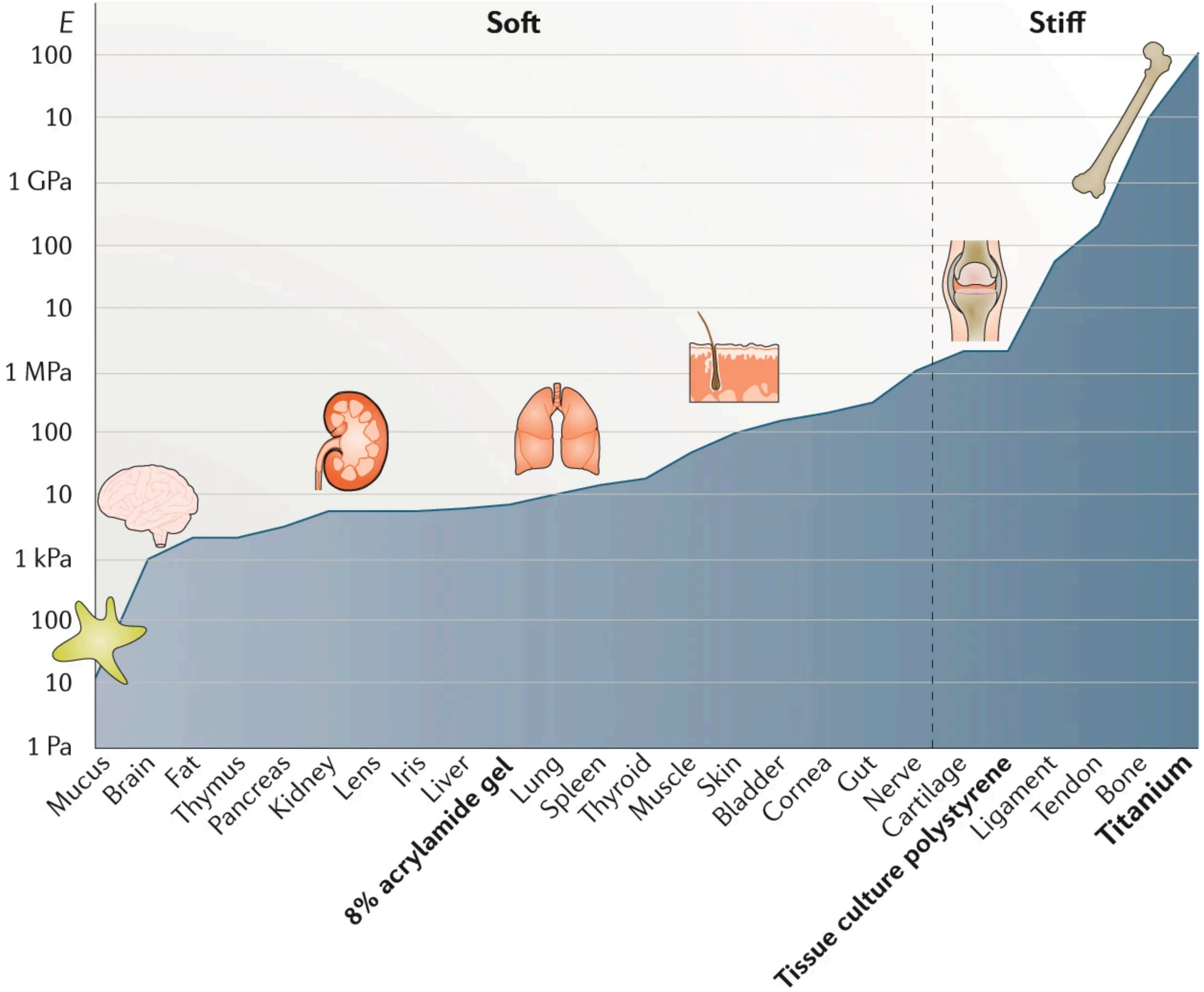




A rheometer

Range of tissue stiffness

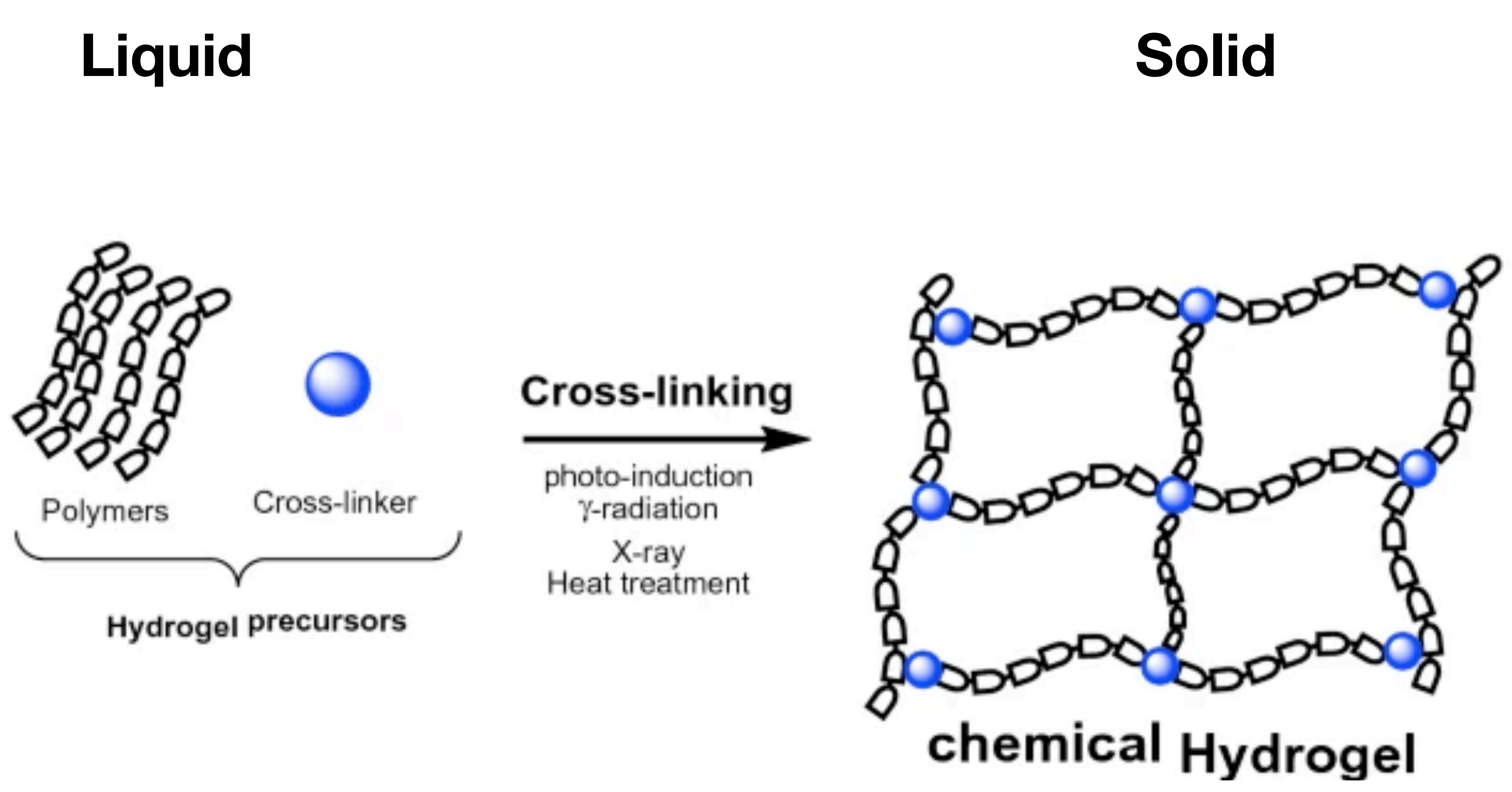
10 Pa to 100 GPa

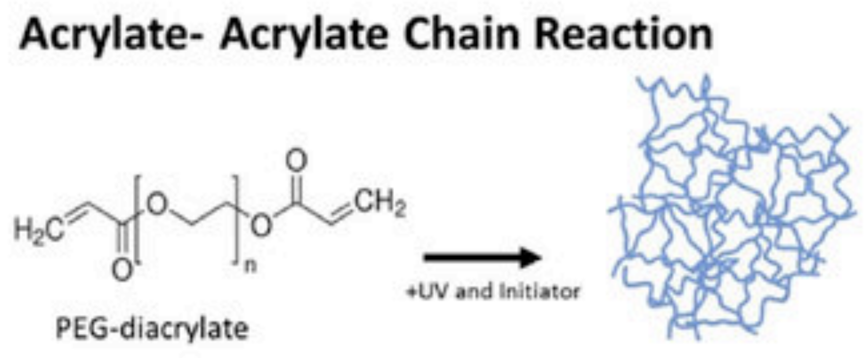


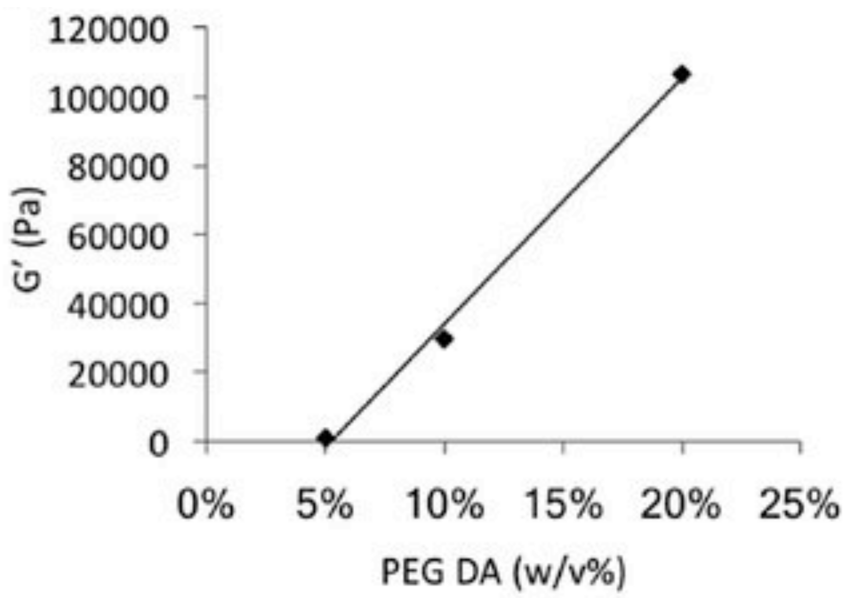
Basic principle for biomaterial design:

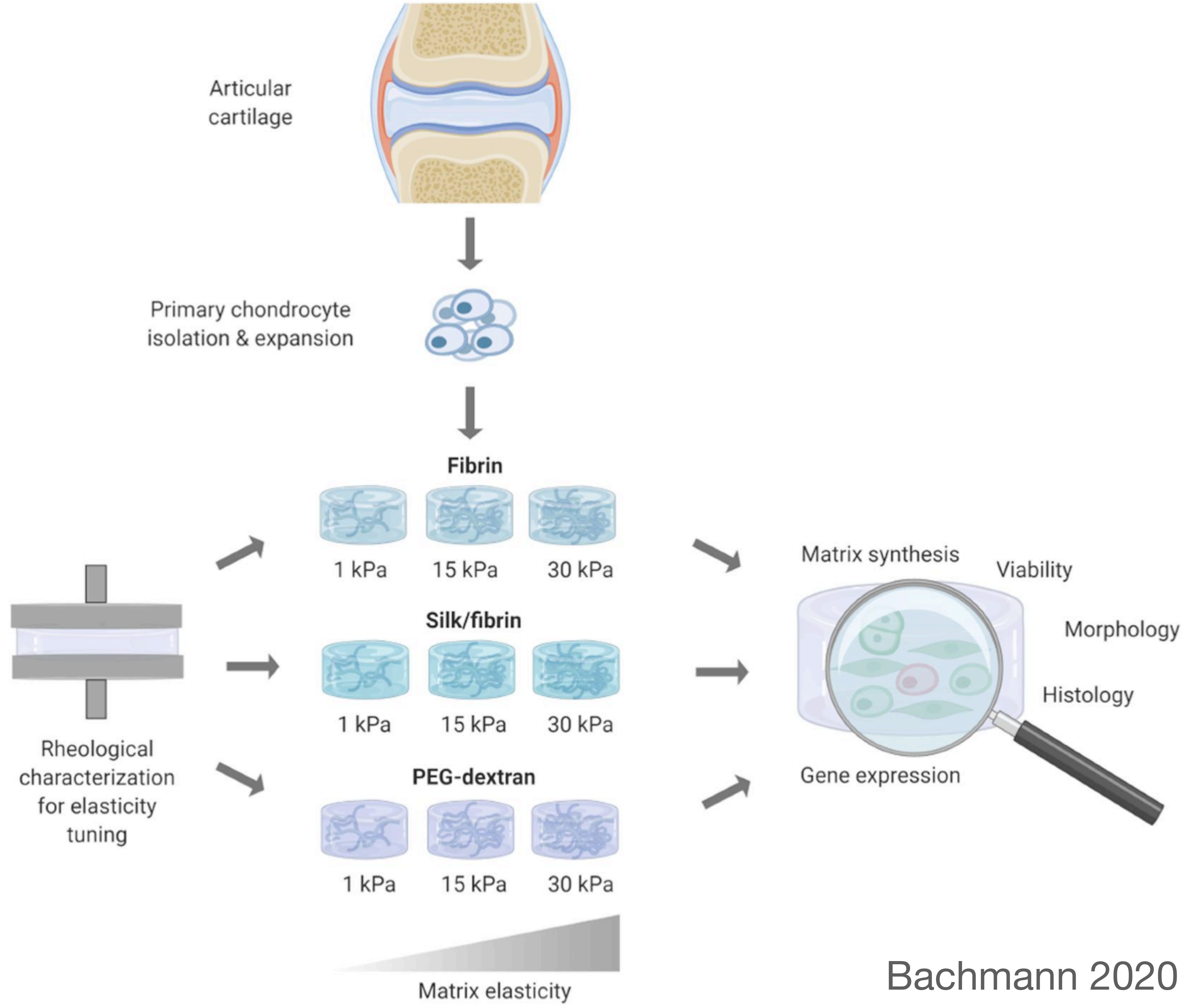
Stiffness-matching

Stiffness control
The case of hydrogels





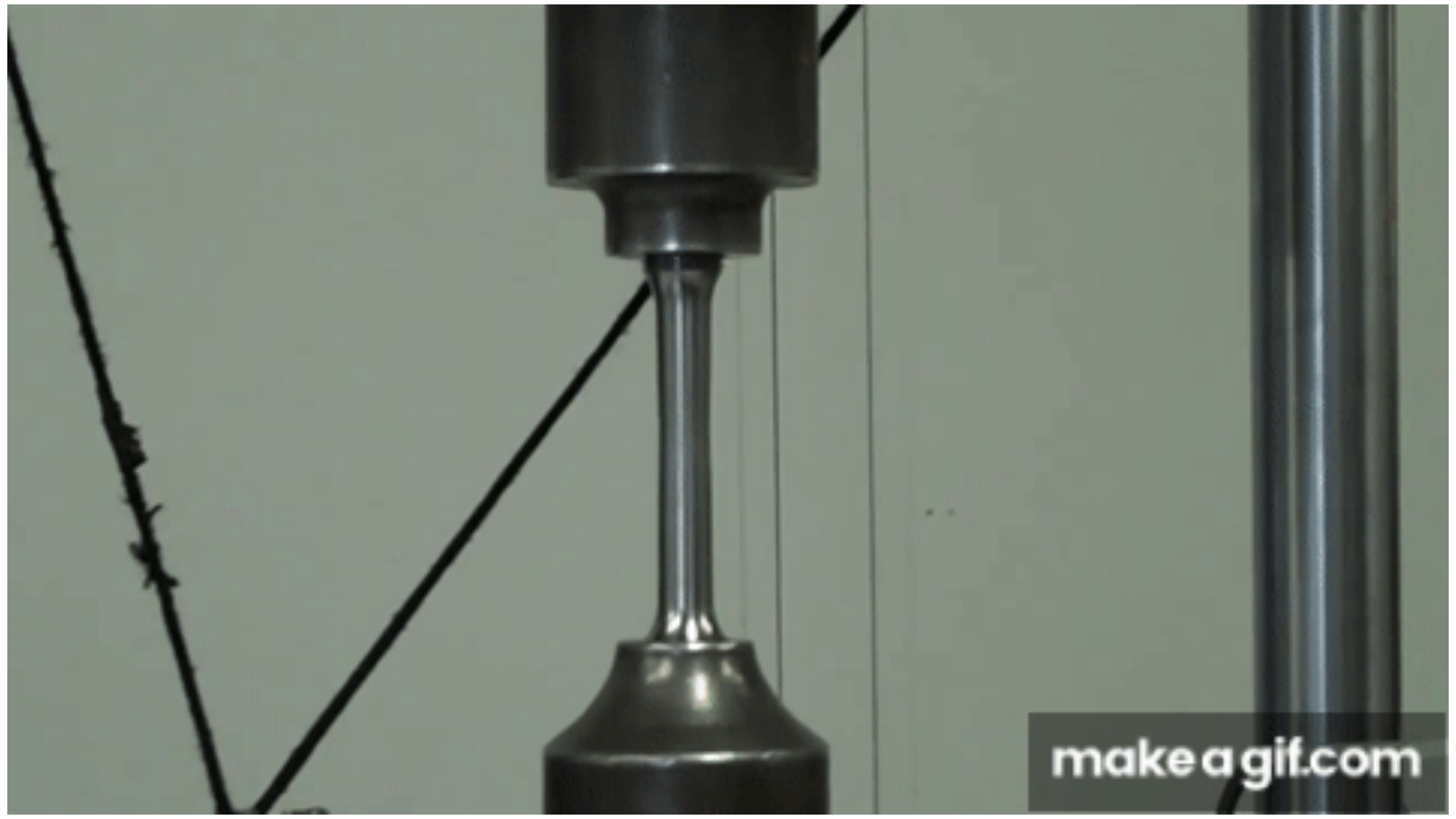


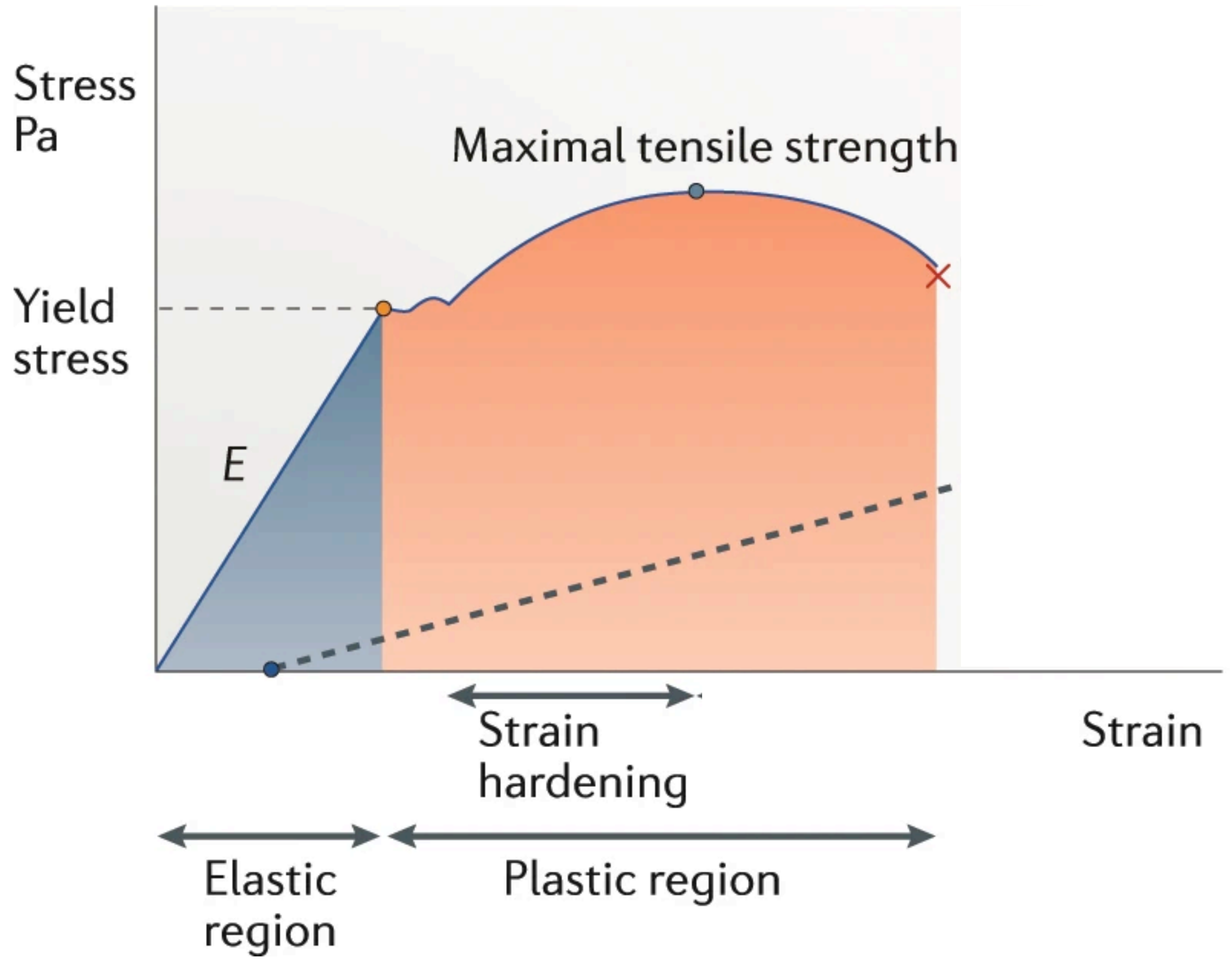


Bachmann 2020

Tensile/compressive strength

Maximum mechanical stress before material breaks



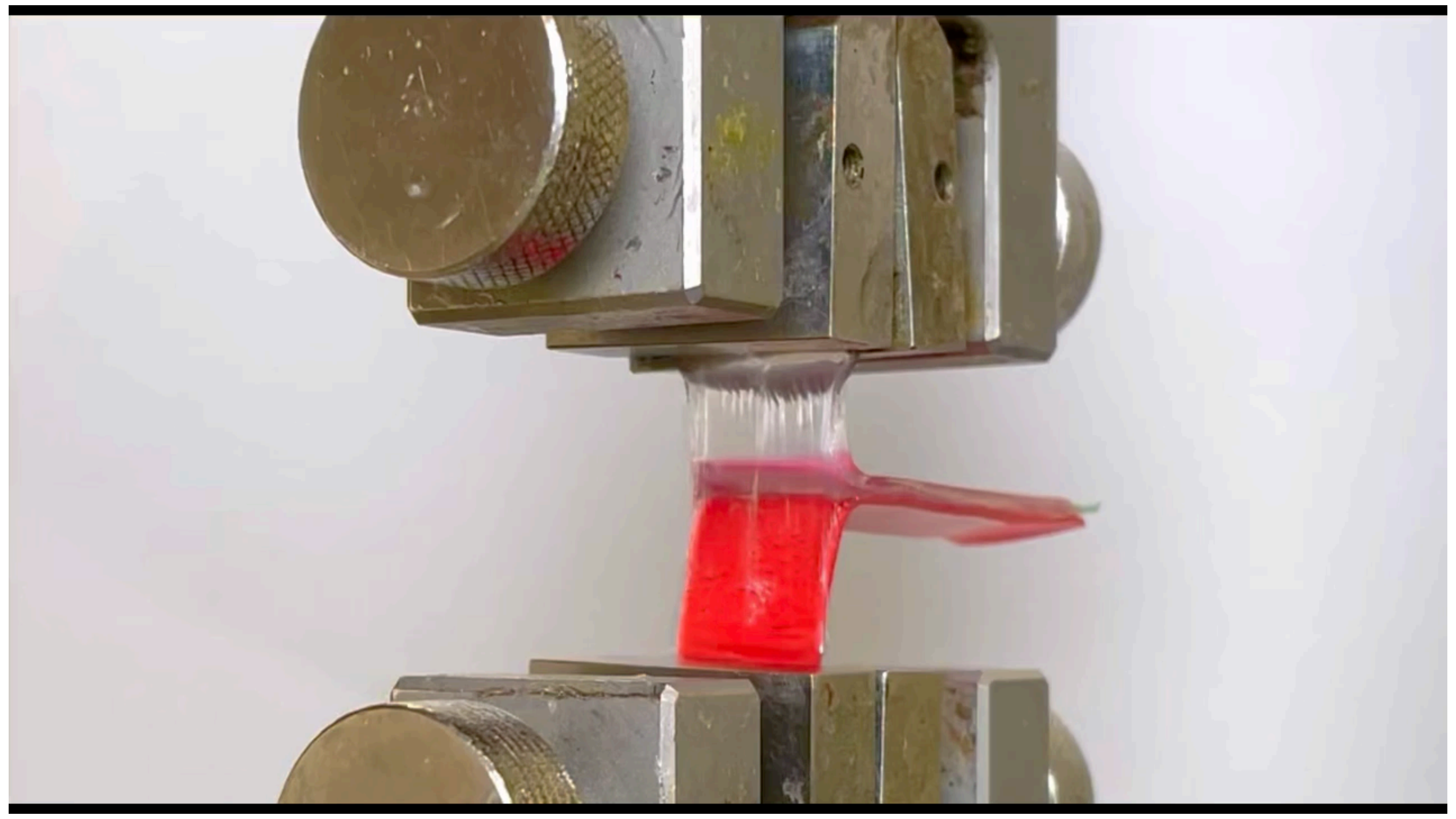


Surface properties

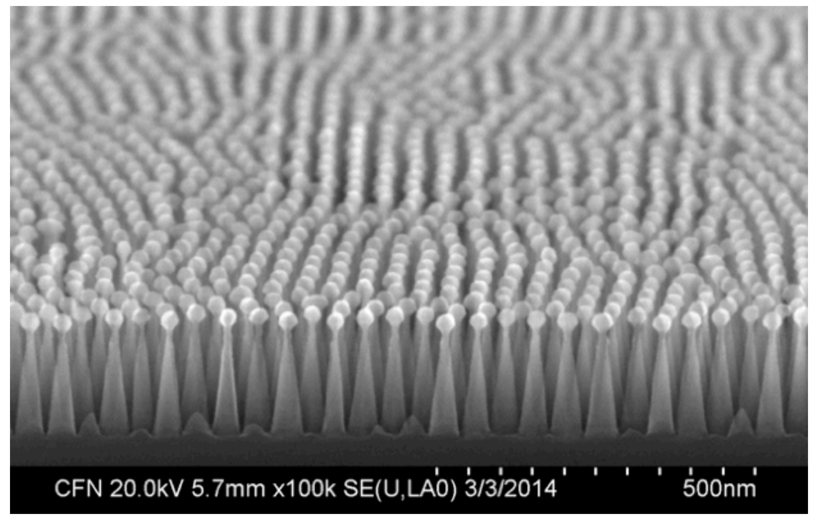
- Adhesion (cells, other substrates)
- Protein adsorption
- Hydrophobicity

Control via:

- Coating (deposition, reaction)
- Nanotexturing



Freedman 2023



Safety!!!

Dalkon shield - Plastic intrauterine device (IUD)

Made of **polyethylene plastic**

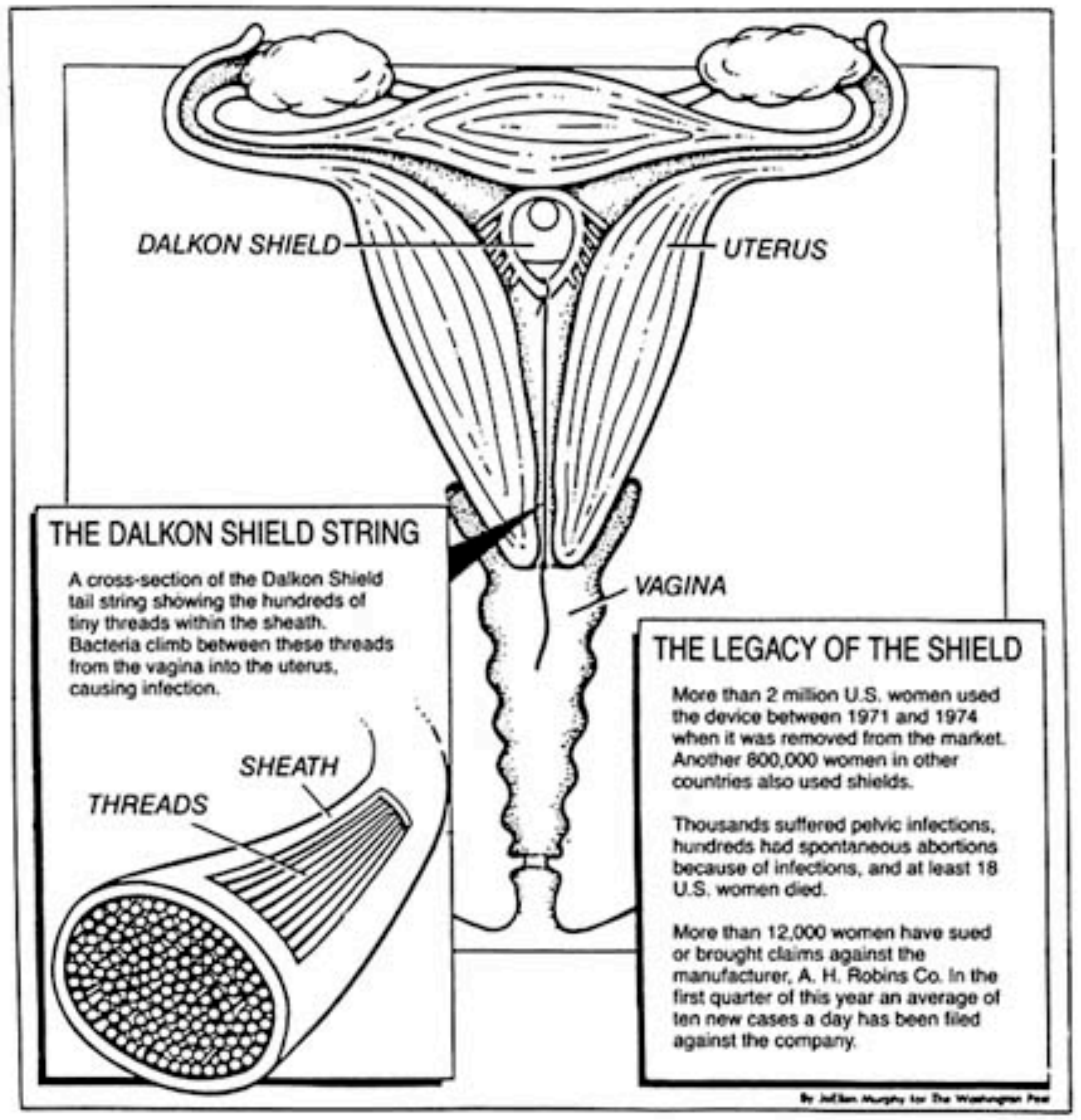
too stiff → uterine damage

Multifilament string (instead of monofilament)

→ Infections

18 maternal deaths
200+ spontaneous septic abortions

DESIGN MATTERS



Safety failures:

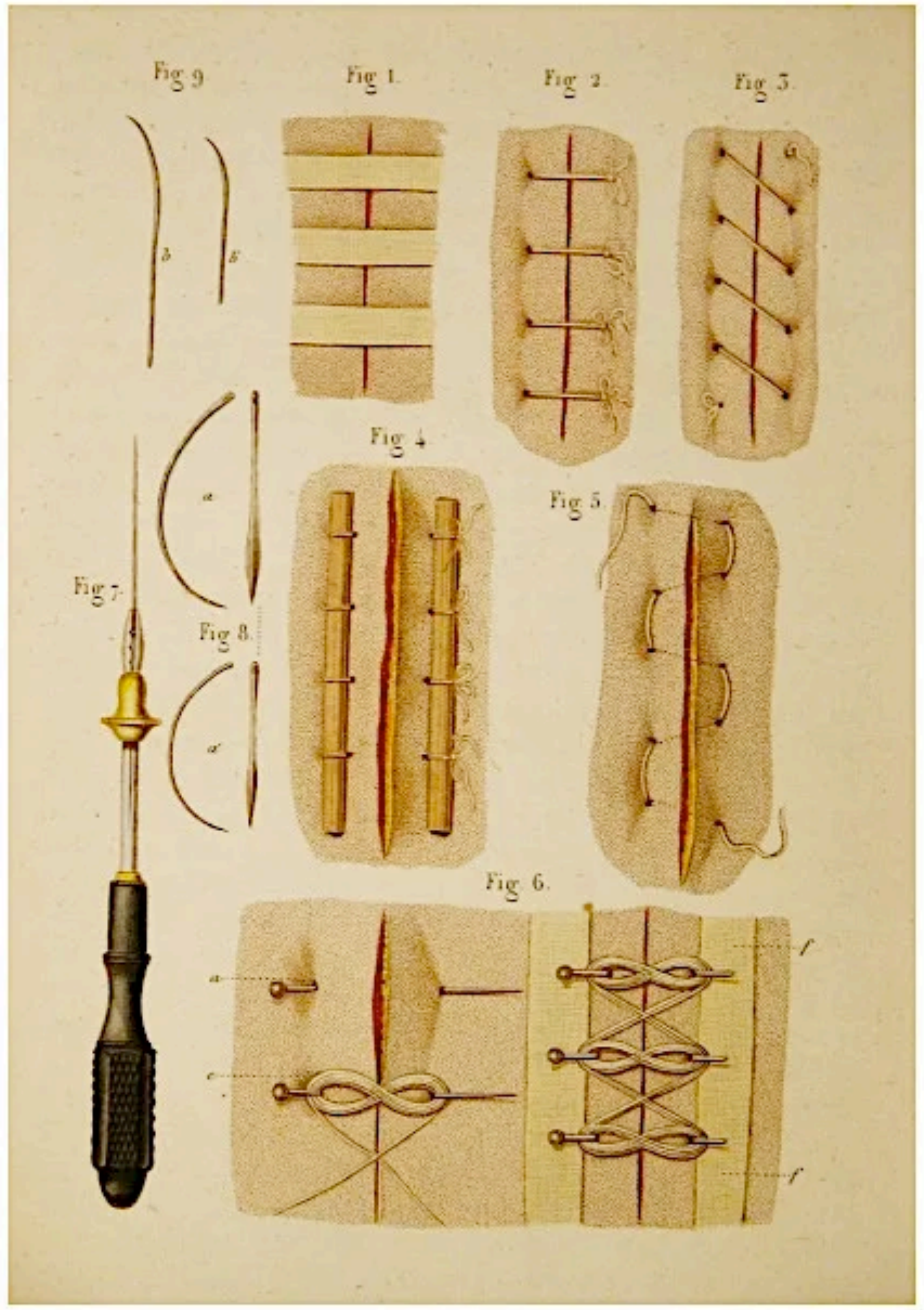
- Rushed Approval
- Inadequate Clinical Trials (tested on only 600 women, sold to 2.5 million users)

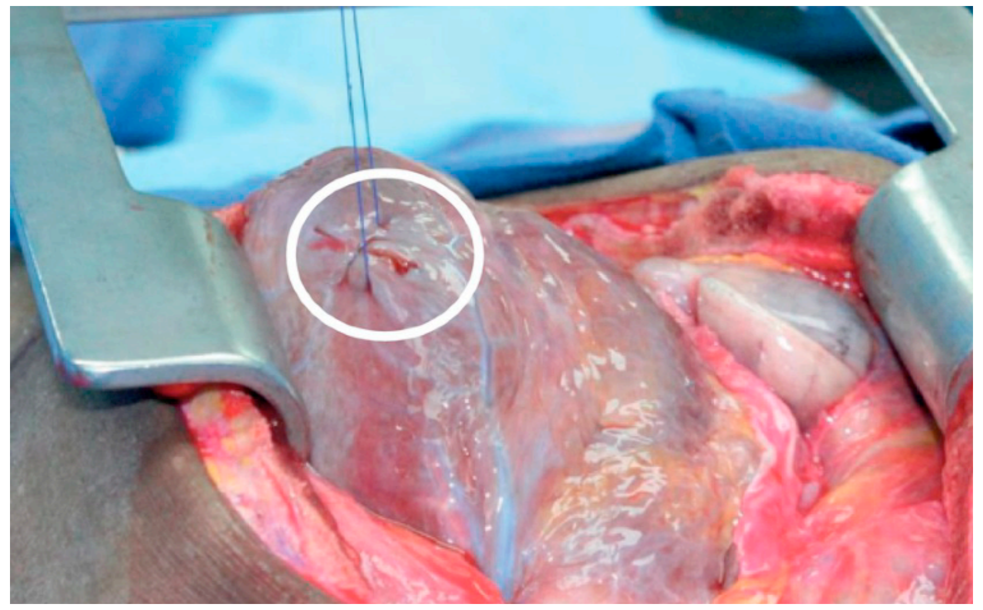
→ FDA imposes regulation on medical device, requiring testing and approval, as for medications

So what are next generation biomaterials?

	Properties		Applications
Inert	→	Responsive and Adaptive	Controlled drug delivery
Passive	→	Active	Autonomous therapy
Tissue-scale	→	Cell and molecular-scale	Precision medicine

Example: why do we still stitch wounds?



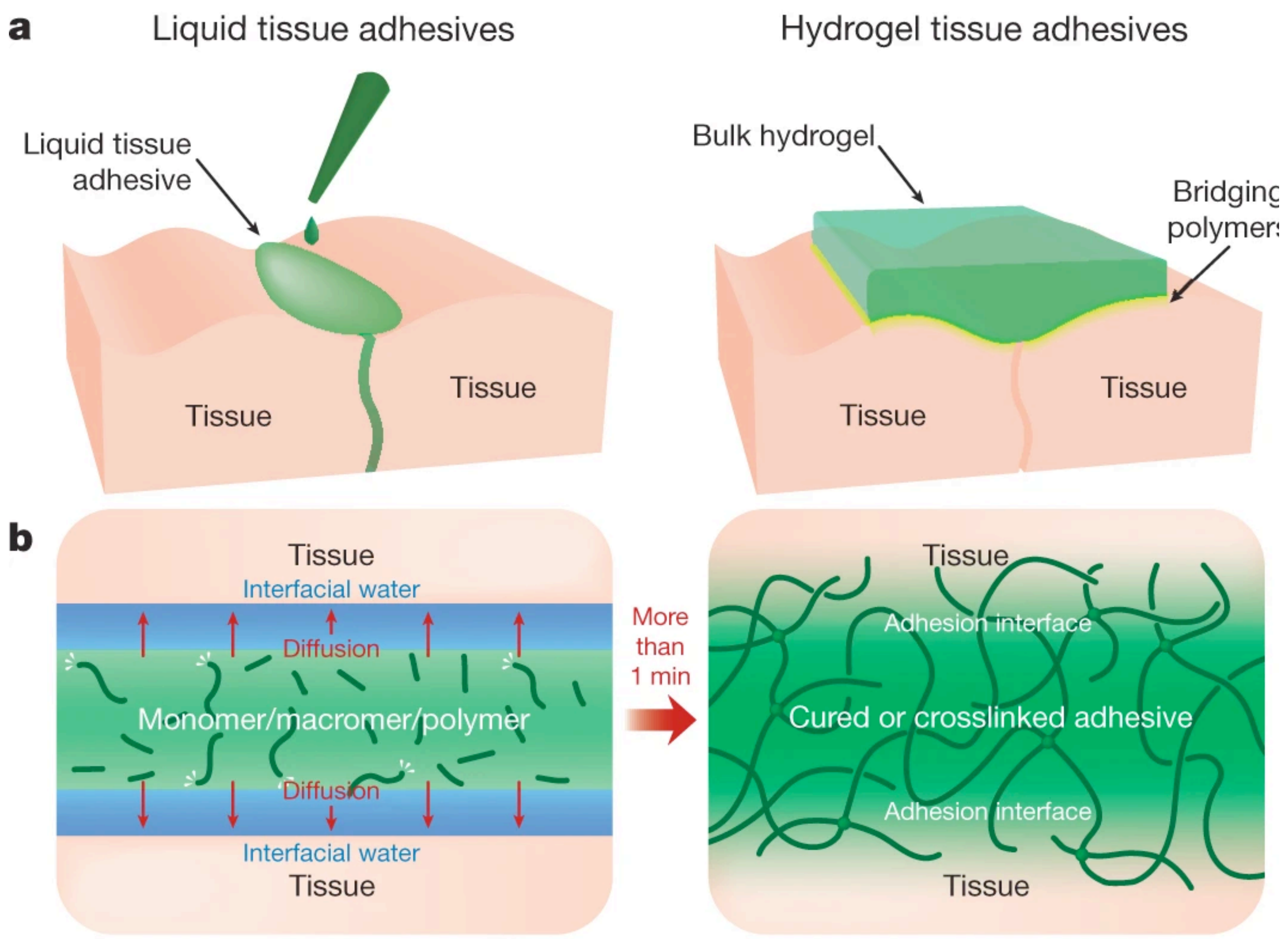


How about taping?

Taping tissue

Can you tape wet surfaces?

Classic adhesive



> need an adhesive that sticks in water, or removes water

Yuk 2019

Adhesion unde wet conditions in nature

Spider webs

Diving bell spider

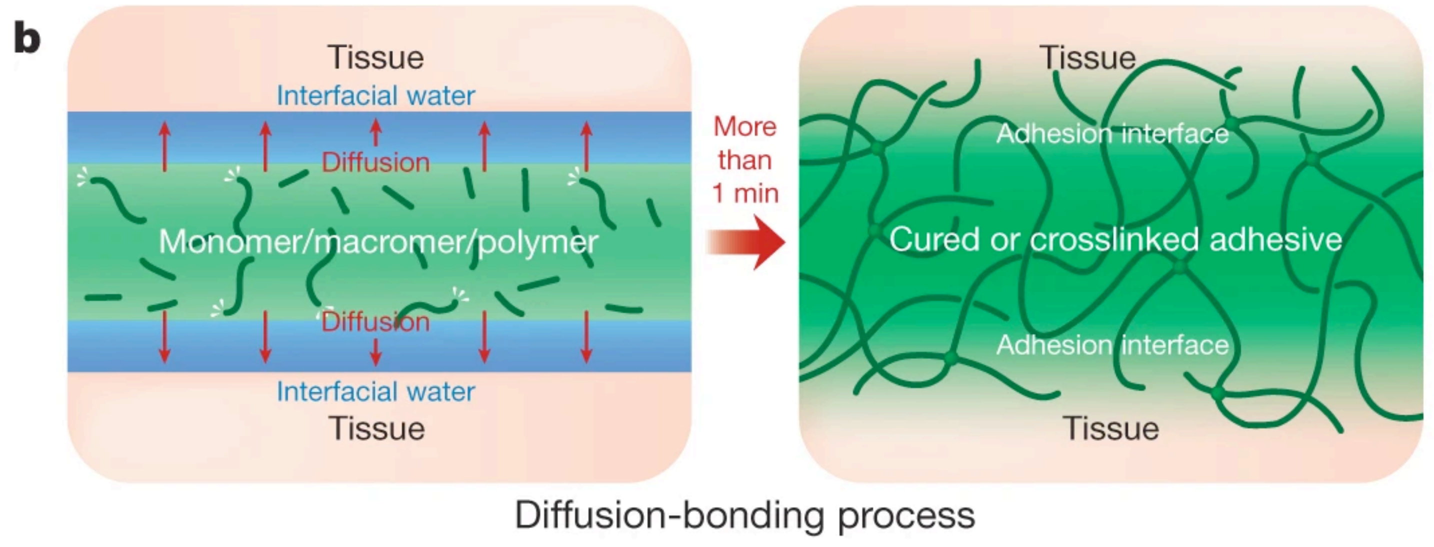
Barnacales

→ **Bio-inspired approach?**

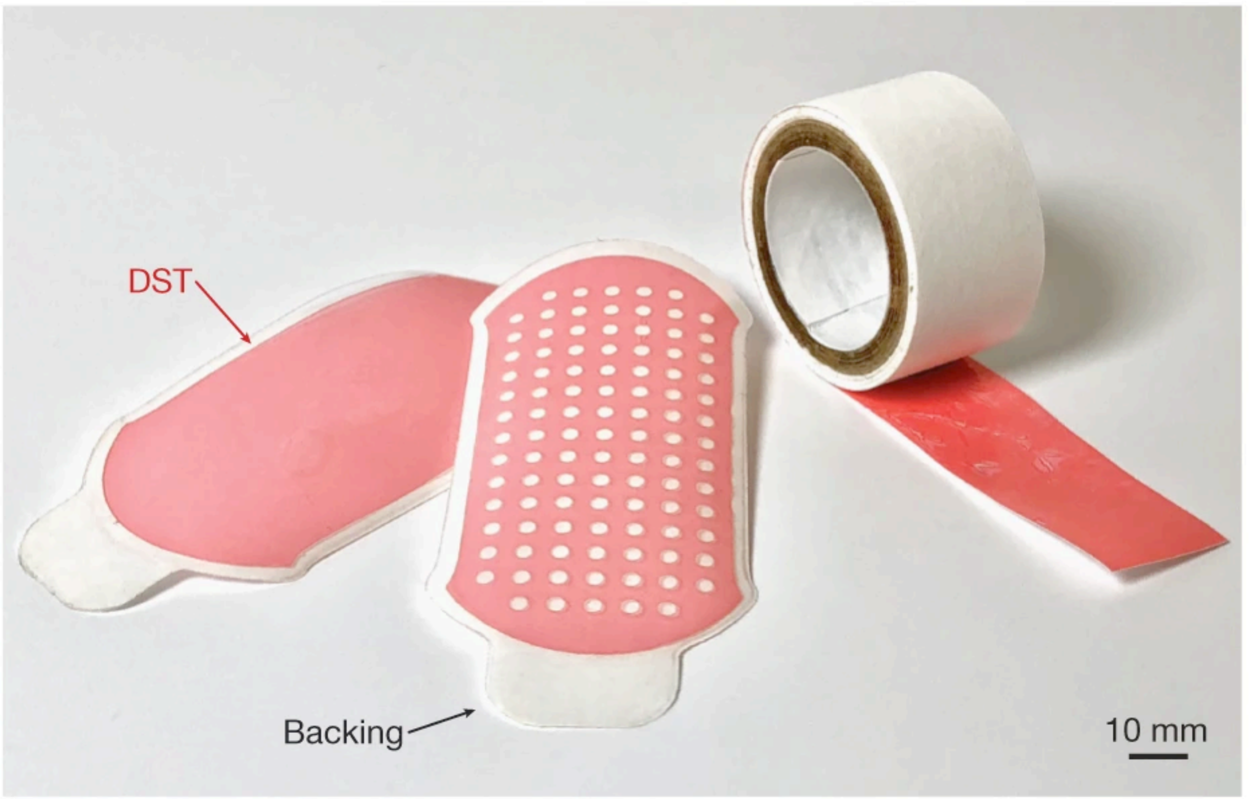
An davanced hydrogel-based solution

A tape drains water and sticks simultaneously

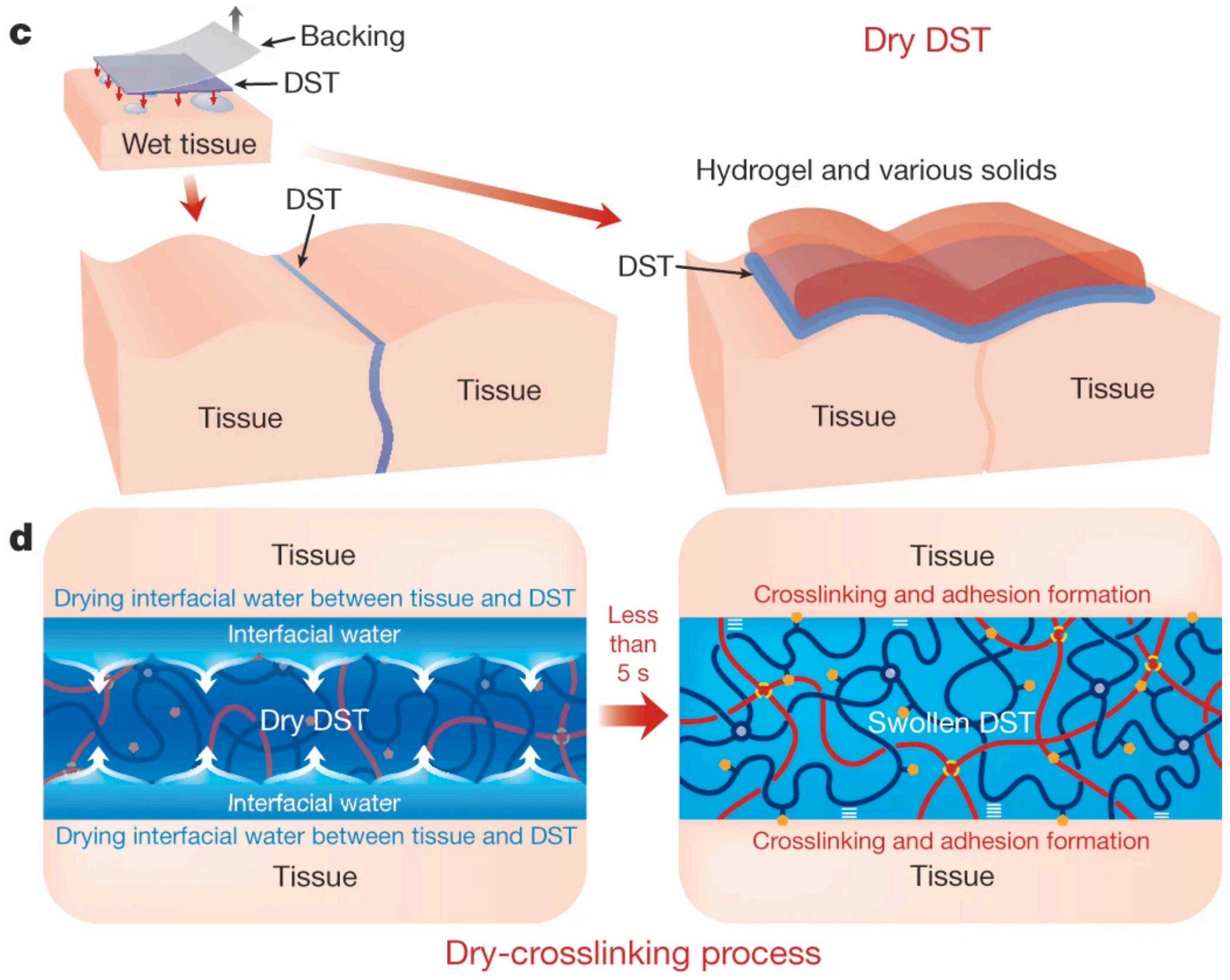
Classic adhesive



Dry double sided tape (DST)



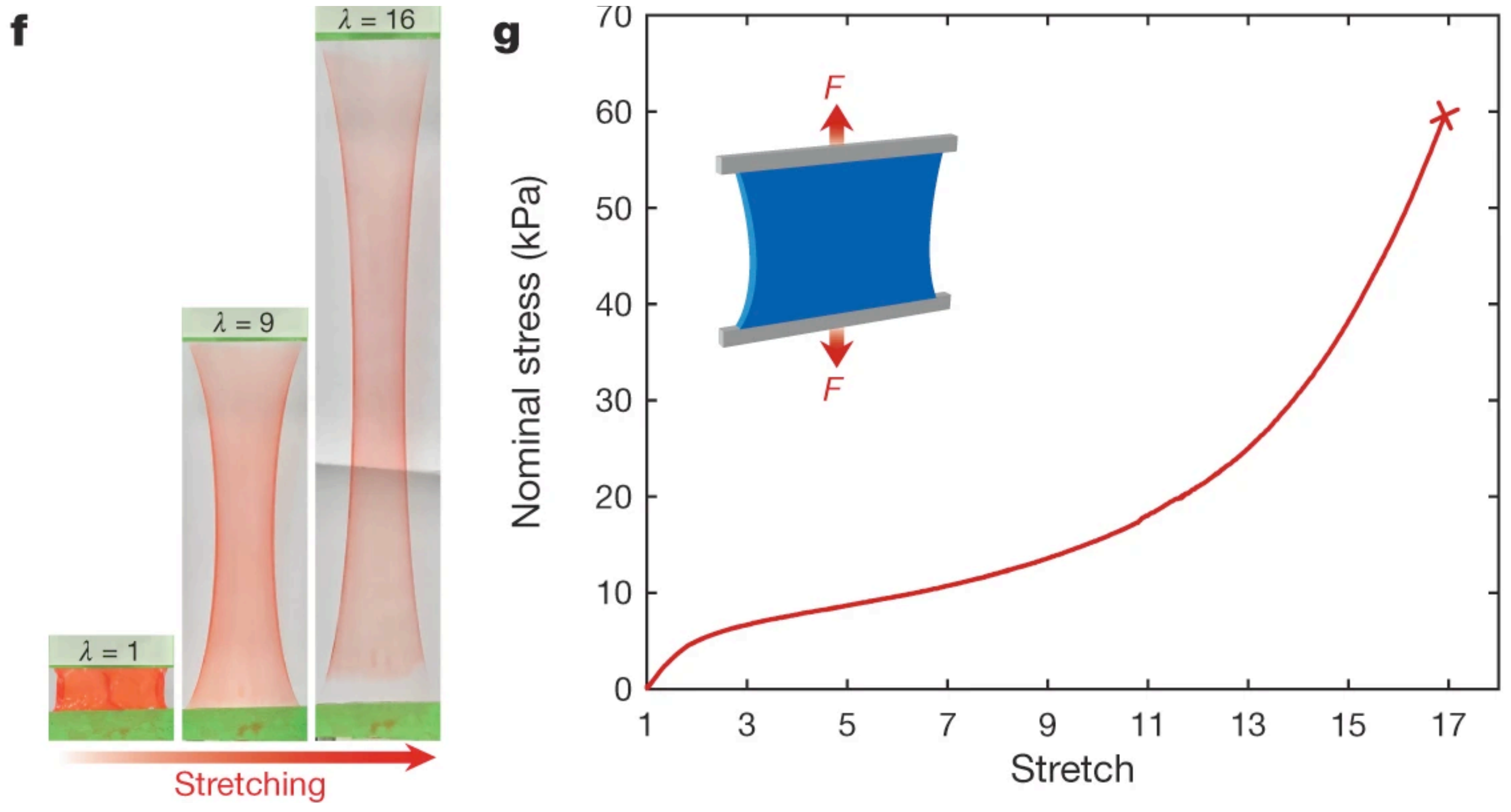
Yuk 2019



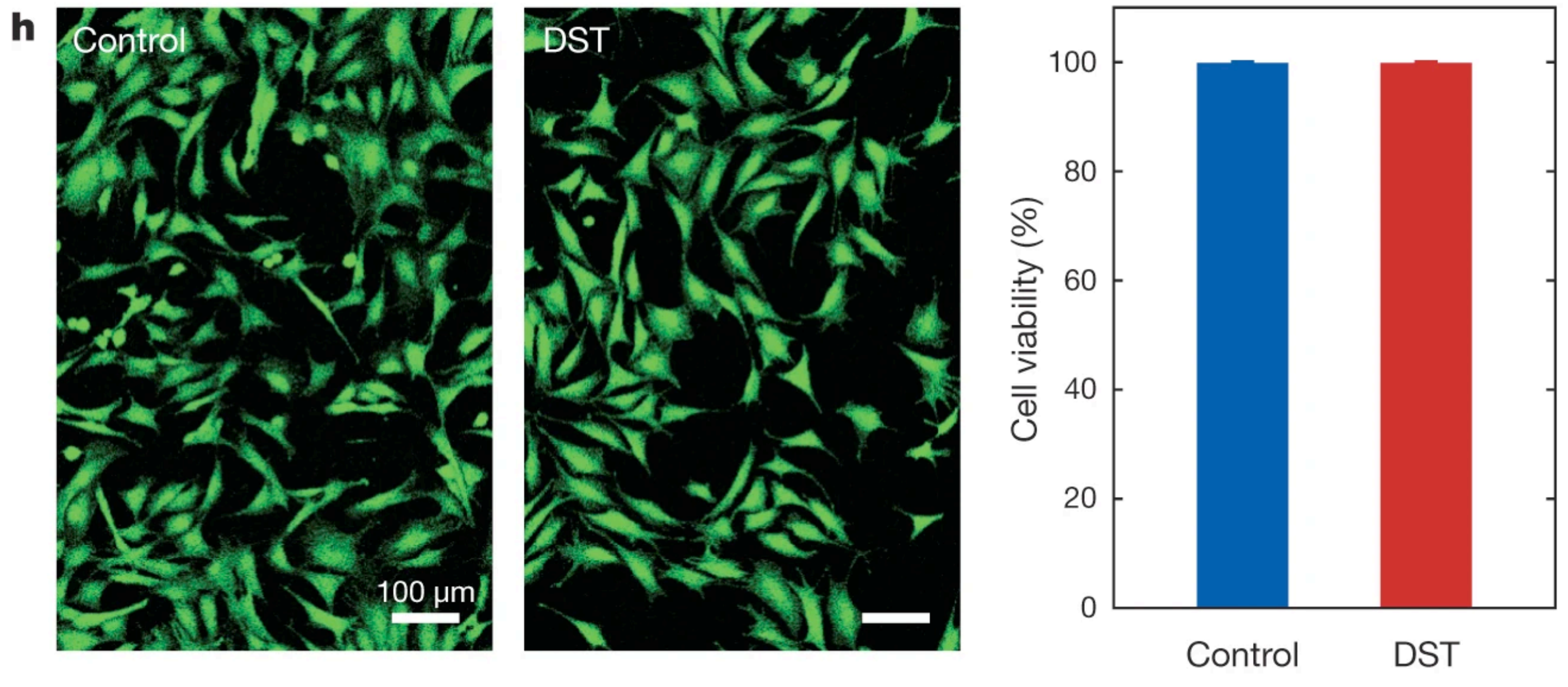
Composite hydrogel:
one dries the surface (absorbs water)
the other crosslinks with surface

mechanics, stability and cytocompatbility

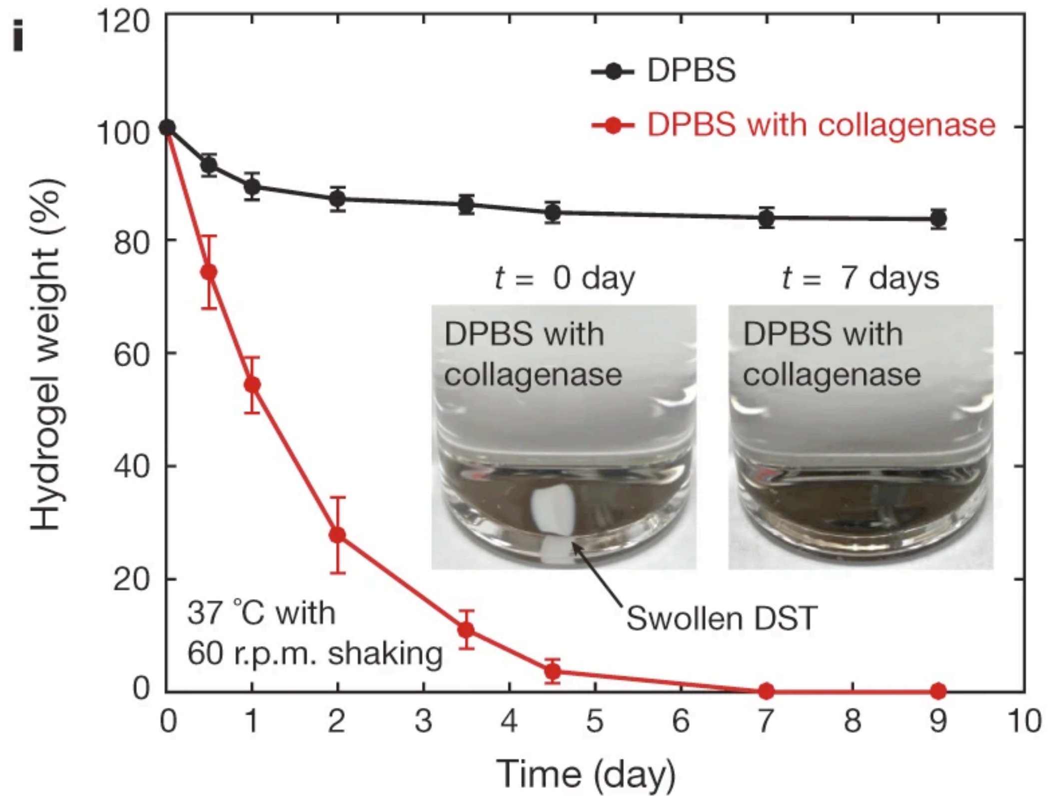
Tensile properties



Cytocompatibility



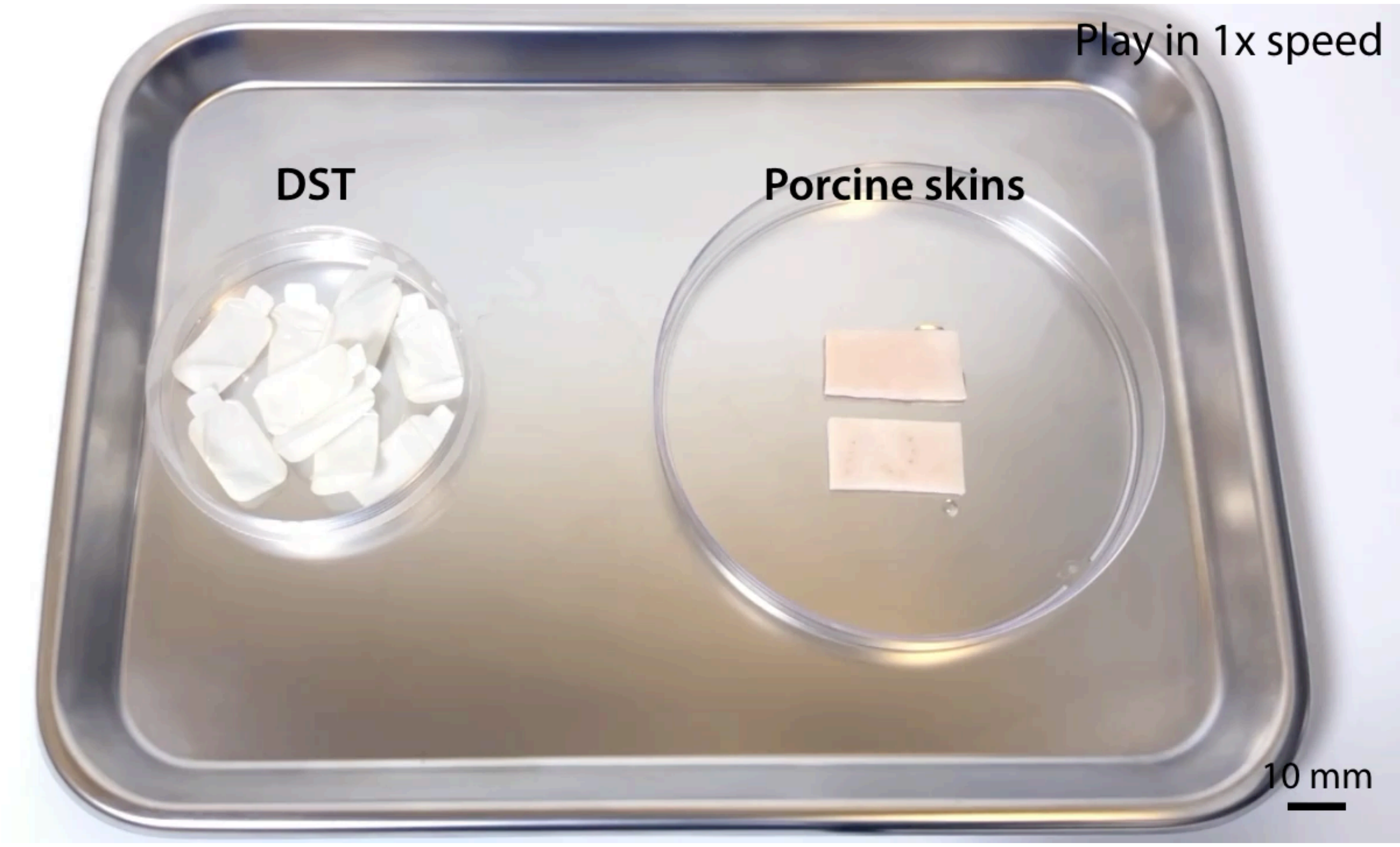
Stability and degradation

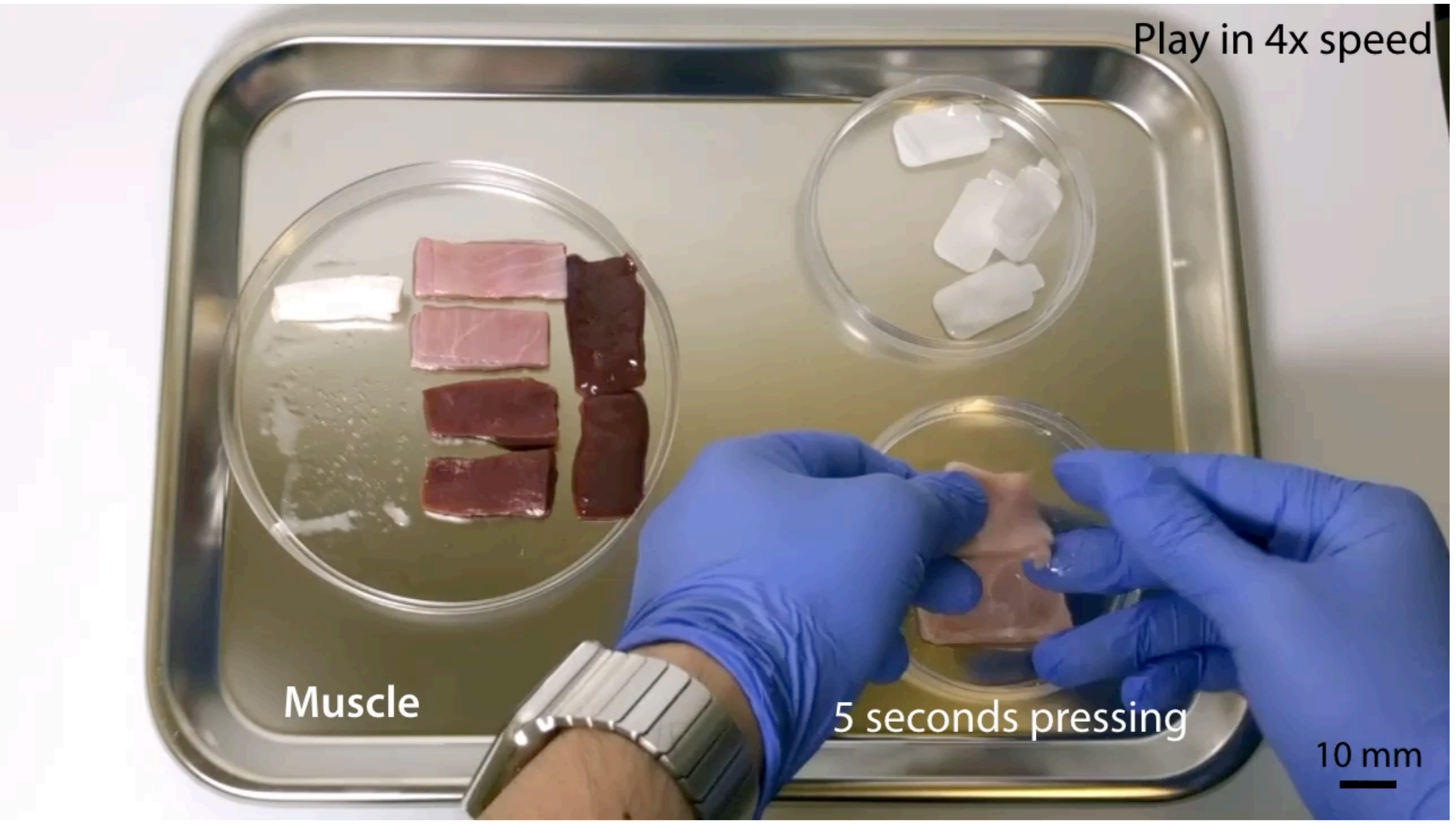


Yuk 2019

ex vivo validation

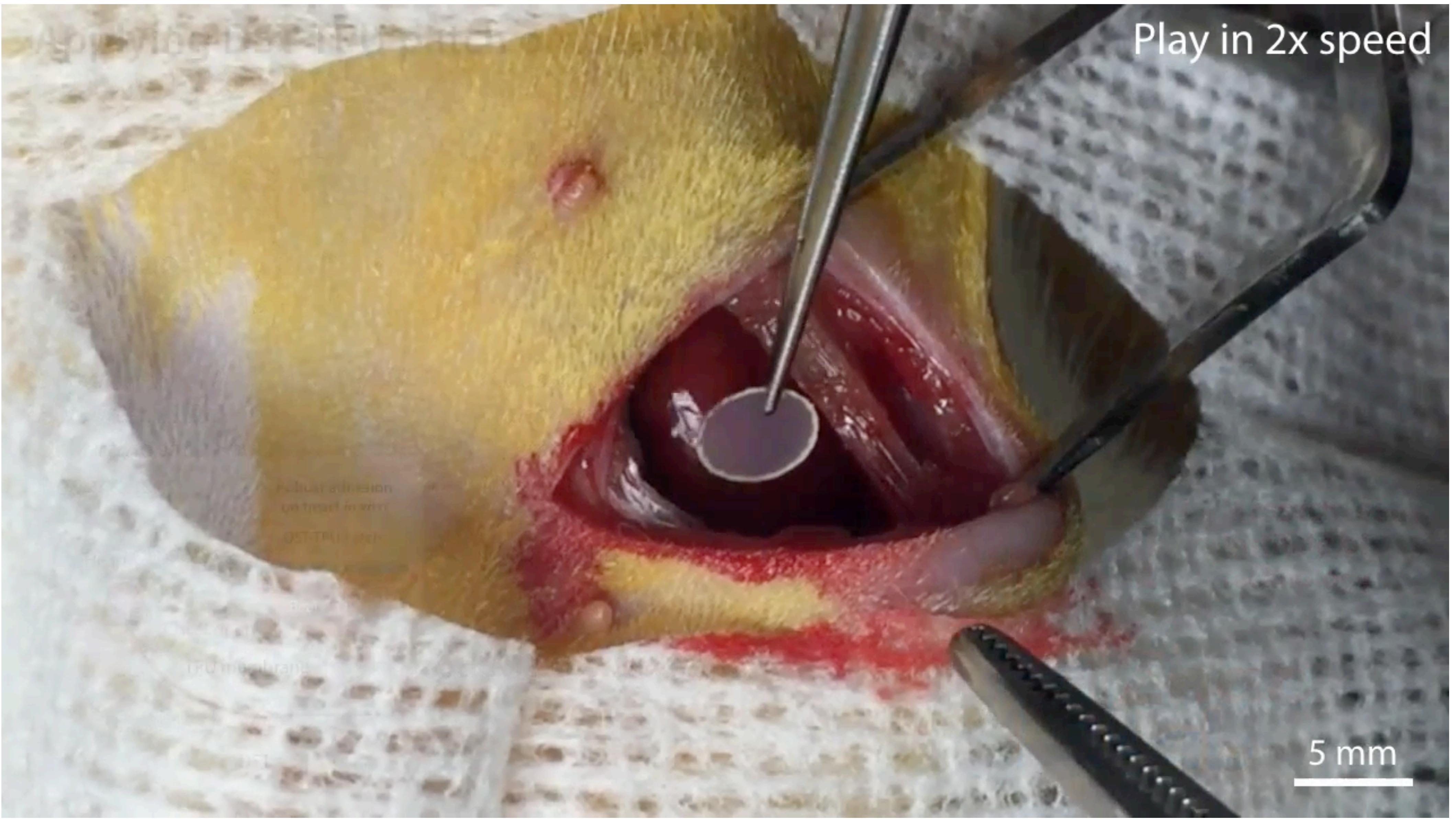
adhesion strength measurements



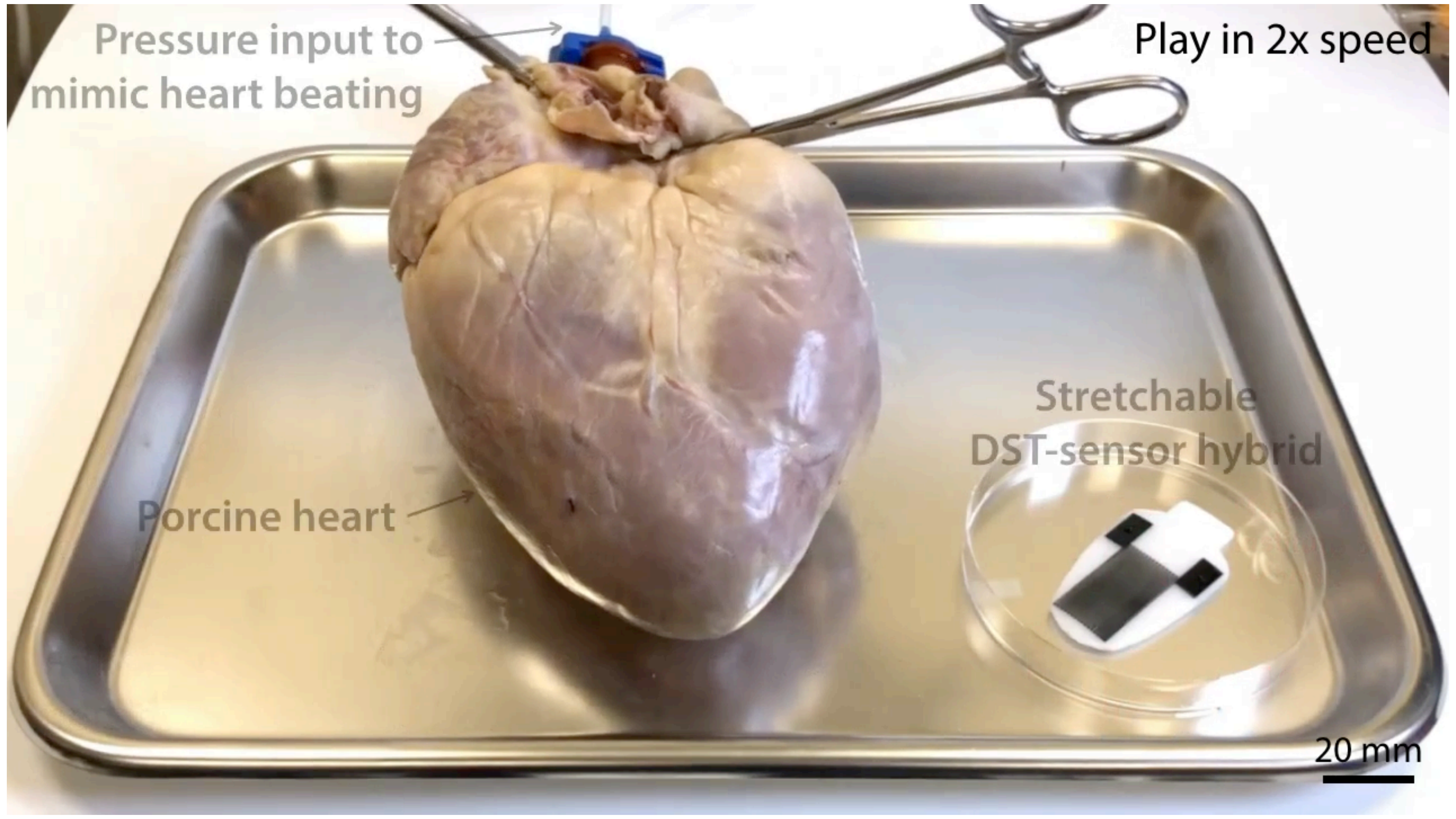


Yuk 2019

in vivo validation and application



Application: sensor integration



→ SanaHeal

Questions?