AWP 2-4 – Polymer Chemistry

Polymers in Life Science – E) Regenerative medicine & implants

University of Potsdam

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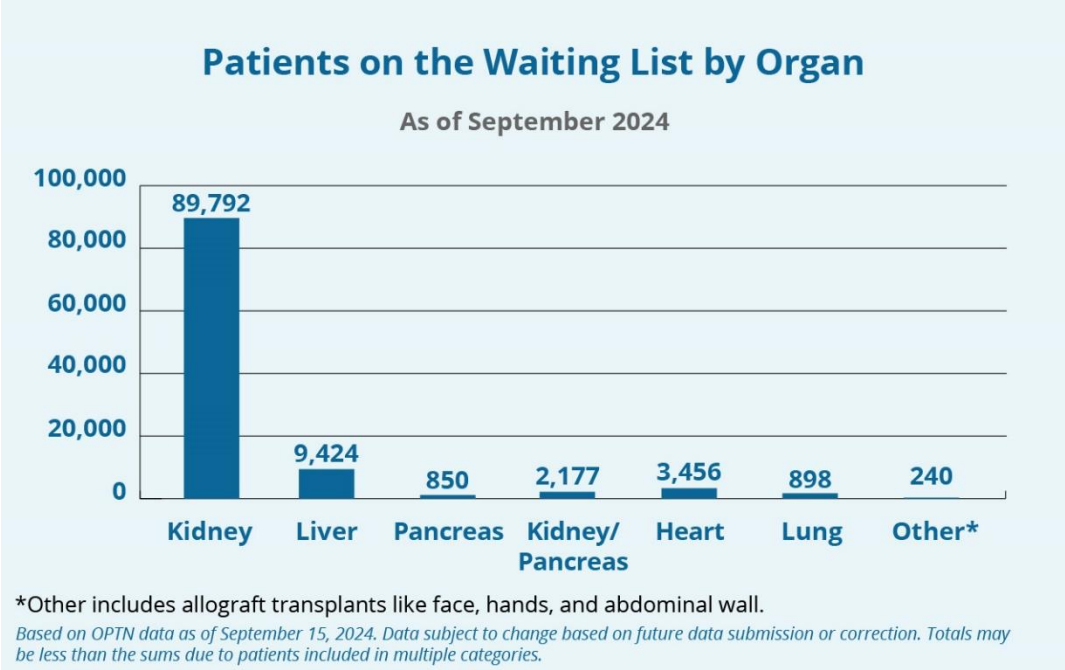
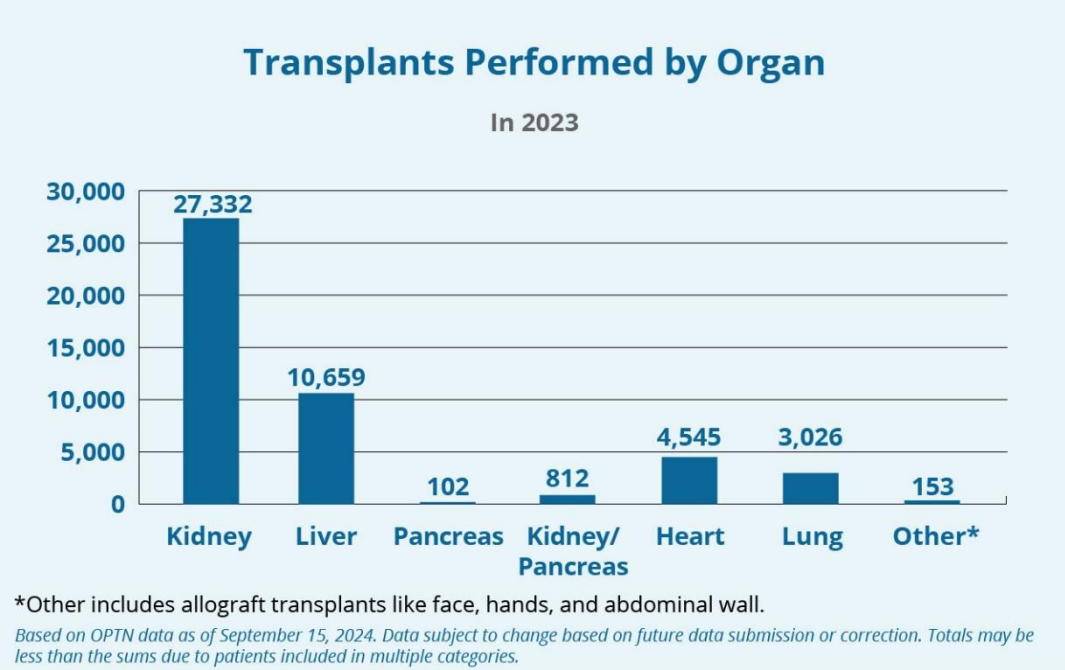
Summer term 2025

Background

- Long waiting lists on transplants
- Also long waiting times and unclear time line!
- Below: some numbers from the US





https://www.organdonor.gov/learn/organ-donation-statistics

Transplantation

- Successful transplantation of bone, soft tissue, and corneas in the 20th century
- 1954 first successful kidney transplant
- 1960s successful transplantation of pancreas/kidney, liver, isolated pancreas & heart
- Transplant surgery success continued into the 1980s with successful heart-lung, single lung, double lung, living-donor liver, and living-donor lung transplants
- Problems:
  - Eventual rejection of foreign organs by immune system
  - Immune suppressive medication necessary
  - Scarcity of available transplants

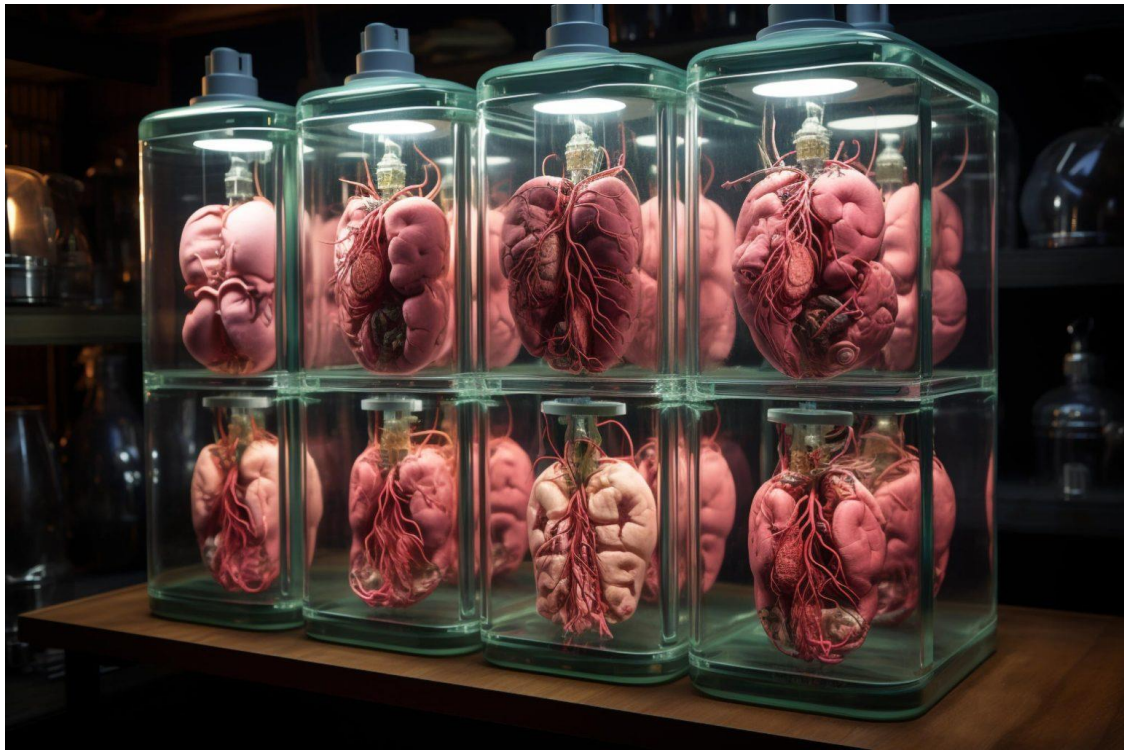
Kidneys from genetically modified pigs

- Progress in xenotransplantation: pig organs are seen as a promising solution to the organ shortage.
- Genetic modification: Pigs are being genetically modified to minimise human rejection.
- Early success: Recently, pig hearts and kidneys have been successfully transplanted into humans.
- Challenges: Immune reactions, viral risks (e.g. porcine endogenous retroviruses) and ethical concerns remain.
- Future prospects: Research is focusing on CRISPR technology and immunosuppressants to improve long-term acceptance.

https://www.nature.com/articles/d41586-025-00368-w?utm_source=Live+Audience&utm_campaign=8074867418-nature-briefing-daily-20250205&utm_medium=email&utm_term=0_b27a691814-8074867418-50100996

3D printed organs?

- Can we just grow new organs in a dish??



- Not quite, but research is ongoing

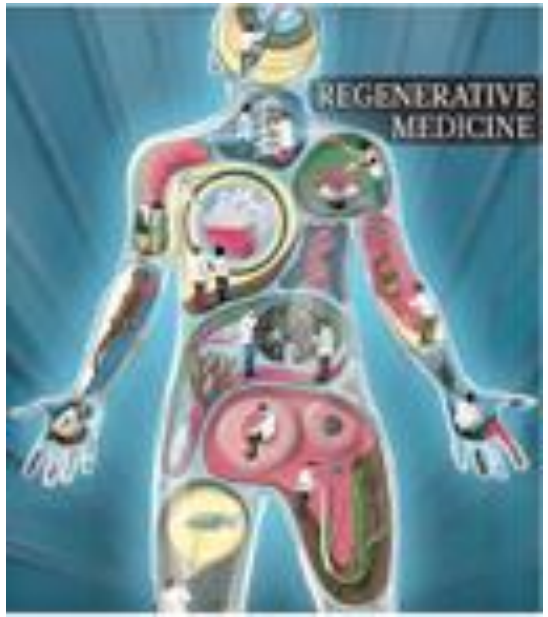
https://scitechdaily.com/japanese-scientists-construct-complex-3d-organoids-with-ingenious-device/

Motivation

Regenerative medicine is concerned with the restoration, repair or replacement of damaged or diseased cells, tissues or organs.

Key fields and technologies

- Stem cell therapy: Using embryonic or adult stem cells to regenerate tissue and organs.
- Tissue engineering: Mixing cells, biomaterials and bioactive molecules to create tissue and organs.
- 3D bioprinting: Printing living tissue or organ structures using bioinks from cells and biomaterials.
- Artificial organs: development of biohybrid or completely artificial organs
- Biological drugs and gene therapy: genetic modifications or growth factors
- Nanotechnology: nanomaterials for cell stimulation, drug release and tissue integration.
- Immunomodulation: influencing the immune system to promote healing



More than science...

1997 Joseph Vacanti and his team includes an image of what appears to be a human ear growing out of a mouse's back. The team hopes that its research will lead to lab-grown ears for people whose ears are damaged. But the image sparks a backlash from animal rights activists and people who find the image shocking.

doi:10.1038/540S50a

„Construction“ of Biology

Cells

- the smallest structural and functional unit of an organism, which is typically microscopic and consists of cytoplasm and a nucleus enclosed in a membrane

Tissue

- distinct types of material of which animals or plants are made, consisting of specialized cells and their products

Organ

- collection of tissues joined in a structural unit to serve a common function.

System

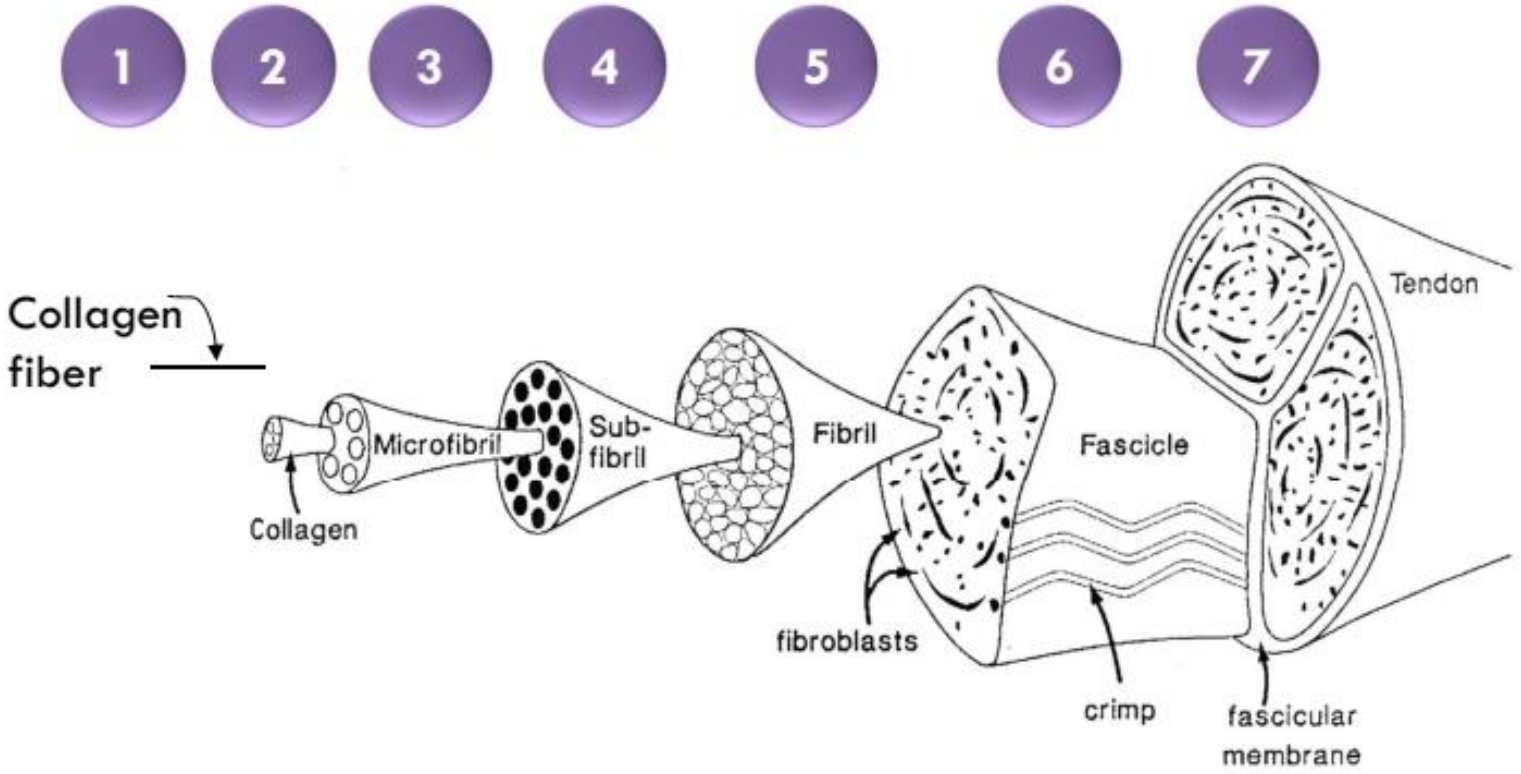
- Functional groups of organs

Organism

- The basic living system, a functional grouping of the lower-level components, including at least one cell

Complexity

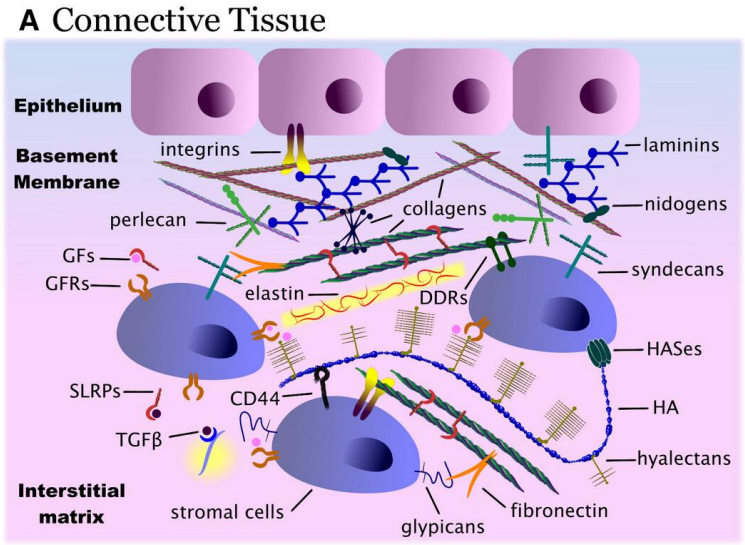
- 7-10 levels of structural organization can be defined in a tissue or organ



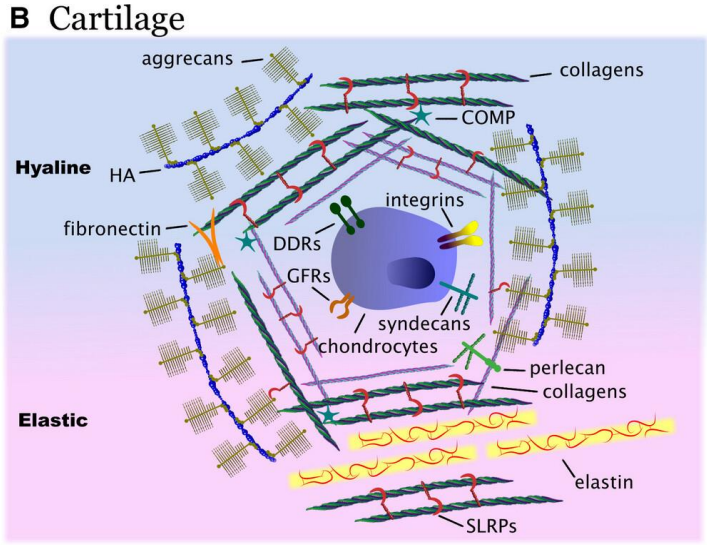
Organization of the tendon

Extracellular matrix

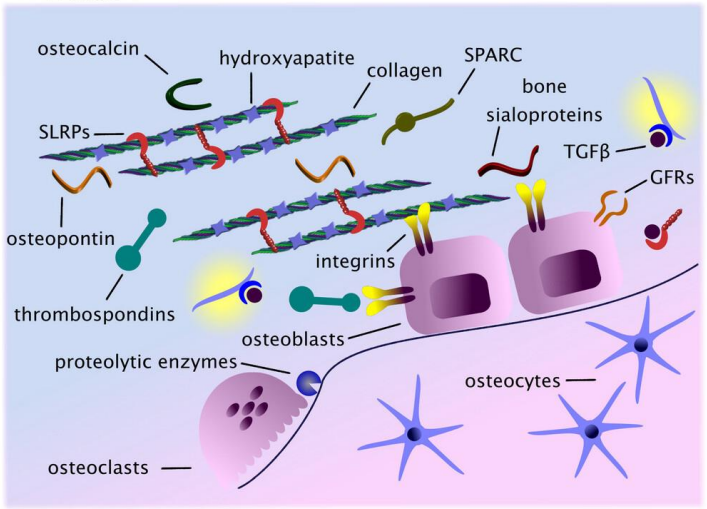
- Network of proteins and poly(saccharide)s
  - Collagen
  - Fibronectin
  - Glycoproteins
  - Proteoglycans
  - Glycoaminoglycans
- Key properties:
  - Mechanical modulus/viscosity
  - Growth factor concentration
  - Binds water & lubricates



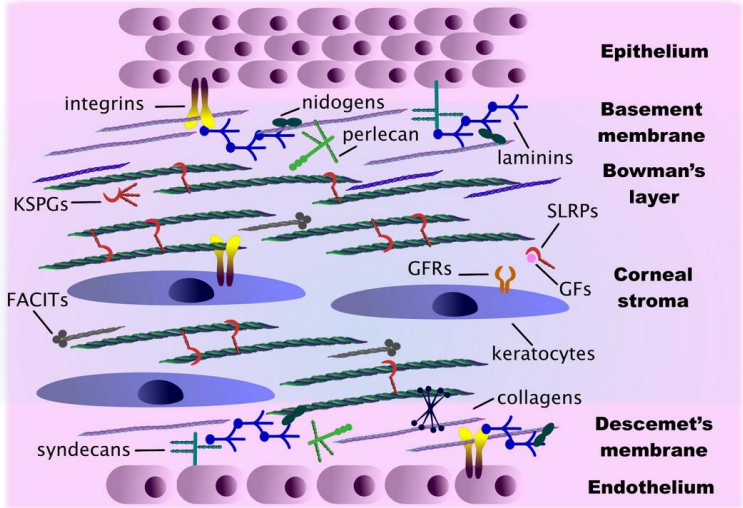
Connection, support, nourishion



Mechanical support, viscoelasticity, lubrication



Durable, strong, stiff sctucture with low elasticity for shock absorption

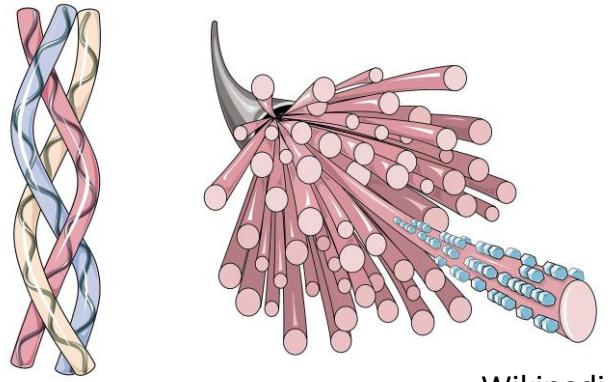


Transparency, refraction

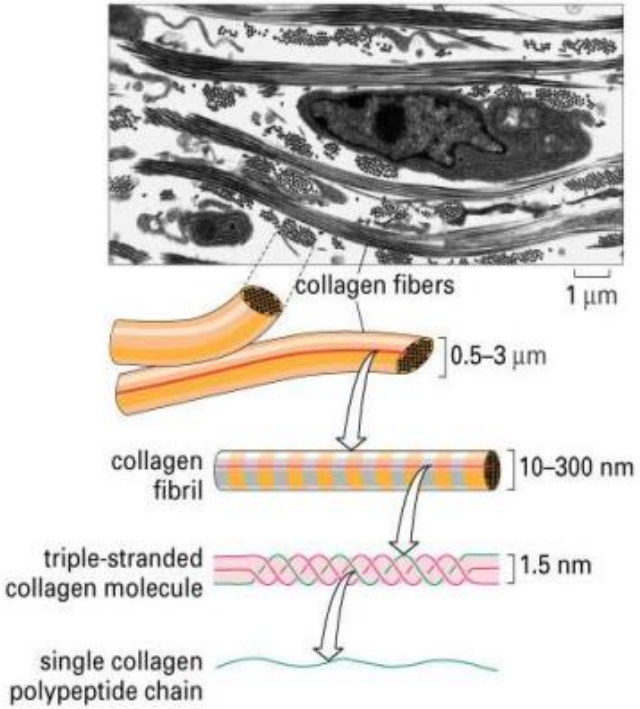
Components of the ECM

Collagen

- Protein (25% of Protein mass in human body)
- Very important in bones, tendons, ligaments and skin
- Degree of mineralization determines rigidity
- Procolagen is produces in the cell (e.g. fibrobalsts) and shipped outside by exocytosis
- There it is cleaved, froms fibers which are chemcially cross-linked



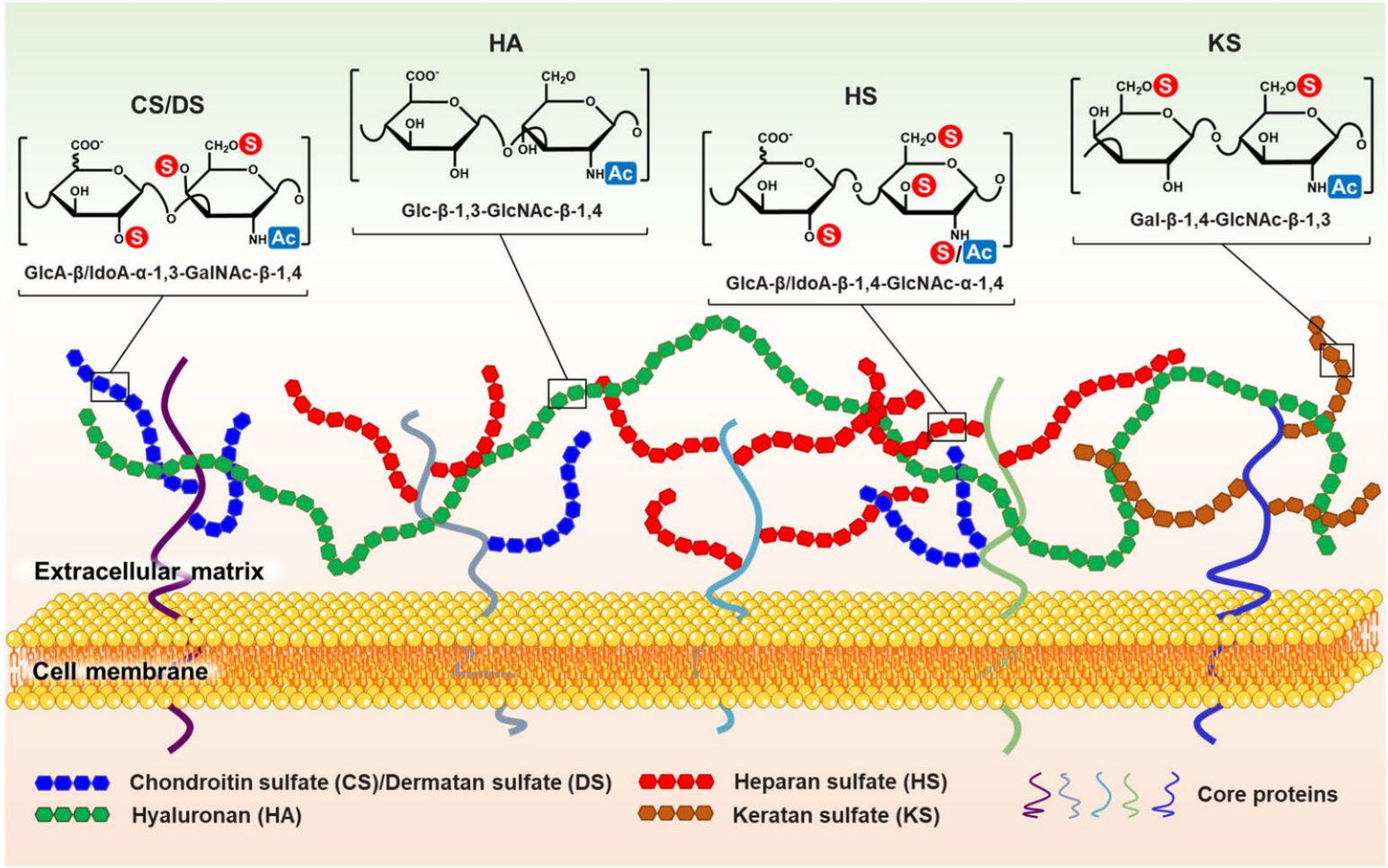
Wikipedia.de



Components of the ECM

Glycoaminoglycans (GAG)

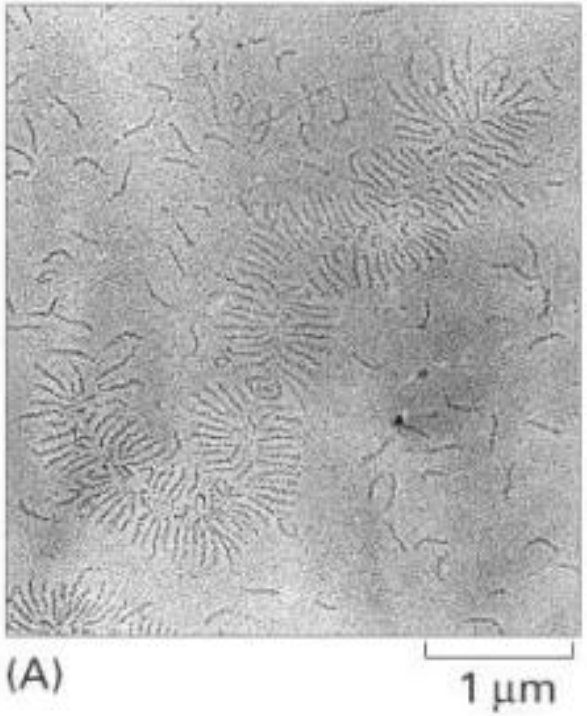
- Negatively charged polysaccharides
- Example hyaloronic acid

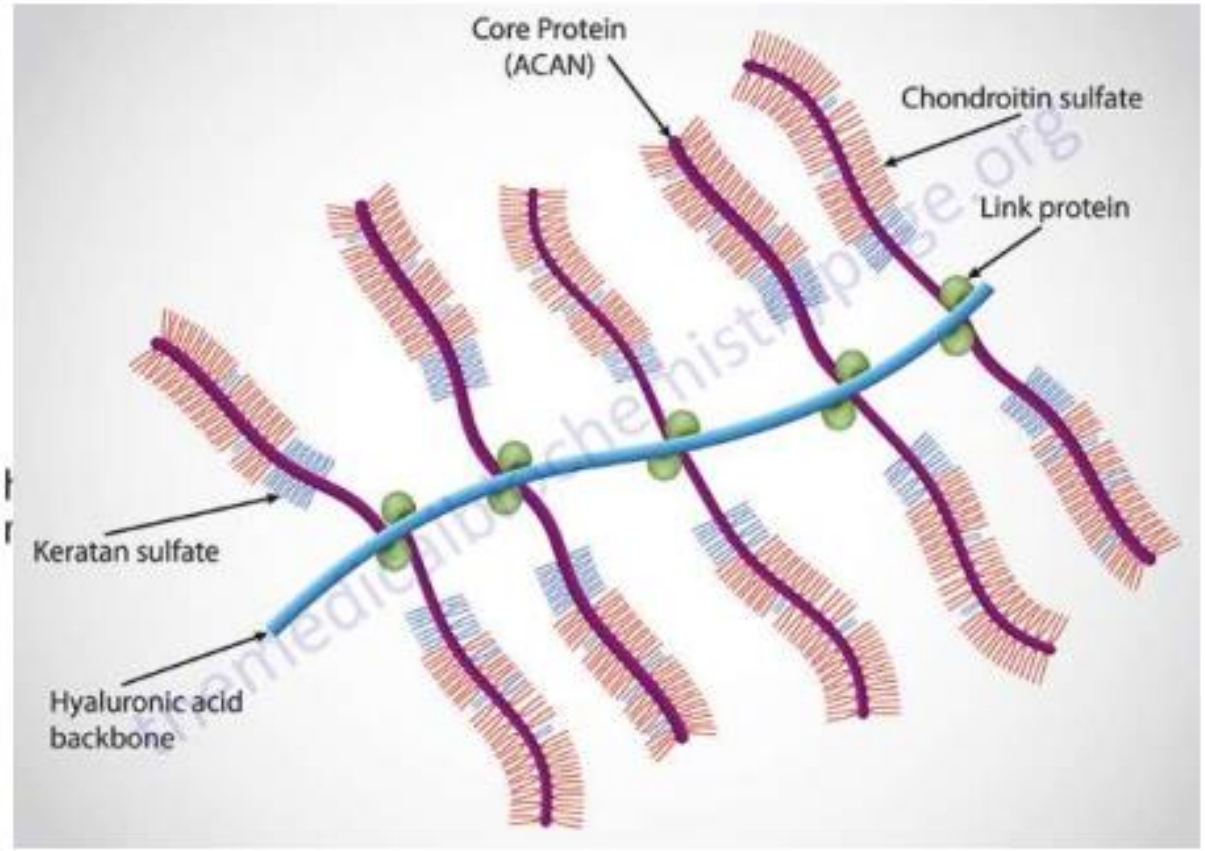


Wang, Q.; Chi, L. The Alterations and Roles of Glycosaminoglycans in Human Diseases. *Polymers* **2022**, *14*, 5014. https://doi.org/10.3390/polym14225014

Proteoglycans

- Proteins linked to the side chain of GAG

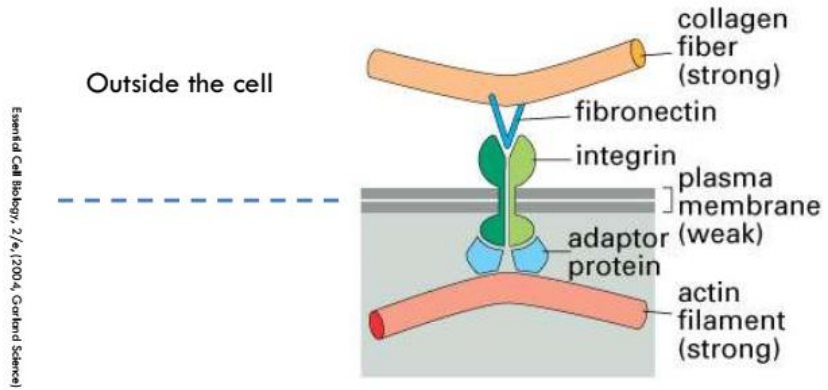


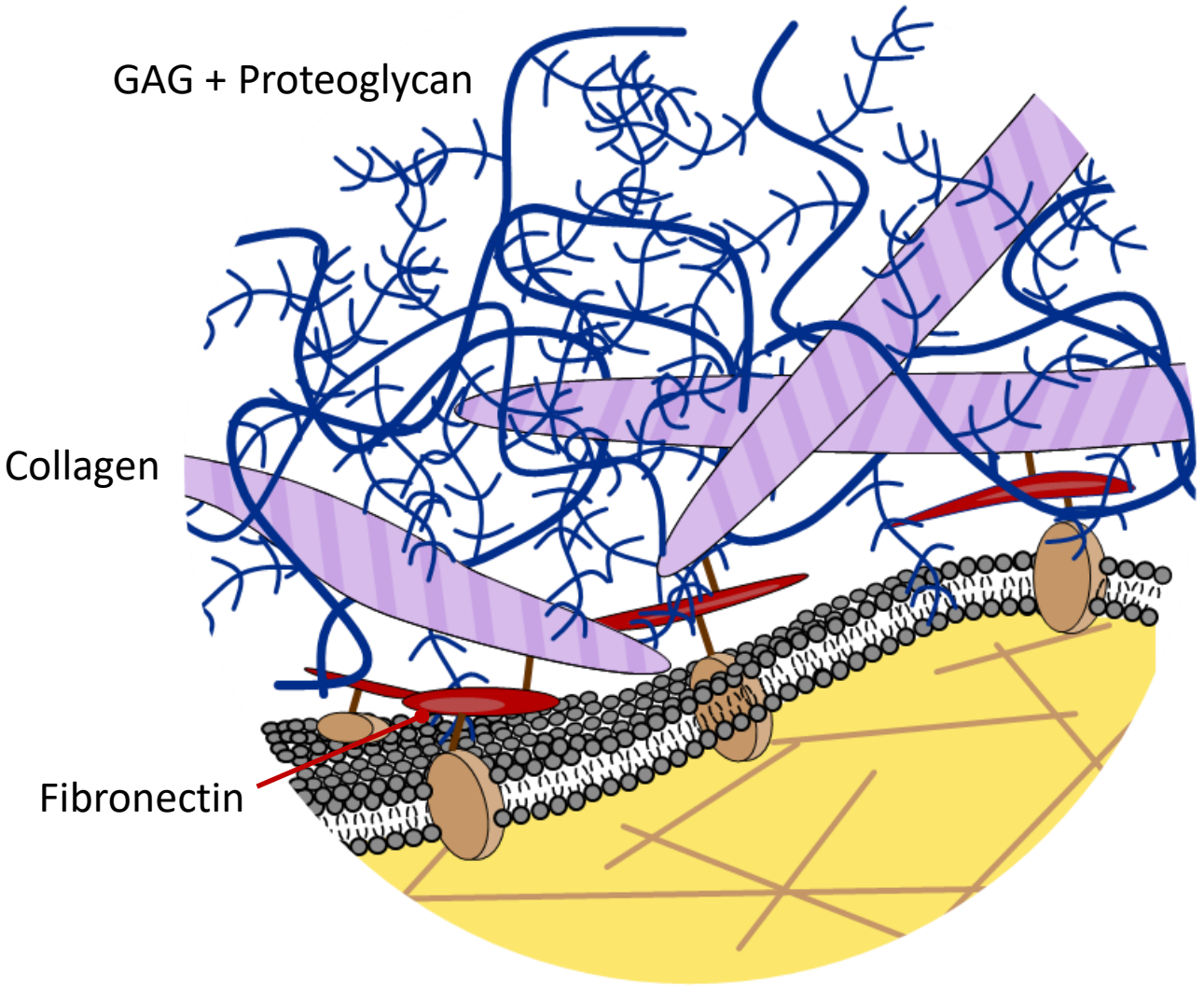


Essential Cell Biology, 2/e, (2004, Garland Science)

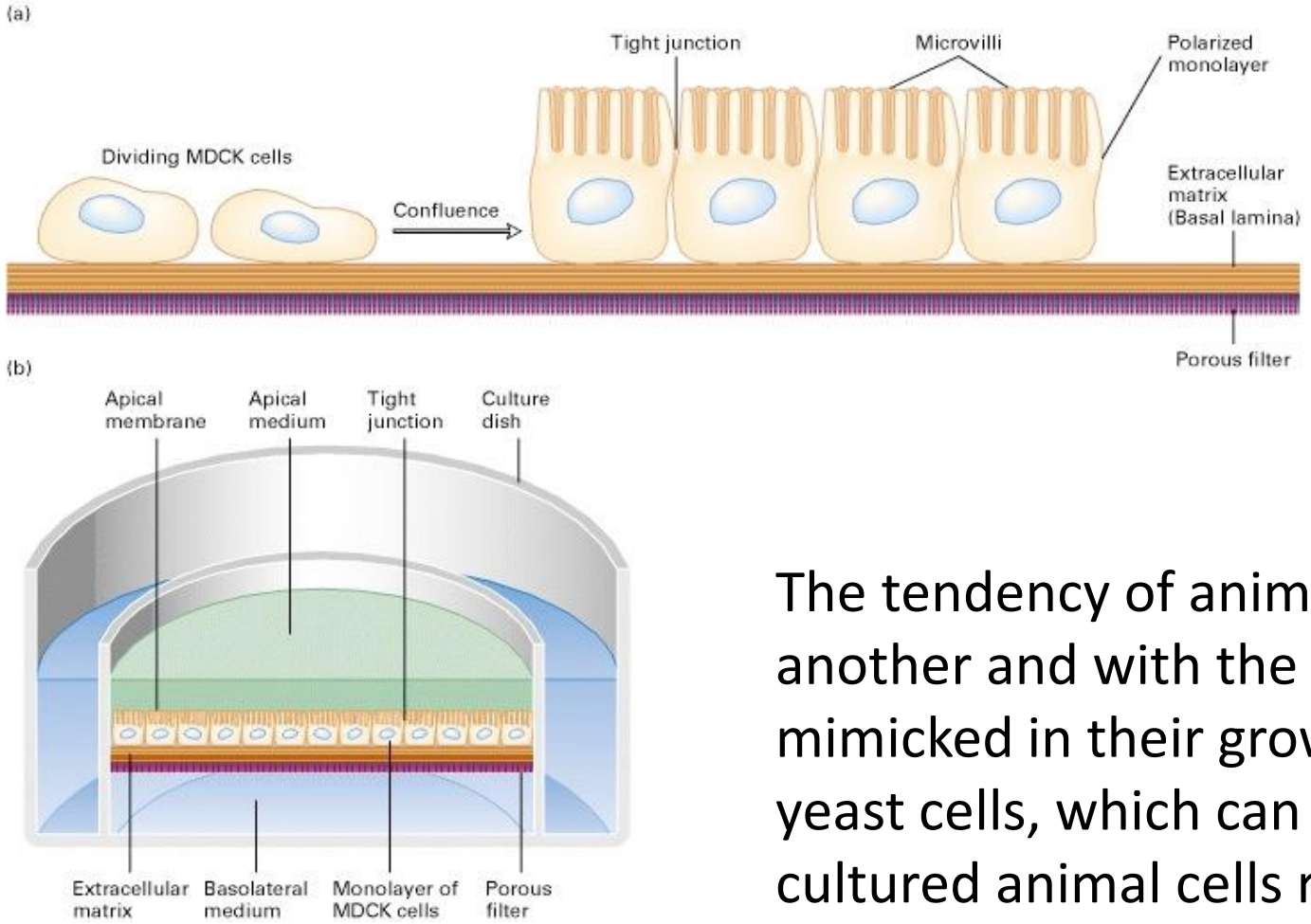
Fibronectin

- High molar mass glycoprotein
- Binds to cellular receptors (integrins) and connects them to the ECM
- Key role in cell migration, growth, differentiation and wound healing





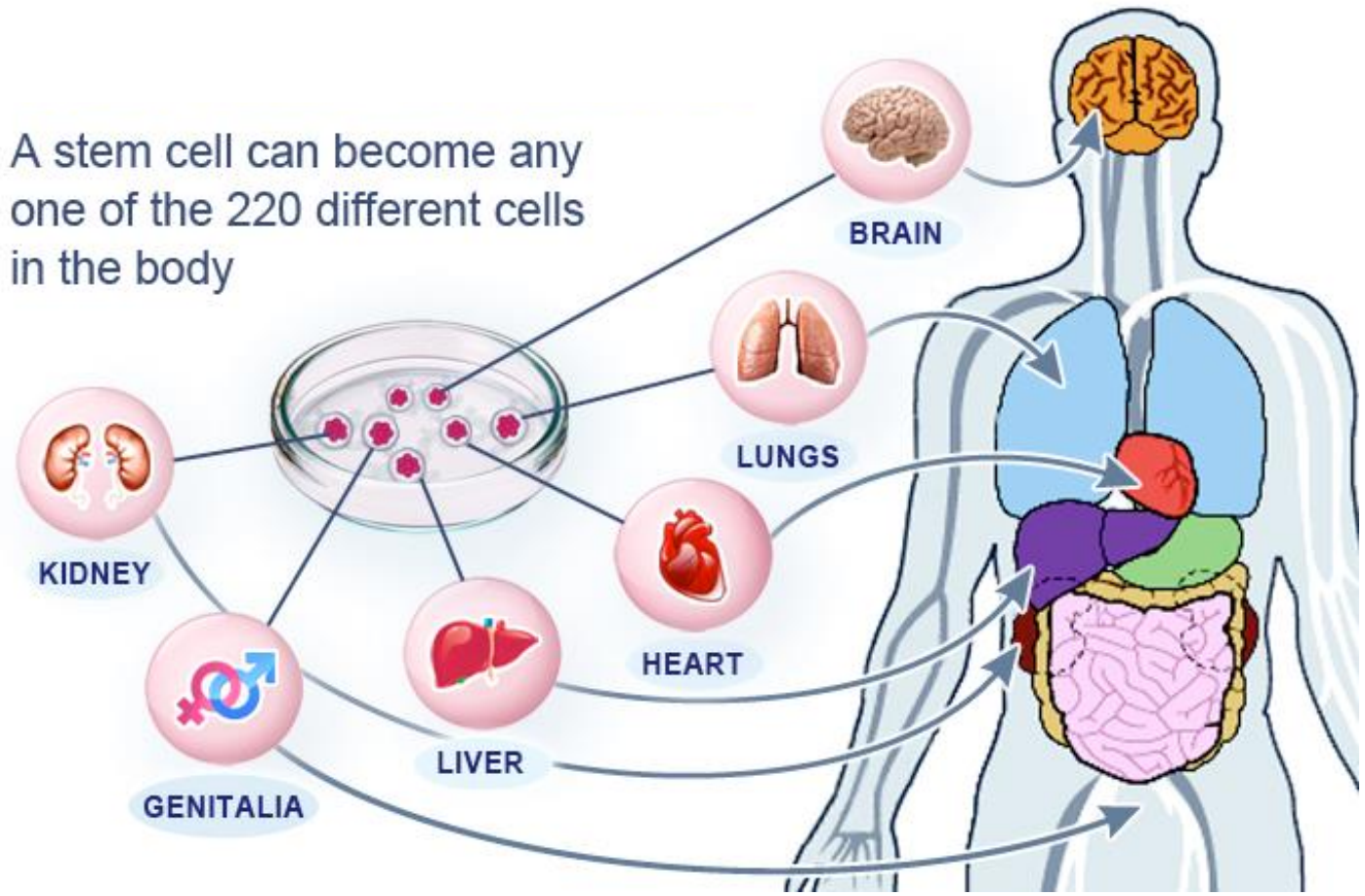
Cells need a „home“



ECM has a key role in the cellular environment!

The tendency of animal cells in vivo to interact with one another and with the surrounding extracellular matrix is mimicked in their growth in culture. Unlike bacterial and yeast cells, which can be grown in suspension, most cultured animal cells require a surface to grow on.

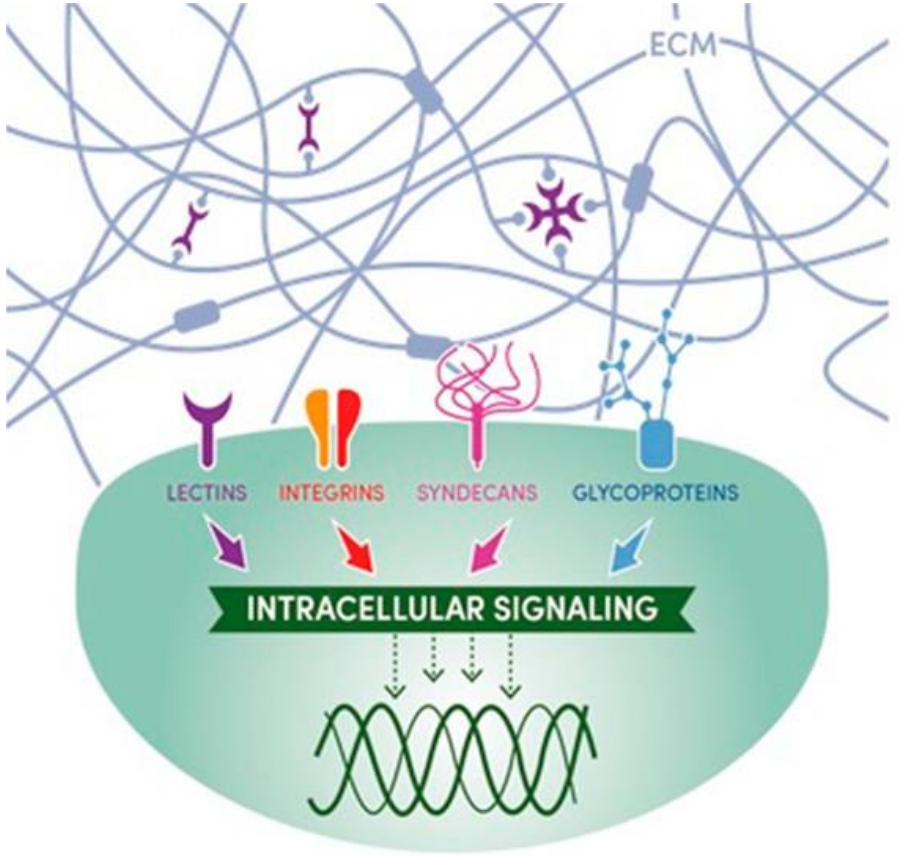
Stem cells

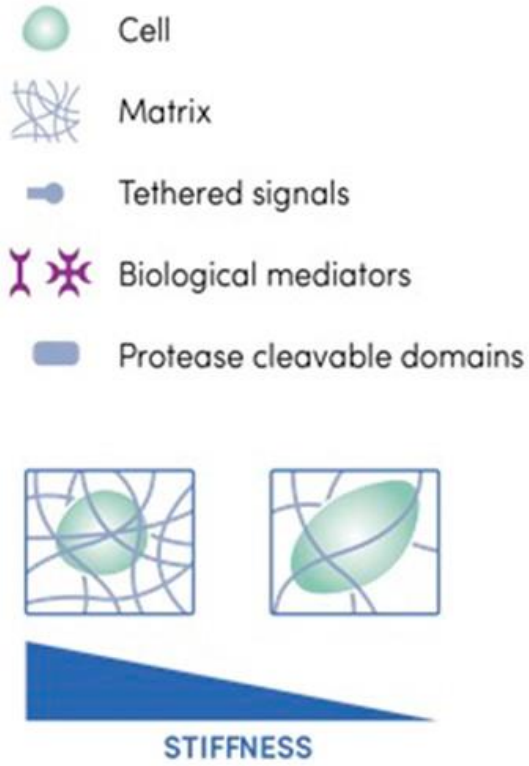


- Stem cells are undifferentiated biological cells that can differentiate into specialized cells.
- Induced pluripotent stem cells (iPS cells) are a type of pluripotent stem cell that can be generated directly from adult cells.
- 4 transcriptional factors (Myc, Oct3/4, Sox2 and Klf4) were sufficient to convert mouse embryonic or adult fibroblasts to pluripotent stem cells

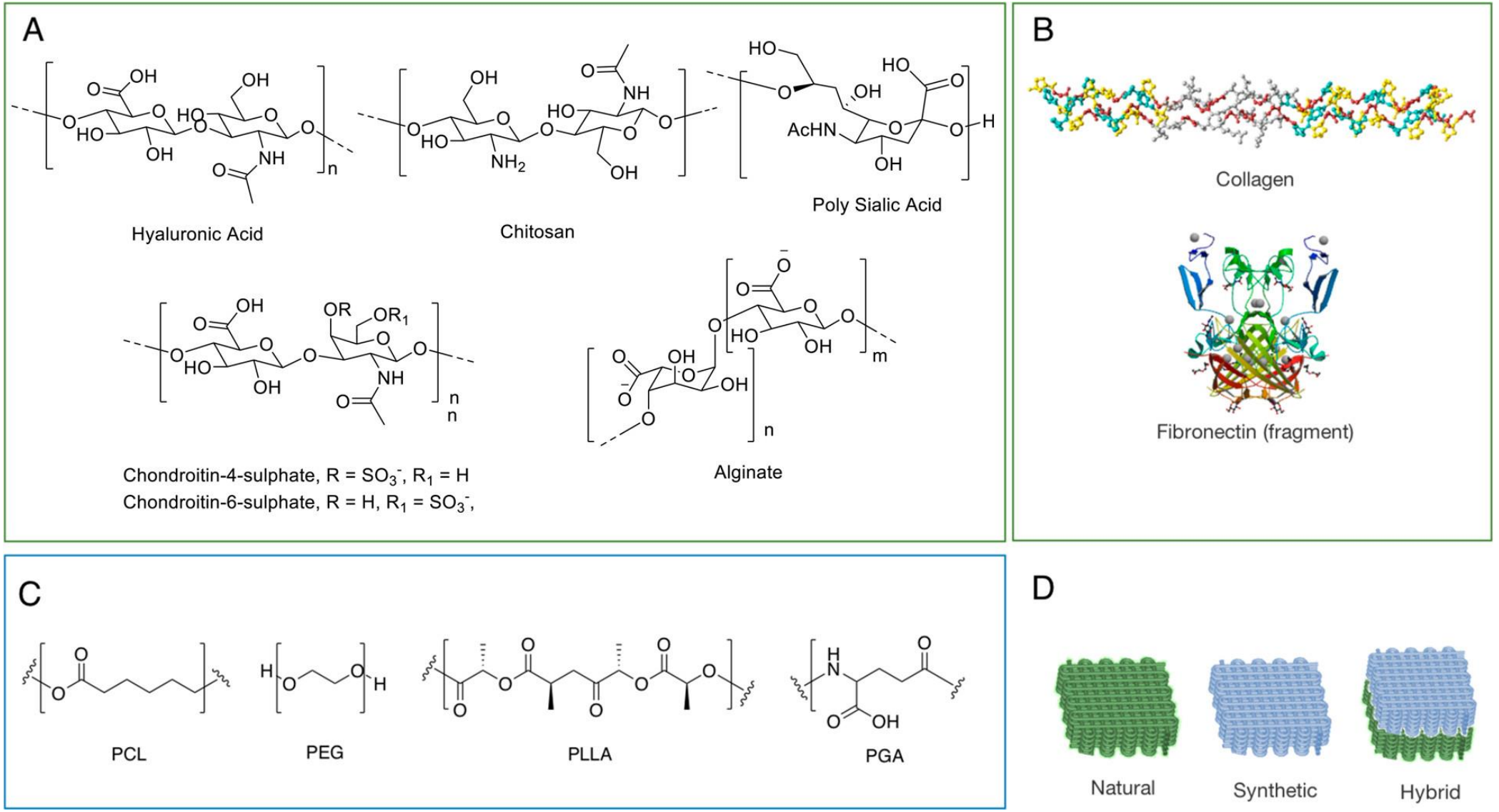
Cell Differentiation in the ECM

- ECM guides differntiation if stem cells based on
- mechanical properties
- Mechanical stress
- Shape of niche
- Signaling ! (growth factors)

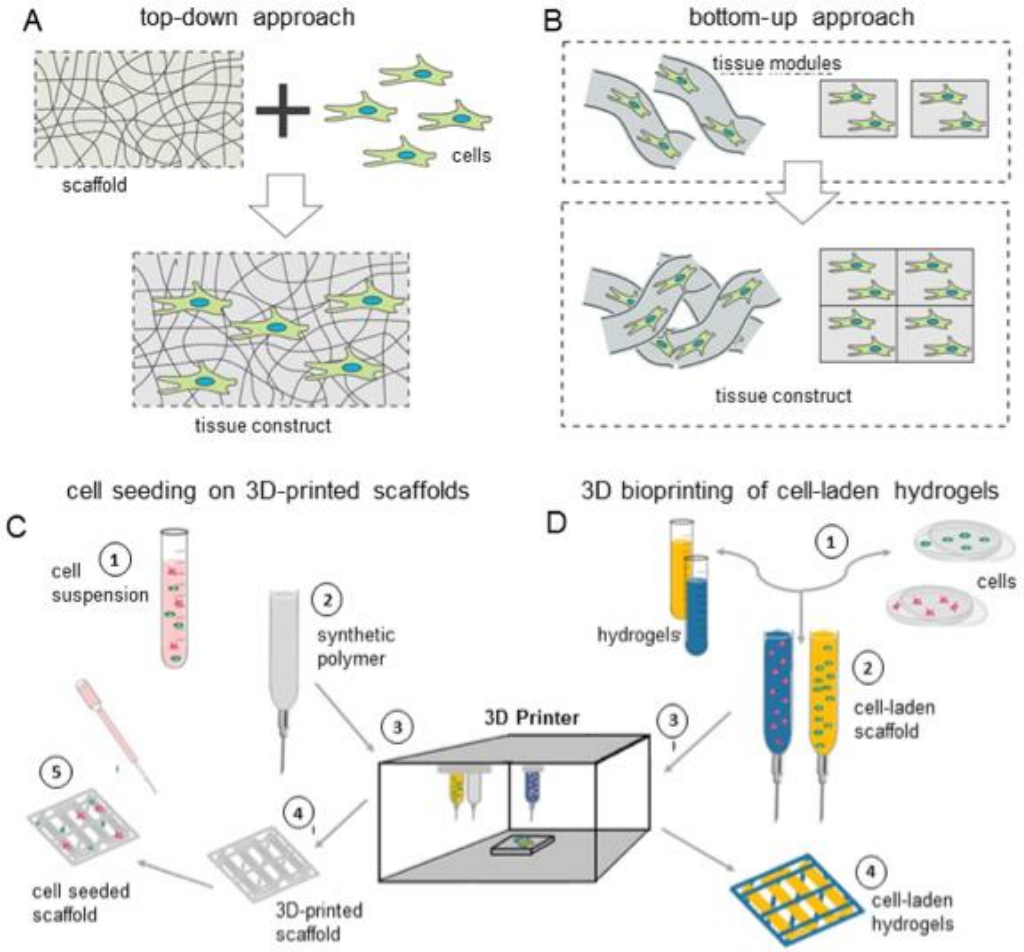


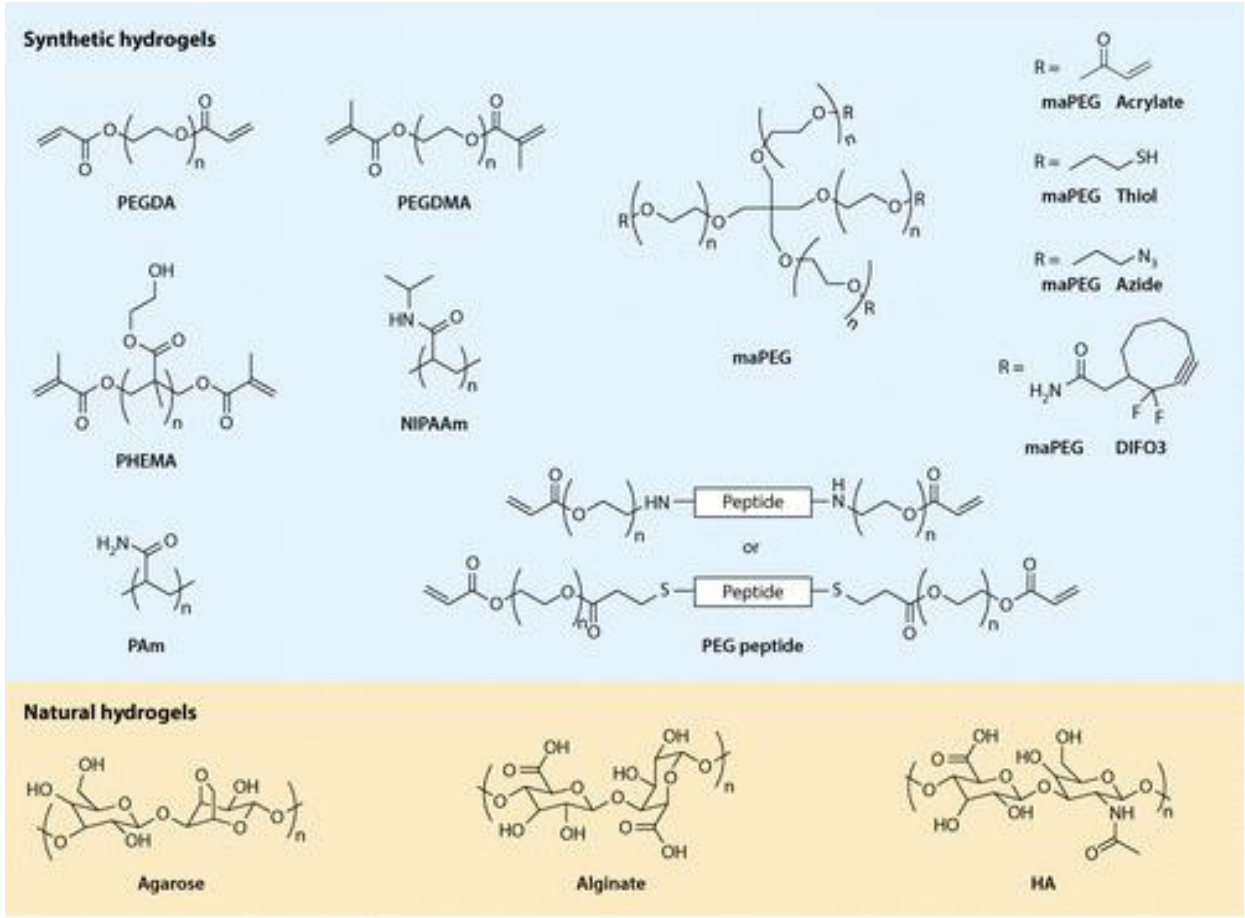


Natural or synthetic ECM?



Hydrogels for Reconstruction





Doi: 10.1002/adma.201606061 and Doi: 10.1146/annurev-bioeng-071813-105155