ETH zürich

Materials and Mechanics in Medicine HS 2019

Exercise 8 – Viscoelasticity

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Extracellular Matrix

- Cells are connected to this protein network (ECM)
- Vital in providing *biochemical* and -*mechanical* cues
- They help drive cell…

…migration

…proliferation

…differentiation

and guides wound healing and embryonic development!

Wound Healing

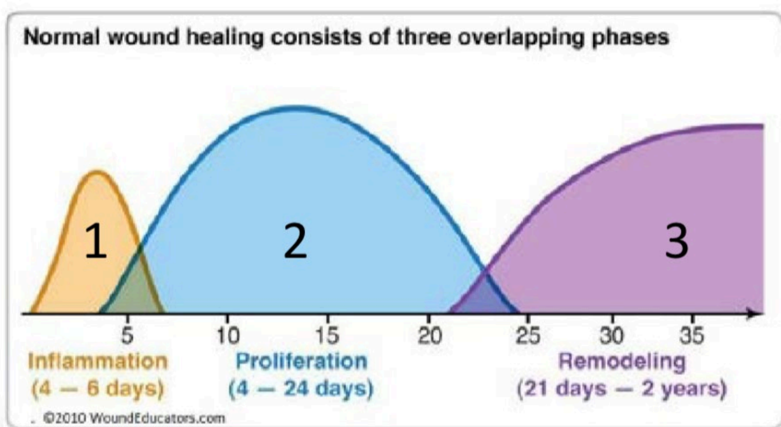
- Last week we had a quick look at these wound healing

(Phase 1): very temporary matrix scaffold (fibrin), stimulatory proteins to recruit vascular and other tissue related stem cells and immune cells.

(Phase 1-2): Granulation tissue forms

(Phase 1-3): Revascularization (vascular modeling) and vascular remodeling

(Phase 3): “Scar” tissue remodeling (toward “normal tissue”)



Collagen

- Most abundant protein in the ECM and human body
- Present in ECM as fibrillar proteins
- Give structural support to resident cells
- Many different subtypes of collagen for all the different types of structures they can form
  - Collagen Type-1, Type-2, Type-3 most common for load bearing in connective tissue

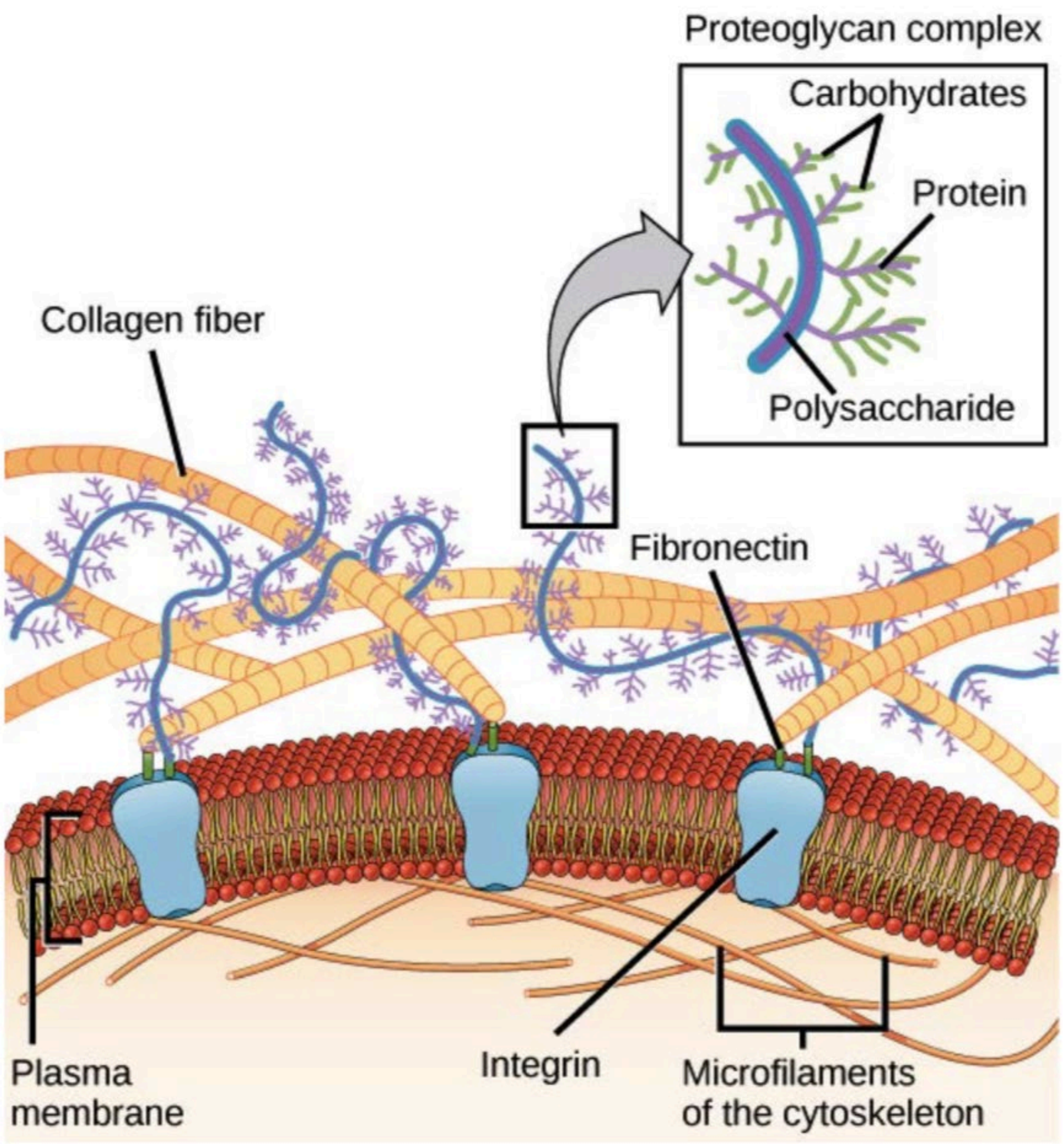
Fibronectin

- Cell adhesion protein (fibronectin, lamin)
- Glycoprotein to connect cells with collagen fibers in ECM
- Allows for mobility through ECM
- Bind collagen and cell-surface integrins
- Is secreted by cells in an unfolded, inactive form
- Provide help at the site of injury
  - Binds to platelets during blood clotting and helps in moving cells to place of injury

Proteoglycans

- Major component of animal ECM
- Sort of *interstitial* substance between cells
- Form large complexes
- Facilitate water retention and influence cell migration and ECM deposition
- Regulate movement of molecules through ECM
- Can serve as lubricants

Overview


Proteoglycan complex
Carbohydrates
Protein
Polysaccharide
Collagen fiber
Fibronectin
Plasma membrane
Integrin
Microfilaments of the cytoskeleton

Proteoglycans

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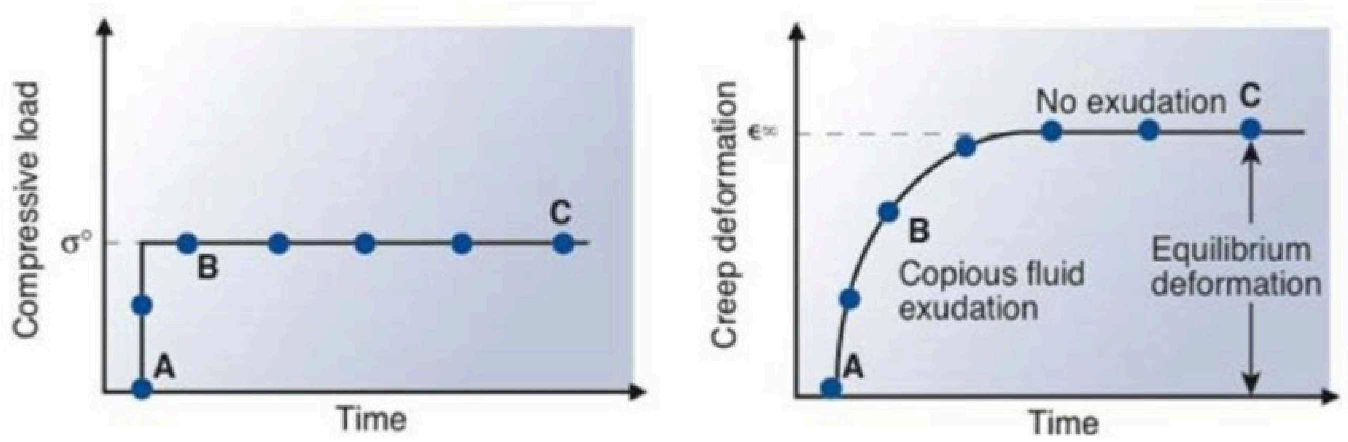
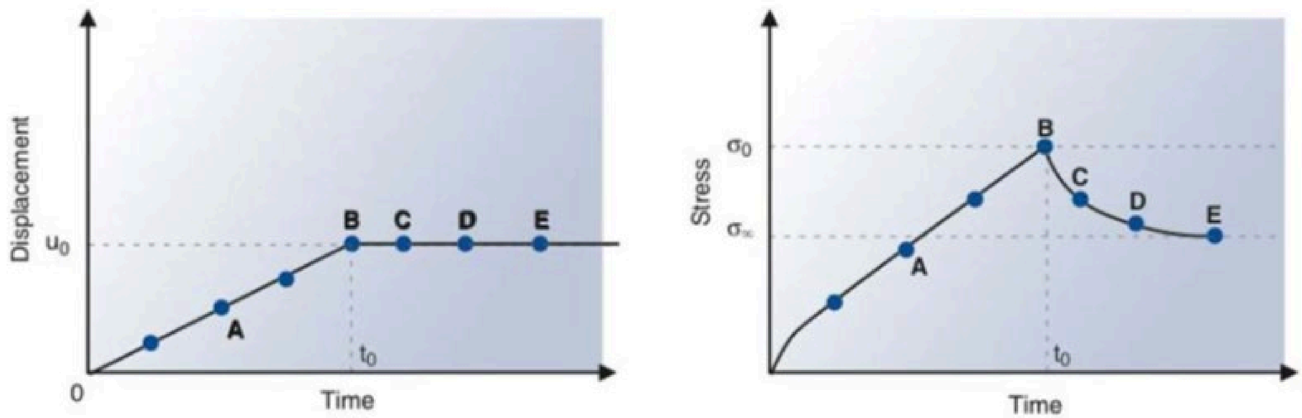
Mechanical Properties: Creep



- So called *creep test*
- *Constant stress* σ_0 is applied
- Measure deformation → increases over time
- Stops when $p_{ext} = p_{osm}$

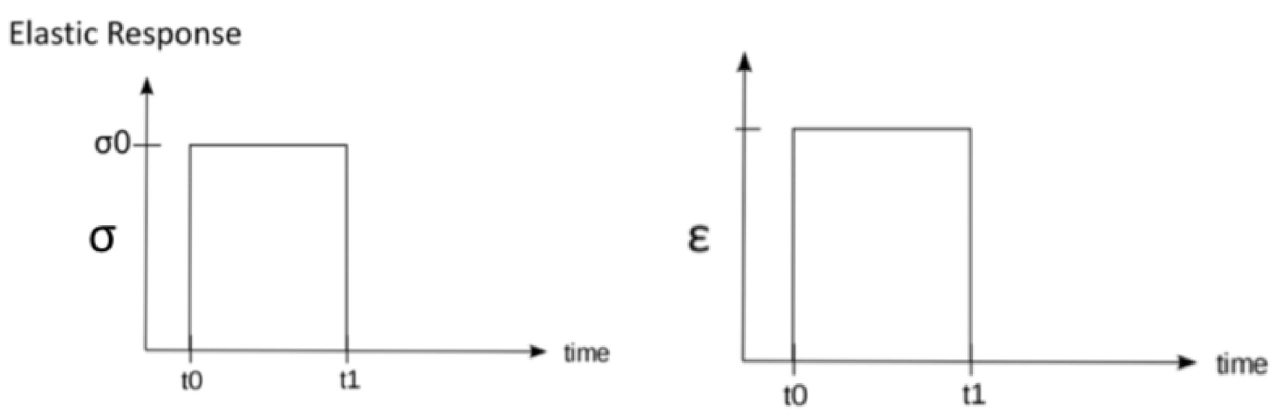
Mechanical Properties: Stress Relaxation



- So called *stress relaxation test*
- Apply constant strain rate until point B and hold the strain
- Stress decreases over time as fluids flow through pores and rearrange until $p_{ext} = p_{osm}$ → point E

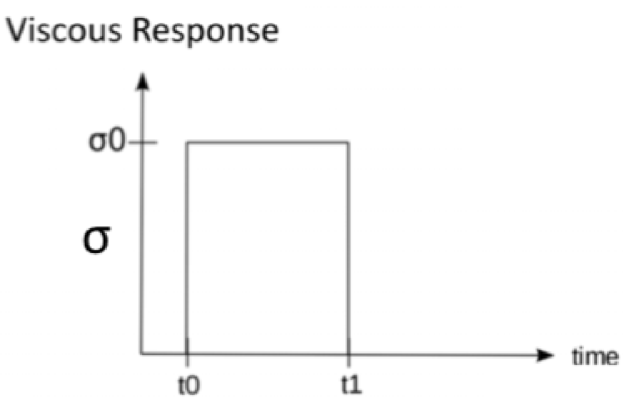
Elastic Materials

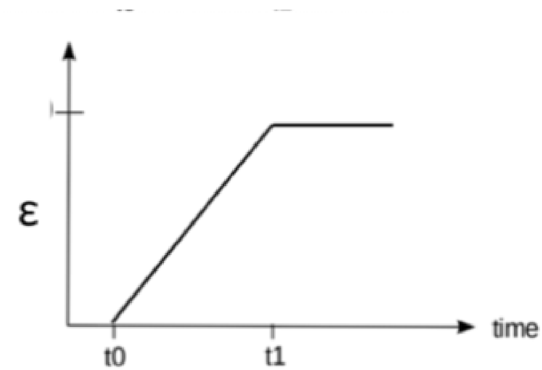
- Deformation is **time <u>in</u>dependent** function of force
- $\varepsilon = \varepsilon(F)$ and $\varepsilon \neq \varepsilon(F, t)$
- Elastic materials translate forces to displacements
  - Immediately and proportionally (linear & non-linear)
  - Remember $\sigma \propto \varepsilon$ or the equality $\sigma = E \cdot \varepsilon$



Viscous Materials

- Deformation is **time dependent** function of force
- $\varepsilon = \varepsilon(F, t)$
- Typical classical fluids
- Stress converts to strain with time lag
- At constant stress, strain continues to increase!
- Remember: creep strain is not recoverable (after unloading)!



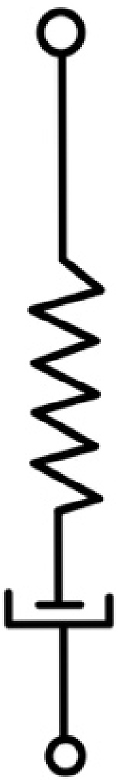


Maxwell's Model

- Consider the elements: ***spring*** (E) and **dashpot** (η)
- Arranged in **series**!
- First order, linear DE:

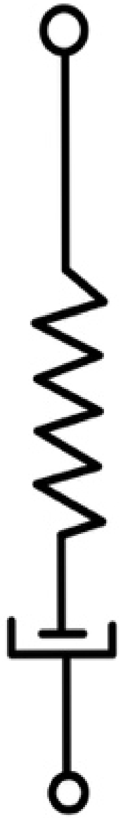
$$\dot{\varepsilon} = \frac{\dot{\sigma}}{E} + \frac{\sigma}{\eta}$$

- Both elements are subjected to same stress!
  - $\sigma_{spring} = \sigma_{dashpot}$
- The total strain is sum of both elemental strains
  - $\varepsilon_{total} = \varepsilon_{spring} + \varepsilon_{dashpot}$



Maxwell‘s Model

- Maxwell says: *stress will decay exponentially over time!*
- Accurate for a wide range of polymers
- **Shortcoming**: does not predict *creep* accurately
  - *Maxwell predicts linearly increasing strain with constant stress application.*
  - *Most polymers show strain rate to decrease over time though!*

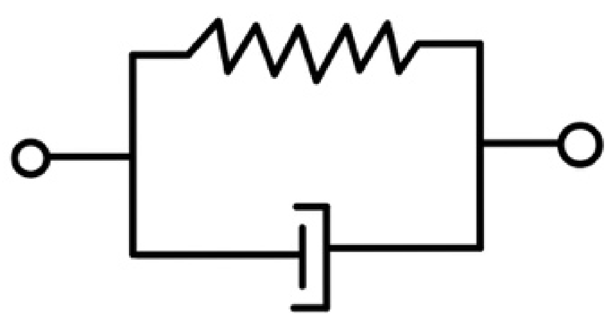


Kelvin-Voigt Model

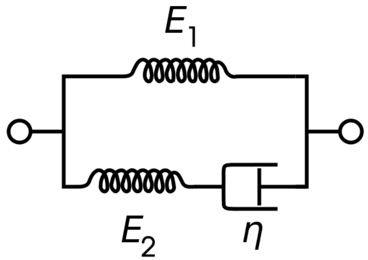
- Consider same elements: ***spring*** (E) and **dashpot** (η)
- Arranged in **parallel**!
- First order, linear DE:

$$\sigma = E \cdot \varepsilon + \eta \cdot \dot{\varepsilon}$$

- Both elements are subjected to same strain (no bending)
  - $\varepsilon_{spring} = \varepsilon_{dashpot}$

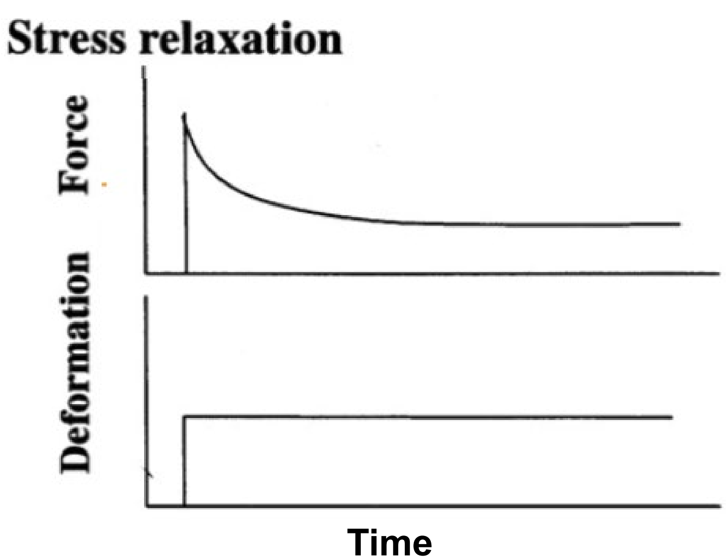


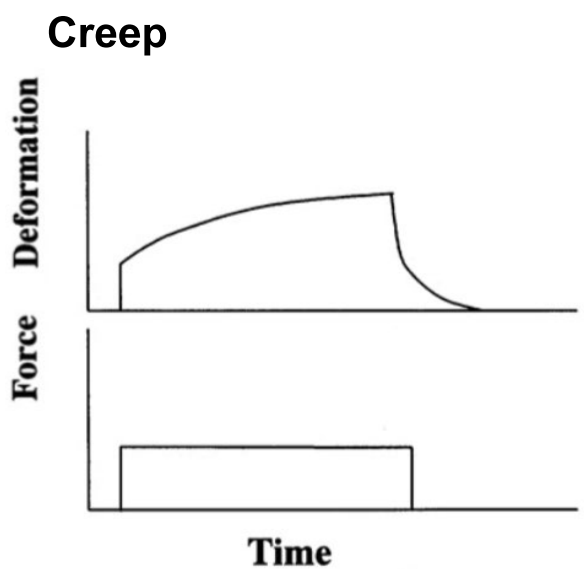
Zener Model



- ***Two springs*** (E_1 and E_2) and **dashpot** (η)
- Describes both creep and relaxation behavior correctly

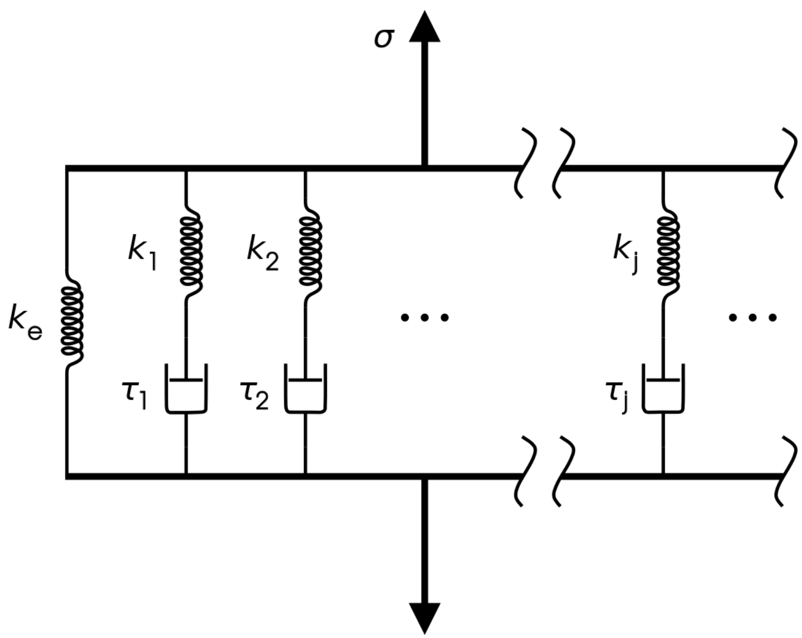
$$\sigma + \frac{\eta}{E_2}\dot{\sigma} = E_1 \cdot \varepsilon + \eta \frac{(E_1 + E_2)}{E_2} \cdot \dot{\varepsilon}$$





Generalized Maxwell Model – Wiechert Model

- **Most general form of linear model for viscoelasticity**
- Many spring-dashpot elements in parallel
- Relaxation does not occur at a single time, but at a *distribution of times*!



Next Week's Quiz

Next Paper due **19th of November 2019**
"Touch, Tension, and Transduction – The Function and Regulation of Piezo Ion Channels"
(Wu et al., 2017)