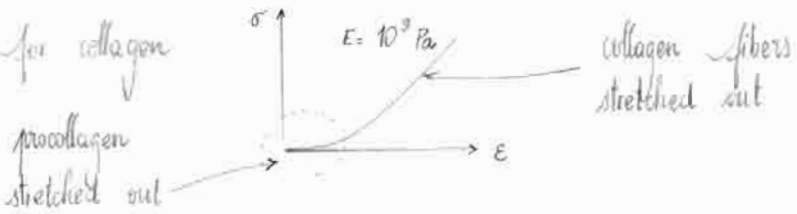
BEH. 410. 03/12/2003
L # 11

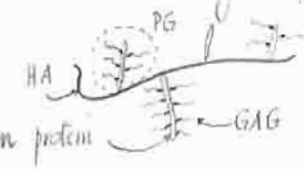
Last time: Tissue mechanics
I. Molecular structure & composition of extracellular matrix (ECM)
- behavior of bone, muscle, tendon
- collagen superfamily (how many? fibrillar, fibril forming, sheet forming)
- processing of collagen
- nonlinear behavior (« wavy » collagen)

Today: Finish I: elastin, proteoglycans & glycosaminoglycans, adhesion proteins
Equilibrium equations
Energy methods (scaling analysis rather than precise solutions)

- Typically for collagen

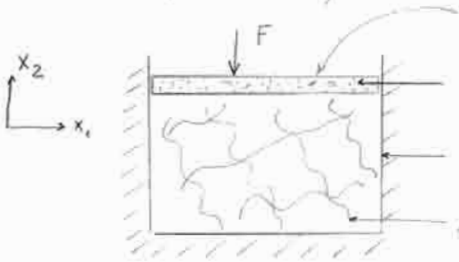


- connections between collagen fibers are proteoglycans or collagen (slide 15)
- elastin more random in character than collagen (straight on short distance, large persistence length)
entropic elasticity (slide 16, 17)
$E_{elastin} = 10^5$ Pa and strains up to 20 % (huge but still linear pretty much)
not much hysteresis (area difference = energy dissipated, not much!)
elastic rather than viscoelastic response of elastin (slide 18)
elastin: lung, blood vessels (collagen for resistance at high strains => don't break)
- radius as a function of pressure at arterial wall
compliant artery first (elastin characteristic), stiffer than (collagen recruited => higher E)
- change stress of living material => remodeling (over time) of cells, they respond to environment
mechanical properties evolve
intima thickened by low shear stress (endothelial cells modified => atherosclerosis for instance)
(slide 20)
- surface tension accounts for difference between air- and liquid-filled lung (slide 21)
surfactants produced to reduce surface tension ↳ stiff ↳ larger volume for given pressure
- aggrecan can be as long as 1 μm. Huge! (slide 26) — GAG
- proteoglycan = core protein + GAGs attached to it — protein
- retain proteoglycan structure (by freezing) for TEM (slide 24) maintain charge repulsion
- hyaluronan molecule can be the core of an array of PGs!
aggrecan is very space-filling
gives rise to ECM compressibility



- highly charged GAGs repel each other (slide 31)
  equilibrium after all liquid is expelled
  change modulus by changing solution ionic strength (charge shielding: of ⊖ GAG charges by ⊕ solution charges)
- 50% of stiffness from charge repulsion
  50% " from collagen's own stiffness (slide 33)

Confined compression experiment



$\sigma_{22} A = -F$ or $\sigma_{22} = -\frac{F}{A} = \lambda \varepsilon_{kk} \delta_{ij} + 2G \varepsilon_{22} = \underbrace{(\lambda + 2G)}_{H} \varepsilon_{22}$

$\varepsilon_{11} = \varepsilon_{33} = 0$

H confined compression modulus

$H = \lambda + 2G$

$K = \frac{2}{3} G + \lambda = \frac{E}{3(1-2\nu)}$ bulk modulus

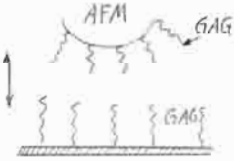
$\lambda = \frac{\nu E}{(1+\nu)(1-2\nu)}$ 2nd Lamé coefficient

$G = \frac{E}{2(1+\nu)}$ shear modulus

for our biological experiments $0.2 \ll \nu \ll 0.5$ typically, so "interchange" G and E

- G ↗ with collagen content
  ↳ accounts for 50% of stiffness
  if you remove PGs, you loose ~ 50% of G
- charge repulsion (high distance d)
  steric effects (≈ 20 nm apart)
  squeezing of water molecules : hydration
  Van der Waals attraction

} constitute GAG interface interaction



- cone-plate rheometer (rather than plate) = same shear rate (slide 37)
  storage modulus (very low for liquid) changes with ionic concentration (G' high after gelation => solid)
  as charges are neutralized (pH ok), gel formation is possible (slide 38, 39)
- glycocalyx (buffy coat) important for microcirculation (sticks ~ 1 µm away from endothelial cells, and prevents red blood cells from approaching the vessel wall)