Modeling of soft and hard biological tissues

Structure and Material properties

UNIVERSITATEA BABEȘ-BOLYAI

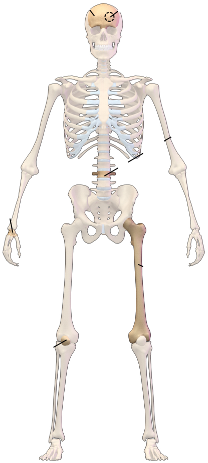
Last update: March 21, 2023

Agenda

- Bones
- Cartilage
- Tendons and ligaments
- Blood vessels

Bone morphology

Types of bones



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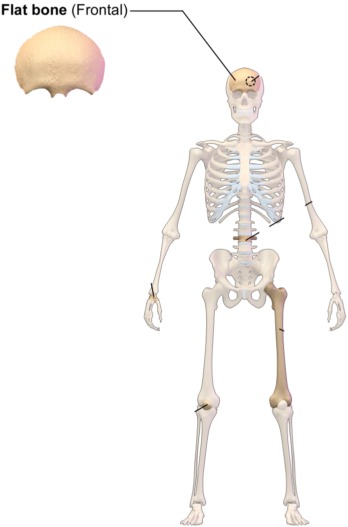

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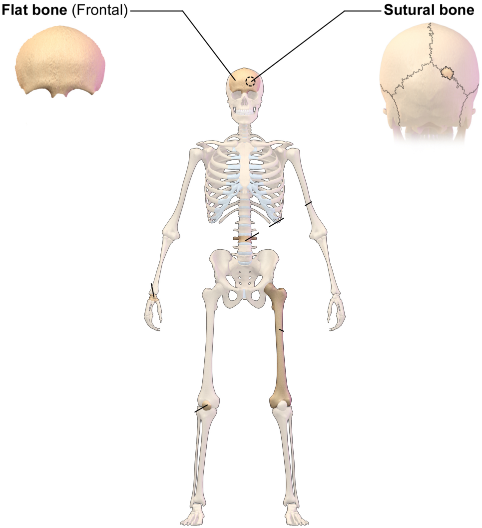

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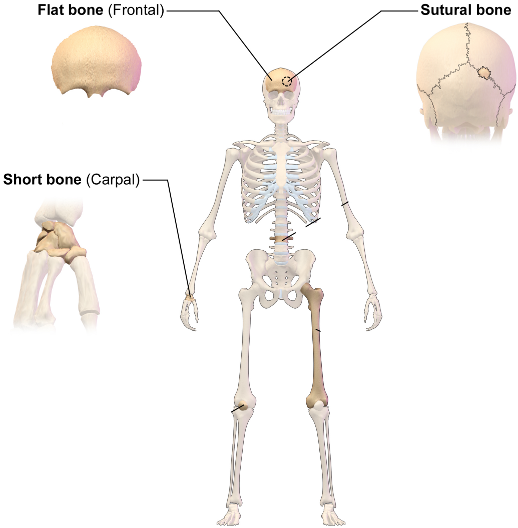

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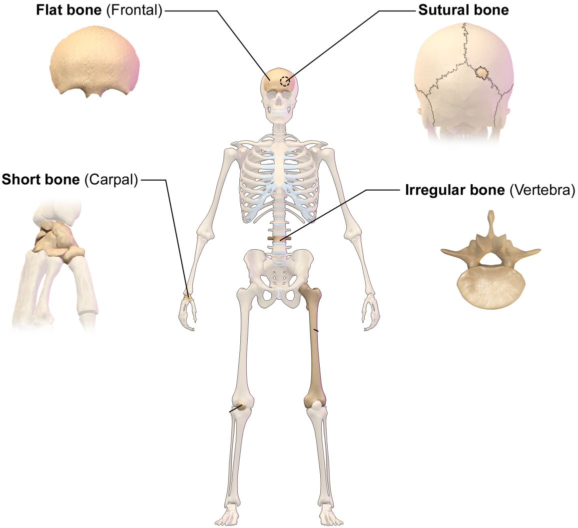

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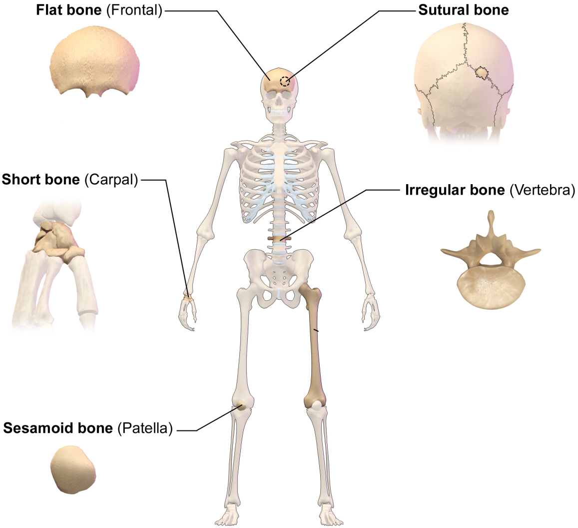

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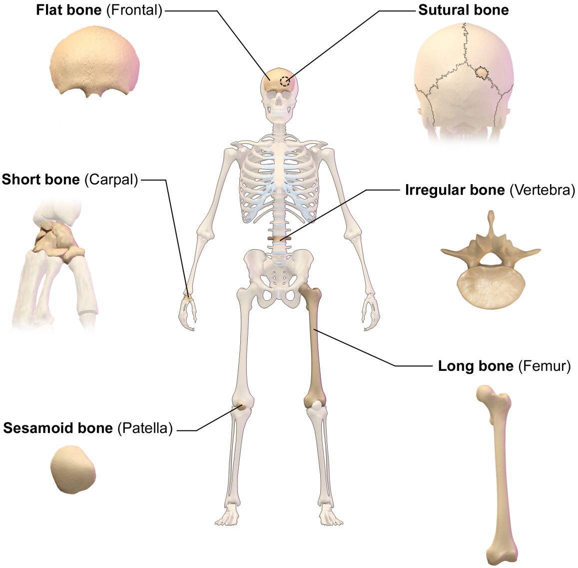

Bone morphology

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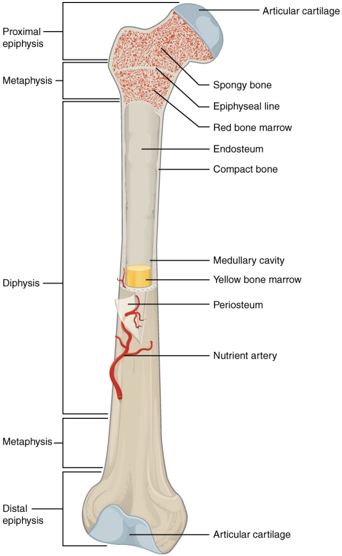
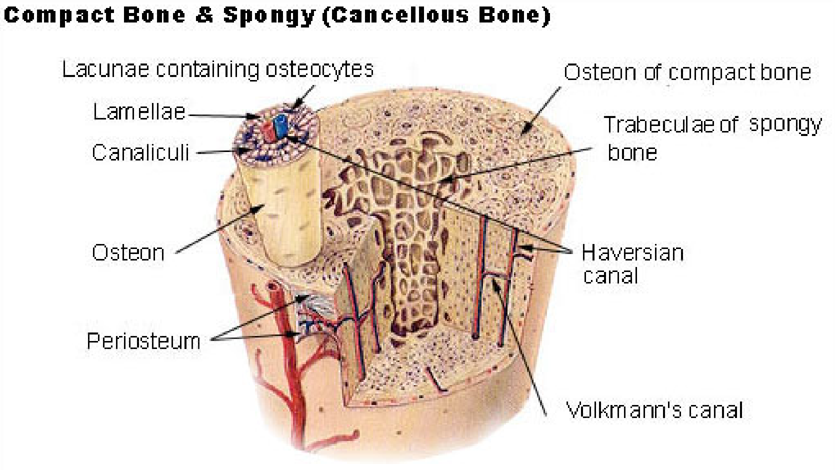
https://www.youtube.com/watch?v=0dV1Bwe2v6c

Bone morphology

Bone structure



Composition of long bones



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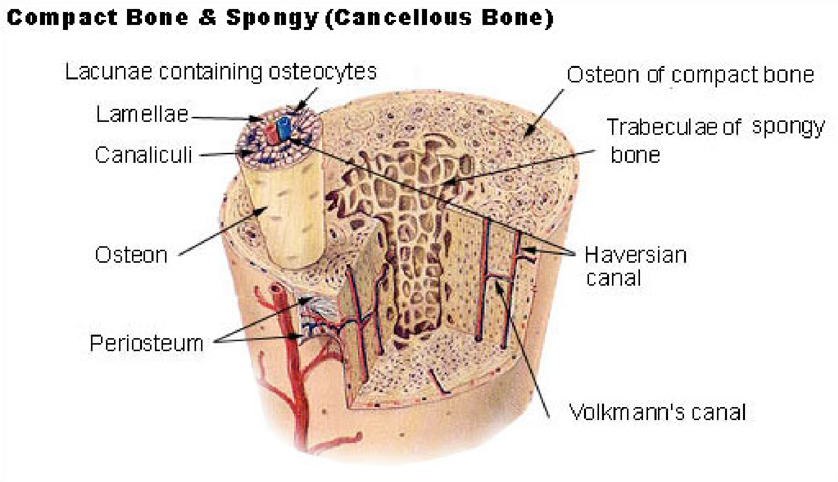
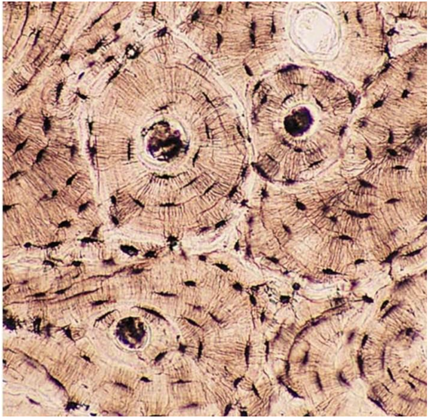


Basic structure is the osteon

Composition of long bones

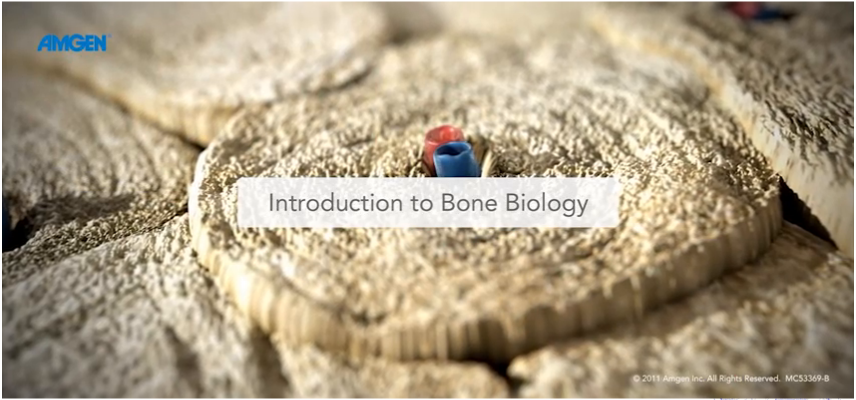
Osteons



Osteons are like tree trunks

Bone morphology

Types of bone structure



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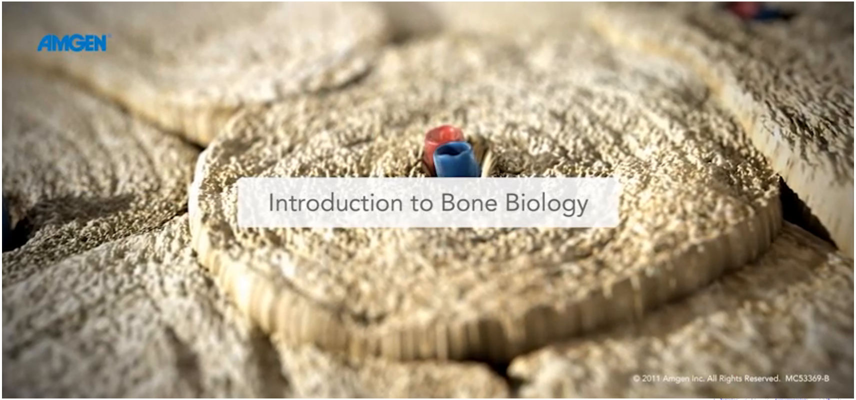

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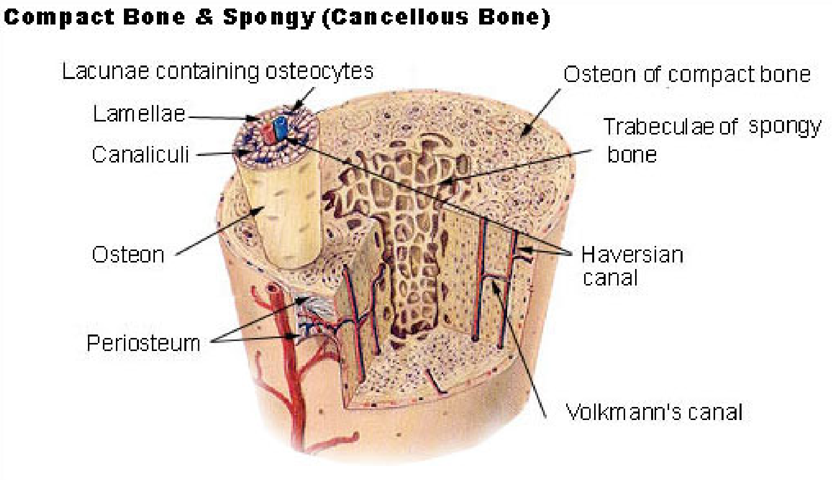
Composition of long bones

Fluids



In the porosity of the bone, there is fluid and bone marrow.

Bone properties

Bone models

At what level do we model our bones?

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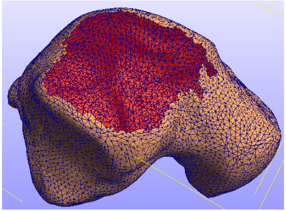

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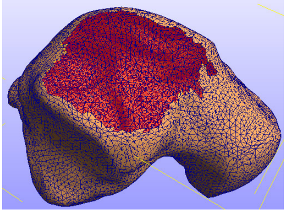

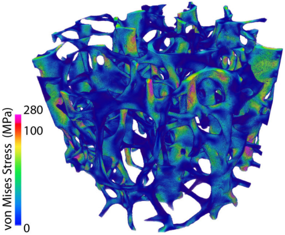

Verbruggen et. al 2016

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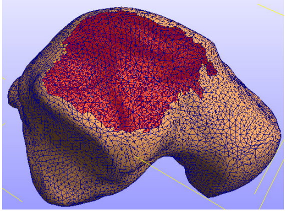

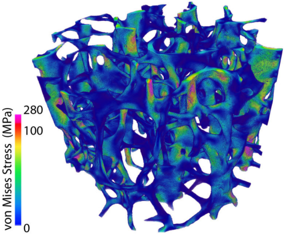

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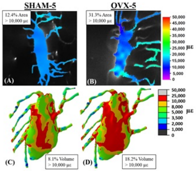

Torres et. al 2016

Bone properties

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$$\sigma + Ap = E\epsilon$$

Where p is the fluid pressure, and A is called the Biot coefficient

Bone properties

Modelling poroelasticity

For an isotropic material, The Biot coefficient is equal to:

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$$\frac{G^d}{G^m} = 1 - \frac{15(1-\nu^m)\phi}{7 - 5\nu^m}$$

Time to breath in

Breath in

Breath in

Breath out

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Then we work as we know. (i.e. Finite Elements)

This approach assumes that the material is elastic, we are therefore in a linear region of the stress-strain relationship

Bone properties

Material properties

$$K^m = 14GPa$$
$$K^d = 12GPa$$
$$G^m = 5.5GPa$$
$$\phi = 0.05$$

Cartilage

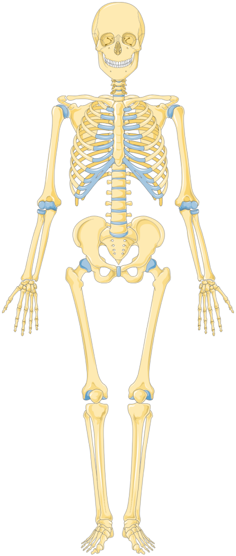
Types of cartilage

Cartilage is found primarily between bones, creating either rigid connections or articulations.

- Fibrous joints
- Cartilaginous joints
- Synovial joints

Cartilage

Articulated joints



Cartilage

Chemical Composition

Hyaline cartilage consists by 40% of Type II collagen. The rest is mainly water and Proteoglycean.

For synovial joints, it is a thin layer (0.5 - 5 mm)

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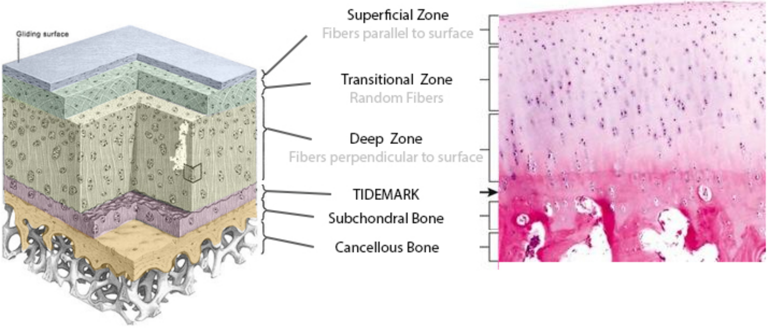

Cartilage

Permeability

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The property of a porous material that describes the ability of a fluid to flow through the material.

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This is a non-linear model

Cartilage
Modelling

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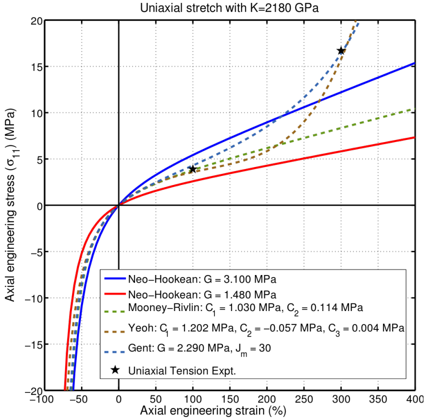

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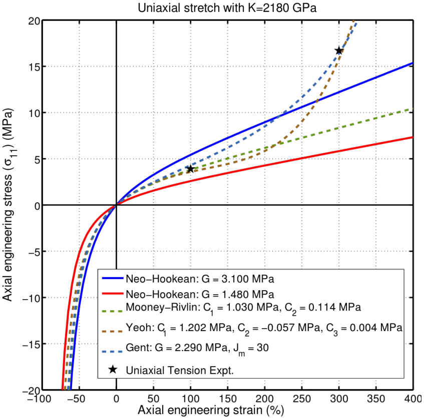


More specifically a *Mooney-Rivlin* material

Tendons and ligaments

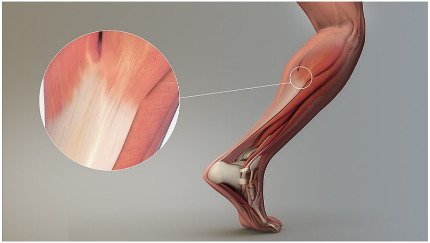
Functionality

Tendons and ligaments

Functionality

Tendons

Fibrous connective tissue connecting muscles to bones. They help translate muscle force production into bone movement.



Tendons and ligaments

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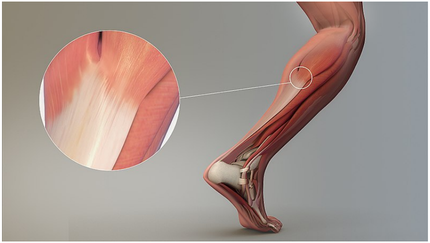
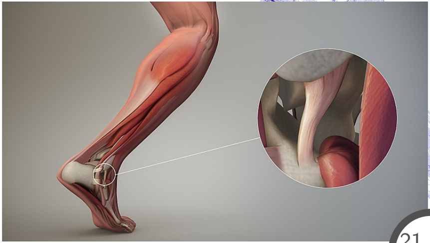
Ligaments

Fibrous connective tissue connecting bones to bones. They help keep bones together, restricting some degrees of freedom in articulations.





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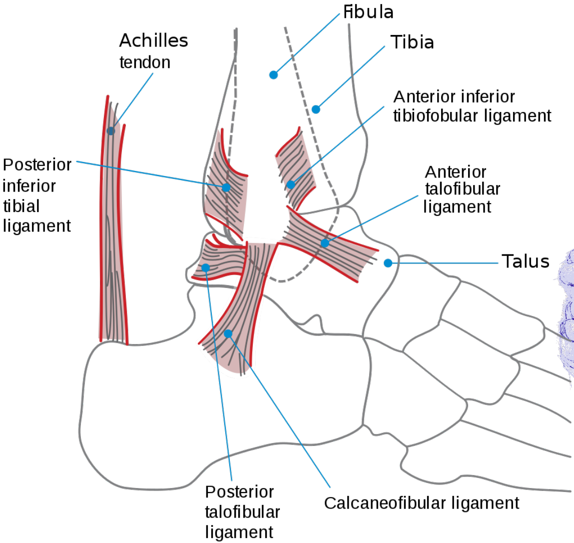

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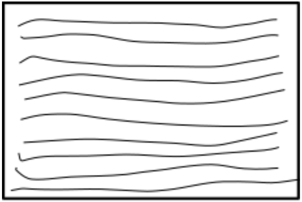

Tendon

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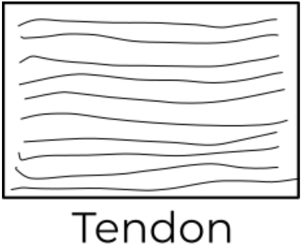

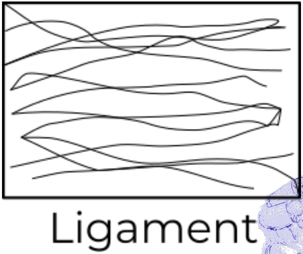

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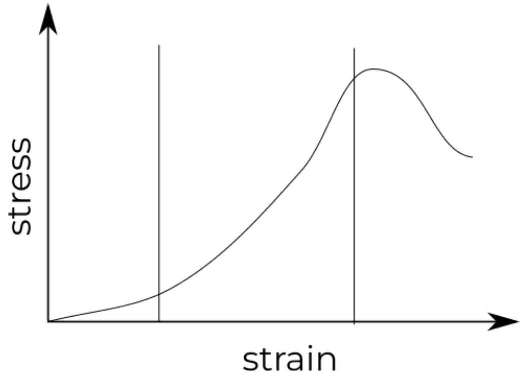

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Viscous effects

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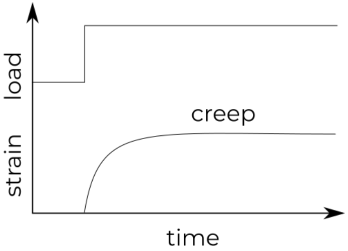

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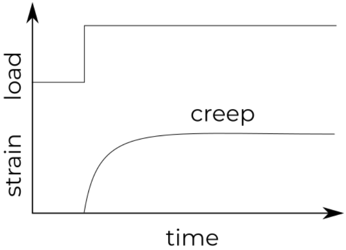

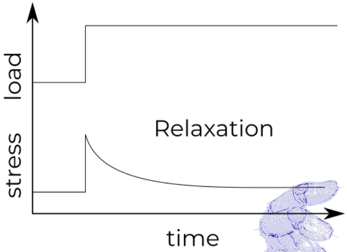

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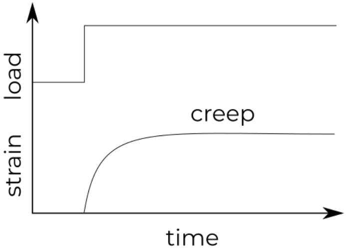

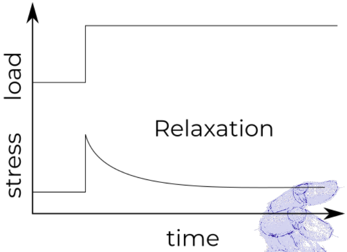

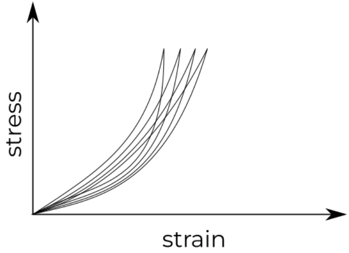

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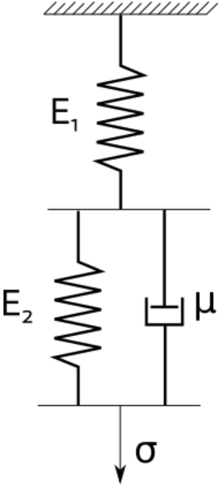

$$\sigma + \frac{\eta}{E_1 + E_2}\dot{\sigma} = \frac{E_1 E_2}{E_1 + E_2}\epsilon + \frac{E_1 \eta}{E_1 + E_2}\dot{\epsilon}$$

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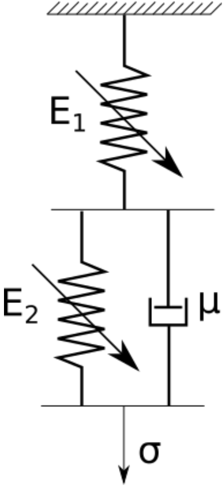

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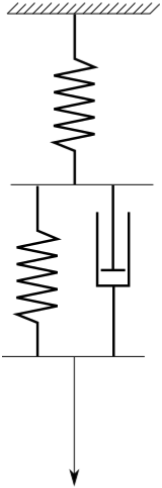
$E_1(\epsilon), E_2(\epsilon)$

Tendons and ligaments

Relaxation



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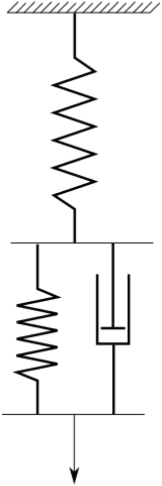

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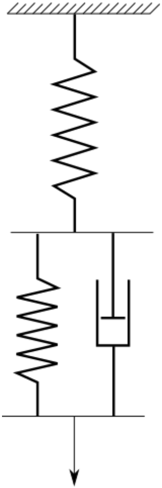

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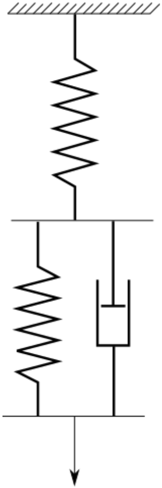

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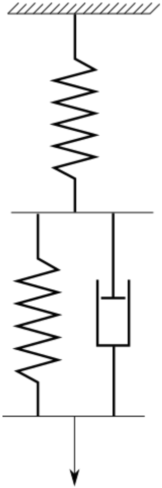

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How do we identify $E(epsilon)$ and η?

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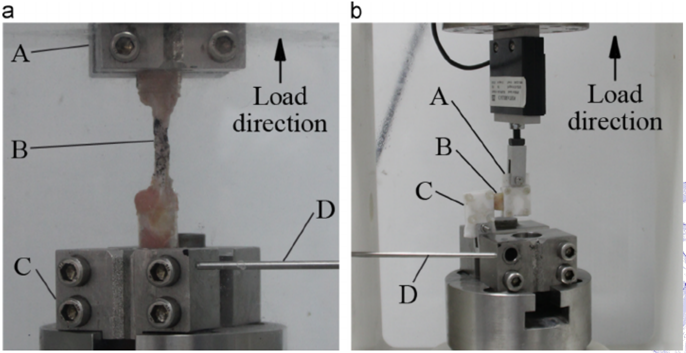

From Chao Wan et al. (2015)

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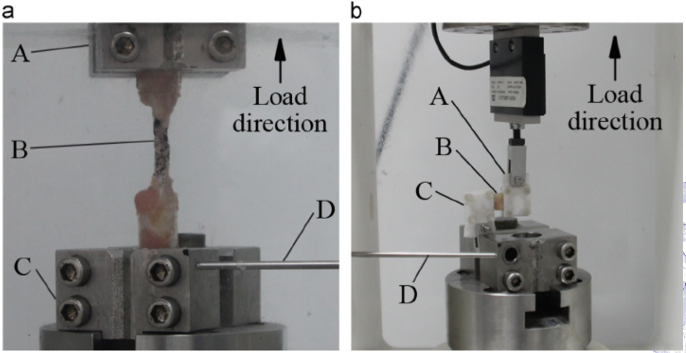
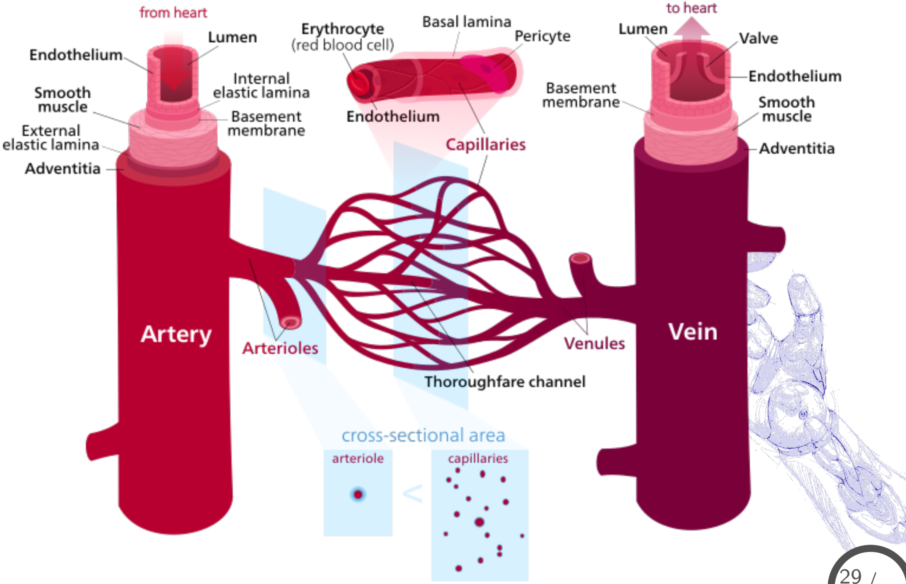


From Chao Wan et al. (2015)

Good news: We are mainly interested in axial loading, since this is physiological

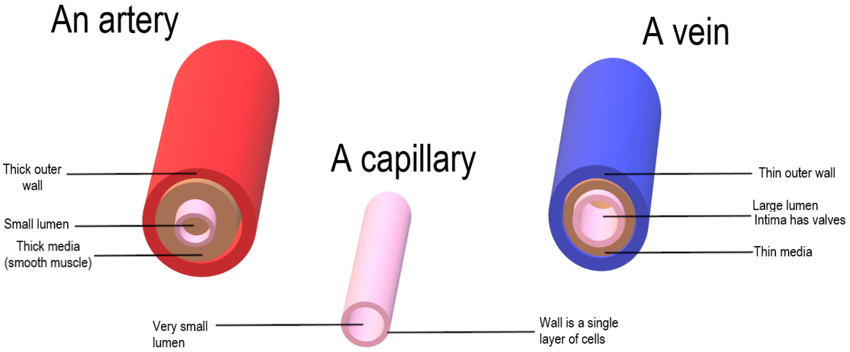
Cardiovascular system

Description



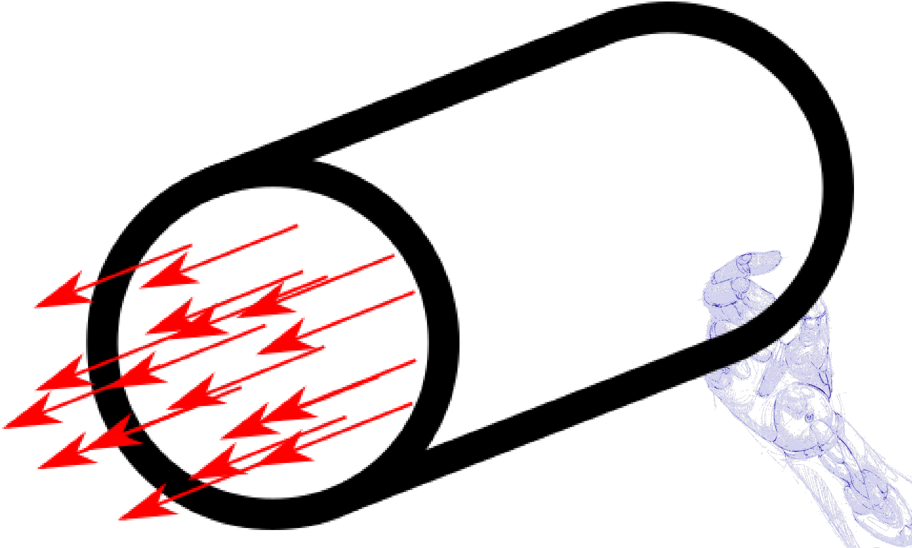
Cardiovascular system

Arteries and Veins



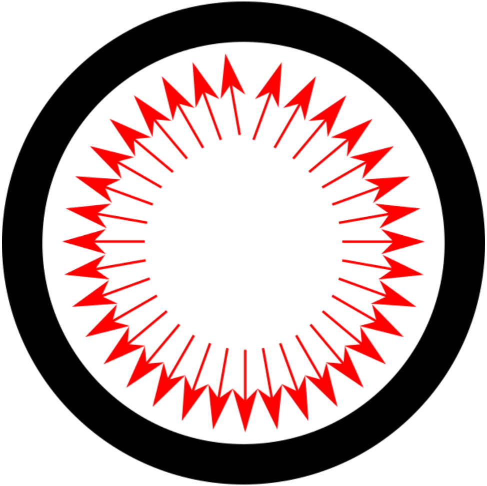
Blood vessels

Stress analysis



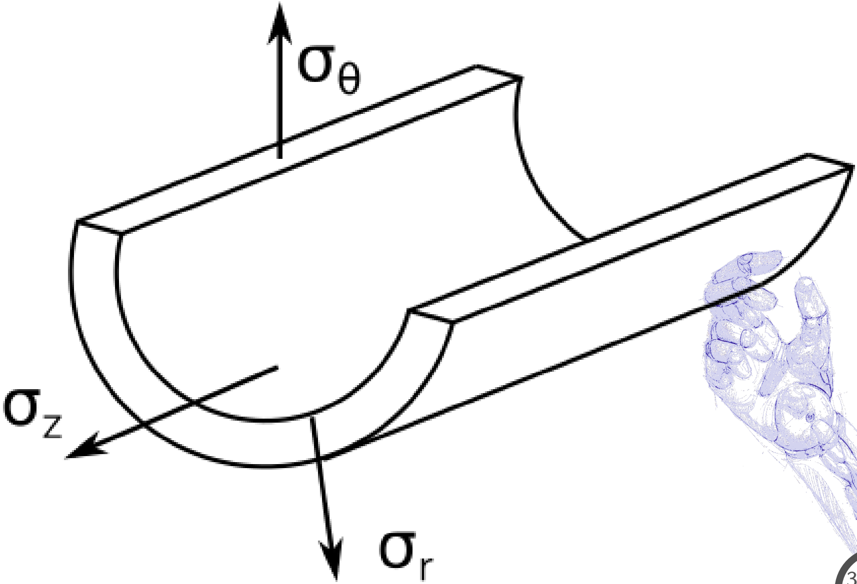
Blood vessels

Stress analysis



Blood vessels

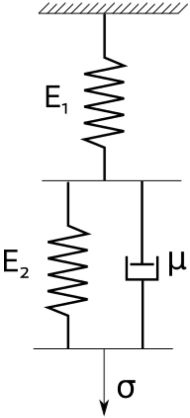
Stress analysis



Blood vessels

Mechanical properties

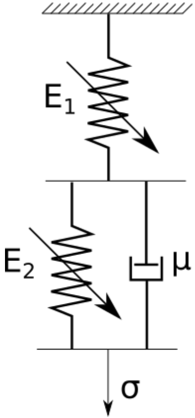
Visco



Blood vessels

Mechanical properties

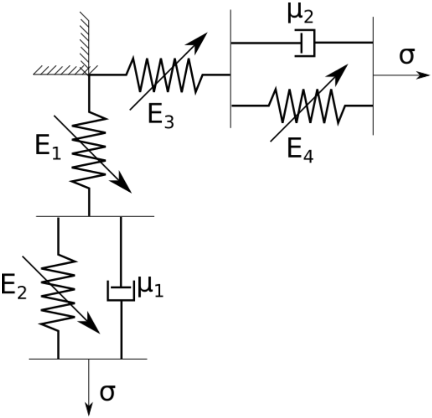
Viscohyperelastic



Blood vessels

Mechanical properties

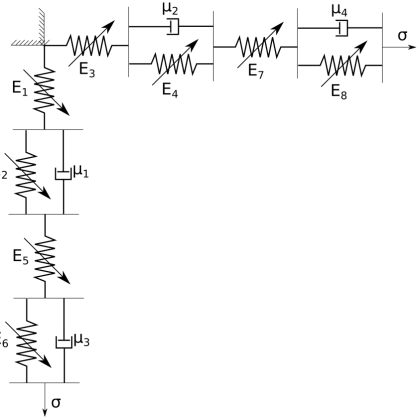
Viscohyperelastic, anisotropic



Blood vessels

Mechanical properties

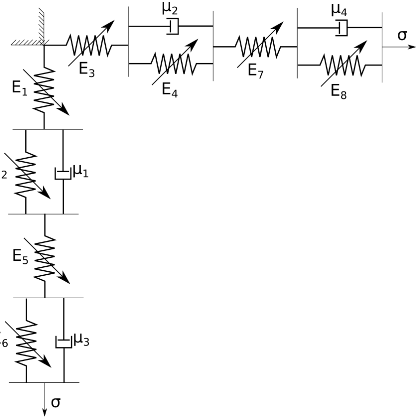
Viscohyperelastic, anisotropic, composite.



Blood vessels

Mechanical properties

Viscohyperelastic, anisotropic, composite.

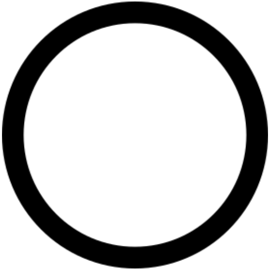


And it exhibits residual stresses!

Blood vessels

Residual stresses

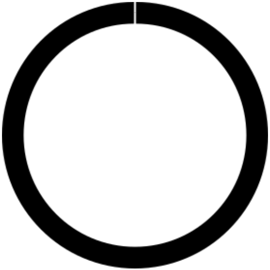
Internal stresses that are present in the vessels, even when there are no external loads.



Blood vessels

Residual stresses

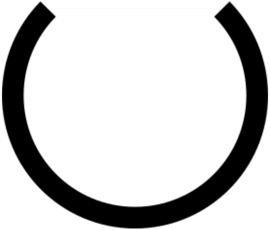
Internal stresses that are present in the vessels, even when there are no external loads.



Blood vessels

Residual stresses

Internal stresses that are present in the vessels, even when there are no external loads.



Blood vessels

Residual stresses

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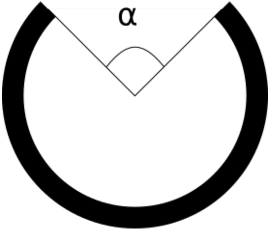

Blood vessels

Residual stresses

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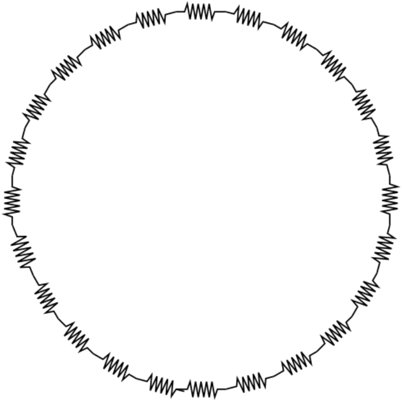

Coming up next

Fluid dynamics in biomechanics

Questions?