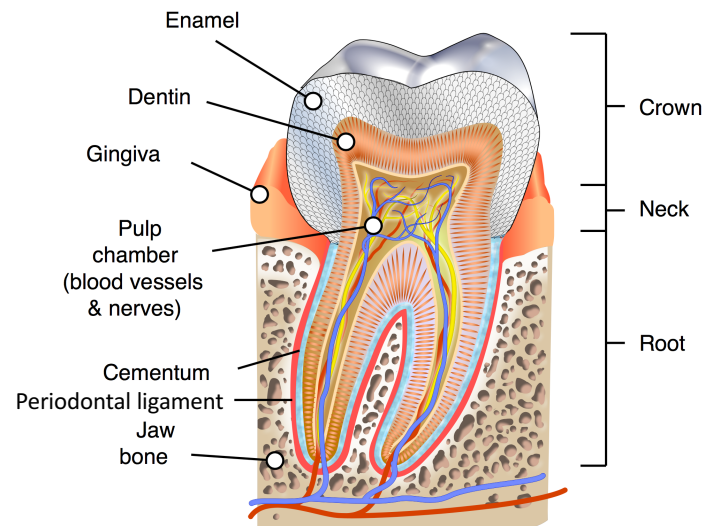


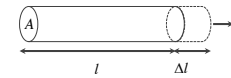
## BIOMECHANICS

### Dental tissue mechanics



## Basics of tissue mechanics

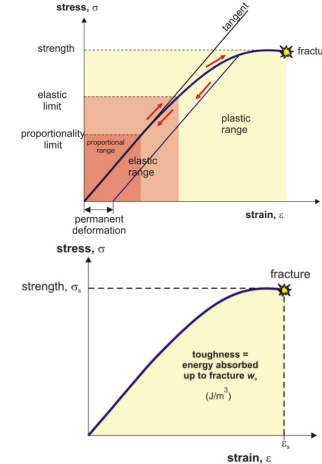
### Hookean elasticity



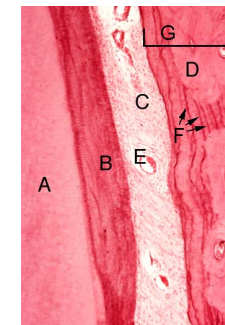
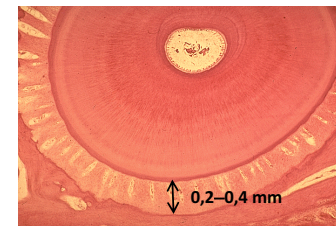
$$\frac{F}{A} = E \frac{\Delta l}{l}$$

$F$  = force  
 $A$  = cross-sectional area  
 $l$  = rest length  
 $\Delta l$  = extension  
 $F/A = \sigma$  = stress ( $\text{N/m}^2 = \text{Pa}$ )  
 $\Delta l/l = \epsilon$  = strain (dimensionless)  
 $E = \sigma / \epsilon$  = Young's modulus ( $\text{Pa}$ )

### Stress-strain diagram



## Periodontal ligament



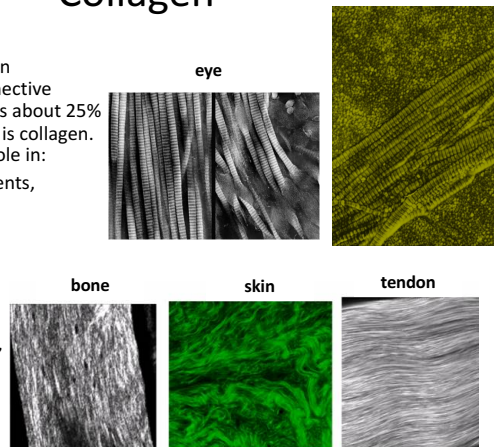
≈ collagen

polymer

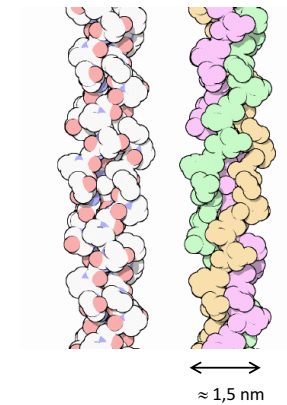
## Collagen

Structural protein, main component of connective tissues, in mammals about 25% of the total protein is collagen. Has an important role in:

- tendons, ligaments,
- skin,
- cartilage,
- bone,
- tooth,
- blood vessels
- vitreous humor,
- cornea,
- etc.

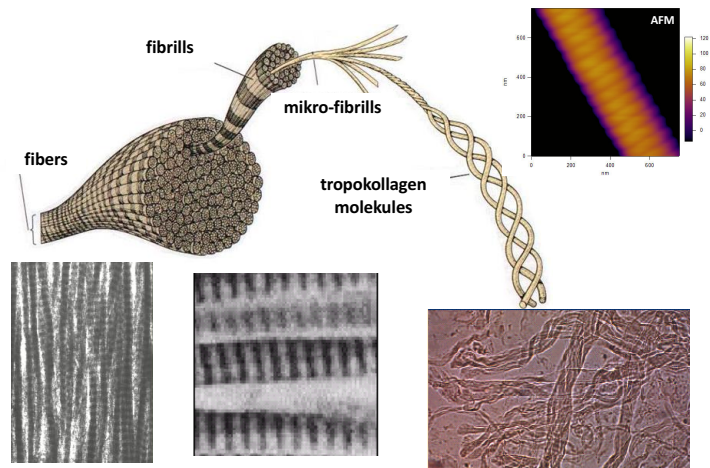


## The collagen molecule

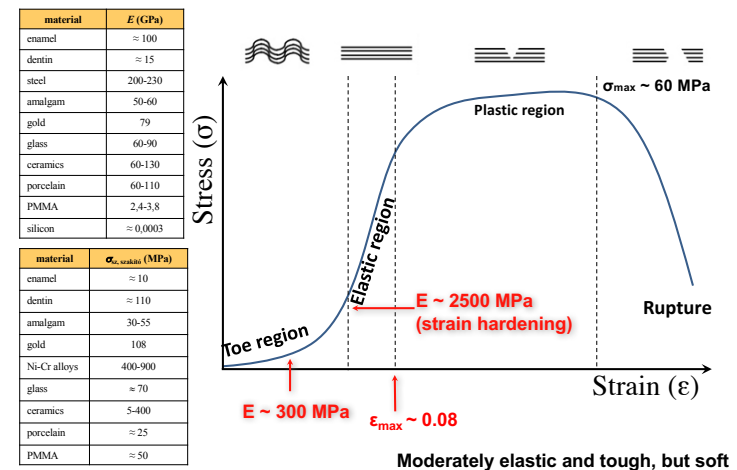


- 1400 aminoacids/chain
- glicin (1/3), prolin (1/10), hidroxi-prolin, ...
- 3 chains  $\rightarrow$  triple helix

## The structure of collagen

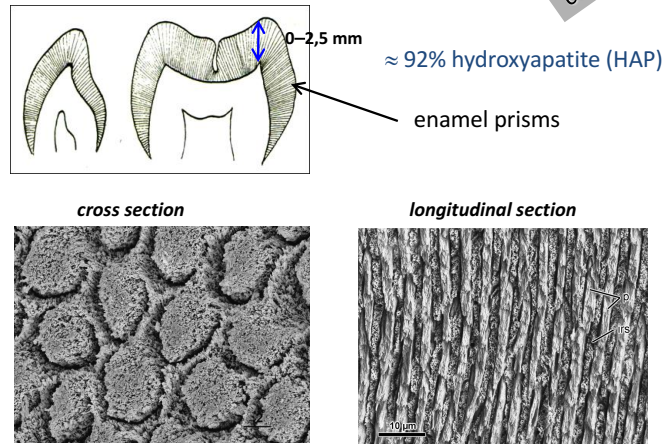


## Stretch diagram of collagen

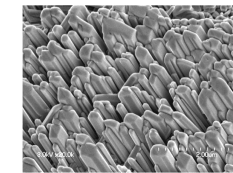


## Enamel

ceramics



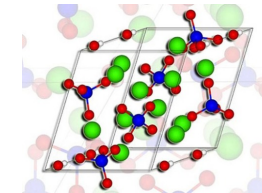
## Hydroxyapatite



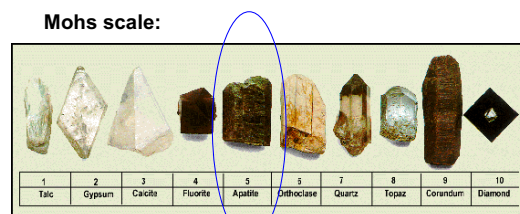
hexagonal ionic crystal



in dentin and bone  
20-60 nm x 6 nm crystals  
in enamel:  
500-1000 nm x 30 nm crystals



## Properties of hydroxyapatite



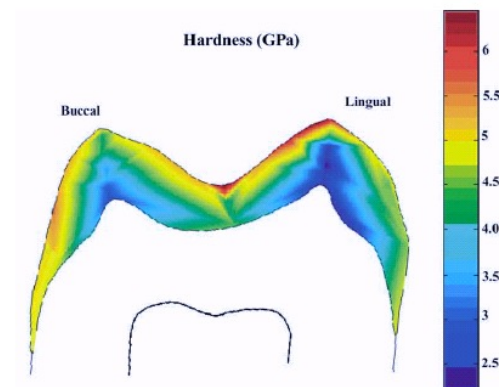
material	HV (MPa)
enamel	≈ 3400
dentin	≈ 600
amalgam	≈ 1000
gold	
gold alloys	600-250
Pd-Ag alloys	1400-1900
Co-Cr alloys	≈ 4000
Ni-Cr alloys	3000-4000
glass	
porcelain	4500-7000
akrylate	≈ 200

**HAP:**  $HV \approx 6 \text{ GPa}$   $E \approx 140 \text{ GPa}$   $\sigma_s \approx 60 \text{ MPa}$  (bending)  
 $\approx 500 \text{ MPa}$  (compression)

**enamel:**  $HV \approx 3-6 \text{ GPa}$   $E \approx 90-100 \text{ GPa}$   $\sigma_s \approx 50 \text{ MPa}$  (tension)  
 $\approx 400 \text{ MPa}$  (compression)

Rigid, hard, strong but brittle!

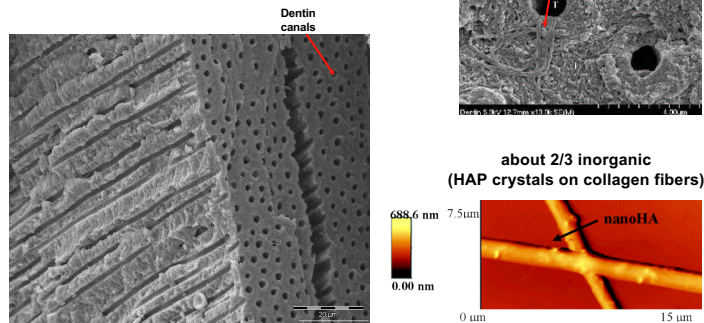
## Hardness distribution of enamel crown



composite

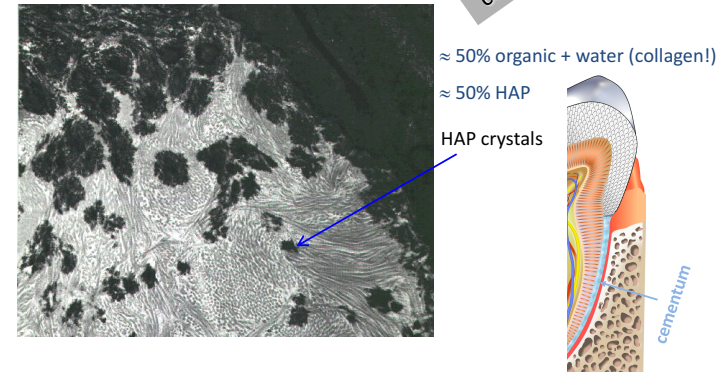
## Dentin

moderately hard, very strong and tough



## Cementum

composite



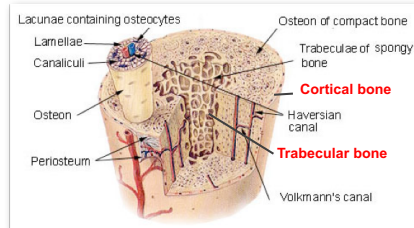
## Bone

Due to the different structure of bone tissue along the cross section of long bones, the **Young's modulus distribution is anisotropic**. Denser cortical bone has greater Young's modulus vs. the trabecular bone..

Young's-modulus: 5-20 GPa

Decalcified bone (acid treatment): flexible

Removal of organic compounds (heating): brittle



30 % Organic matrix: collagen

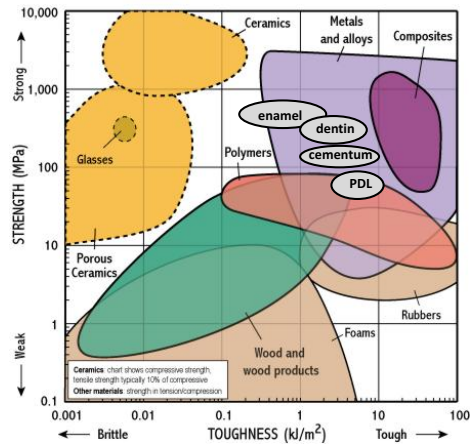
70 % Inorganic salt: Hydroxylapatite

composite

## Properties of dental biomaterials

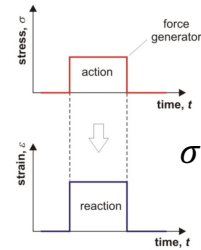
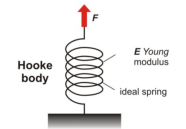
	PDL (≈ collagen)	dentin (≈ 1/3 collagen, 2/3 apatite)	enamel (≈ apatite)
Young's modulus ( $E$ ) (GPa)	0,3–2,5	10–20	90–100
strength ( $\sigma_{\max}$ ) (MPa)	60	110 (tensile) 300 (compress)	50 (tensile) 400 (compress)
toughness (kJ/m <sup>3</sup> )	1–10	0,5–5	0,1–1
hardness HV (GPa)	<i>too soft to measure</i>	0,5–1	3–6





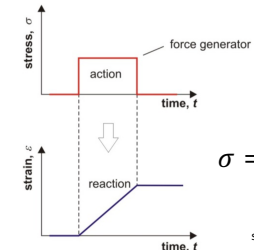
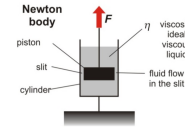
## Viscoelasticity (mechanical model)

### Elastic body



$$\sigma = E \varepsilon$$

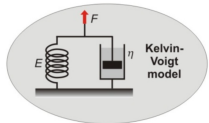
### Viscous body



$$\sigma = \eta \frac{\Delta \varepsilon}{\Delta t}$$

viscosity  
strain rate

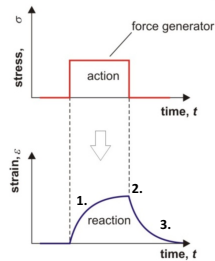
## Viscoelasticity (mechanical model)



Viscoelasticity means to co-appearance of viscous and elastic behavior. A

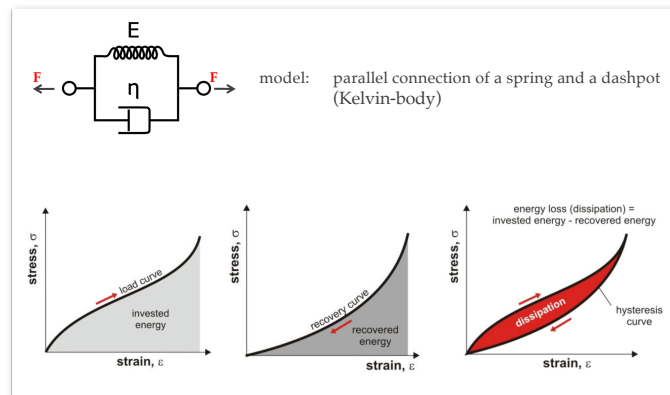
model: parallel connection of spring and dashpot  
(Kelvin-Voigt model)

Spring: ideal elastic (Hooke) body  
Dashpot: ideal viscous (Newton) body

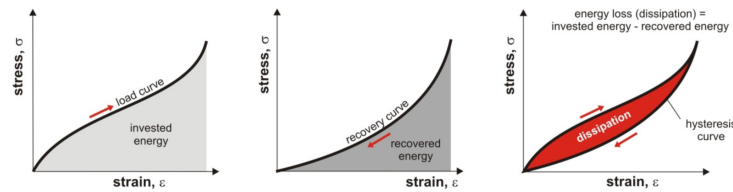


1. Upon stretch, the extension of the spring is slowed down by the dashpot.
2. Extension stops when the elastic spring force equals the external force.
3. When the external force is quenched, the contraction of the spring is slowed down by the dashpot.

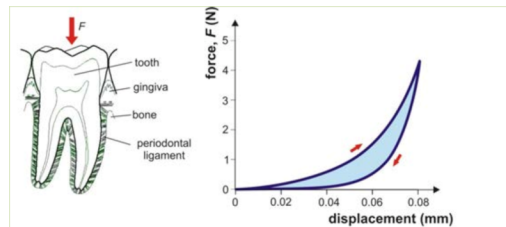
## Visco-elasticity (mechanical model)



## Energy dissipation in viscoelastic system

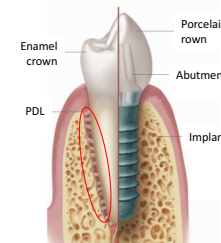


Periodontal ligament



## Example: Implants vs natural tooth

PDL makes the difference!



Absence of PDL result in :

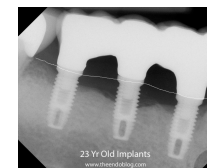
- loss of masticatory force perception
- loss of visco-elastic (damper) effect
- loss of force sensory mechanisms
- No implant movement

Implant is in direct contact with bone tissue

Increased compressive stress

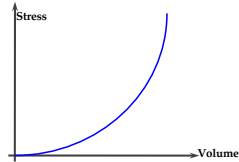
Bone loss (0.2 mm / year)  
Loss of gingival height

Implants ↔ Root Canal Treatment



## Biomechanics of elastic arteries

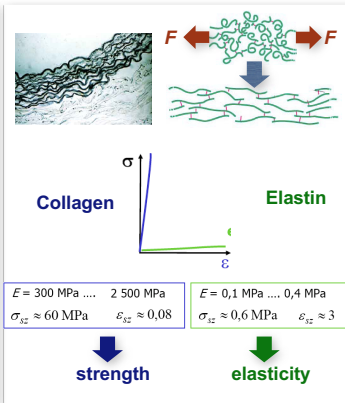
**Non-linear elasticity**  
Strain is not linearly proportional to stress.



**Determinants of vascular elasticity:**

Elastin  
Collagen  
Smooth muscle

**Implications of vascular elasticity:**  
Storage of potential (elastic) energy  
Dampening of pressure pulses  
Constant flow rate



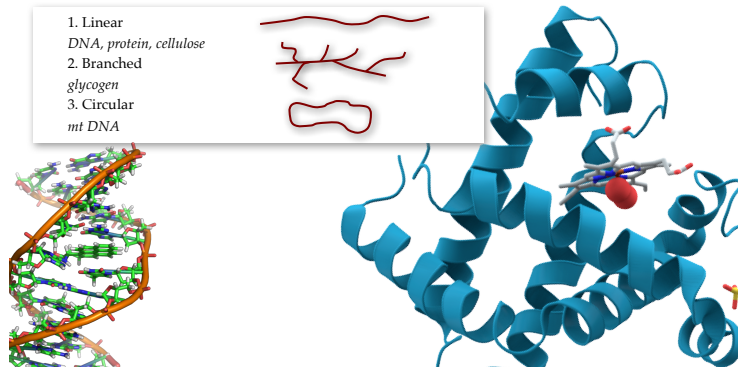
Physical bases of dental material science

## BIOMECHANICS

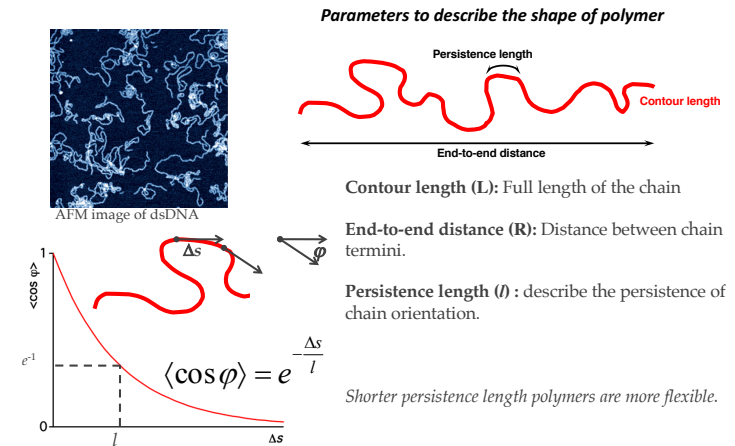
### Molecular nanomechanics

## Biomolecules are polymers

**Common feature:** Linear primary structure (protein, DNA)  
**Strong bonds between monomers (covalent)**  
**Weaker interactions between distant region of polymer chain**

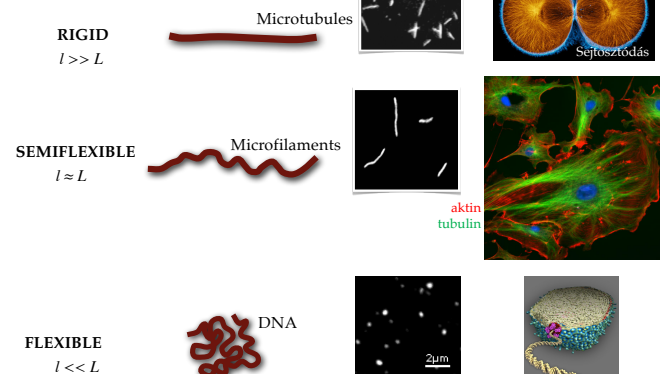


## What is the shape of biopolymers?



## Biopolymer classification based on flexibility

$l$  = persistence length  
 $L$  = contour length



## Are biopolymers elastic?

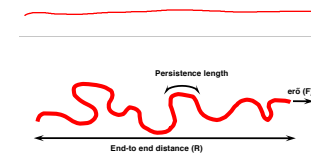
Yes, but Hooke's law is not valid! Non-linear elasticity.

### Entropic elasticity

Thermal energy ( $k_B T$ ) excites bending movements in the chain

The chain's disorder (entropy) increases

The chain shortens

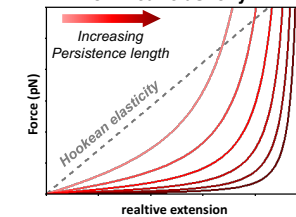


### Force is needed to stretch an entropic chain

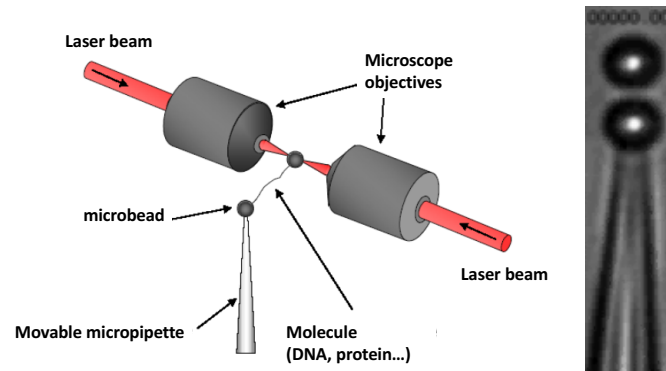
$$F \sim \frac{k_B T}{l} \cdot \frac{R}{L} + \left(\frac{R}{L}\right)^a$$

$F$  = force  
 $l$  = persistence length  
 $k_B$  = Boltzmann constant  
 $T$  = absolute temperature  
 $L$  = contour length  
 $R$  = end-to-end distance  
 $R/L$  = relative extension

### Nonlinear elasticity

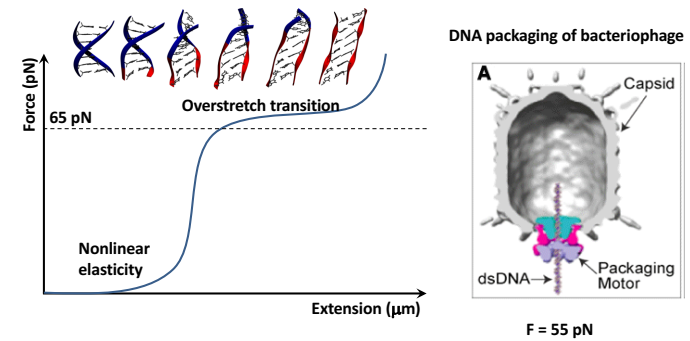


## How to stretch single molecules? *Optical tweezers*

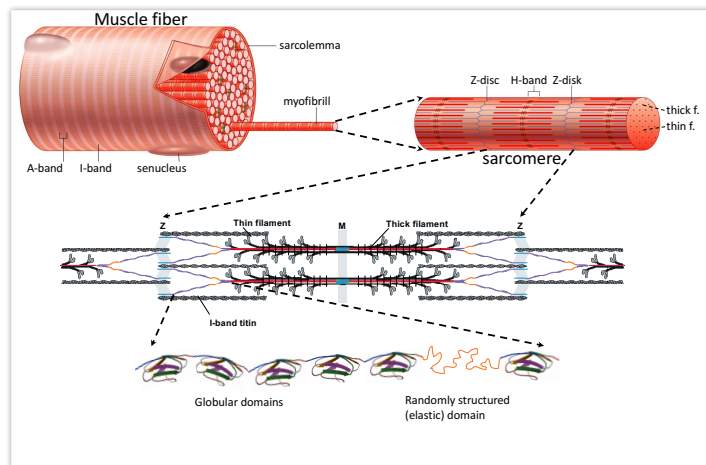


<http://glass.phys.uniroma1.it/dileonardo/Applet.php?applet=TrapForcesApplet>

## Stretching dsDNA with optical tweezers



## Titin: elastic filament of the sarcomere



## Titin is the main determinant of muscle elasticity

