Biomechanika vazů a chrupavek

Struktura, viskoelasticita, poroelasticita

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Šlacha a vaz

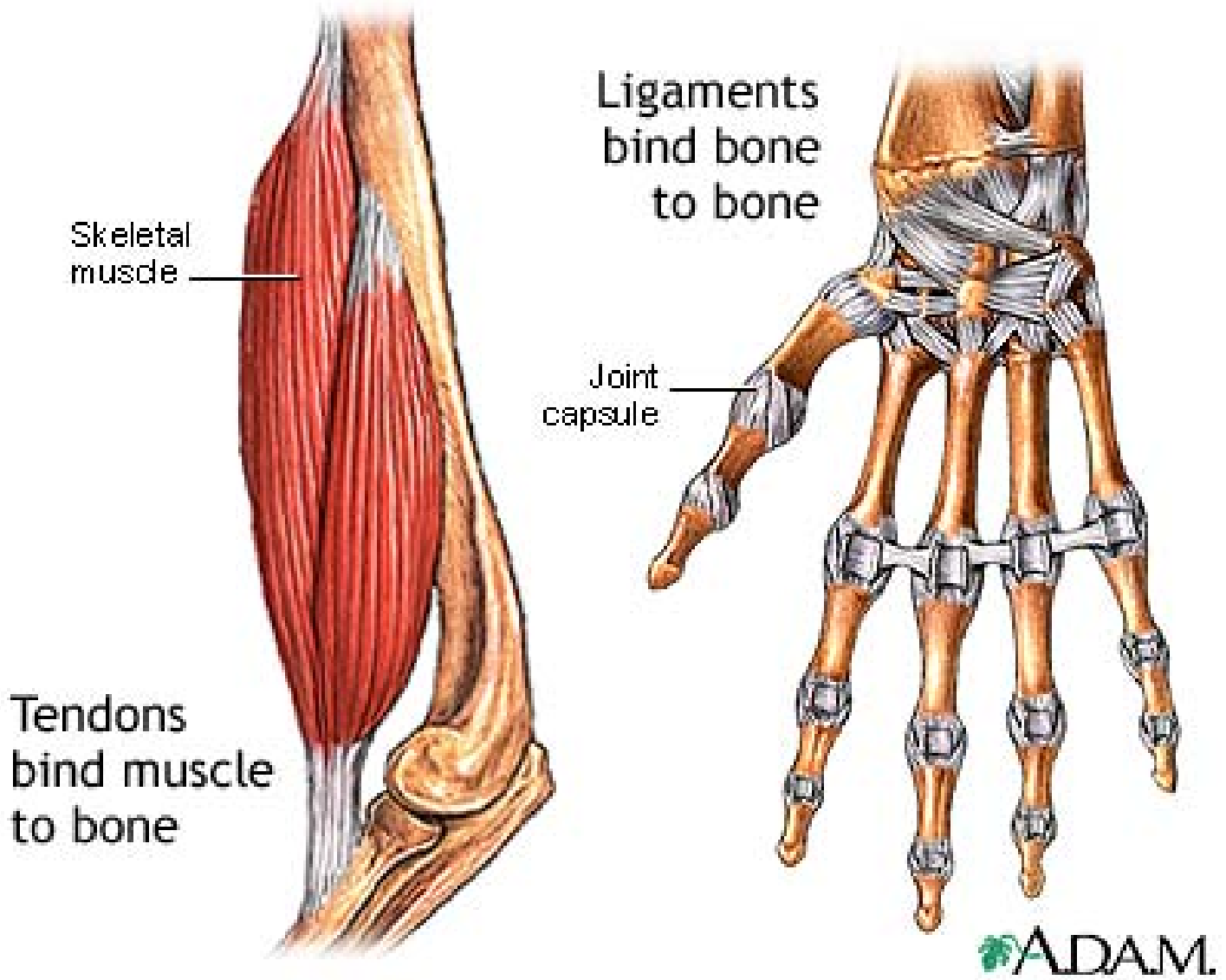
Šlacha vazivo spojující sval s kostí

Vaz je součástí kloubů, kde spojuje jednotlivé kosti nebo drží orgány ve správné poloze (játra, močový měchýř).

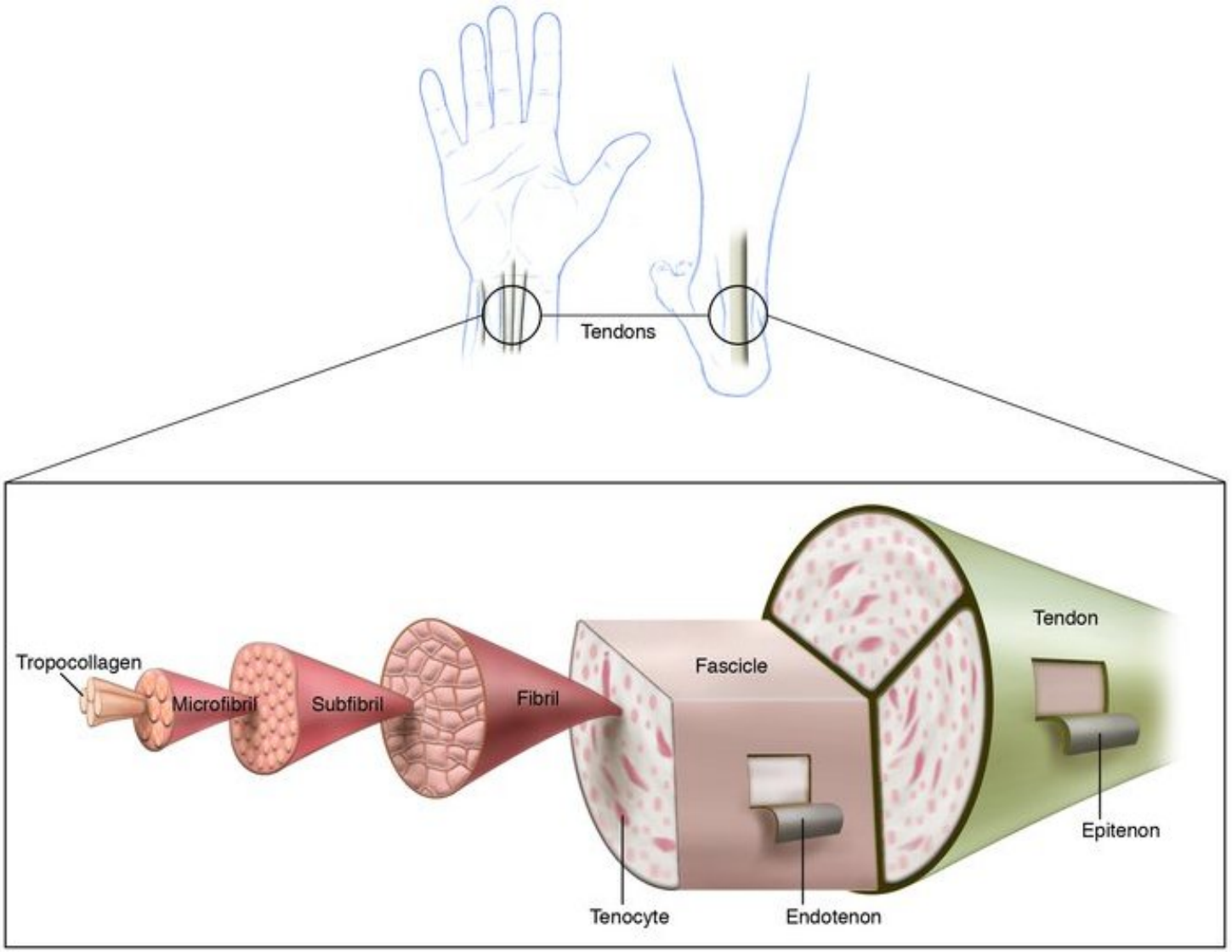
Vlastnosti

- bílá měkká pojivová tkáň
- uspořádané svazky kolagenu
- buňky - fibroblasty

Šlacha a vaz


Skeletal muscle
Tendons bind muscle to bone
Ligaments bind bone to bone
Joint capsule
A.D.A.M.

Struktura


Tendons
Tropocollagen
Microfibril
Subfibril
Fibril
Fascicle
Tendon
Epitenon
Tenocyte
Endotenon

Složení

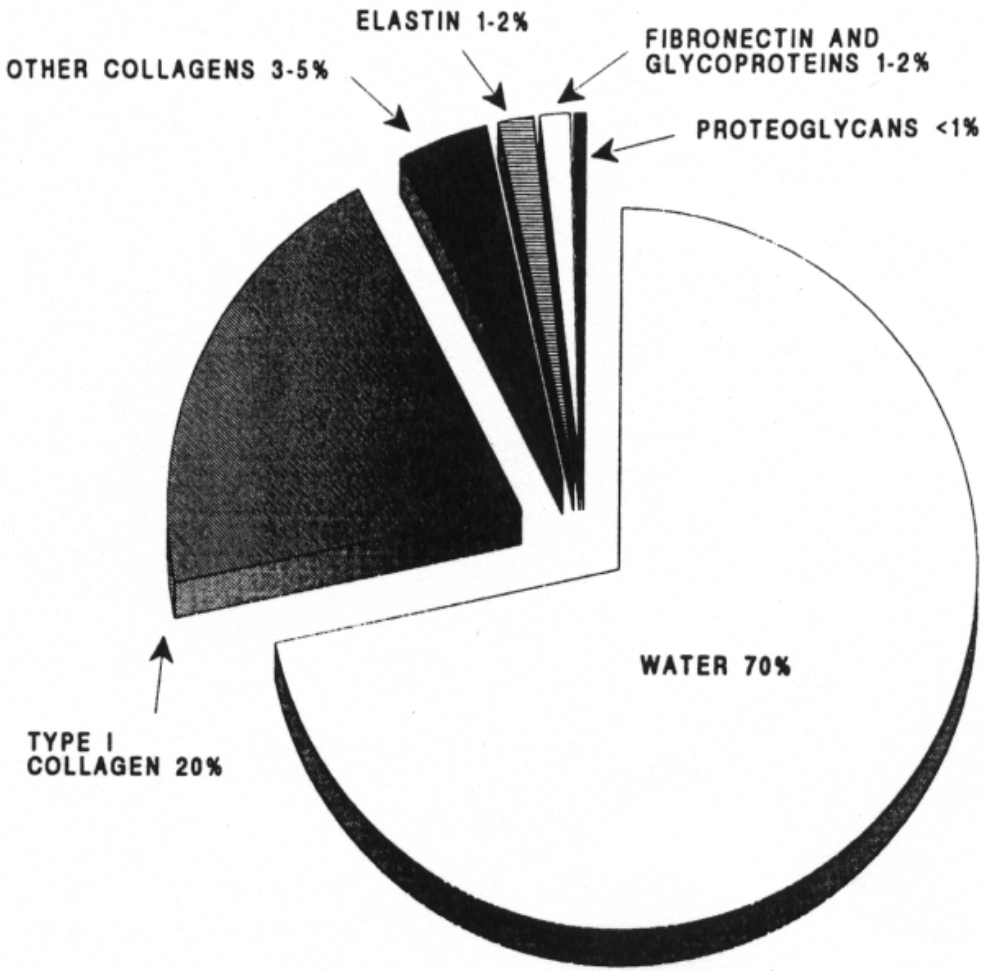
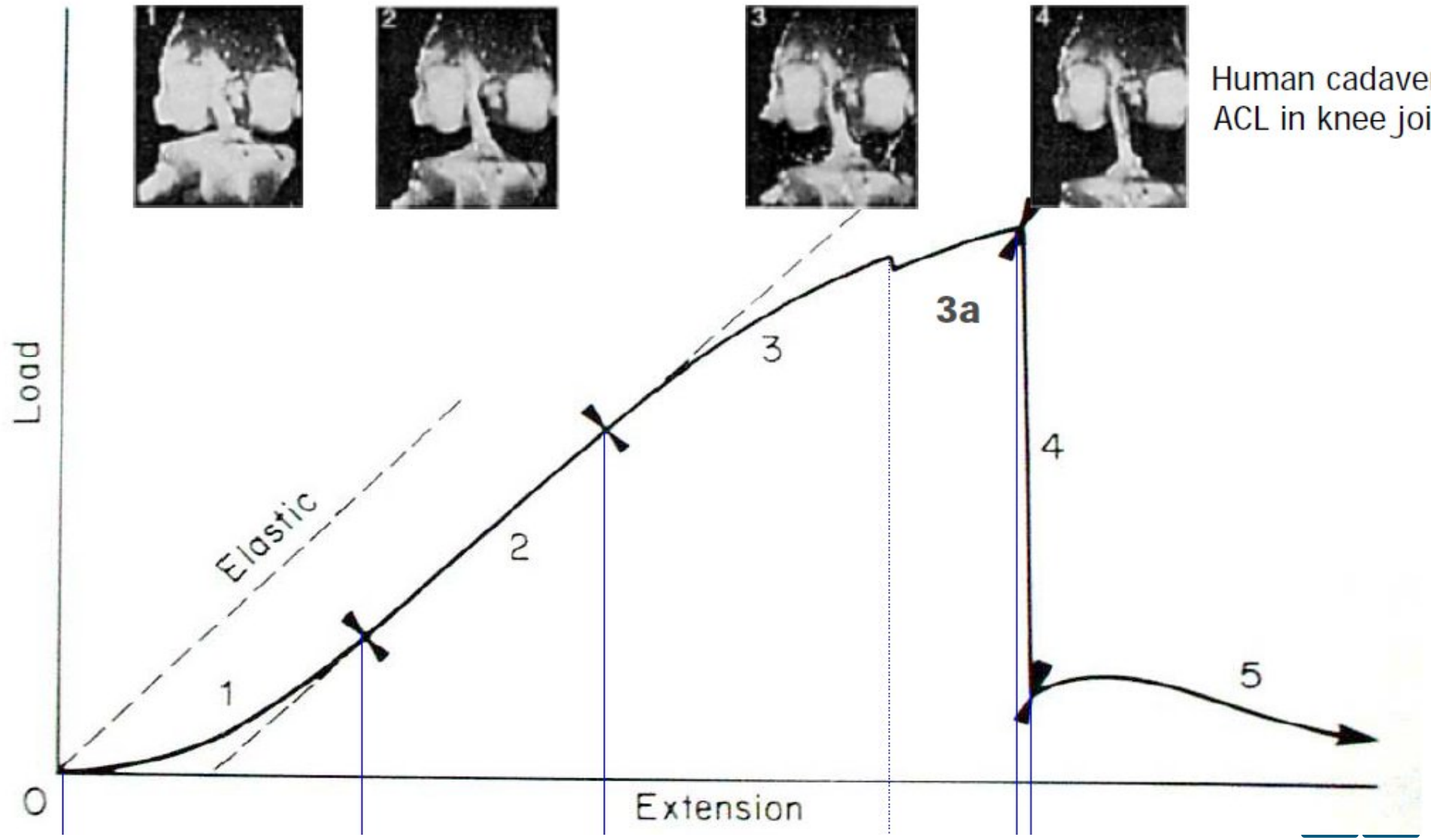


Figure 3.3 Pie graph showing the normal biochemical composition of a typical ligament (used with permission from Frank *et al.*, 1994).

Porovnání

	Vaz	Šlacha
% kolagenu	nižší	vyšší
organizace	více náhodná, zvlněná	ve směru dlouhé osi

Tahová zkouška



Mikrostruktura

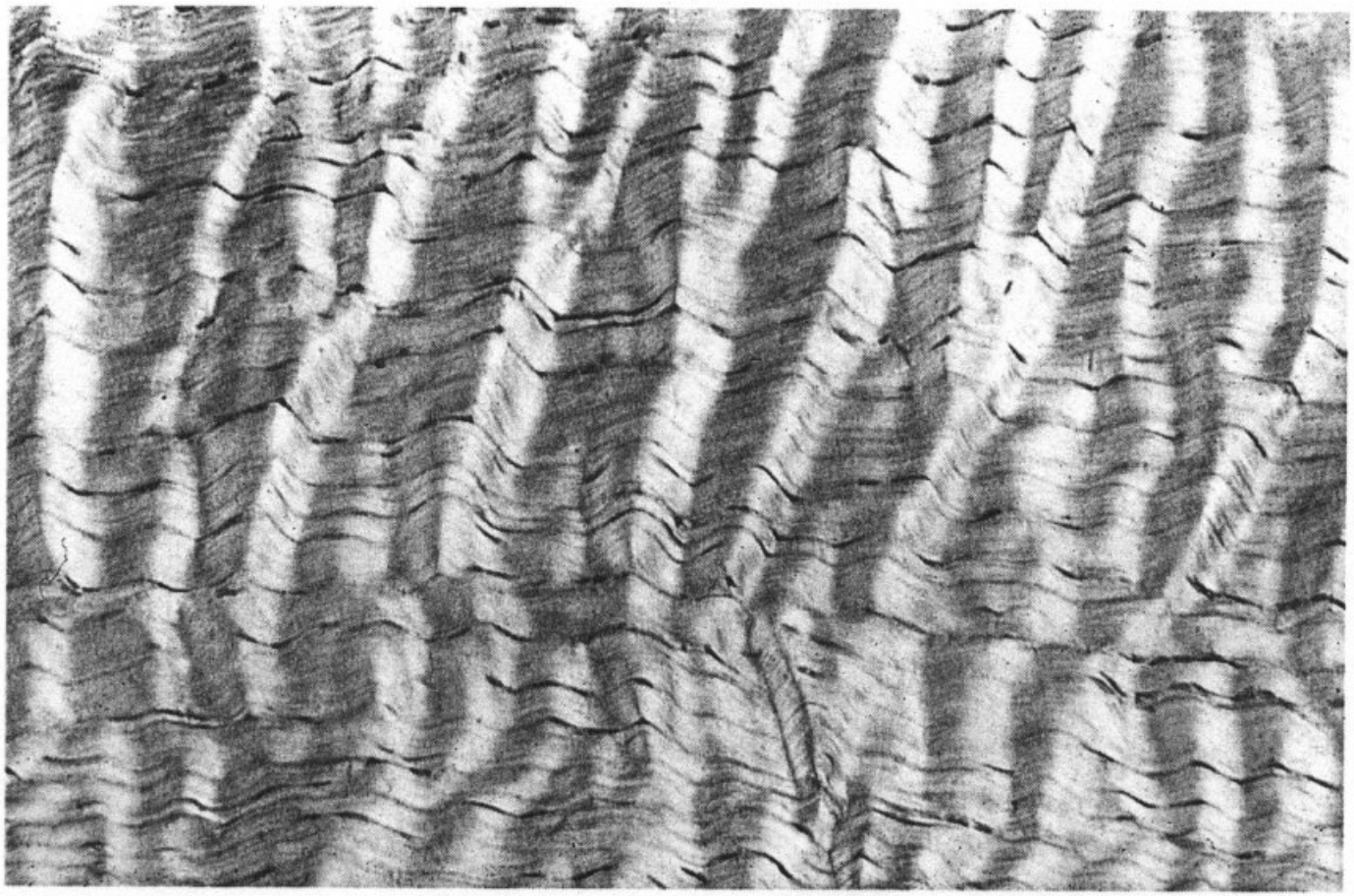
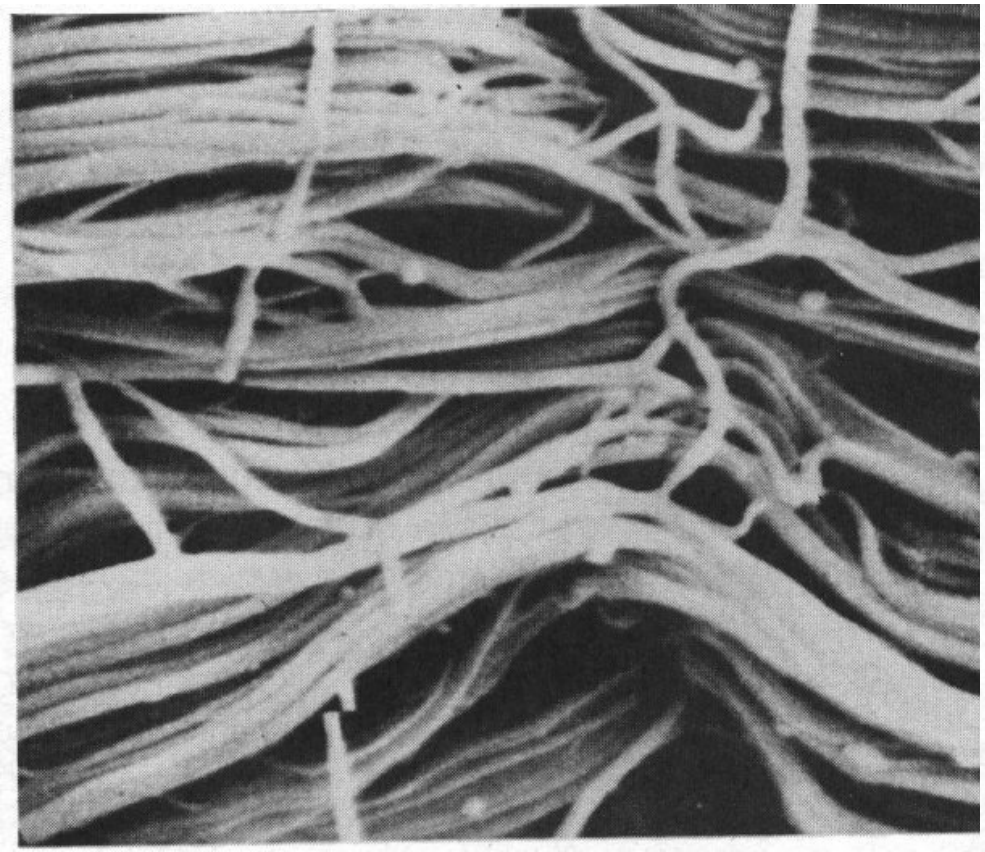
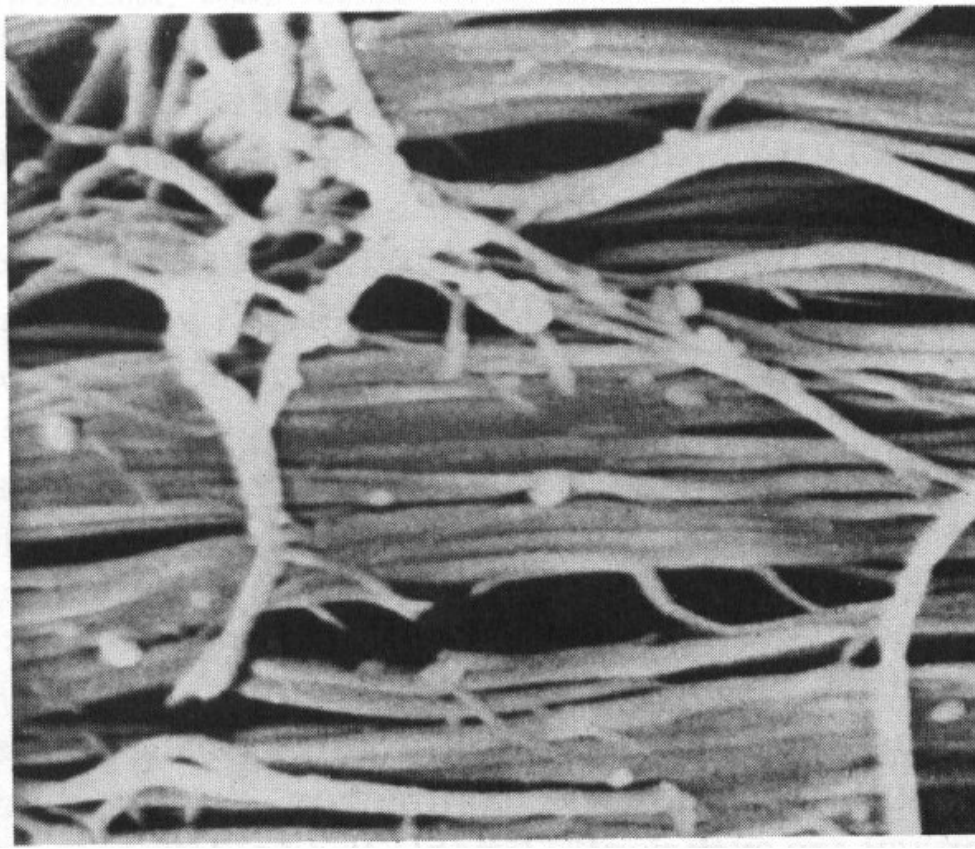


Figure 3.2 The microscopic appearance of ligament 'crimp'. This is one of the keys to normal fibre recruitment (H&E, × 60).

Změna po zátížení



Před zatížením

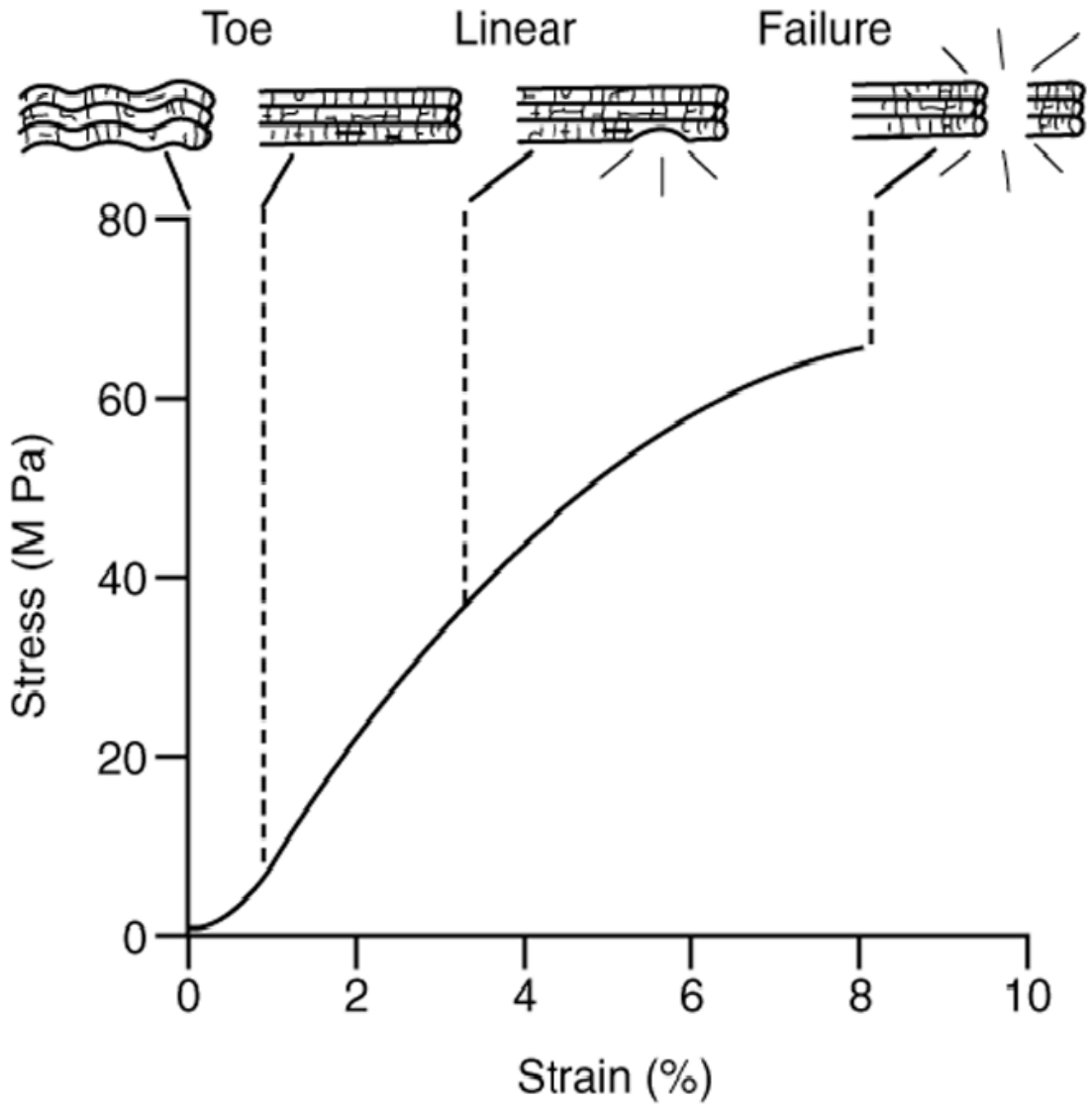


Po zatížení

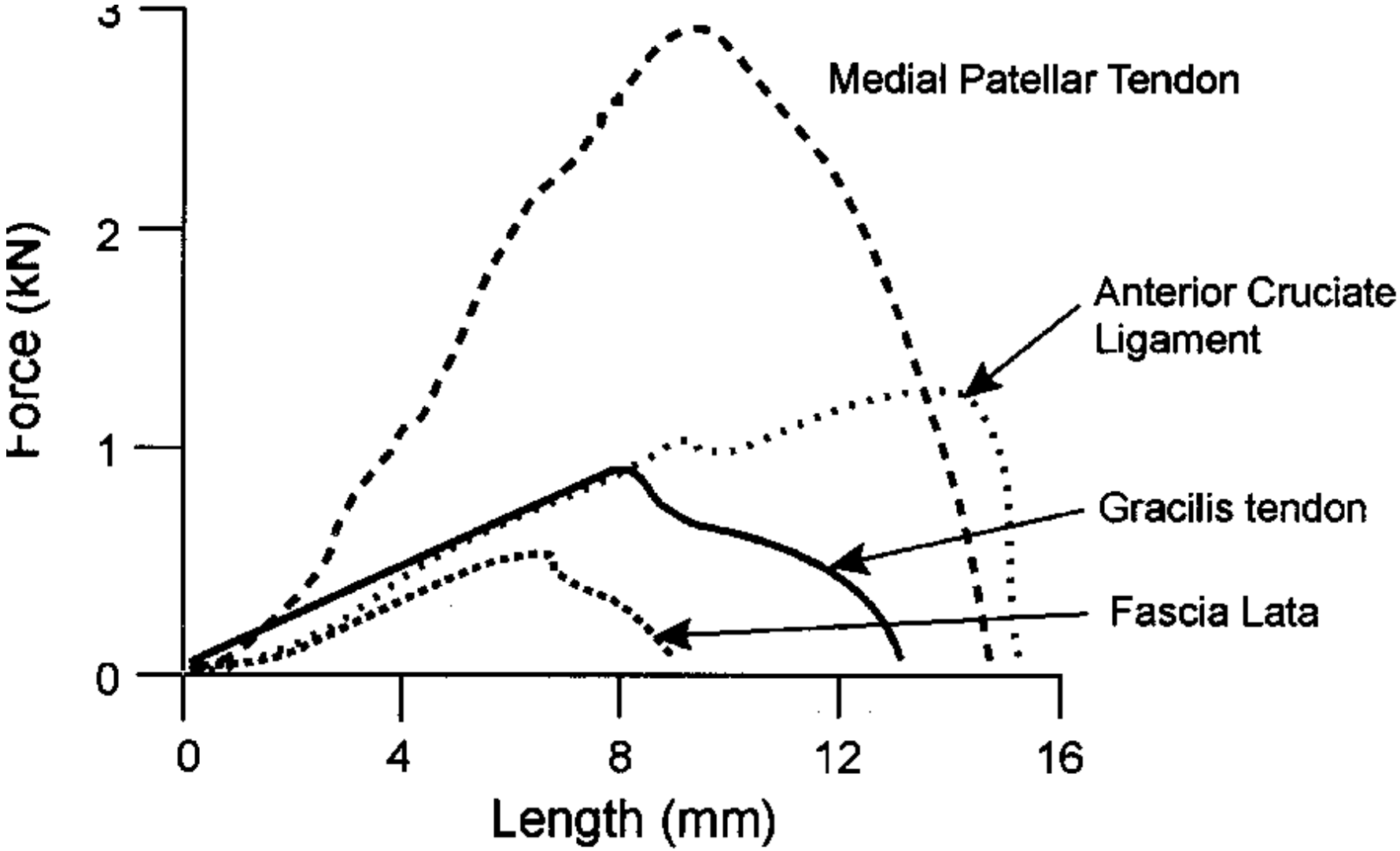
Pružnost a pevnost

	Vaz	Šlacha
mez pevnosti	méně než šlacha	50-150 MPa
E	150-350 MPa	1200 - 1800 MPa

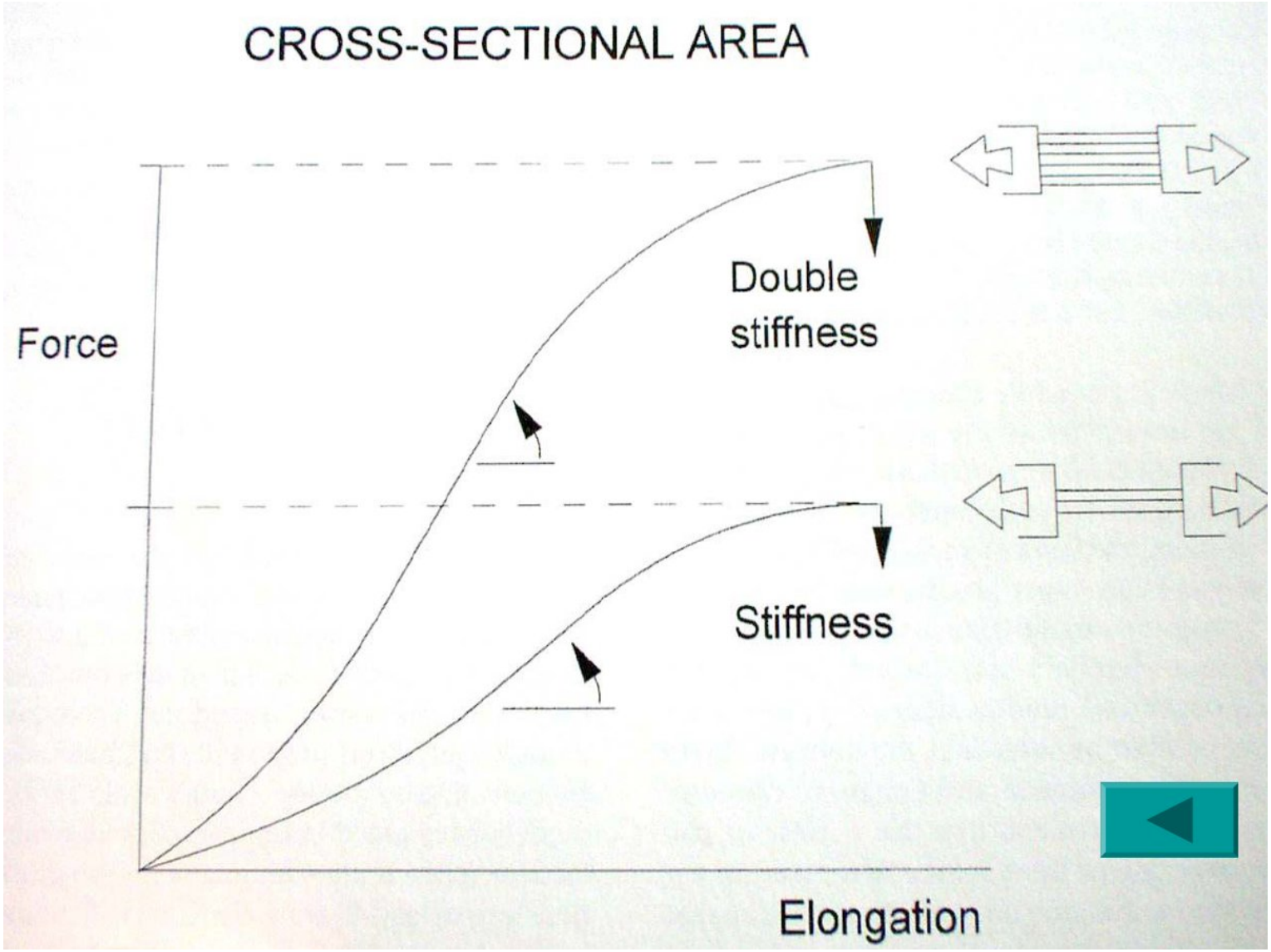
Pracovní diagram šlachy



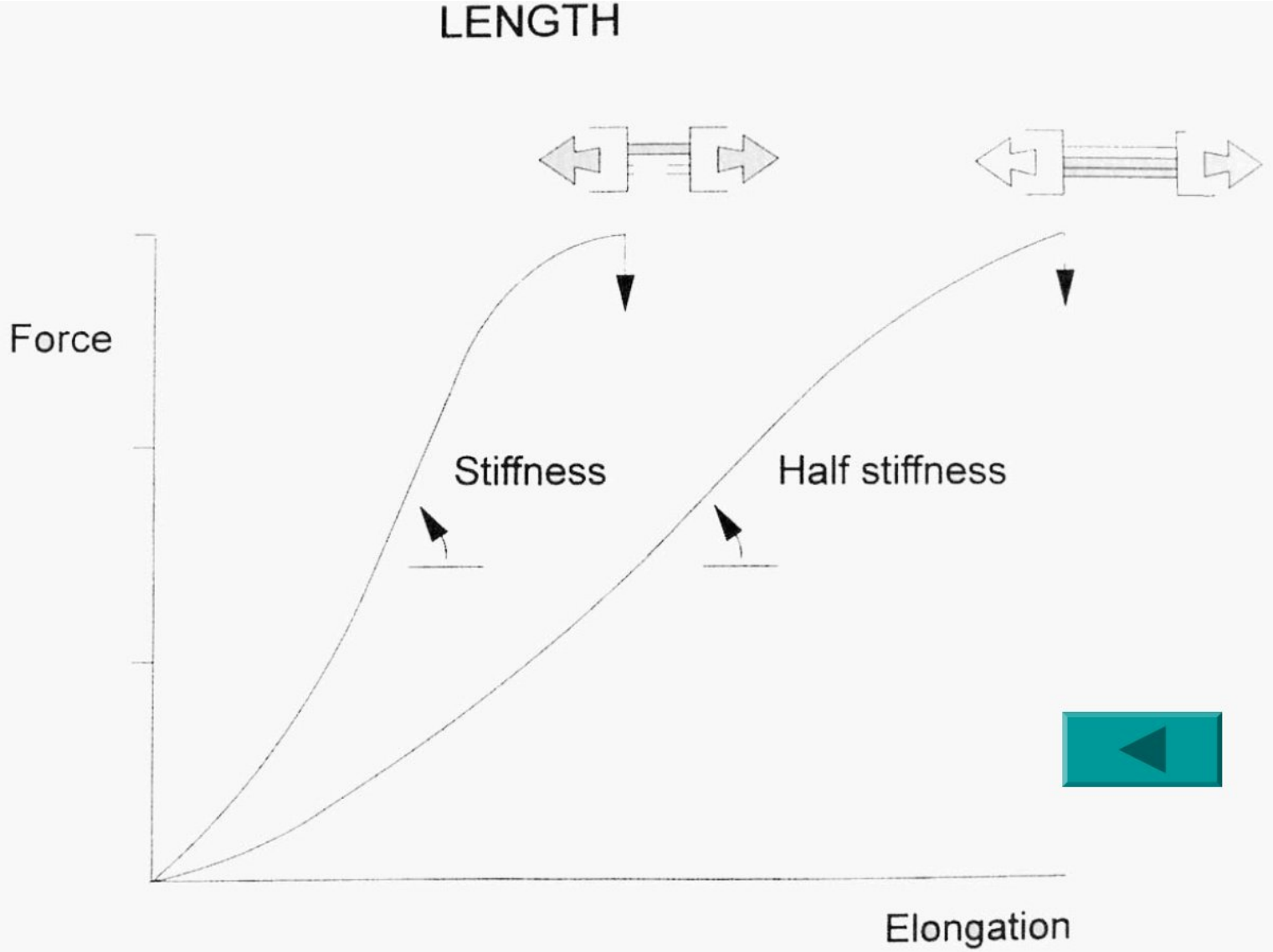
Sila/deformace šlachy



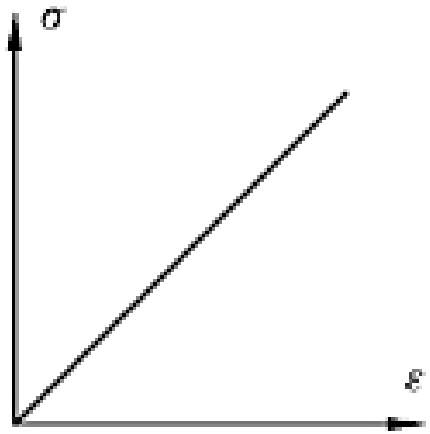
Hookeův zákon



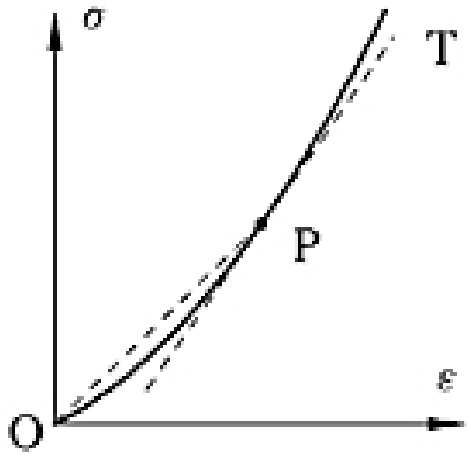
Hookeův zákon



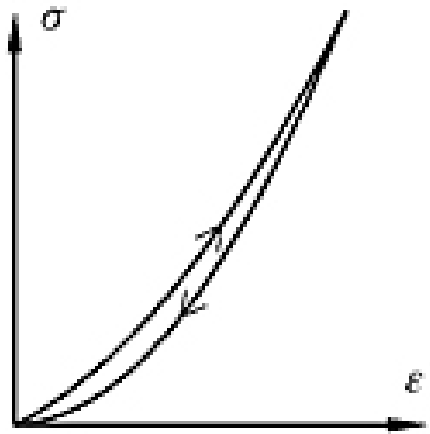
Nelineární elasticita



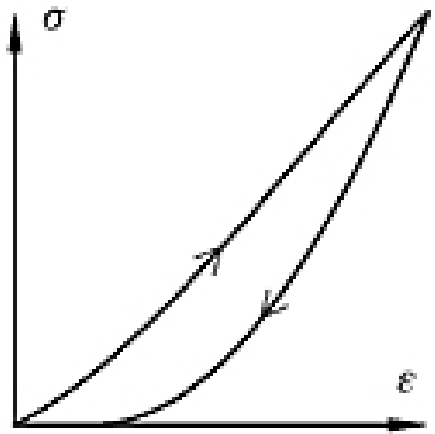
a)



b)

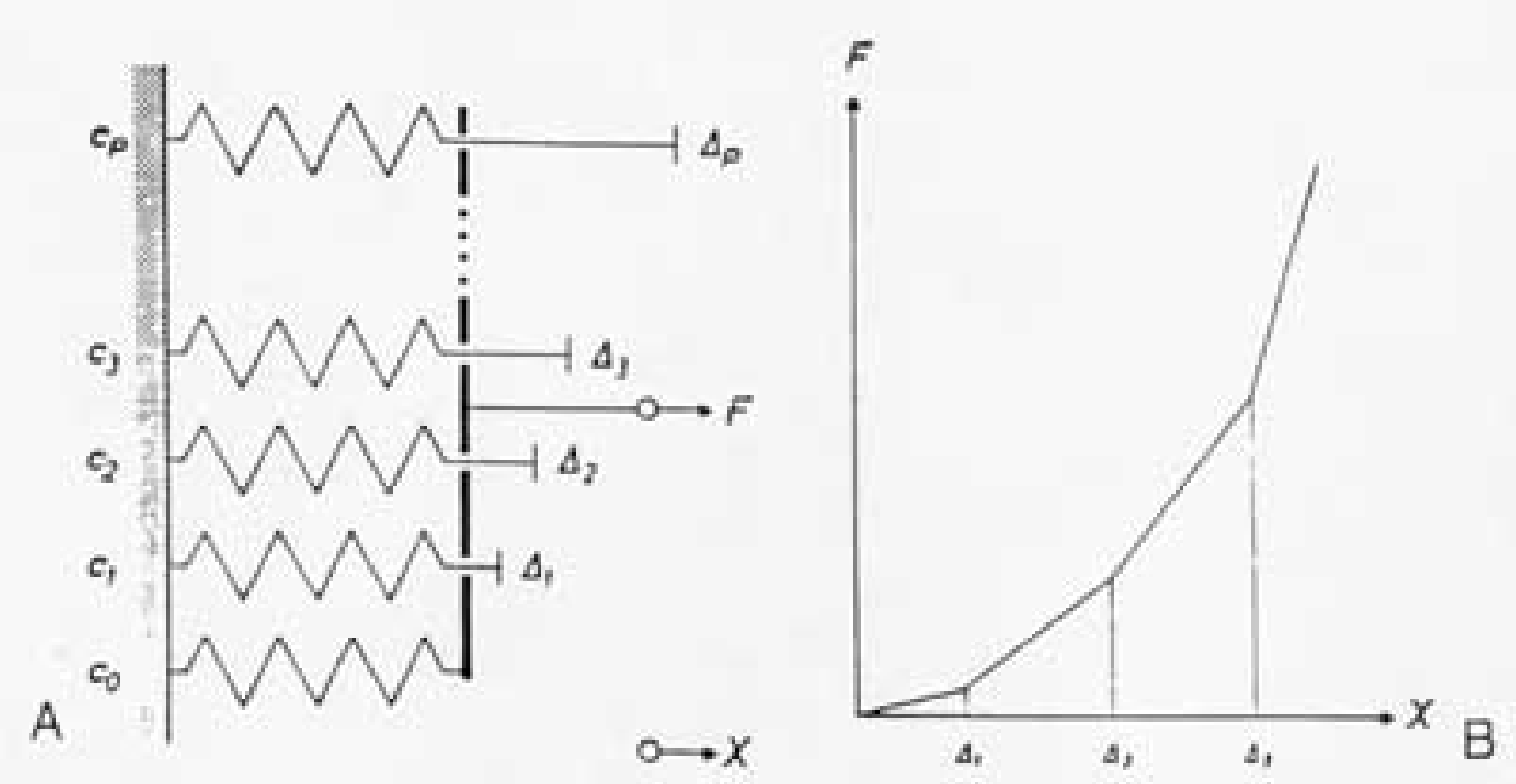


c)

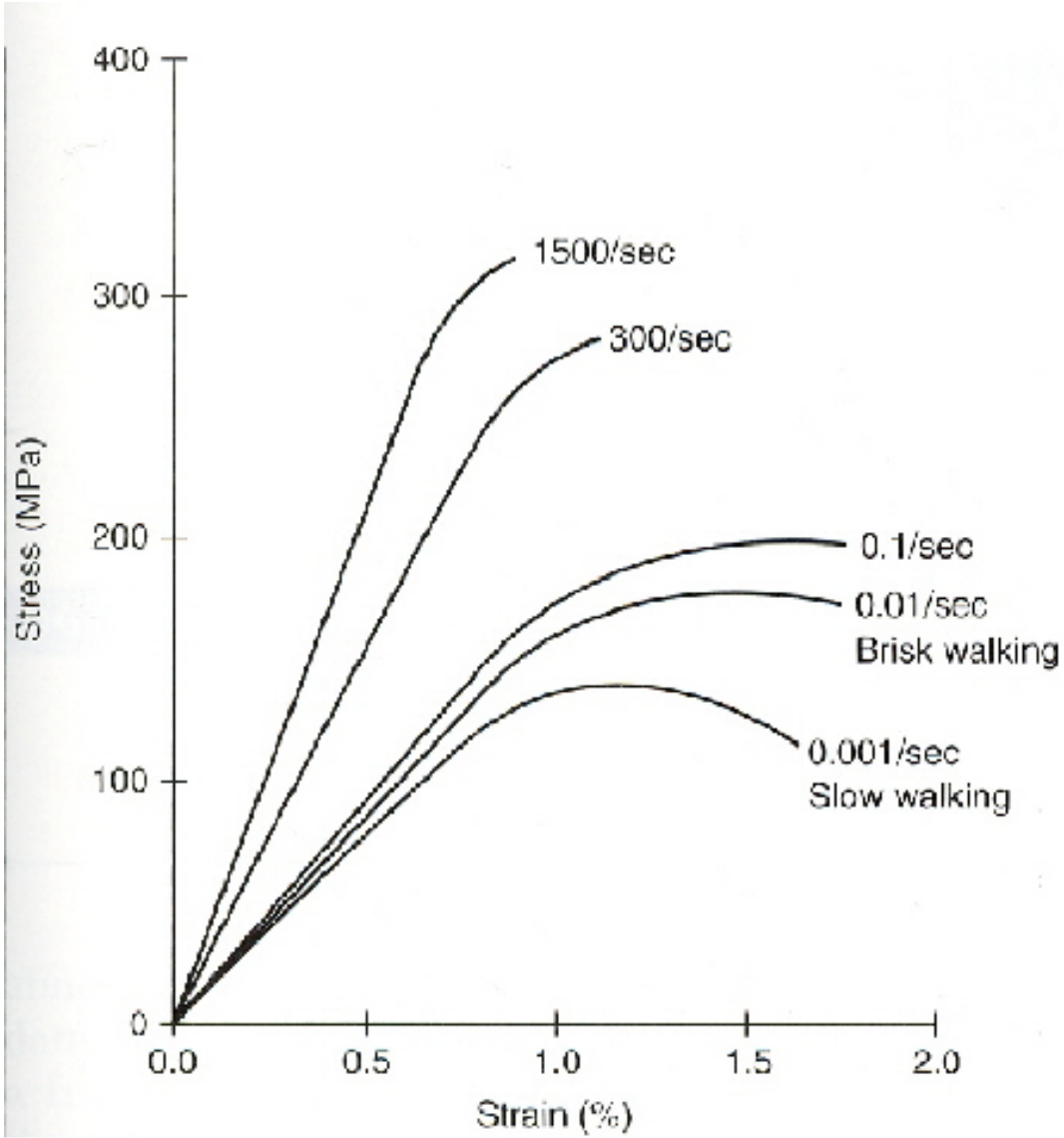


d)

Nelineární elasticita



Rychlost zatěžování



Viskoelasticita

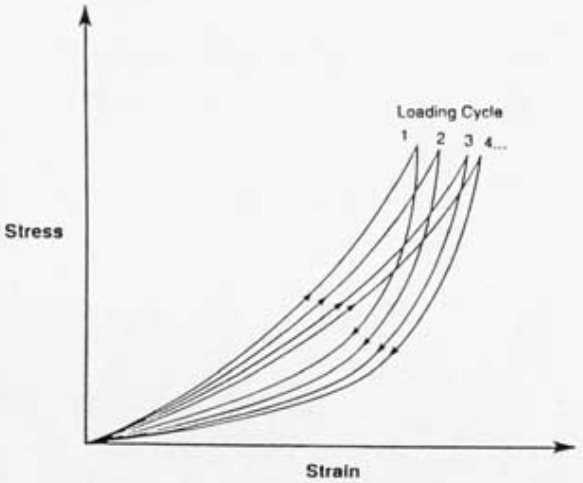
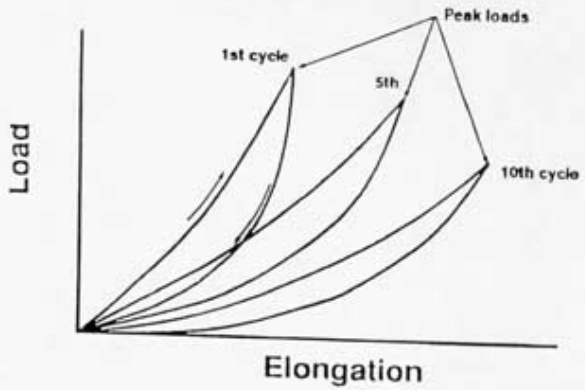
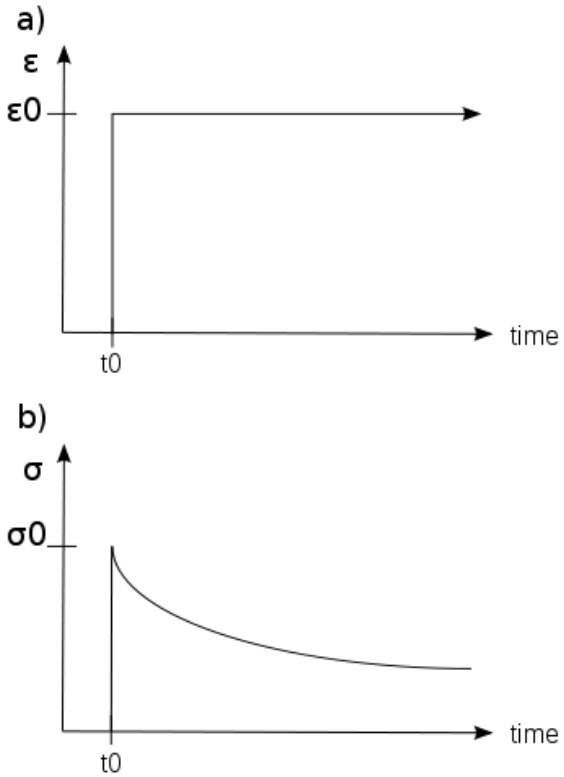


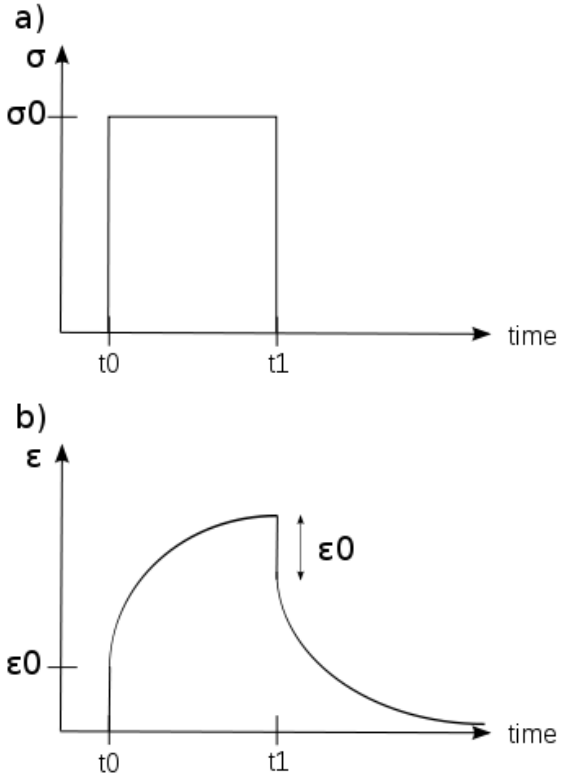
Figure 14
During cyclic loading of tendon, the stress-strain curve gradually shifts to the right. Usually, after 10 cycles, the curves become quite repeatable and steady.



Viskoelasticita



relaxace napětí

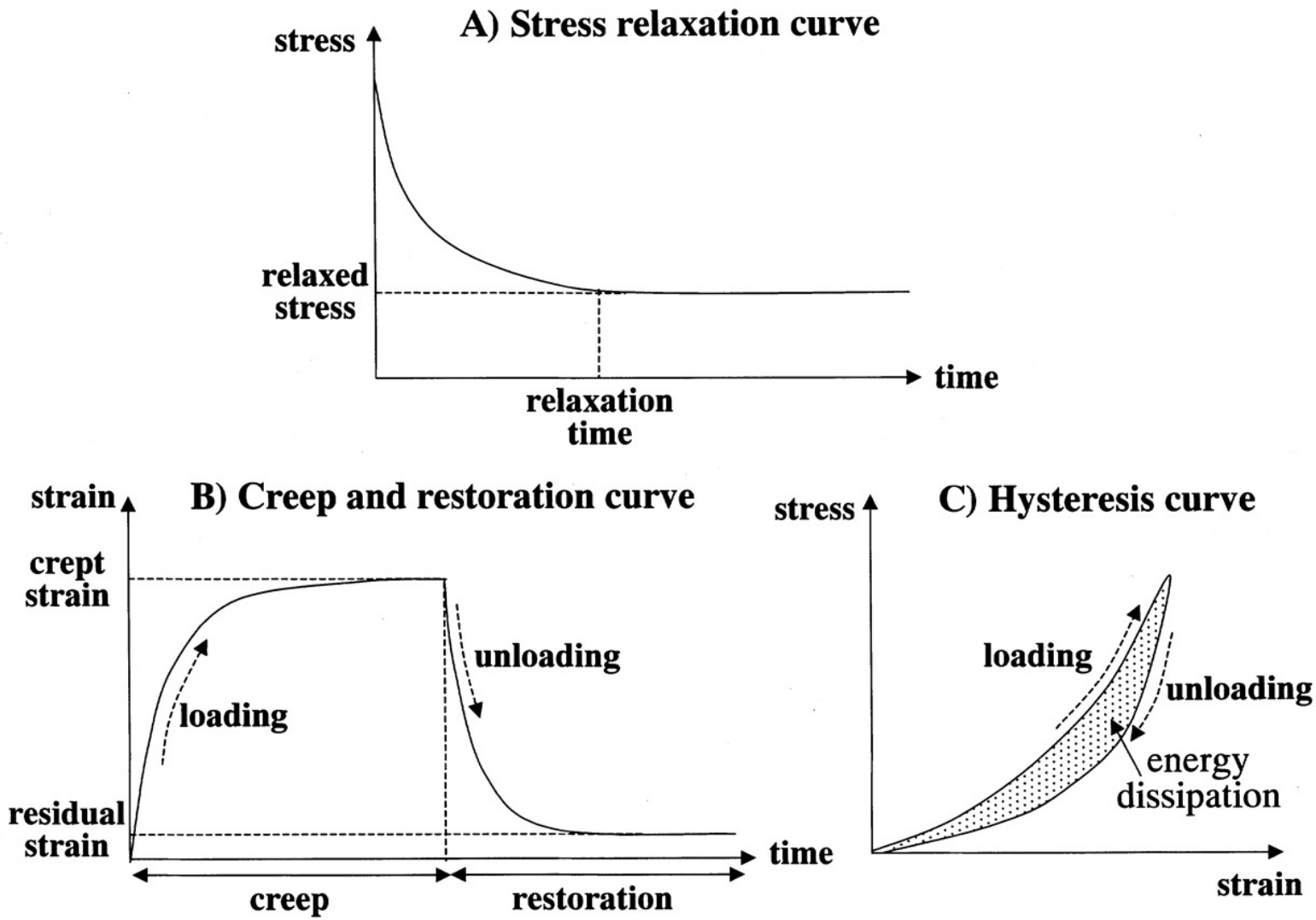


creep

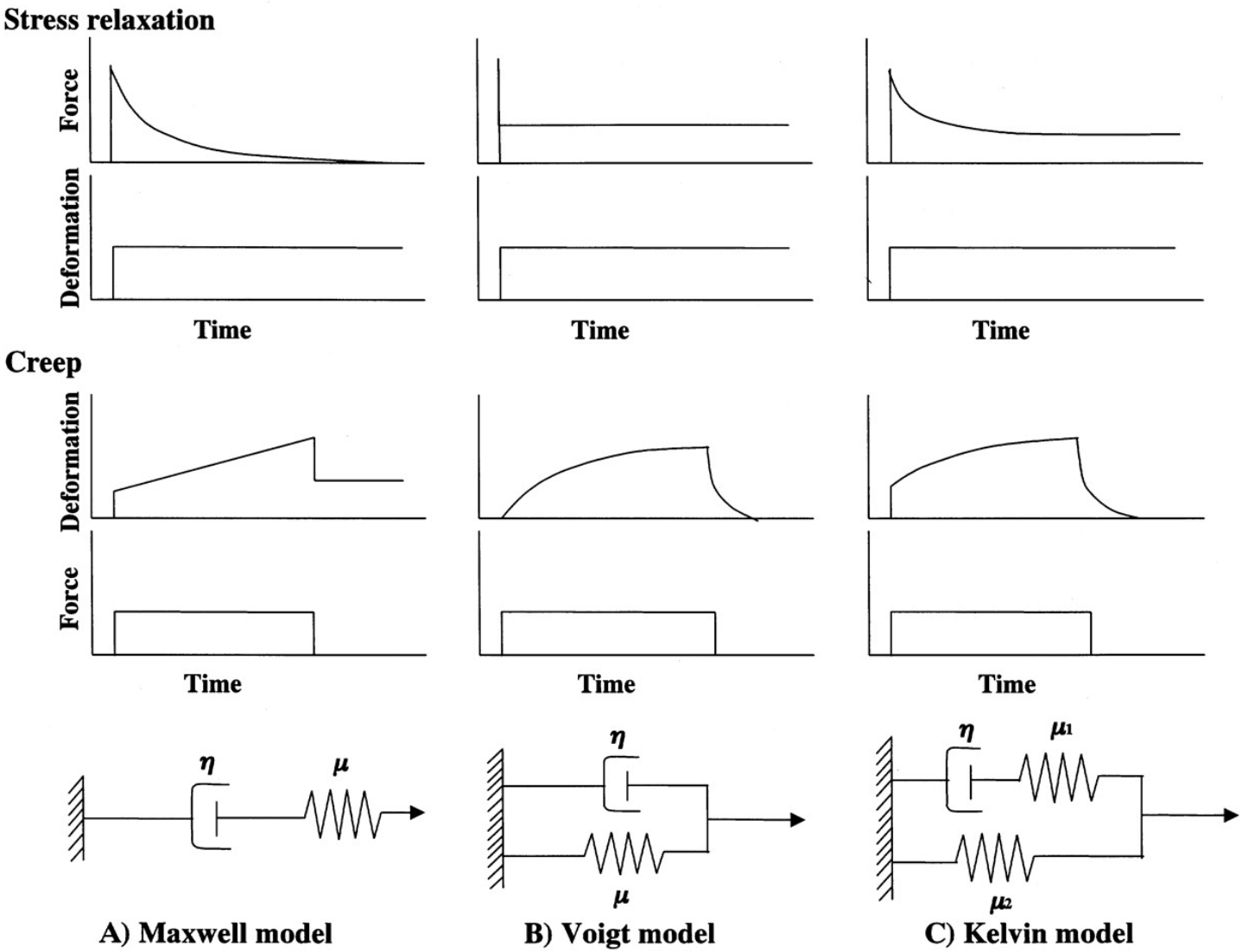
Viskoelasticita

časová závislost vztahu napětí a deformace

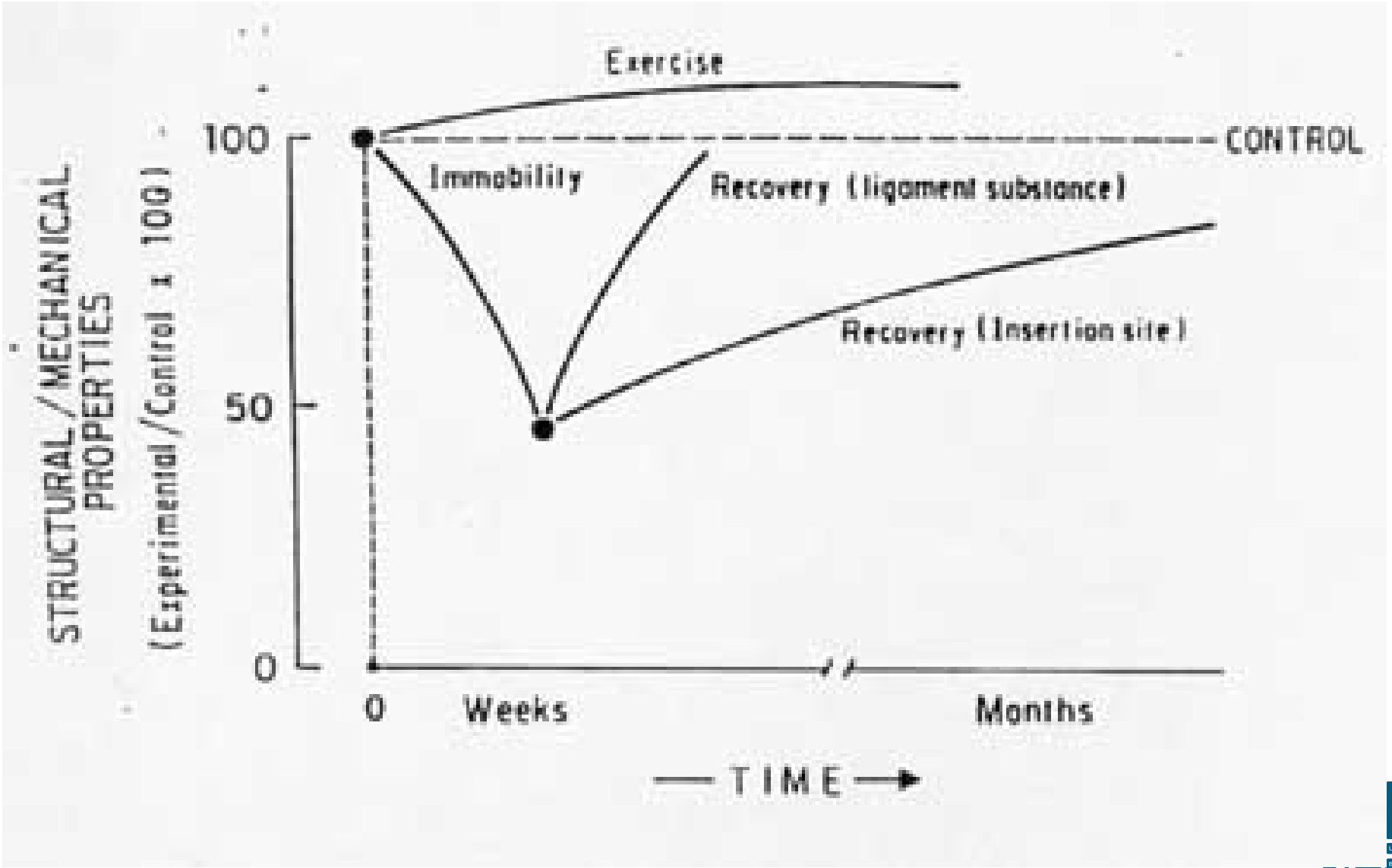
Viskoelasticita



Modely


Stress relaxation
Force
Deformation
Time
Time
Time
Creep
Deformation
Force
Time
Time
Time
η
μ
η
μ
η
μ1
μ2
A) Maxwell model
B) Voigt model
C) Kelvin model

Remodelace šlachy



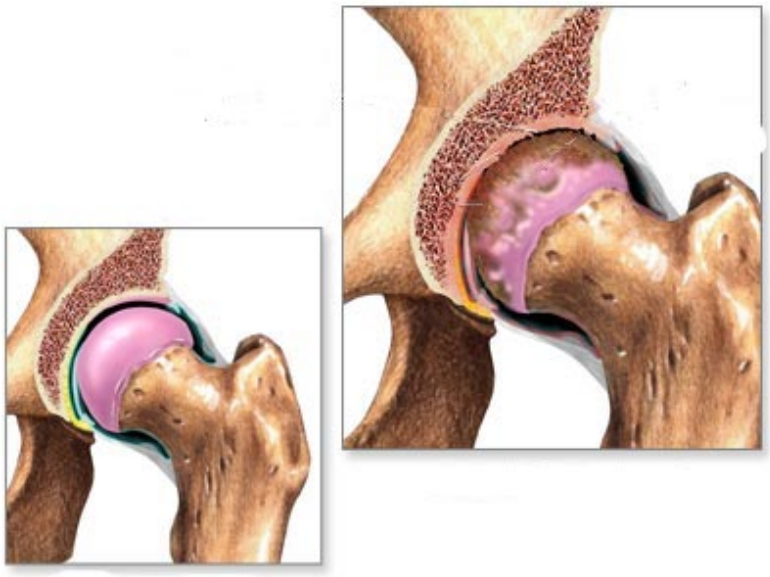
Chrupavka

Hyalinní chrupavka (sklovitá, kloubní) nejběžnější, tvrdá, hladká, průhledná, kryje povrchy kostí a kloubů;

Elastická chrupavka ušní boltec, příklopka hrtanová a drsné průdušky;

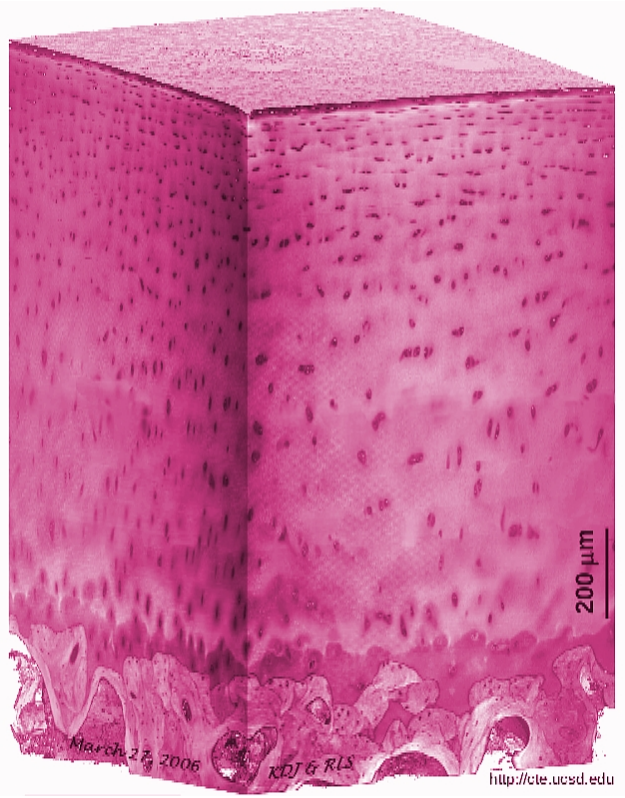
Vazivová chrupavka velmi odolná mechanicky, v meziobratlových ploténkách, symfýza;

Složení a funkce



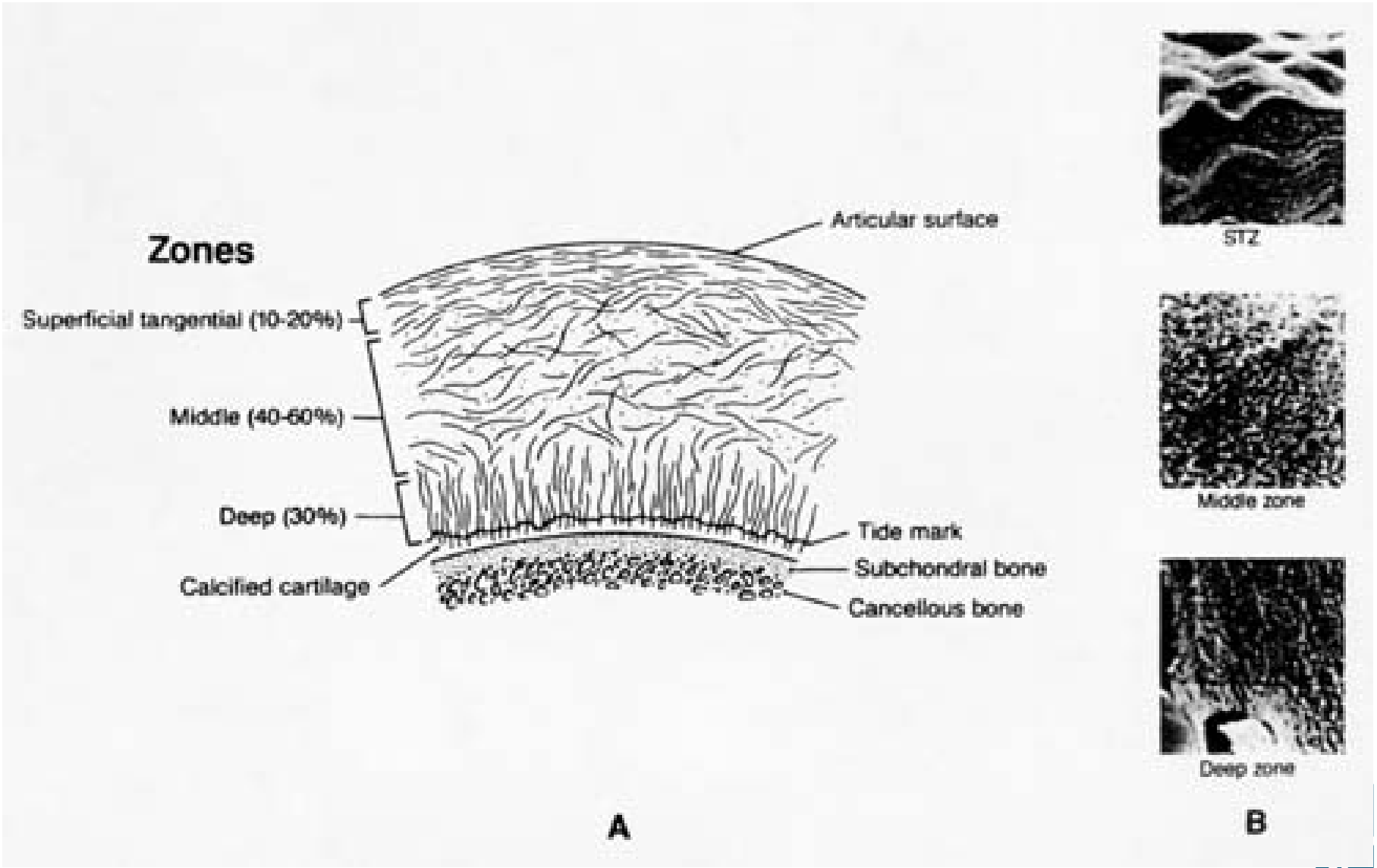
Funkce

- kryje kosti
- snižuje tření
- absorbuje nárazy

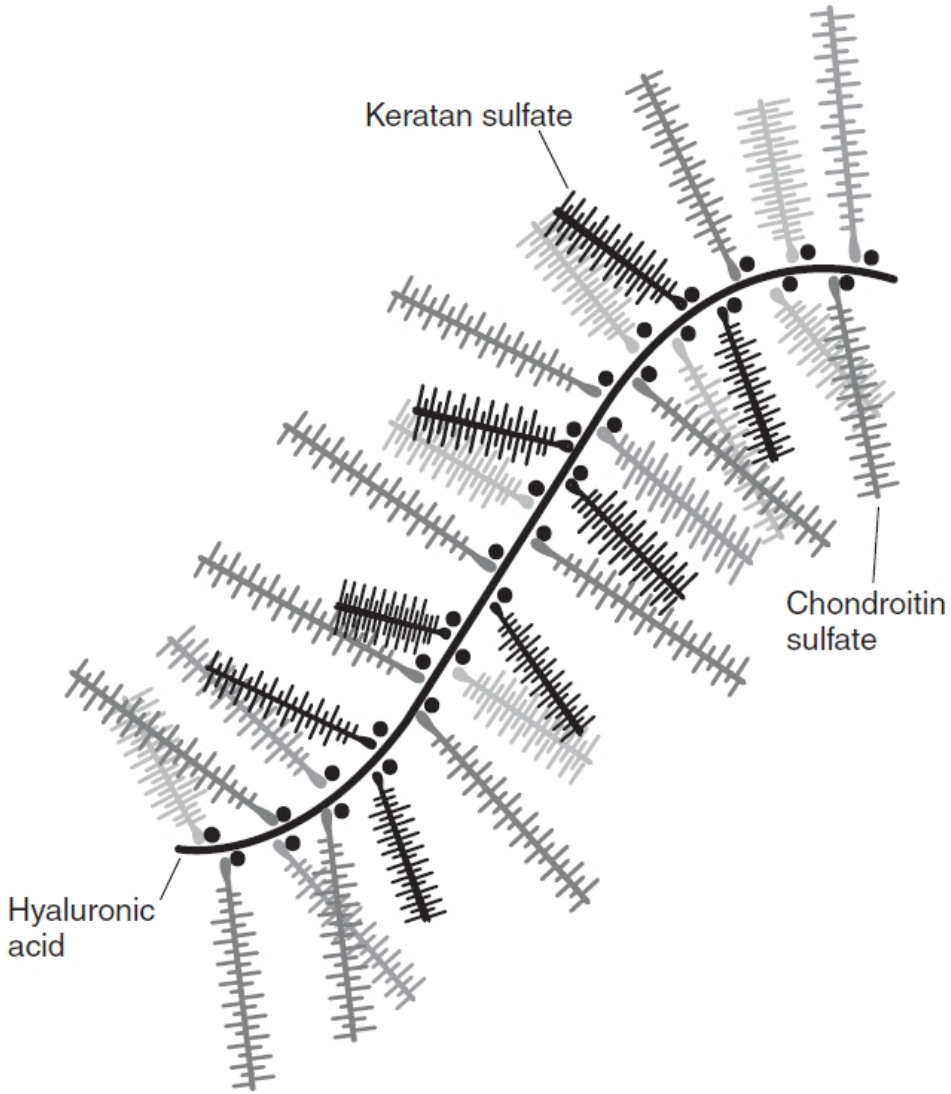


Struktura kolagen, proteoglykany, chondrocyty

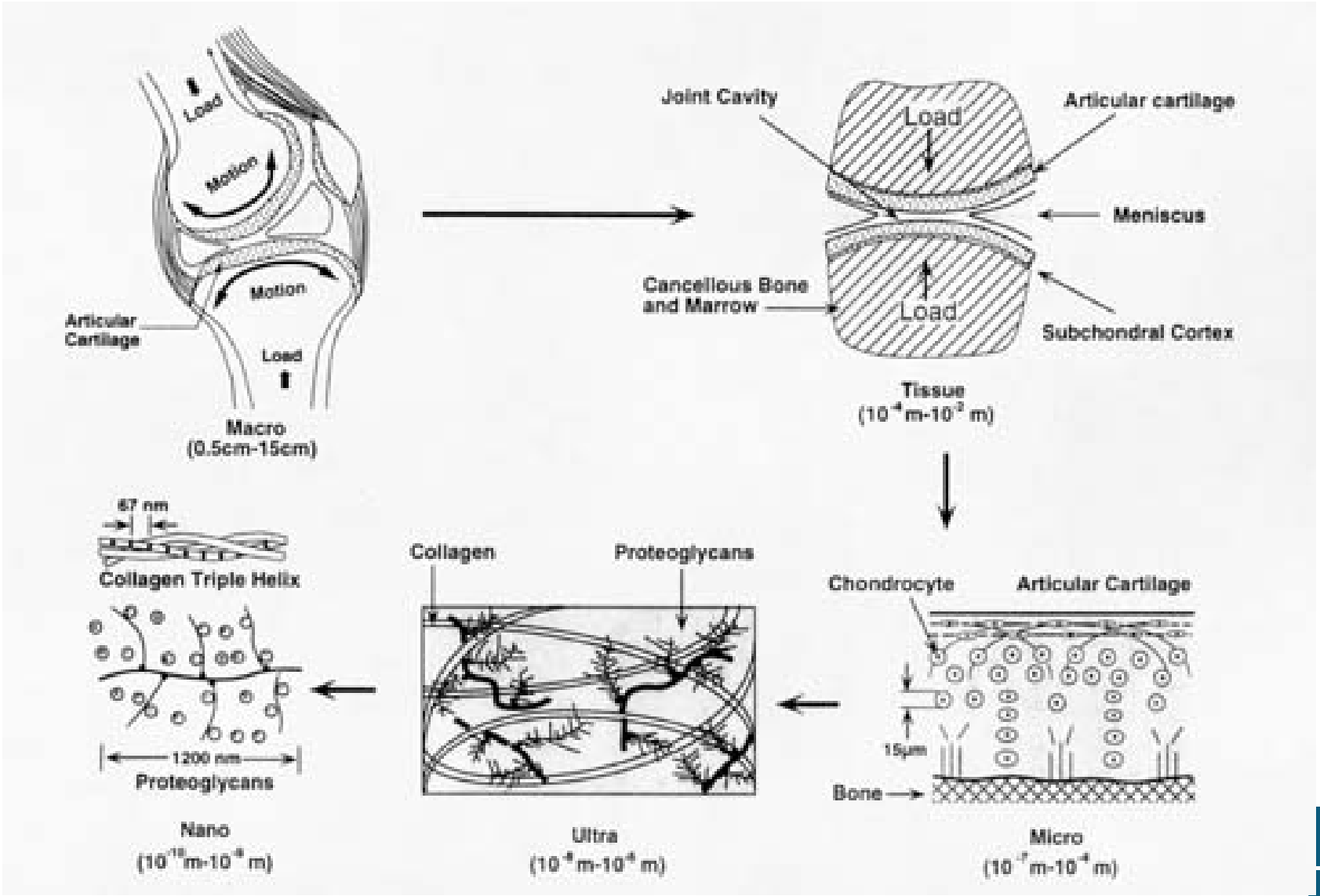
Chrupavka


Zones
Articular surface
Superficial tangential (10-20%)
Middle (40-60%)
Deep (30%)
Calcified cartilage
Tide mark
Subchondral bone
Cancellous bone
A
STZ
Middle zone
Deep zone
B

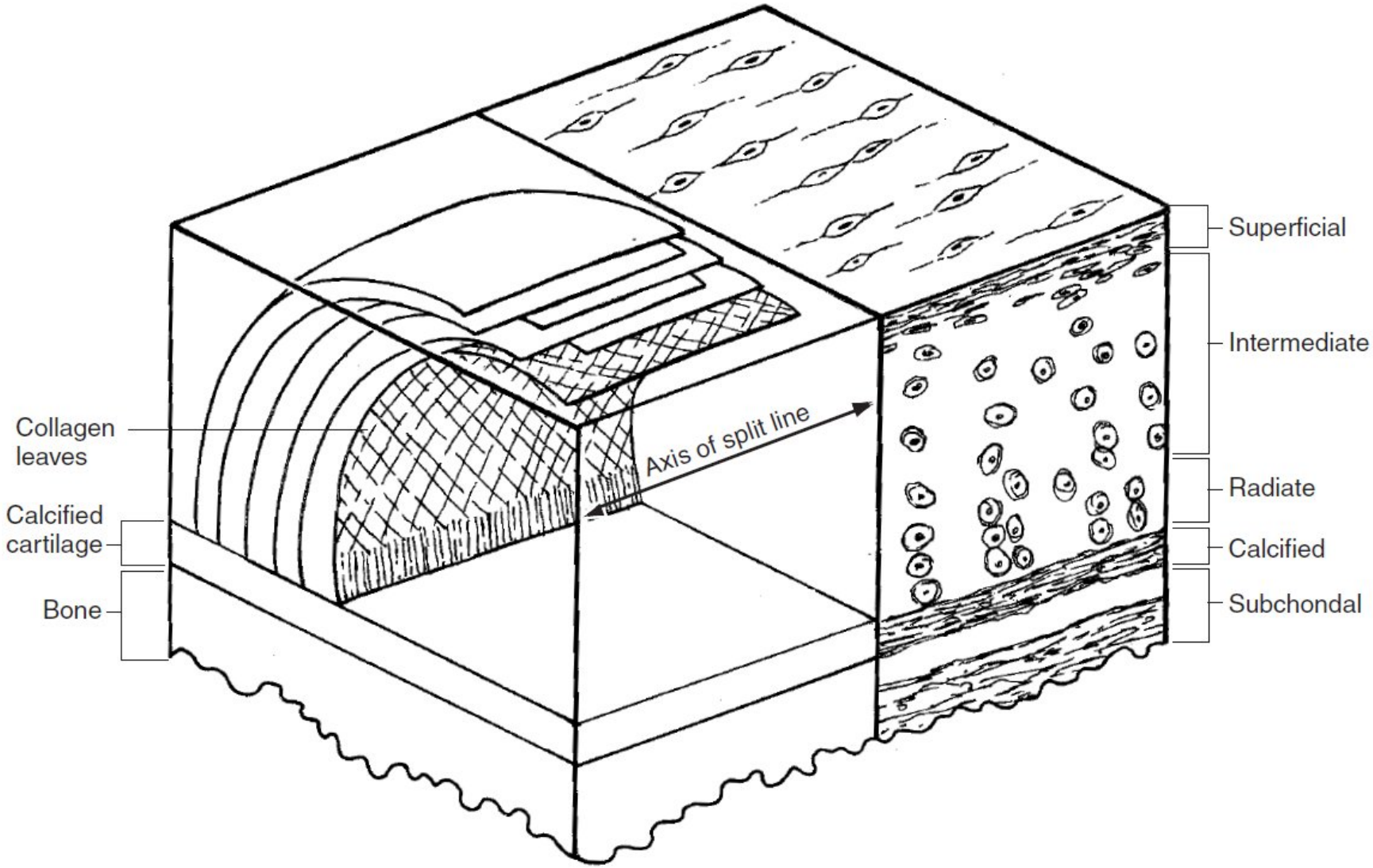
GAG



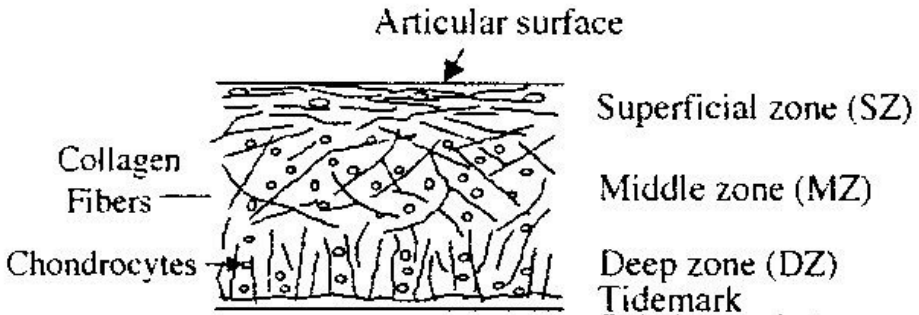
Chrupavka


Load
Motion
Motion
Articular Cartilage
Load
Macro
(0.5cm-15cm)
Joint Cavity
Load
Articular cartilage
Meniscus
Cancellous Bone and Marrow
Load
Subchondral Cortex
Tissue
(10⁻⁴m-10⁻² m)
67 nm
Collagen Triple Helix
1200 nm
Proteoglycans
Nano
(10⁻⁹m-10⁻⁸ m)
Collagen
Proteoglycans
Ultra
(10⁻⁸m-10⁻⁶ m)
Chondrocyte
Articular Cartilage
15μm
Bone
Micro
(10⁻⁷m-10⁻⁴ m)

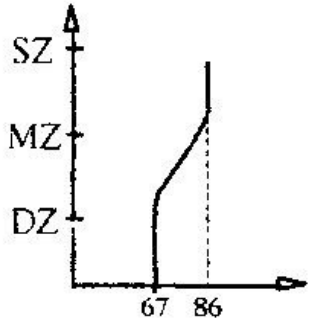
Struktura


Collagen leaves
Calcified cartilage
Bone
Axis of split line
Superficial
Intermediate
Radiate
Calcified
Subchondal

Zonální struktura chrupavky

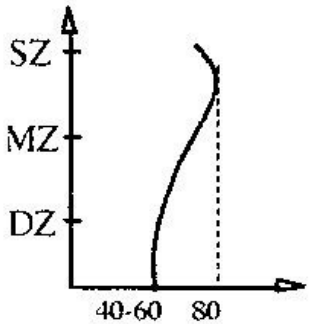


(a)



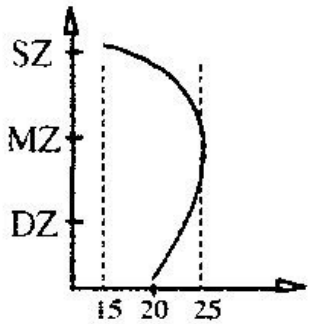
% collagen content (dry weight)

(b)



% water content

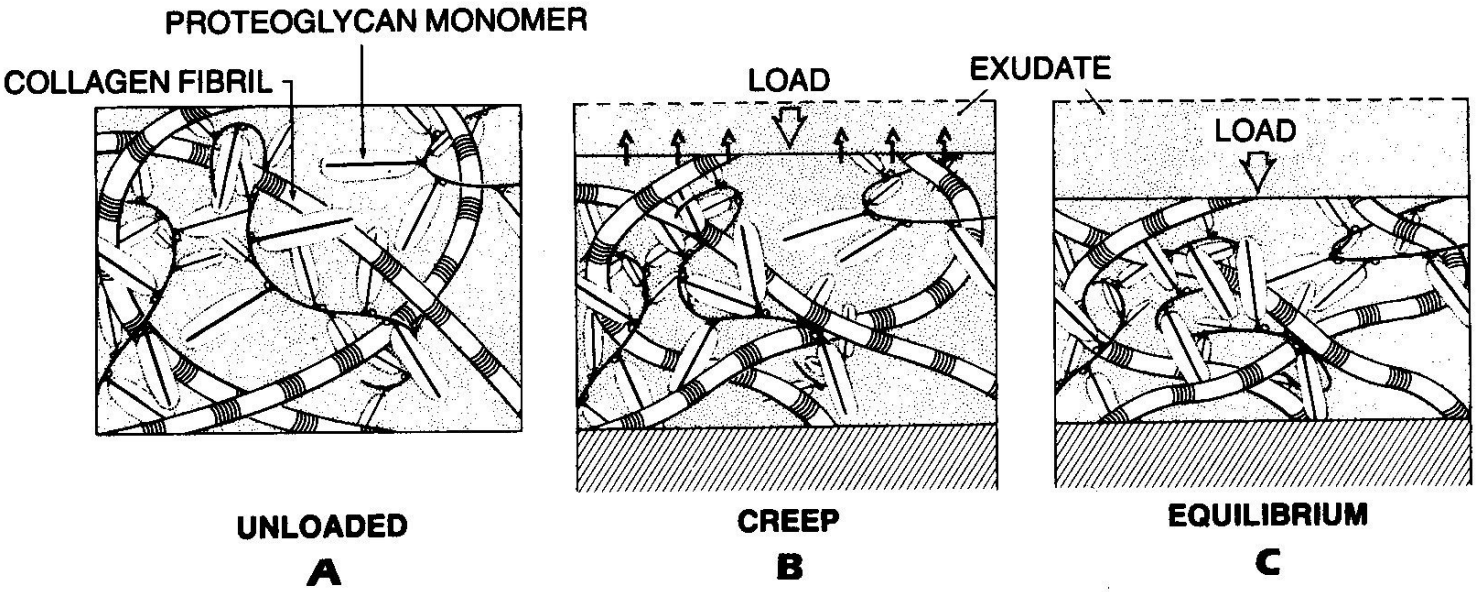
(c)

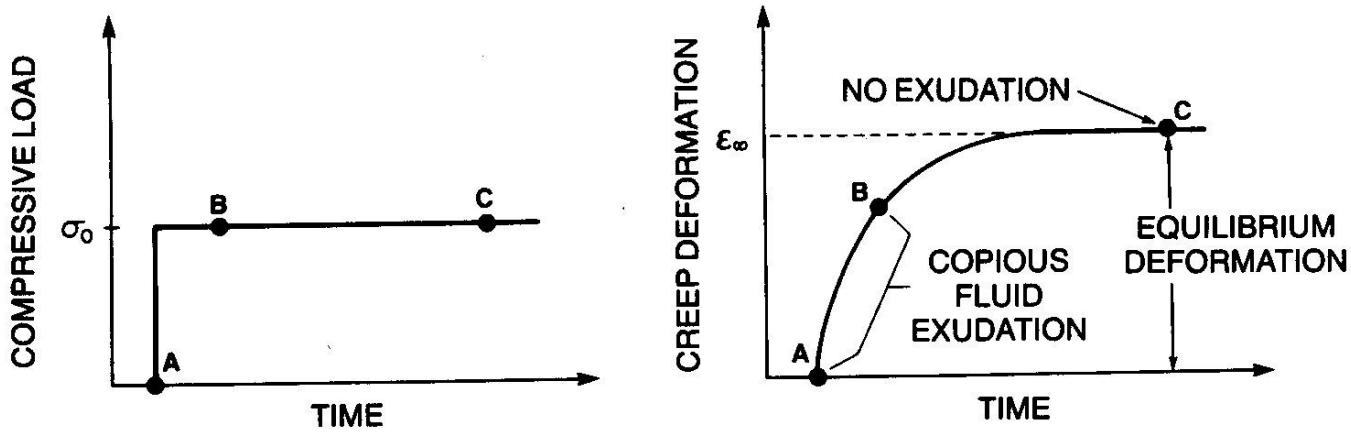


% proteoglycan content (dry weight)

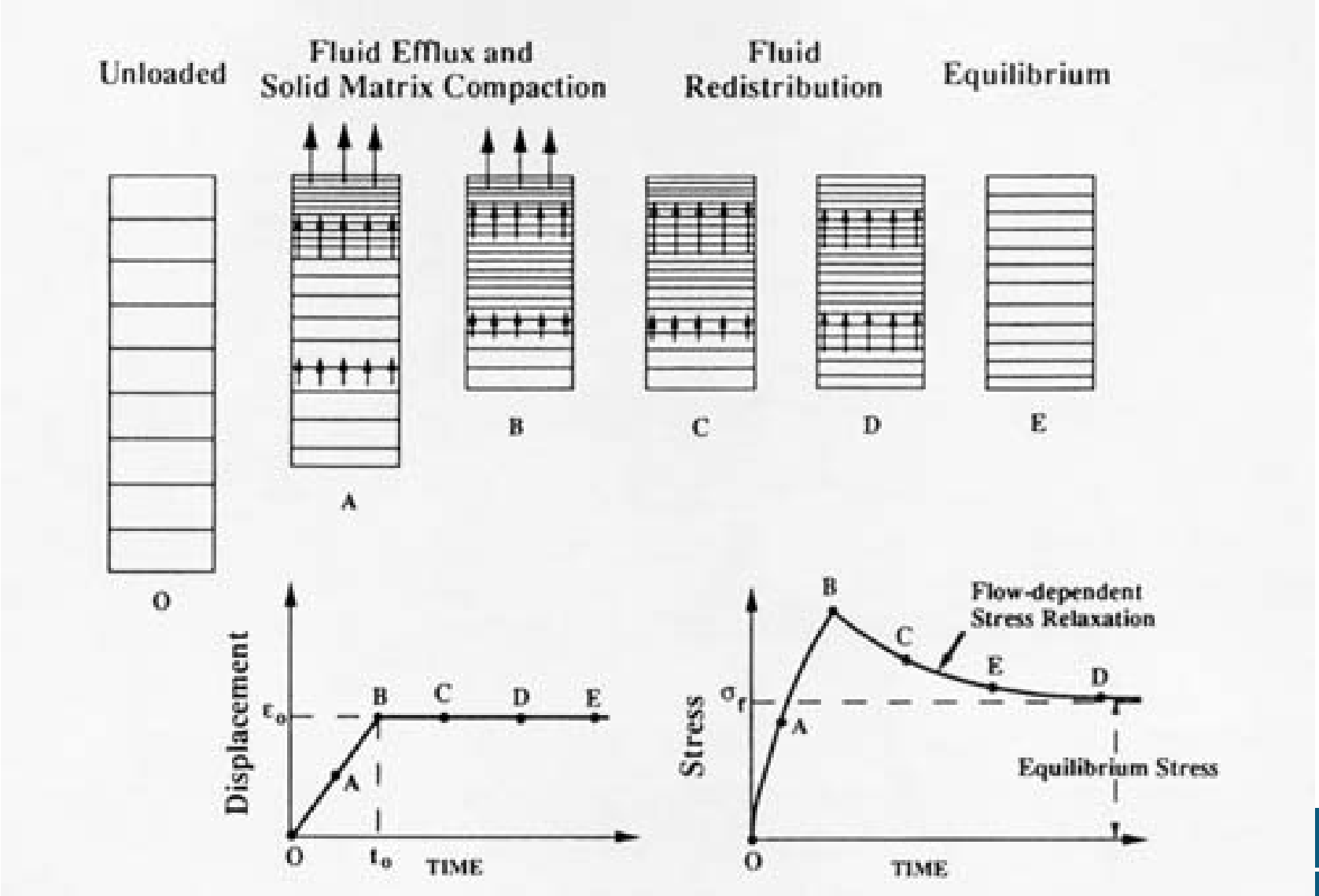
(d)

Mechanické vlastnosti

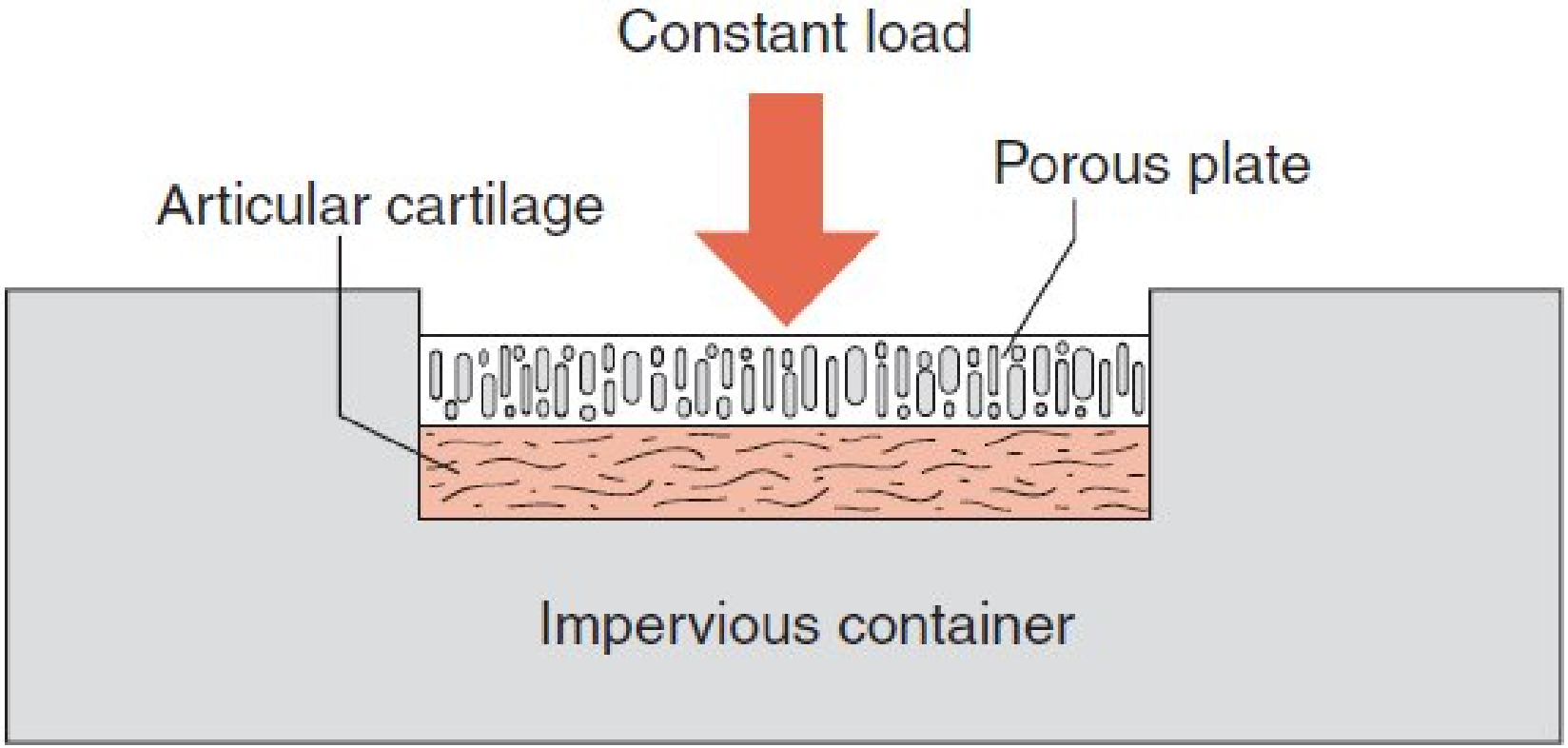




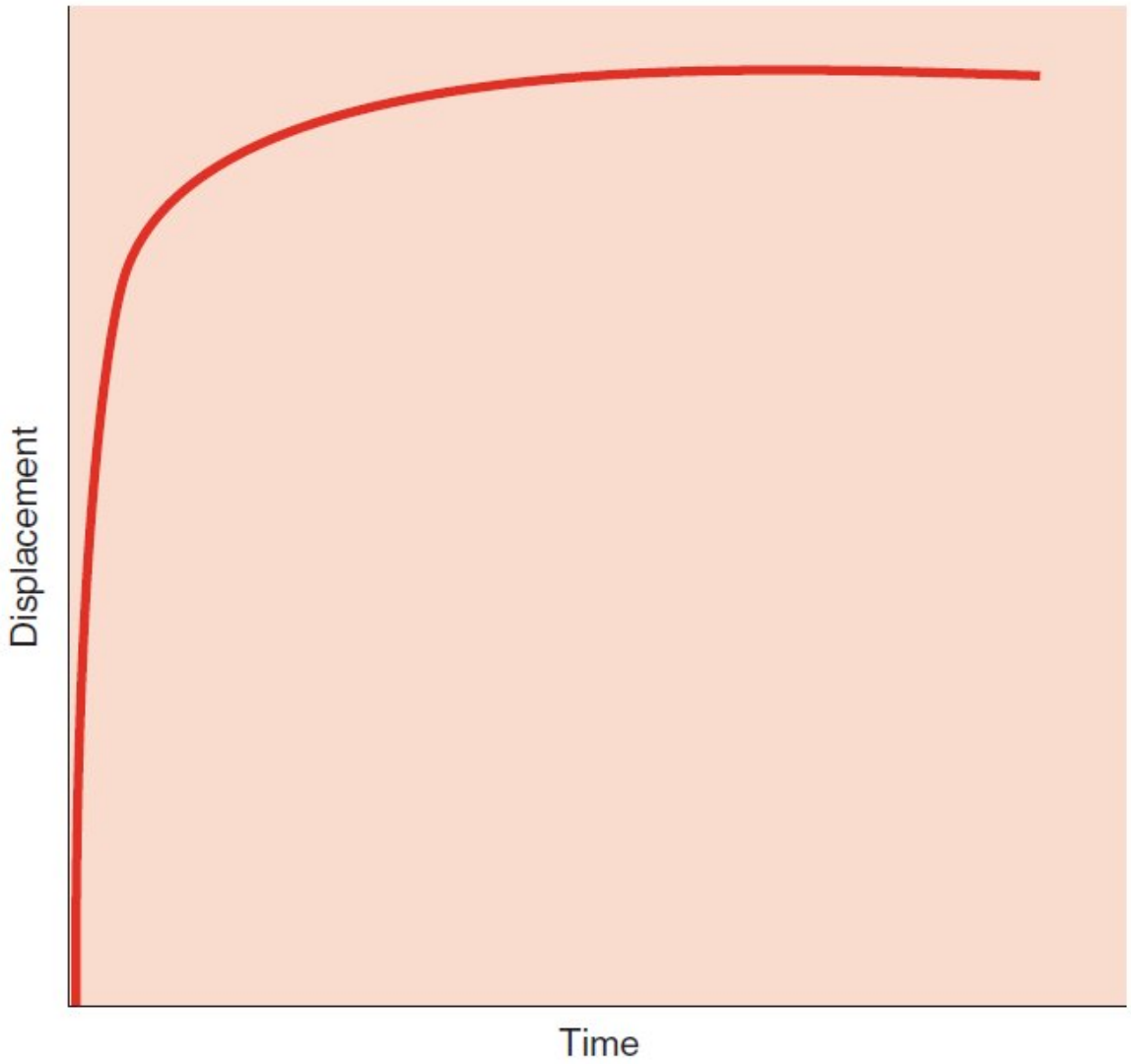
Chrupavka


Unloaded
Fluid Efflux and Solid Matrix Compaction
Fluid Redistribution
Equilibrium
O
A
B
C
D
E
Displacement
ε_0
TIME
t_0
Stress
σ_f
Flow-dependent Stress Relaxation
Equilibrium Stress

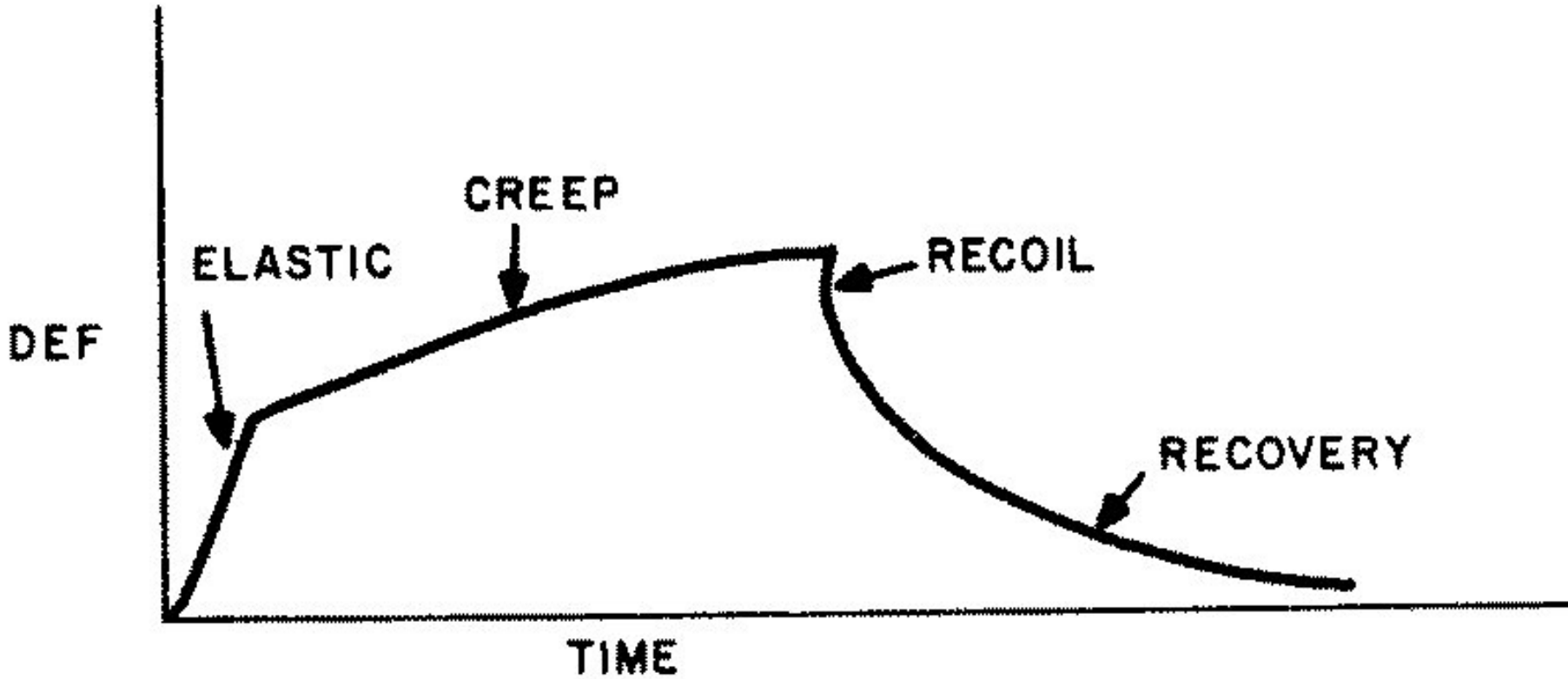
Confined compression



Confined compression



Creep chrupavky



Permeabilita

Darcyho zákon

Darcyho zákon je matematický vztah, který definuje rychlost průtoku kapaliny nebo plynu pevným porézním tělesem.

$$v = k\nabla p$$

Permeabilita

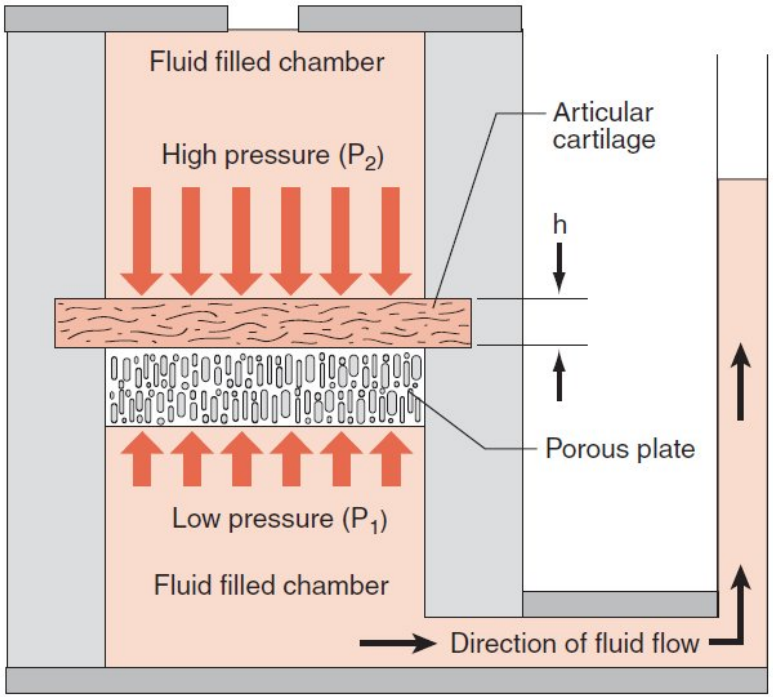
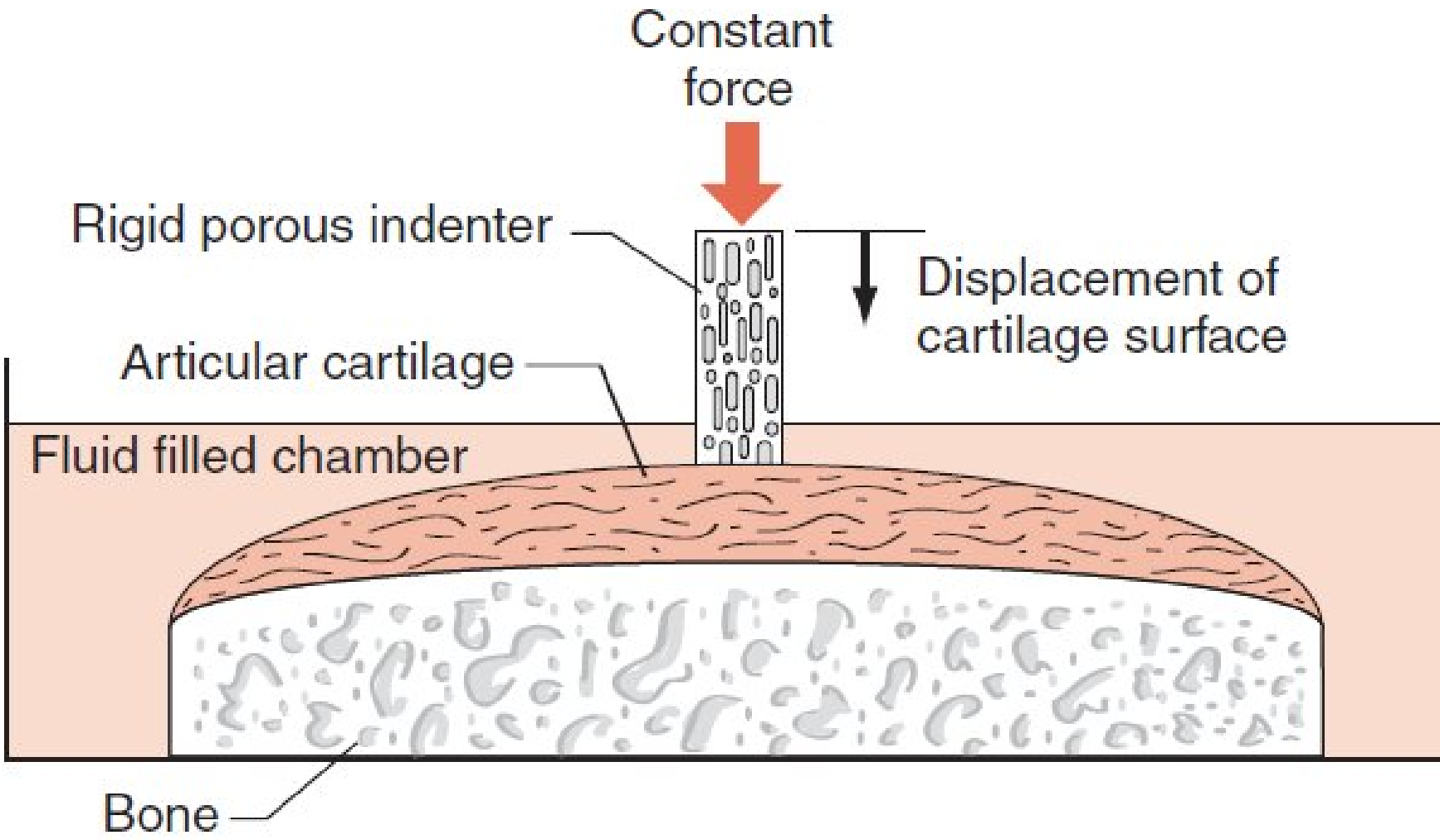


Figure 5.6: Schematic representation of a device used to measure the permeability of cartilage. A slice of cartilage is supported on a porous plate in a fluid-filled chamber. High pressure applied to one side of the cartilage drives fluid flow. The average fluid velocity through the cartilage is proportional to the pressure gradient, and the constant of proportionality is called the *permeability*.

$$\nabla p = \frac{P_2 - P_1}{h}, \; k = k_0 e^{M\varepsilon}$$

Indentace


Constant
force
Rigid porous indenter
Displacement of
cartilage surface
Articular cartilage
Fluid filled chamber
Bone

Mechanické testy chrupavky

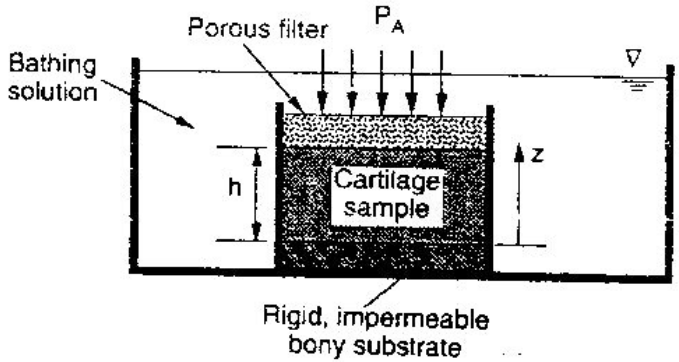
Confined compression agregovaný modul pružnosti (H_A) 0.1-2.0 MPa

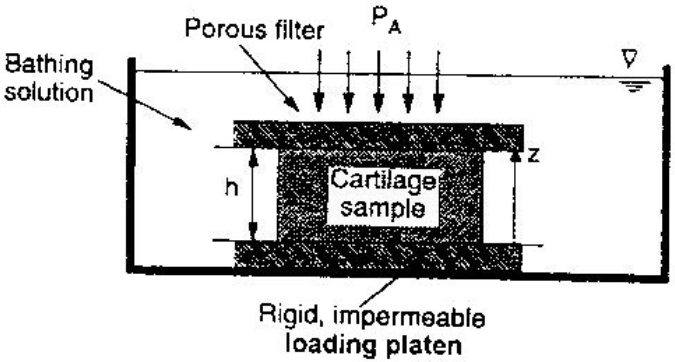
Unconfined compression – Youngův modul (E) from 0.41-0.85 MPa

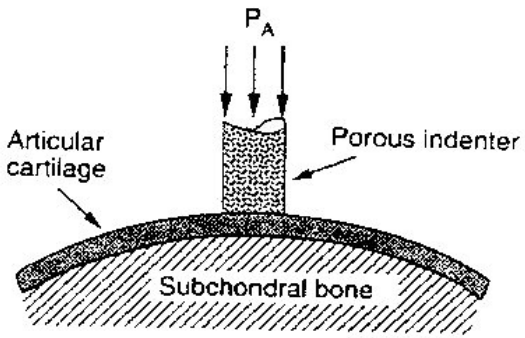
Poissonovo číslo

$$H_A = \frac{E(1-\nu)}{(1+\nu)(1-2\nu)}$$

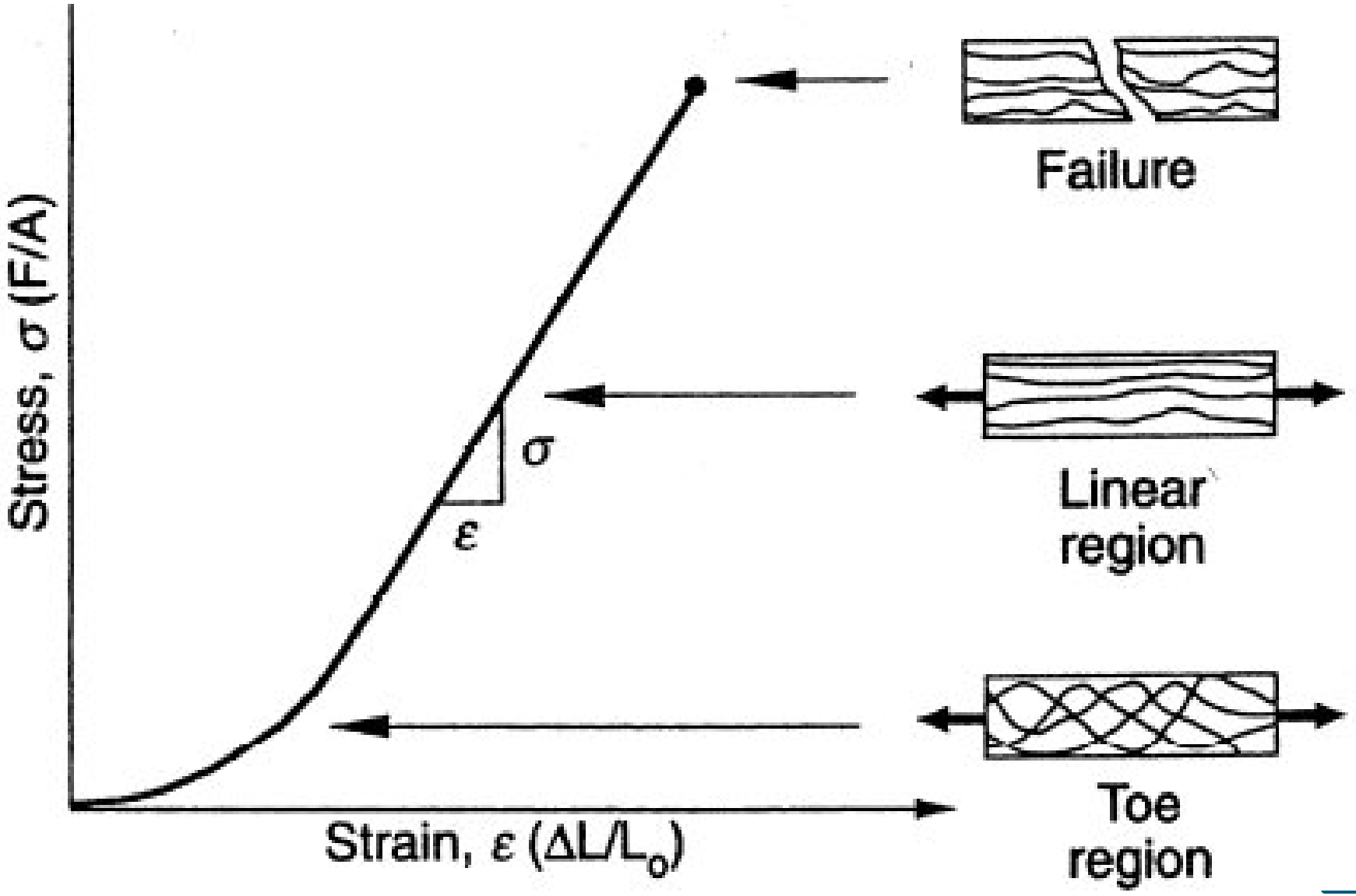
Indentace



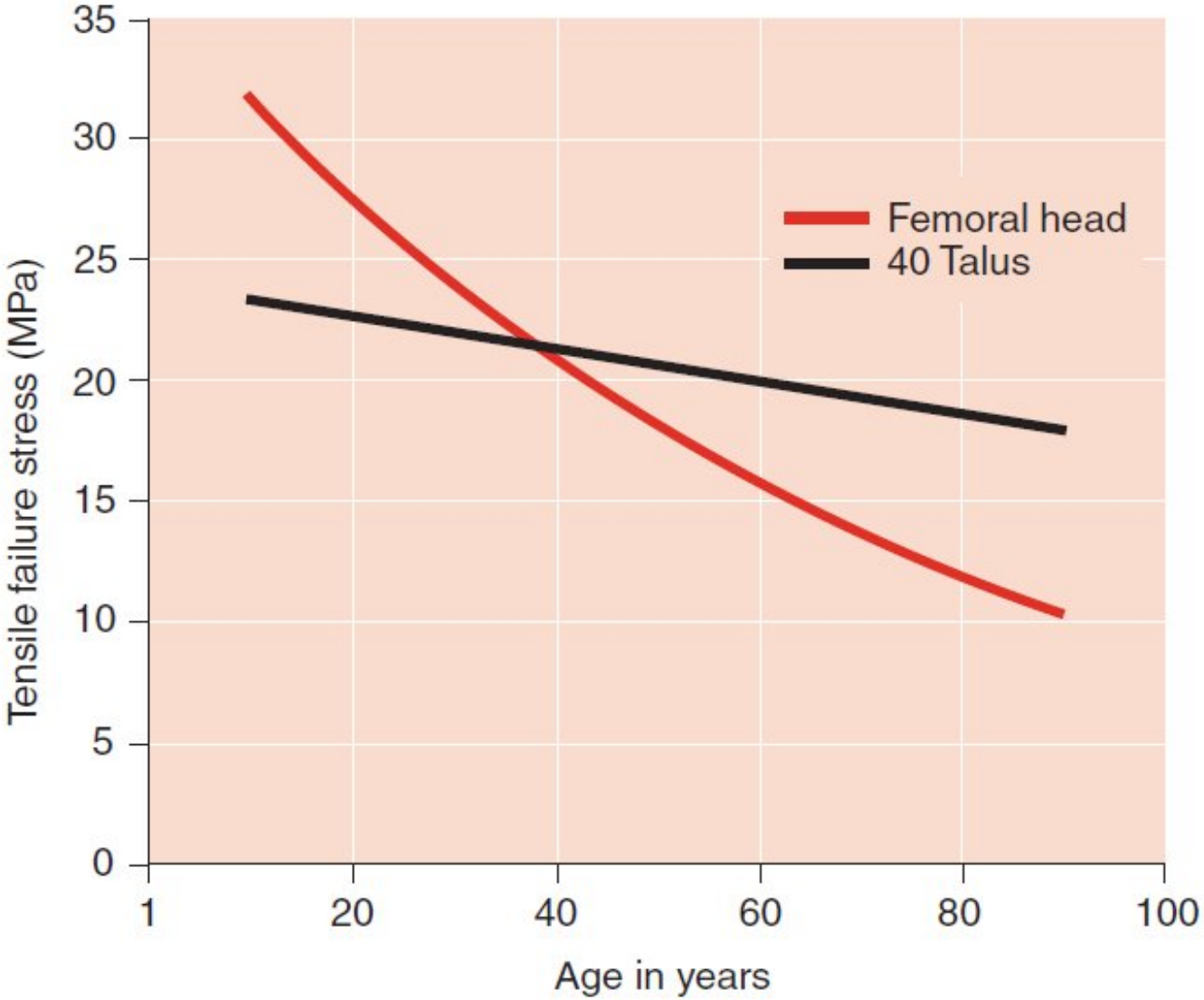




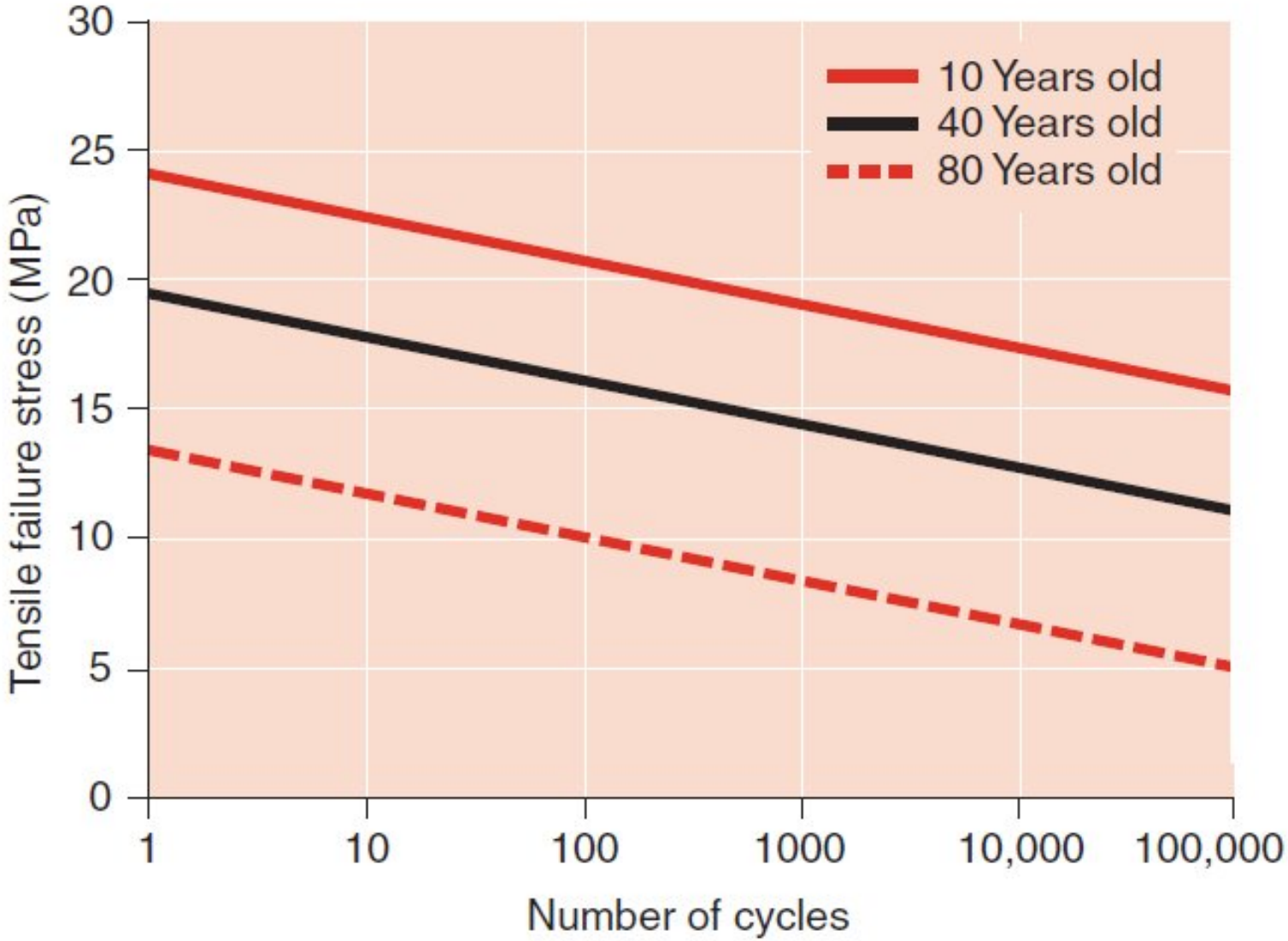
Testování tahem



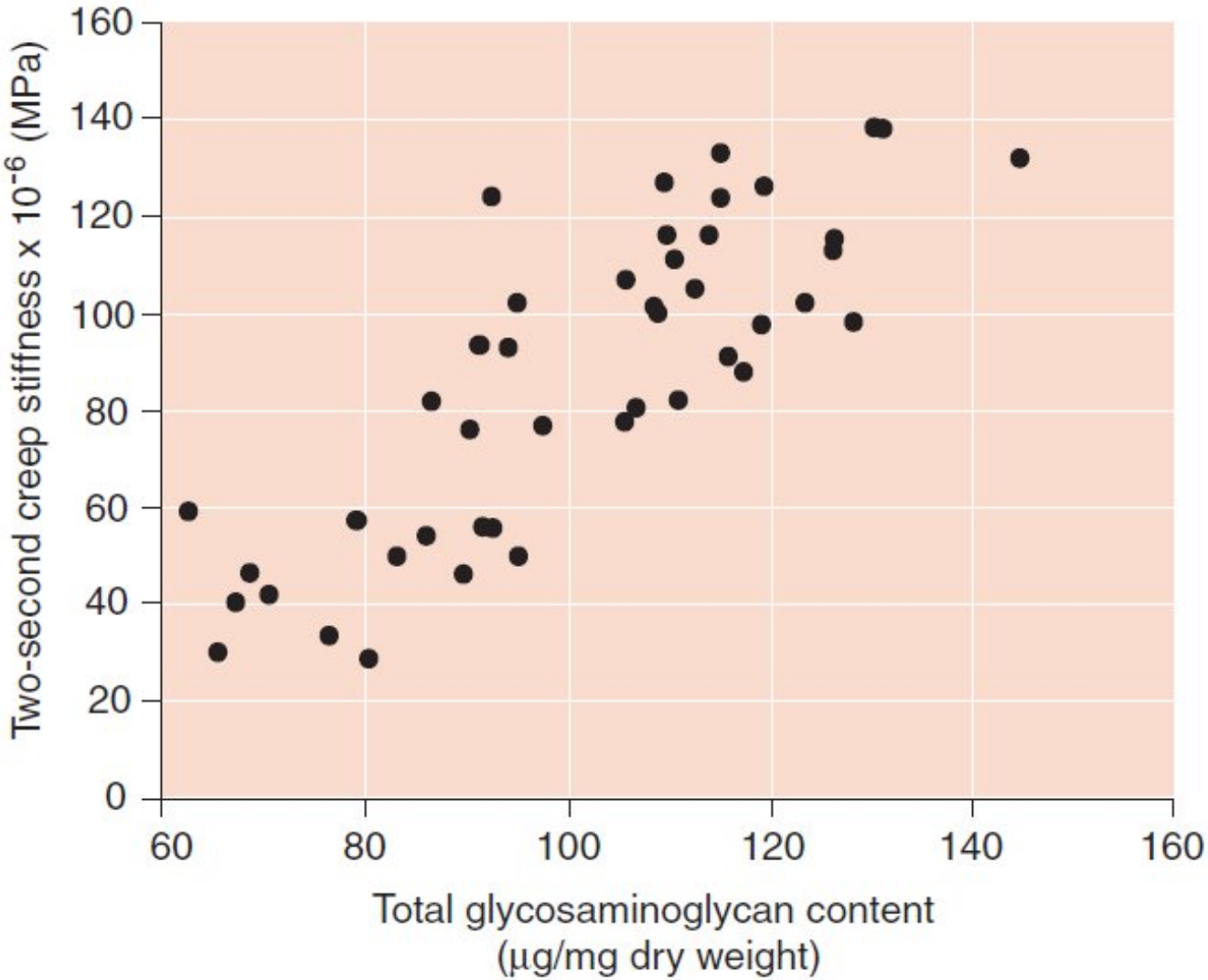
Testování tahem



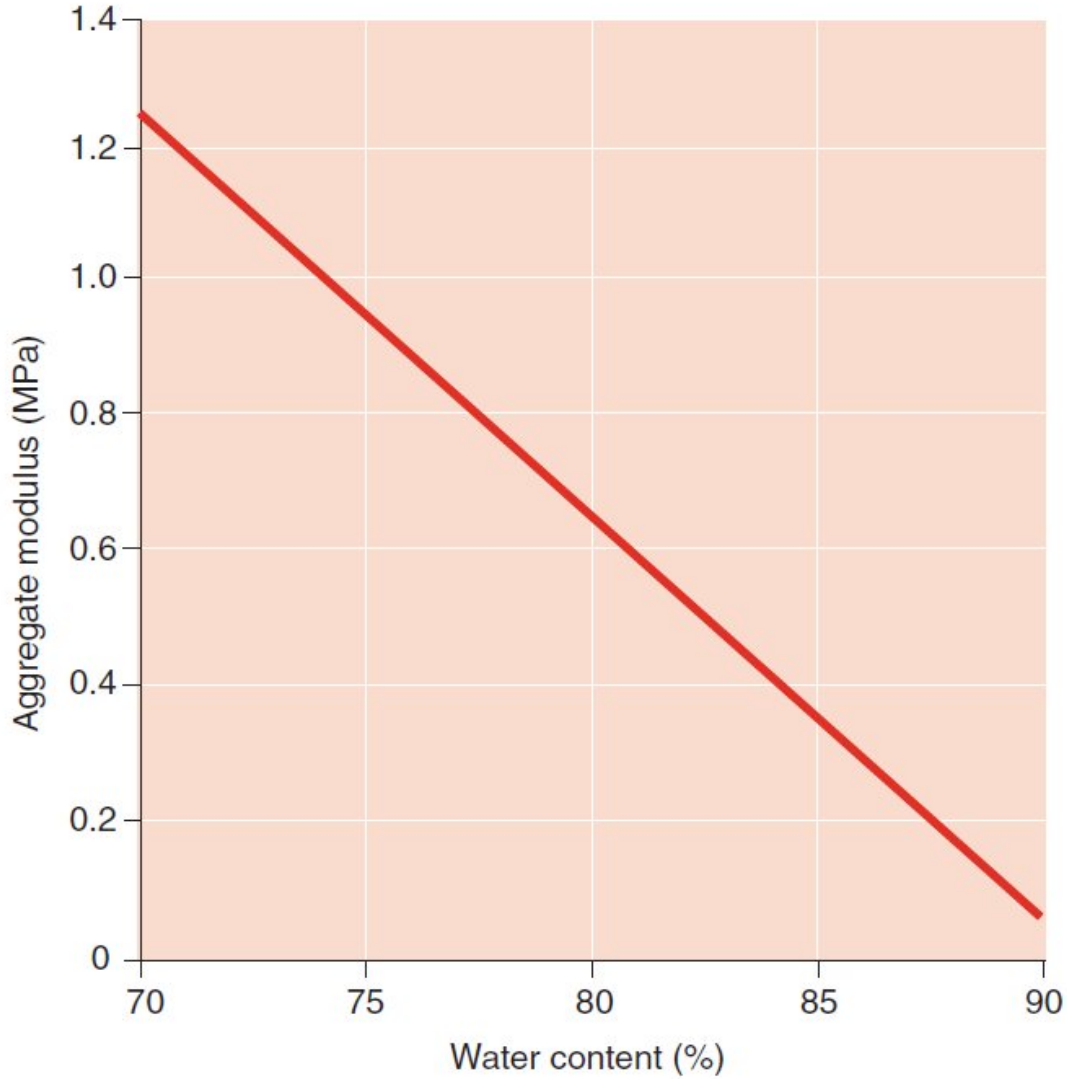
Únava materiálu



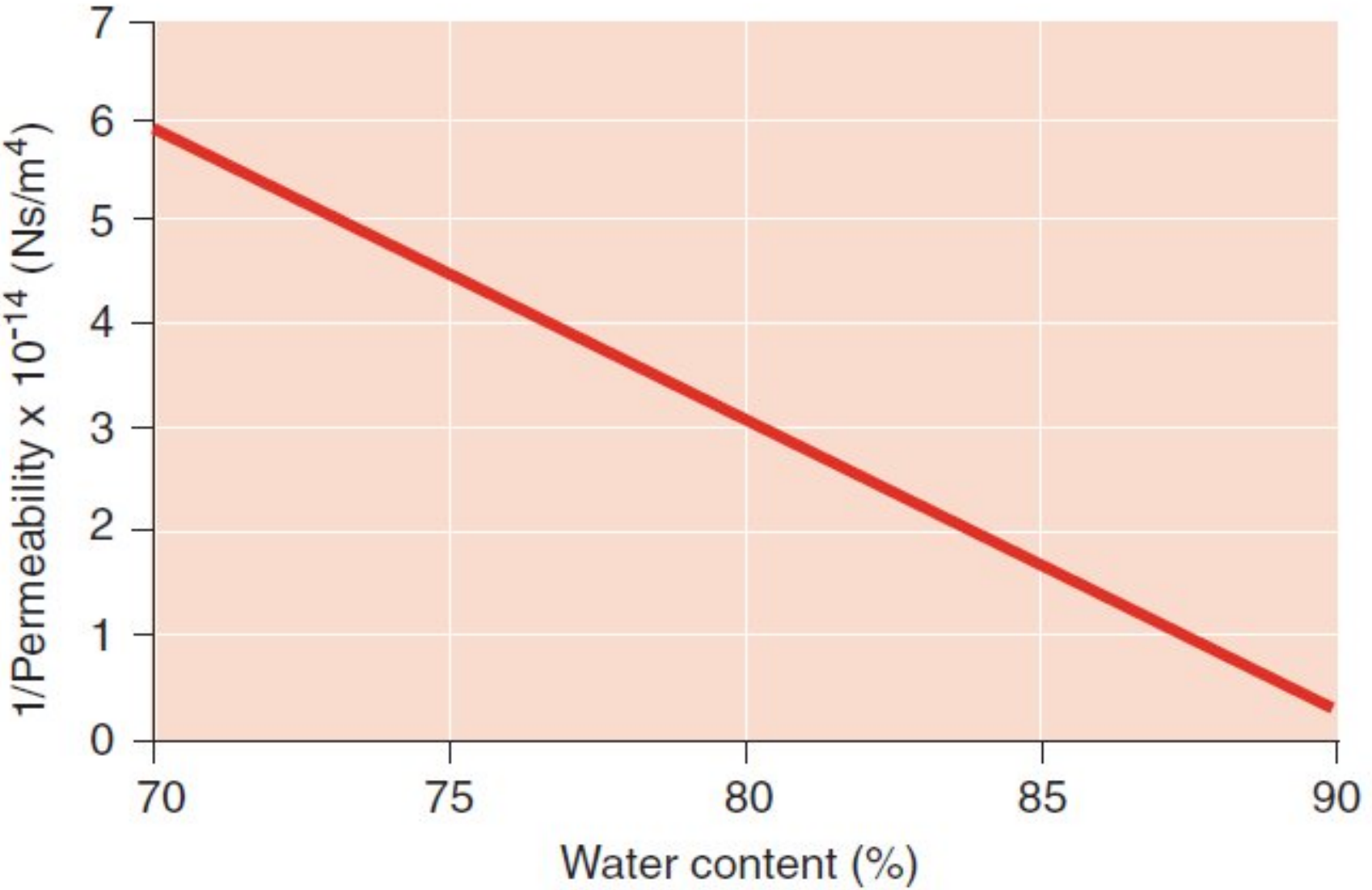
GAG vs. tuhost



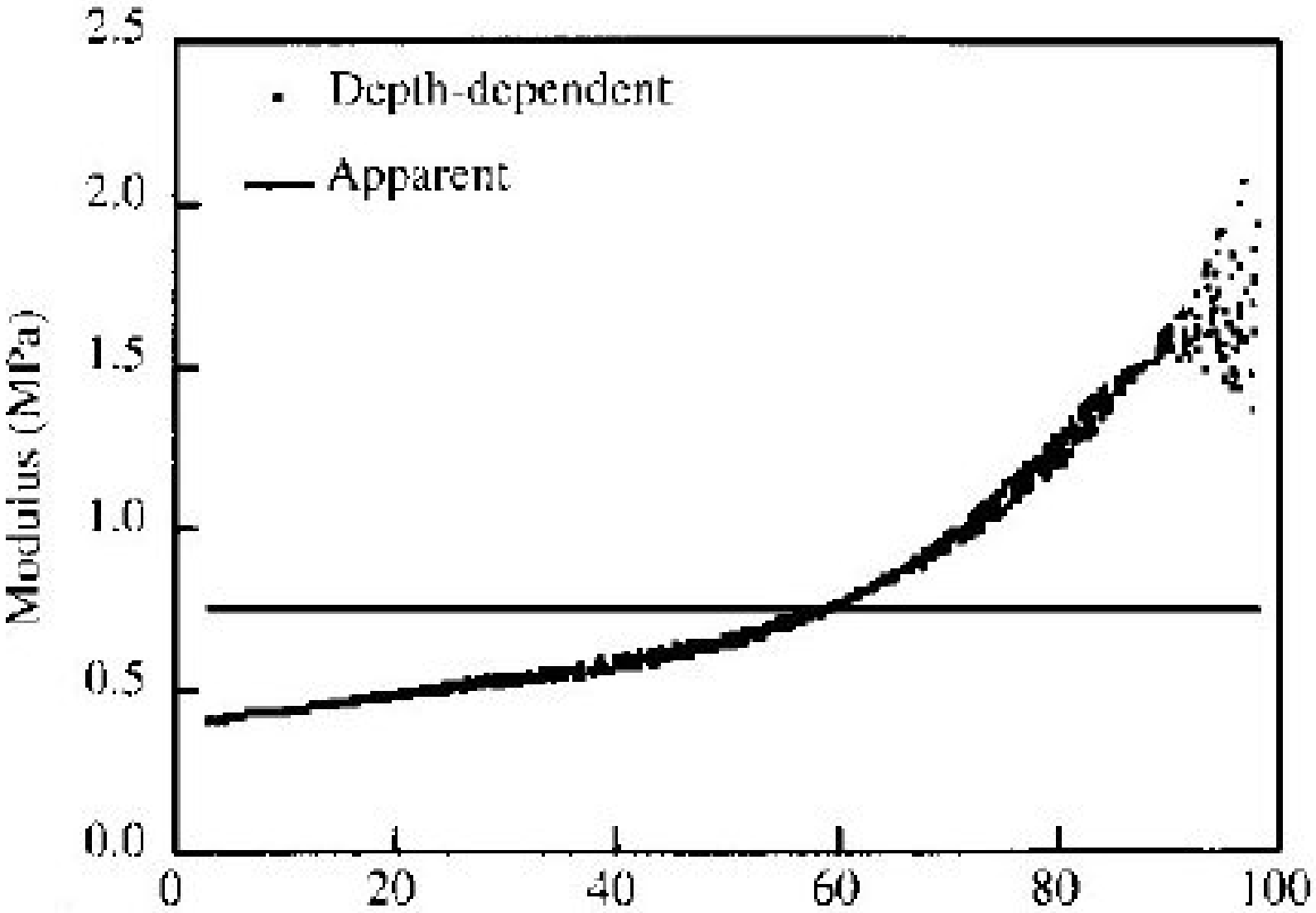
Agregovaný modul pružnosti



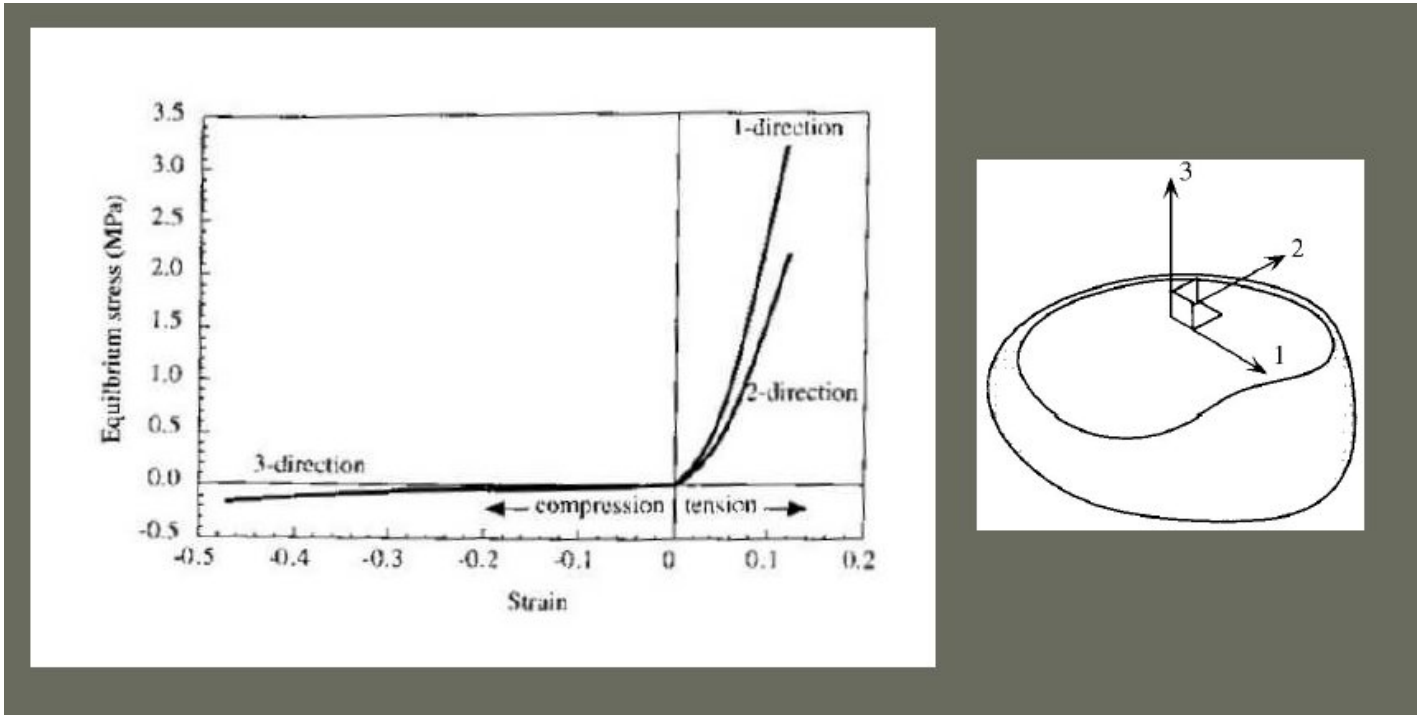
Permeabilita



Nehomogenita



Nelinearita v tahu a tlaku



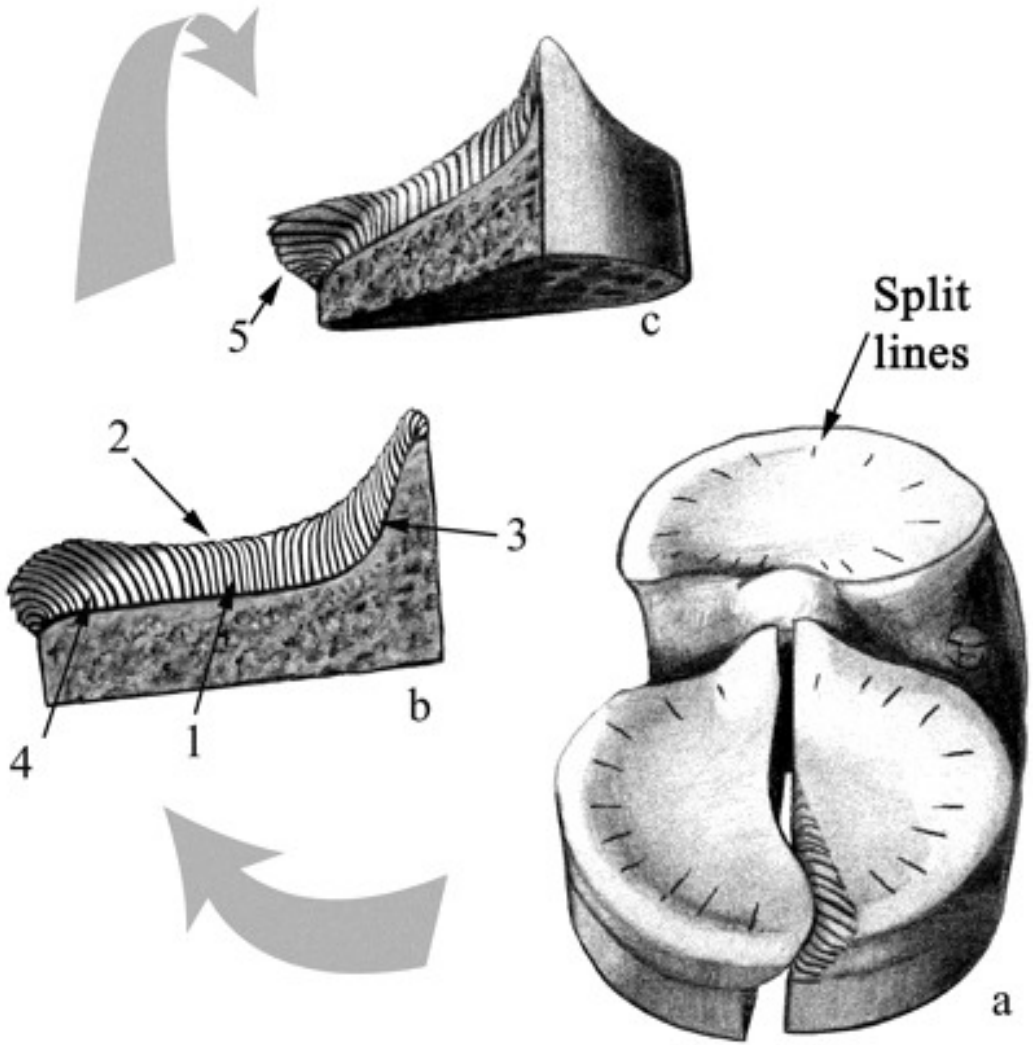
Nelinearita v tahu a tlaku

Split lines

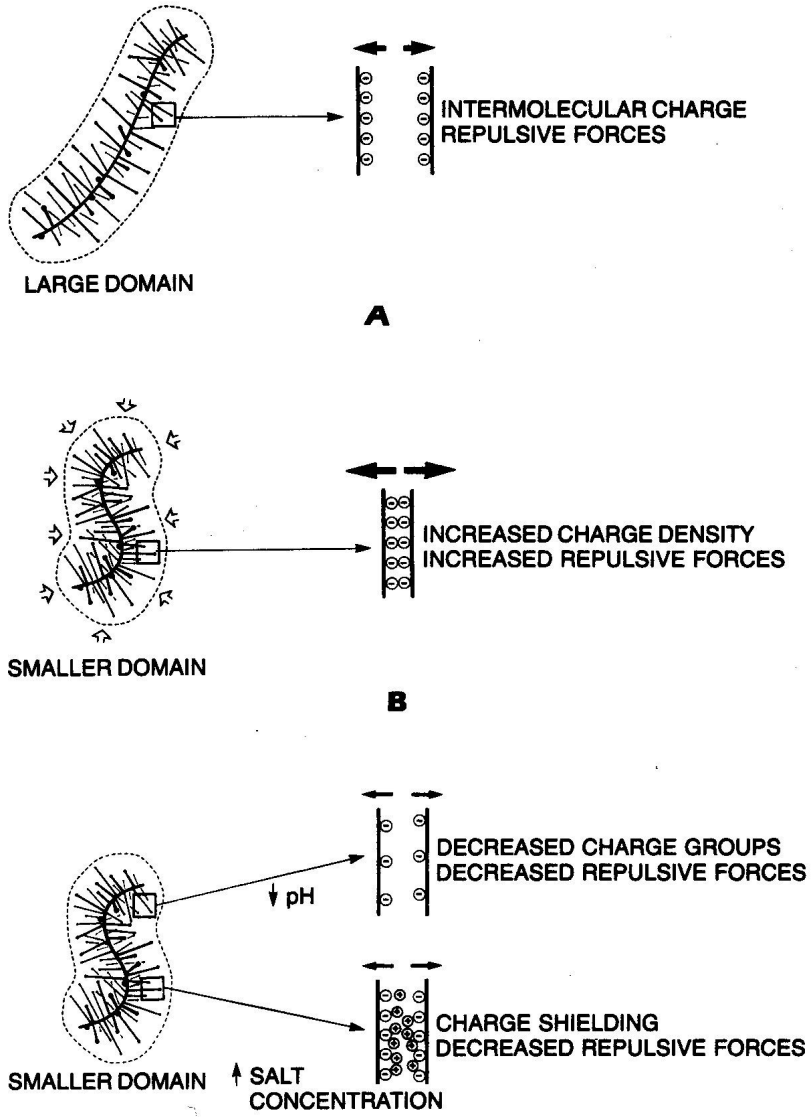
po vpichu jehlou kruhového průřezu vznikne oválný vpich

- 5.9 MPa vs 7.8 MPa ve směru malé deformace
- 26 MPa vs 43 MPa ve směru velké deformace

Split lines



Mechano-elektro-chemické vlastnosti



Tření

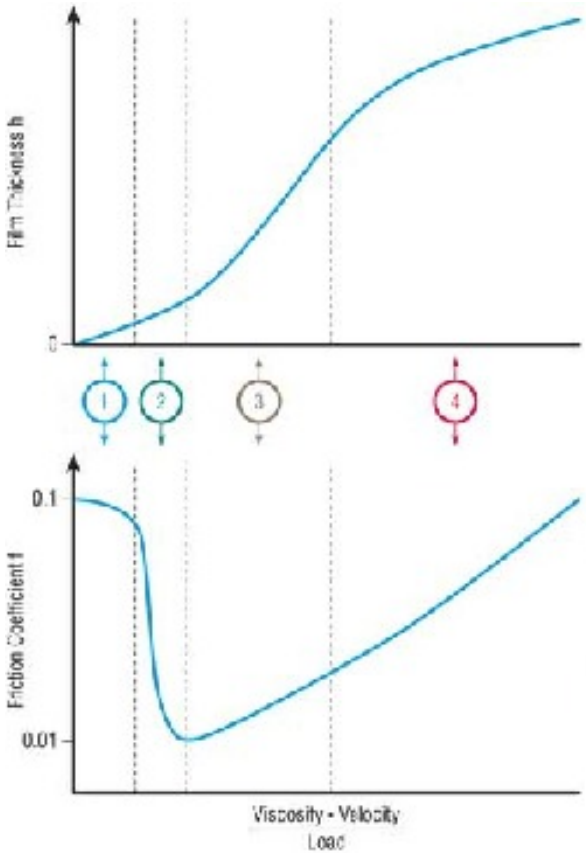
Tribologie

z řeckého - třít
je vědecký obor, zabývající se procesy tření, opotřebení a mazání.

Tření

1. Hydrodynamické mazání – mezi dvojicí povrchů je vrstva maziva
2. Elastohydrodynamické mazání – dvojice povrchů je nazvájem odělena velmi tenkou vrstvou maziva
3. Smíšené mazání – dvojice povrchů je částečně oddělena mazivem ale existují části, kde jsou tyto povrchy v přímém kontaktu.
4. Suché tření - přímý kontakt mezi kontaktními povrchy

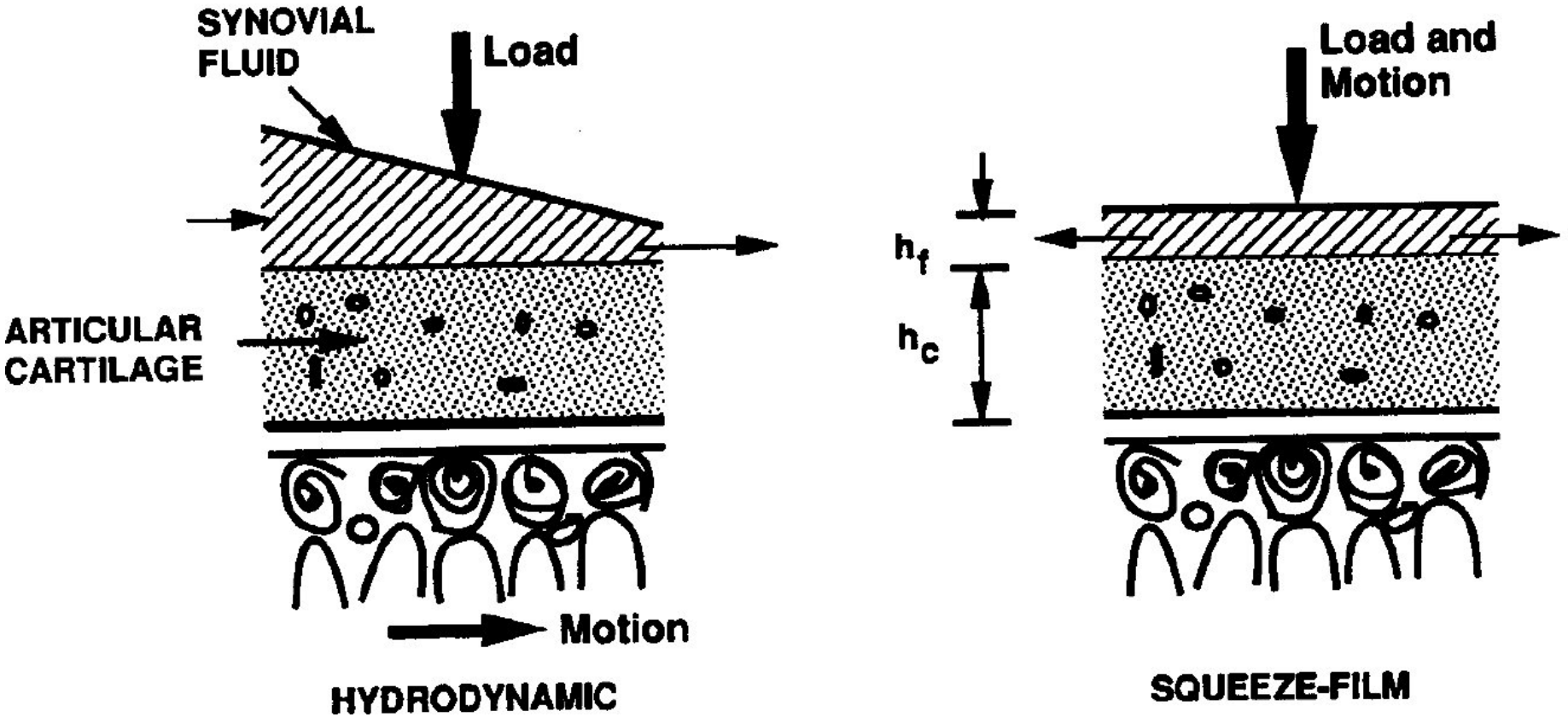
Tření


Film Thickness h
0
1
2
3
4
0.1
Friction Coefficient f
0.01
Viscosity • Velocity
Load

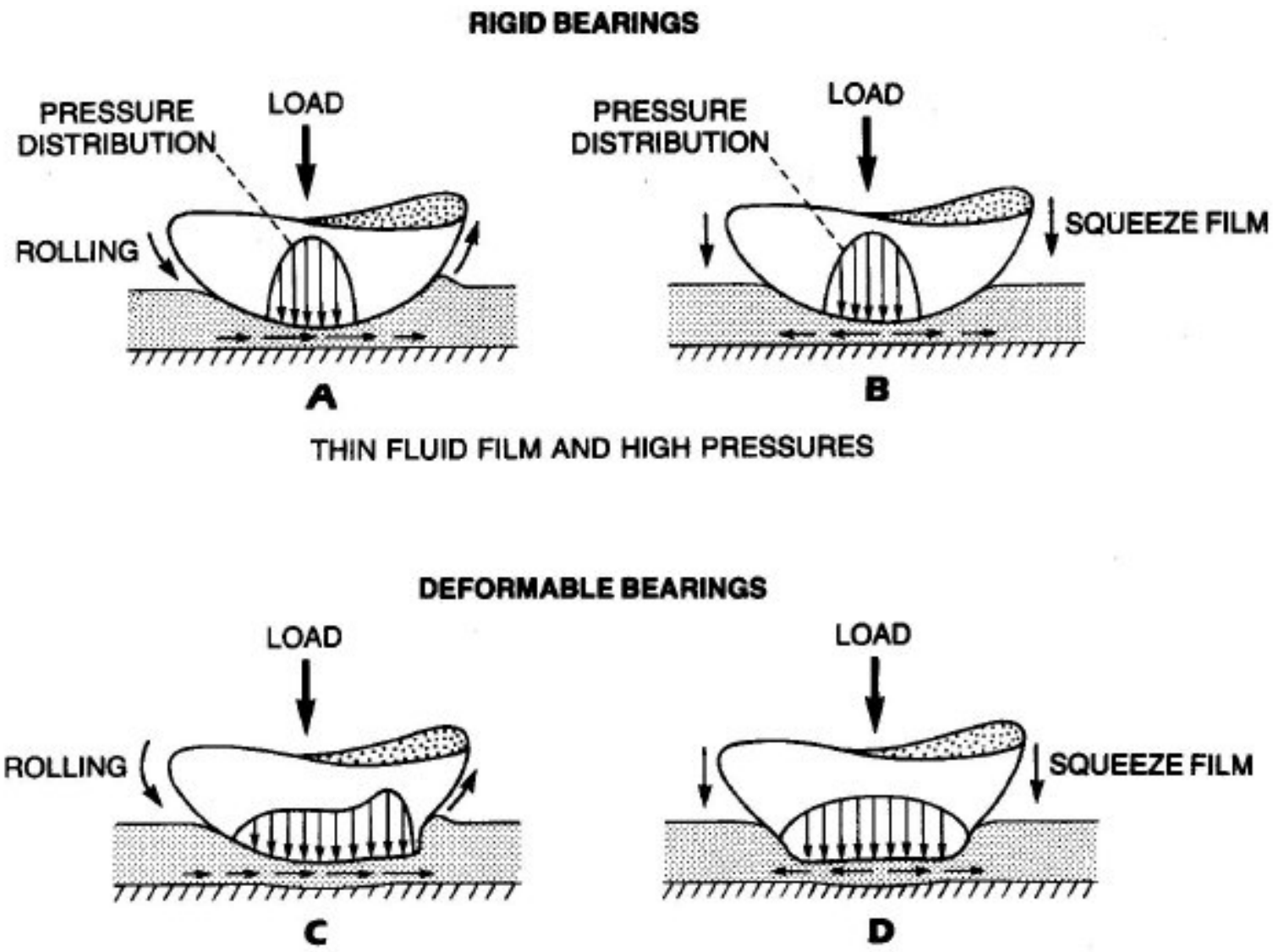

v
h
Lubricant Film
Material Pair
Surface Roughness
1 Boundary Friction
2 Mixed Film Friction
3 Elastohydrodynamic Lubrication
4 Hydrodynamic Lubrication


MIXED FILM LUBRICATION
BOUNDARY LUBRICATION
HYDRODYNAMIC LUBRICATION

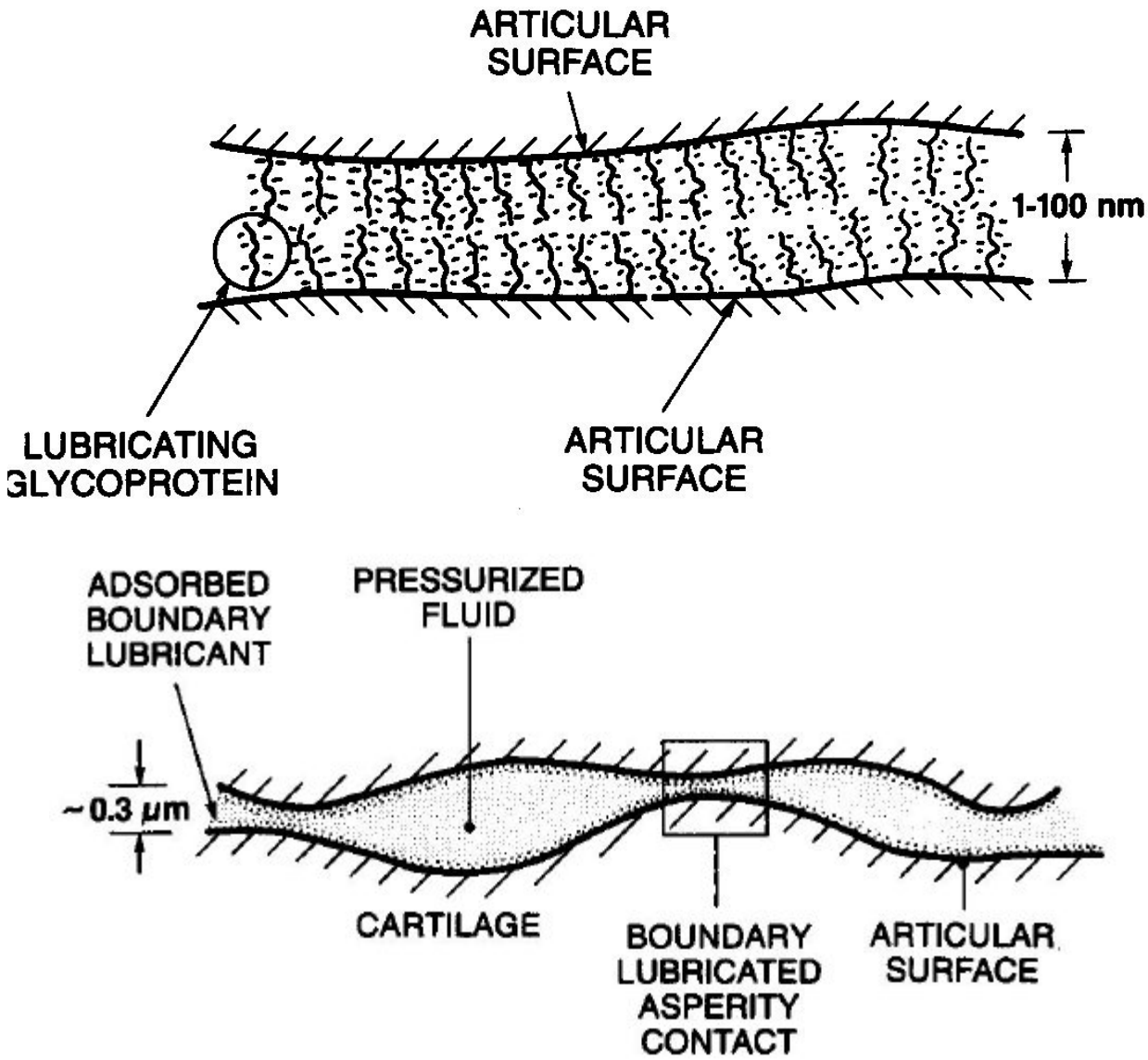
Chrupavka - hydrodynamické a tenký film



Elastohydrodynamické mazání



Chrupavka - smíšené mazání



Funkce menisků