Materials in Orthopaedics

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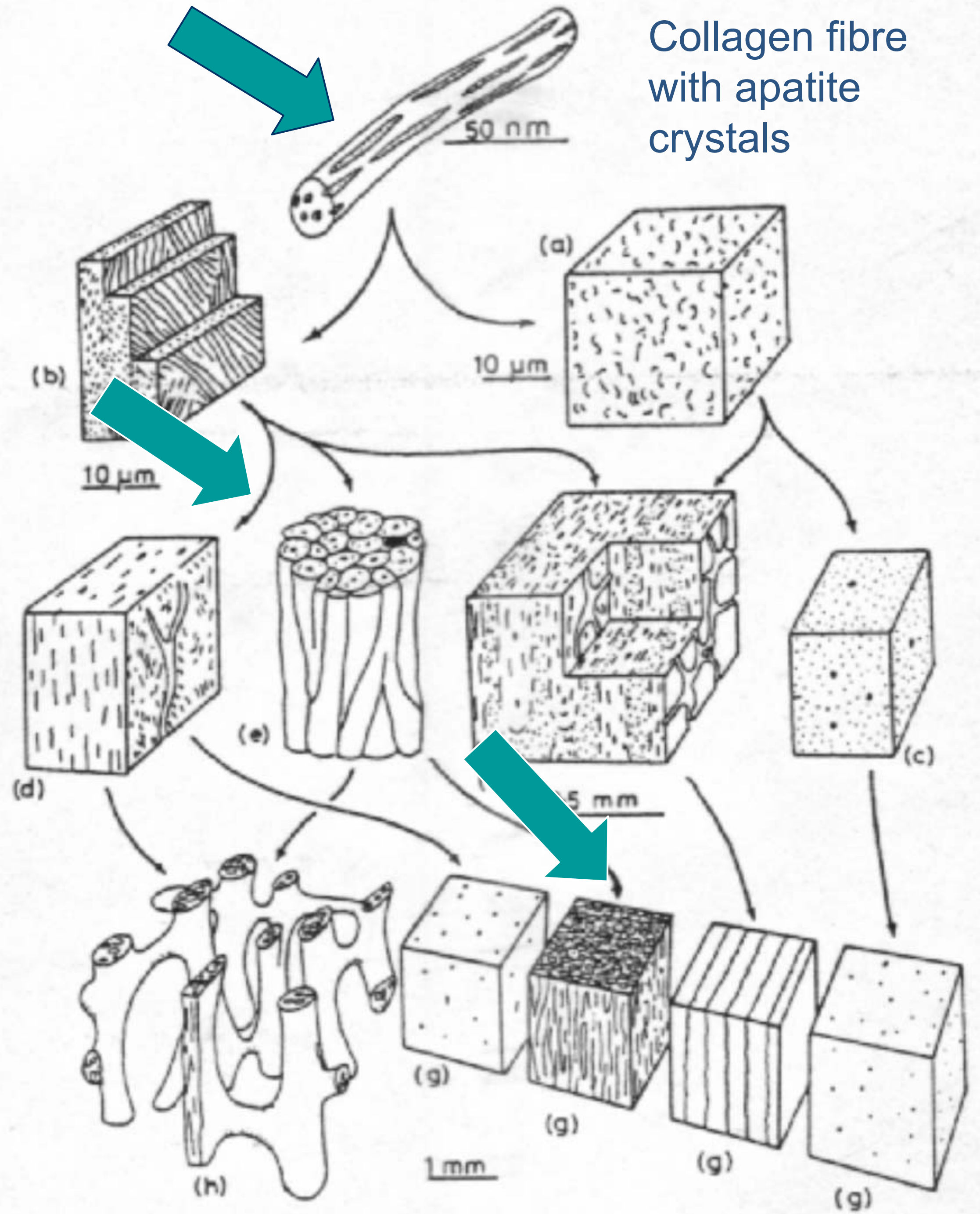
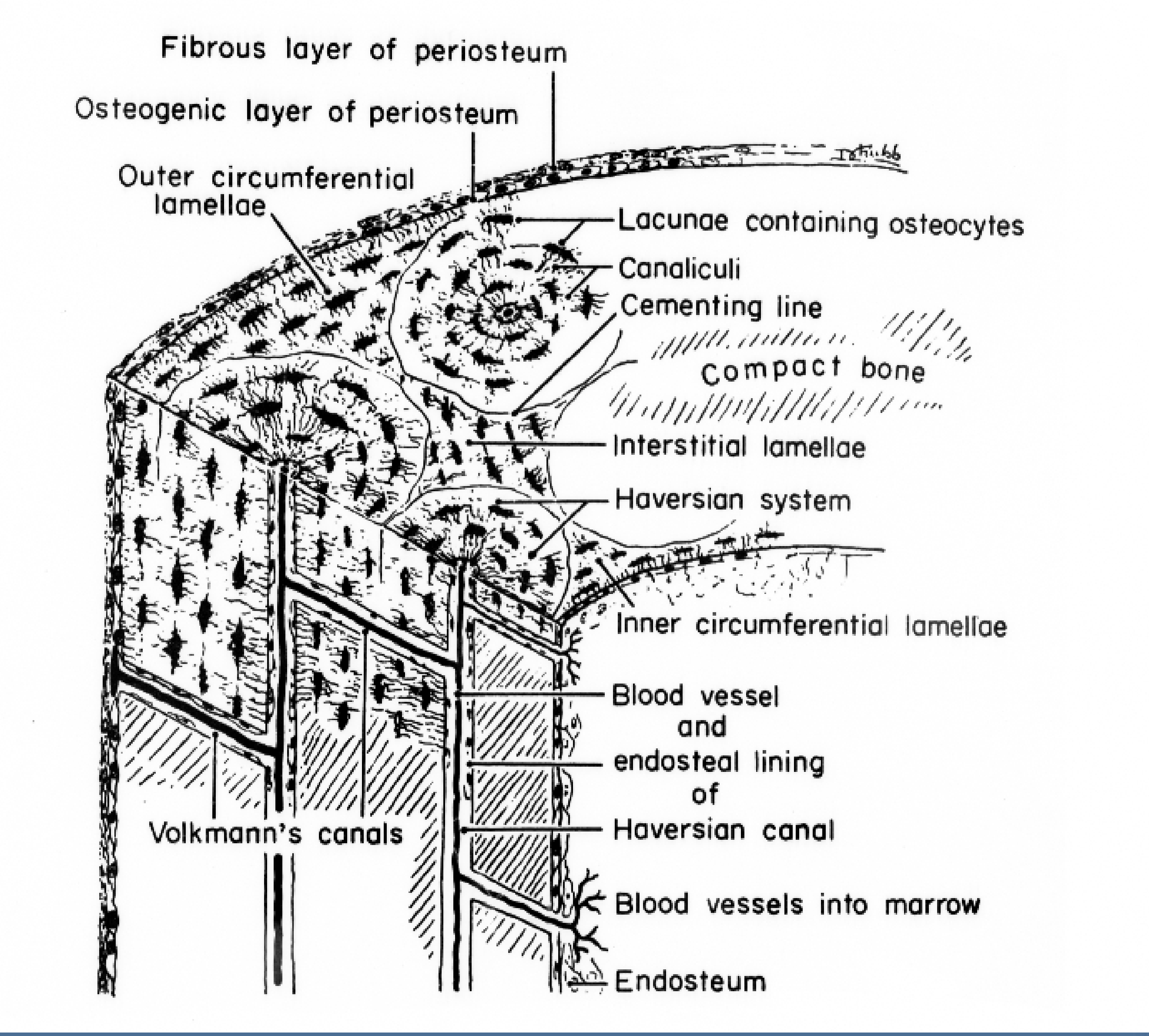
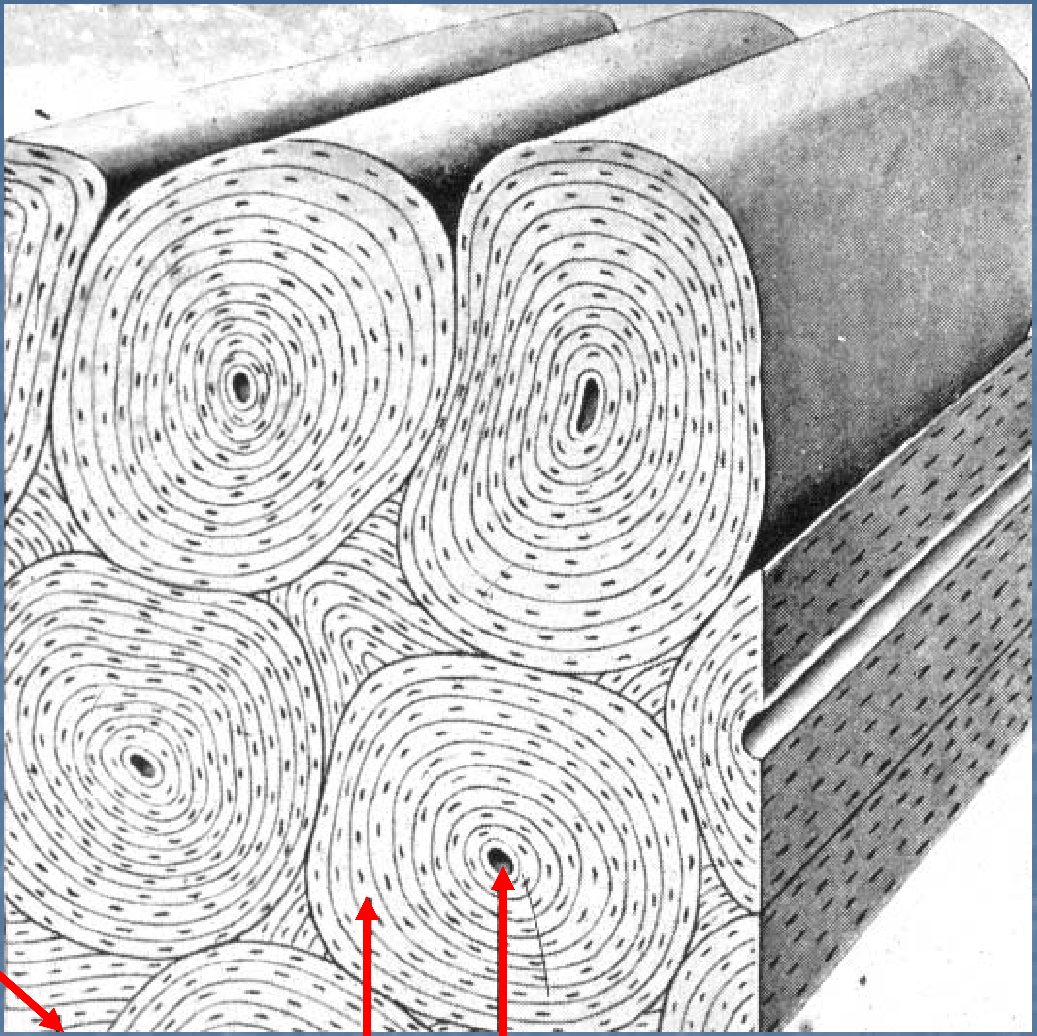
Physical structure of bone



Haversian system



Haversian Bone

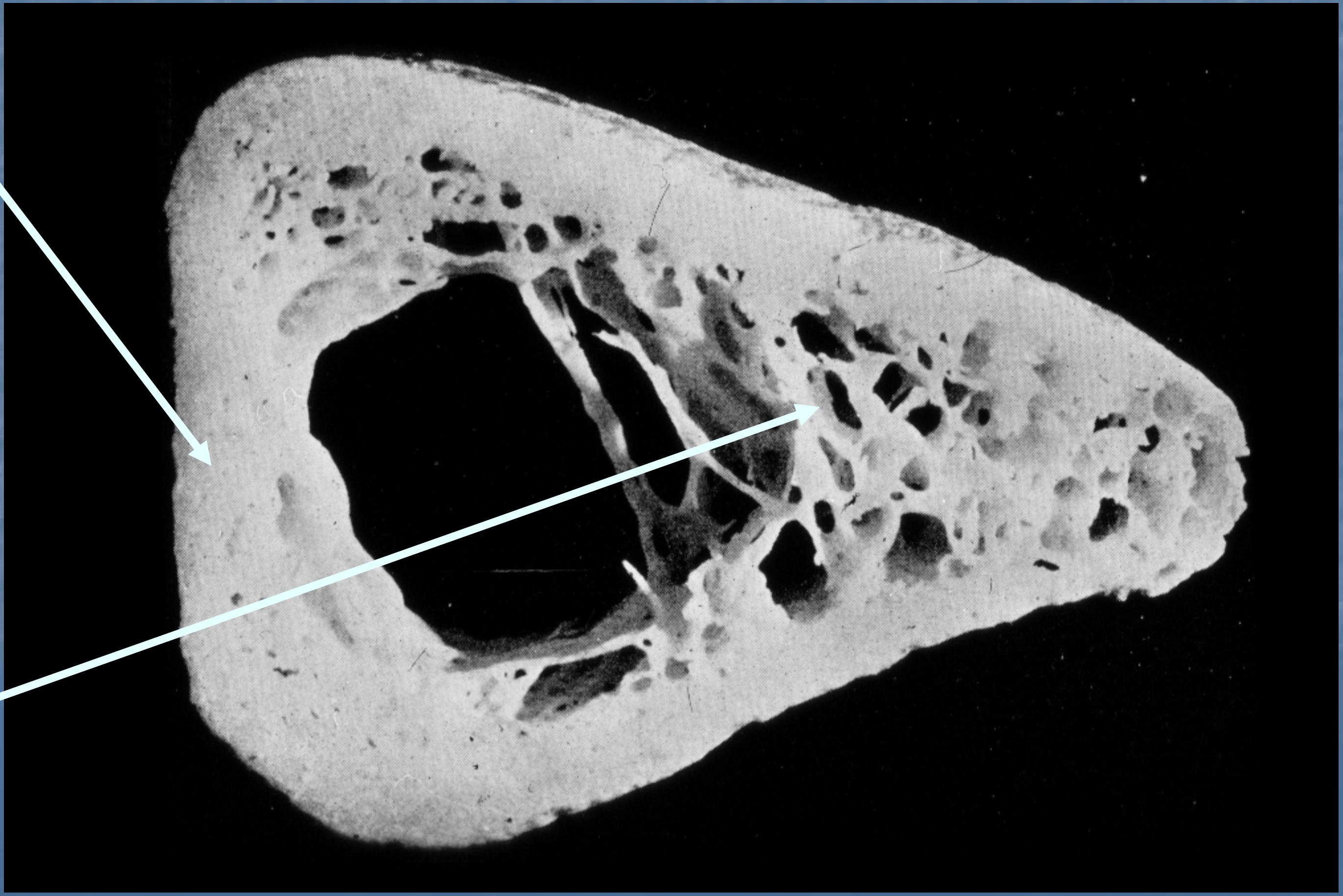


Interstitial lamellae

osteoblasts

Haversian canal

Cortical and cancellous bone



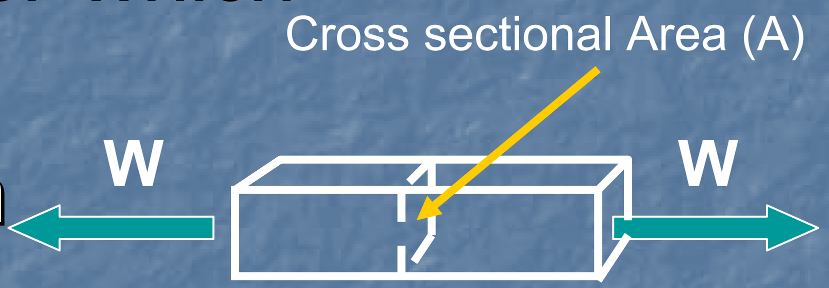
Cortical bone

(compact)

Cancellous bone

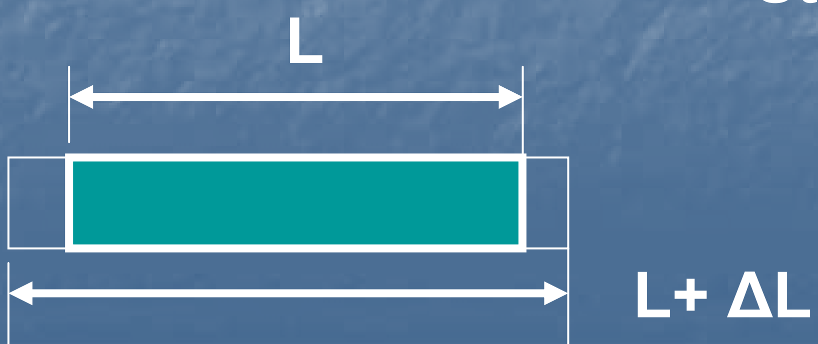
Stress and Strain

- Stress is load/area over which the load acts
- Strain is the change in length/original length

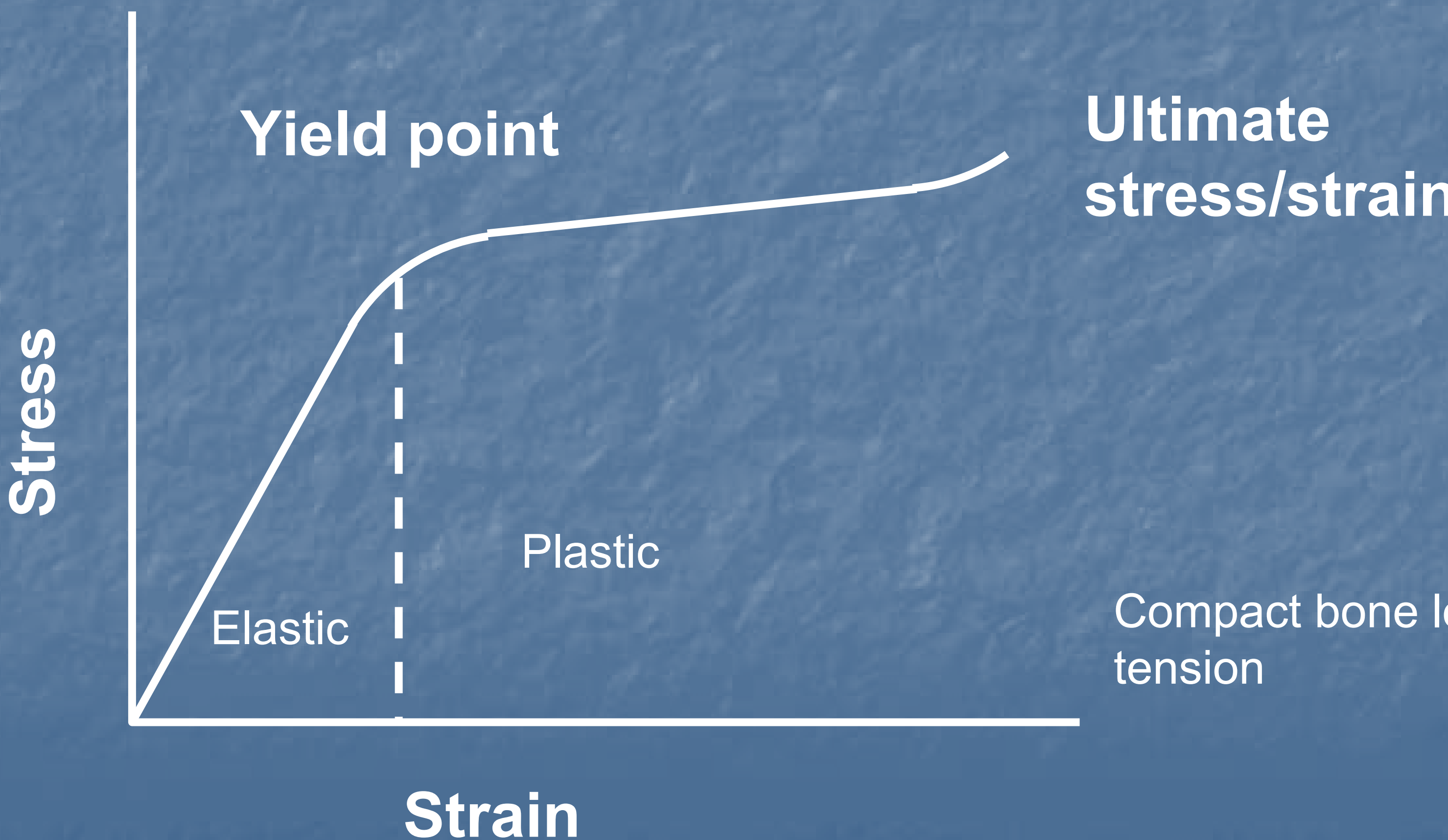


Tensile stress = W/A

Strain = ΔL/L

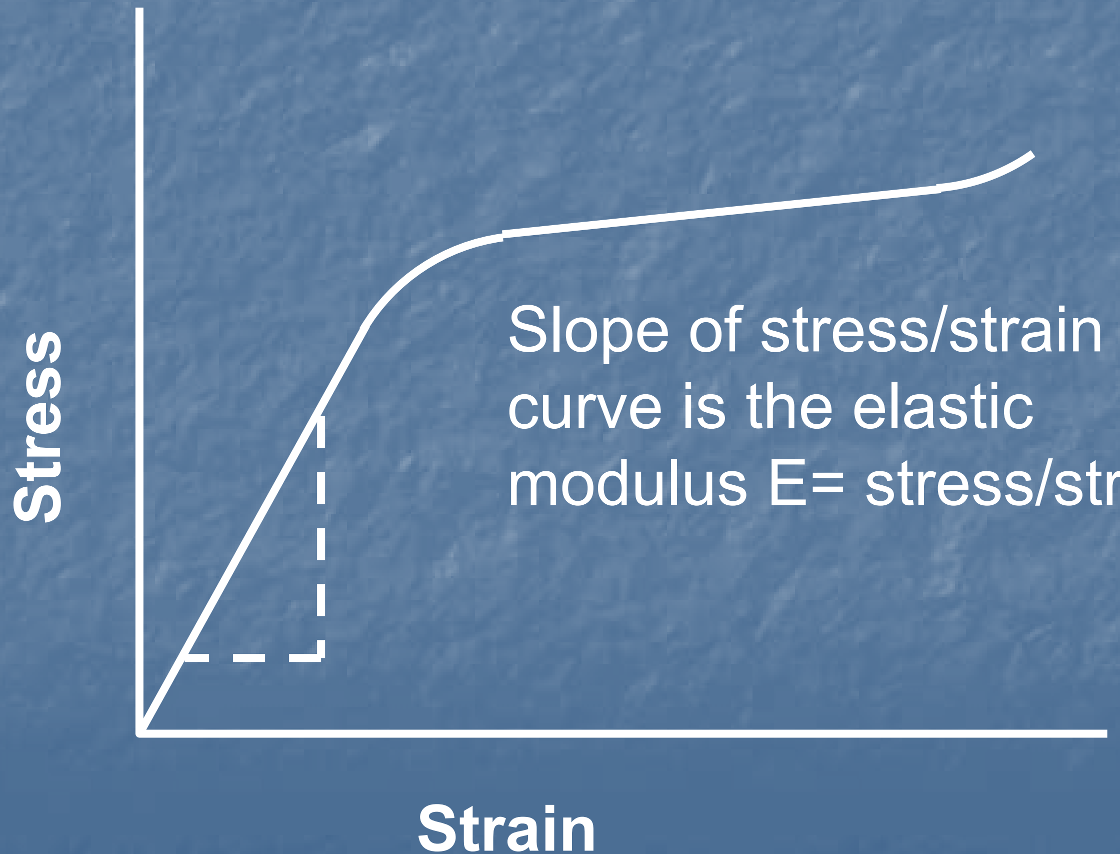


Load-deformation (stress-strain)



Compact bone loaded in tension

Load-deformation (stress-strain)



Compact bone loaded in tension

Mechanical Properties of Human Haversian Bone

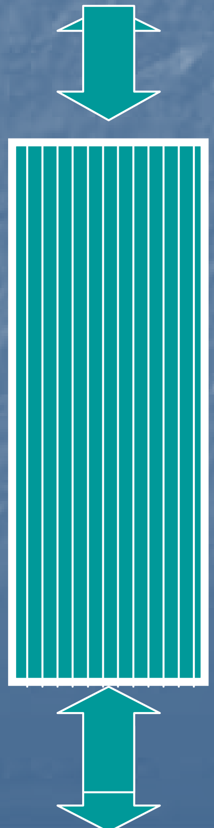
(Reilly and Burstein,1974, J.Biomechanics. 8, 393)

	Tension		Compression	
	Longitudinal	Transverse	Longitudinal	Transverse
Elastic Modulus GPa	17.9	10.1	18.2	11.7
Ultimate Stress MPa	135	53	205	130
Ultimate Strain	0.031	0.007	0.019	0.040

Hence clinically more bones fail in tension than compression

Bones are Anisotropic: properties are different in different directions

Direction of loading



Tension: all fibres pulled together

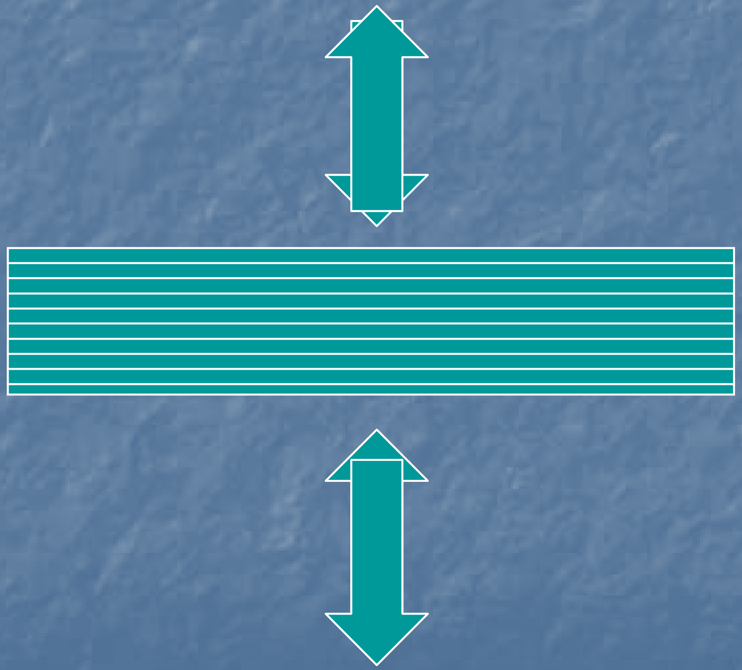
Compression: all fibres pushed together

Hence Modulus is high

Transverse Loading

Compression:
Stiff and strong

Tension:
less stiff and weaker



Cortical Bone

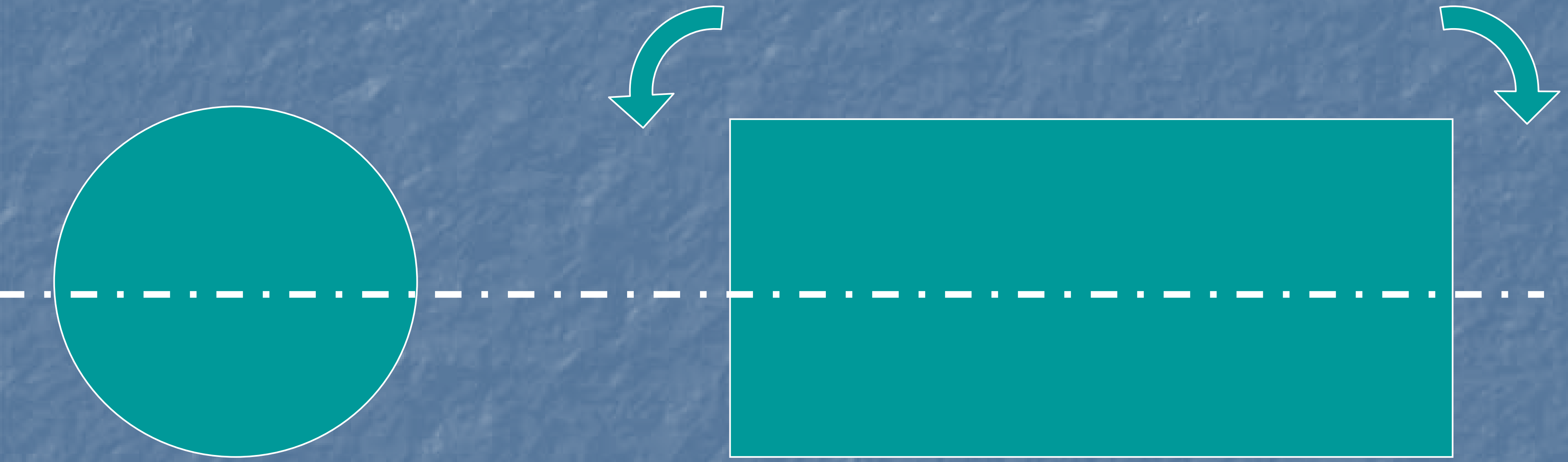
Cortical bone is slightly visco-elastic this means that the higher the strain rate, the greater the stiffness, the yield stress and the ultimate stress.

If you increase the strain rate by 1000, yield stress increases by 55 per cent. Compressive Elastic Modulus by 49 per cent and ultimate compressive stress by 39 per cent.

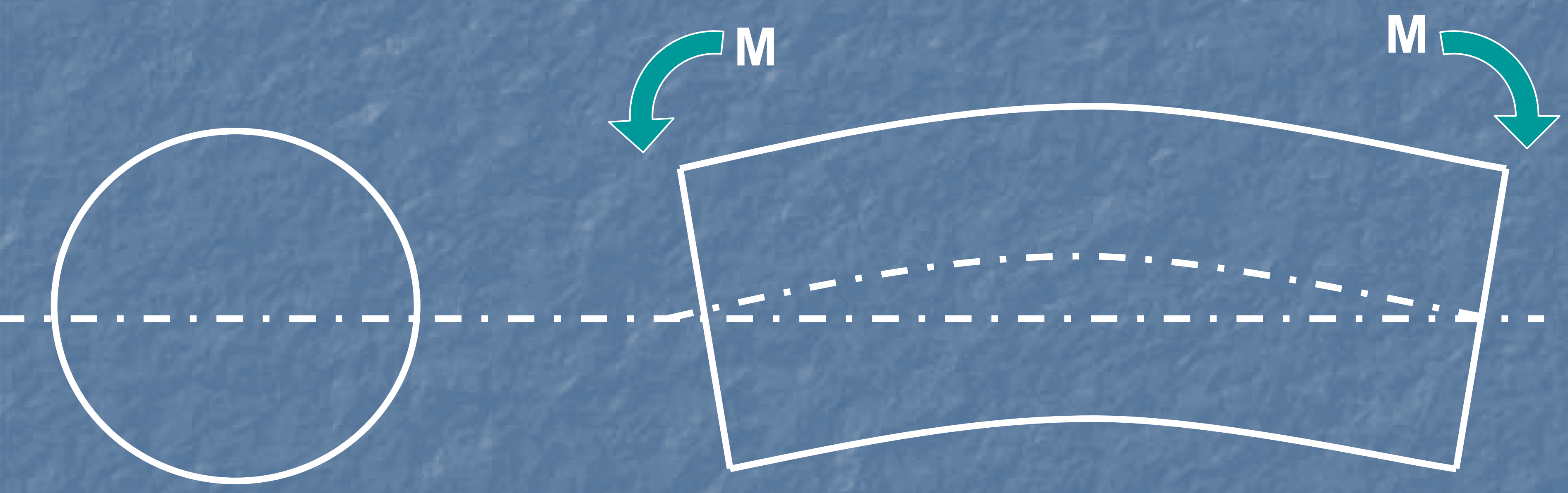
Currey,1975,J Biomechanics, 8, 81

If you experience trauma, shear rate will be high and bone will be stronger

Why are bones hollow?



Why are bones hollow?

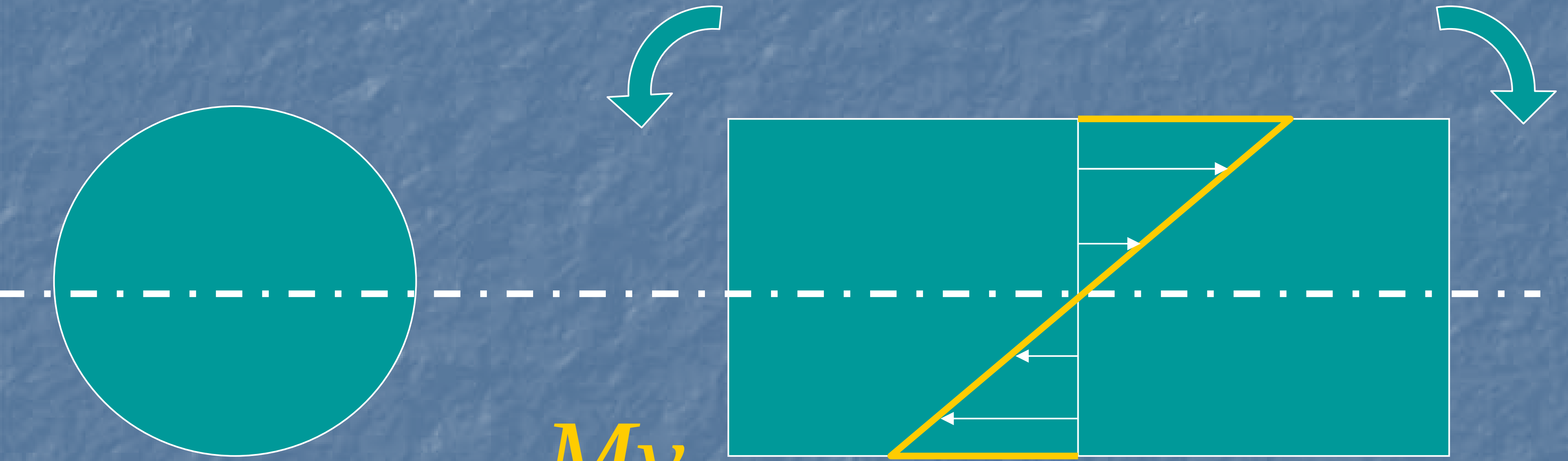


$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}$$

Definitions

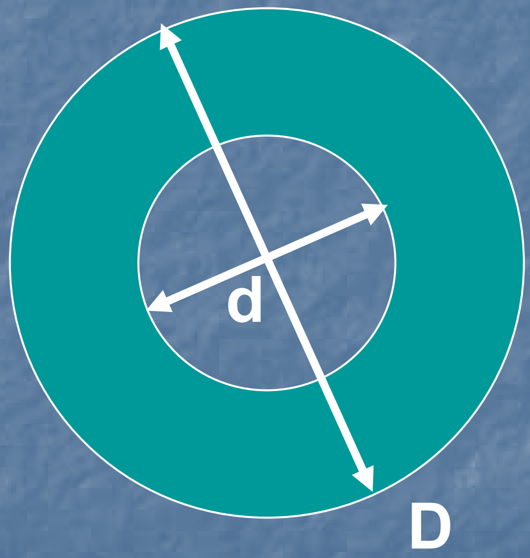
M	Applied Moment Nm
I	Second moment of area. $bd^3/12$ (rectangle)
	or $\pi D^4/64$ (circle)
σ	stress N/m^2
y	distance from neutral axis m
E	Elastic Modulus N/m^2
R	Radius of curvature

Why are bones hollow?



$$\sigma = \frac{My}{I}$$

Remove unnecessary material



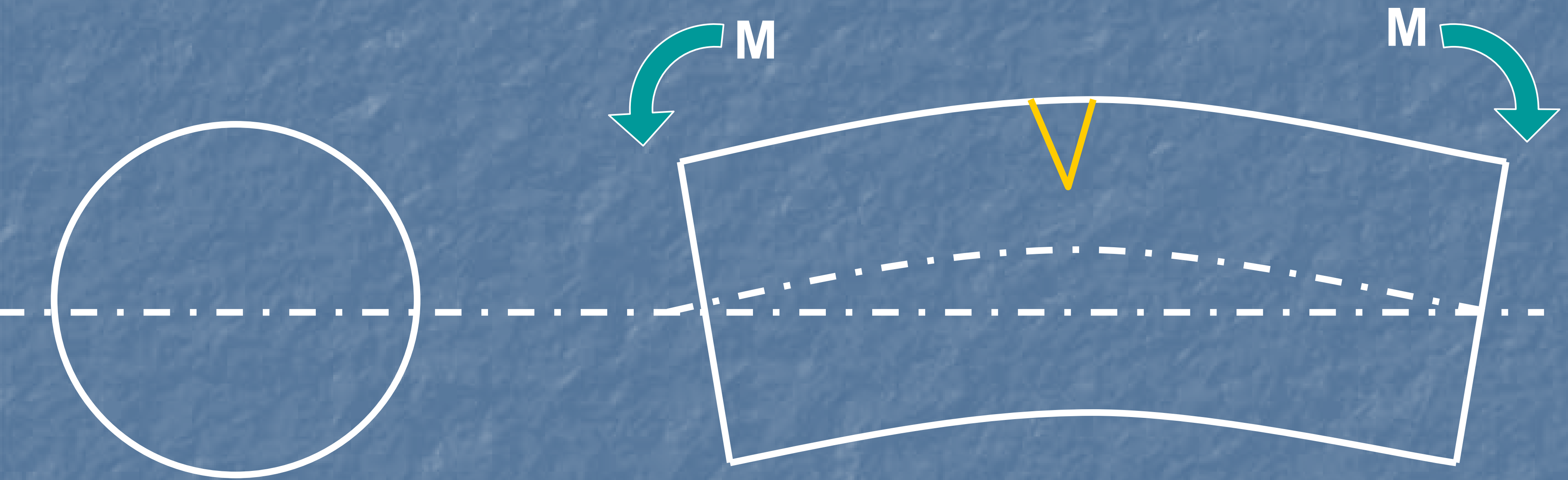
$I = \pi(D^4 - d^4)/64$

Thus if D=30mm and d=20mm,

Maximum stress is 25% more but the material saved is 45%

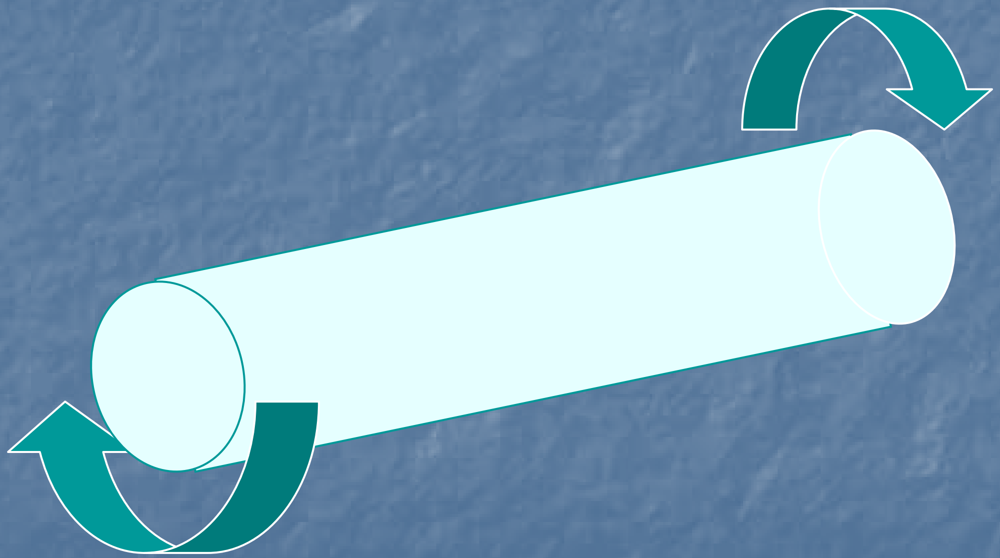
To keep the stress level the same the outer radius would need to move to 32mm and material saved would be 31%.

Failure on the tensile side



$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}$$

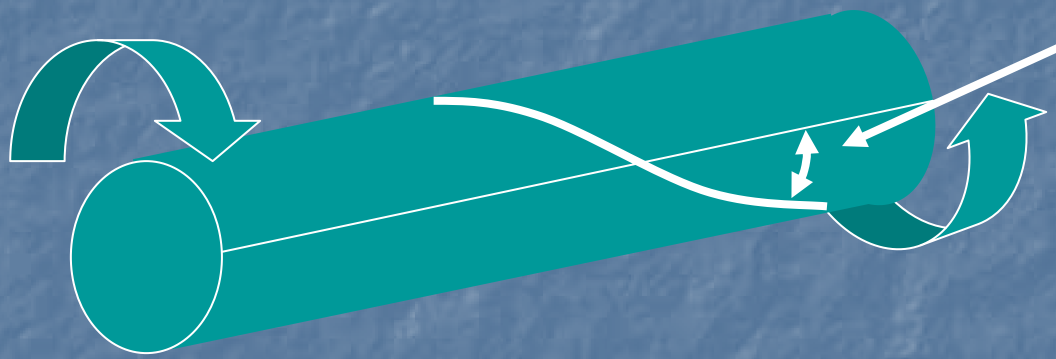
Torsional loading



Maximum tensile stress is at 45^0 to the axis

Hence often produces a spiral fracture

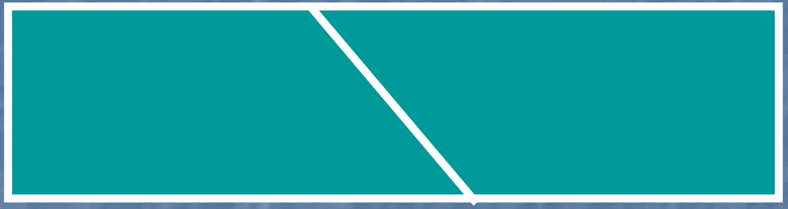
Torsional fracture- skiing



Angle is 45^0

Hence often produces a spiral fracture

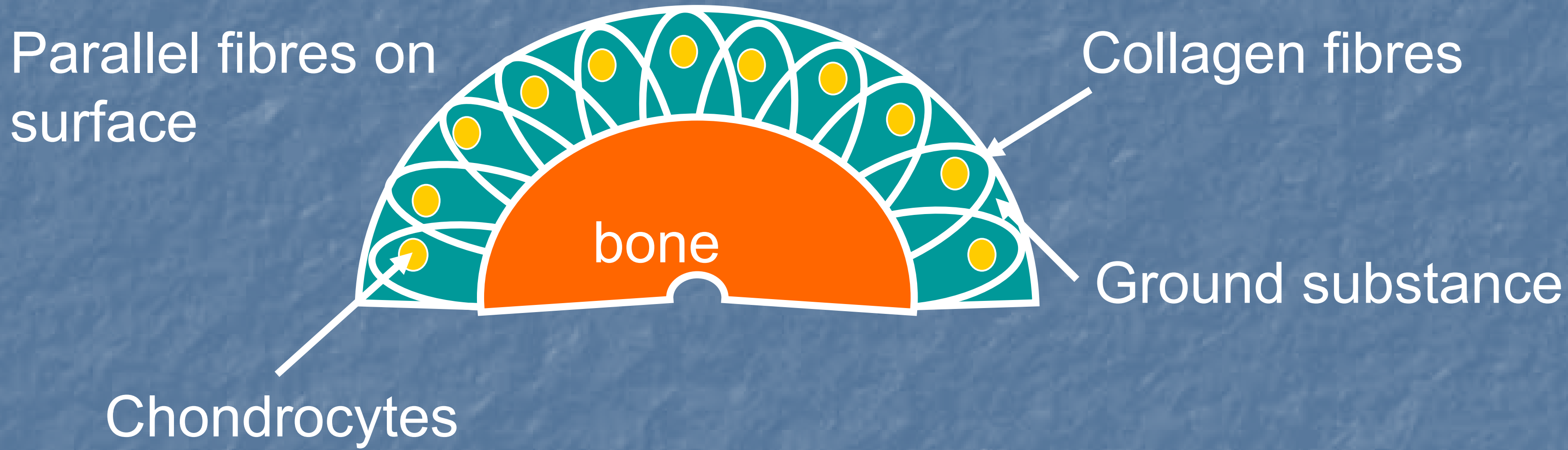
Torsional failure



Normal Hip Joint

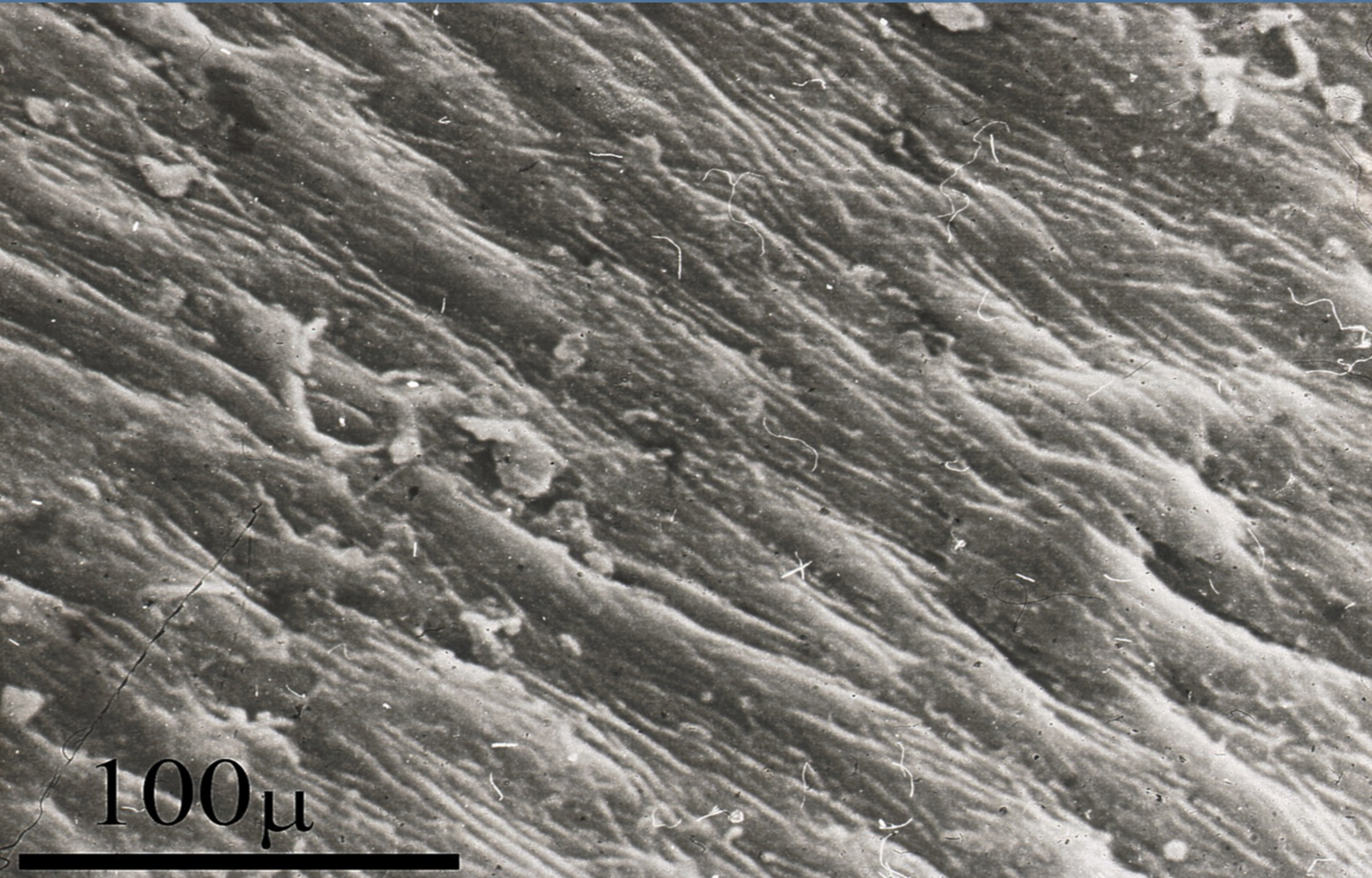
Osteo-arthritic Hip

Cartilage



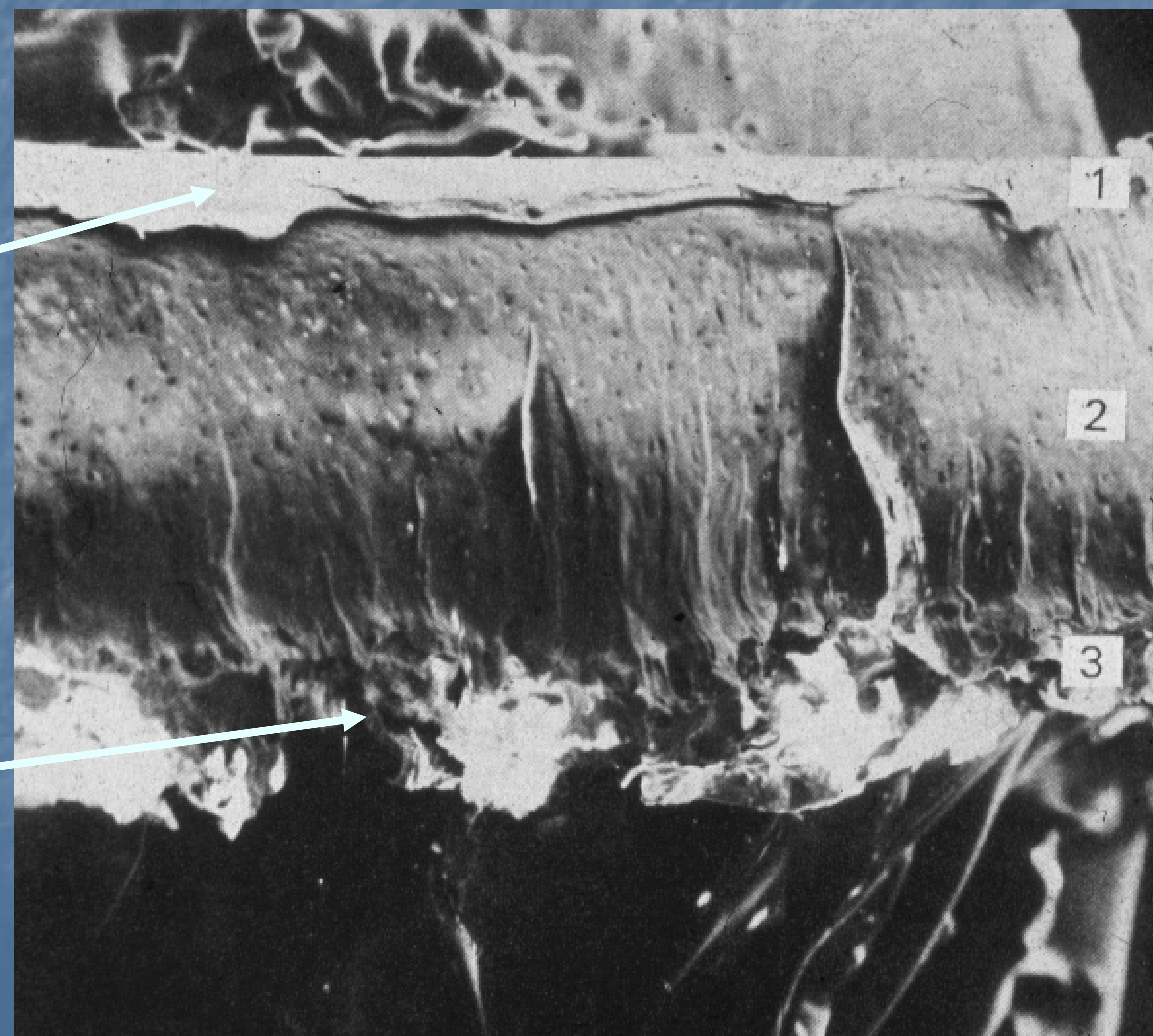
Benninghoff, 1924

Normal Healthy Cartilage



Section through cartilage

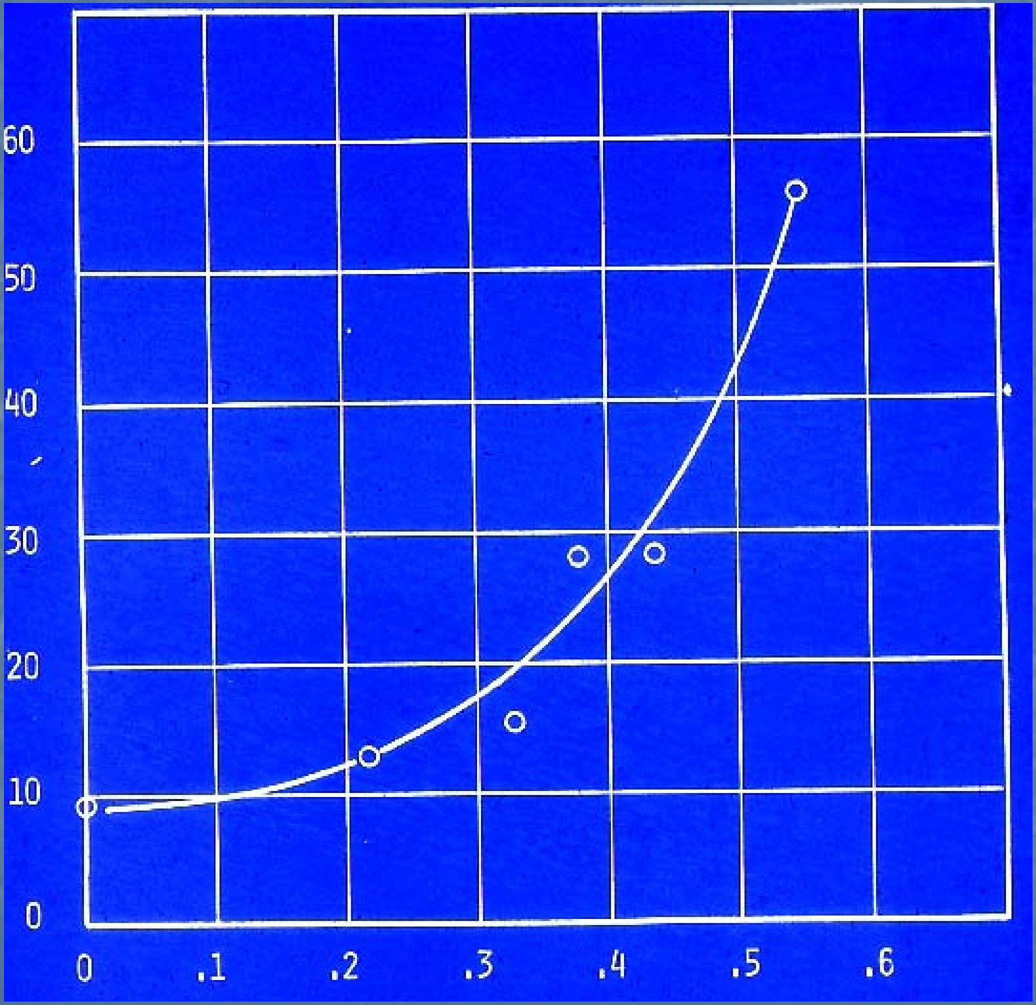
Surface layer



Underlying bone

Cartilage deformation

(unconfined)

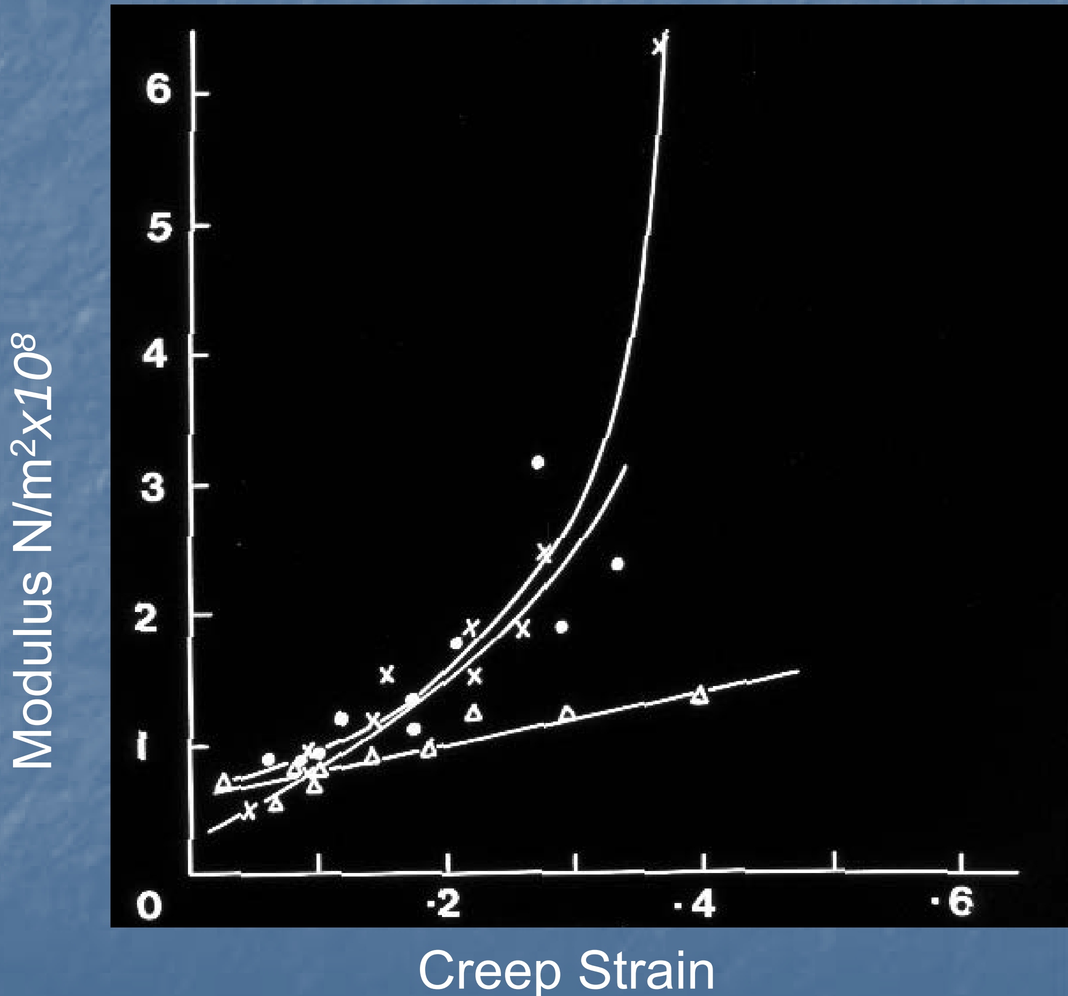


Elastic Modulus MN/m²

Creep Strain

Modulus of elasticity

Human patellar cartilage (confined)

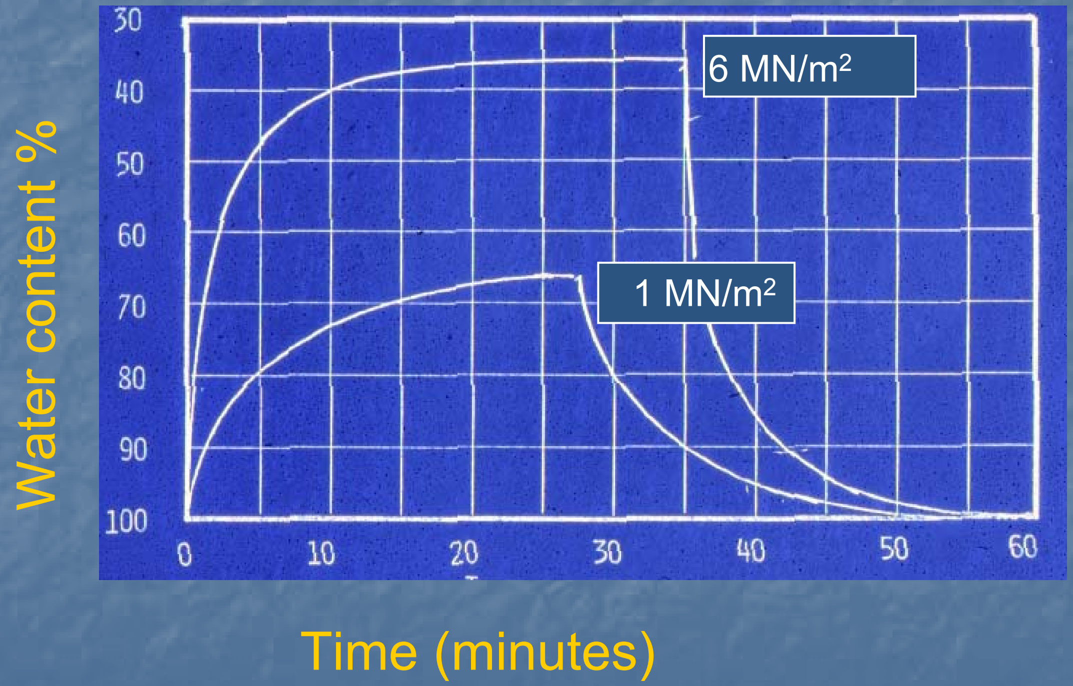


Cartilage Elasticity (Confined and Unconfined) with Creep- Human patellae

Creep strain	Modulus (C) MN/m^2			Modulus (U)
0.1	70	70	90	10
0.2	160	100	150	12
0.3	270	120	200	18
0.4	1000	150	550	28
0.5				42

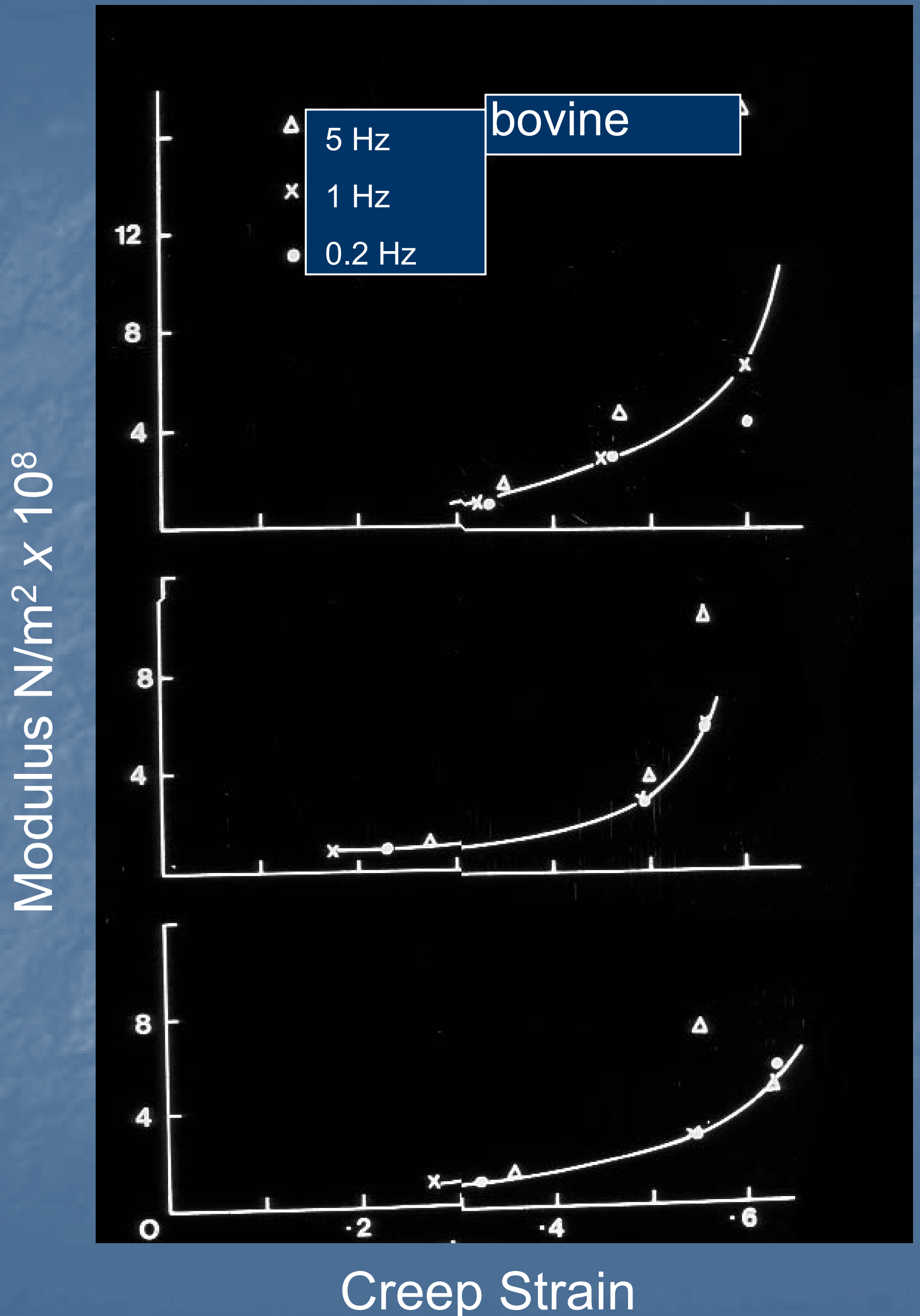
Cortical bone is 15,000 MN/m^2 ; UHMWPE is 1000 MN/m^2

Water content of cartilage under stress

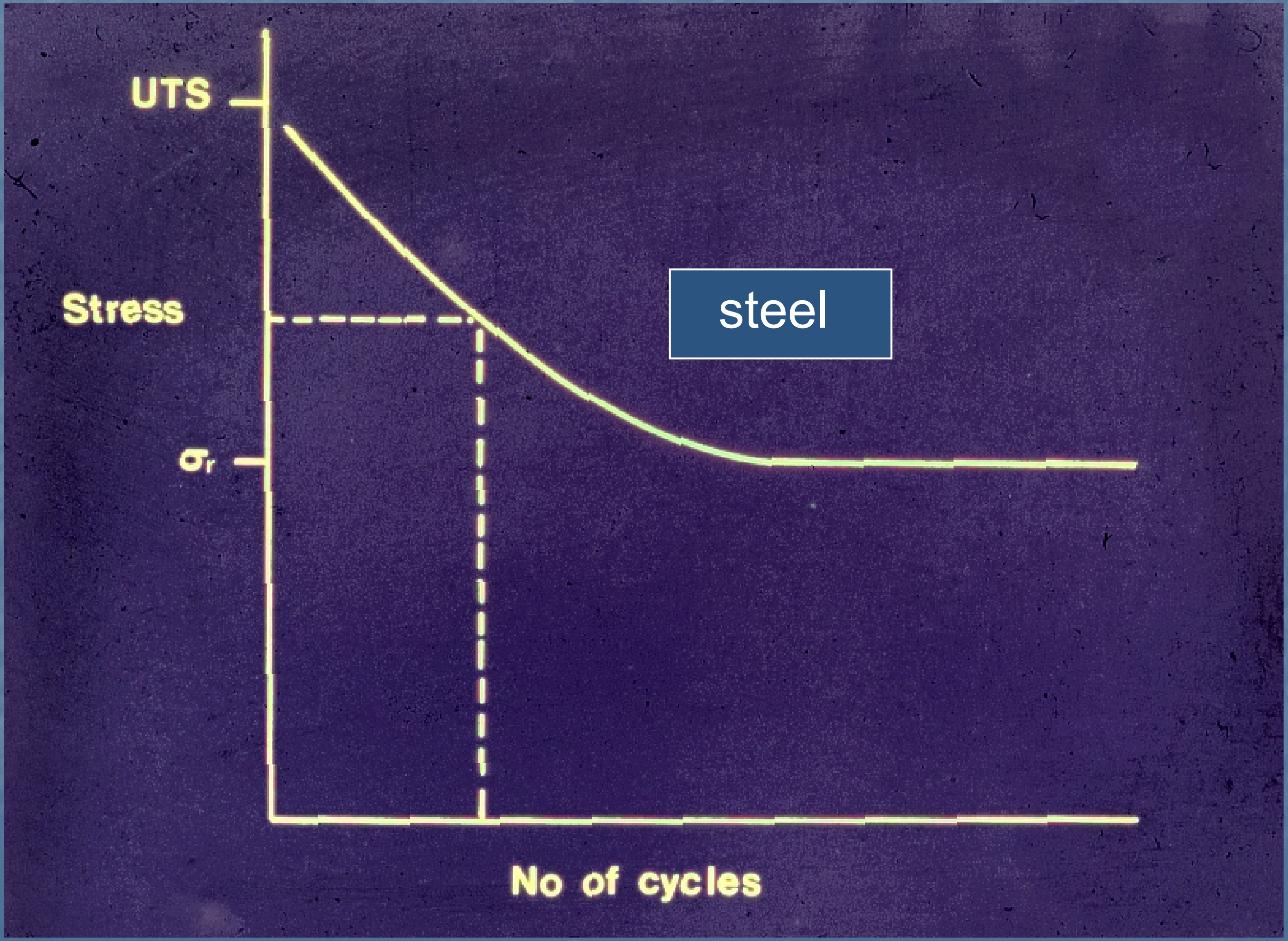


Effect of loading rate on bovine cartilage

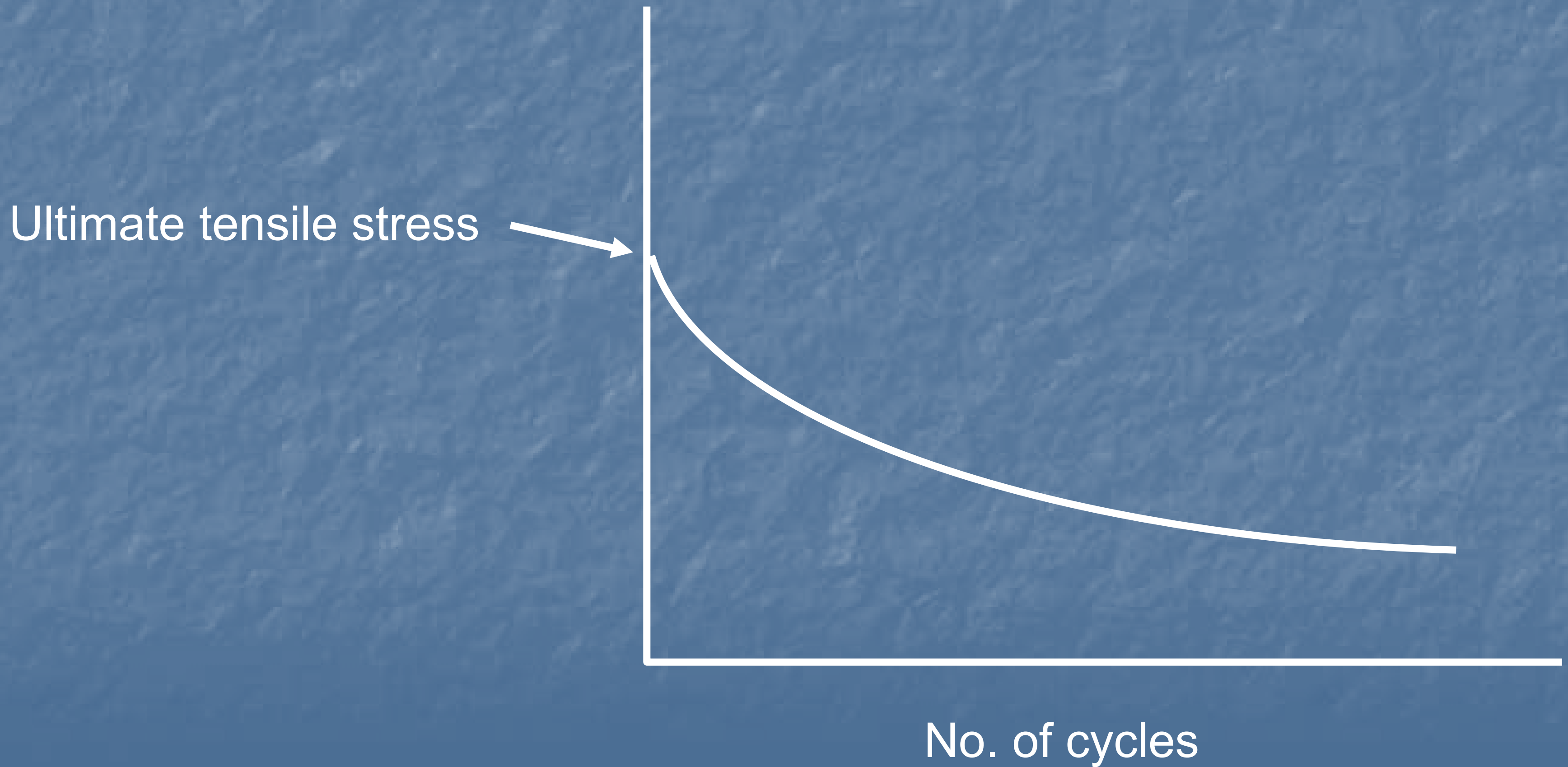
Higher frequencies increase modulus



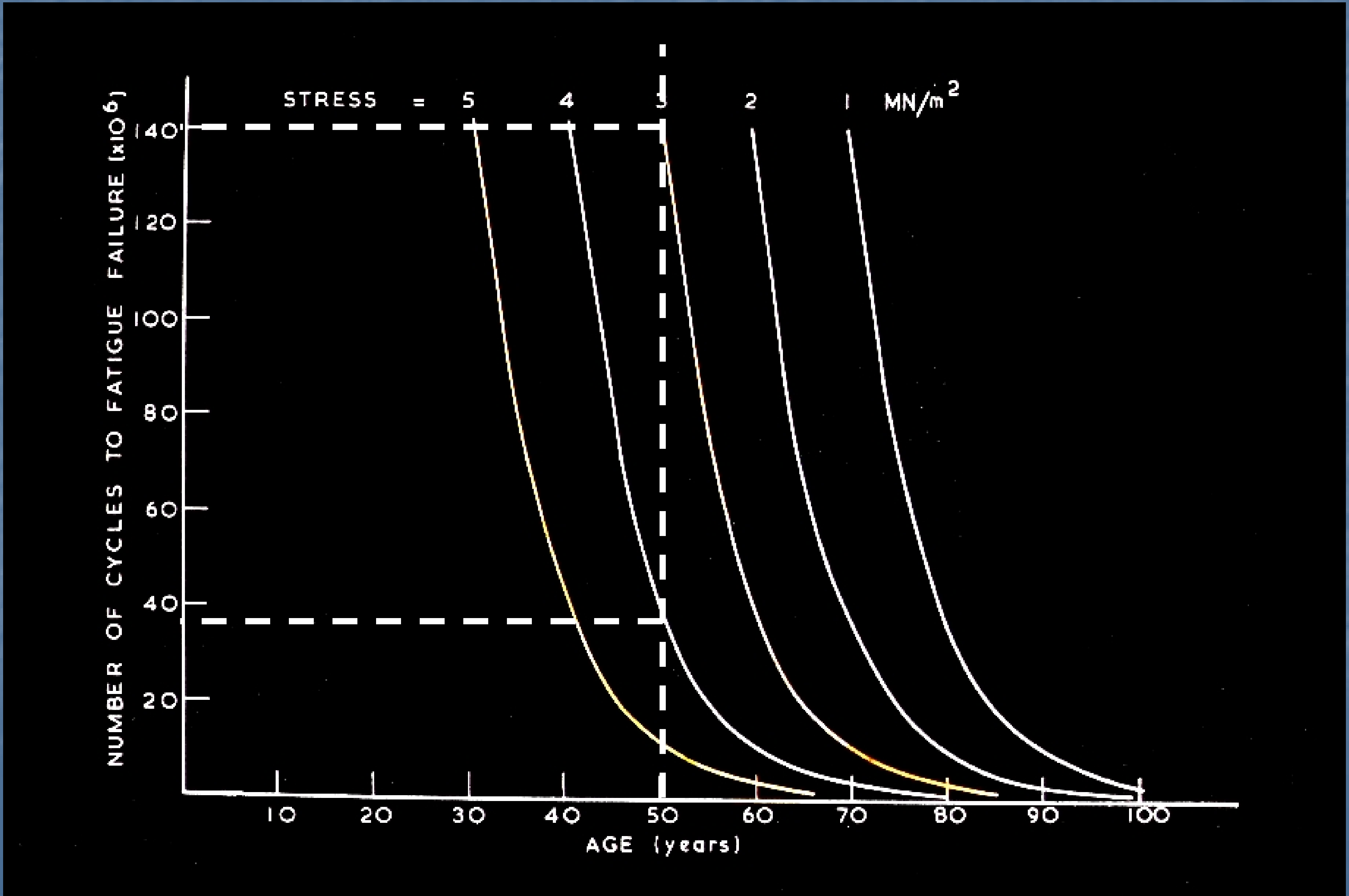
Fatigue



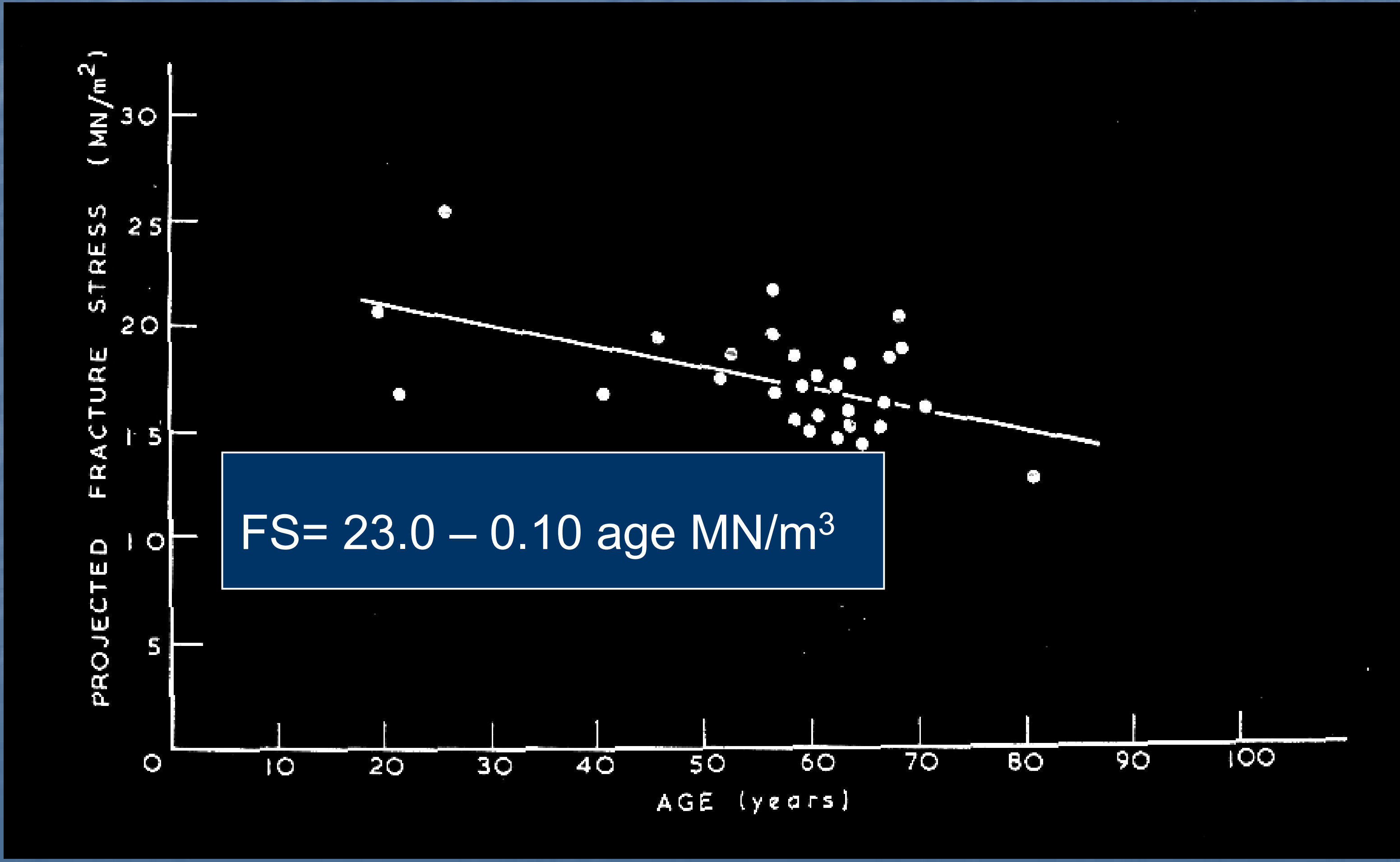
Fatigue behaviour of cartilage



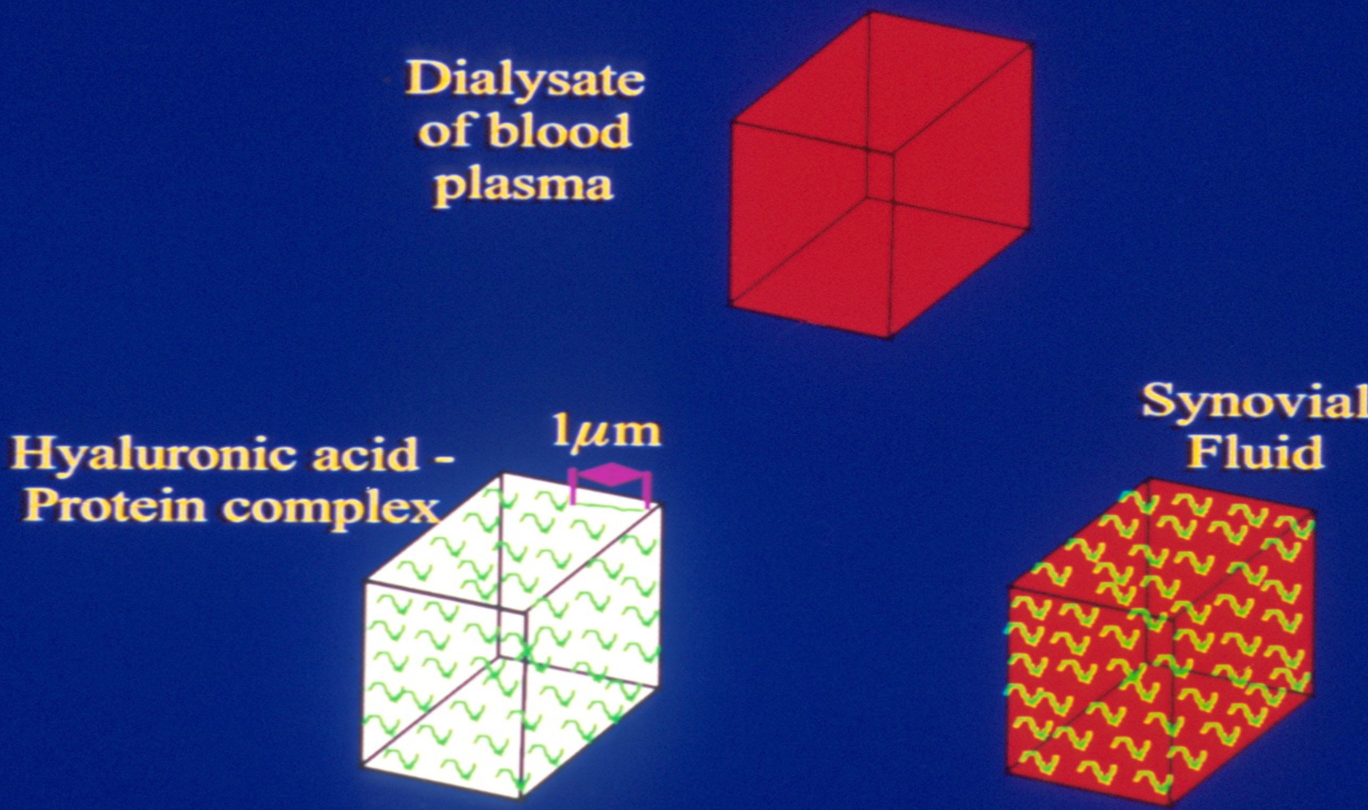
Fatigue in cartilage (effect of age)



Fracture stress of cartilage

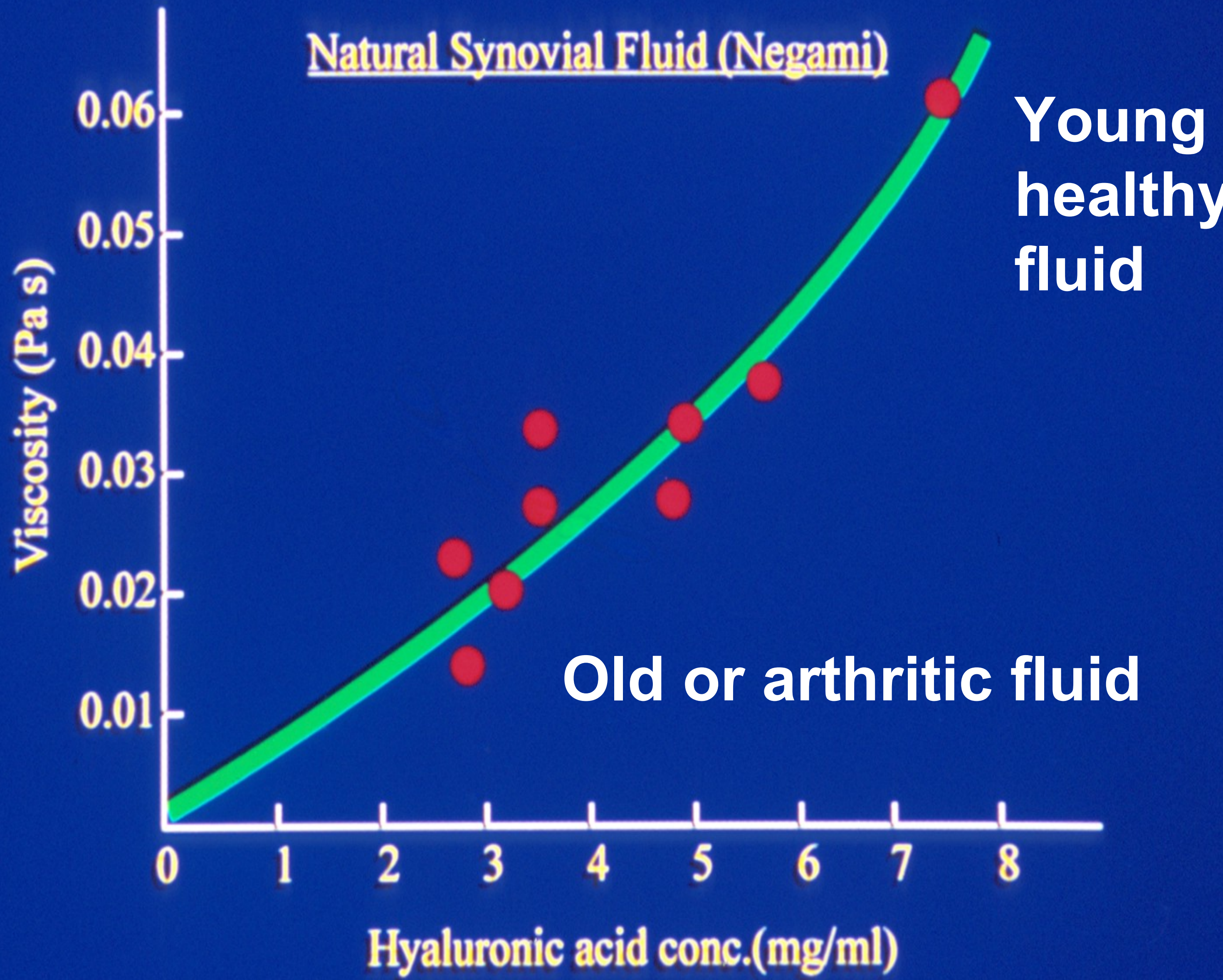


Synovial Fluid



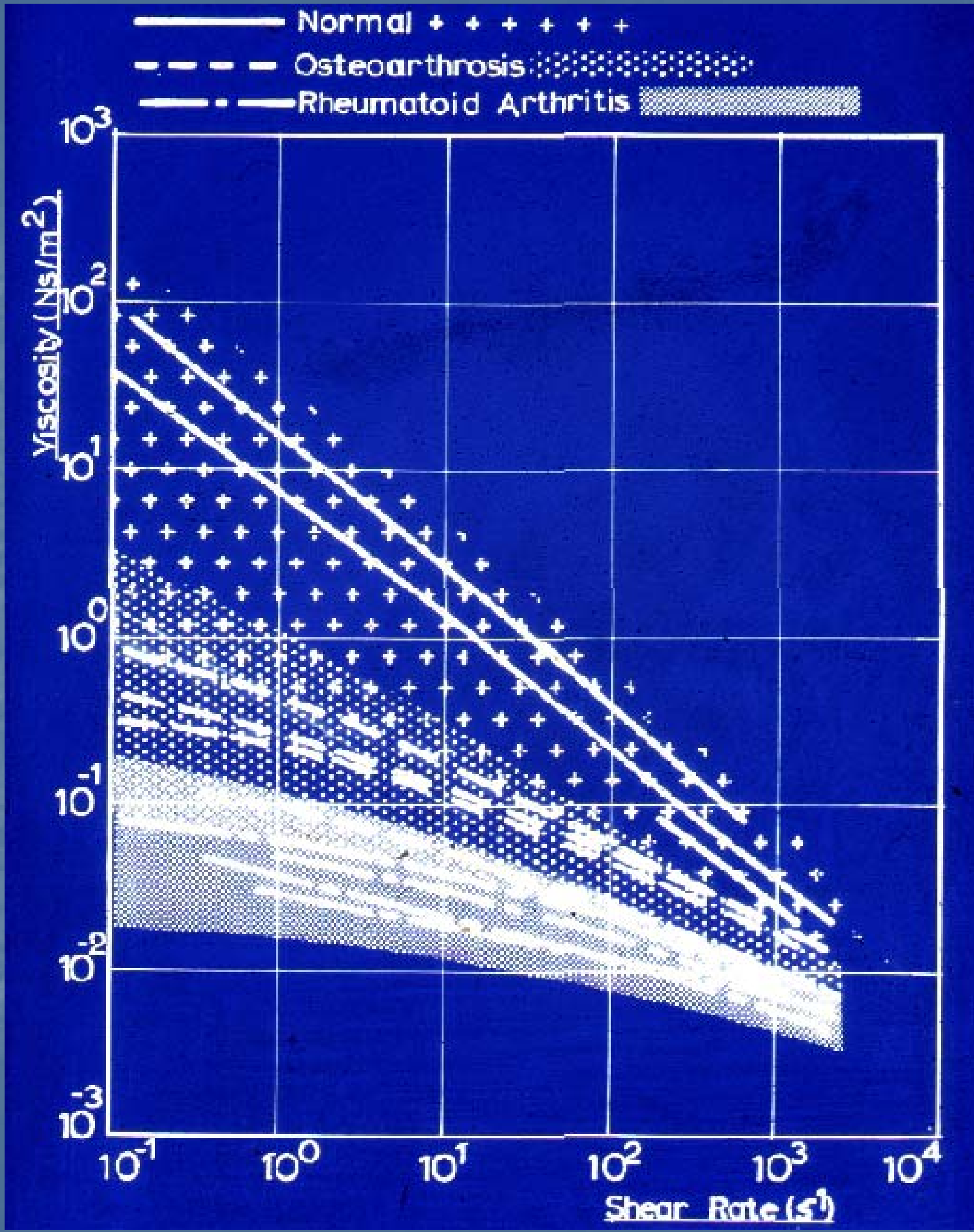
Synovial fluid

- Provides nutrition for cartilage
- Lubricates the articular cartilage



Natural Synovial Fluid (Negami)
Young healthy fluid
Old or arthritic fluid
Viscosity (Pa s)
0.06
0.05
0.04
0.03
0.02
0.01
0
1
2
3
4
5
6
7
8
Hyaluronic acid conc.(mg/ml)

Normal and pathological synovial fluid



Common Materials in Orthopaedics

UHMWPE

Stainless Steel

Cemented PMMA

Alumina ceramic

Titanium supports

Hydroxyapatite coating

Silicone elastomer

CoCrMo Alloys, as cast and modified

Material Properties

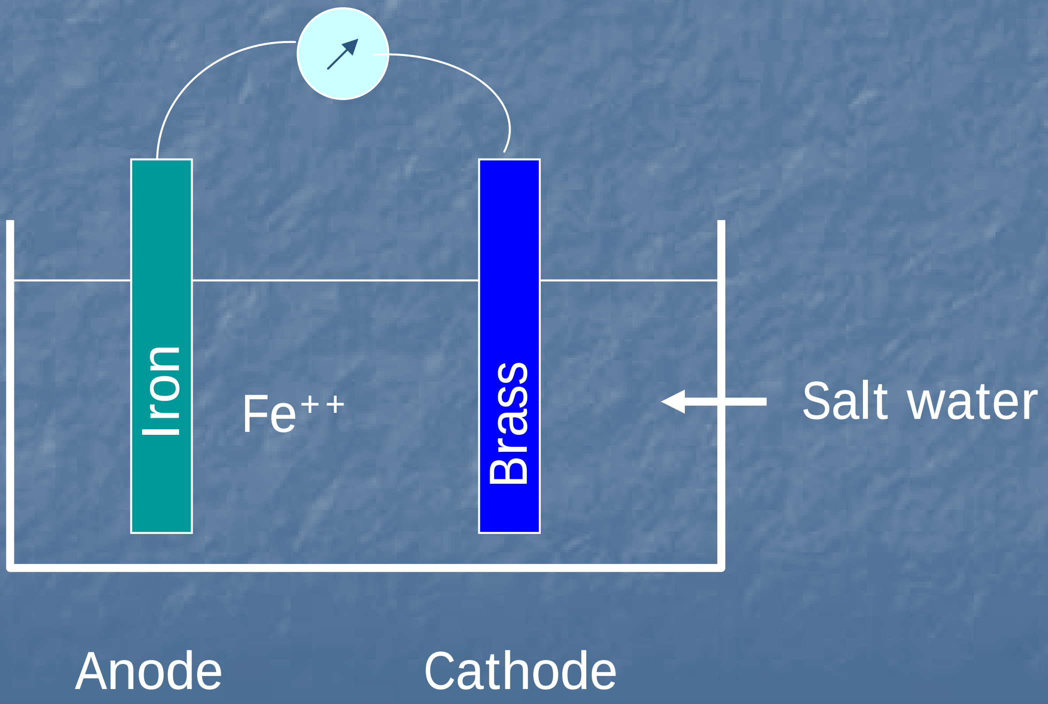
	Tensile Modulus (GPa)	Ultimate Stress (MPa)		Strain to Failure (%)
St. Steel	193	834-1035cw		28-72
CoCrMo	200	655cast-1790cw		8-50
Ti Alloy	105	860-963		10-36
UHMWPE	0.94-1.05	39		420-525
PMMA	1.6-2.6	25-48 (70 compress)		5-10
Silicone	0.004	10-12		700-800
Cort bone	15	200		2

Ceramics Al_2O_3

- Tensile Modulus 380 GPa (193 StSt)
- Compressive Strength 4000 MPa (1000 StSt)

Corrosion

- Direct Chemical Attack
- Galvanic Corrosion



What about Prostheses?

Galvanic Series

Magnesium

Zinc

Low carbon steel

Stainless Steel (unpassivated)

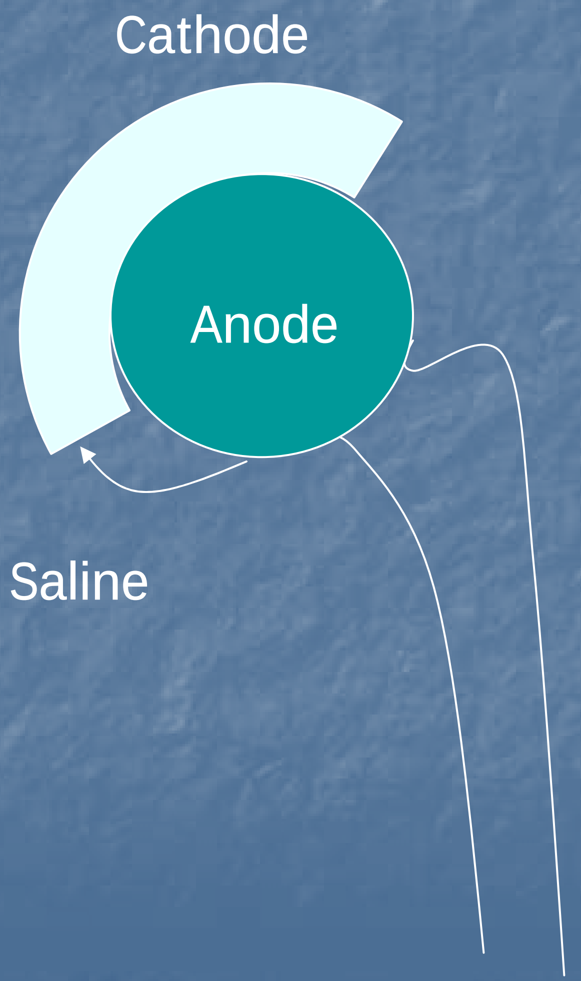
Copper

Nickel

Silver

Stainless Steel (passivated)

Titanium



Prevention

- Use like metals
- Use at least one non-conductor

Corrosion in a single piece of material