Cold Spring Harb Perspect Biol 2012

Overview of the "Matrisome"—An Inventory of Extracellular Matrix Constituents and Functions

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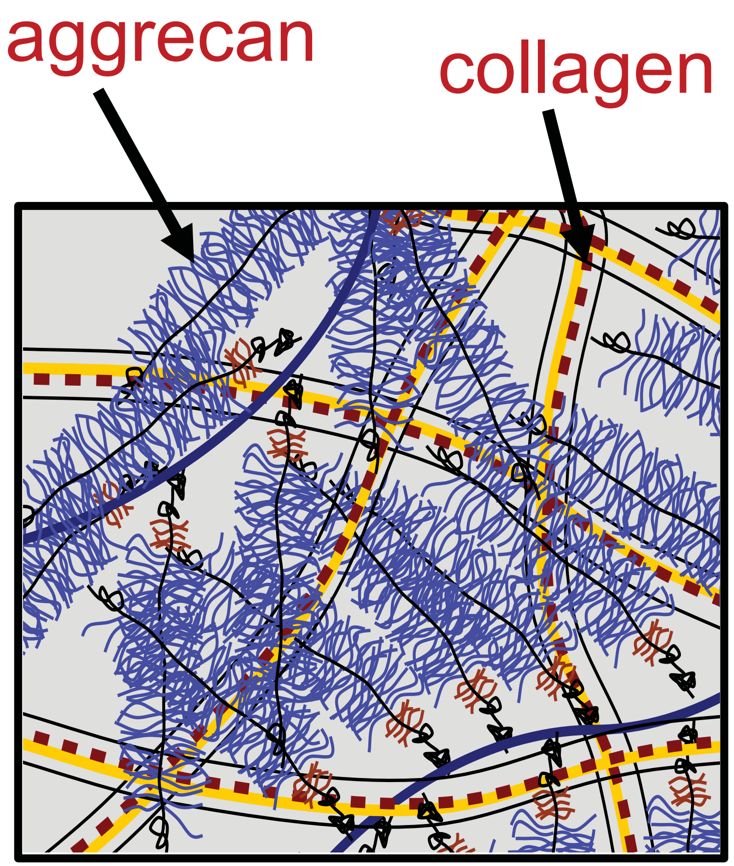
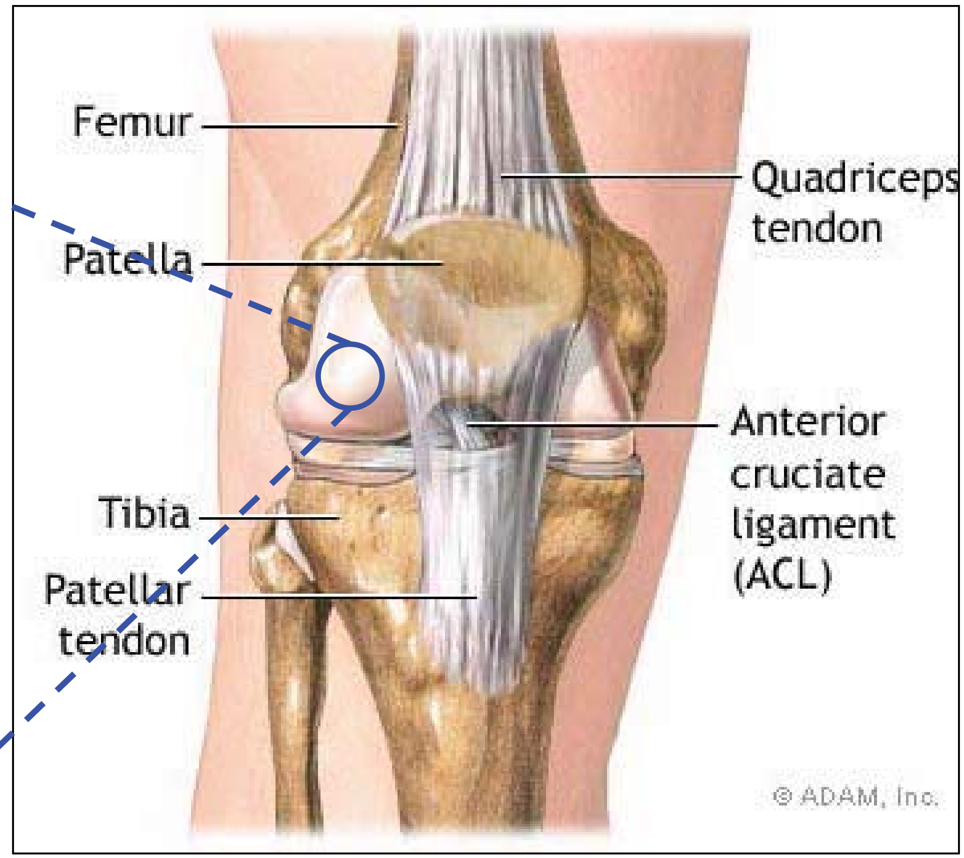
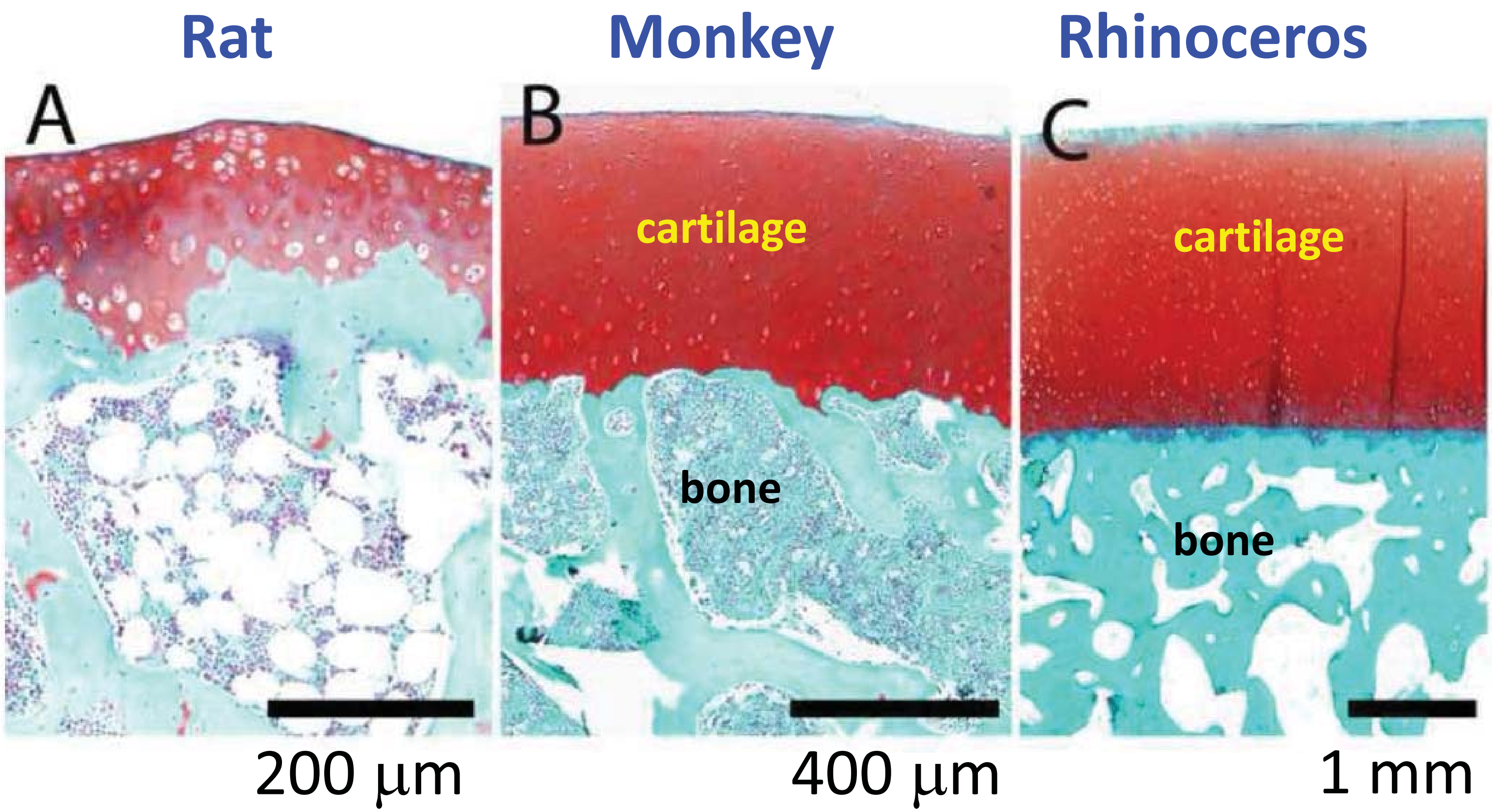
- Completion of genome sequences for many organisms defines the complete "list" of extracellular matrix (ECM) proteins.
- In mammals: **"core matrisome" comprises ~300 proteins**. Also: large numbers of ECM modifying *enzymes* & ECM-binding *growth factors*
- These ECM & ECM-associated proteins cooperate to assemble & remodel extracellular matrices and bind to cells through receptors so cells can survive, proliferate, differentiate, shape, and migrate.
- **ECM proteins were the key to the transition to multi-cellularity, the *arrangement of cells into tissues*, and the elaboration of novel structures during vertebrate evolution.**

Aggrecan: Resists Compression (in Cartilage)

Collagen: Resists Tension (in Cartilage)







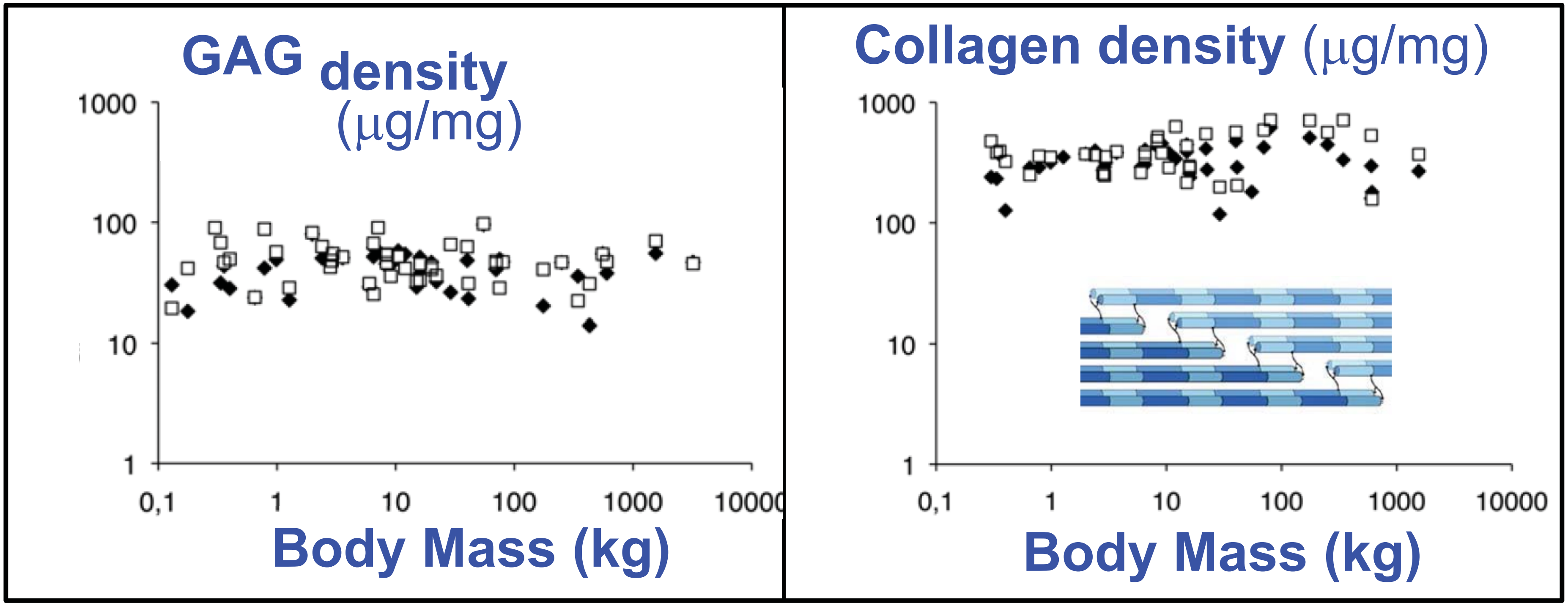
"Safranin-O" (red) stains Glycosaminoglycans (of Proteoglycans)

Source: Malda, Jos, et al. "Of Mice, Men and Elephants: The Relation between Articular Cartilage Thickness and Body Mass." *PloS one* 8, no. 2 (2013): e57683.

Tensile & Shear Modulus: Collagen

Compressive Modulus: Aggrecan-GAGs

(**Modulus**: an **"intrinsic material property"**
.....**independent of size, shape**....)

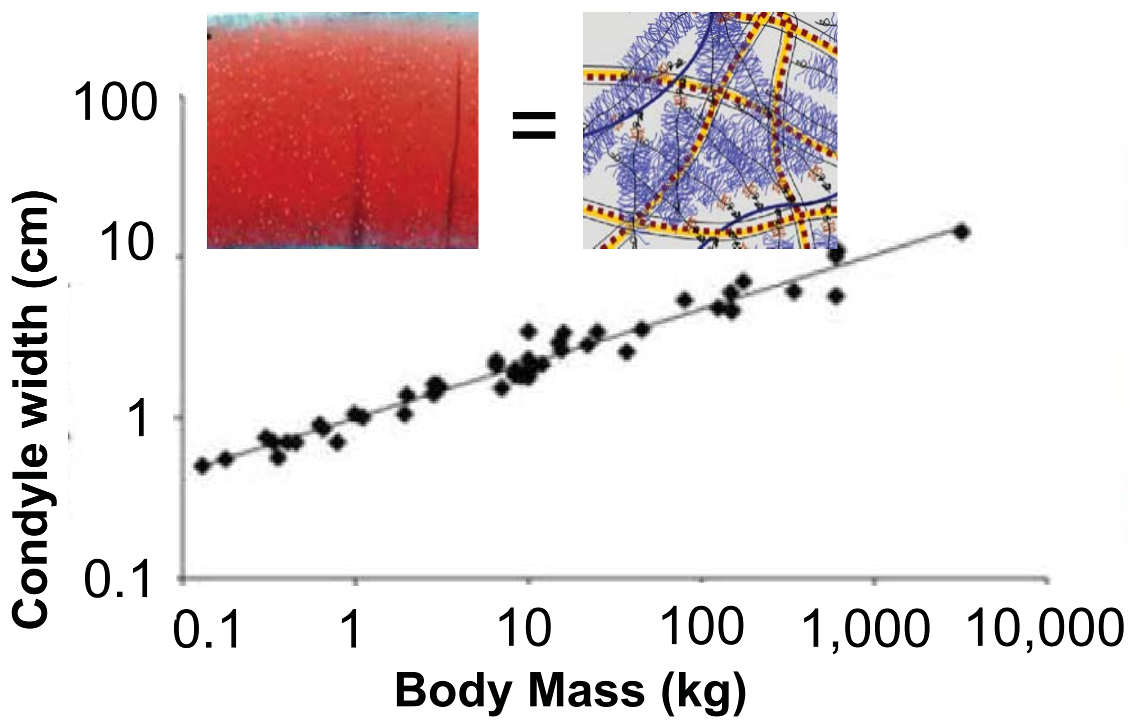


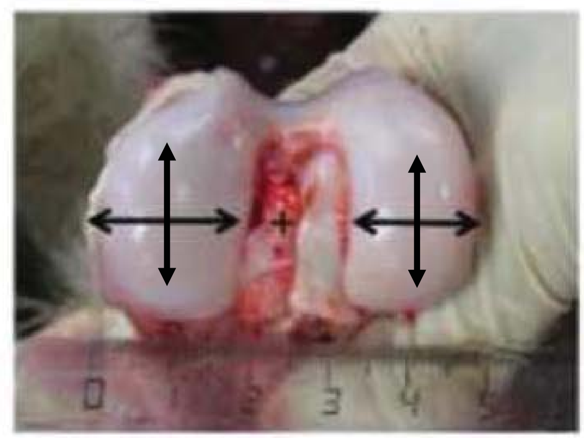
Courtesy of the authors. Used with permission.
Source: Malda, Jos, et al. "Of Mice, Men and Elephants: The Relation between Articular Cartilage Thickness and Body Mass." *PloS one* 8, no. 2 (2013): e57683.

Loading Area $\propto$ [width]^2 **scales as** $(\textbf{Body Mass})^{\frac{2}{3}}$

Stress = **(Force/Area)** on Joint surface is **~ Same**

$\therefore$ **cells have optimized the appropriate ECM**





"$\sigma \simeq E_{cart}\,\varepsilon$"

Courtesy of the authors. Used with permission.
Source: Malda, Jos, et al. "Of Mice, Men and Elephants: The Relation between Articular Cartilage Thickness and Body Mass." *PloS one* 8, no. 2 (2013): e57683.

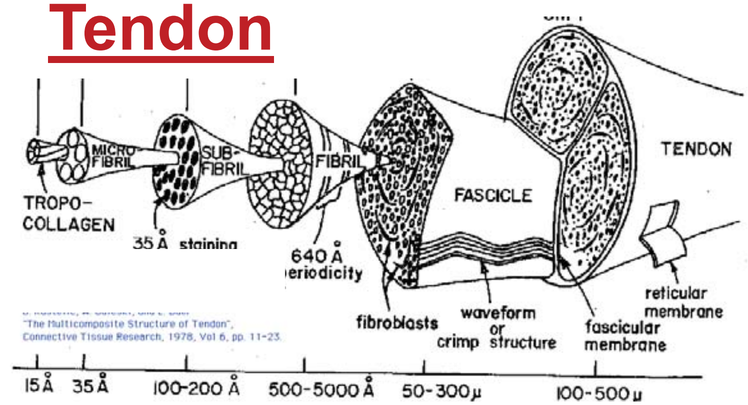
Google: "elastic moduli"

Every elastic modulus can be expressed in terms of two other moduli

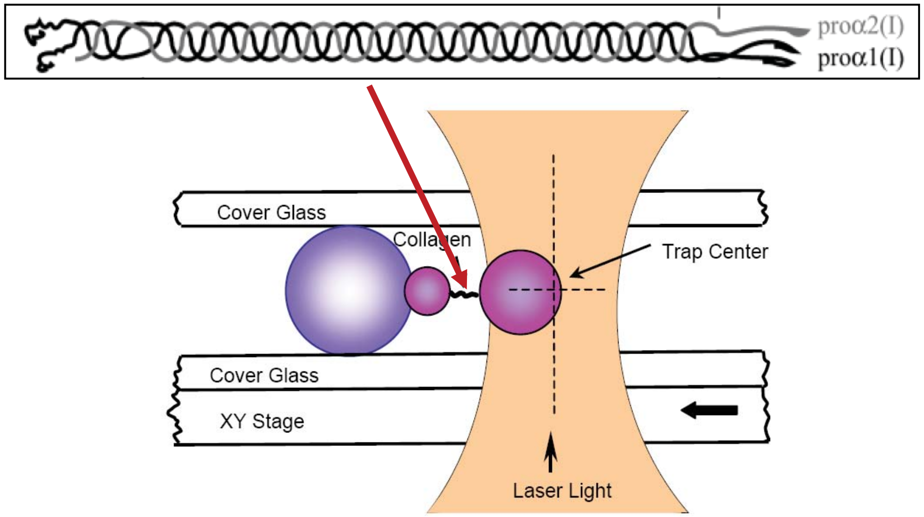
	bulk	Young's	Lamé #2	Shear	Poisson	Longitudinal
	$K=$	$E=$	$\lambda=$	$G=$	$\nu=$	$M=$H
$(K,\,E)$	K	E	$\frac{3K(3K-E)}{9K-E}$	$\frac{3KE}{9K-E}$	$\frac{3K-E}{6K}$	$\frac{3K(3K+E)}{9K-E}$
$(K,\,\lambda)$	K	$\frac{9K(K-\lambda)}{3K-\lambda}$	λ	$\frac{3(K-\lambda)}{2}$	$\frac{\lambda}{3K-\lambda}$	$3K-2\lambda$
$(K,\,G)$	K	$\frac{9KG}{3K+G}$	$K-\frac{2G}{3}$	G	$\frac{3K-2G}{2(3K+G)}$	$K+\frac{4G}{3}$
$(K,\,\nu)$	K	$3K(1-2\nu)$	$\frac{3K\nu}{1+\nu}$	$\frac{3K(1-2\nu)}{2(1+\nu)}$	ν	$\frac{3K(1-\nu)}{1+\nu}$
$(K,\,M)$	K	$\frac{9K(M-K)}{3K+M}$	$\frac{3K-M}{2}$	$\frac{3(M-K)}{4}$	$\frac{3K-M}{3K+M}$	M
$(E,\,\lambda)$	$\frac{E+3\lambda+R}{6}$	E	λ	$\frac{E-3\lambda+R}{4}$	$\frac{2\lambda}{E+\lambda+R}$	$\frac{E-\lambda+R}{2}$
$(E,\,G)$	$\frac{EG}{3(3G-E)}$	E	$\frac{G(E-2G)}{3G-E}$	G	$\frac{E}{2G}-1$	$\frac{G(4G-E)}{3G-E}$
$(E,\,\nu)$	$\frac{E}{3(1-2\nu)}$	E	$\frac{E\nu}{(1+\nu)(1-2\nu)}$	$\frac{E}{2(1+\nu)}$	ν	$\frac{E(1-\nu)}{(1+\nu)(1-2\nu)}$
$(\lambda,\,G)$	$\lambda+\frac{2G}{3}$	$\frac{G(3\lambda+2G)}{\lambda+G}$	λ	G	$\frac{\lambda}{2(\lambda+G)}$	$\lambda+2G$

Pro-collagen molecule

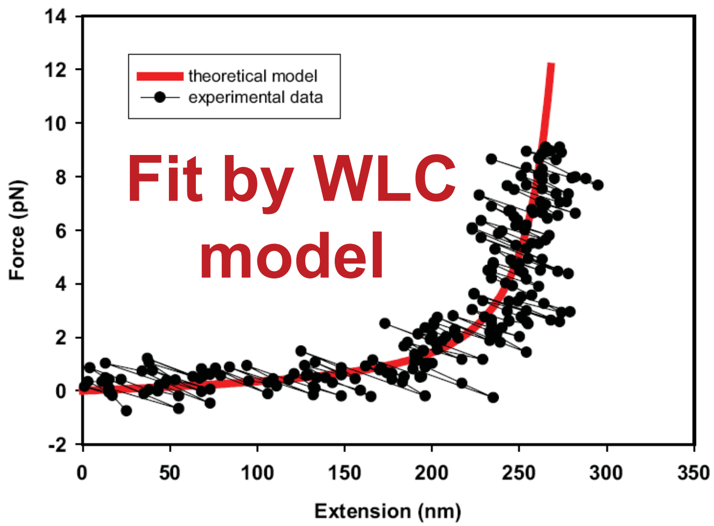
Tendon



Source: Kastelic, J., A. Galeski, et al. "The Multicomposite Structure of Tendon." *Connective Tissue Research* 6, no. 1 (1978): 11-23.

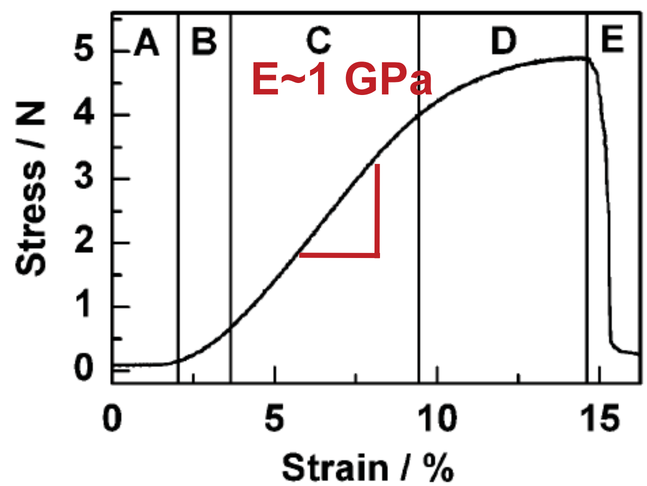


Force - extension



(Sun+, J Biomechanics, 2004)

Source: Sun, Yu-Long, et al. "Stretching Type II Collagen with Optical Tweezers." *Journal of Biomechanics* 37, no. 11 (2004): 1665-9.

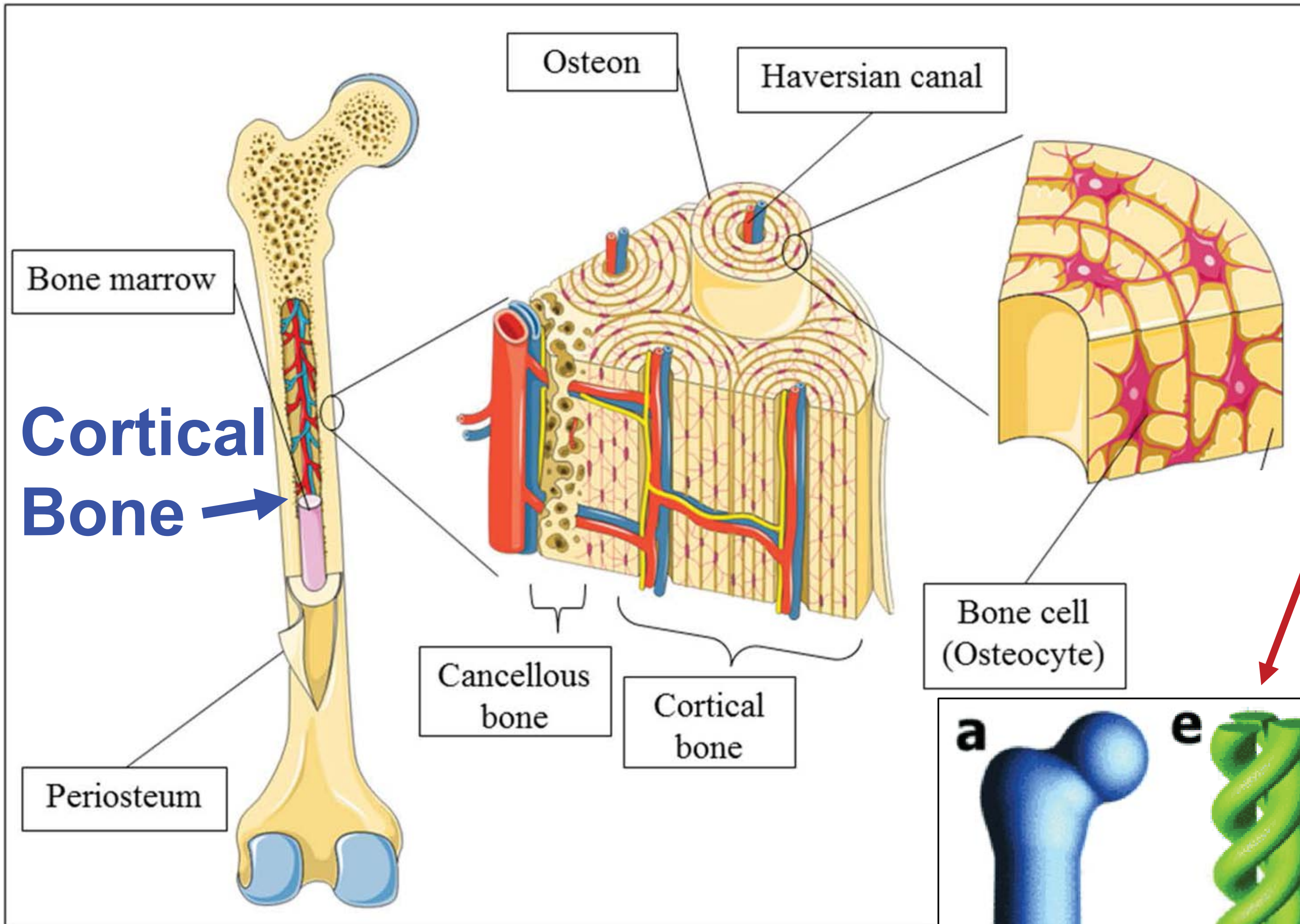


Source: Gutsmann, Thomas. "Force Spectroscopy of Collagen Fibers to Investigate their Mechanical Properties and Structural Organization." *Biophysical Journal* 86, no. 5 (2004): 3186-93.

Stress vs strain curve of a rat tail tendon: (A-B) Toe - heel region, **(C) linear region**, (D) plateau, (E) rupture of the tendon.

(Gutsmann+, Biophys J, 2004)

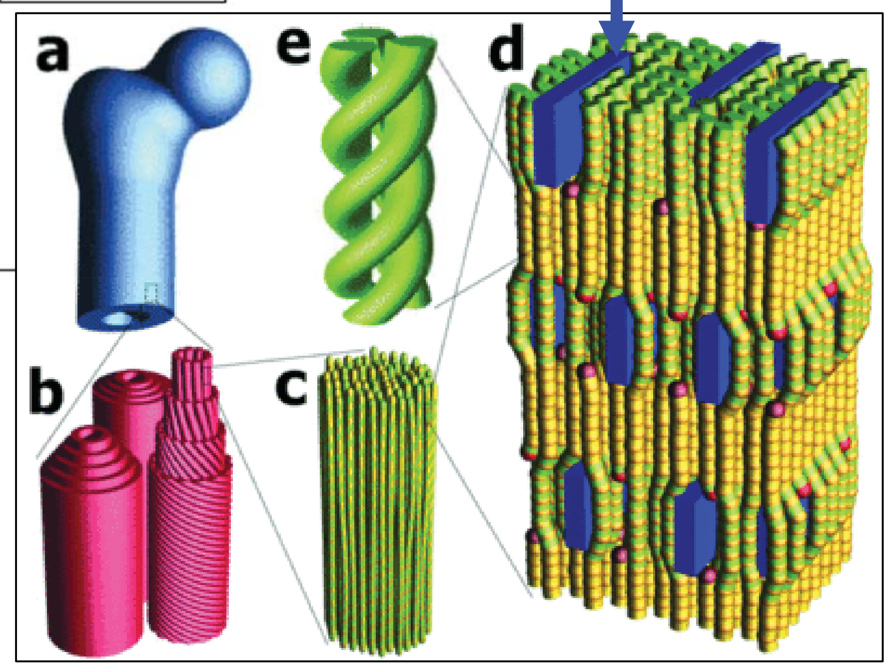
Bone



Source: Bao, Chao Le Meng, et al. "Advances in Bone Tissue Engineering." *Regenerative Medicine and Tissue Engineering* (2013): 599-614.

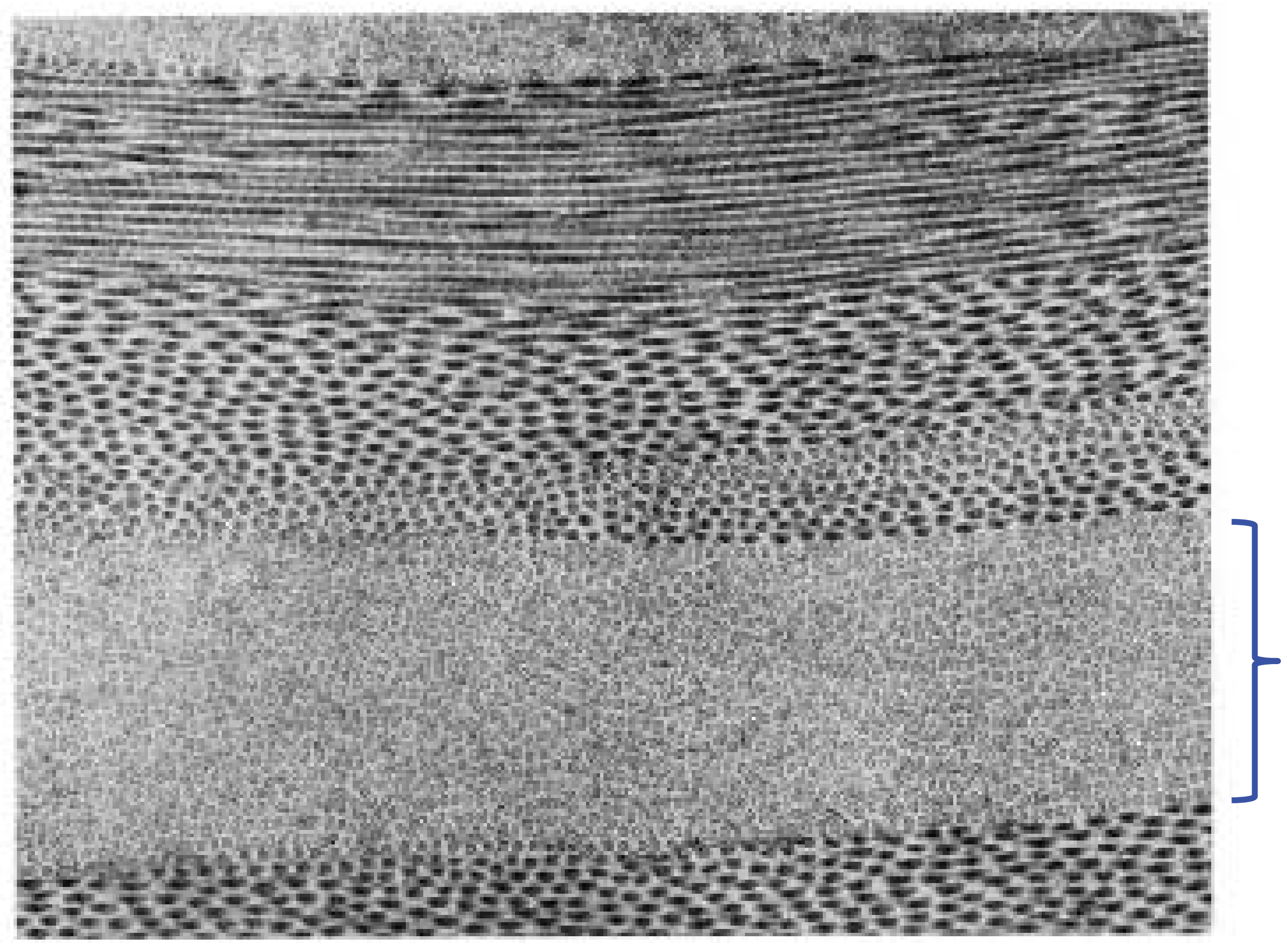
Collagen (I)

Mineral (hydroxyapatite)



Source: Zhou, Hongwen, et al. "Small-angle X-ray Study of the Three-dimensional Collagen/Mineral Superstructure in Intramuscular Fish Bone." *Applied Crystallography* (2007).

Corneal Stroma (normal)



Poisson's Ratio υ ~0 ….HOW?

(Text book page 241)

Regulation of gene expression in intervertebral disc cells by low and high hydrostatic pressure

(Eur Spine J, 2006)

**Cornelia Neidlinger-Wilke · Karin Würtz ·
Jill P. G. Urban · Wolfgang Börm · Markus Arand ·
Anita Ignatius · Hans-Joachim Wilke ·
Lutz E. Claes**

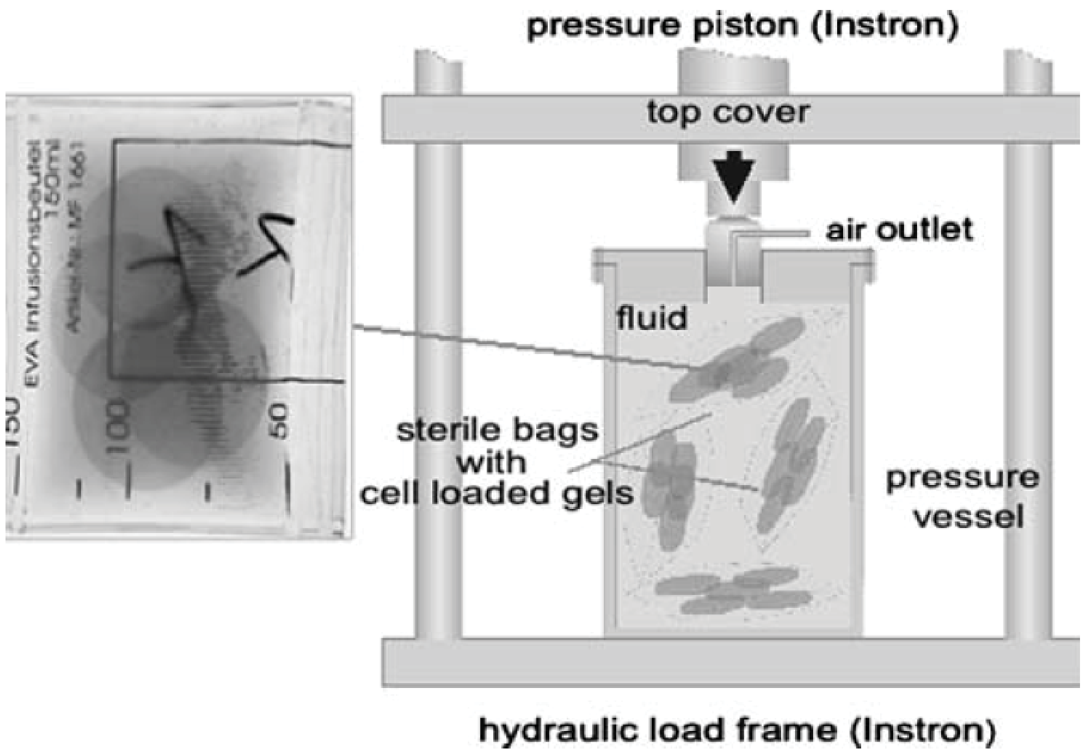


Fig. 1 Scheme of the stimulation device for the application of high hydrostatic pressure (2.5 MPa) and photo of a sterile bag with cell-seeded collagen gels

Source: Neidlinger-Wilke, Cornelia, et al. "Regulation of Gene Expression in Intervertebral Disc Cells by Low and High Hydrostatic Pressure." *European Spine Journal* 15, no. 3 (2006): 372-8.

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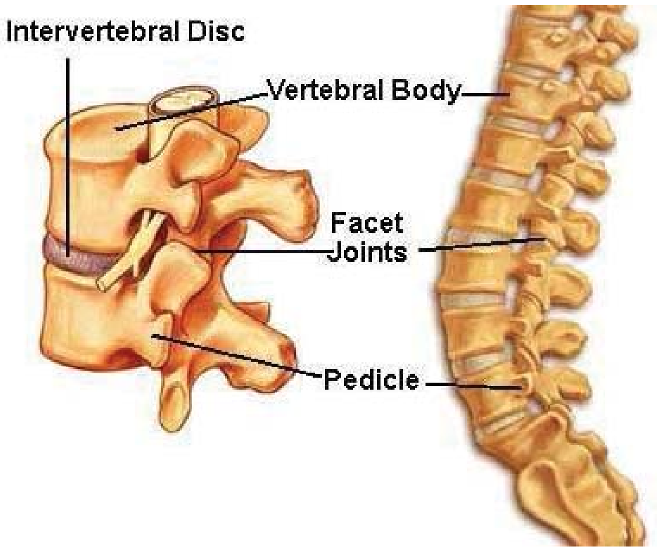
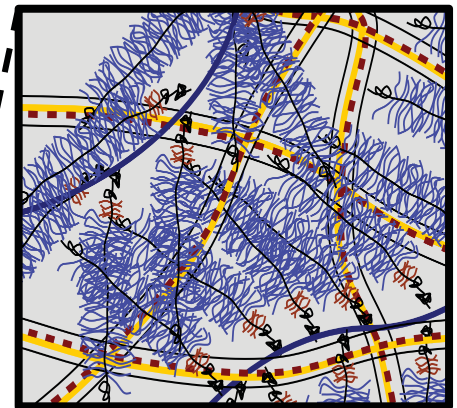
$(K,\, \lambda)$	K	$\frac{9K(K-\lambda)}{3K-\lambda}$	λ	$\frac{3(K-\lambda)}{2}$	$\frac{\lambda}{3K-\lambda}$	$3K - 2\lambda$
$(K,\, G)$	K	$\frac{9KG}{3K+G}$	$K - \frac{2G}{3}$	G	$\frac{3K-2G}{2(3K+G)}$	$K + \frac{4G}{3}$
$(K,\, \nu)$	K	$3K(1-2\nu)$	$\frac{3K\nu}{1+\nu}$	$\frac{3K(1-2\nu)}{2(1+\nu)}$	ν	$\frac{3K(1-\nu)}{1+\nu}$
$(K,\, M)$	K	$\frac{9K(M-K)}{3K+M}$	$\frac{3K-M}{2}$	$\frac{3(M-K)}{4}$	$\frac{3K-M}{3K+M}$	M
$(E,\, \lambda)$	$\frac{E+3\lambda+R}{6}$	E	λ	$\frac{E-3\lambda+R}{4}$	$\frac{2\lambda}{E+\lambda+R}$	$\frac{E-\lambda+R}{2}$
$(E,\, G)$	$\frac{EG}{3(3G-E)}$	E	$\frac{G(E-2G)}{3G-E}$	G	$\frac{E}{2G} - 1$	$\frac{G(4G-E)}{3G-E}$
$(E,\, \nu)$	$\frac{E}{3(1-2\nu)}$	E	$\frac{E\nu}{(1+\nu)(1-2\nu)}$	$\frac{E}{2(1+\nu)}$	ν	$\frac{E(1-\nu)}{(1+\nu)(1-2\nu)}$
$(\lambda,\, G)$	$\lambda + \frac{2G}{3}$	$\frac{G(3\lambda+2G)}{\lambda+G}$	λ	G	$\frac{\lambda}{2(\lambda+G)}$	$\lambda + 2G$

Intervertebral Disc

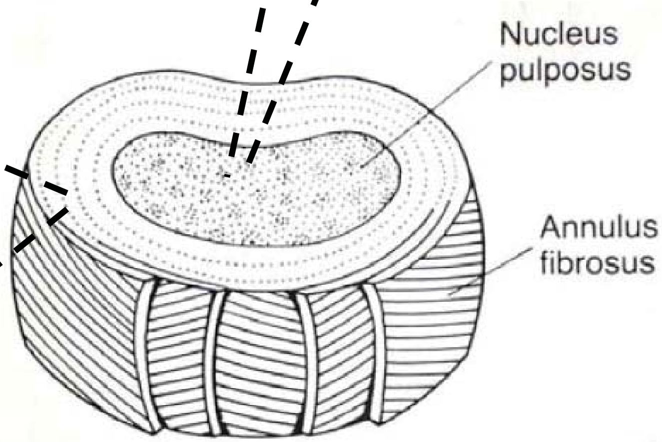
(Peter Roughley, Spine, 2004)





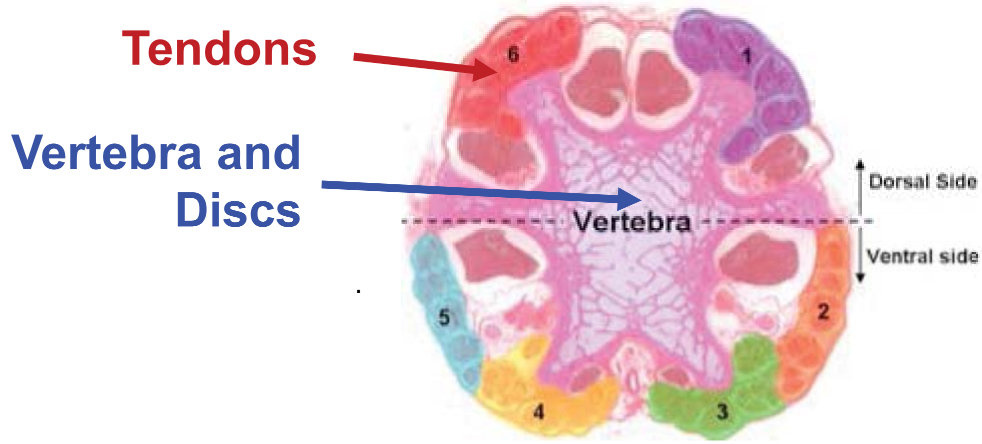
collagen II
aggrecan

col I,III

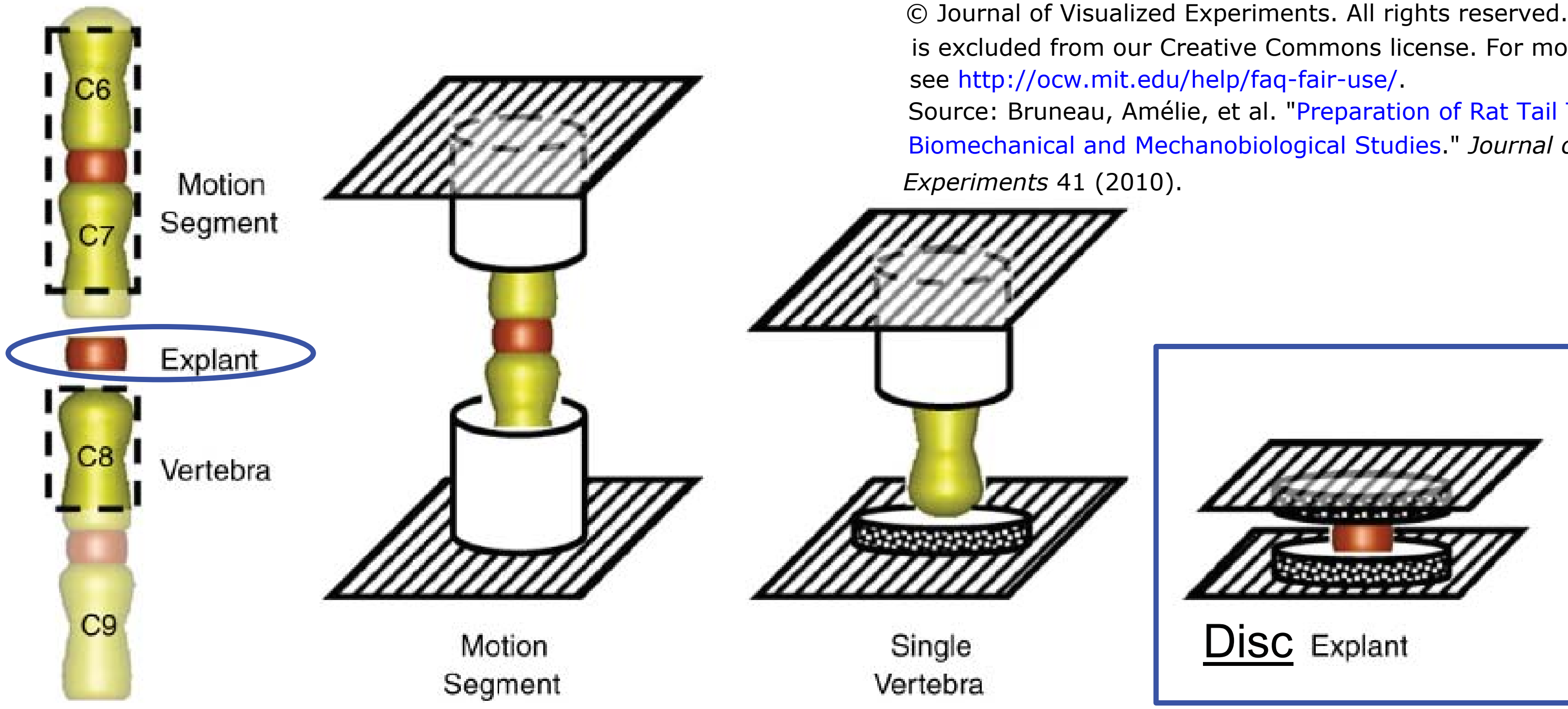


Source: Roughley, Peter J. "Biology of Intervertebral Disc Aging and Degeneration: Involvement of the Extracellular Matrix." *Spine* 29, no. 23 (2004): 2691-9.

“Creep-Compression” of intervertebral disc (rat tail)



Source: Bruneau, Amélie, et al. "Preparation of Rat Tail Tendons for Biomechanical and Mechanobiological Studies." *Journal of Visualized Experiments* 41 (2010).

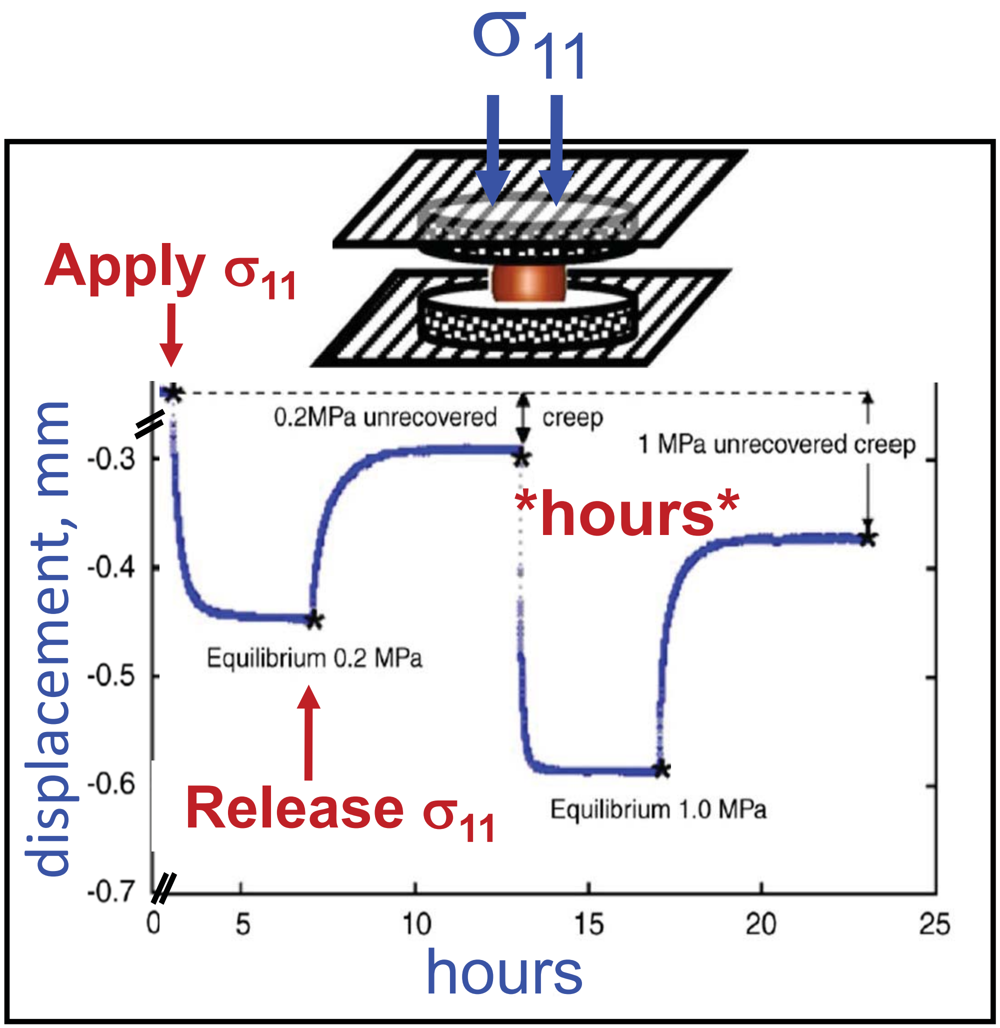


Source: MacLean, Jeffrey J. "Role of Endplates in Contributing to Compression Behaviors of Motion Segments and Intervertebral Discs." *-RXUQDO RI %LRPHFKDQLFV* 40, no. 1 (2007): 55-63.

(MacLean+, J Biomechanics, 2007)

"Creep-Compression" of intervertebral disc (rat tail):

Apply constant stress (σ_{11}) and measure displacement (strain) vs time



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Source: MacLean, Jeffrey J. "Role of Endplates in Contributing to Compression Behaviors of Motion Segments and Intervertebral Discs." -RXUQD0 RI %LRPHFKDQLFV 40, no. 1 (2007): 55-63.

(MacLean+, J Biomechanics, 2007)