



The Harvey M. Krueger Family Center  
for Nanoscience and Nanotechnology

Prof. Oded Shoseyov  
The Hebrew University of Jerusalem  
Shoseyov@agri.huji.ac.il

## NANO BIO MIMETICS: MATERIALS FOR THE FUTURE

Oded Shoseyov



Our current  
**materials,  
structures  
and machines**





Our current  
**materials and  
structures**



3 billion years of  
**evolution resulted in super  
performing materials and  
structures.**







**Sequoia trees;**  
**hundreds of tons for hundreds of years**





**in the sun and UV light**



it is made of





it is made of



**Sugar!!!**



# 10

times  
stronger  
than steel !!!





# CNC; The future of the Industry





Google™



Alibaba.com™

ebay™





Pulp & Paper Industry Waste,  
**a Perfect Source for CNC**





Pulp & Paper Industry Waste,  
**a Perfect Source for CNC**



**11M ton  
waste  
annually**  
in Europe alone







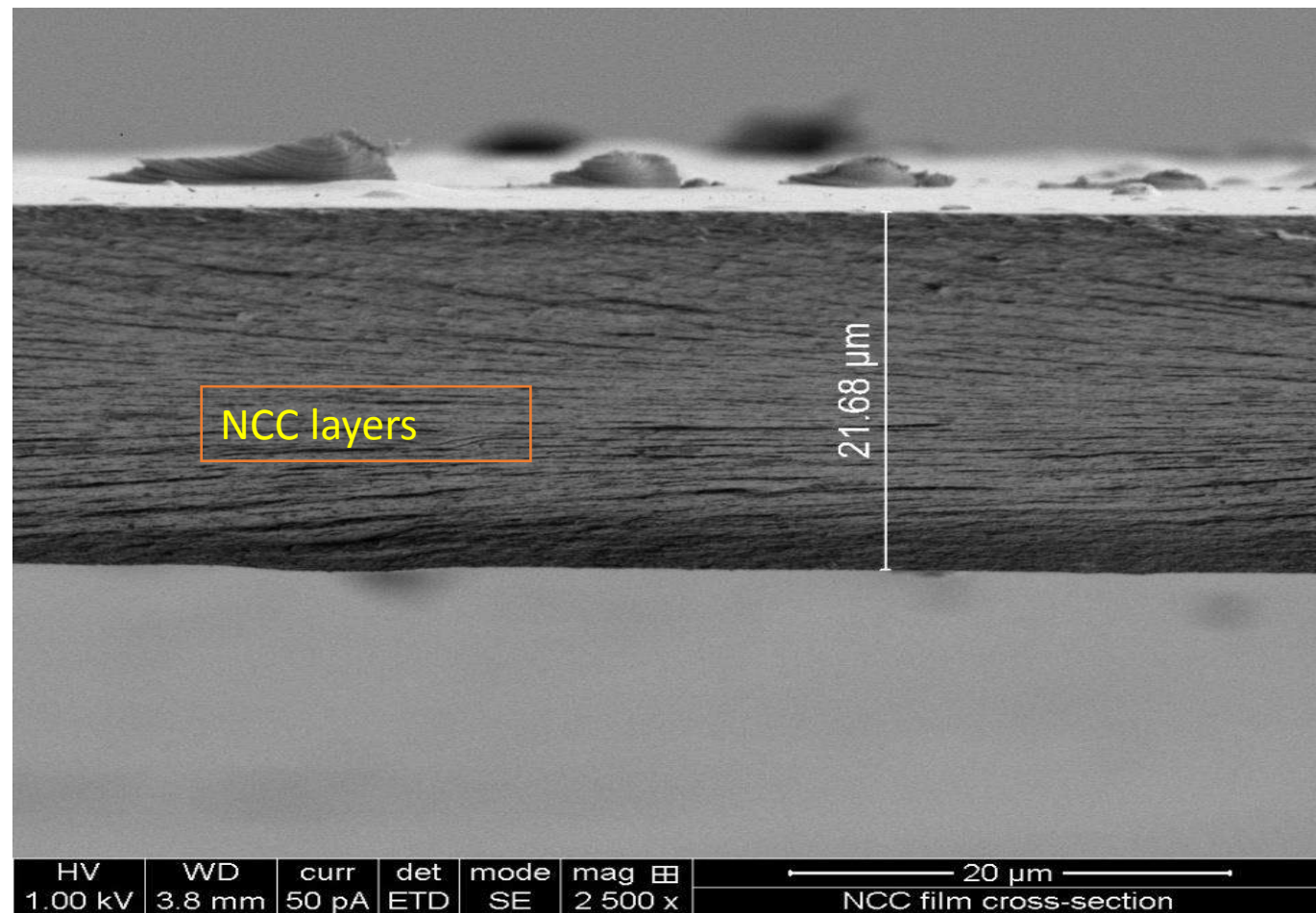
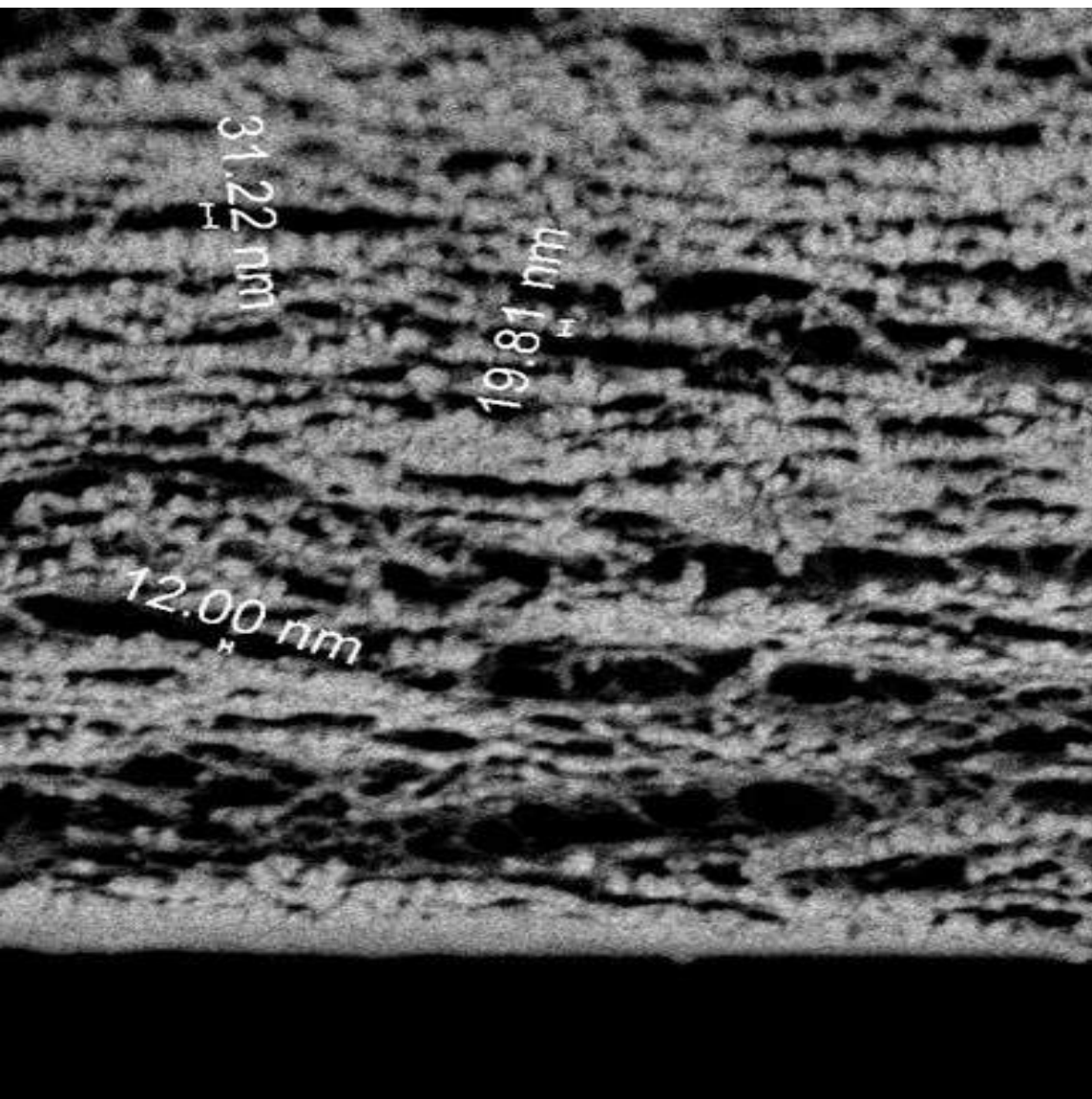
Converting  
environmental problem  
**to a goldmine**



**Electron  
Microscope  
image of  
the CNC**



# Highly Ordered CNC Films trapping Nano Particles

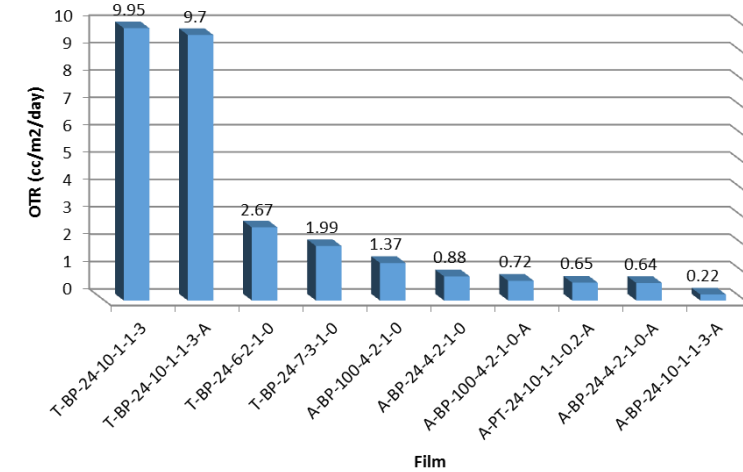
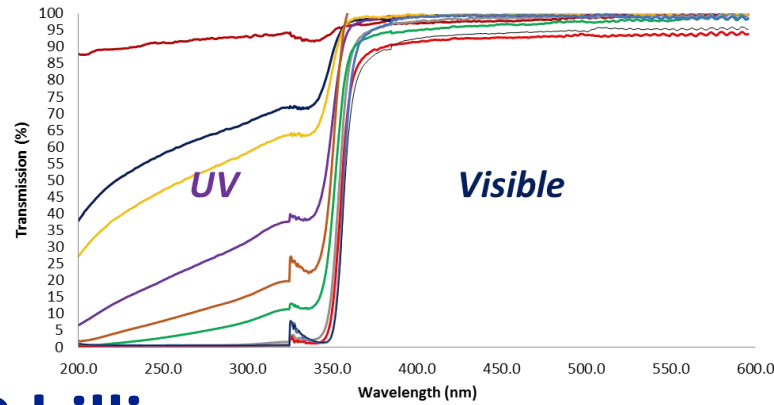


Extreme High Resolution SEM (Magellan™) scan



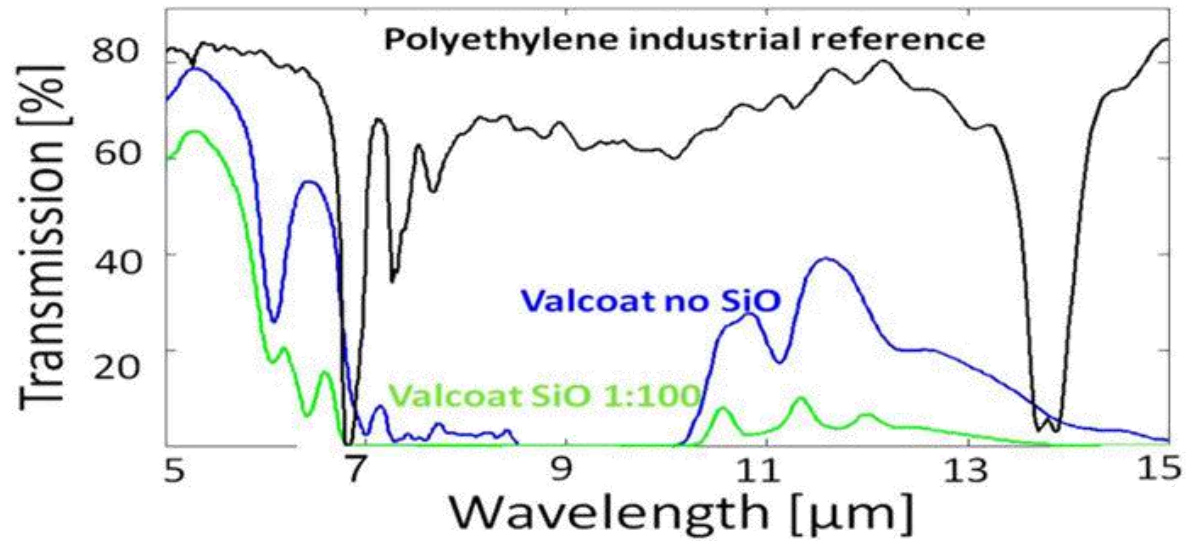
# Markets Are Moving to Advanced Materials

- Need gas + UV barrier
- Trend from rigid to flexible
- Flexible food packaging: **\$110 billion**



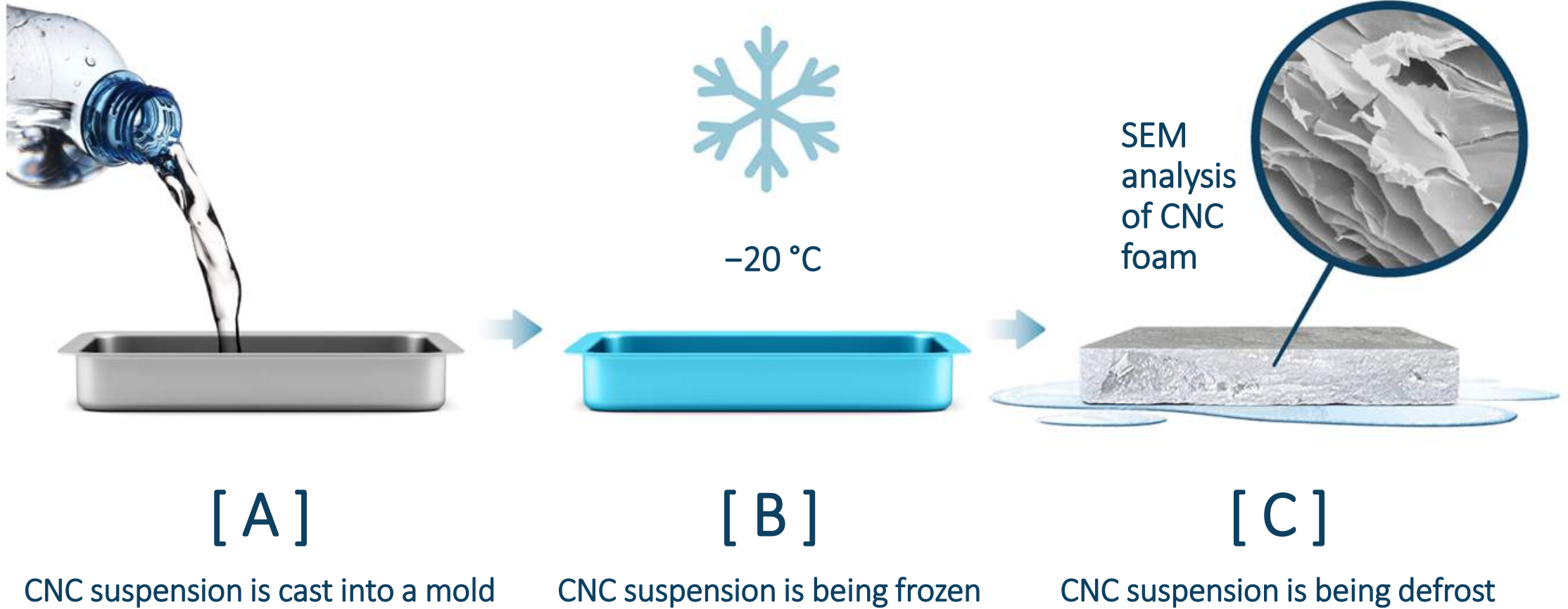
# Saving energy and cost of greenhouses

## Blocking IR radiation by CNC-SiO<sub>2</sub> NPs



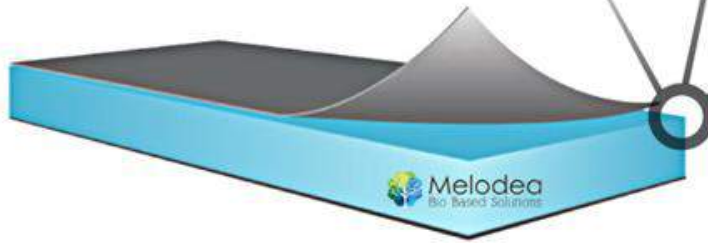


# CNC Foam





Traditional cores are produced from fossil oil based materials

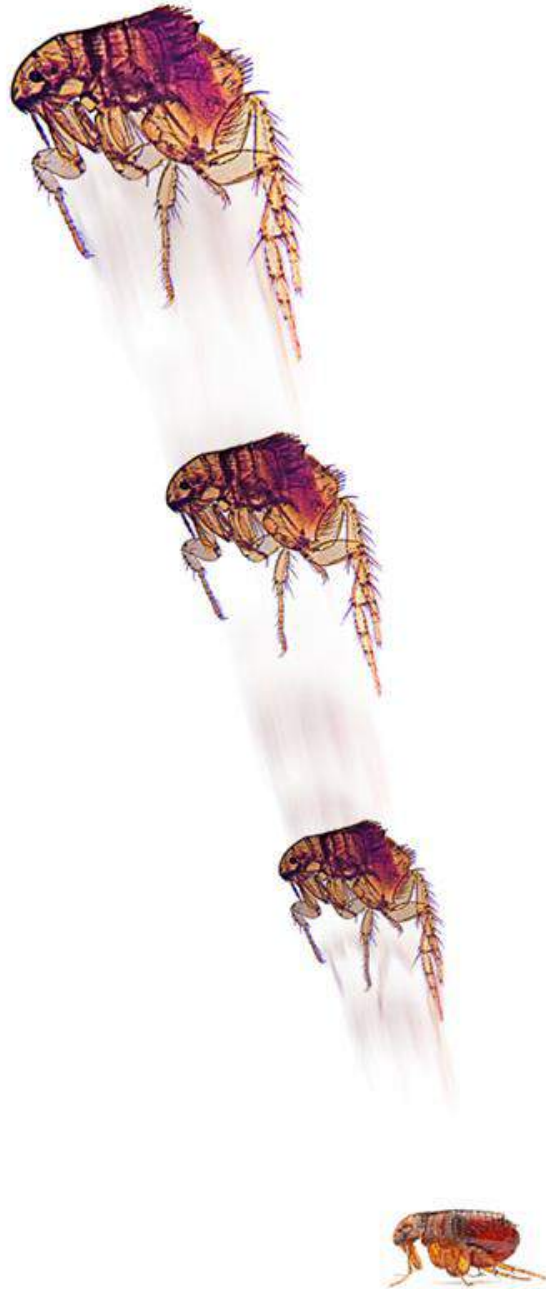


# Sandwich Composites



CatFleas

# Jumping Skills

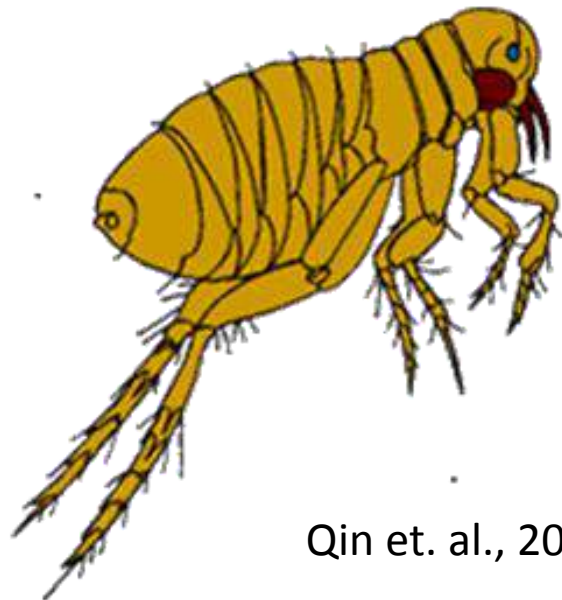


Equivalent  
to Human  
**Jumping**  
**400 m High**





# Production of Recombinant Resilin Engineered With a Cellulose Binding Domain (CBD)



Qin et. al., 2009. Biomacromolecules. 10(12):3227-34.

# Adding a drop of resilin into a stiff CNC foam







JUMP **HIGHER**





# Combining

Plant kingdom strength with  
Animal kingdom elasticity





# Res-CBD-CNC film

Super performing material !!!



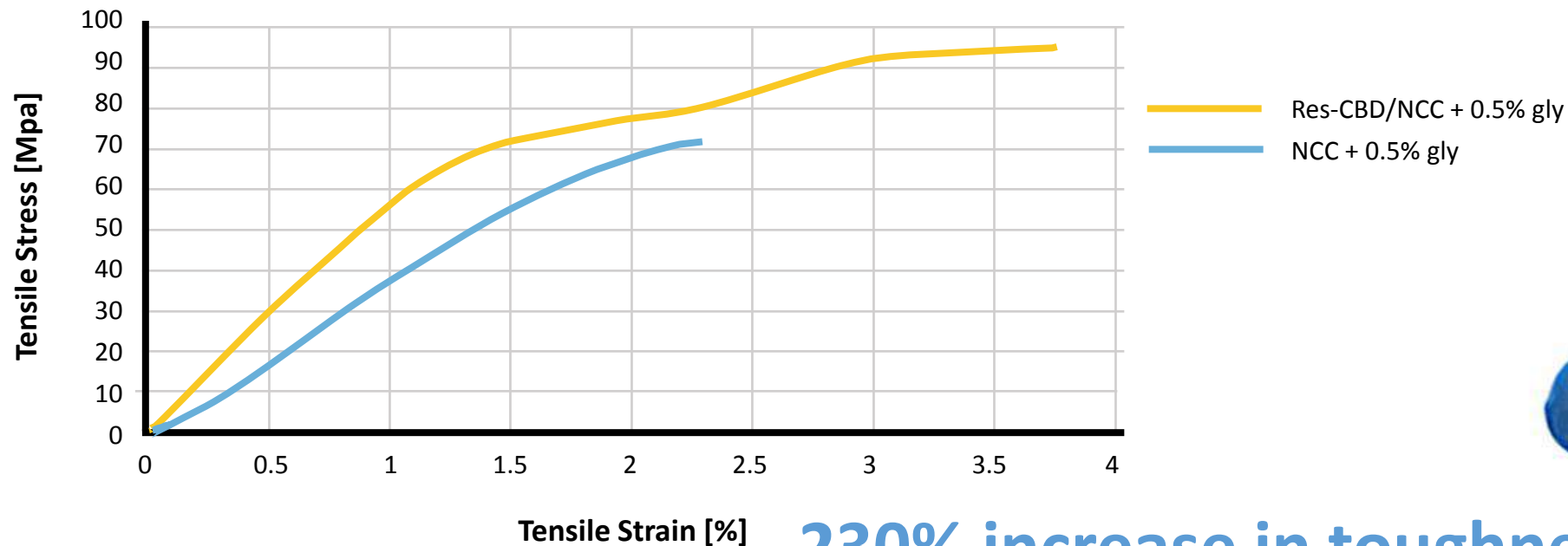


# Res-CBD-CNC film

## Super performing material !!!

# Tough, Elastic, Transparent

Stress-Strain curves of Instron tested NCC and Res-CBD-NCC containing films



### Toughness measurements:

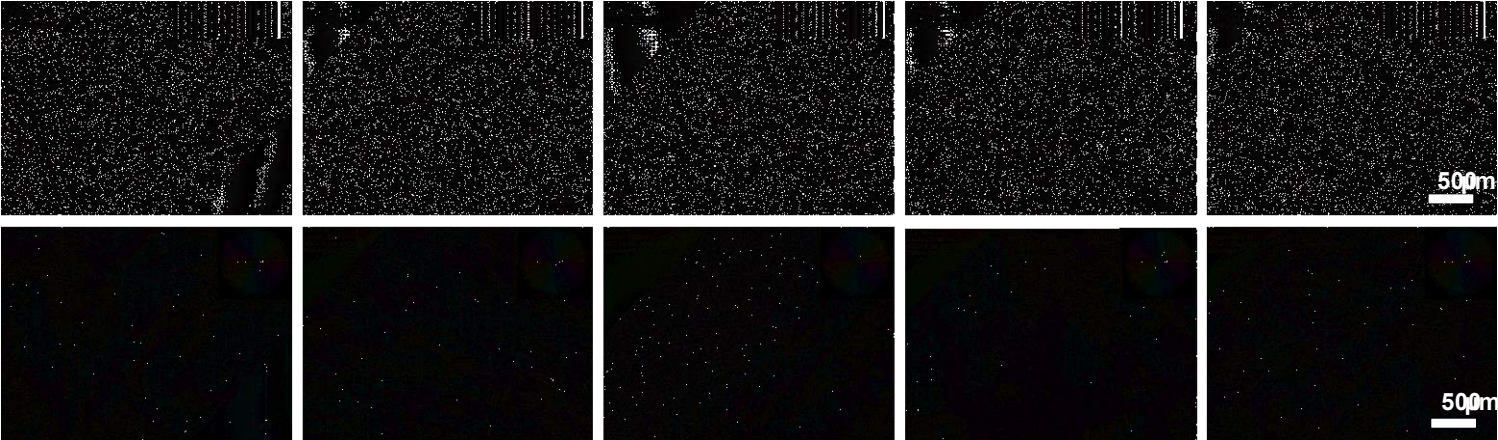
- Res-CBD/NCC + 0.5% glycerol: 2.36 [MJ/m<sup>3</sup>]
- NCC + 0.5% glycerol: 1 [MJ/m<sup>3</sup>]

## 230% increase in toughness

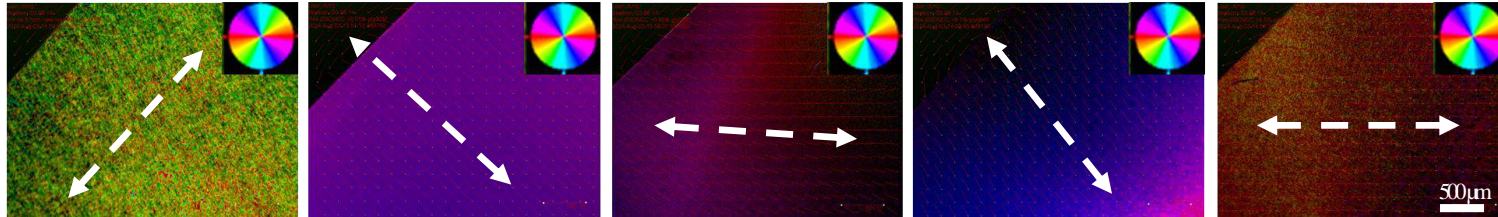
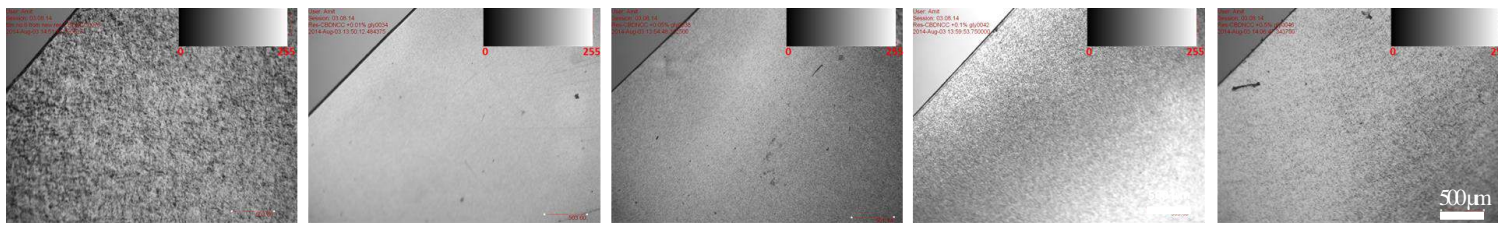
Rivkin et al., 2015. Industrial Biotechnology. 11(1): 44-58.

# Resilin-CBD impose long-range molecular order in CNC films

Polarized optical microscopy



CNC                      CNC + 05 wt. % glycerol    CNC + 2.5 wt. % glycerol    CNC + 5wt. % glycerol    CNC + 25 wt. % glycerol



Res-CBD-CNC                      Res-CBD-CNC + 0.5 wt. % glycerol    Res-CBD-CNC + 2.5 wt. % glycerol    Res-CBD-CNC + 5 wt. % glycerol    Res-CBD-CNC + 25 wt. % glycerol



# Strong transparent touch-screens

for smartphones  
and computers









**Synthetic**  
medical implants  
“screw and glue”

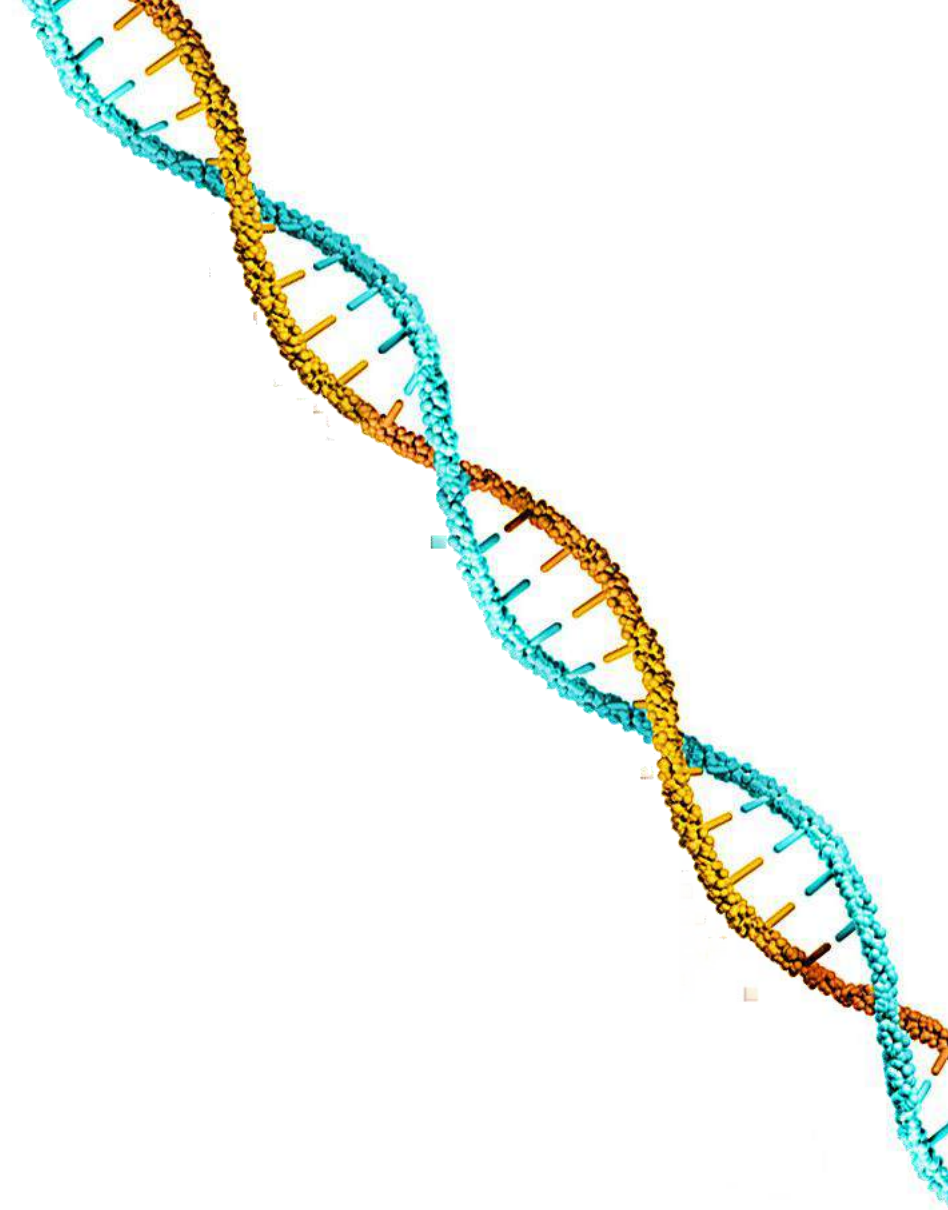


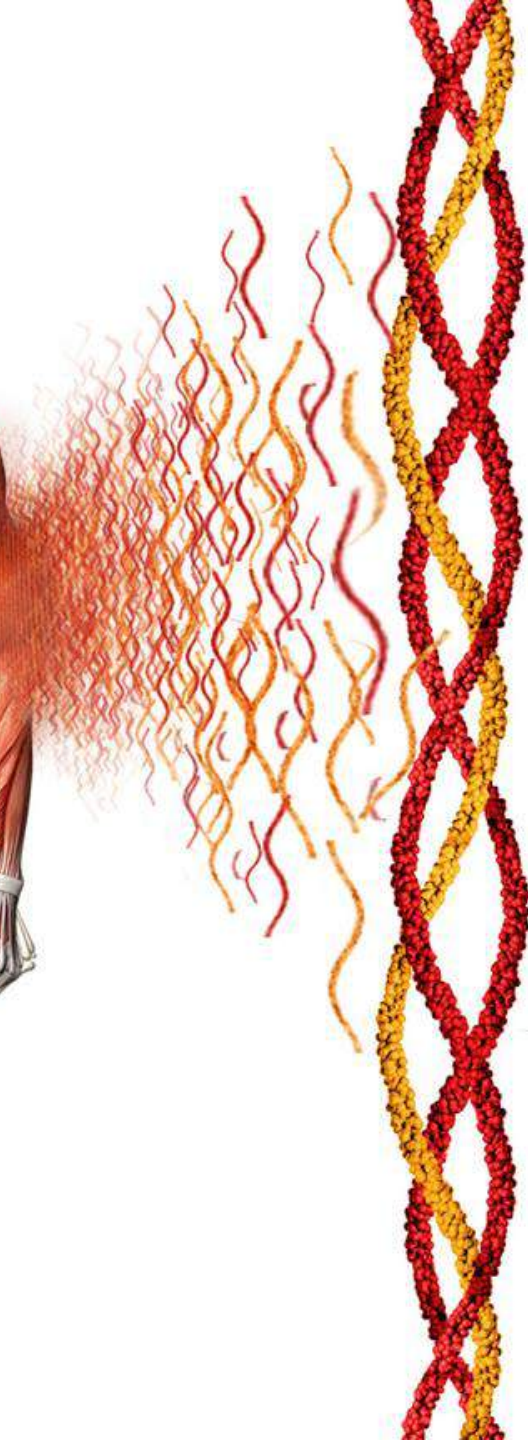
Synthetic materials  
**fail to perform**





In nature  
organisms  
**are self  
assembled**





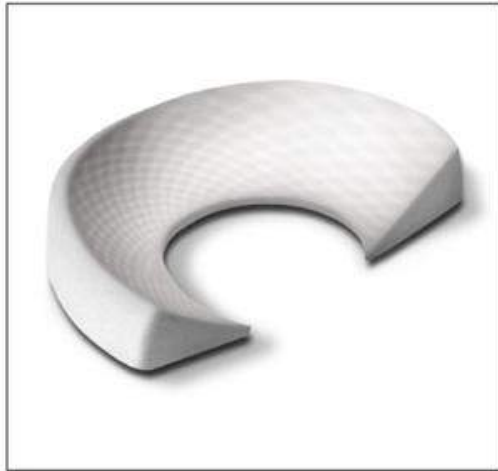
Our body  
is made of  
**collagen**

TRIPLE COLLAGEN HELIX

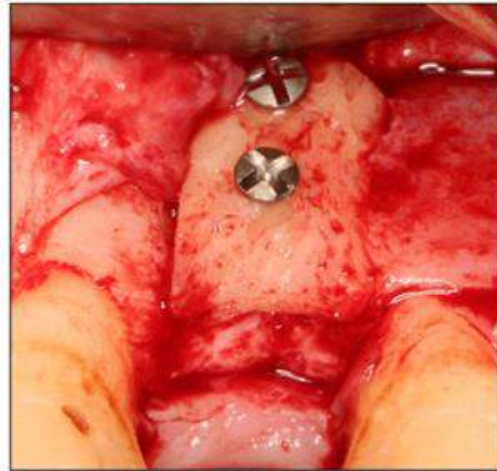




### ARTIFICIAL MENISCUS



### AUTOGENOUS BLOCK GRAFT

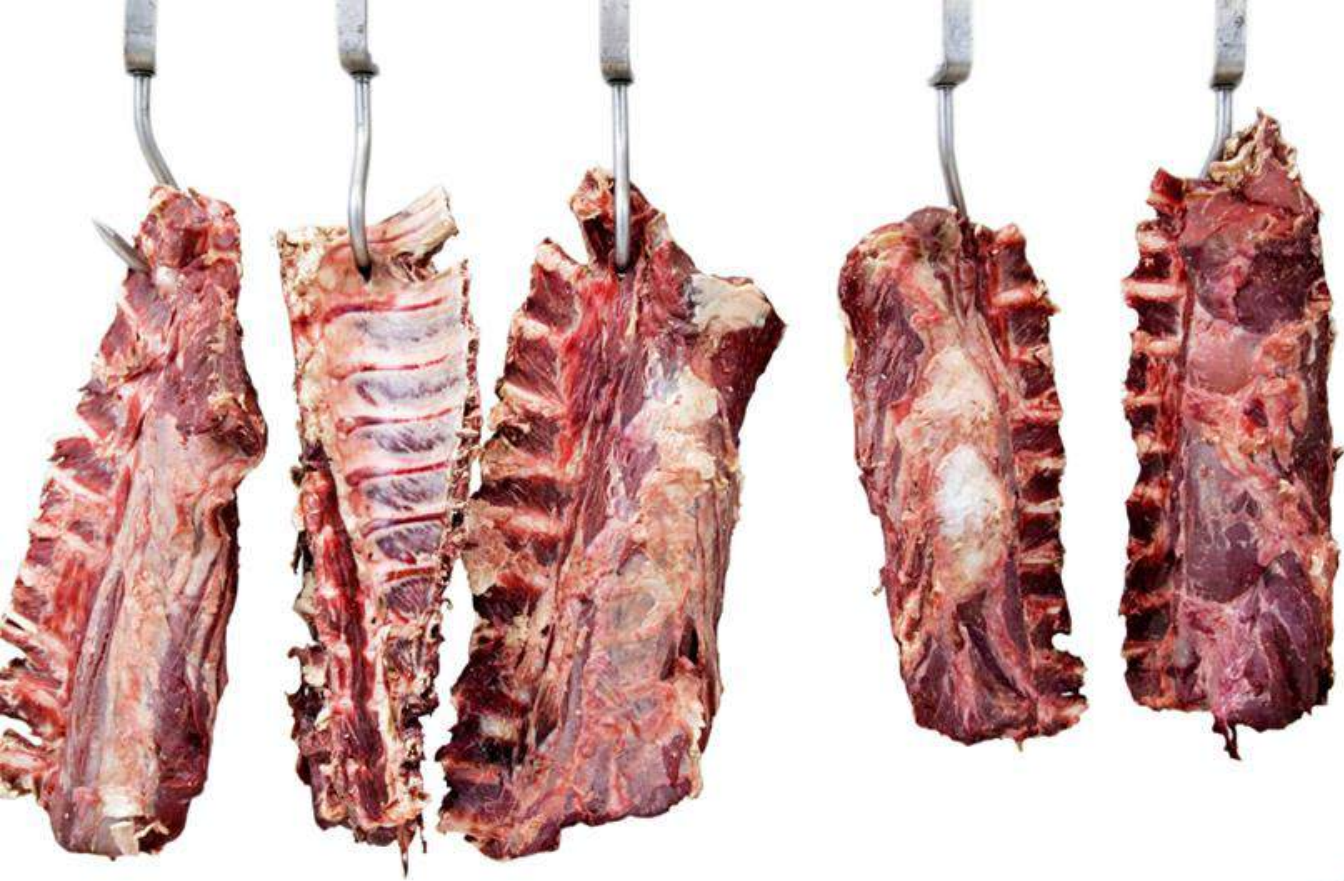


### BIOLOGICAL HEART VALVE



"Autogenous block graft" by Dental Specialty Group - Own work. Licensed under Creative Commons Attribution-Share Alike 3.0 via Wikimedia Commons - [http://commons.wikimedia.org/wiki/File:Autogenous\\_block\\_graft.jpg#mediaviewer/File:Autogenous\\_block\\_graft.jpg](http://commons.wikimedia.org/wiki/File:Autogenous_block_graft.jpg#mediaviewer/File:Autogenous_block_graft.jpg)

"Carpentier-Edwards biological heart valve" by Stif Komar - Own work. Licensed under Creative Commons Attribution-Share Alike 3.0 via Wikimedia Commons - [http://commons.wikimedia.org/wiki/File:Carpentier-Edwards\\_biological\\_heart\\_valve.jpg#mediaviewer/File:Carpentier-Edwards\\_biological\\_heart\\_valve.jpg](http://commons.wikimedia.org/wiki/File:Carpentier-Edwards_biological_heart_valve.jpg#mediaviewer/File:Carpentier-Edwards_biological_heart_valve.jpg)



Safety is a  
**big issue**







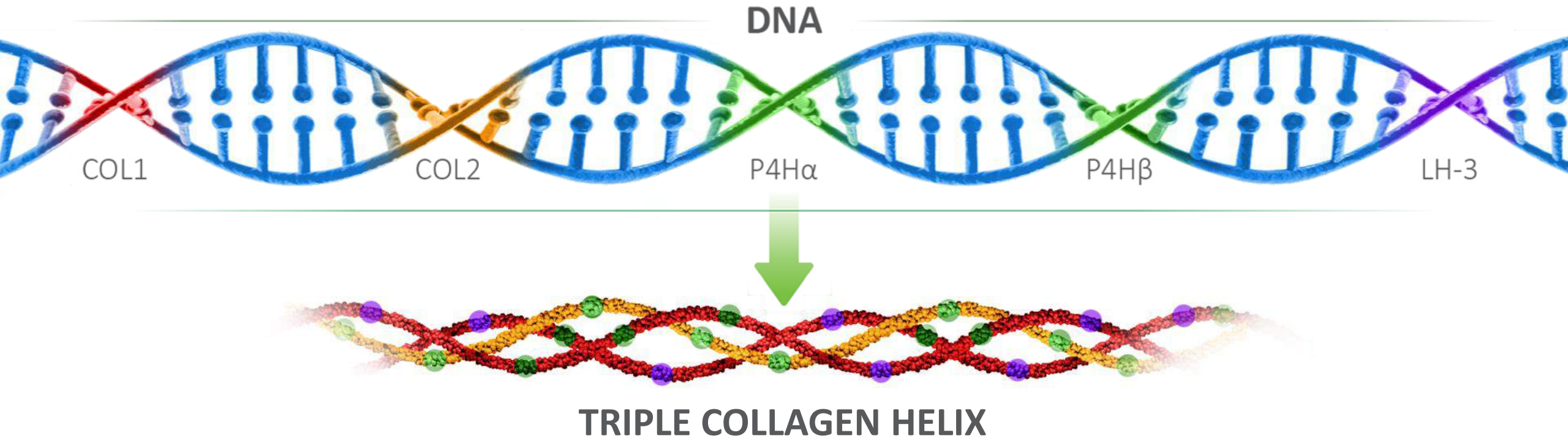
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Federal Register  
January 12, 2007:

**The FDA is proposing  
to prohibit the use of  
certain cattle material  
in drugs, biologics and  
medical devices  
intended for use  
in humans**

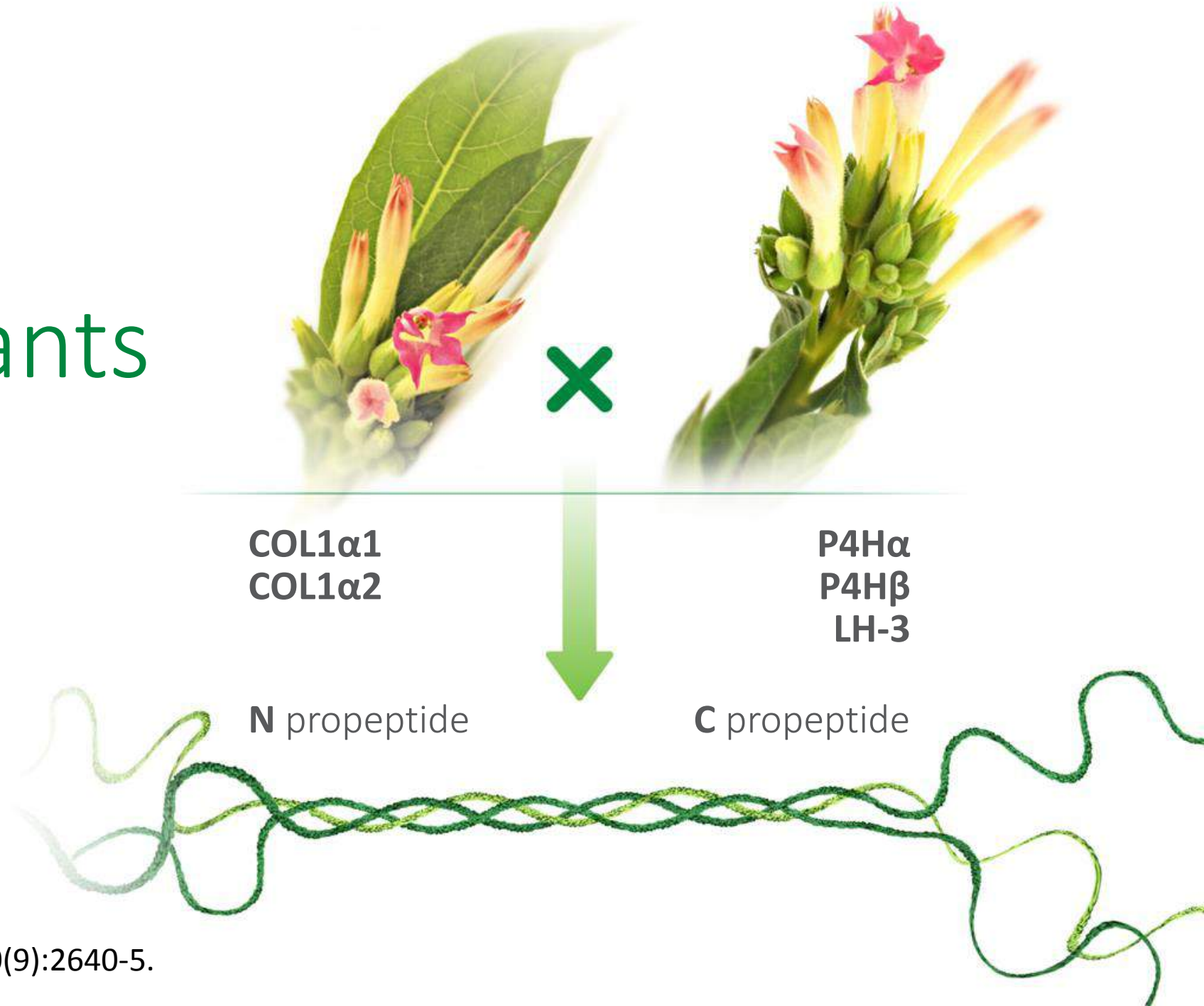
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# Human collagen is difficult to make





Transgenic  
tobacco plants  
expressing  
**5 human  
genes**







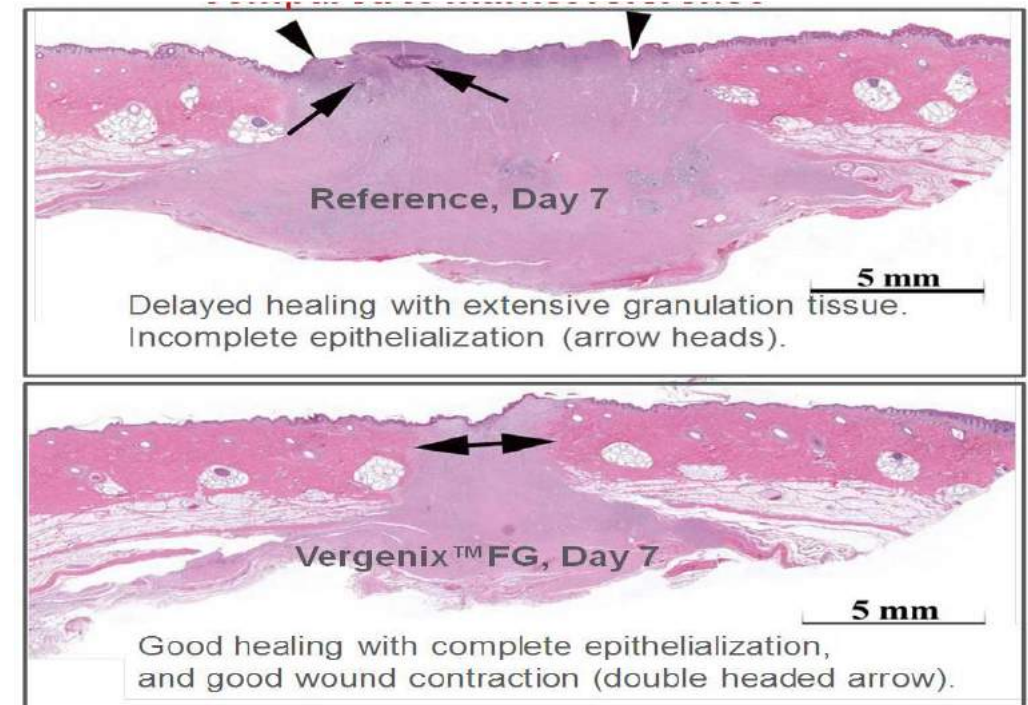
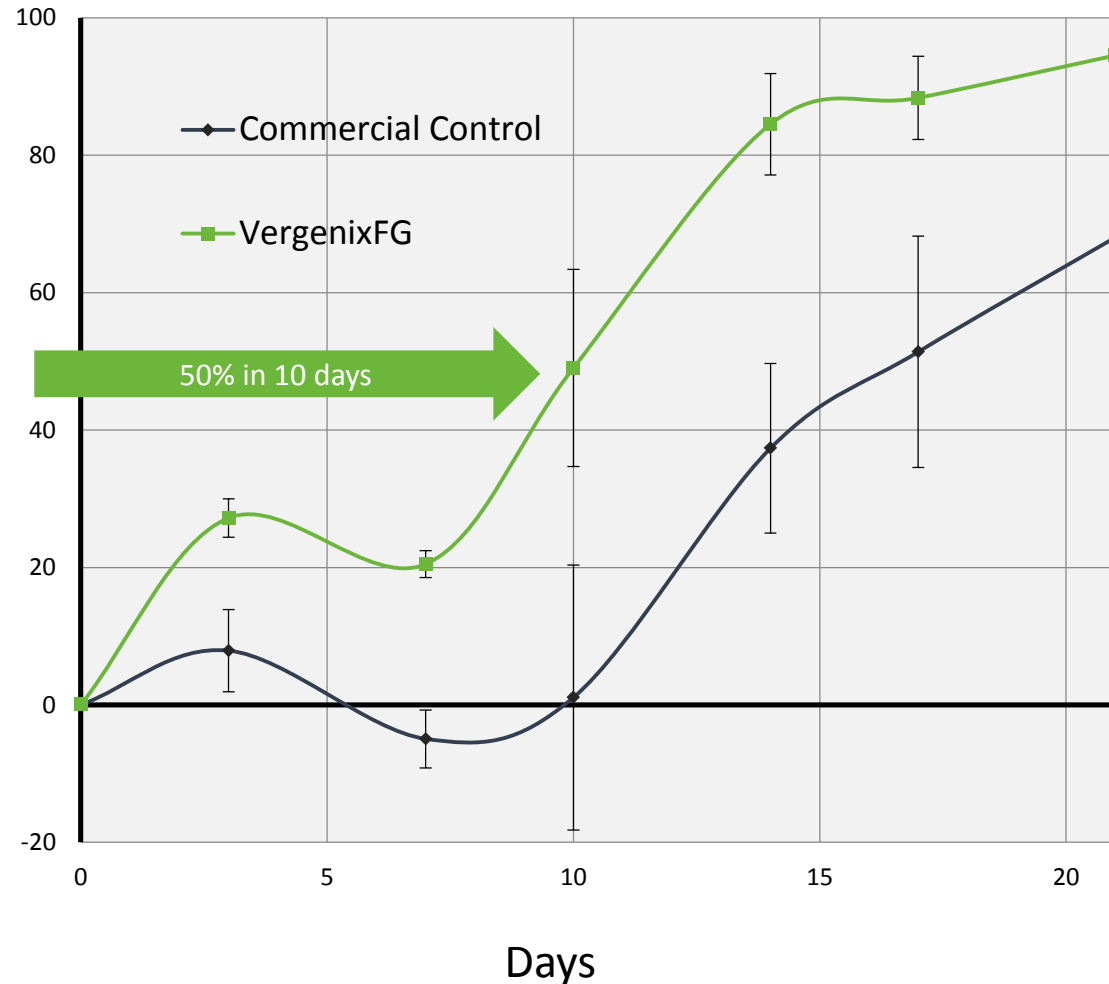


# Large scale Human collagen produced in tobacco plants



# rhCollagen has better wound closure rates compared with bovine collagen

% wound closure



- Epithelialization was more extensive for the Vergenix™FG-treated wounds
- Vergenix™FG induces earlier blood vessel formation (angiogenesis) and resolution indicating enhanced wound healing, compared to market reference



# Clinical trial in diabetic ulcers Wound closure after 4 weeks



- 11 patients out of 16 had a wound closure between 80 to 100 % within 4 weeks and after a **single** treatment

Patient 1

Day 0



Day 28

(wound closed)

Patient 2

Day 0



Day 28

(95 % reduction)

# Soft tissue repair rhCollagen/PRP injection

Vergenix™ STR Kit

PRP collection tube  
from any commercial PRP Kit



Plasma

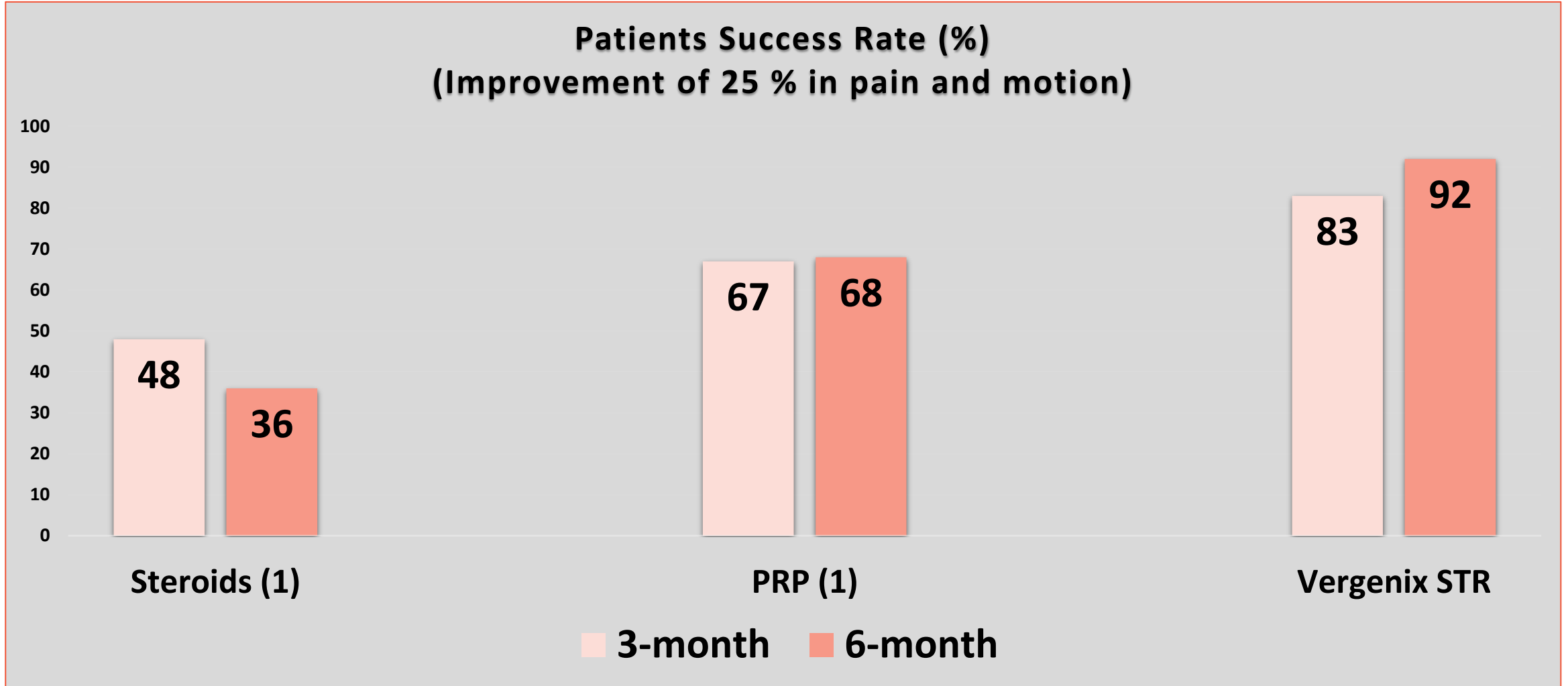
Platelet-Rich Plasma

Red Blood Cells

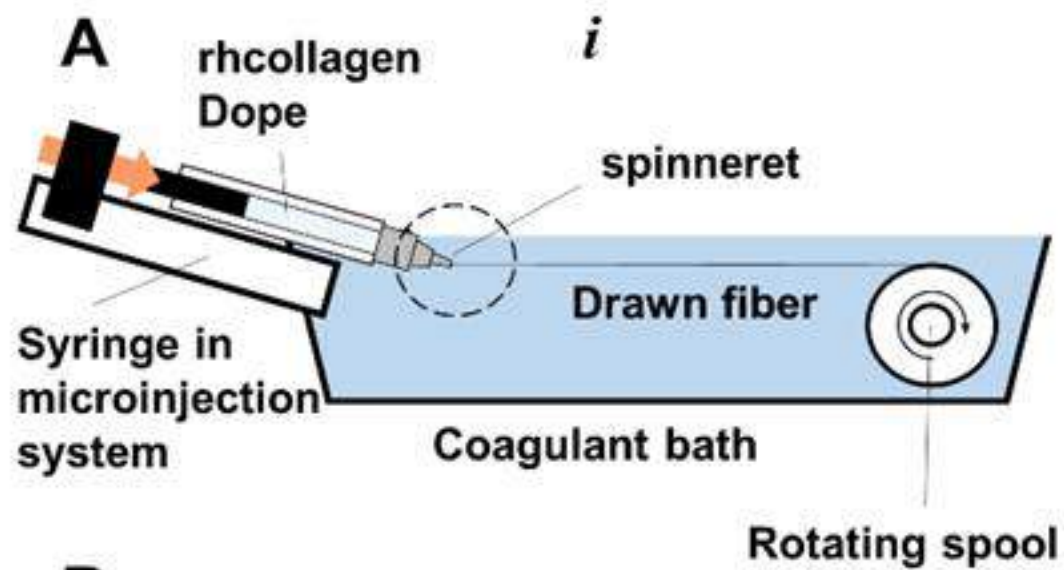




# Vergenix STR reduced pain and improve motion in tennis elbow tendinopathy



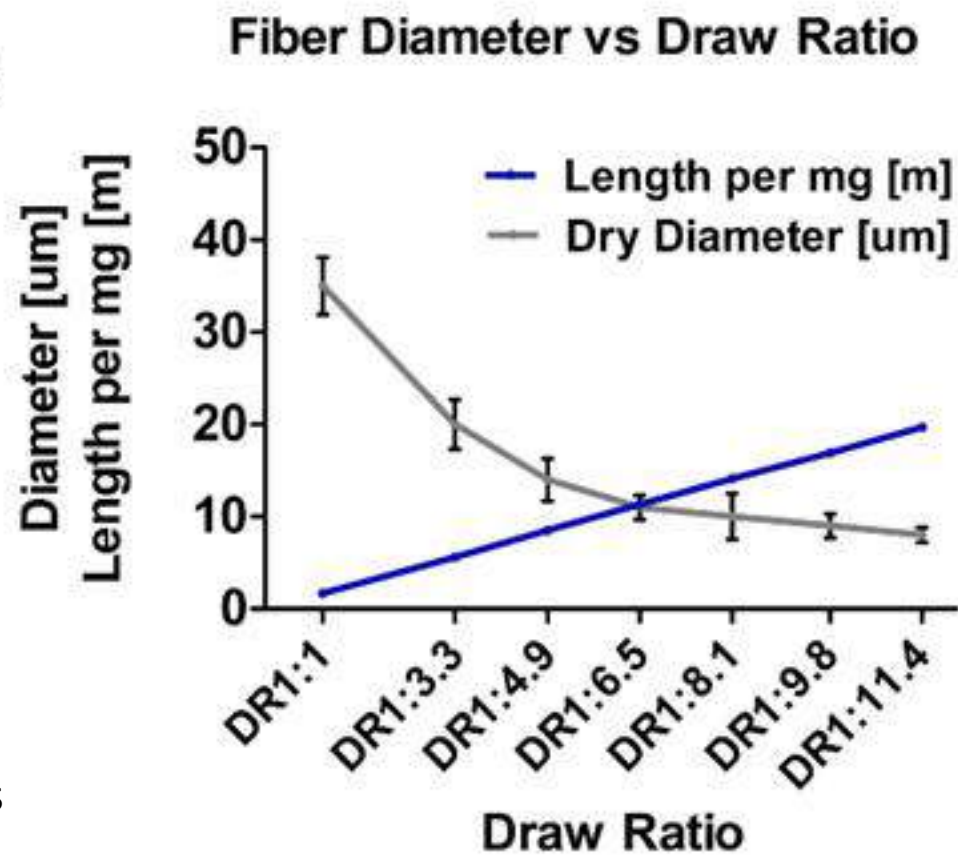
(1) Positive Effect of an Autologous Platelet Concentrate in Lateral Epicondylitis in Double-Blind Randomized Controlled Trial. Platelet-Rich Plasma versus Corticosteroid injection with a 1-year follow up. Peerbooms et Al The America Journal of Sports Medicine Vol. 38 No 2 2010



**B**



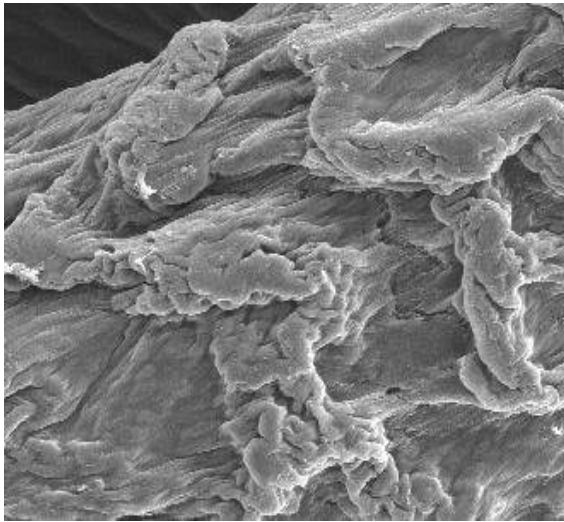
**C**



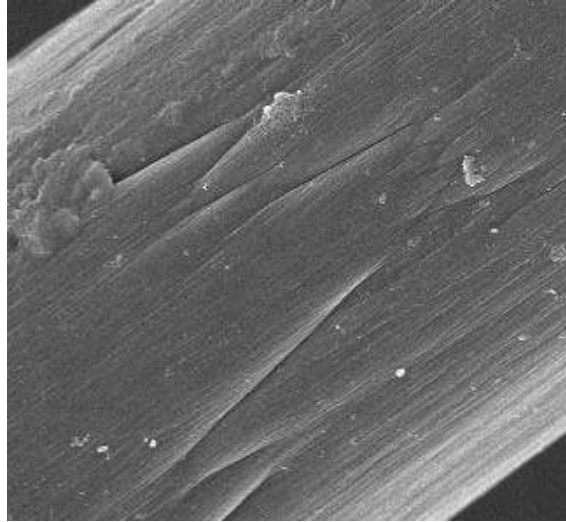


# Fiber Morphology Reflects Degree of Alignment

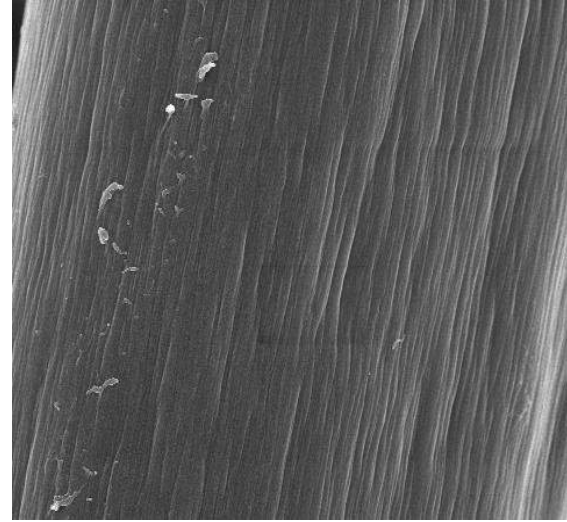
Scanning Electron Microscopy of fibers



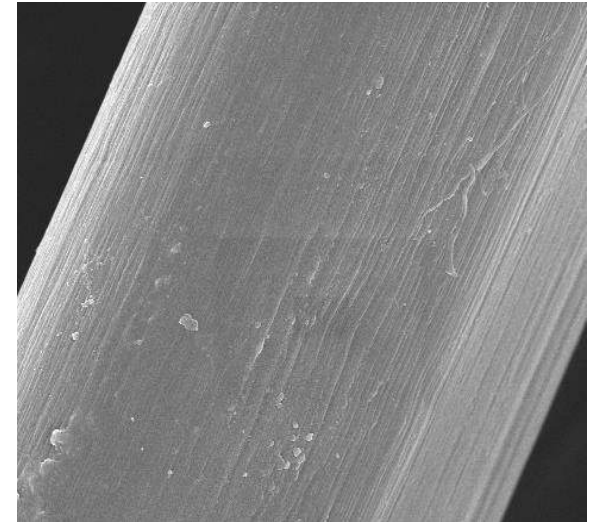
Mag 2,300X  
DR 1.0  
(DR - Draw Ratio)



Mag 7,000X  
DR 4.9



Mag 9,200X  
DR 8.1

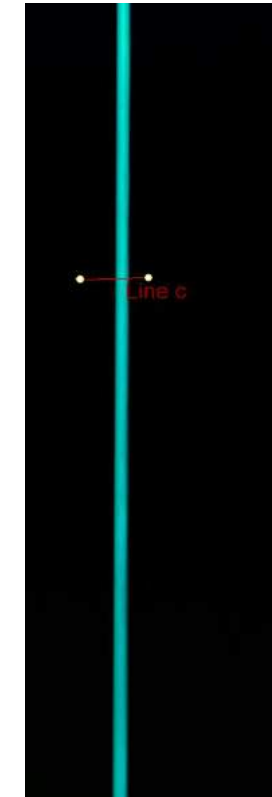
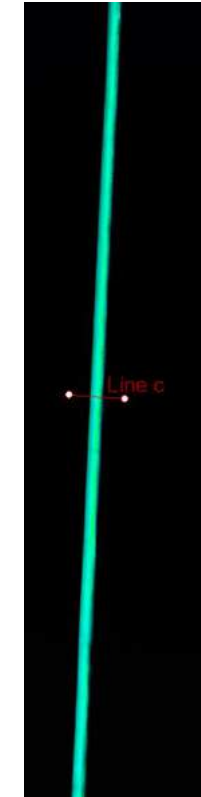
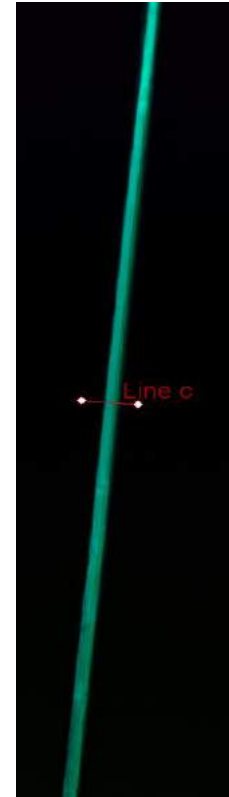
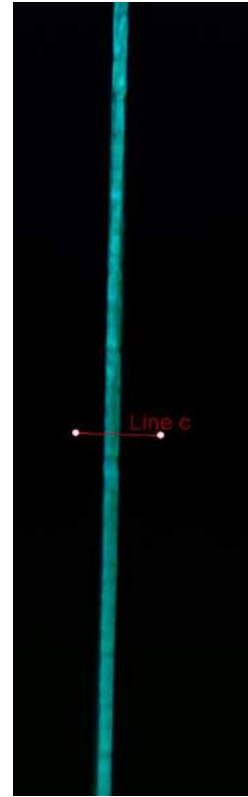
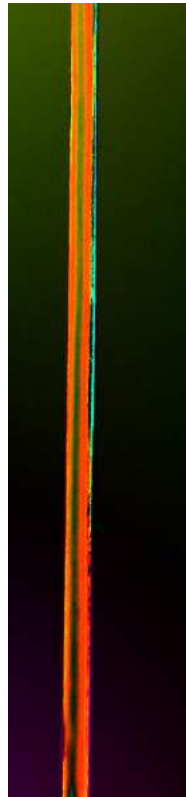
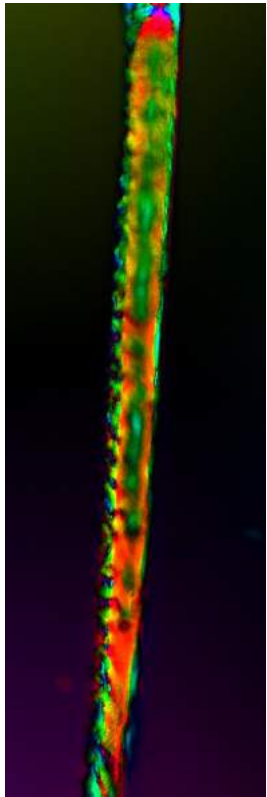
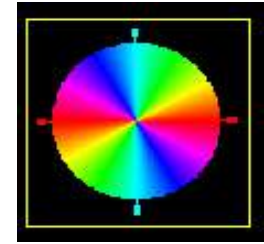


Mag 9,200X  
DR 11.4

# Polarized Light Microscopy

Color denotes orientation.

Images taken and processed with "Abrio 2.2" software.



**DR 1.0**

**DR 3.3**

**DR 4.9**

**DR 6.5**

**DR 8.1**

**DR 9.8**

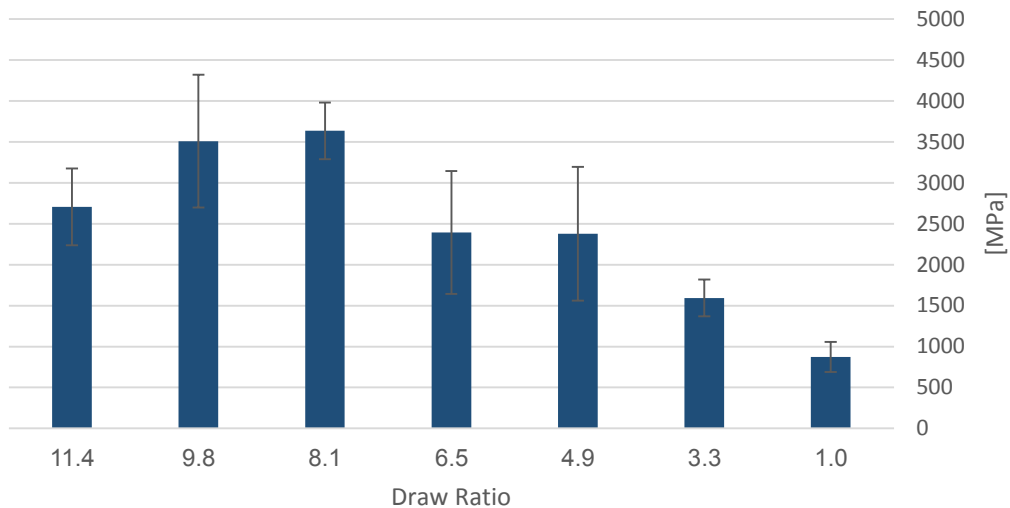
**DR 11.4**

(DR - Draw Ratio)

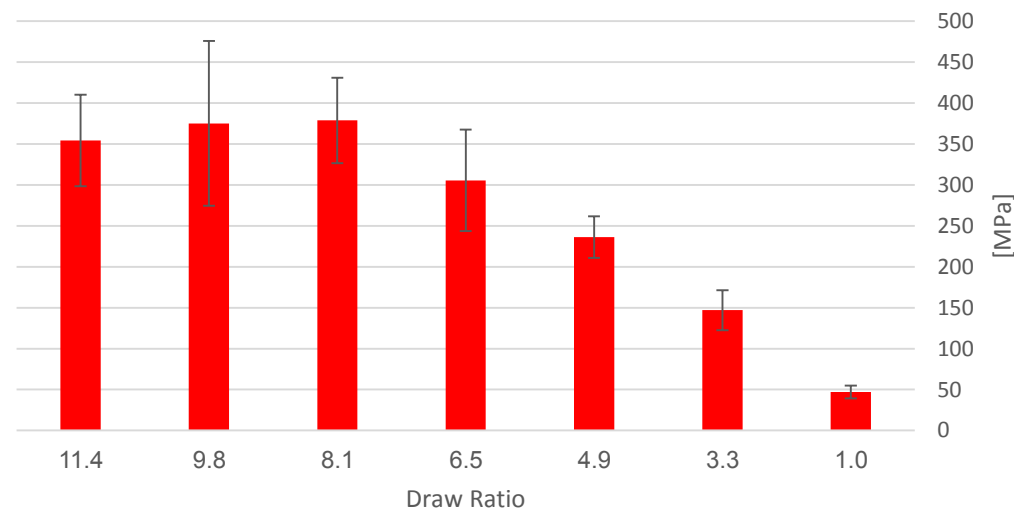


# Fiber Mechanical Properties Versus Draw Ratio

Young's Modulus [MPa]

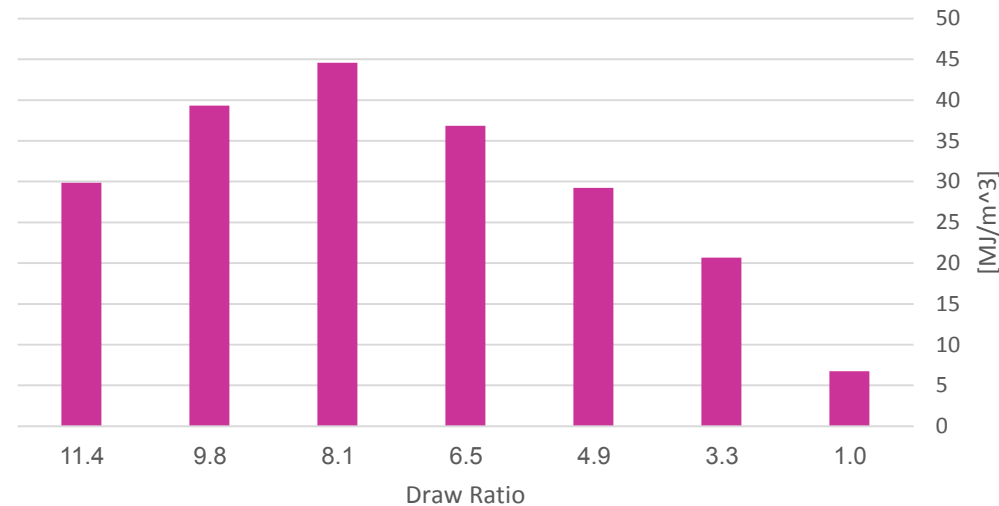


Tensile Stress at Break [MPa]

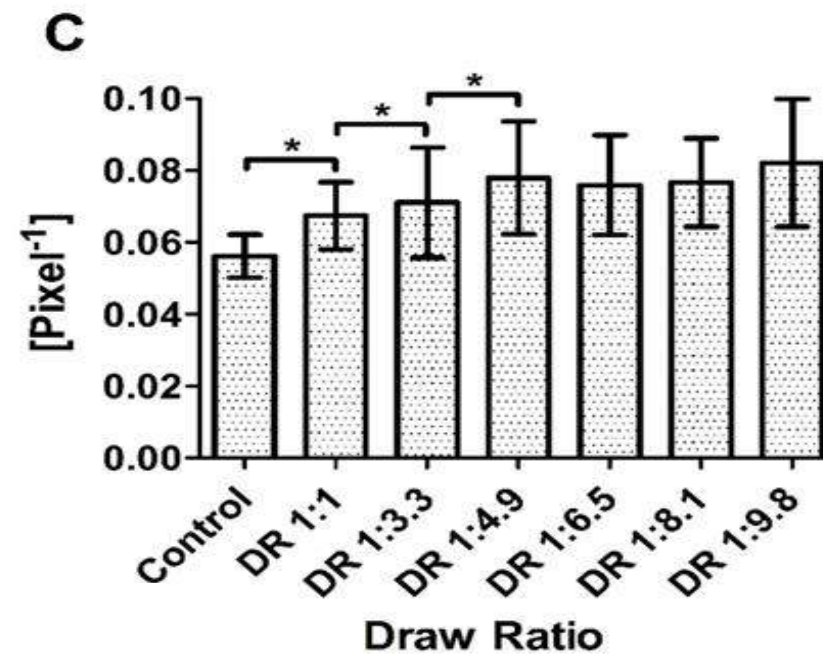
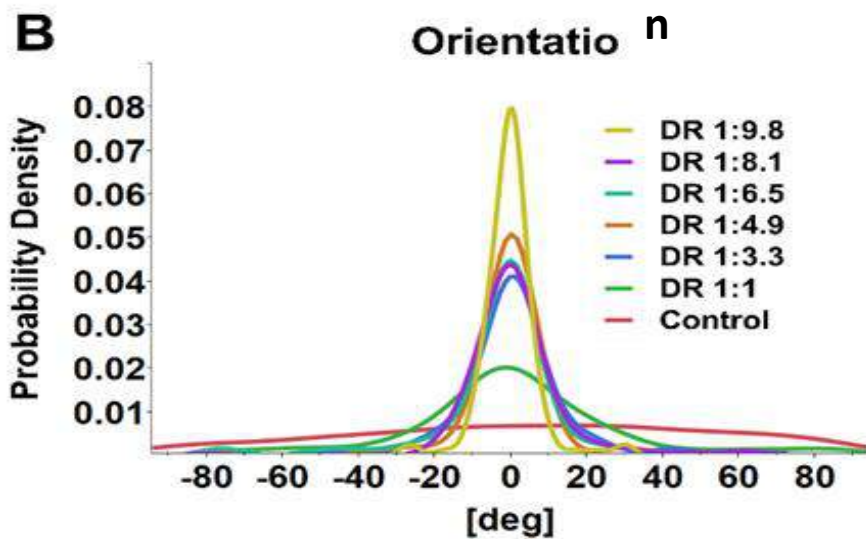
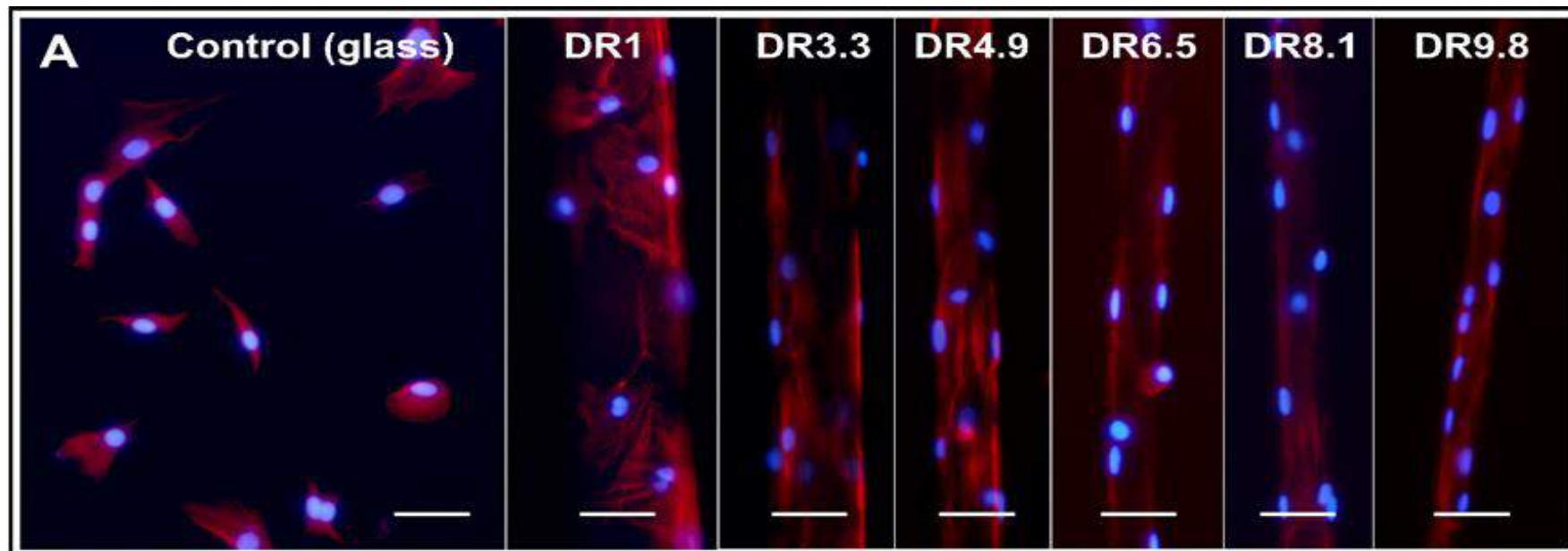


Fiber	Strength [GPa]	Toughness [MJ/M <sup>3</sup> ]
rhCollagen wet spun fibers	0.4	44
<i>Araneus</i> MA silk	1.1	160
<i>Araneus</i> viscid silk	0.5	150
<i>Bombyx mori</i> cocoon silk	0.6	70
Tendon collagen	0.15	7.5
Bone	0.16	4

Energy at Break [MJ/m<sup>3</sup>]

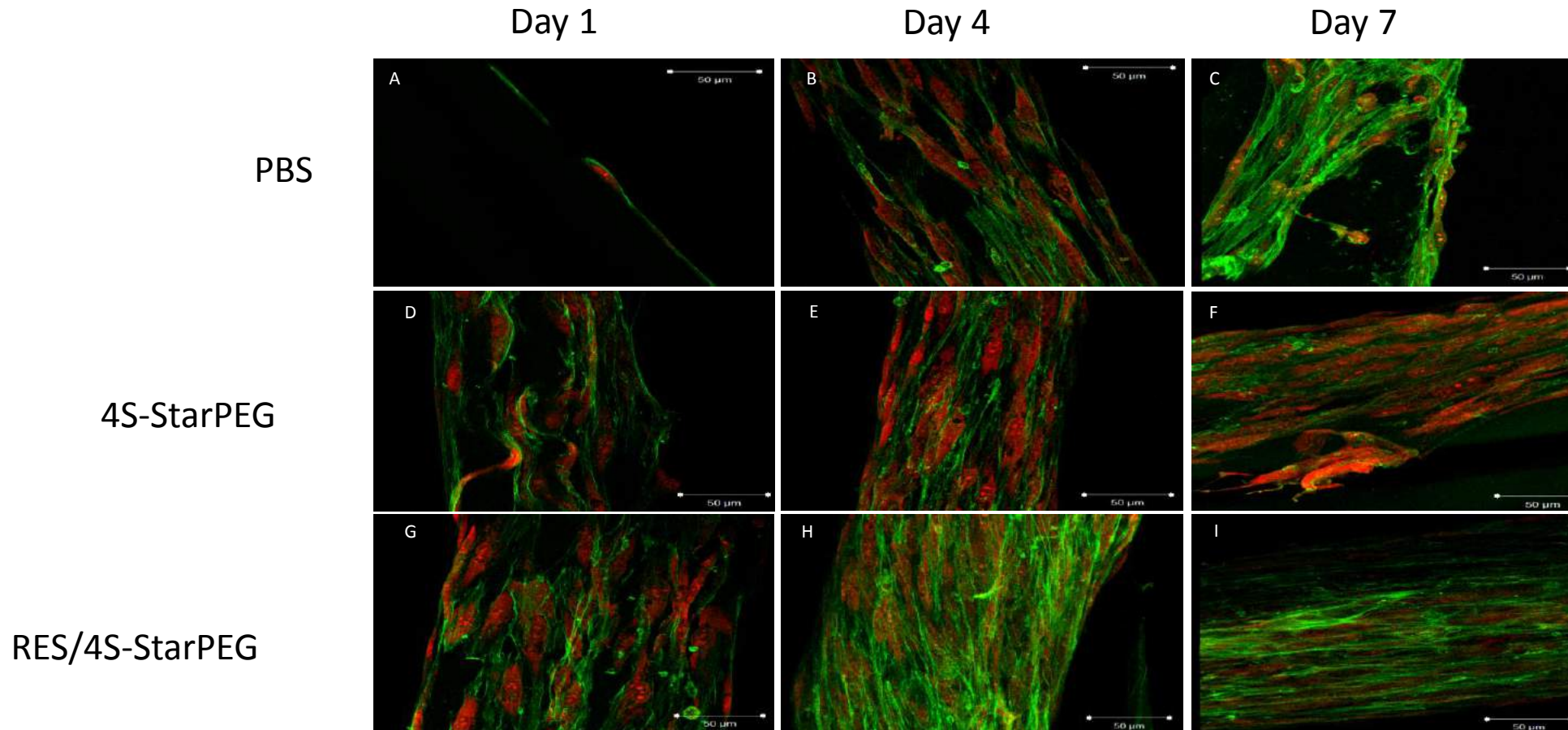


# Rat tenocytes alignment on drawn rhcollagen fibers



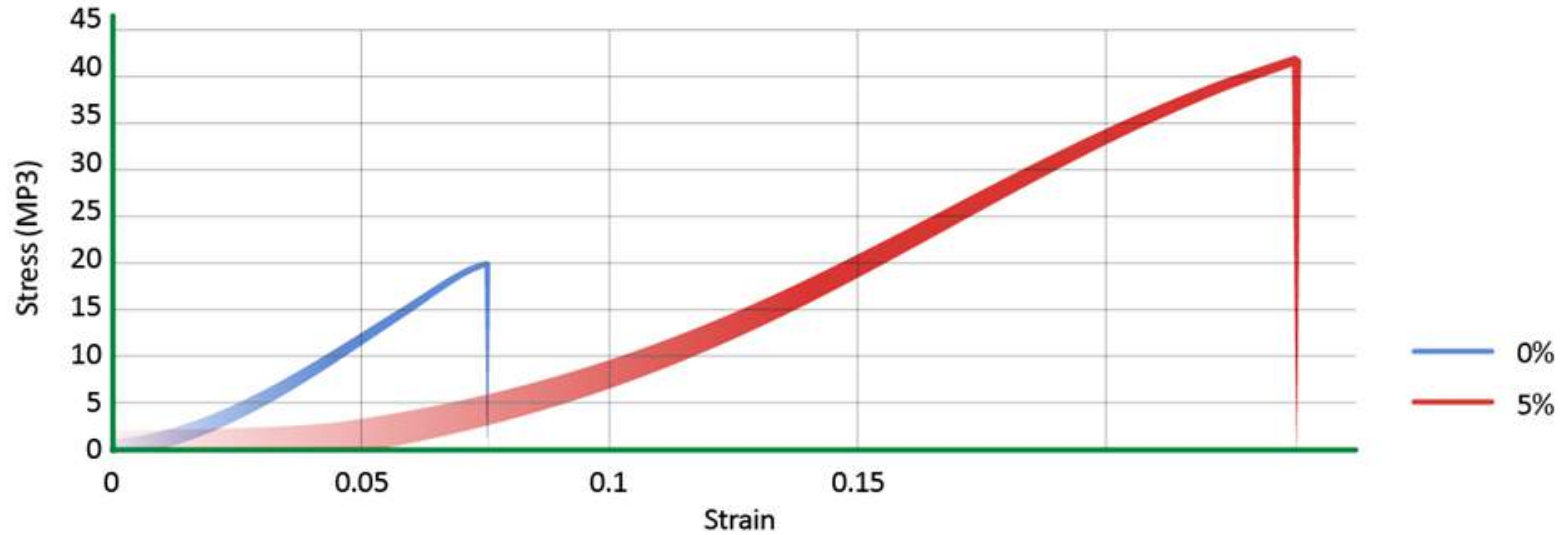


# Collagen-Resilin Composite Fibers



Cytoskeletal organisation of the HDFs seeded on the scaffolds, cells were stained for F-actin using rhodamine-phalloidin and nuclear staining using ethidium after 1, 4, and 7 days of incubation.

Stress Strain curves of 0 and 5% Resilin in Collagen Fibers



380% **increase** in toughness

300% **increase** in strain at break

## Collagen-Resilin

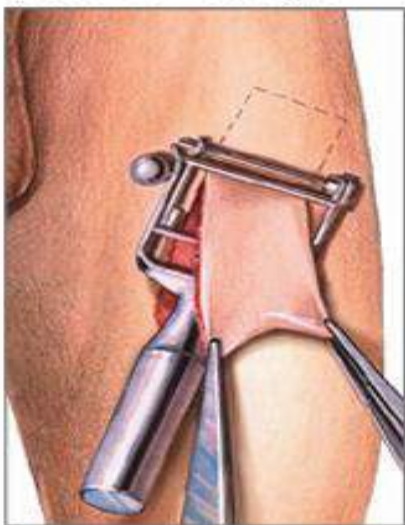
artificial tendon and ligaments



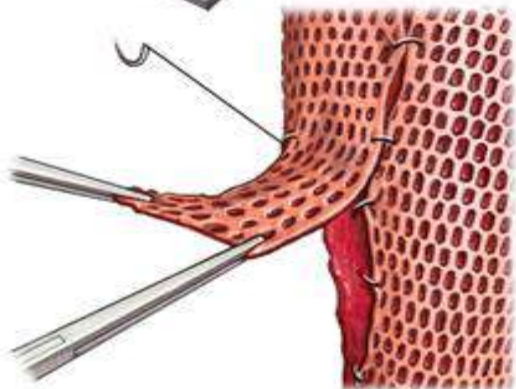
# Nowadays materials



Graft taken from patient's healthy skin



Skin is meshed to cover a large wound





# Fabricate organs for transplantation







if you want a new idea, **open an old book**