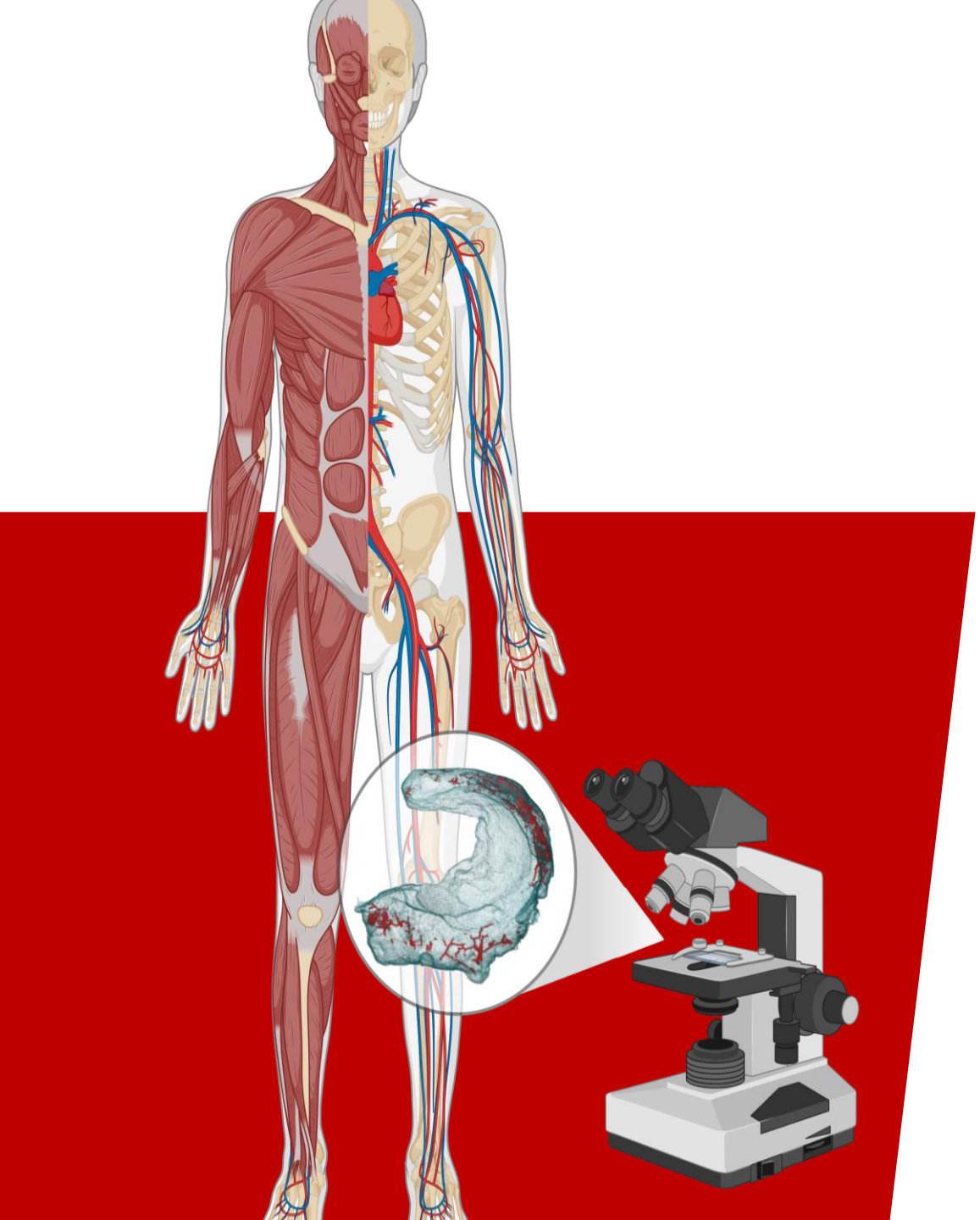


Empa

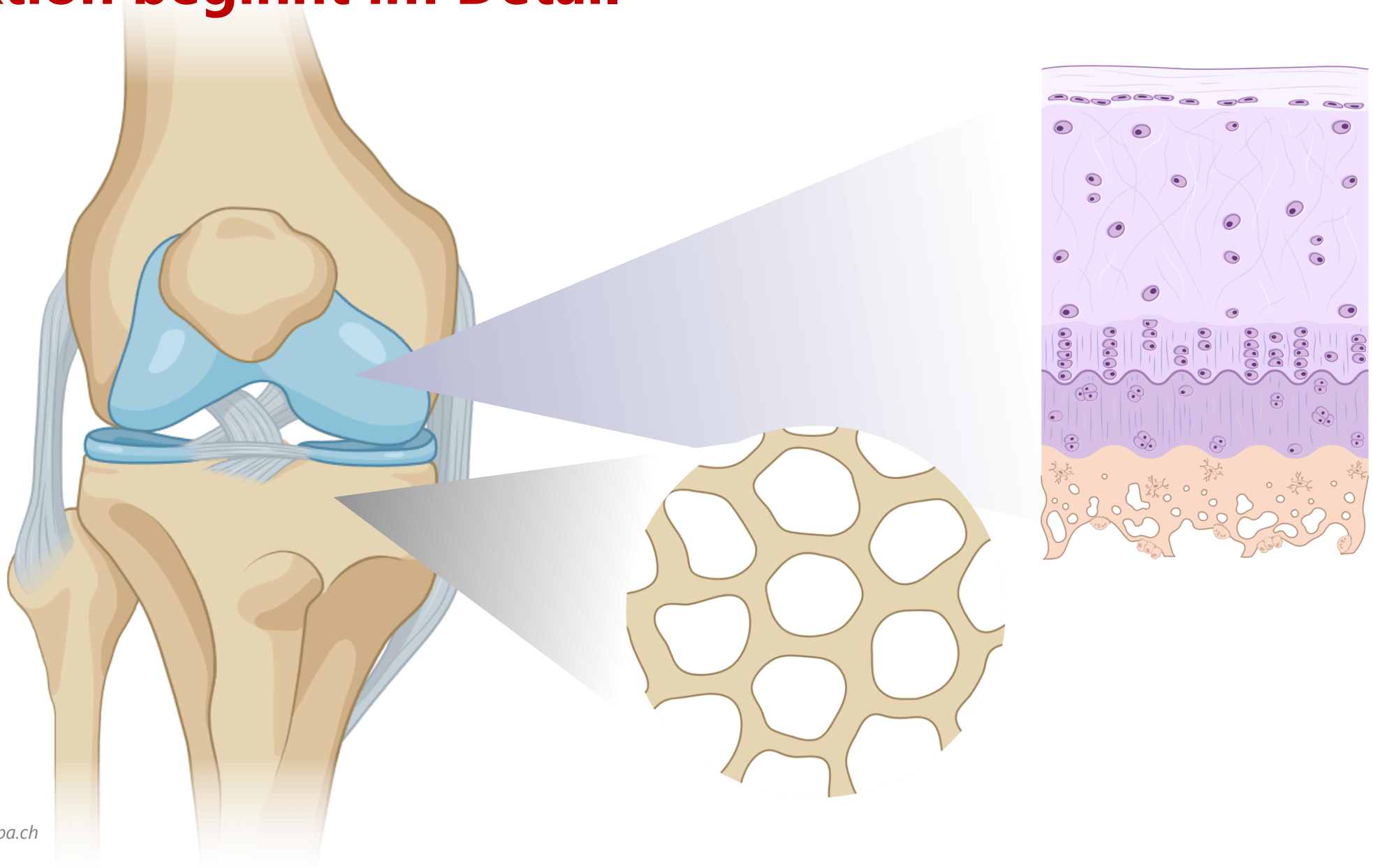
Materials Science and Technology

# High-Resolution 3D Imaging in Musculoskeletal and Orthopedic Applications

## Bridging Microscopic Insights with Macroscopic Functionality

27 May 2025 – Annapaola Parrilli

# Funktion beginnt im Detail - The need for multi-scale vision



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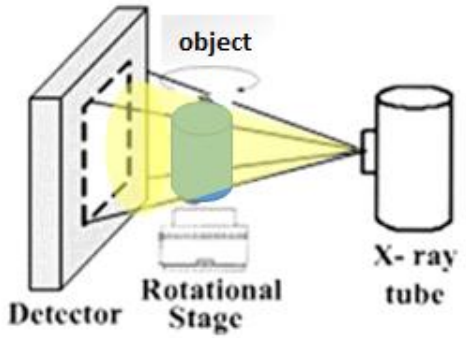
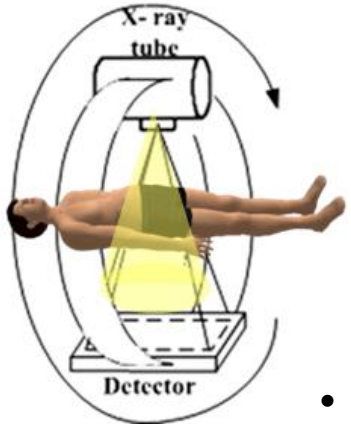
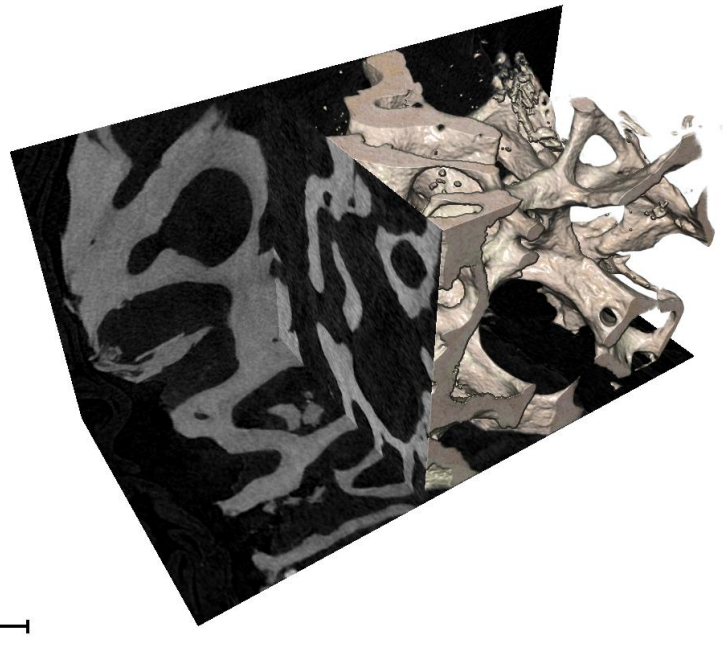
# X-ray Lab micro/nano CT




## From Hard Tissue Imaging to Soft Tissue Revelation

- High-resolution, non-destructive 3D imaging
- Gold standard for bone architecture (trabecular and cortical)
- Enabling quantification, morphometry, and modeling
- Applications from implant assessment to regenerative tissue evaluation
- Emerging role in soft tissue imaging via contrast-enhanced micro-CT

  - bone anatomy
  - bone growth
  - bone regeneration
  - bone mineral content (densitometry)

  - osteointegration
  - osteoinduction
  - biomaterial and medical devices structure characterization both in pre-implant and in the explant phase

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# Cranial Hydroxyapatite Prosthesis Implantation CLINICAL TRASLATION

Two cases of patients who were implanted with custom-made bioceramic porous hydroxyapatite prosthesis after cranial decompression.

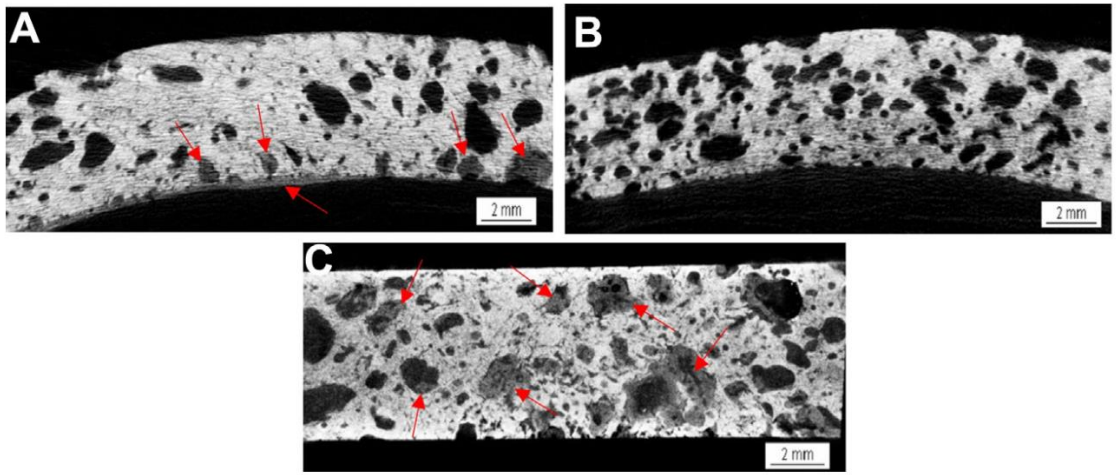



**Figure 4.** Microtomographical sections (**A** and **C**): newly formed bone (*red arrows*) and implant resorption of case #1A and case #2; (**B**) absence of bone newly formed bone in case #1B.

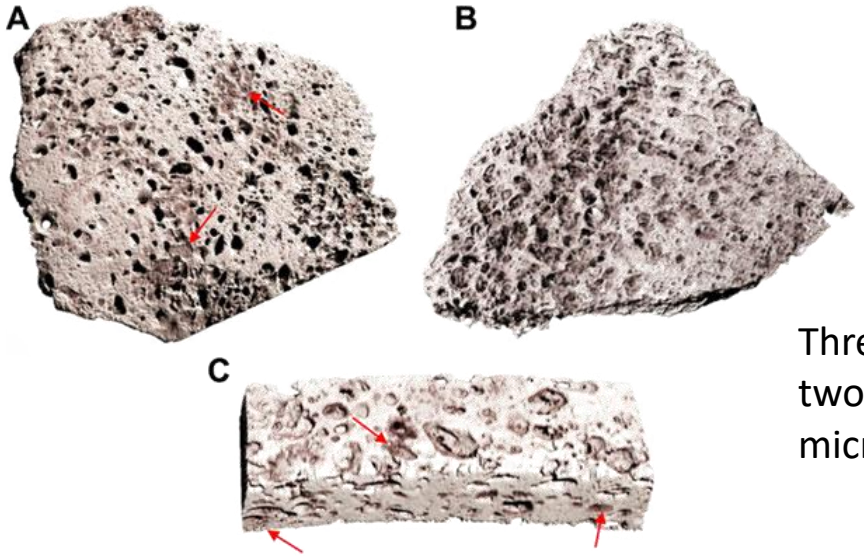
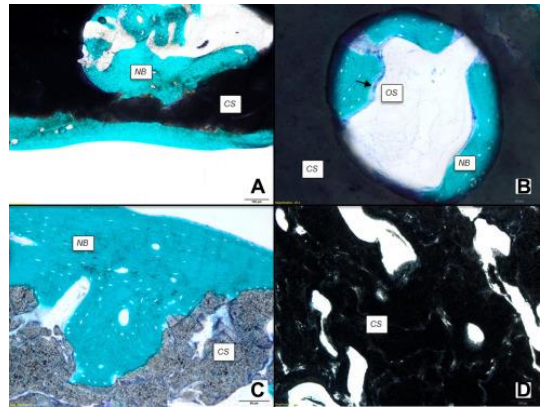



**Figure 5.** Three-dimensional virtual models of cranial prosthesis of (**A**) case #1A, (**B**) case #1B, and (**C**) case #2.

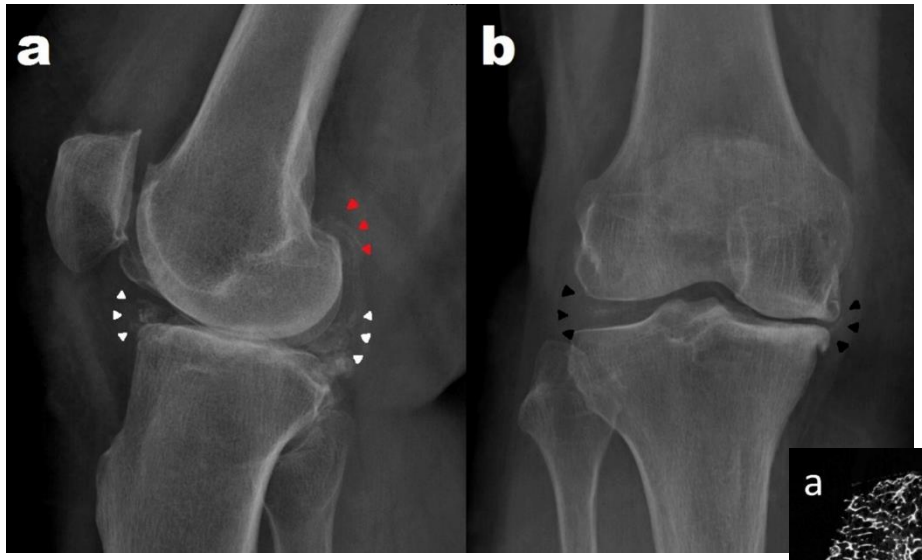
Three explants obtained from two different patients were analyzed microtomographically and histologically.

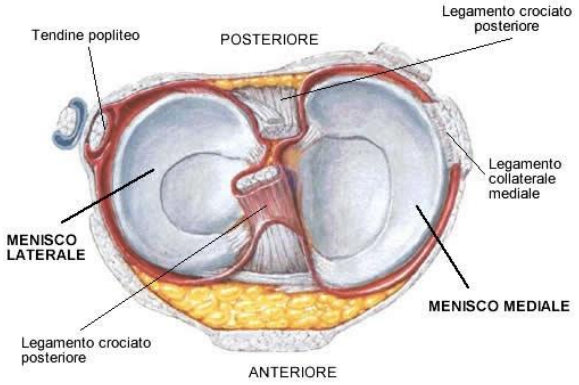
2D histology




*Fricia et.al, World Neurosurgery 2015*

# Human Knee

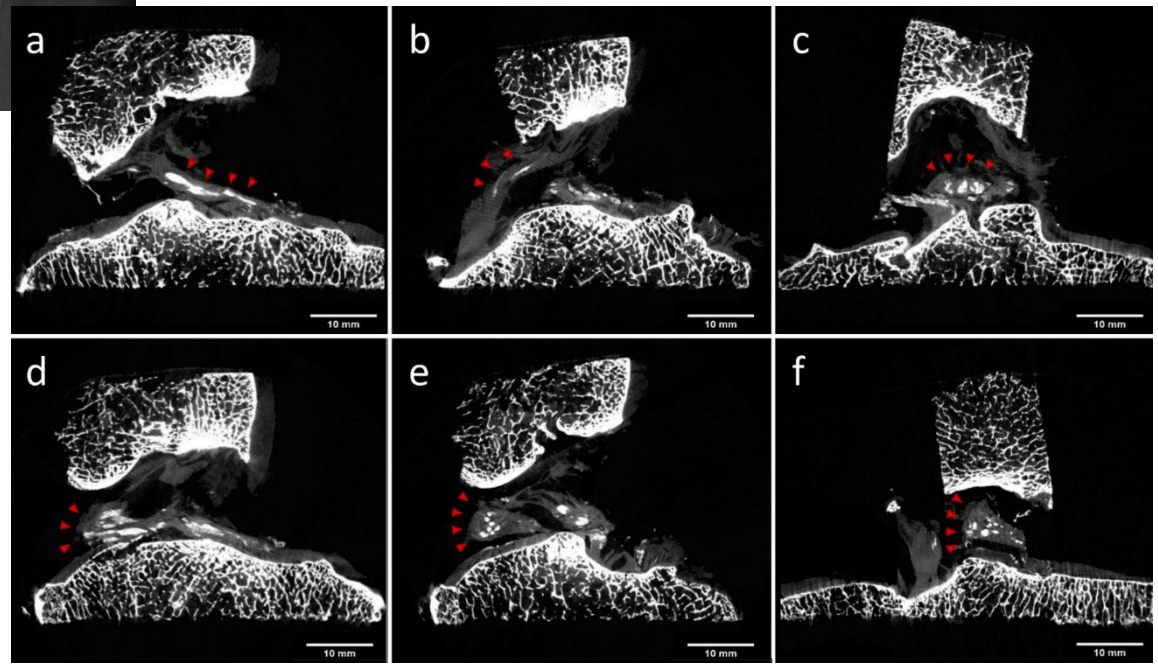


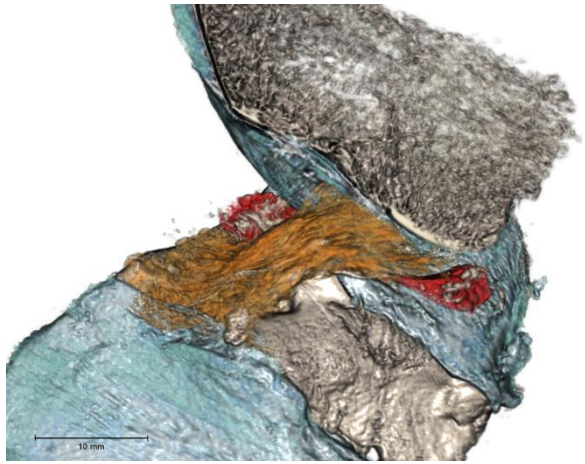




**Case Report: Anterior Cruciate Ligament Calcification in a Patient With Chondrocalcinosis: Micro-Computed Tomography Presentation**

*Alberto Grassi[1*], Giacomo Dal Fabbro[1], Milena Fini[2], Stefano Zaffagnini[1] and Annapaola Parrilli[3*]*

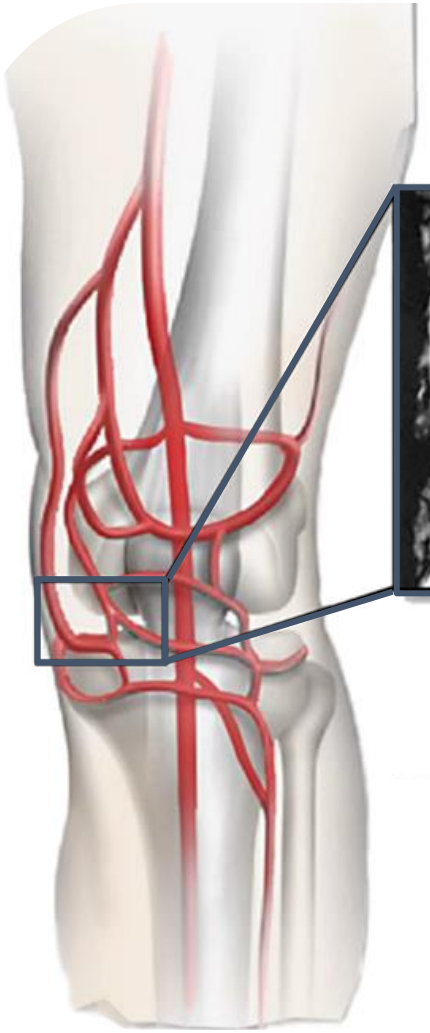
Reference:
Grassi et.al & Parrilli, Frontiers in Surgery, 2021, 8, 680234
https://www.frontiersin.org/articles/10.3389/fsurg.2021.680234/full



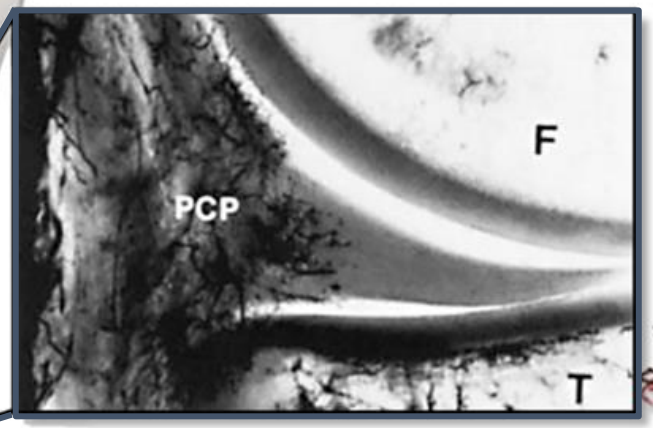



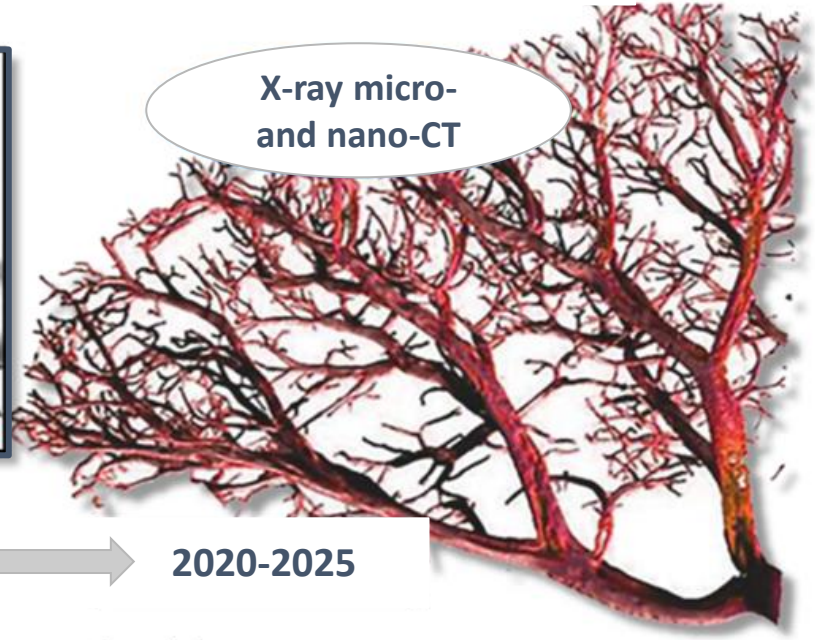
# 3D Imaging of the Microvasculature of the Meniscus

Schweizerischer Nationalfonds



going from 2D → … to 3D




1982 → 2020-2025

## Microvasculature of the human meniscus

**Principal Investigator:**
Annapaola Parrilli, PD Dr.

**PhD Student:**
Federica Orellana

**Project partners:**
Alberto Grassi, MD, IOR

Stefano Zaffagnini, Prof. MD, IOR

Peter Wahl, PD Dr. MD, KSW

Katja Nuss, Dr. Med. Vet., UZH

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Istituto Ortopedico Rizzoli di Bologna
Istituto di Ricovero e Cura a Carattere Scientifico

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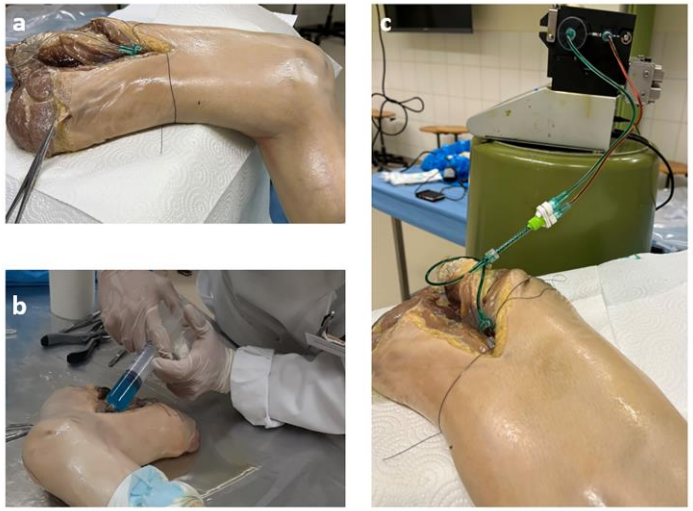
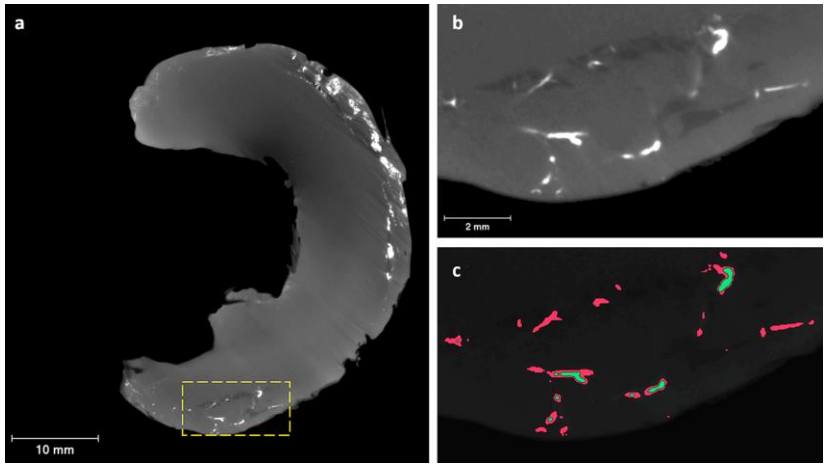
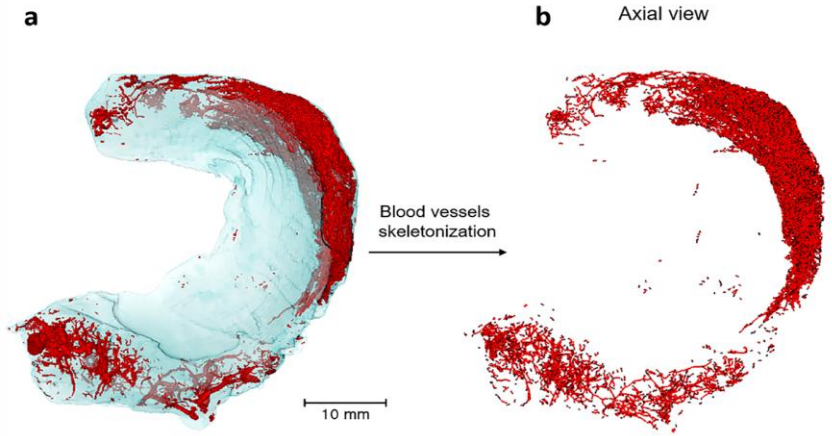
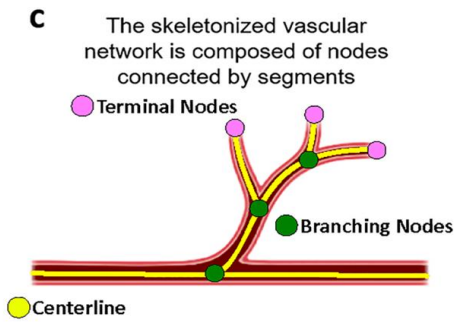
# 3D Imaging of the Microvasculature of the Meniscus

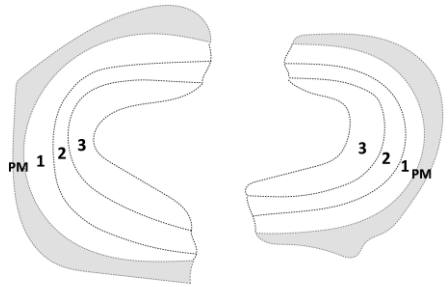
**µAngiofil CA Injection**

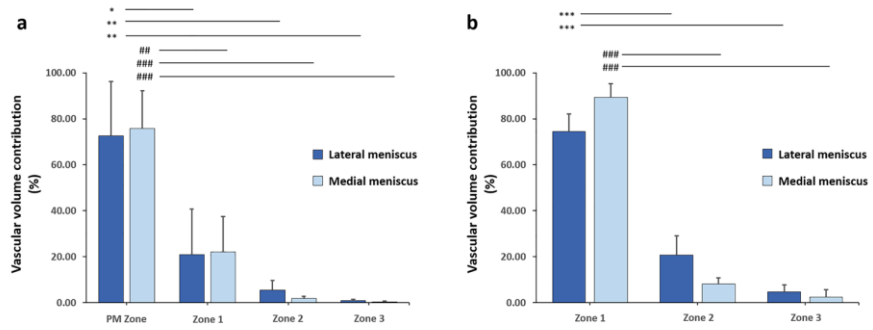


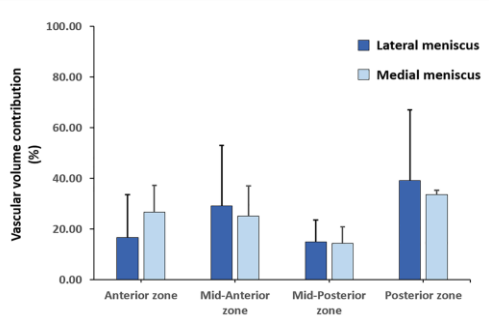



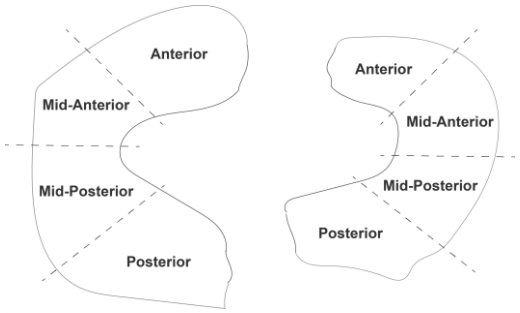




- More than 72% of the blood vessels are located in the **PM zone,**
- Without the PM area, **zone 1** displayed the highest vascular volume.




- The **mid-posterior portions** showed the lowest contribution in both lateral and medial meniscus.

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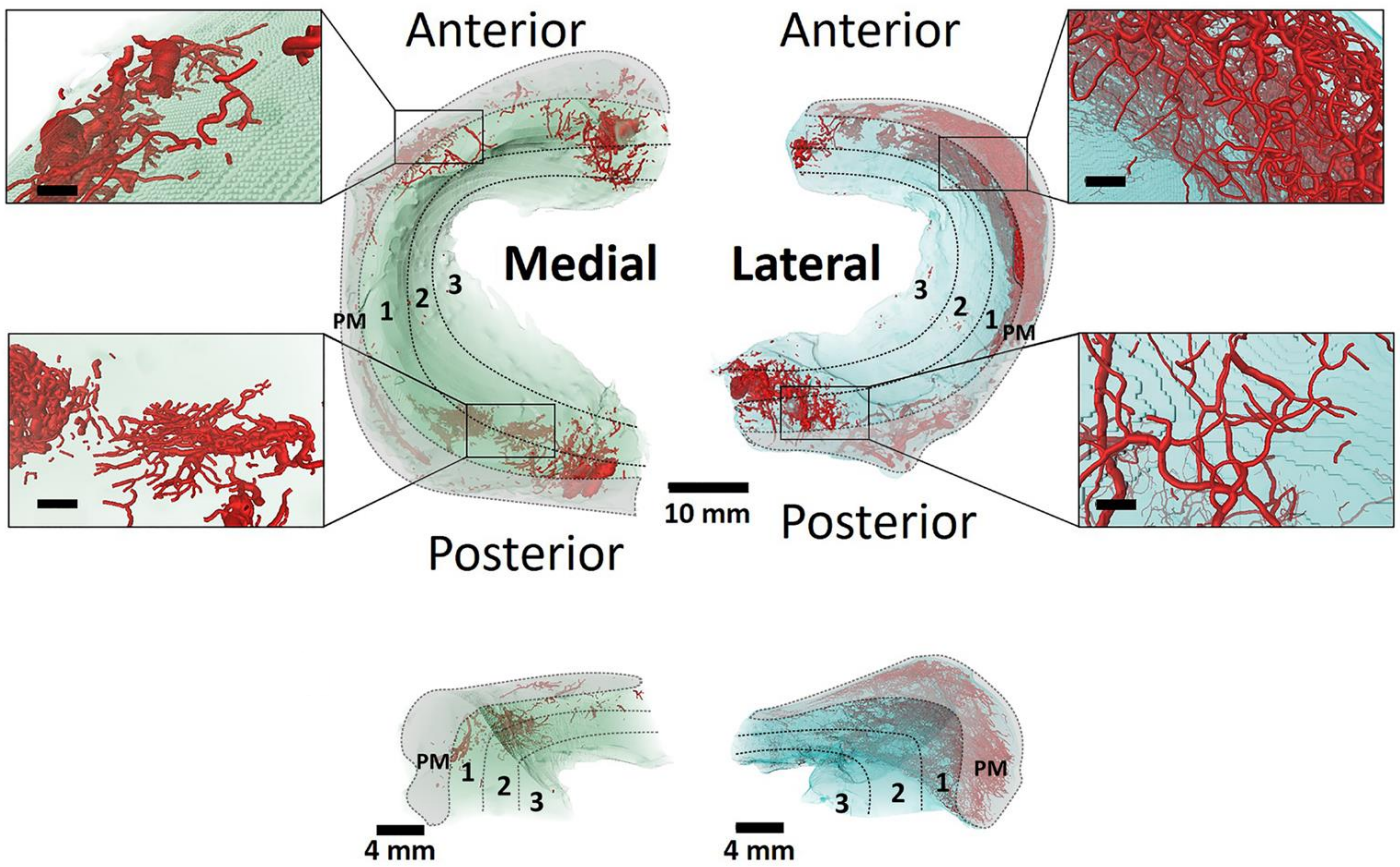
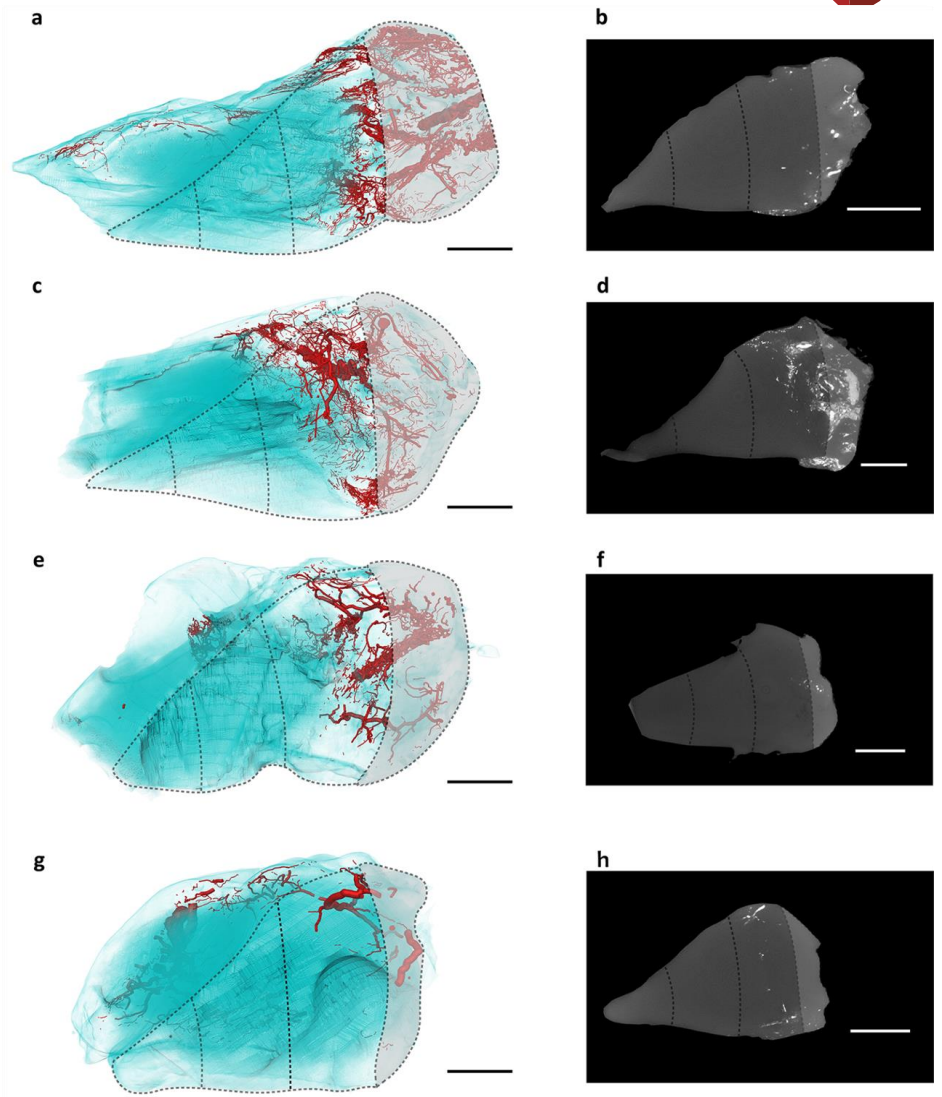
***Orellana, F., …Parrilli A**. Scientific Reports (2024).*

# 3D Imaging of the Microvasculature of the Meniscus




PM = Perimeniscal Zone, Cooper Zone 1 (RR), Cooper Zone 2 (RW), Cooper Zone 3 (WW).

Vx size 30 µm




Vx size 15 µm

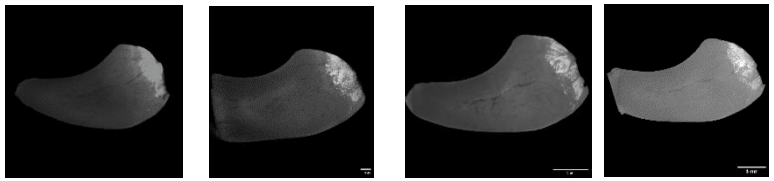
**Vasculature of the Radial Meniscal Portions**

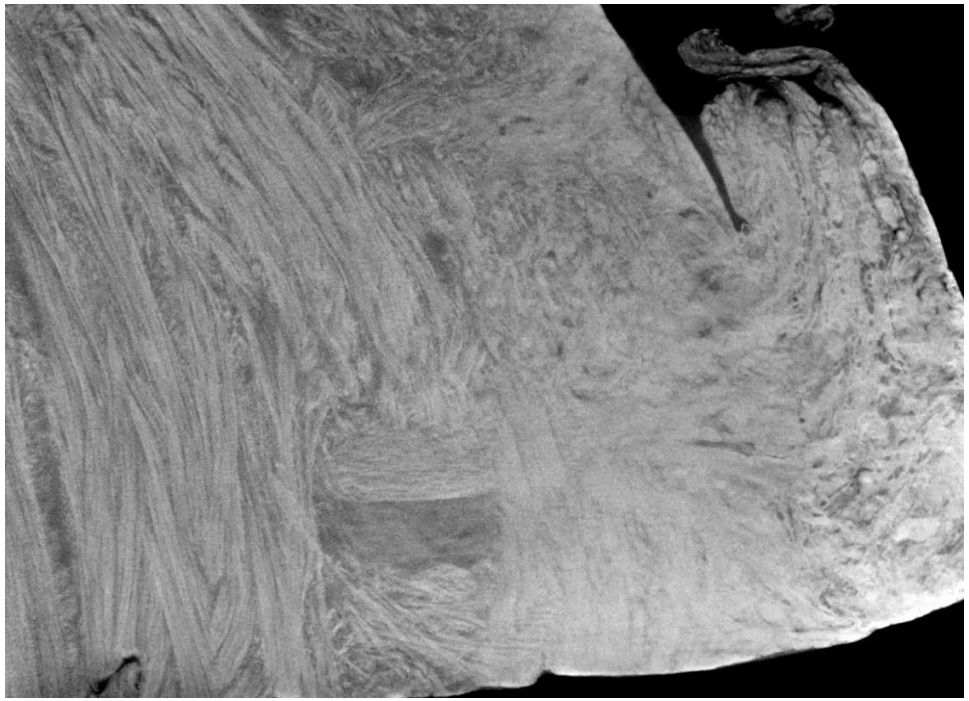
*annapaola.parrilli@empa.ch*

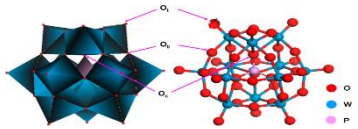
***Orellana, F., …Parrilli A**. Scientific Reports (2024).*

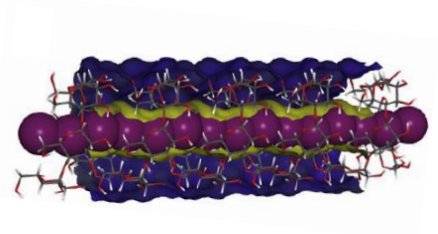
# 3D Imaging of Fibrocartilaginous Tissues

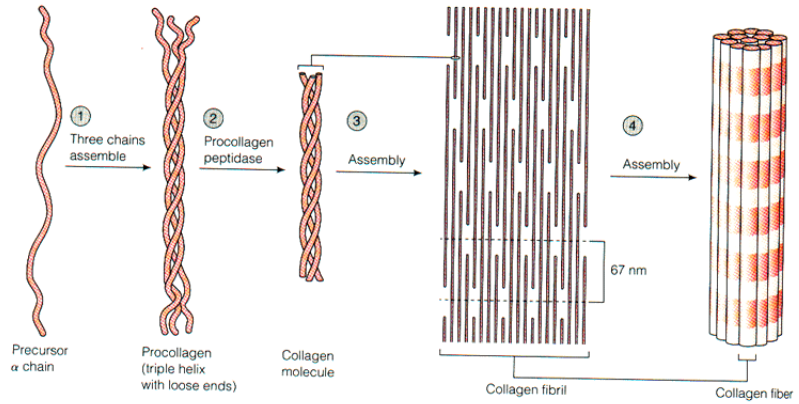
**Immersion in X-ray costrast enhancement solution (days)**

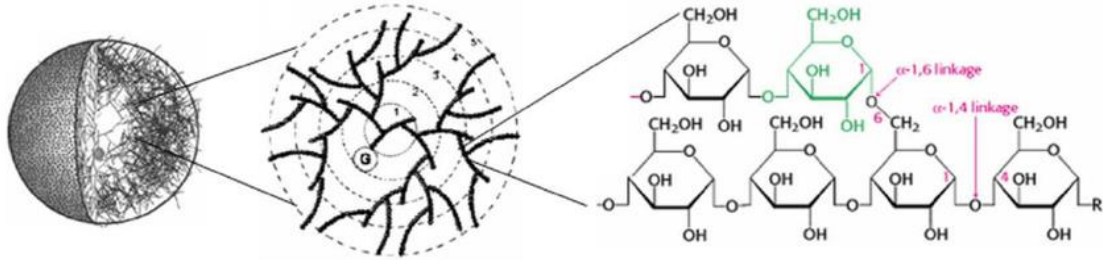












Contrast enhancement X-ray solutions are important as they help highlight fine structures of soft tissues, enabling healthcare professionals to obtain clearer images and improve diagnostic accuracy in identifying potential abnormalities or diseases.

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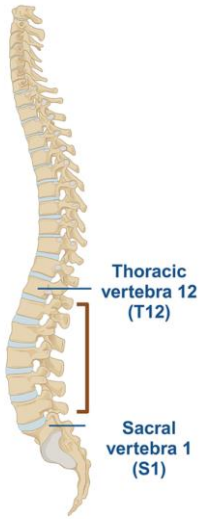
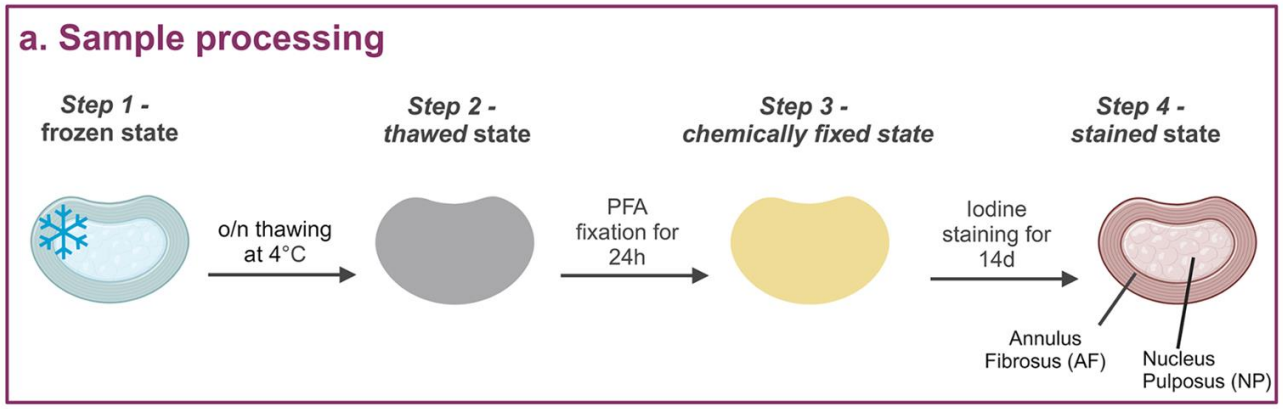
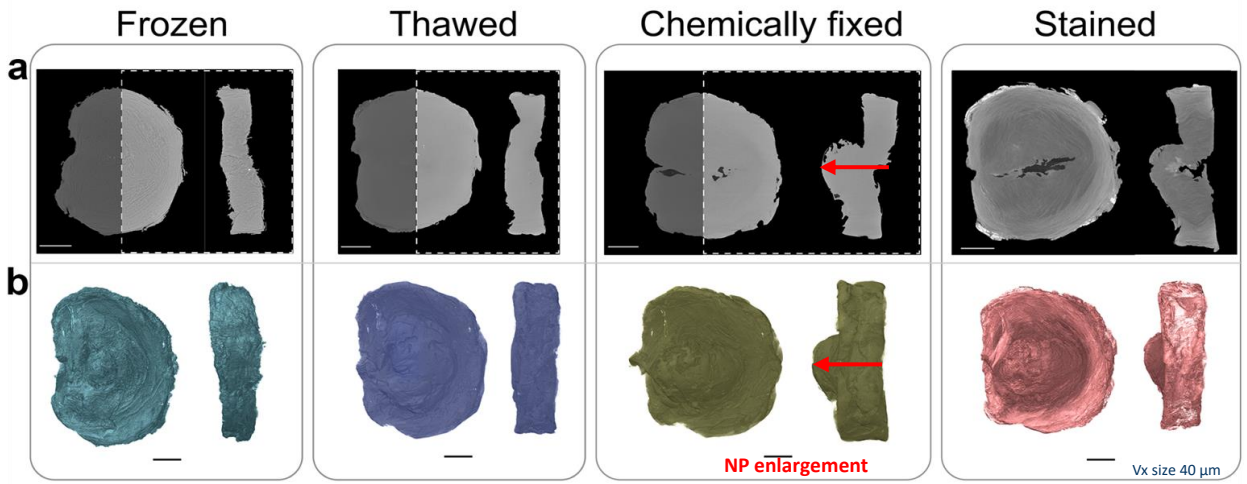
# Analysis of the 3D architecture of human intervertebral discs

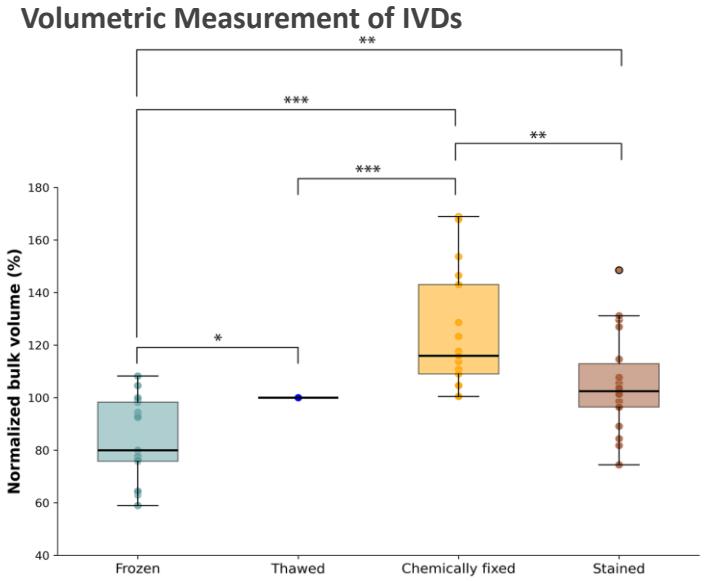
Balgrist Universitätsklinik

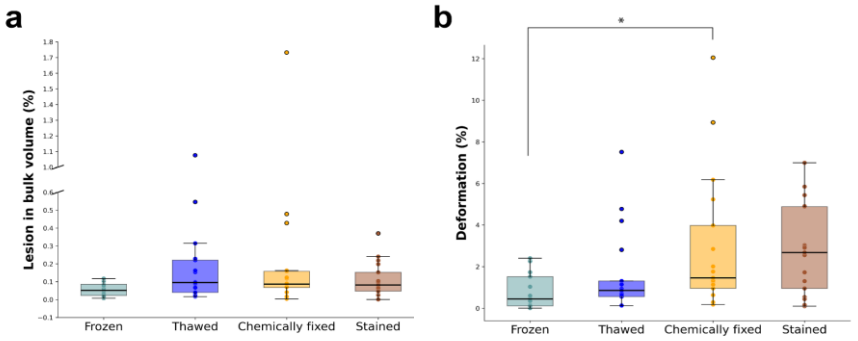



Lateral view of healthy human spine with IVDs



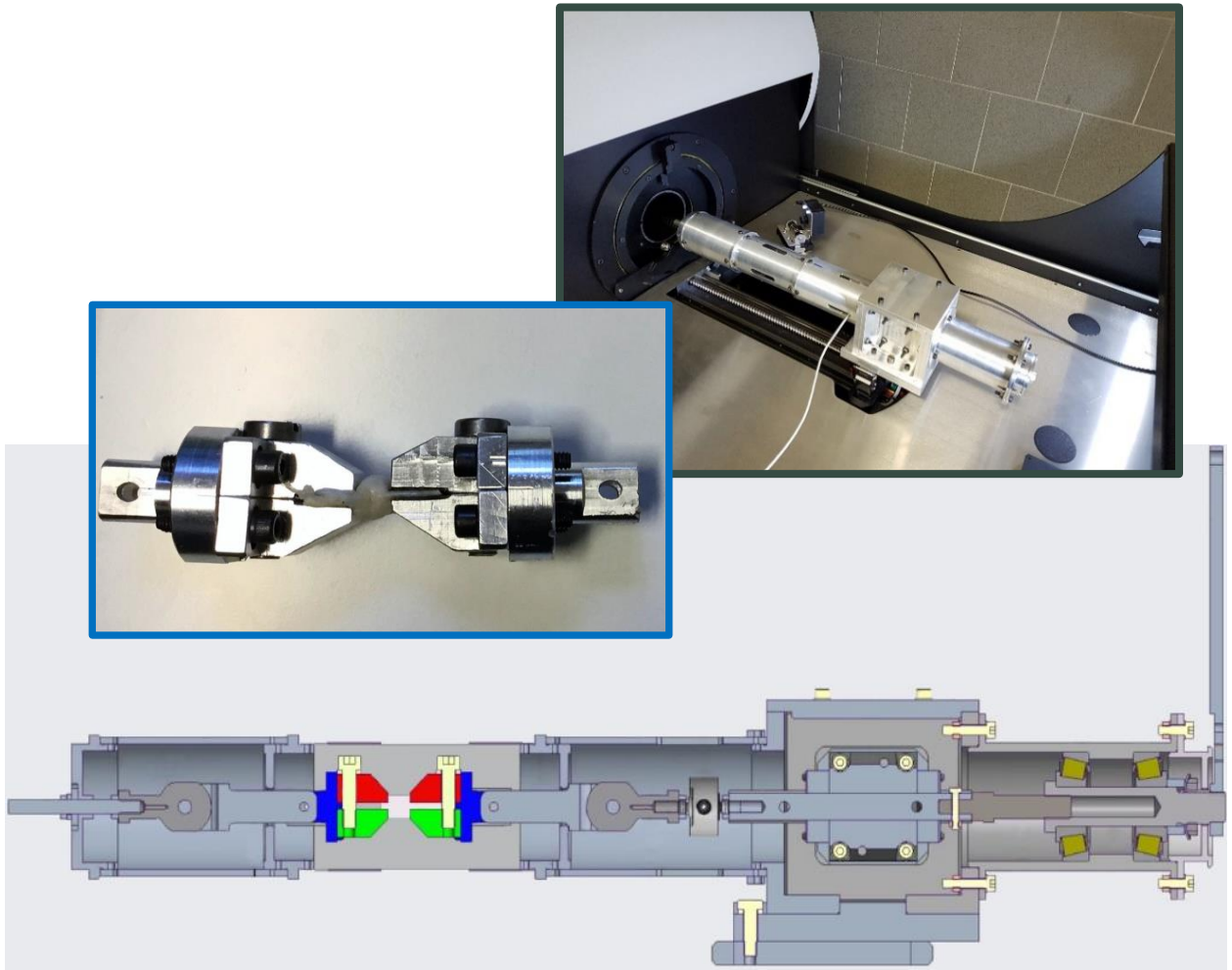



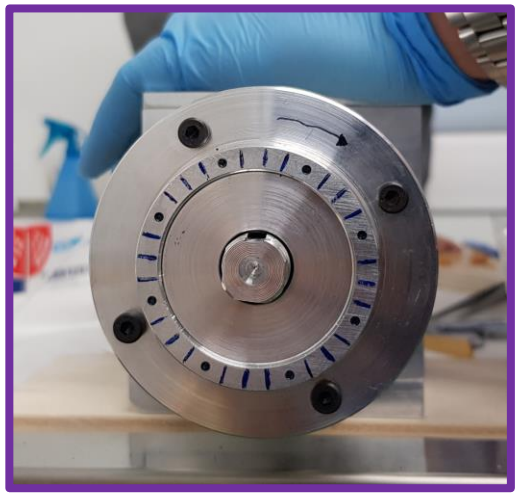

Lesions and Deformation Measurements of IVDs

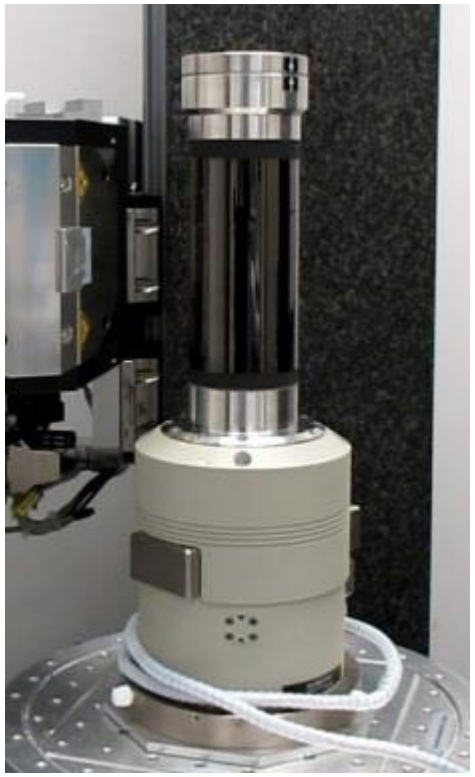
**Orellana**, F., and Barna, R.-A.-M. *et al.* Stepwise micro-CT analysis of the 3D architecture of human intervertebral discs. Under review

*annapaola.parrilli@empa.ch*

# Assessment of human soft tissue microstructure under tensile load







## Integration of:

- Custom-made and commercial Tensile system for ligaments
- Staining to enhance X-ray contrast of the Ligament Fibers

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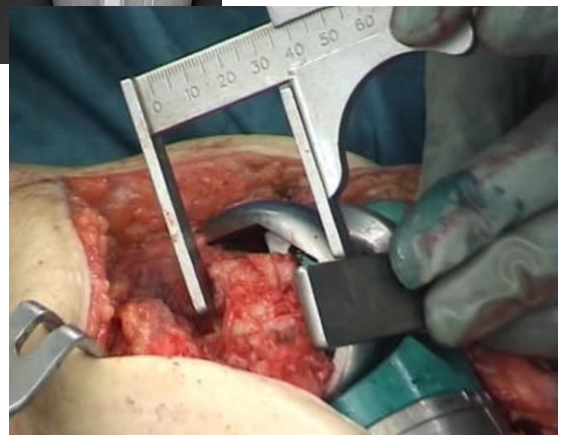
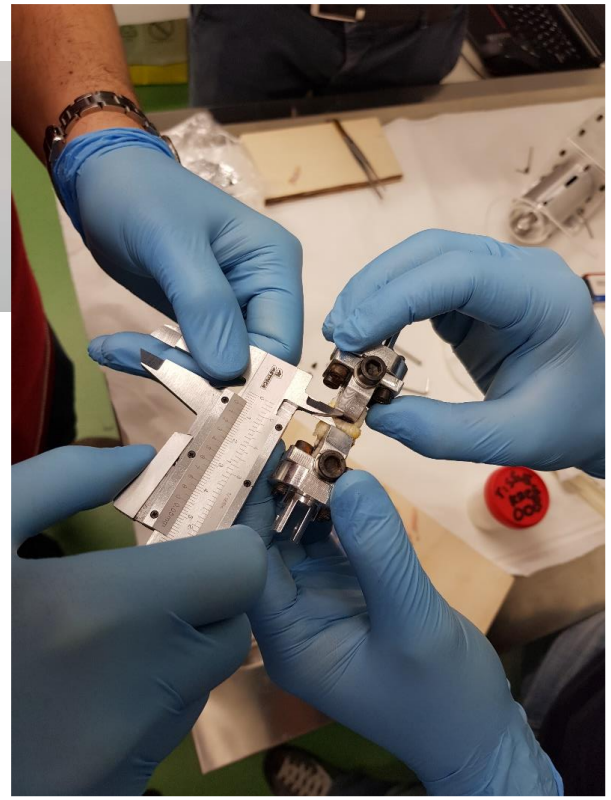
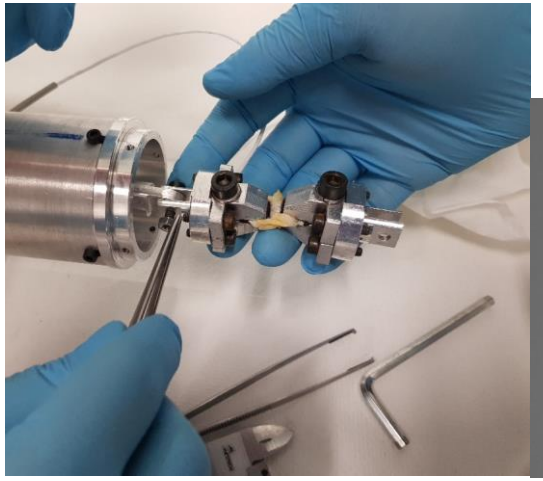
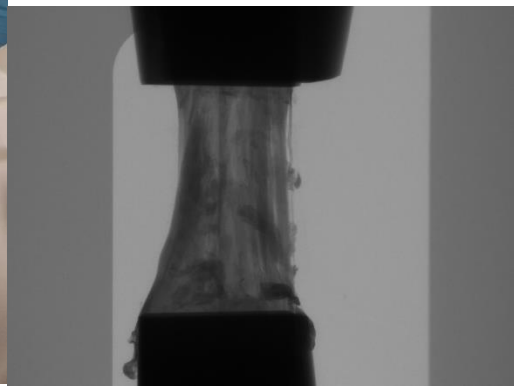
# Assessment of human soft tissue microstructure under tensile load

Understanding the Structure-Function Relationship through 3D Imaging and Biomechanical Analysis:
A Novel Methodological Approach Applied to Anterior Cruciate Ligaments

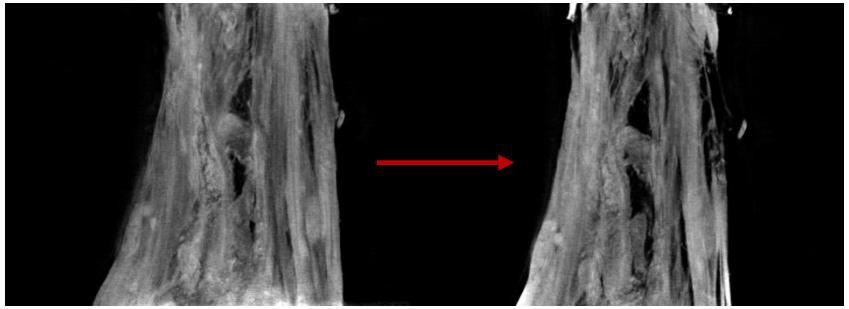








ε=0% vs ε=8%



Bontempi…Parrilli, Lopomo, Biomimetics 2024 - https://pubmed.ncbi.nlm.nih.gov/39194456/

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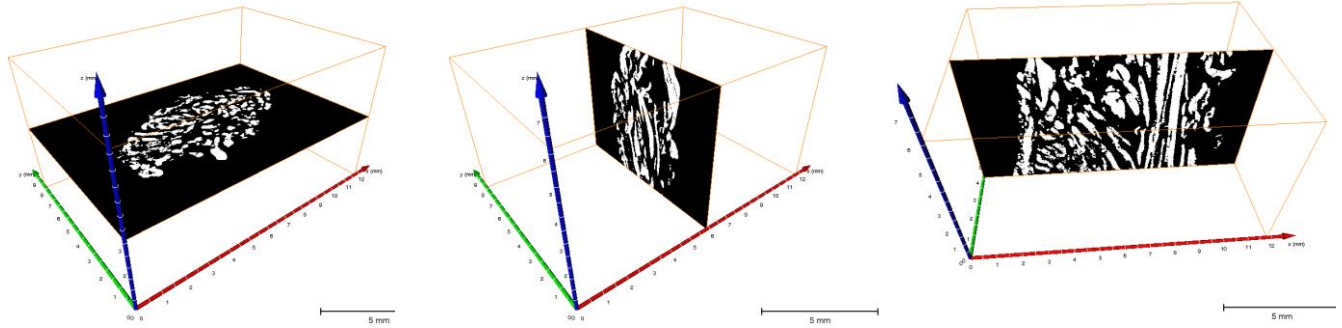
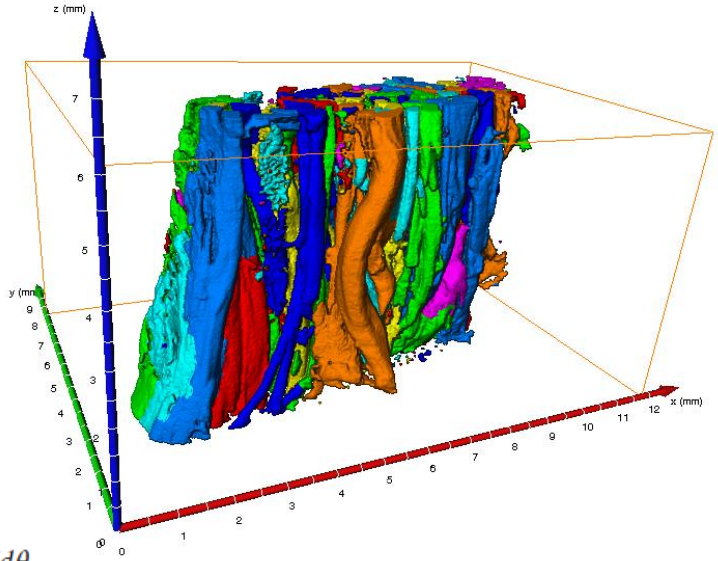
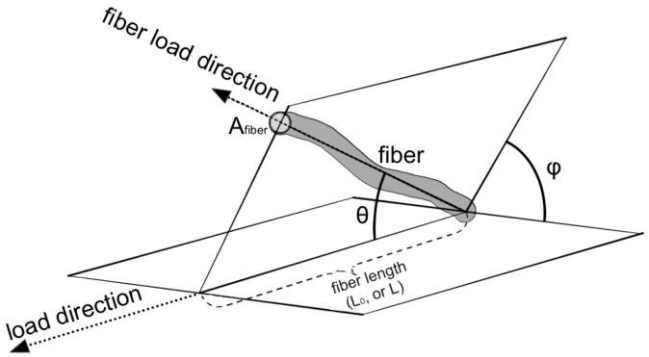
# Structure-Function Relationship of ACL through 3D imaging



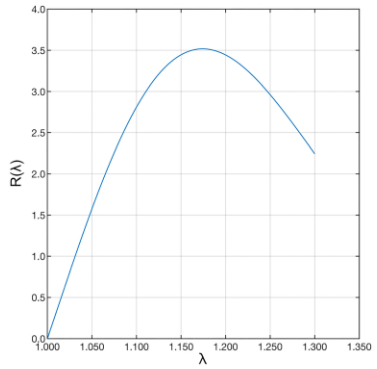


$$F(L) = N_0 \int_{L_0}^{L} R(x) f(L-x) dx \quad \Rightarrow \quad \sigma(\lambda) = 2\pi N_0 E_f \int_0^{\frac{\pi}{2}} \int_{\frac{1}{\cos\theta}}^{\frac{\lambda}{\cos\theta}} R(\xi) P(\theta, \xi) \left( \frac{\lambda}{\cos\theta} - \xi \right) \nu(\xi, \theta) \cos^2\theta \sin\theta d\xi d\theta$$

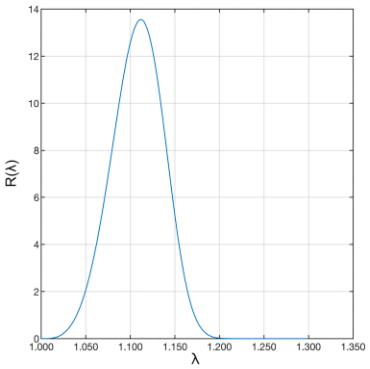
$$(\xi) = \frac{\beta}{\delta} \left( \frac{\xi - \gamma}{\delta} \right)^{\beta-1} e^{-\left( \frac{\xi - \gamma}{\delta} \right)^{\beta}}$$




Model geometry representation.
The picture shows the parameters used in the model: orientation of the fiber (θ, ϕ angles), the length of the fiber ($L_0$, L), and the cross area ($A_{fiber}$) of the fiber.




(a)




(b)

Bontempi…Parrilli, Lopomo, Biomimetics 2024 - https://pubmed.ncbi.nlm.nih.gov/39194456/

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# Conclusions

**Seeing structures means understanding healing**


**The better we can see tissue, the better we can preserve it, repair it, or create new tissue**

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