Changes in subchondral bone microstructure and shape with age in tibial knee

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[3] University of Sheffield, UK
[4] KU Leuven, Belgium

Musculoskeletal/joint biomechanics III: Bone and tendon

ESB2023
28th Congress of the European Society of Biomechanics
9-12 July 2023, Maastricht, The Netherlands

10/07/2023
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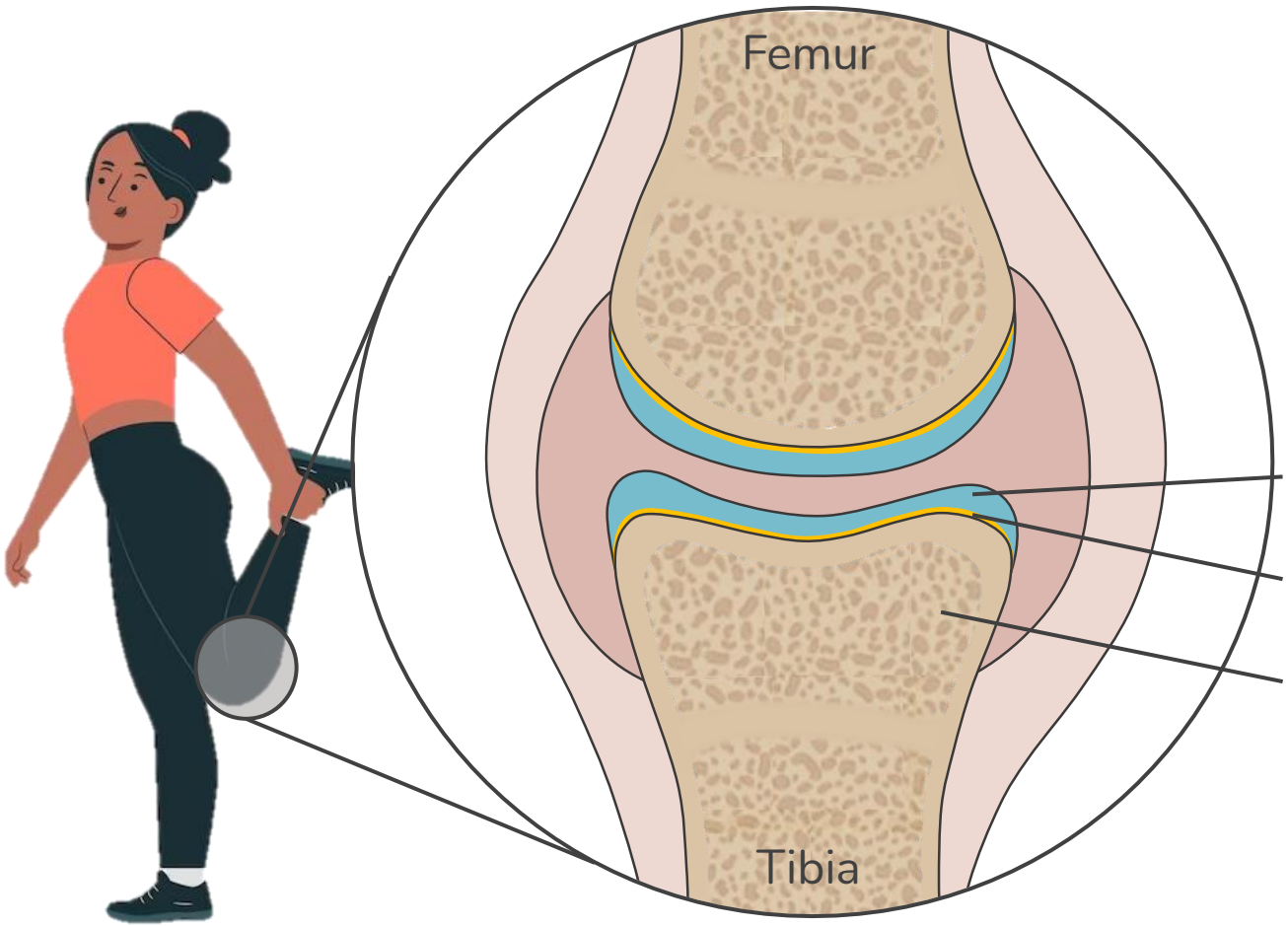
MBBM

Knee is a complex structure



Knee
- Very dissimilar tissues
- Functional unit
- Changes (disease, aging,...) in one layer impacting the others

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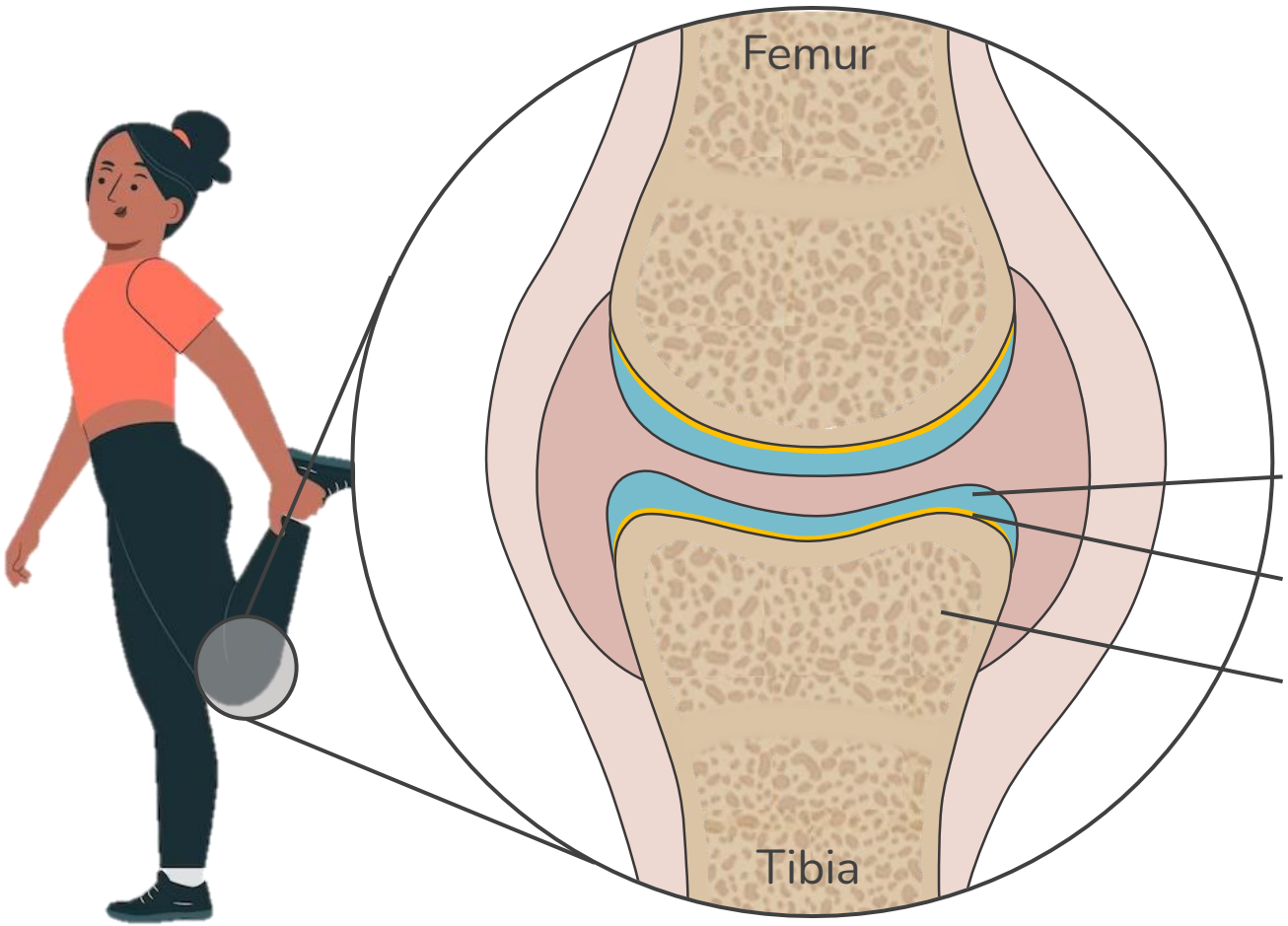


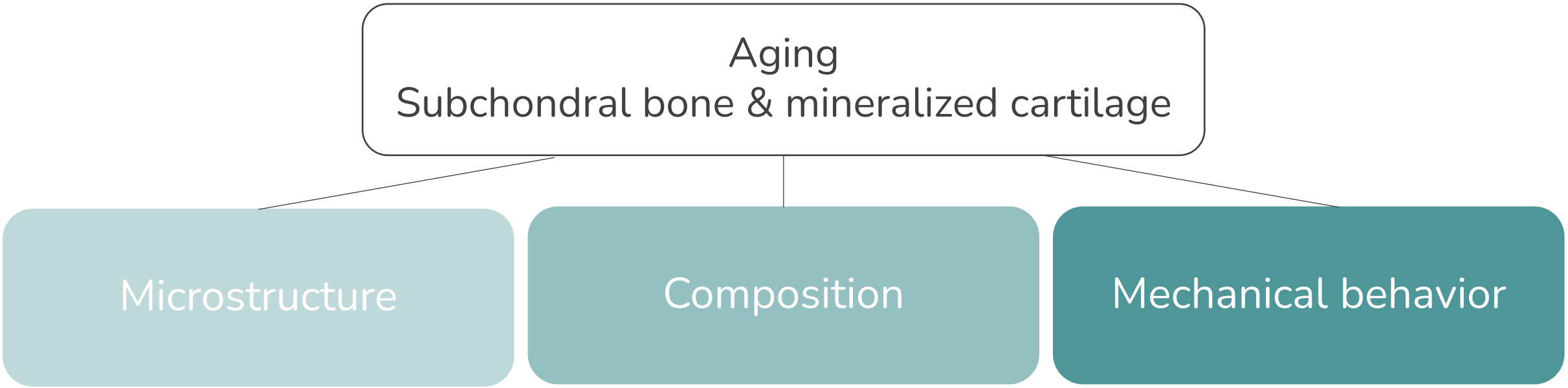
Knee
- Very dissimilar tissues
- Functional unit
- Changes (disease, aging,...) in one layer impacting the others

Articular cartilage

Mineralized cartilage

Subchondral bone

Aims of the thesis



Aims of the thesis

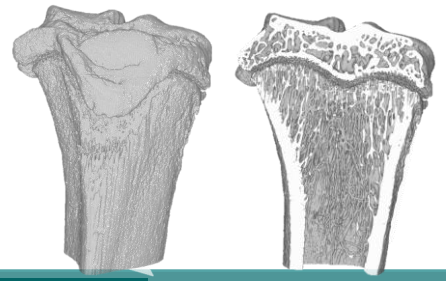
Aging
Subchondral bone & mineralized cartilage

Microstructure

Composition

Mechanical behavior

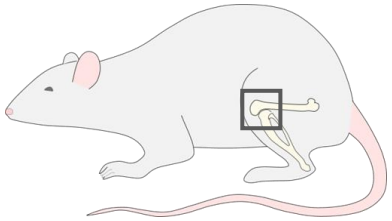
How are mineralized tissues changing with respect to regions far away from the joint?



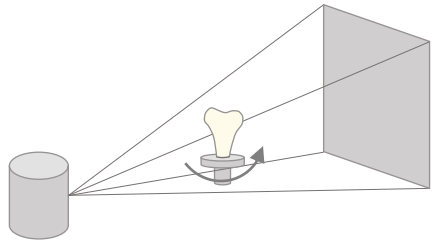
Epiphysis

Metaphysis

Methods – Trabecular bone characteristics



Distal tibia extraction
Wistar rats
- ADULT 3 months (n=10)
- OLD 13 months (n=6)

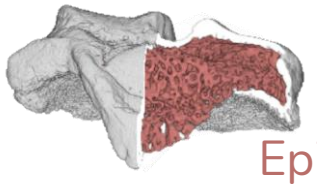


Micro-computed tomography
(MicroCT) - SkyScan1272
10 µm

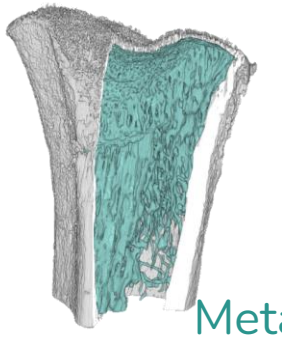
KU LEUVEN

Image processing
- Bone alignment
- Segmentation

Trabecular bone analysis



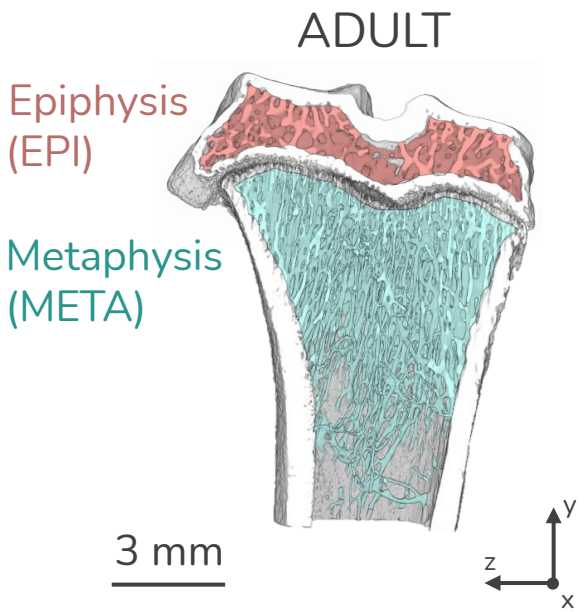
Epiphysis

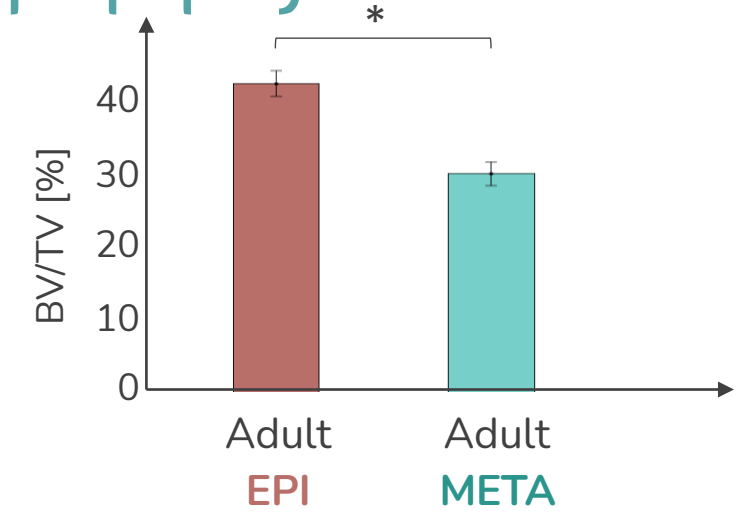


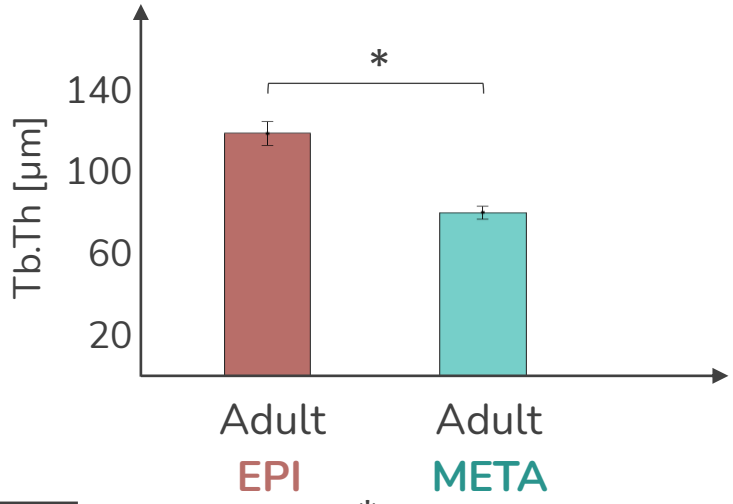
Metaphysis

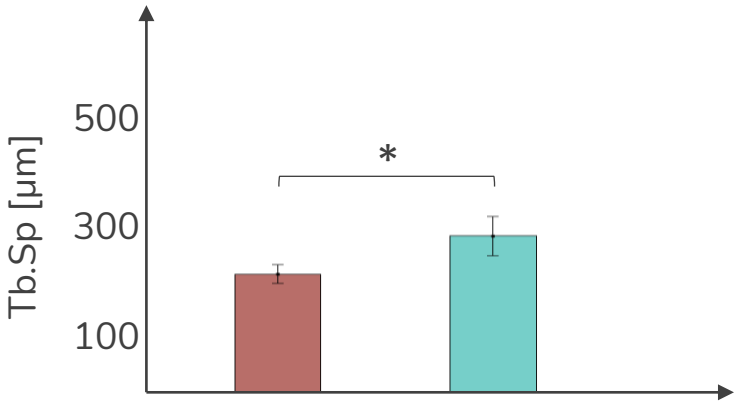
Avizo, CTAn

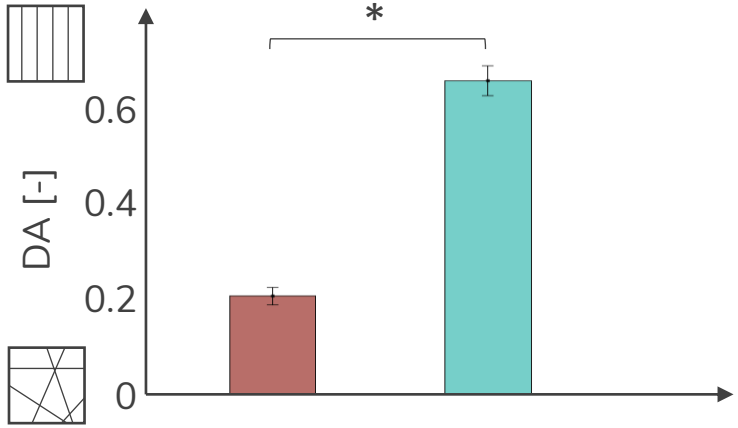
Comparison of epiphysis & metaphysis in adults











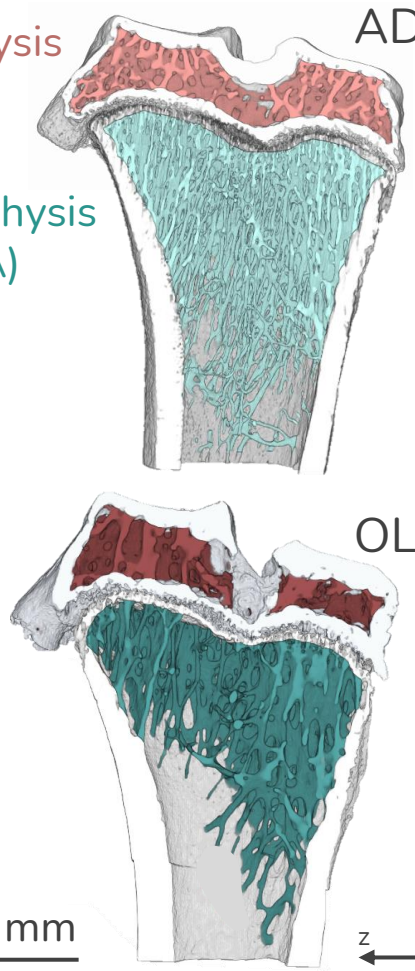
- META: less but more aligned bone
- META & EPI have distinct structures → different mechanical functions?

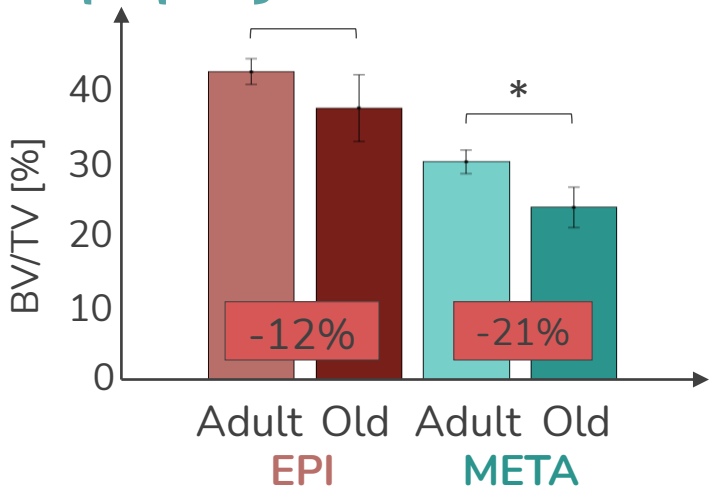
* Significant ($p<0.05$)

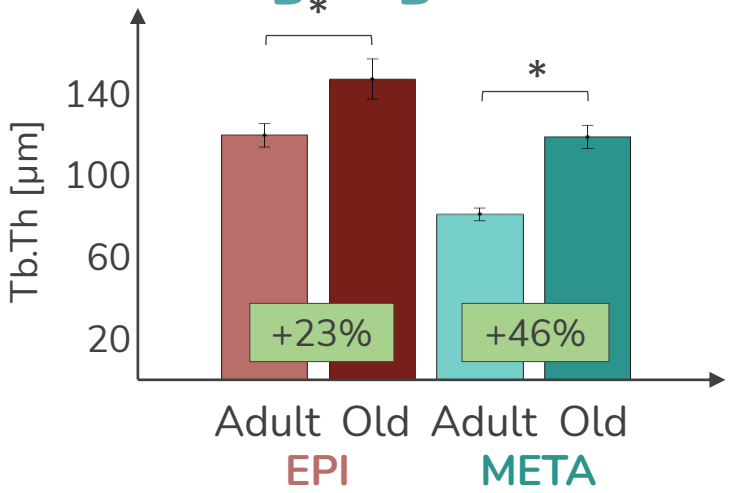
Comparison of epiphysis & metaphysis in aging

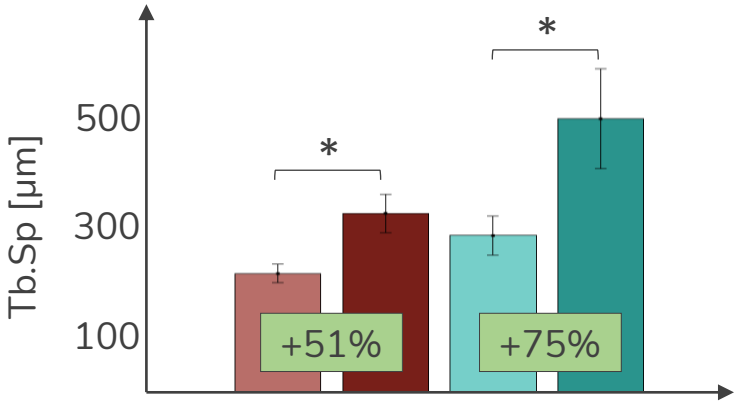
Epiphysis (EPI)

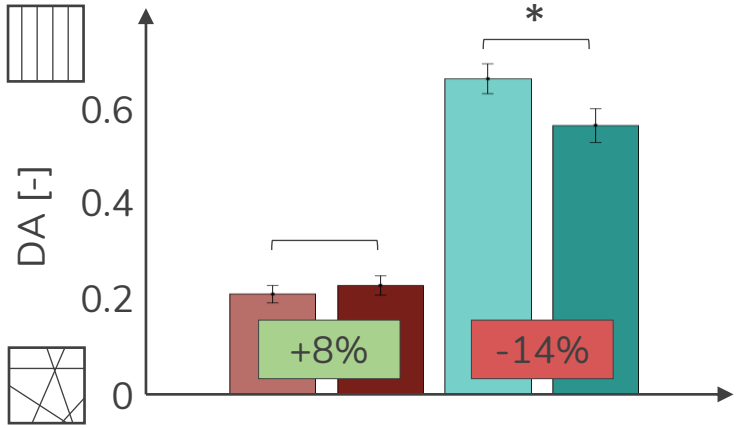
Metaphysis (META)







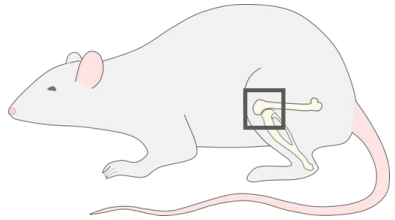




* Significant ($p<0.05$)

- META & EPI: BV/TV ↘ & network becomes coarser → changes stronger in META
- Opposite changes in degree of anisotropy

Methods – Trabecular bone characteristics



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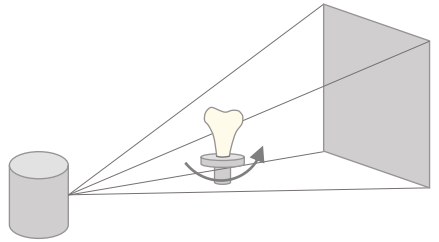

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10 µm

KU LEUVEN

Image processing
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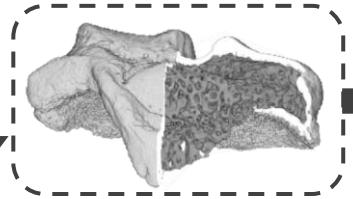
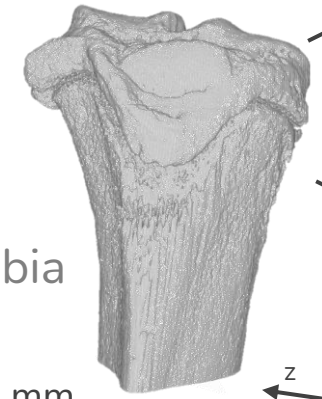
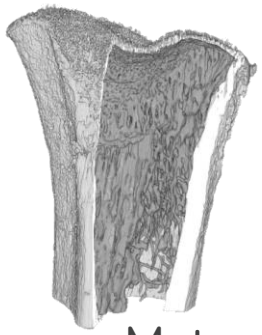
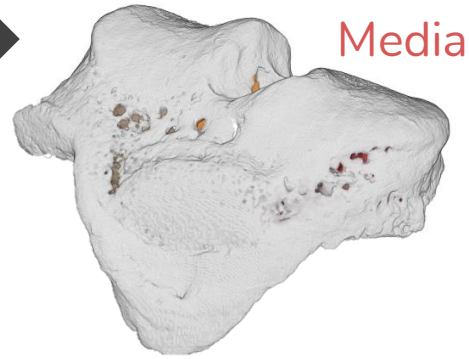






Avizo, CTAn

Trabecular bone analysis



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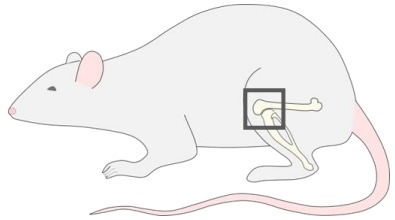

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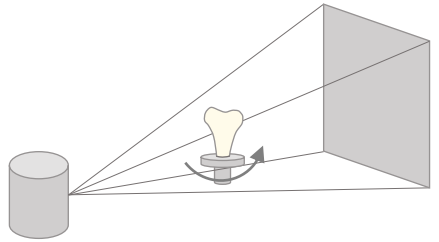

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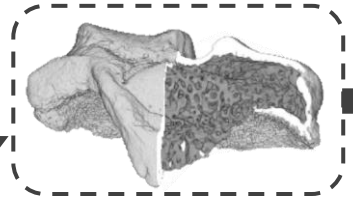

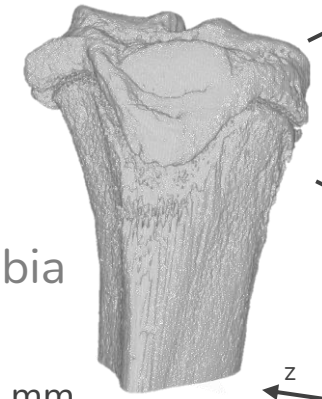

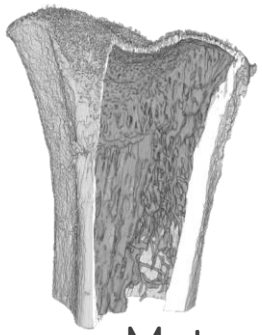

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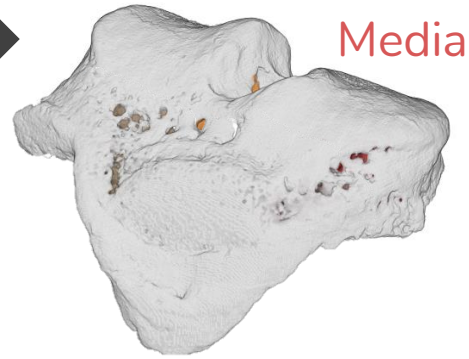
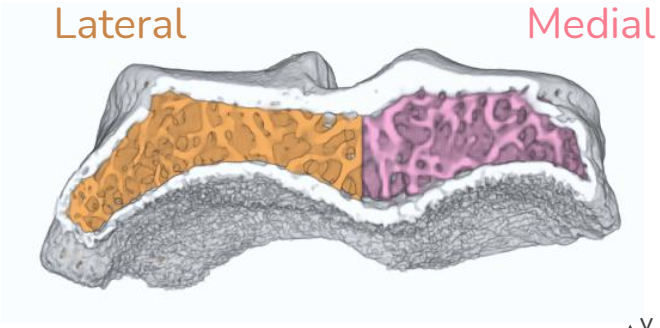
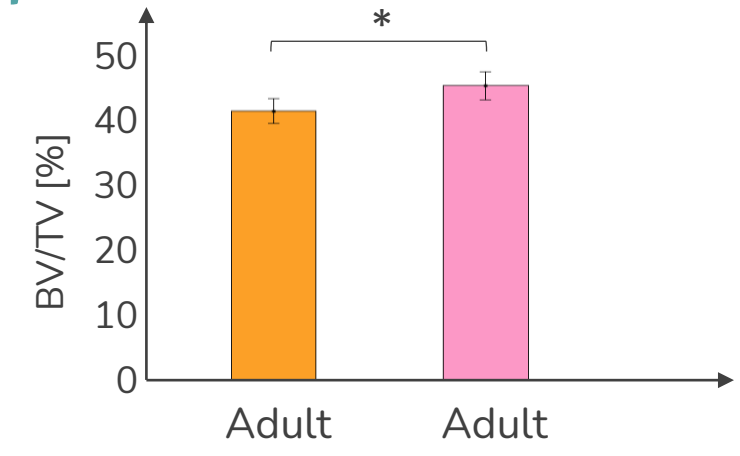


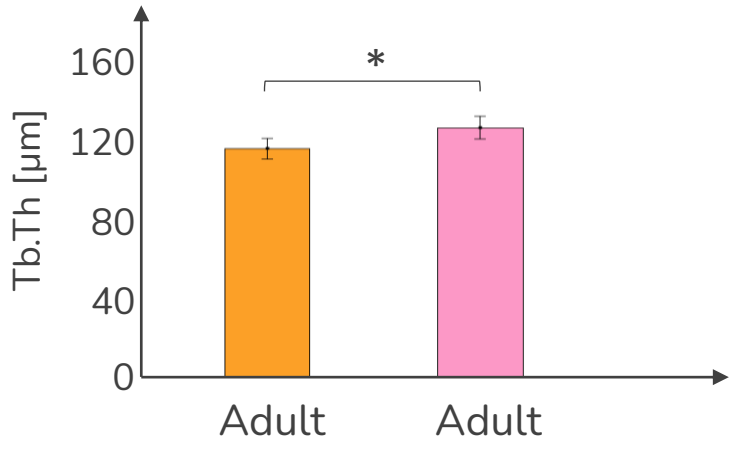
CTAn

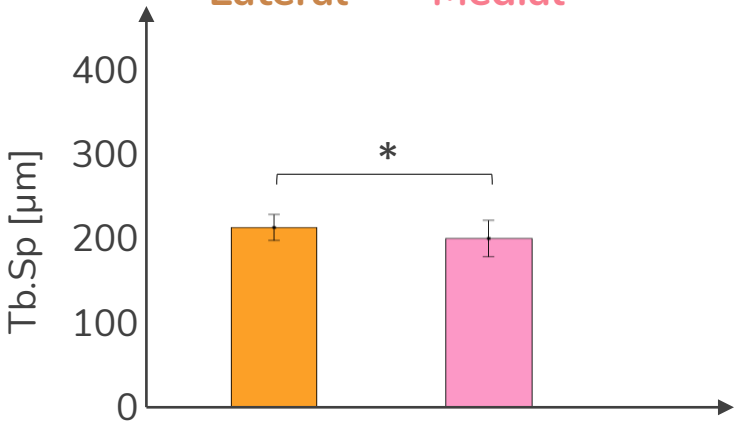
Comparison of lateral & medial regions in adults

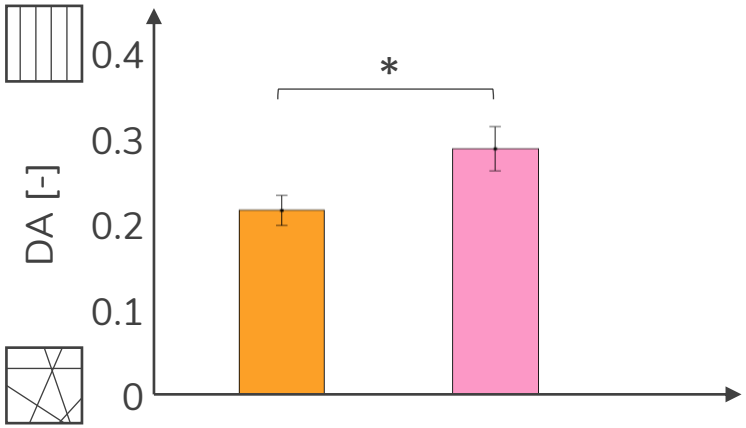
ADULT







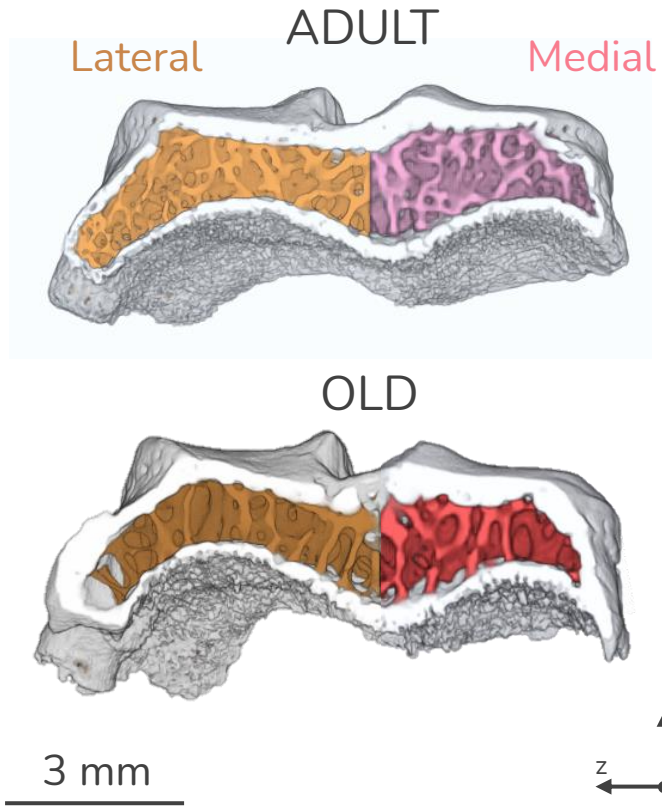


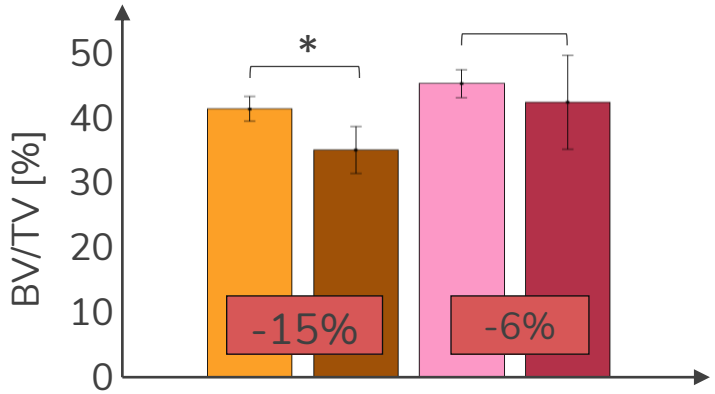


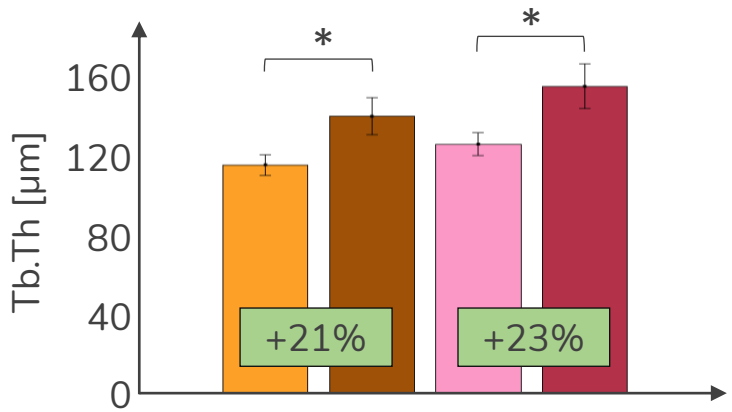
Medial region: higher bone density and more aligned bone

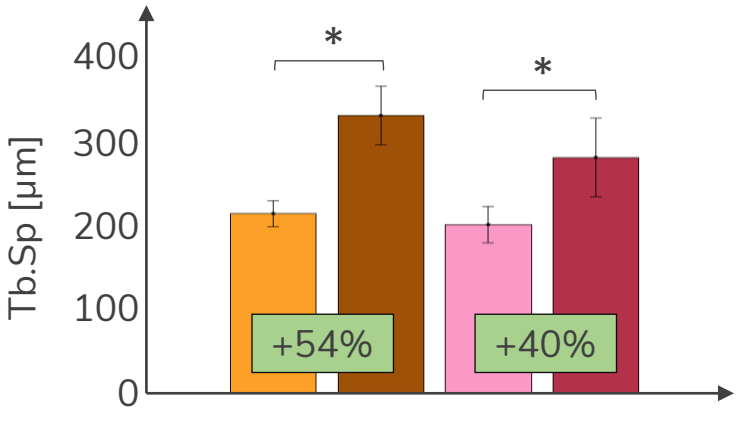
* Significant ($p<0.05$)

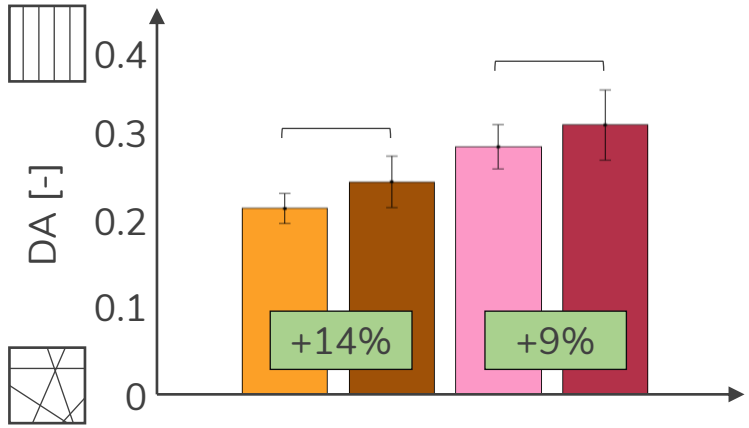
Comparison of lateral & medial regions in adults









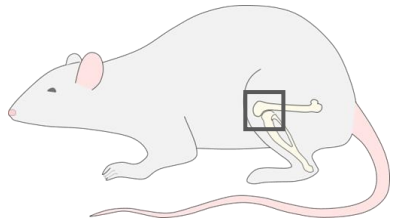


- Stronger changes in lateral
- Tb.Sp is the strongest change

→ Same trend, more marked for META (except for DA)

* Significant ($p<0.05$)

Methods – Thickness



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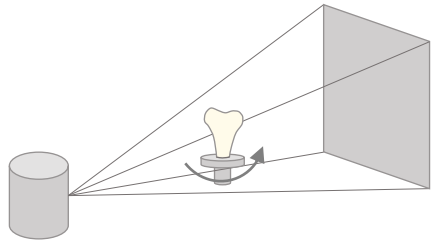

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KU LEUVEN

Image processing
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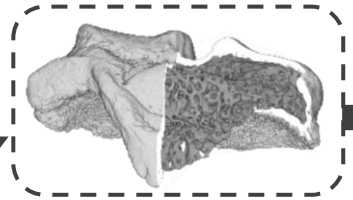
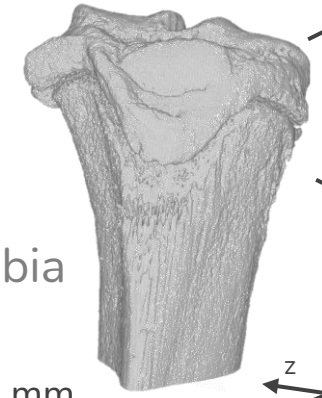
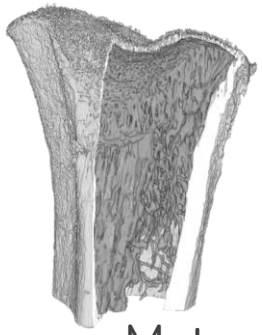
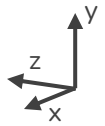
Epiphysis







Tibia



3 mm

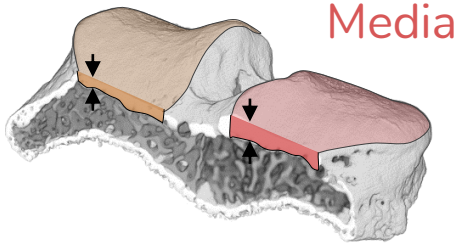
Metaphysis

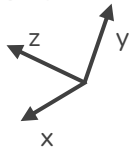
Avizo, CTAn

Thickness analysis
Subchondral mineralized tissue region (SM)

Lateral

Medial

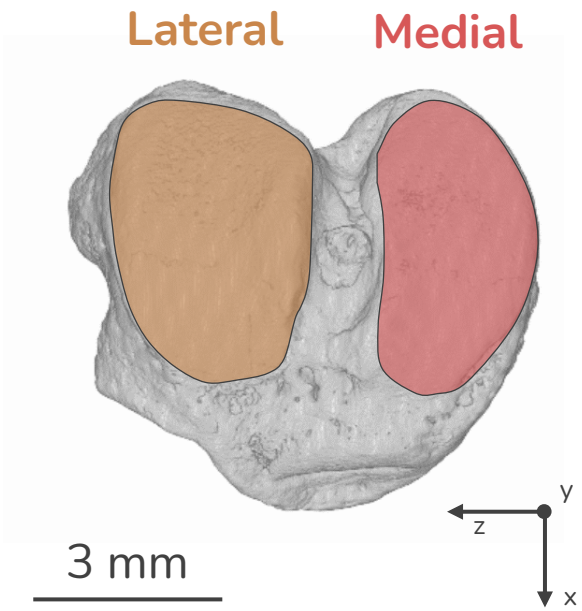


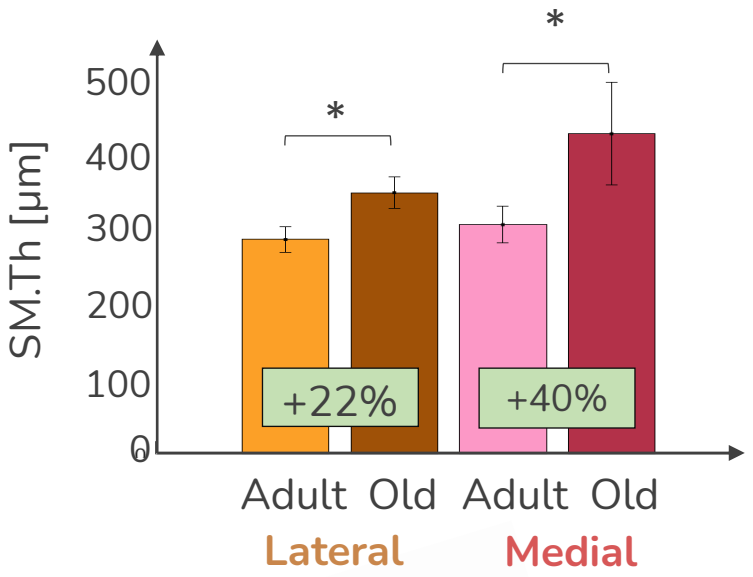


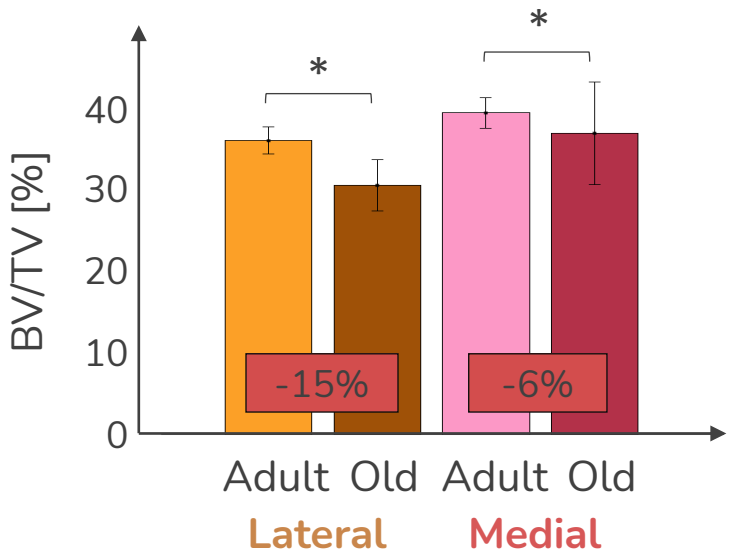
3 mm

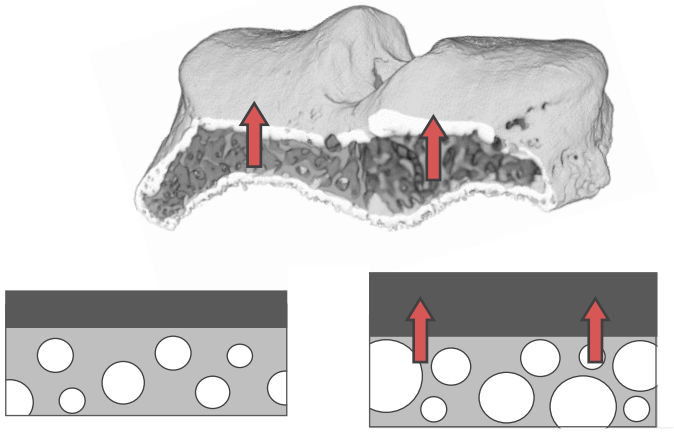
CTAn, ImageJ, Avizo

Mean thickness analysis





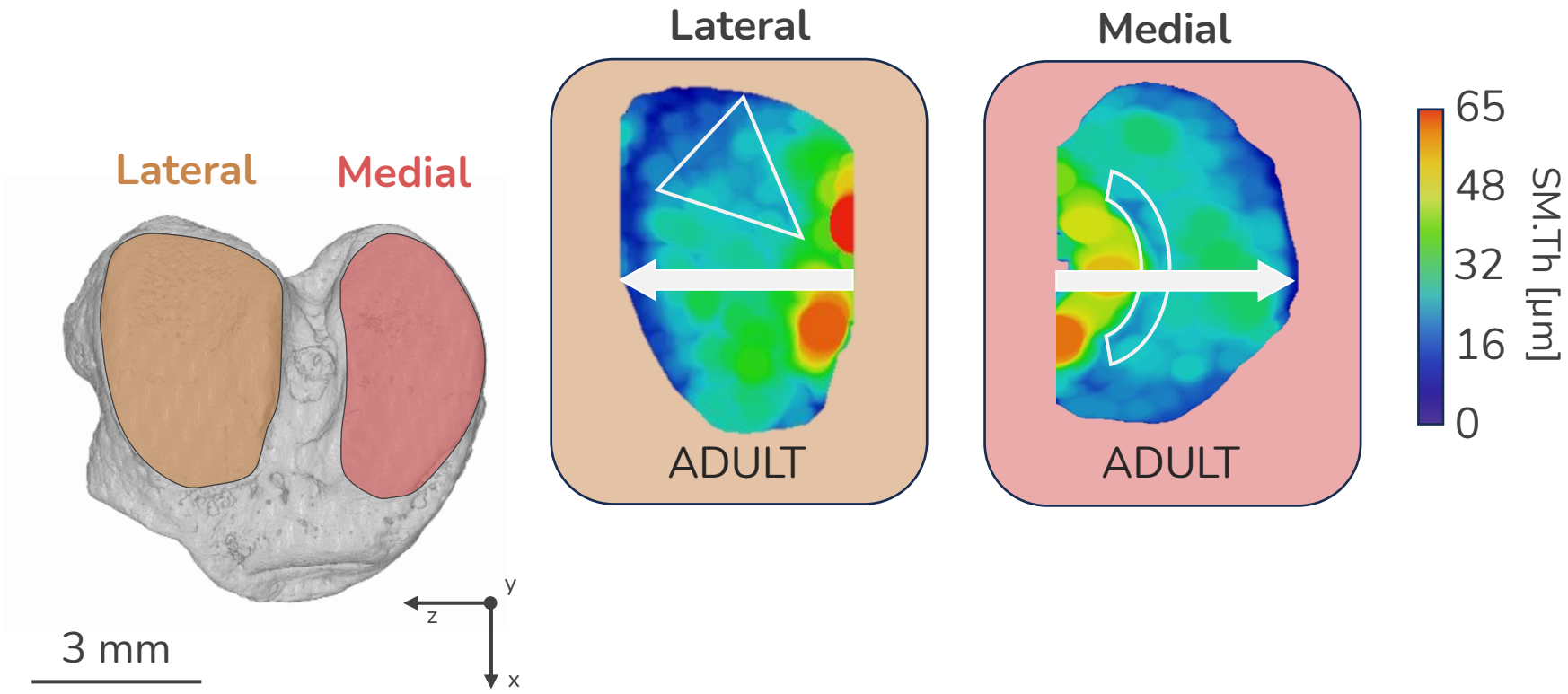




- SM thickness increases (doubles in the medial region)
- Opposite to the decrease of BV/TV

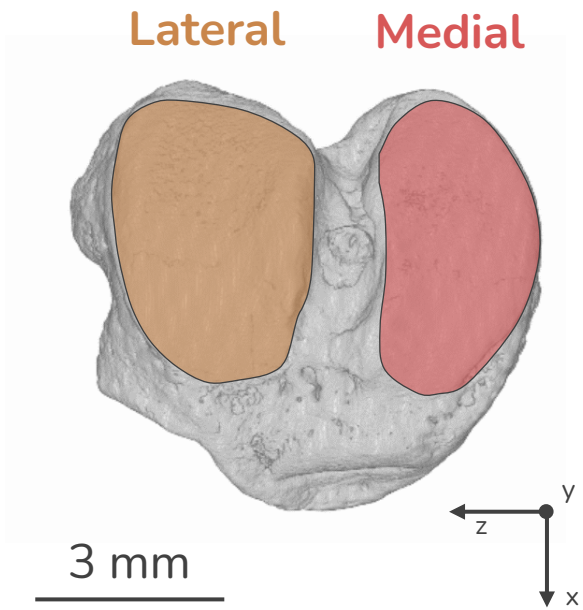
→ Impact on deformation mechanisms

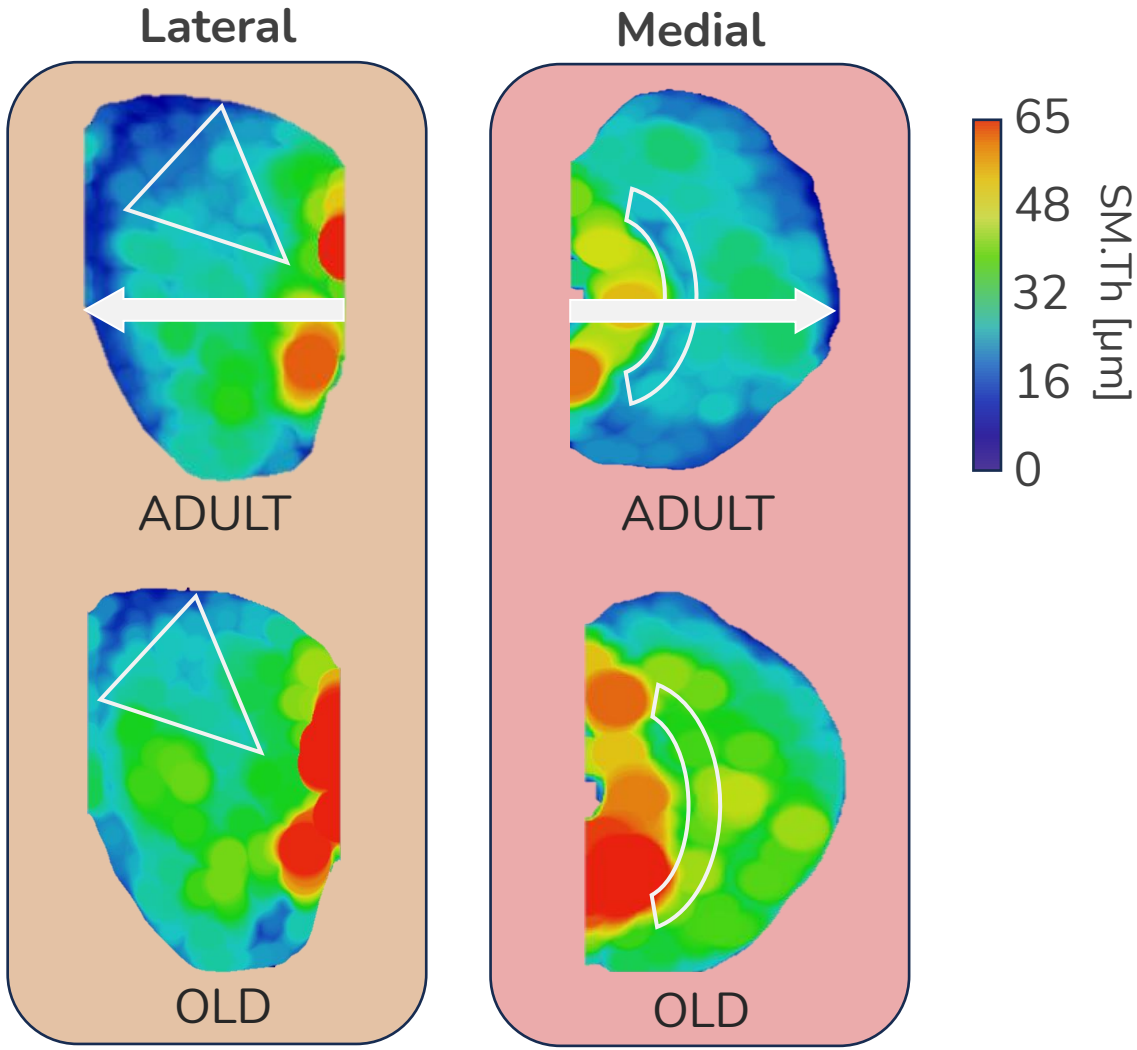
Thickness mapping in adults



Thickness decreases from the center to the border, gradually only in the lateral region

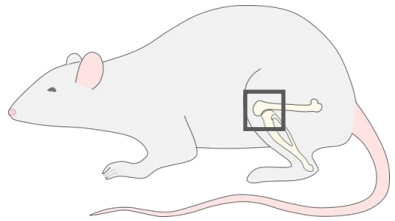
Thickness mapping in aging



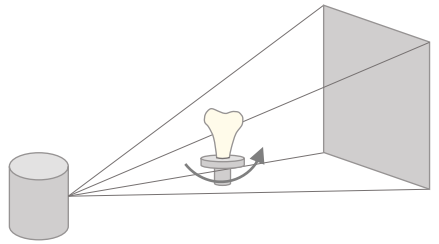


Proportional thickness increase in the lateral compartment

Methods - Curvature



Distal tibia extraction
Wistar rats
- ADULT 3 months (n=10)
- OLD 13 months (n=6)



Micro-computed tomography
(MicroCT) - SkyScan1272
10 µm

KU LEUVEN

Image processing
- Bone alignment
- Segmentation

Epiphysis

Tibia

Metaphysis

3 mm

Avizo, CTAn

Lateral

Medial

3 mm

CTAn, ImageJ, Avizo

Curvature analysis

5th degree polynomial in x and y

High

Low

K_1

K_2

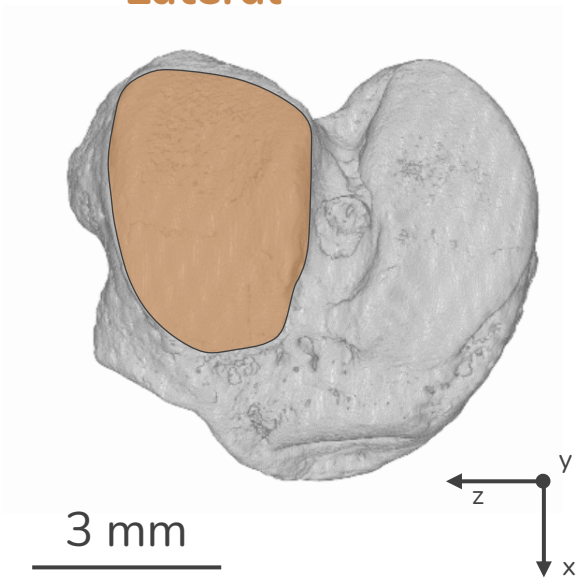
$K = K_1 . K_2$

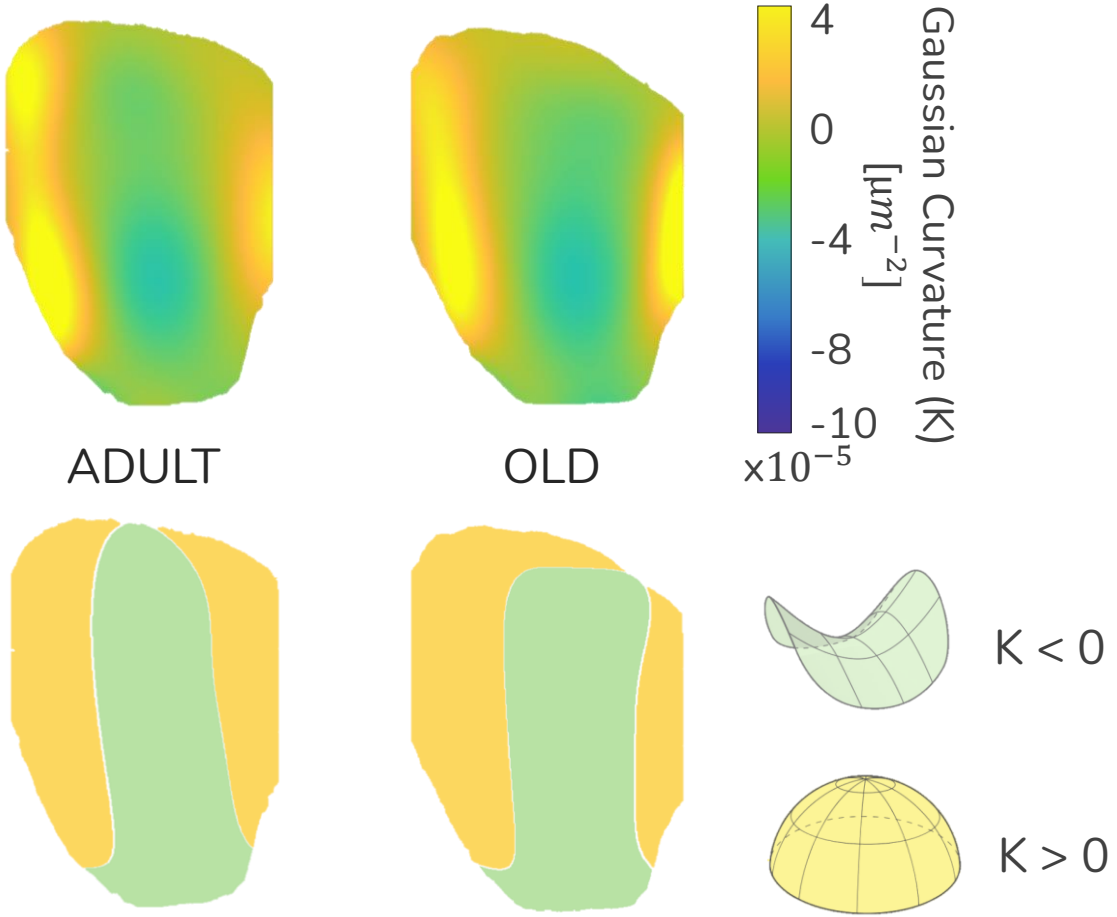
Gaussian curvature (K)

Matlab

Gaussian curvature mapping in lateral plateau

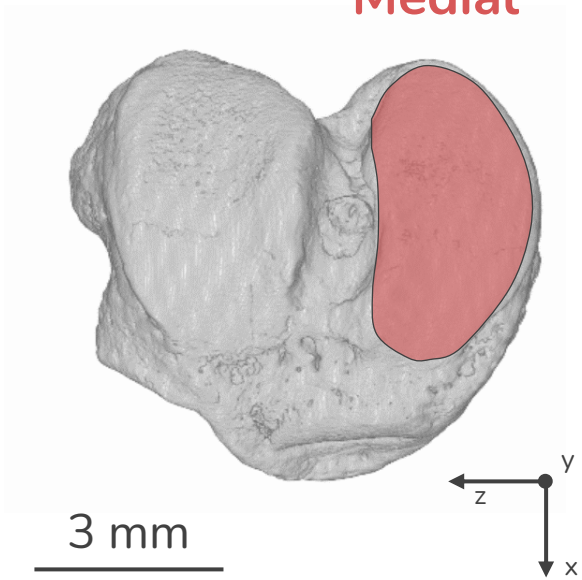
Lateral

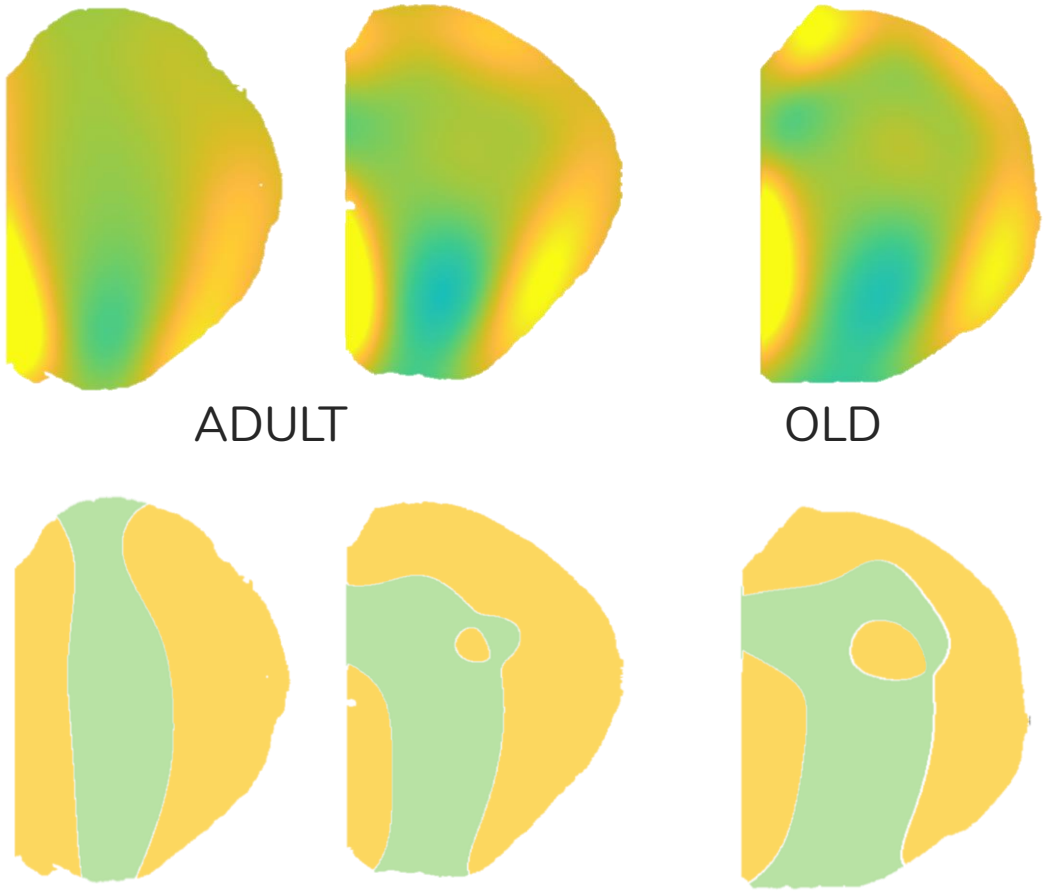


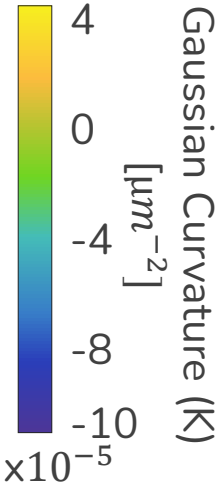


No striking changes with age

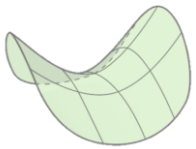
Gaussian curvature mapping in medial plateau







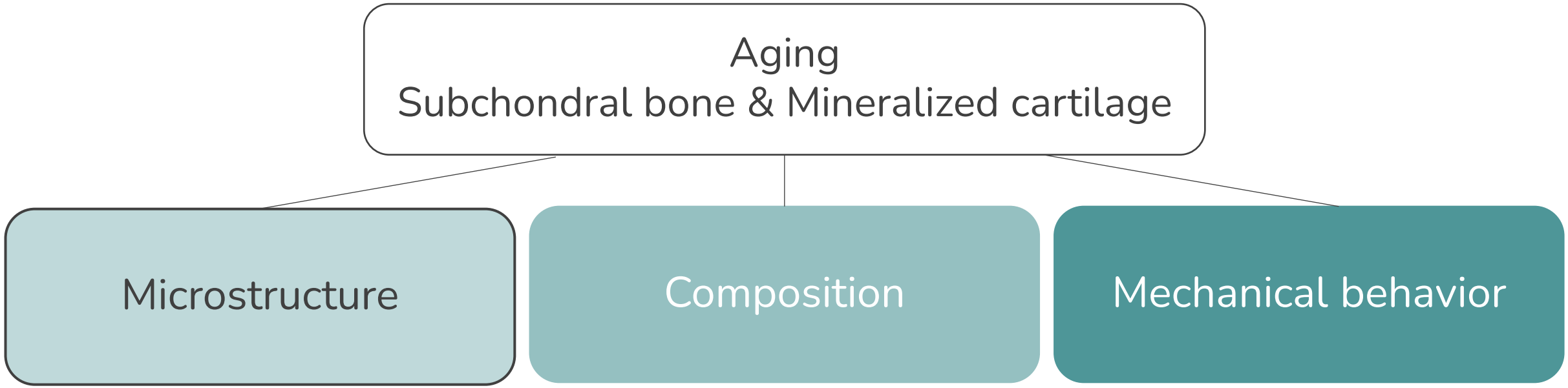
- 2 typical patterns in adult bone
- More pronounced changes with age



K < 0

K > 0

Conclusion & perspectives



Mineralized tissues change differently in the different regions & structures

Conclusion & perspectives

Aging
Subchondral bone & mineralized cartilage

Microstructure	Composition	Mechanical behavior
Higher resolution scans	**Mineral content**	**Load repartition**
MicroCT	Quantitative backscattered electron imaging	MicroCT & digital volume correlation
KU LEUVEN	LUDWIG BOLTZMANN INSTITUT Osteologie	University of Sheffield
		Mechanical properties
		Nanoindentation

Thanks to all co-authors!

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Thank you for your attention!

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