A New Quantitative Approach for Measuring Changes of 3D Structures in Trabecular Bone

Norbert Marwan

Peter Saparin, Jesper S. Thomsen, Jürgen Kurths

Nonlinear Dynamics Group University of Potsdam
MPI Colloids and Interfaces Golm
Århus University

MAP AO-099-030
contract #14592

Problem

Bone Loss in Space

- bone loss in space: 1.5% per month
- 2nd important problem after radiation

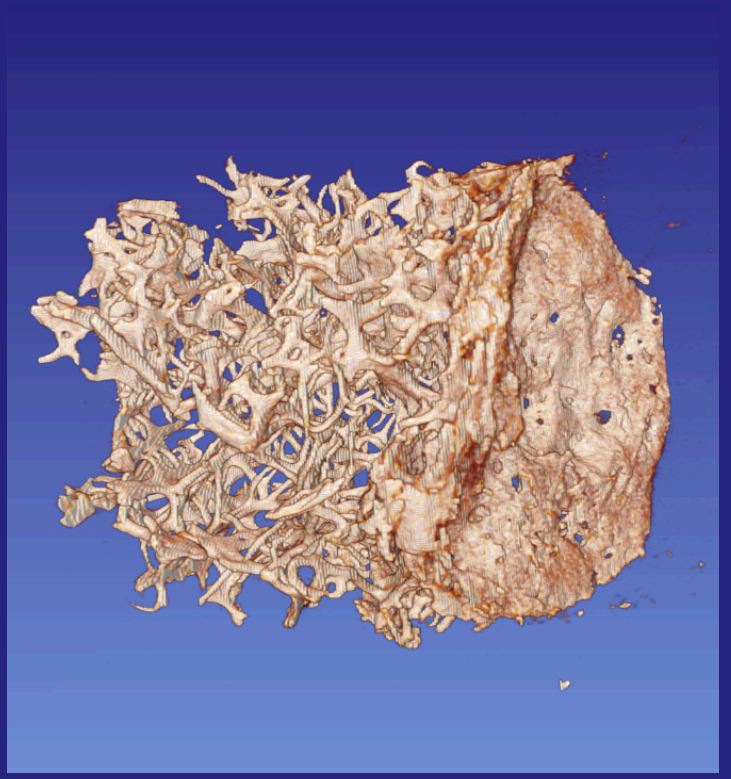
✦ monitoring bone alterations during space flights

Trabecular Bone Structure

- plays important role for bone strength
- changes during development of osteoporosis or in micro-gravity

Purpose of this Study

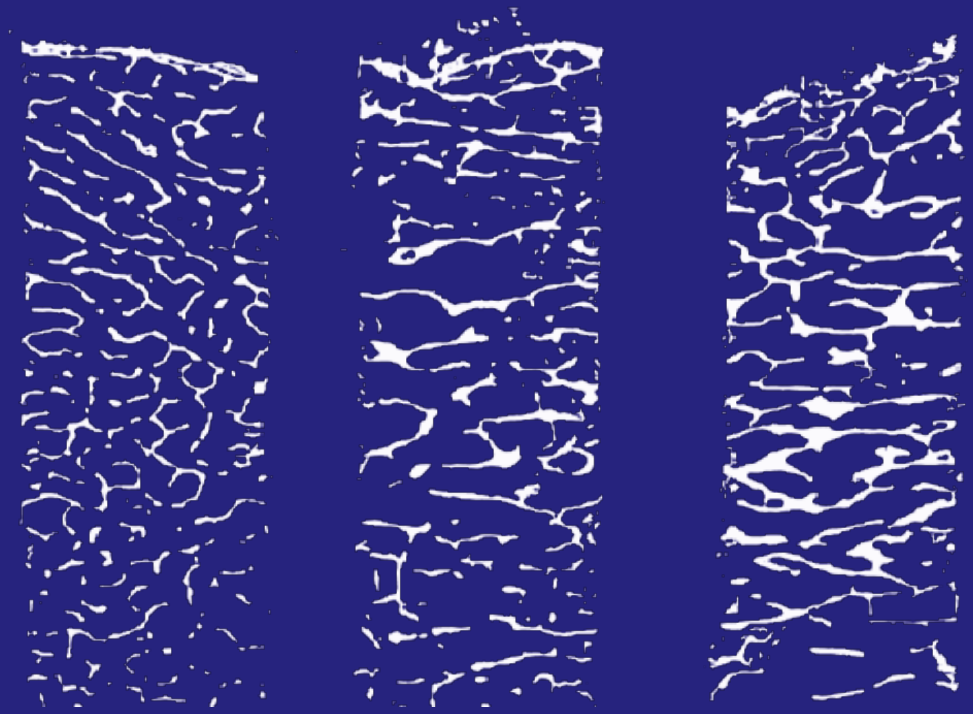
- define measures of complexity for 3D
- quantification of micro-architecture of trabecular bone (3D μCT)
- osteoporosis used as a model for bone loss in micro-gravity



Structural Quantification

Histomorphometry

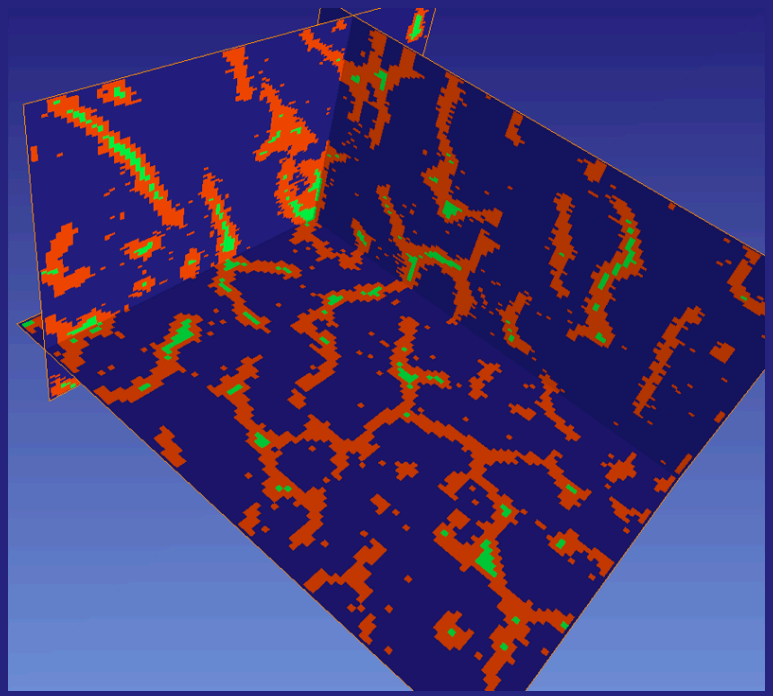
- "gold standard"
- invasive method



Structural Quantification

Measures of Complexity

- three symbols
- marrow (blue)
- internal bone (green)
- surface (red)



Structural Quantification

Measures of Complexity (cont.)

- 3D Normalised Entropy (NormEnt)
- Structure Complexity Indices ($SCI_{BV/TV}$, SCI3D)
- Surface Complexity Index (SurfCI)

Saparin, et al: Quantification of spatial structure of human proximal tibial bone biopsies using 3D measures of complexity, Acta Astronautica, 56, 2005

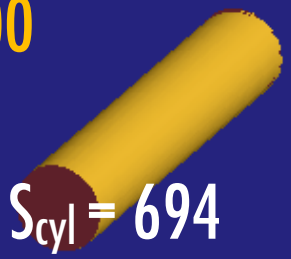
New Approach

3D Measures of Complexity

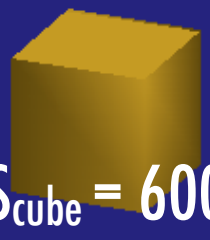
Shape Related Measures

- quantification of the 3D shape by volume and surface

V = 1000



$S_{cyl} = 694$



$S_{cube} = 600$

$S_{sph} = 484$

3D Measures of Complexity

Shape Related Measures

- Shape Index (SHI)

$$SHI = \frac{S_{\text{bone}}}{S_{\text{sphere}}} = \frac{S_{\text{bone}}}{\sqrt[3]{36\pi V_{\text{bone}}^2}}$$

- Averaged Shape Index (ASHI)

$$ASHI = \langle SHI_{\text{loc}} \rangle_{\text{VOI}}$$

3D Measures of Complexity

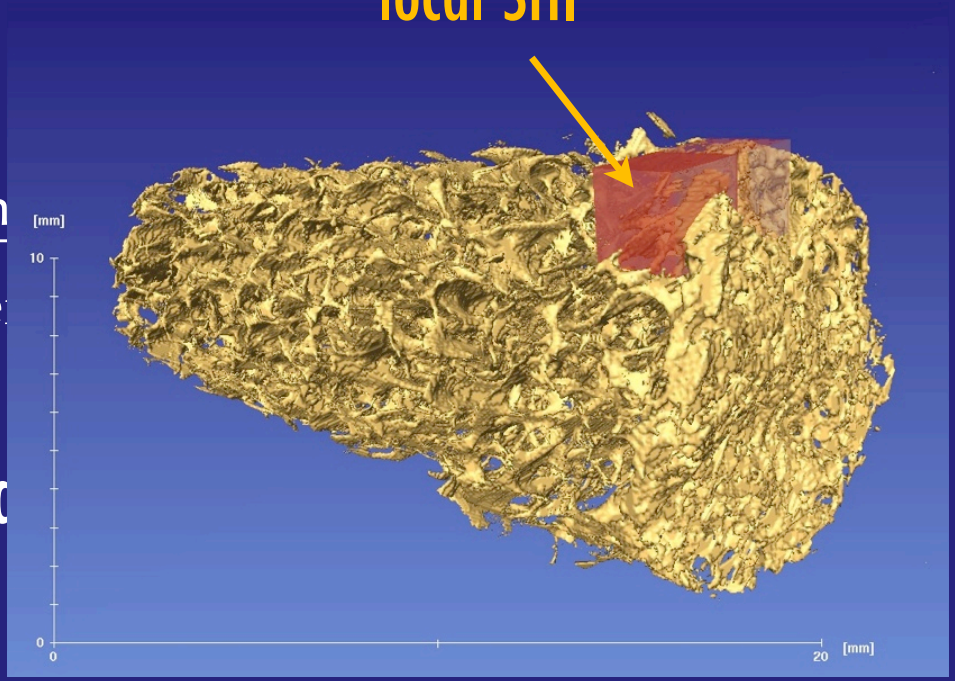
Shape Related Measures

- Shape Index (SHI)

$$SHI = \frac{S_{bon}}{S_{sphe}}$$

- Averaged Shape Inc

$$ASHI =$$



3D Measures of Complexity

Shape Related Measures

- Shape Complexity (SHC)

$$SHC = -\sum p(S_{\text{loc}}, V_{\text{loc}}) \log \frac{p(S_{\text{loc}}, V_{\text{loc}})}{p(V_{\text{loc}})}$$

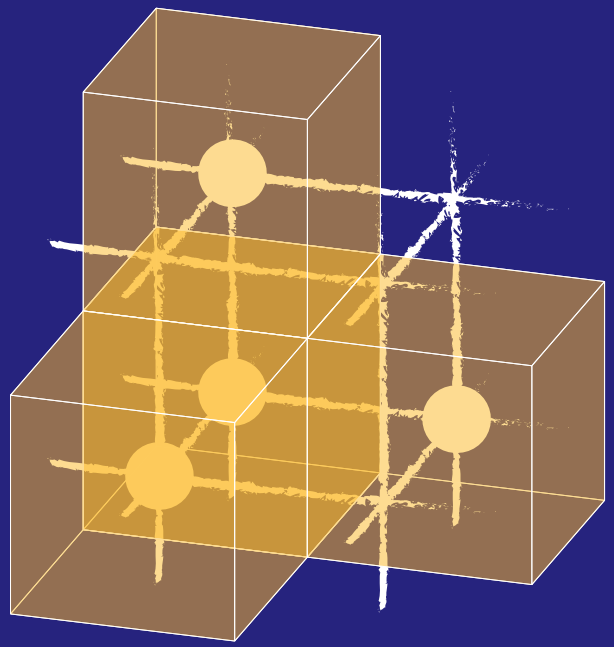
- Shape Index Entropy (ISHI)

$$ISHI = -\sum p(SHI_{\text{loc}}) \log p(SHI_{\text{loc}})$$

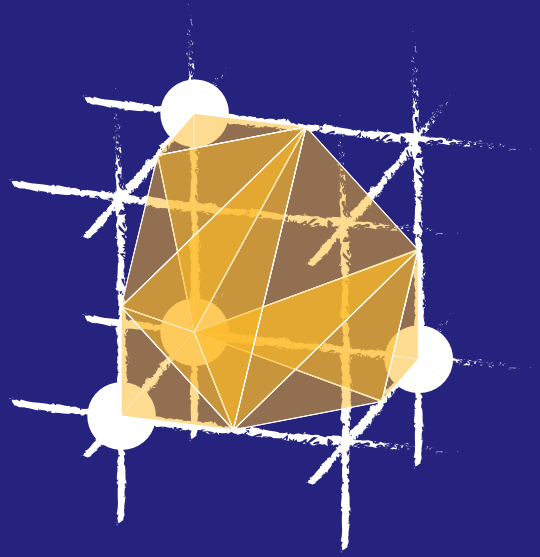
variability/ complexity of the shapes

3D Measures of Complexity

Volume and Surface Estimation



voxel counting

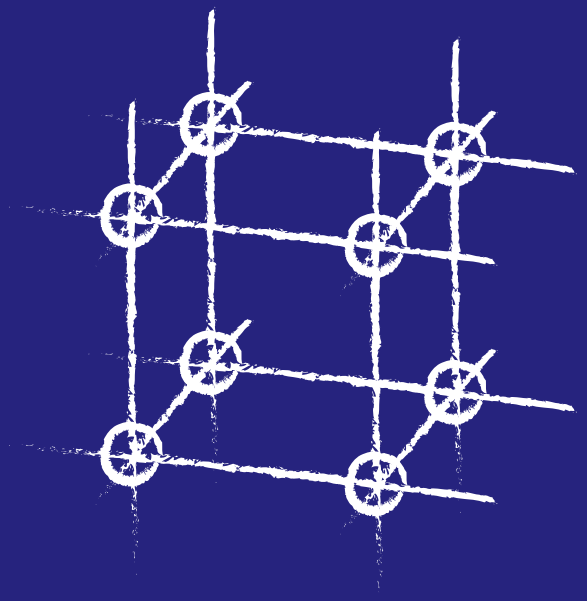


marching cube (MC)

3D Measures of Complexity

Marching Cubes

- eight voxels form a marching cube (MC)
- iso-surfaces
- 3D rendering



Lorensen, et al: Marching cubes, SIGGRAPH, 21, 1987

3D Measures of Complexity

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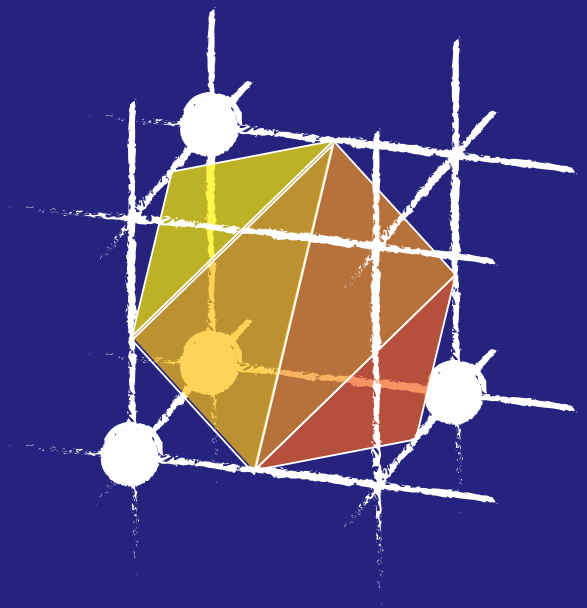
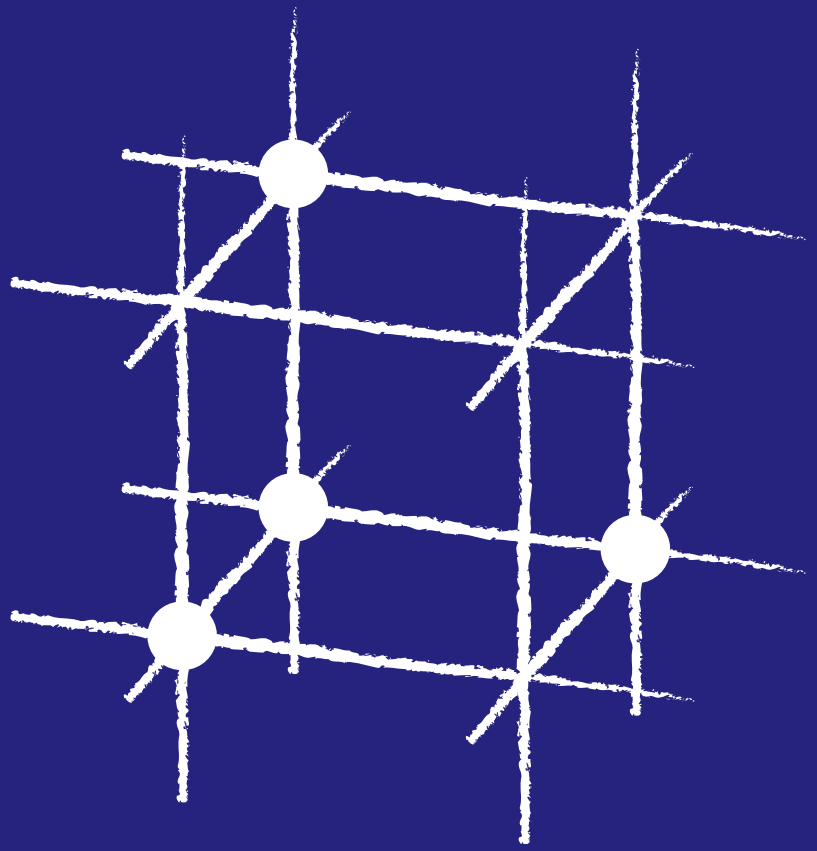


Lorensen, et al: Marching cubes, SIGGRAPH, 21, 1987

3D Measures of Complexity

Marching Cubes Filling (Volume Estimation)



3D Measures of Complexity

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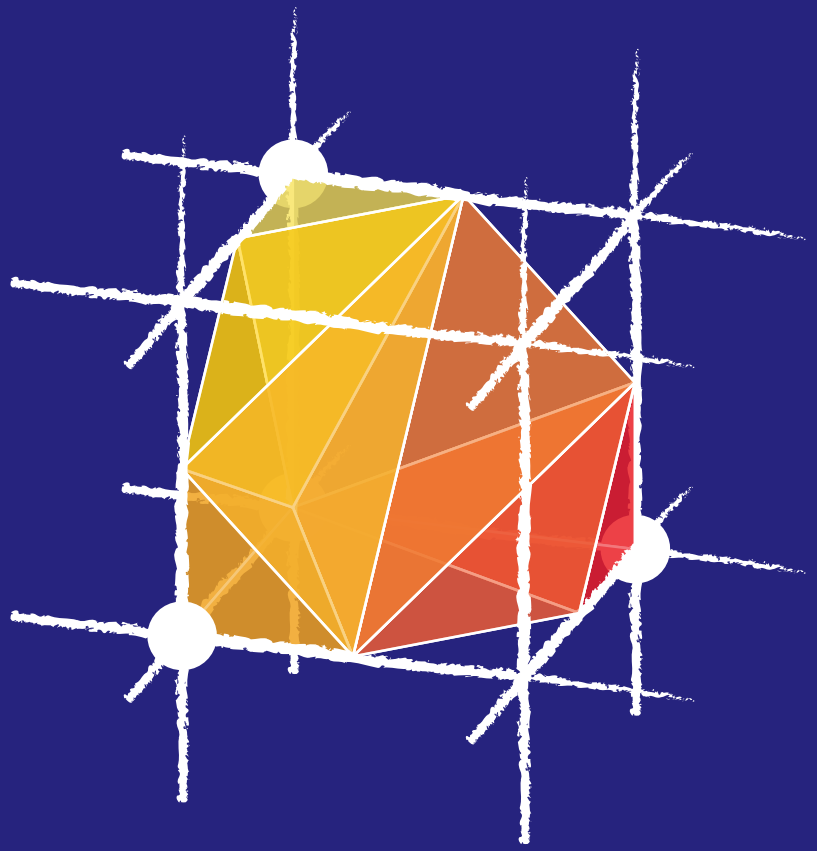
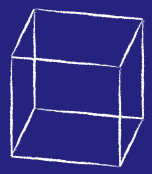


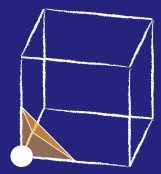
3D Measures of Complexity

Marching Cubes Cases

MC 0

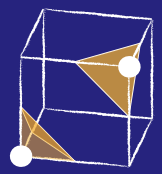


MC 1

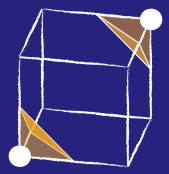


MC 2

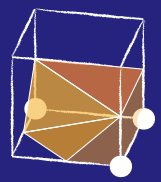
MC 3



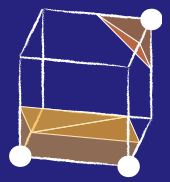
MC 4



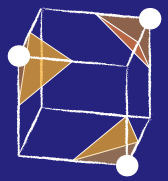
MC 5



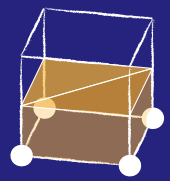
MC 6



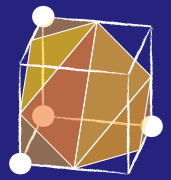
MC 7



MC 8



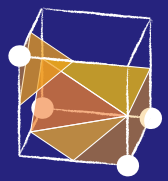
MC 9



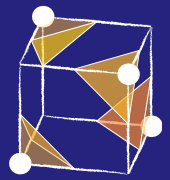
MC 10

MC 11

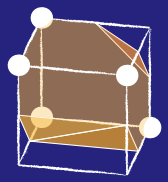
MC 12



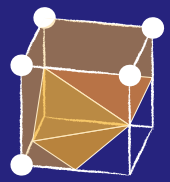
MC 13



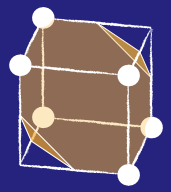
MC 14



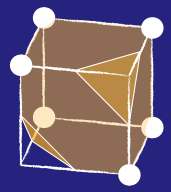
MC 15



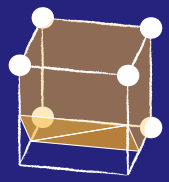
MC 16



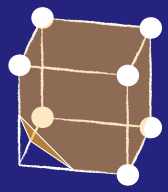
MC 17



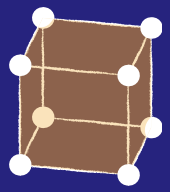
MC 18



MC 19



MC 20



3D Measures of Complexity

Marching Cubes Based Measures

- Marching Cubes Entropy Index MCE

$$MCE = -\sum p(MC) \log p(MC)$$

- Marching Cubes Complexity MCC

$$MCC = \langle N_{\text{tetra}} \rangle_{\text{VOI}}$$

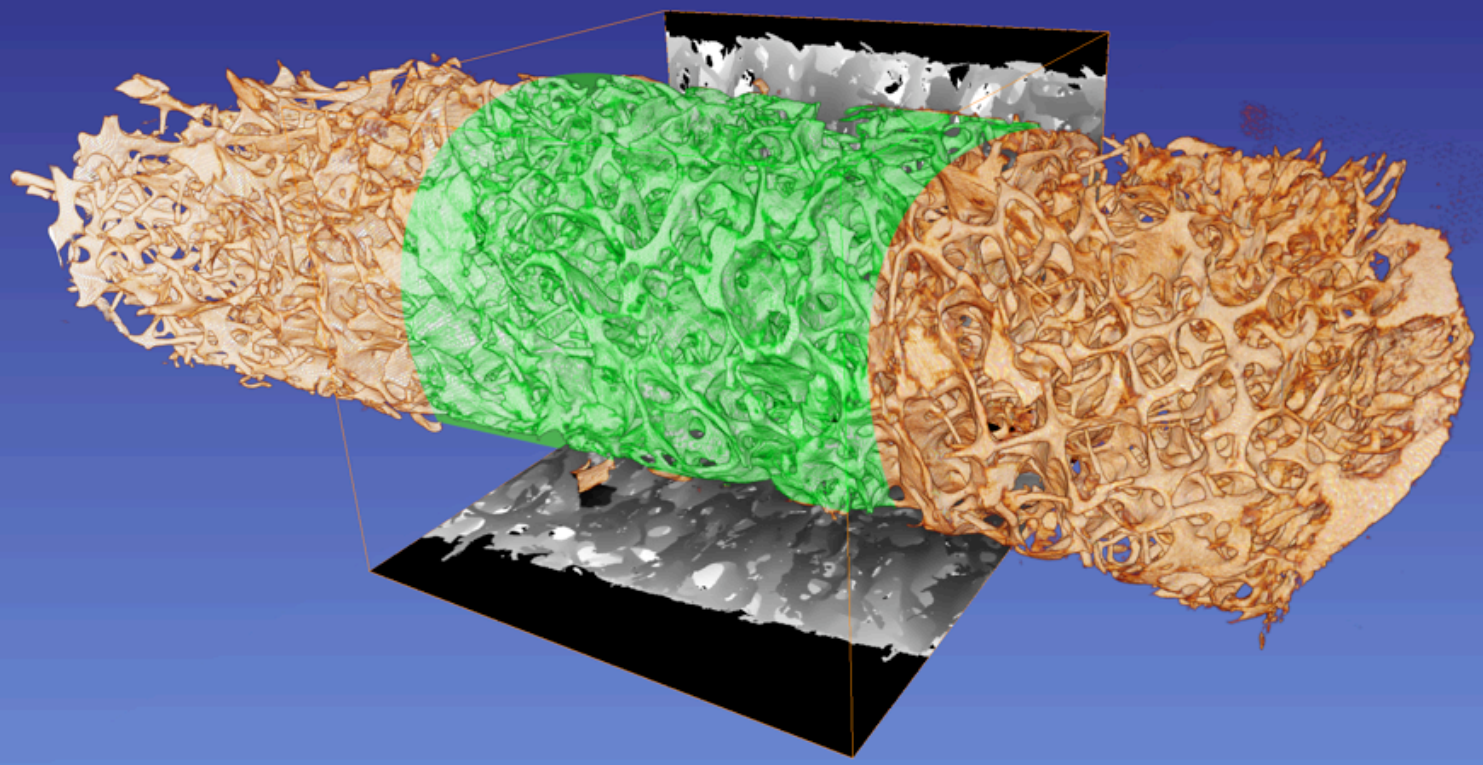
complexity of the surface

Data & Results

Proximal Tibia

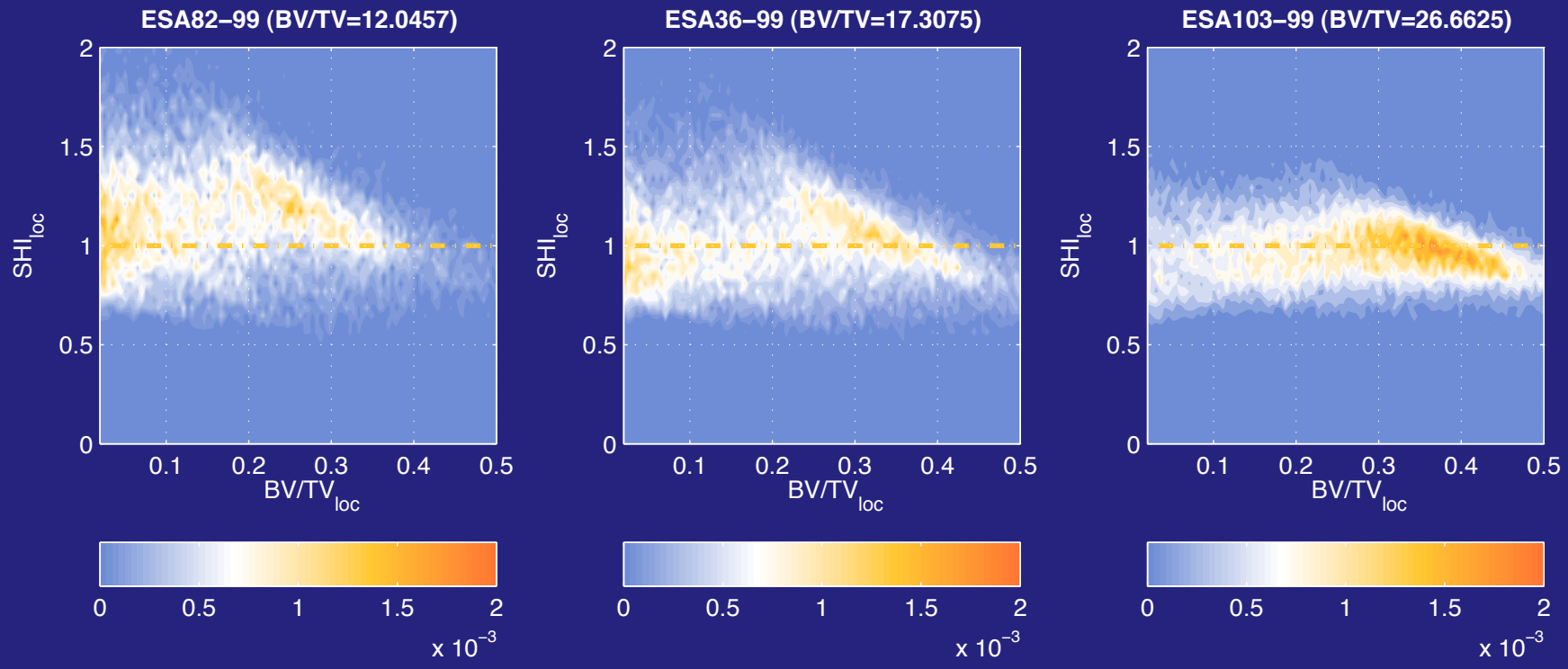
- cylindrical biospies
- 7 mm diameter
- 17 mm below tibial plateau
- 29 specimens
- VOI: 5 mm below cortical shell, 10 mm long

Proximal Tibia



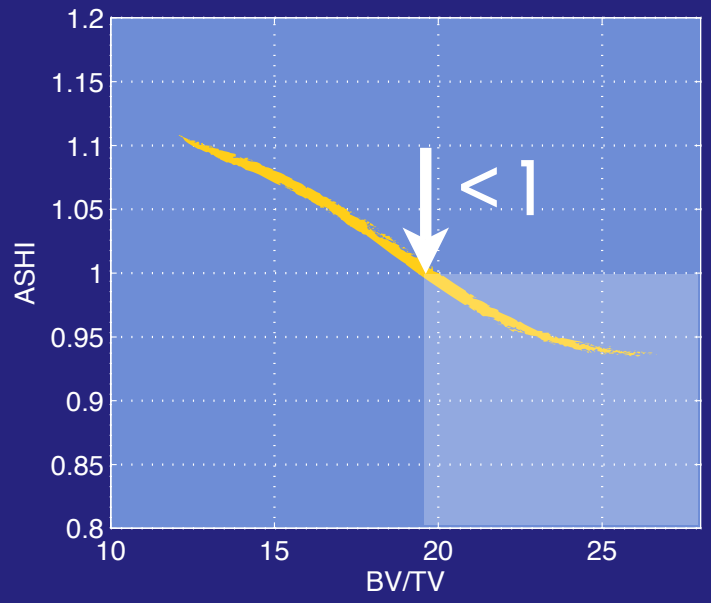
Shape Index Distribution

- concave structures

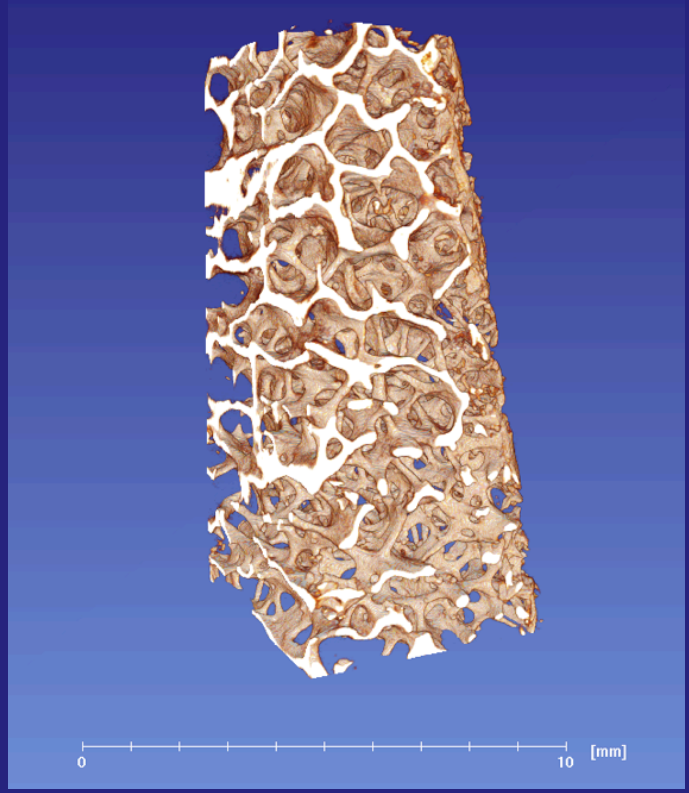


Shape Index

- correlation with bone density

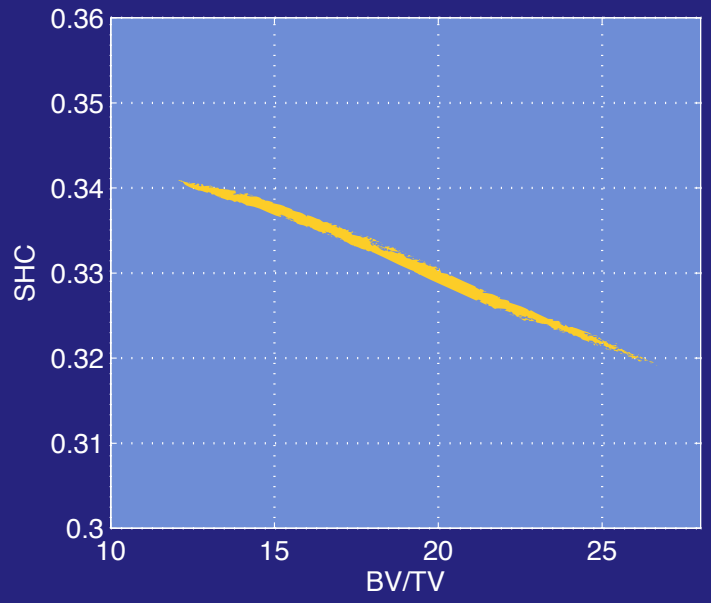


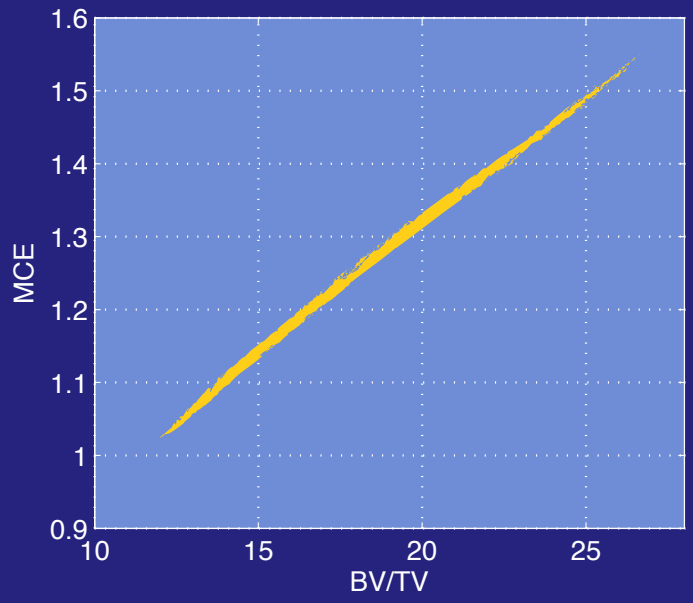
concave structures



Bone Volume Fraction

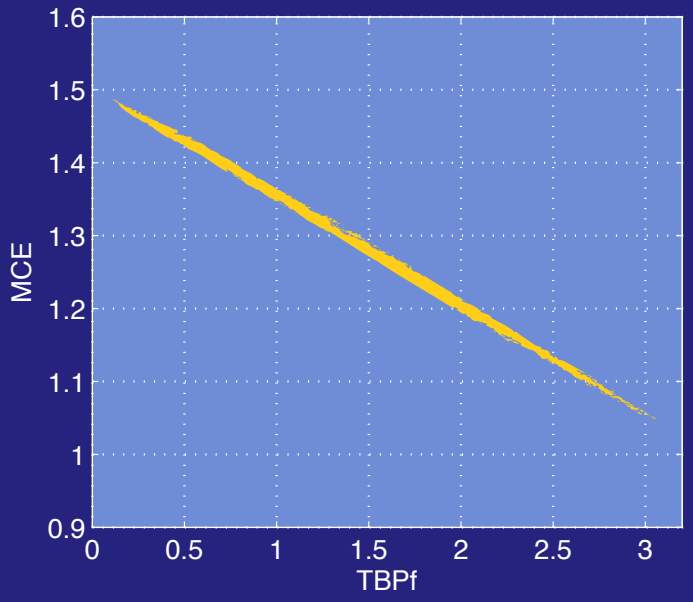
- correlation with SHC and MCE

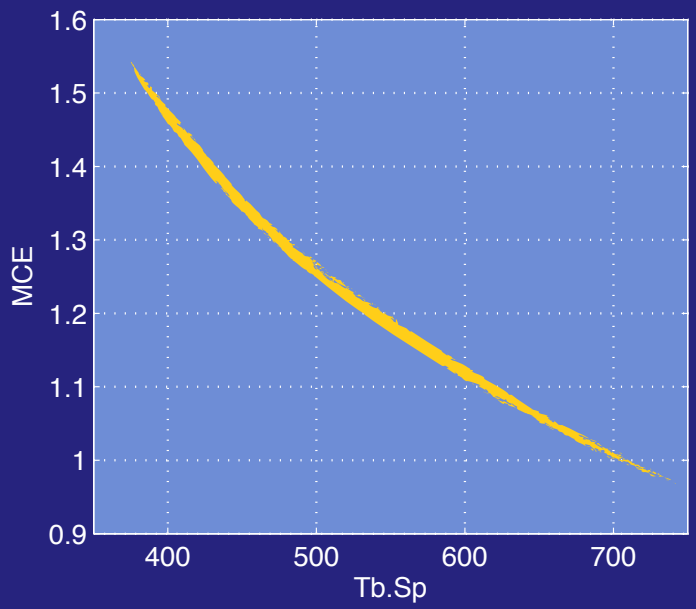




MC Entropy

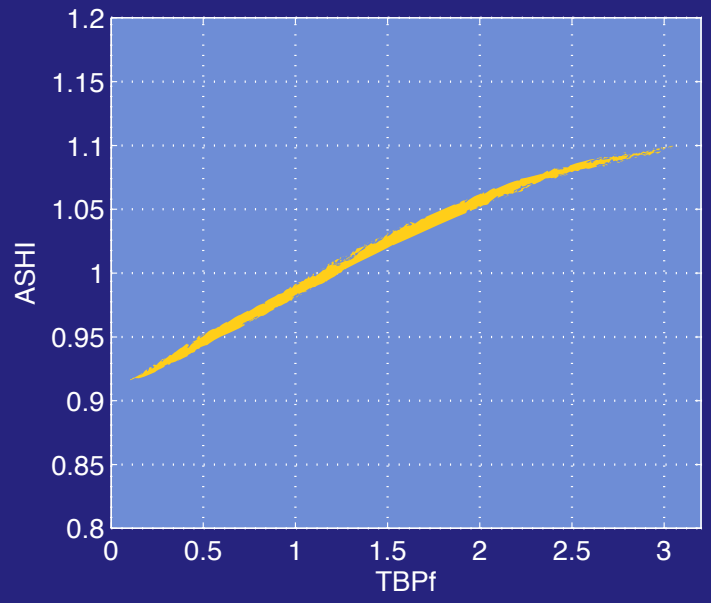
- correlation with TBPf and Tb.Sp

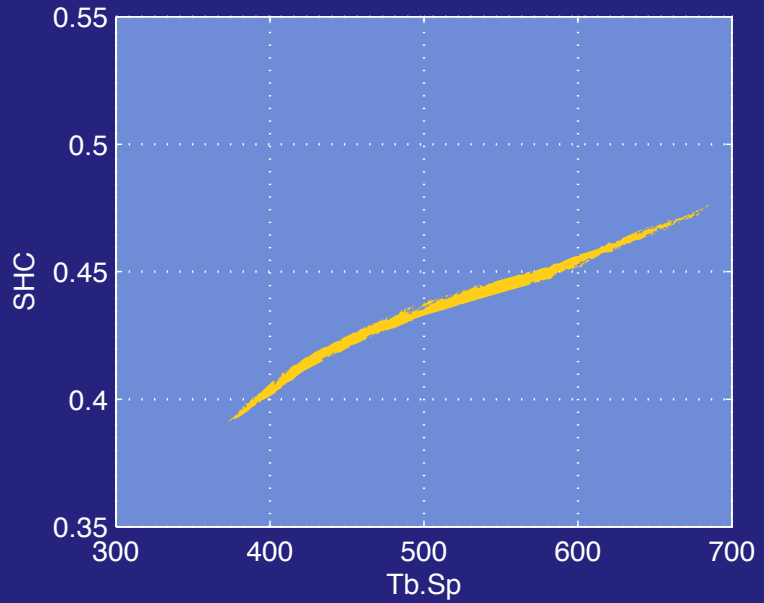




Histomorphometry

- correlation with MCE, ASHI and SHC



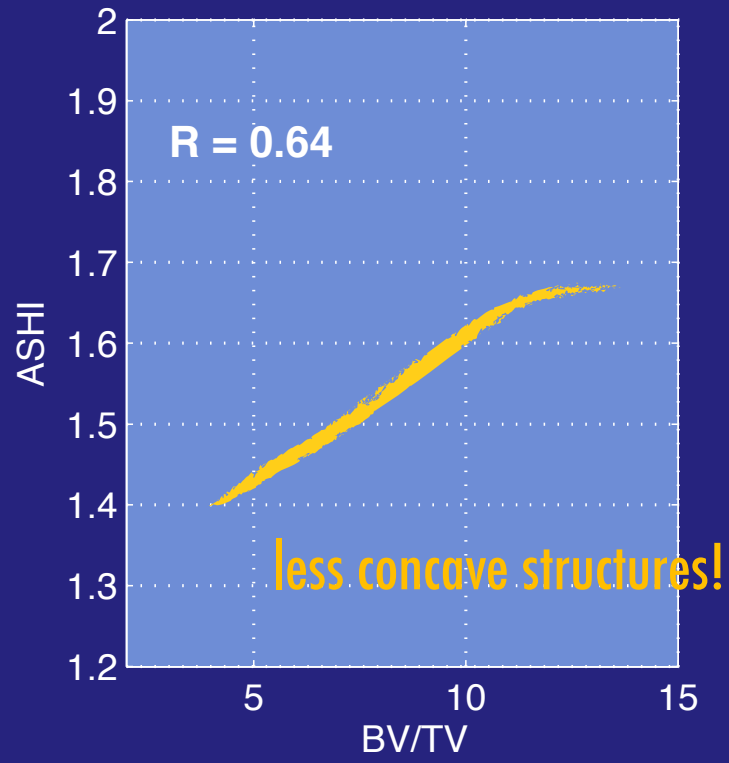


Rank Correlation

	ASHI	ISHI	SHC	MCE
3D BV/TV	−0.74		−0.72	0.87
TBPf	0.66		0.63	−0.88
Nd/Tm	−0.68		−0.63	0.68
Tb.Sp	0.50	0.51	0.66	−0.68

Lumbar Vertebra

- confirmation of results



Conclusion

Conclusions

- measures of complexity for 3D image analysis
- quantify 3D micro-structure of trabecular bone
- bone loss (proximal tibia):
  - complexity of bone surface decreases
  - amount of concave structures decreases
  - variation of the trabecular' shapes increases

Conclusions

- potential applications:
  - quantification of bone loss in micro-gravity
  - diagnostics of pathological changes in bone structure in patients on Earth
  - evaluation of medical treatment results