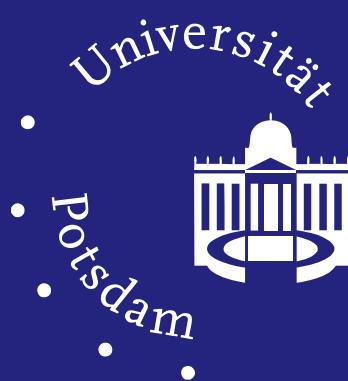# A New Quantitative Approach for Measuring Changes of 3D Structures in Trabecular Bone

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

eesa

MAP AO-099-030
contract #14592

Montag, 3. März 2014

Problem

Bone Loss in Space

© Courtesy of NASA, 2005

Bone Loss in Space

- bone loss in space: 1.5% per month

© Courtesy of NASA, 2005

Bone Loss in Space

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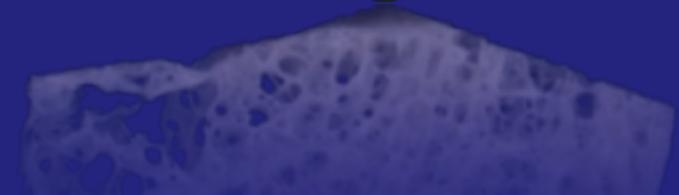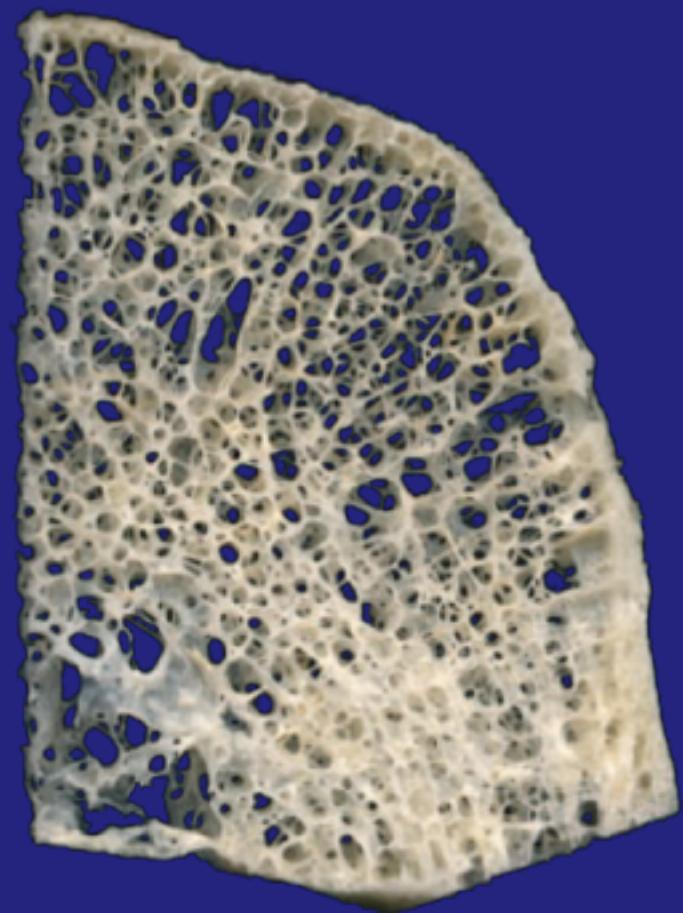

© Courtesy of NASA, 2005

Bone Loss in Space

- bone loss in space: 1.5% per month
- 2nd important problem after radiation
- ✦ monitoring bone alterations during space flights
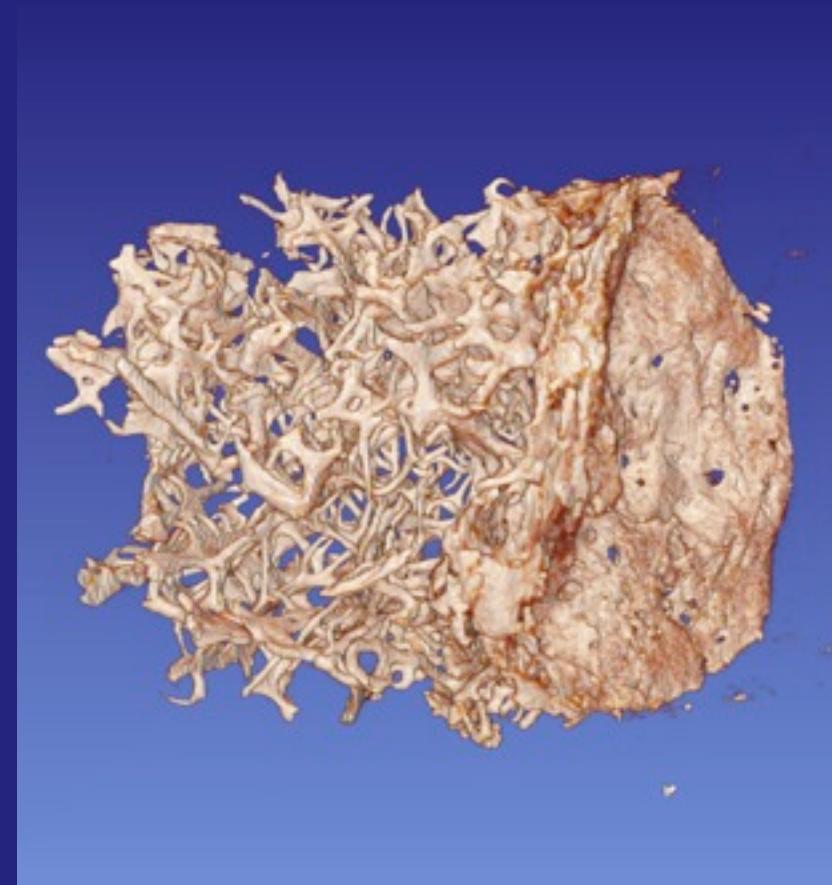

© Courtesy of NASA, 2005

Trabecular Bone Structure

- plays important role for bone strength

- changes during development of osteoporosis or in micro-gravity
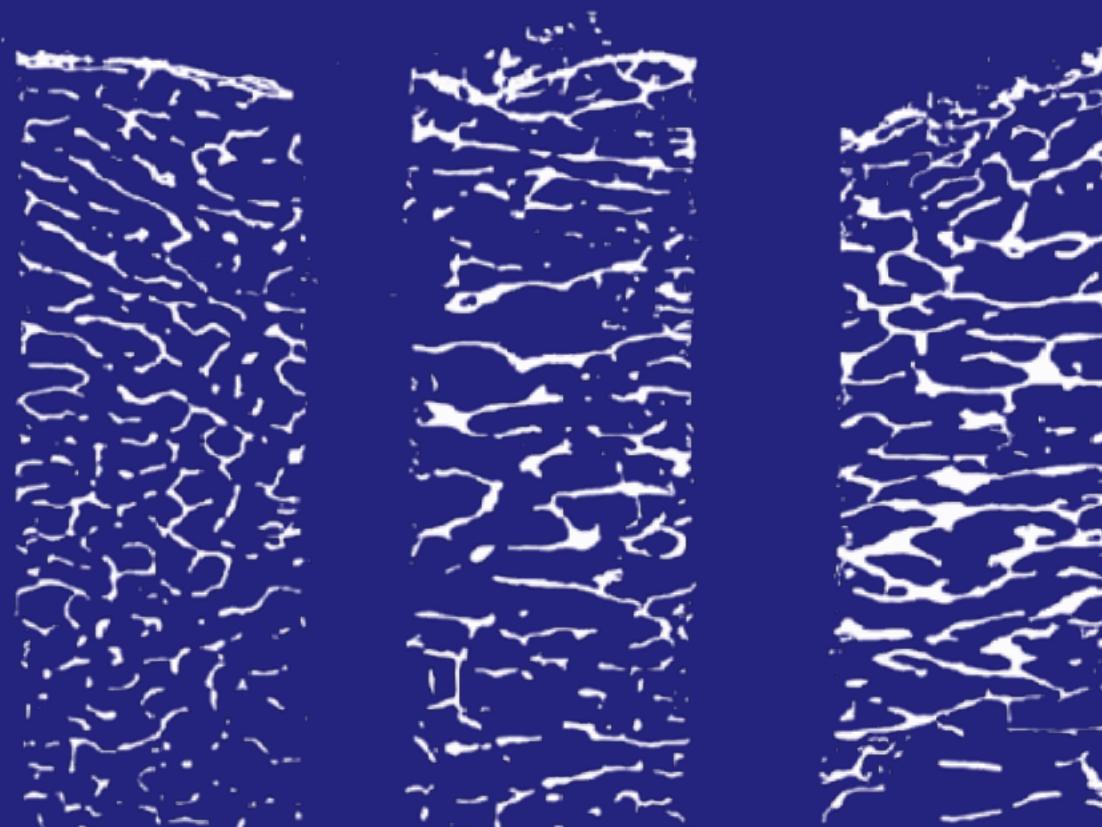
Purpose of this Study

- 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
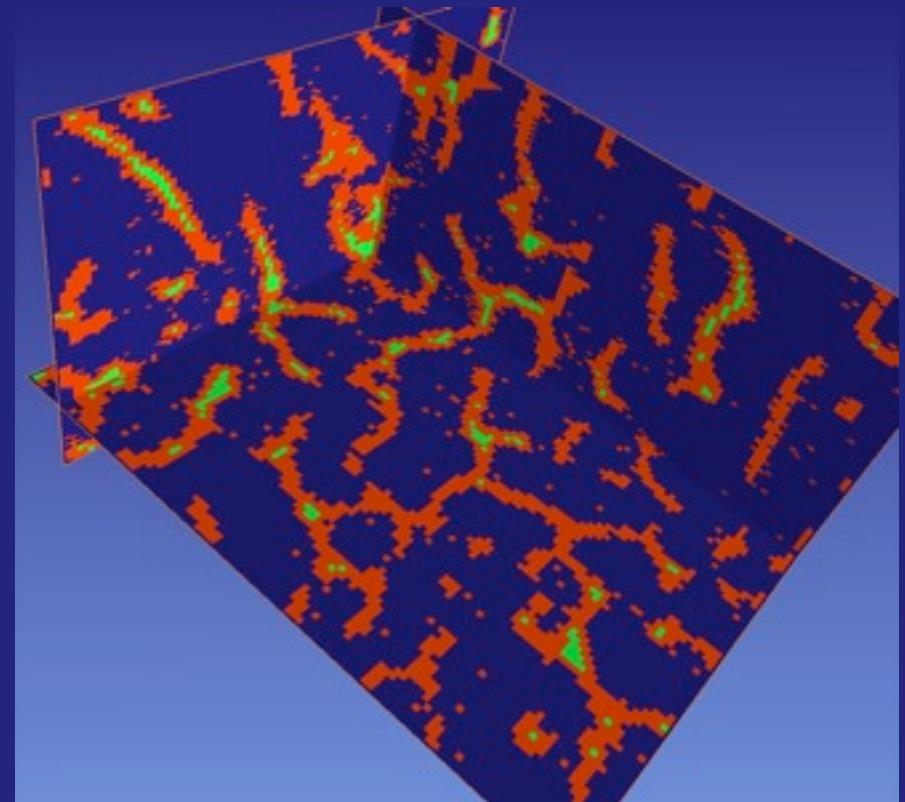
Structural Quantification

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)
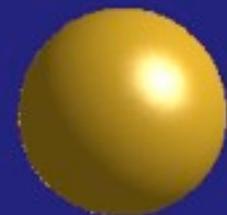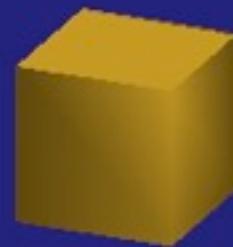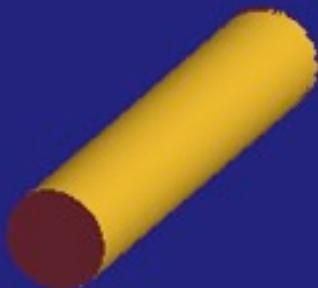
- Surface Complexity Index (SurfCI)

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

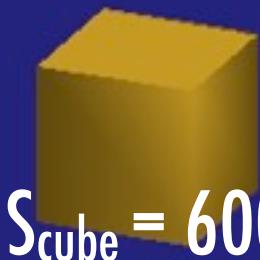- quantification of the 3D shape by volume and surface

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)

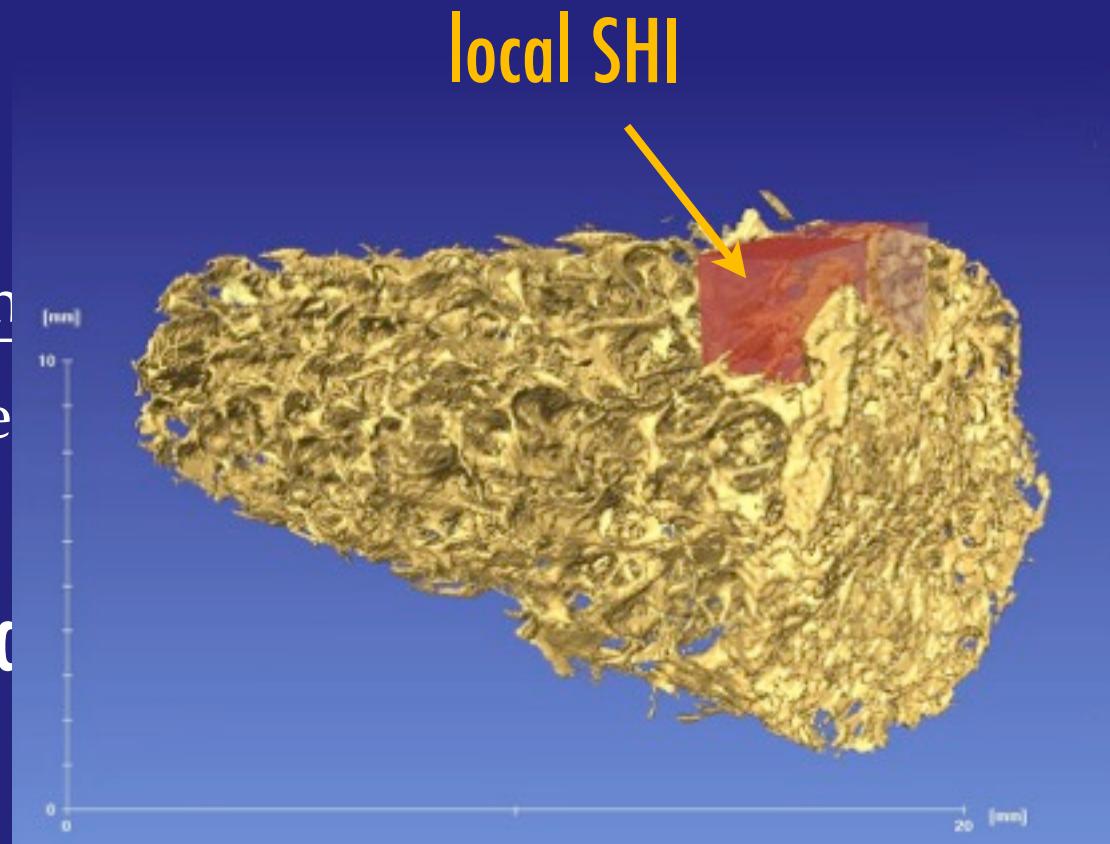$$ASHI = \langle SHI_{\text{loc}} \rangle_{\text{VOI}}$$

3D Measures of Complexity

Shape Related Measures

- ## Shape Index (SHI)

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

- ## Averaged Shape Ind

$$ASHI =$$

local SHI

3D Measures of Complexity

Shape Related Measures

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$$ASHI = \langle SHI_{\mathrm{loc}} \rangle \mathrm{VOI}$$

3D Measures of Complexity

Shape Related Measures

- ## Shape Complexity (SHC)

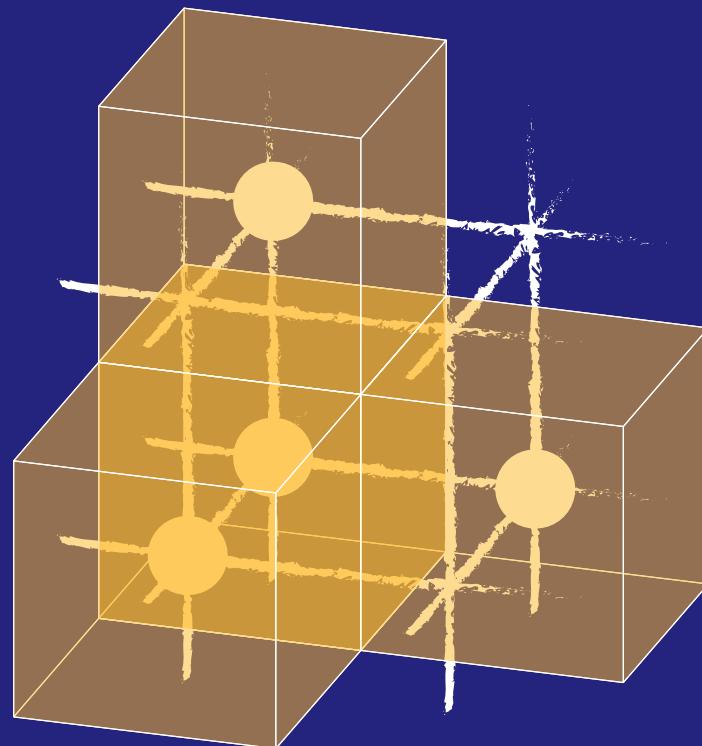$$SHC = -\sum p(S_{\text{loc}}, V_{\text{loc}}) \log \frac{p(S_{\text{loc}}, V_{\text{loc}})}{p(V_{\text{loc}})}$$

- ## Shape Index Entropy (ISHI)

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

3D Measures of Complexity

Shape Related Measures

- ## Shape Complexity (SHC)

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

- ## Shape Index Entropy (ISHI)

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

variability/ complexity of the shapes

3D Measures of Complexity

Volume and Surface Estimation

voxel counting
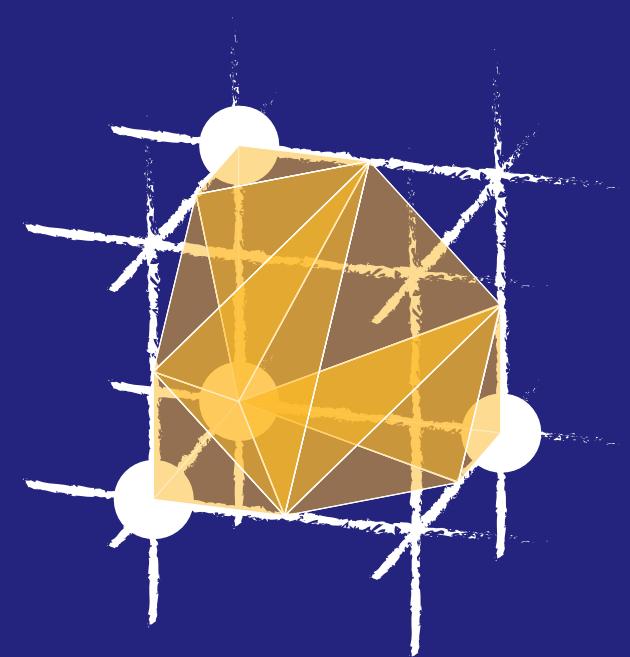
marching cube (MC)

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

Marching Cubes

- eight voxels form a marching cube (MC)

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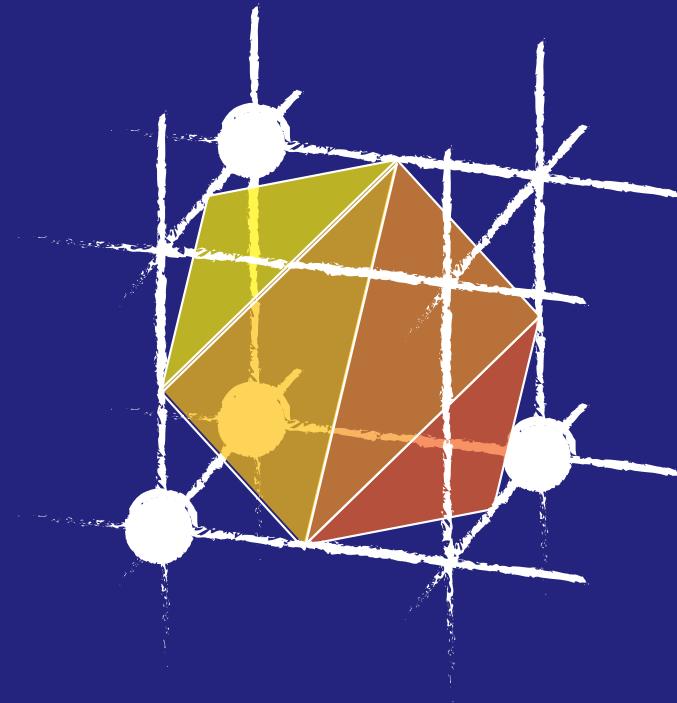
Lorensen, et al: Marching cubes, SIGGRAPH, 21, 1987

3D Measures of Complexity

Marching Cubes Filling (Volume Estimation)

3D Measures of Complexity

Marching Cubes Filling (Volume Estimation)

3D Measures of Complexity

Marching Cubes Filling (Volume Estimation)
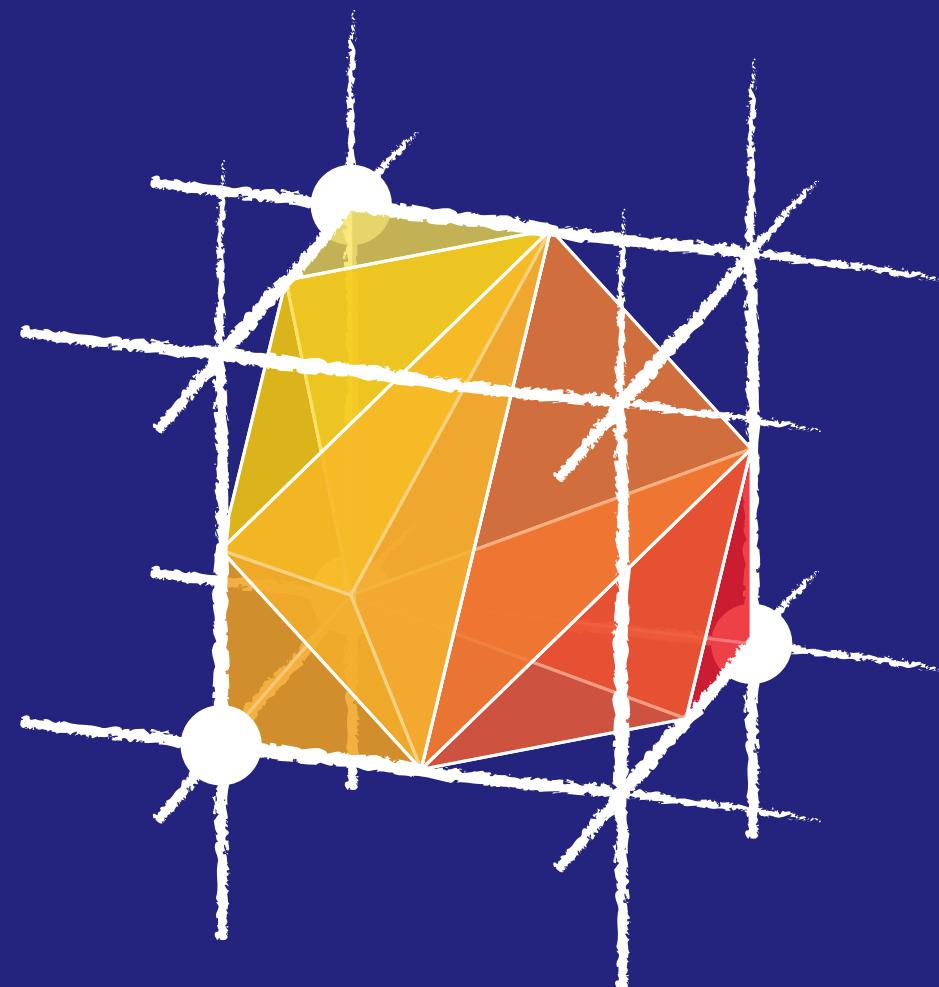
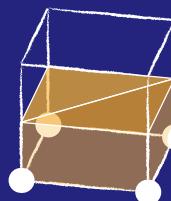# 3D Measures of Complexity

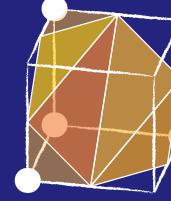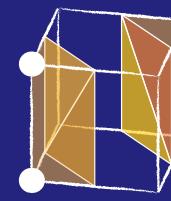## Marching Cubes Cases
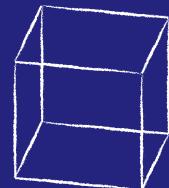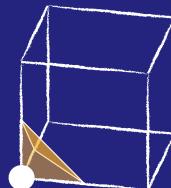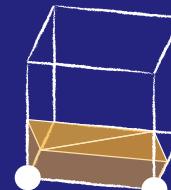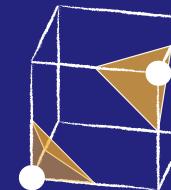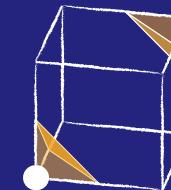
MC 0   MC 1   MC 2   MC 3   MC 4   MC 5   MC 6
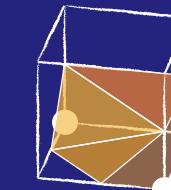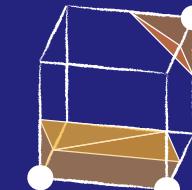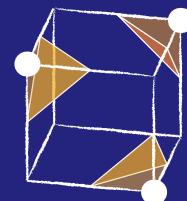
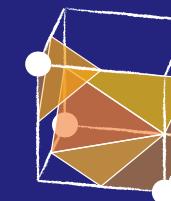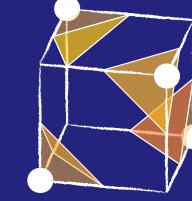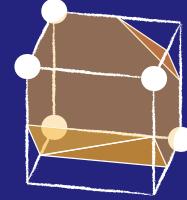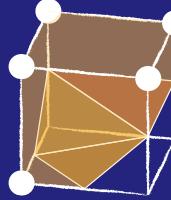MC 7   MC 8   MC 9   MC 10   MC 11   MC 12   MC 13
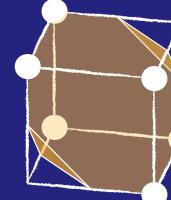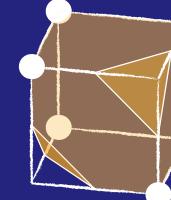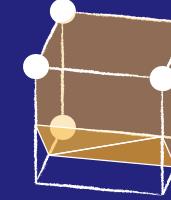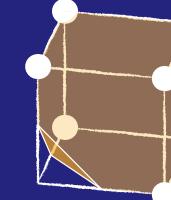
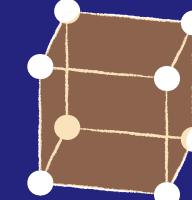MC 14   MC 15   MC 16   MC 17   MC 18   MC 19   MC 20

3D Measures of Complexity

Marching Cubes Based Measures

- **Marching Cubes Entropy Index MCE**

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

- **Marching Cubes Complexity MCC**

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

3D Measures of Complexity

Marching Cubes Based Measures

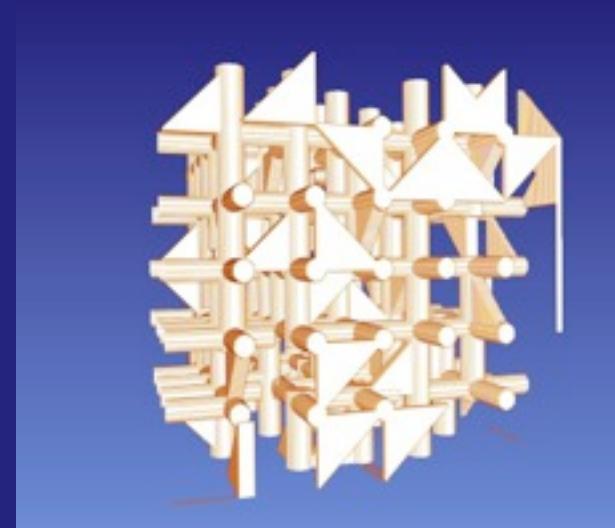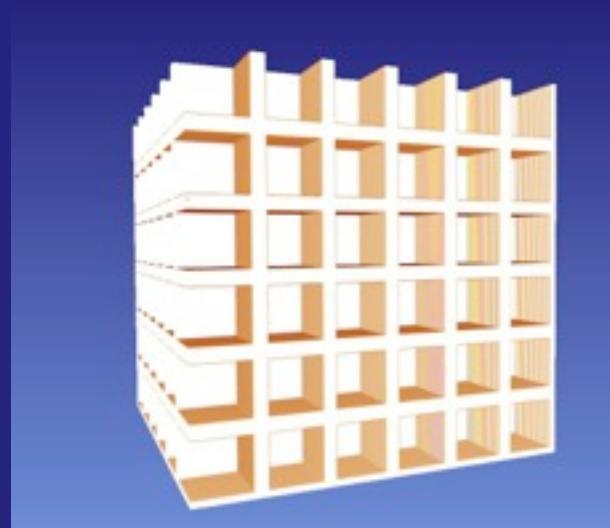- ## Marching Cubes Entropy Index MCE

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

- ## Marching Cubes Complexity MCC

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

complexity of the surface

Prototypical Examples
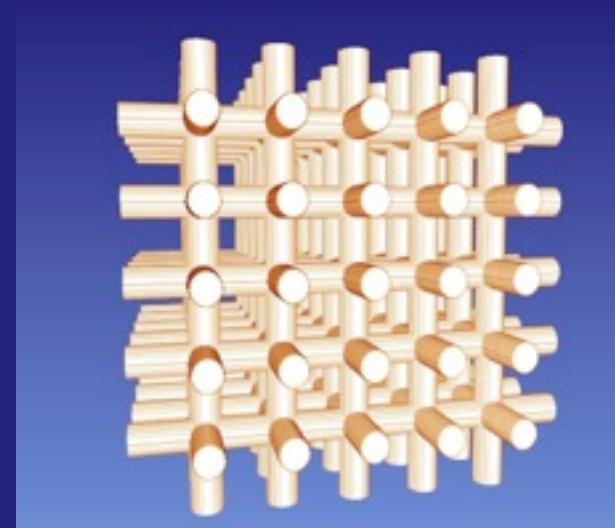
Prototypical Examples

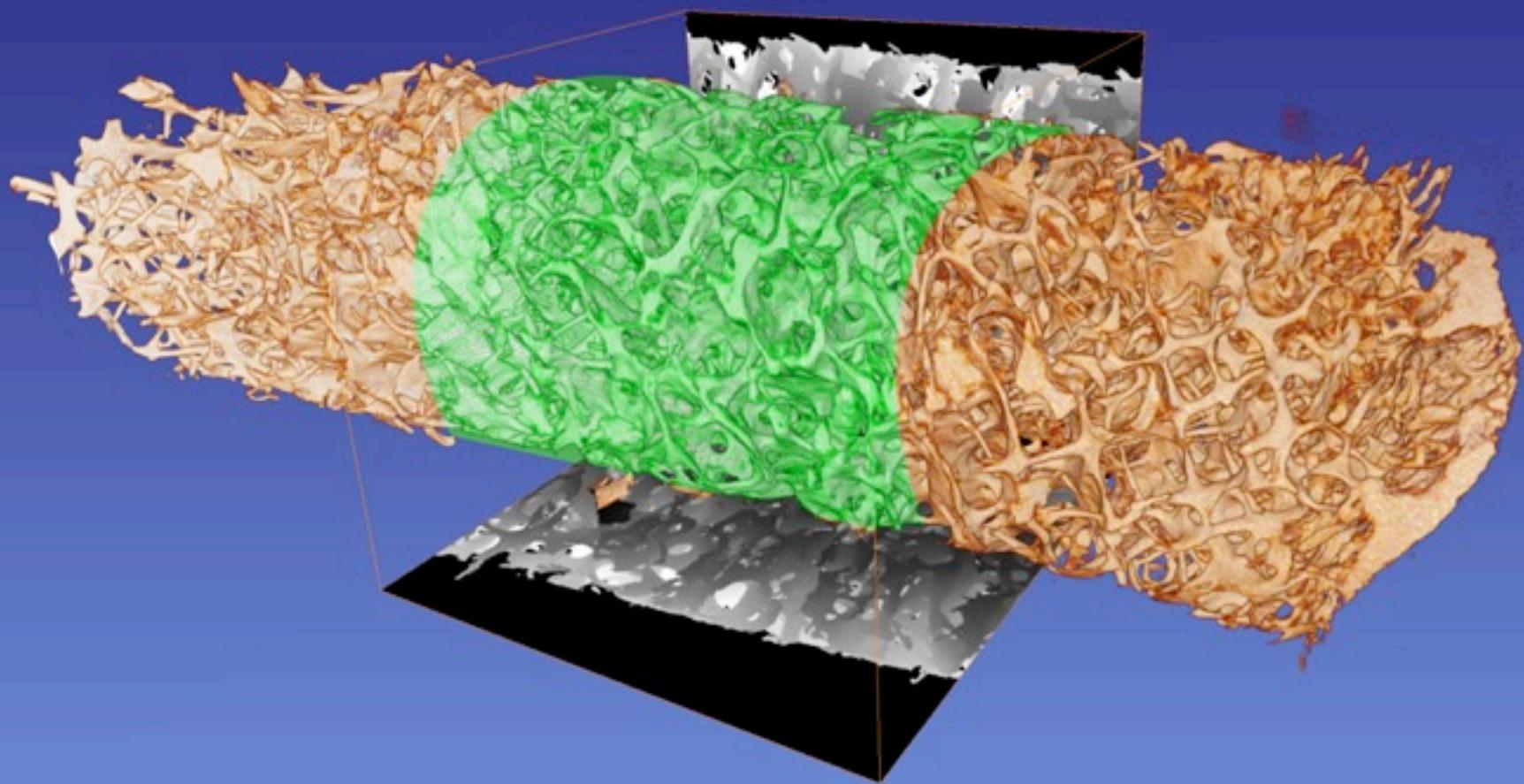|	ASHI	ISHI	SHC	MCC
Balls	1.00	0.70	0.33	5.92
Rods	1.22	0.16	0.02	6.12
Plates	1.16	0.18	0.09	7.21
Random	1.31	0.55	0.24	5.98

Data & Results

Proximal Tibia

- cylindrical biospies

- 7 mm diameter

- 17 mm below tibial plateau

- 29 specimens (of different BV/TV)

- VOI: 5 mm below cortical shell, 10 mm long

Proximal Tibia
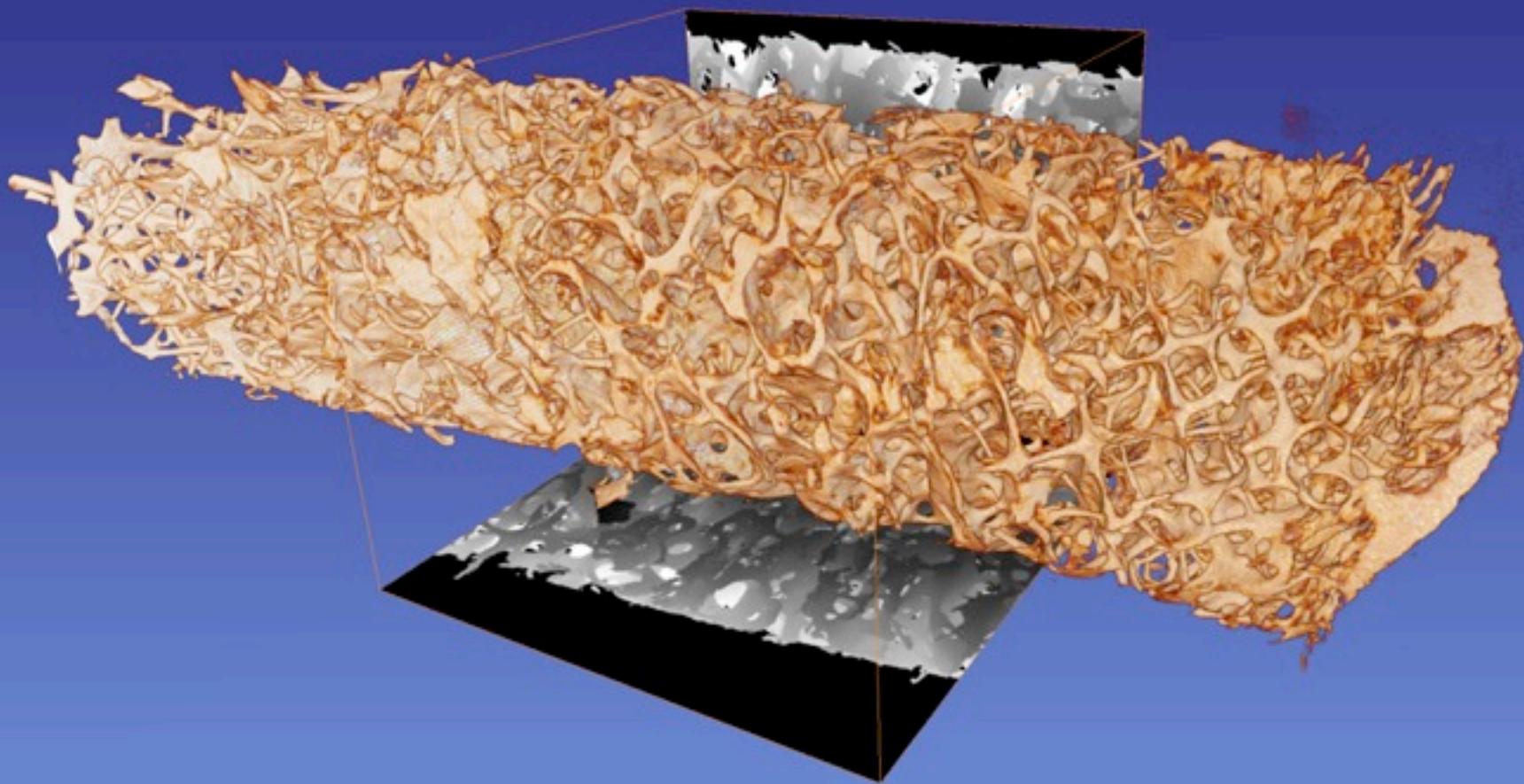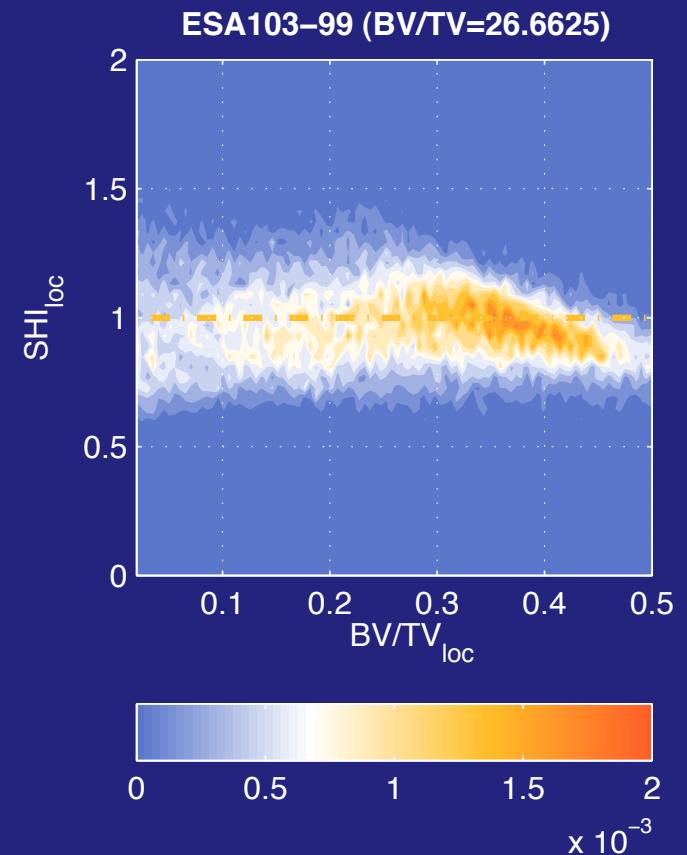
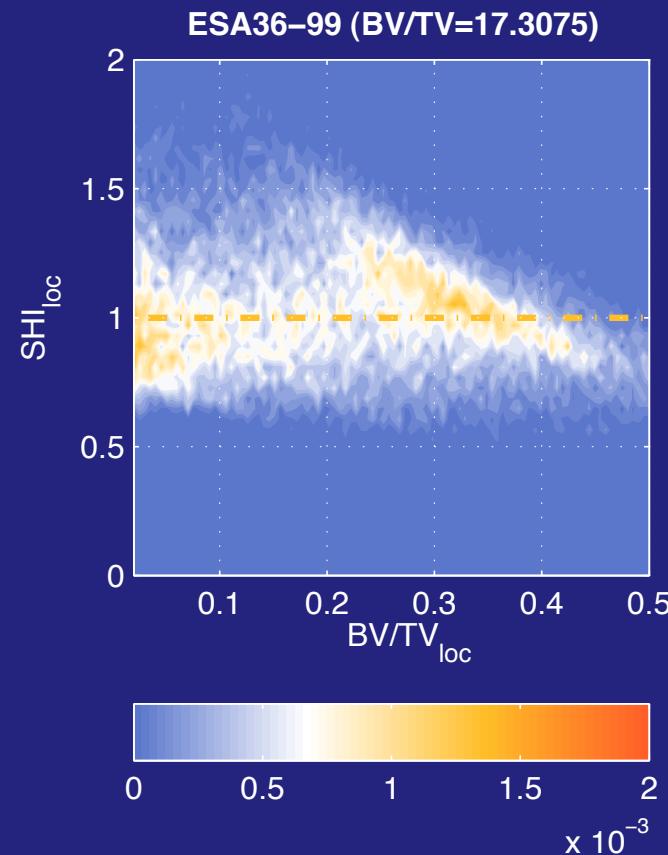# Proximal Tibia

Shape Index Distribution

- concave structures
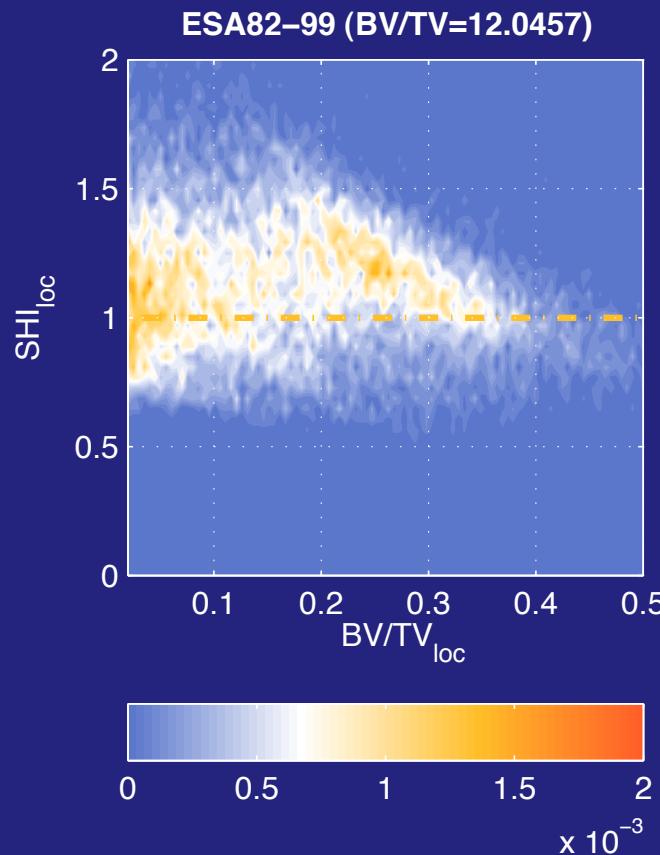
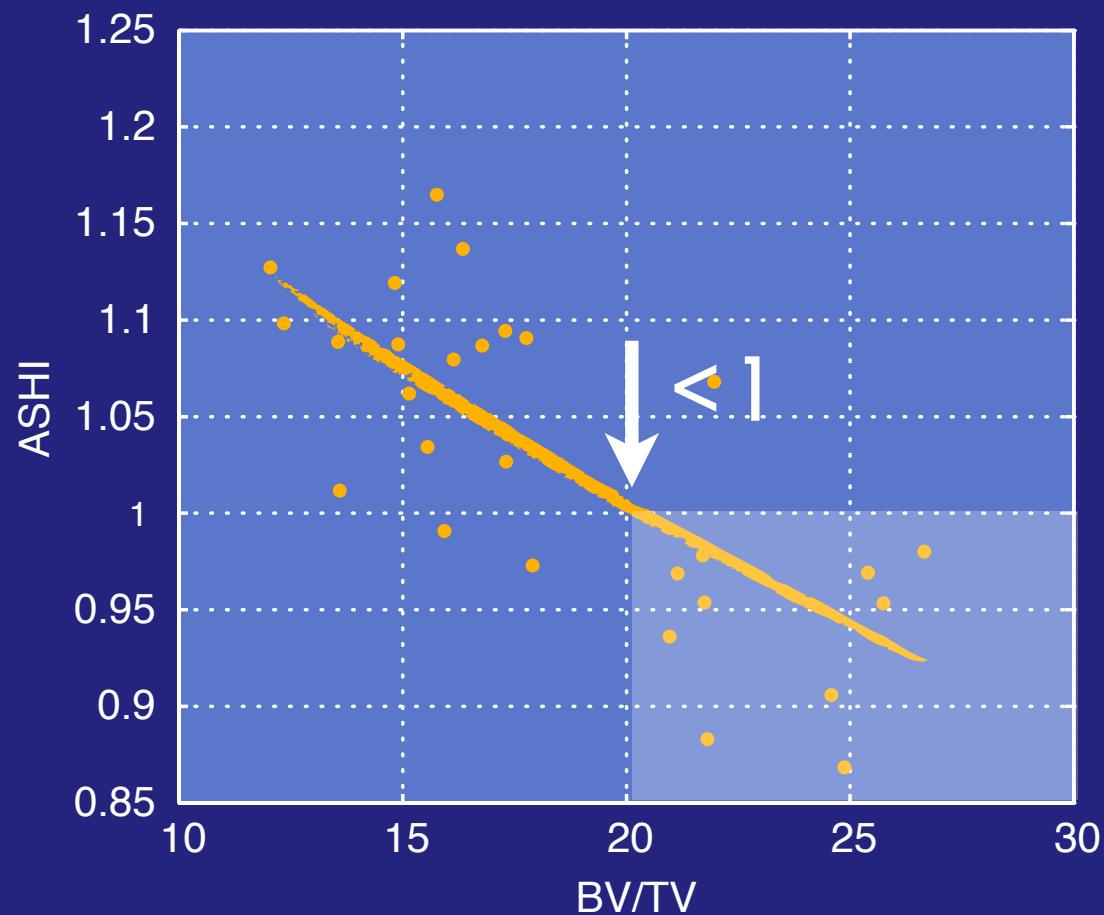ESA82−99 (BV/TV=12.0457)   ESA36−99 (BV/TV=17.3075)   ESA103−99 (BV/TV=26.6625)

Shape Index

- correlation with bone density
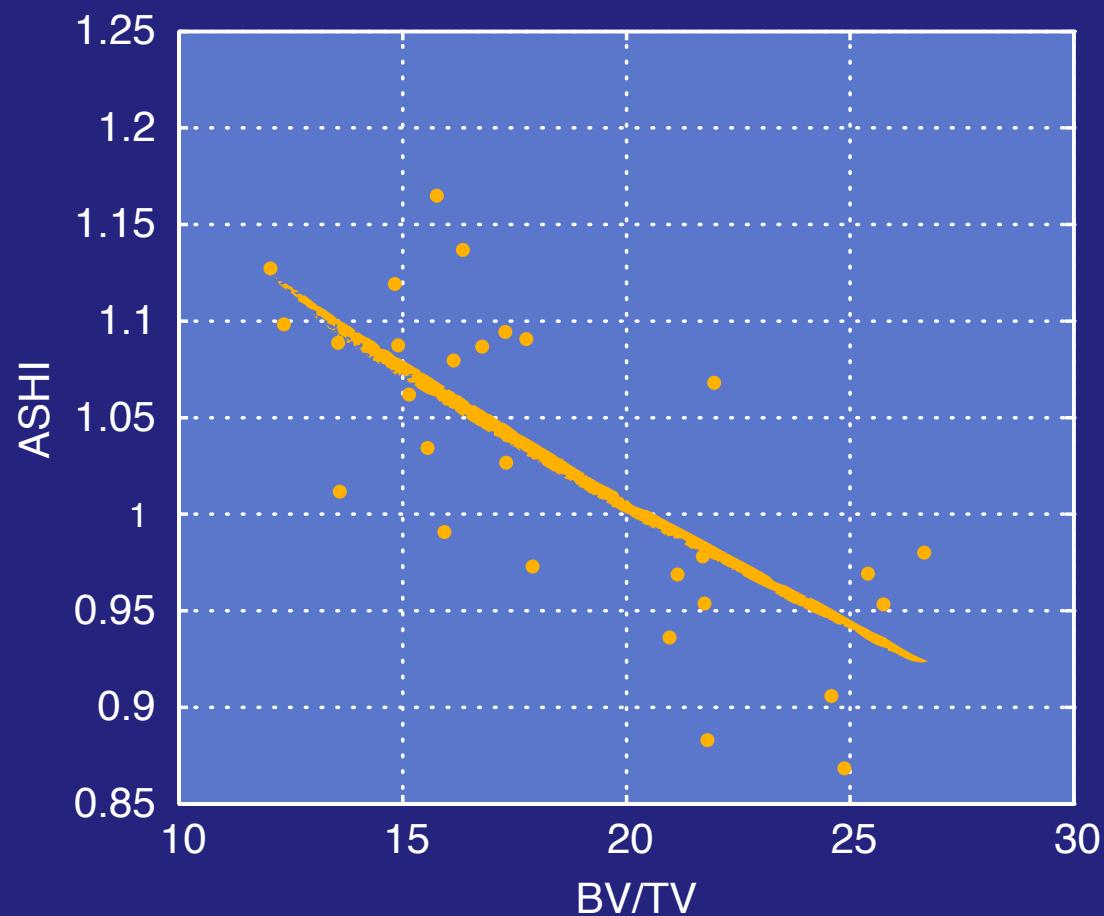
Shape Index

- correlation with bone density

Shape Index

- correlation with bone density

concave structures
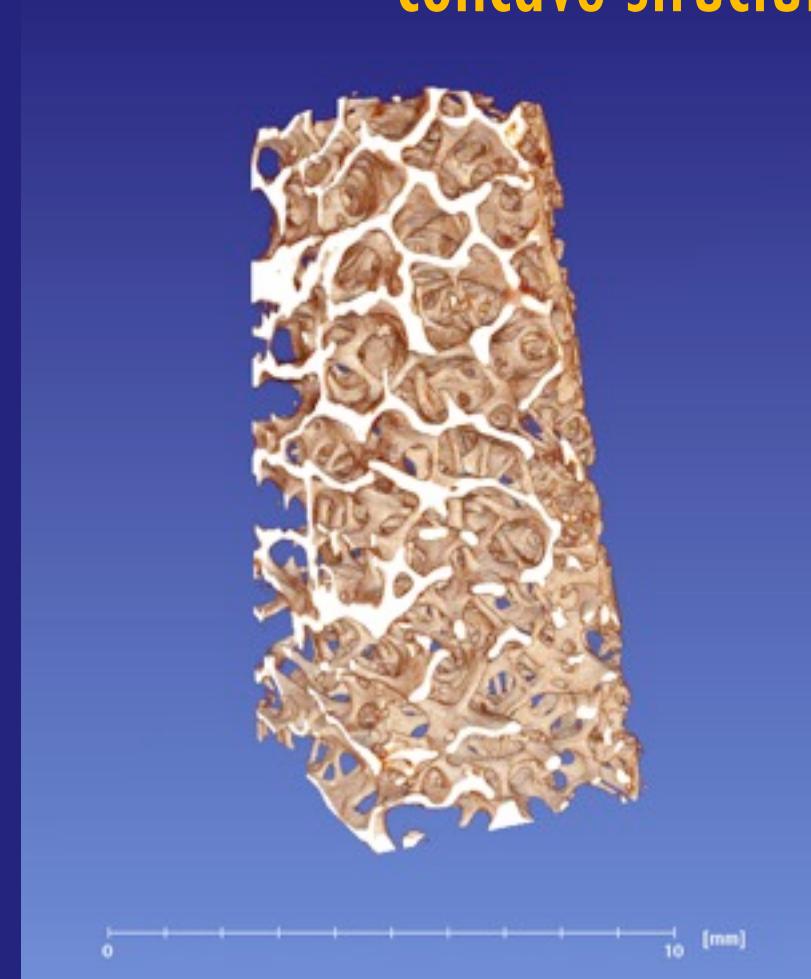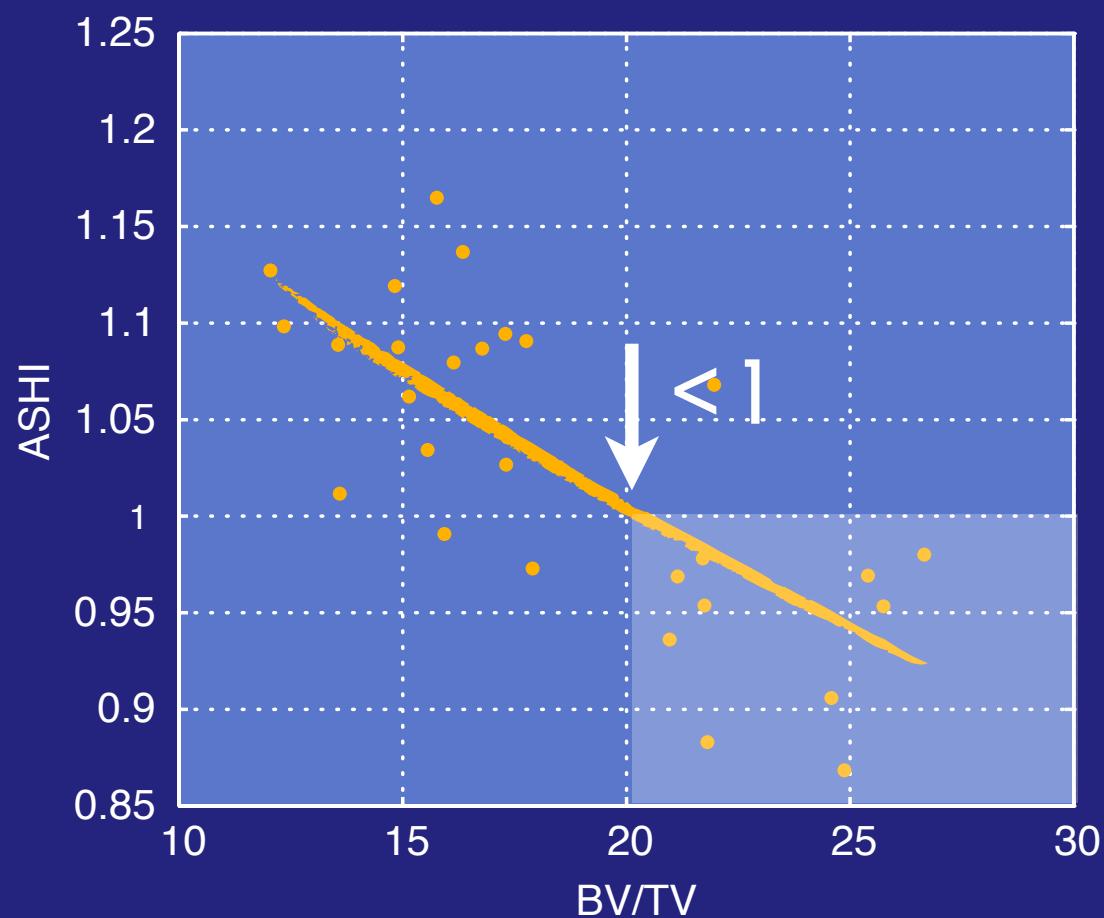
Bone Volume Fraction

- correlation with SHC and MCC
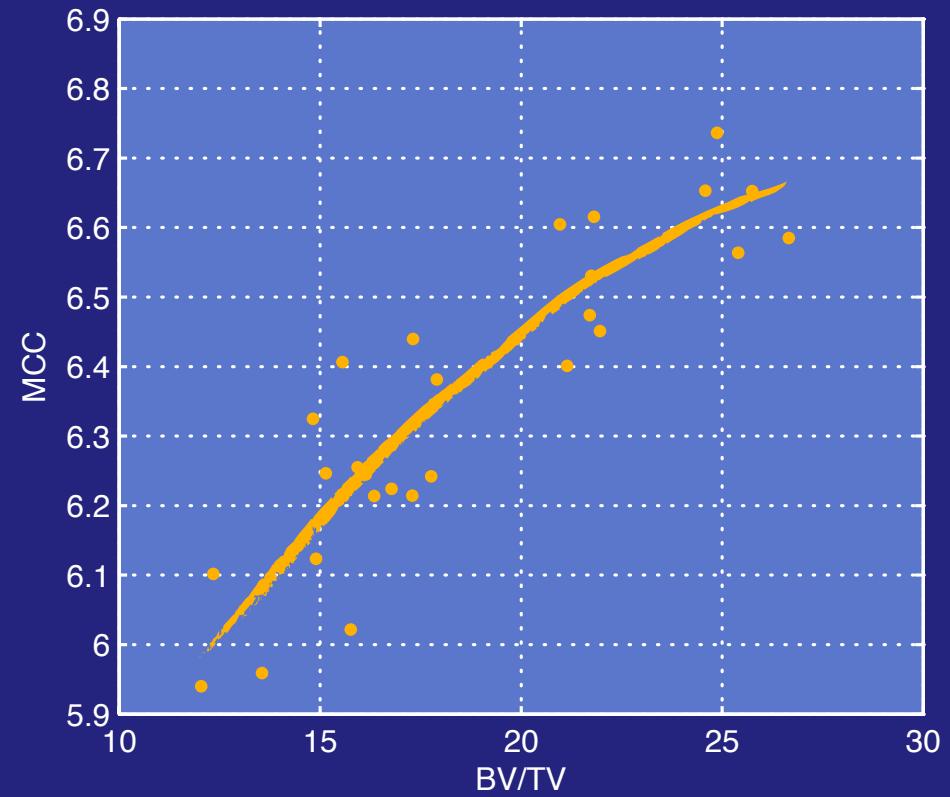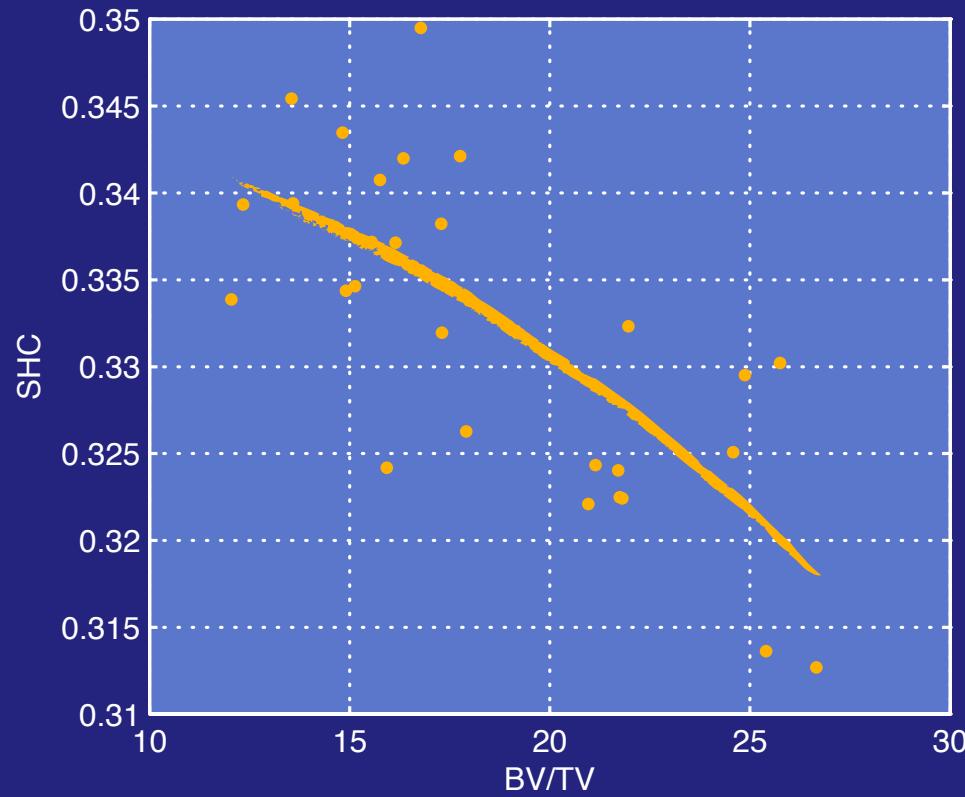
MC Entropy

- correlation with TBPf and Tb.Sp
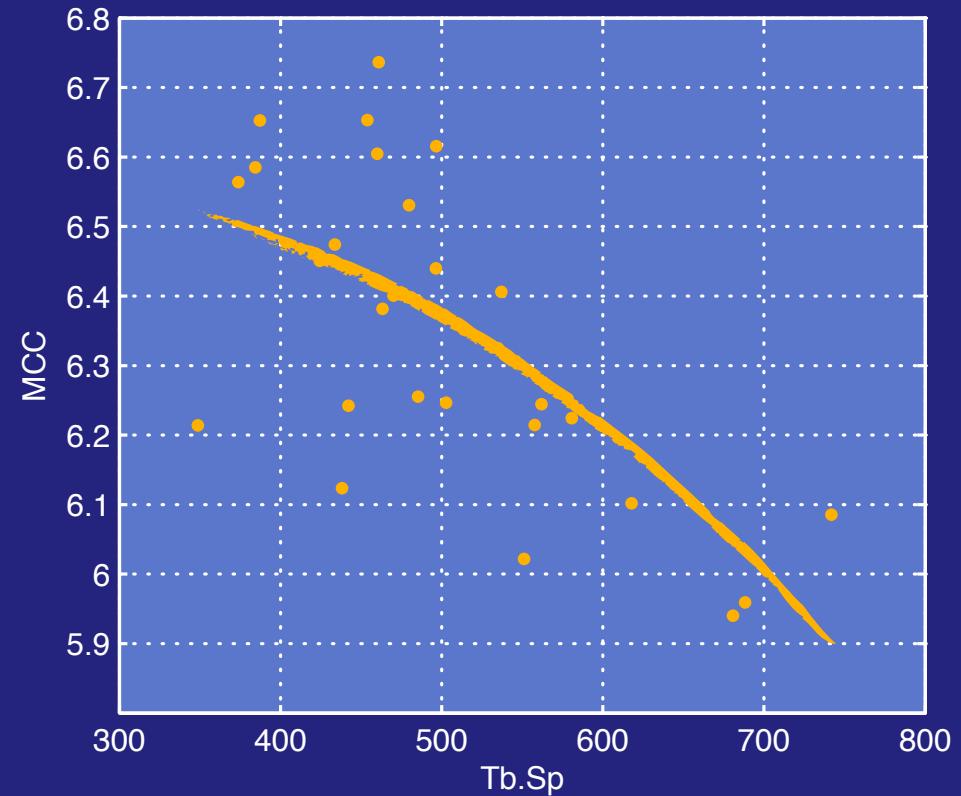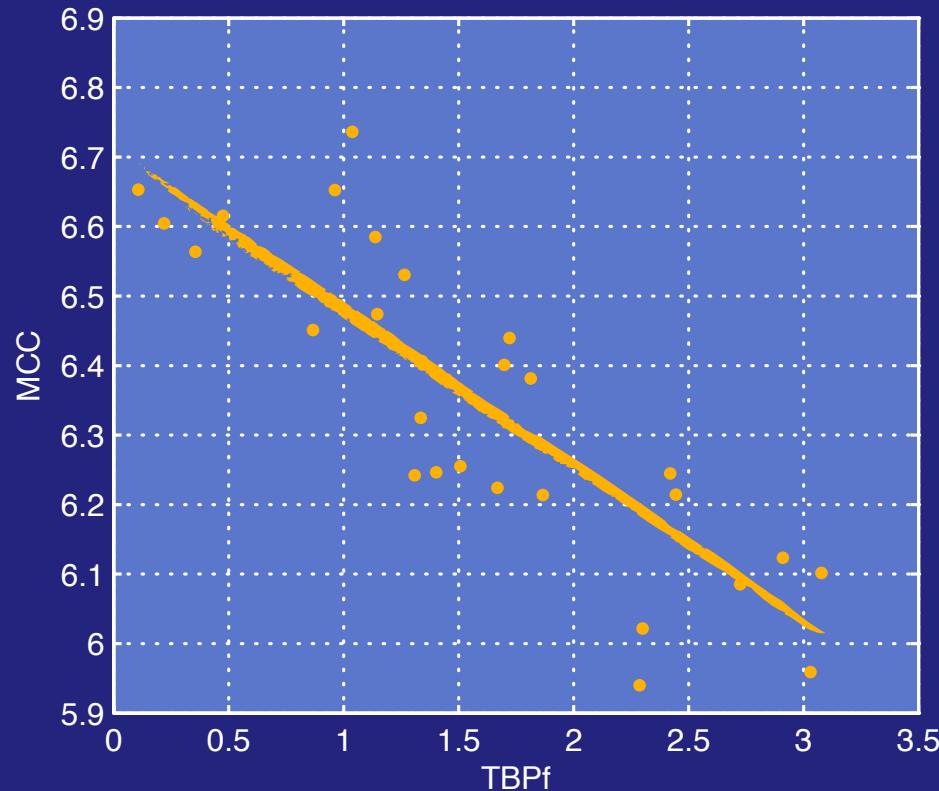
Histomorphometry

- correlation with MCC, ASHI and SHC
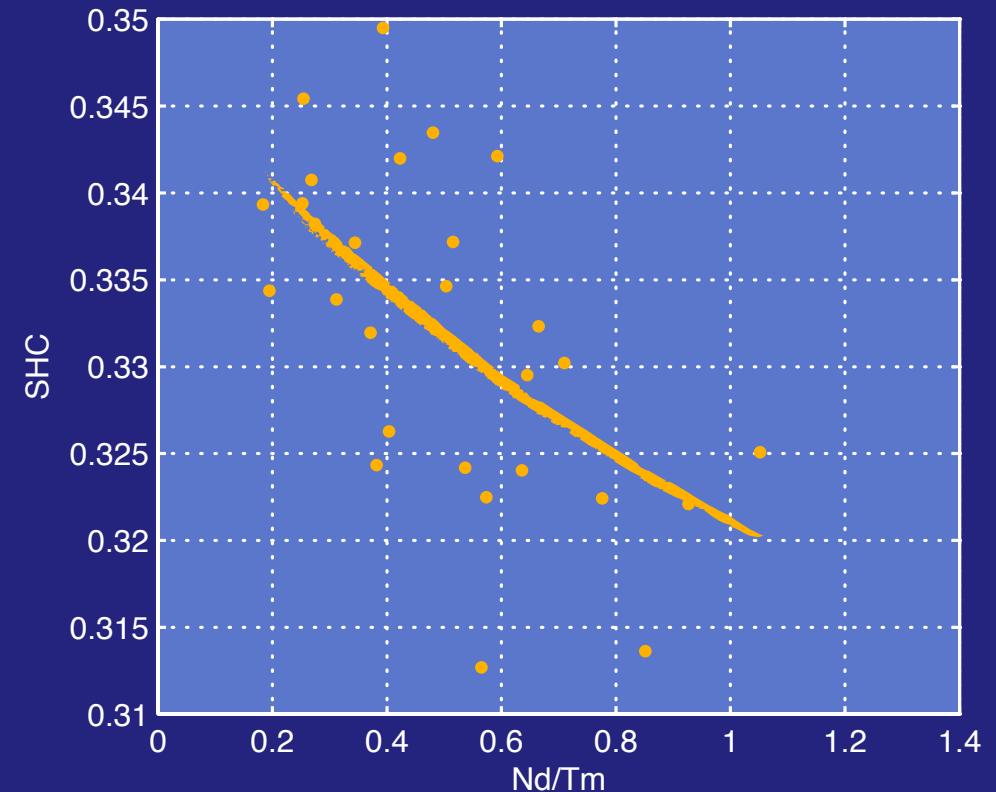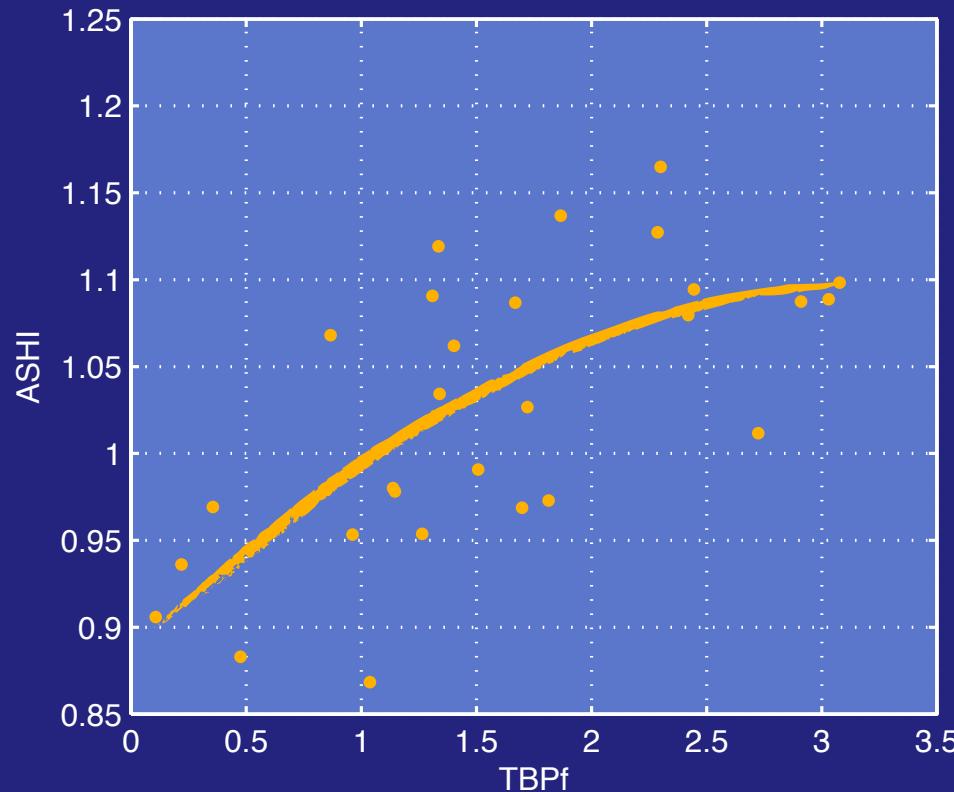
Rank Correlation

	ASHI	ISHI	SHC	MCC
3D BV/TV	−0.74	−0.05	−0.73	0.89
TBPf	0.66	0.11	0.61	−0.85
Nd/Tm	−0.69	0.07	0.60	0.82
Tb.Sp	0.36	0.25	0.54	−0.67

Lumbar Vertebra

- confirmation of results
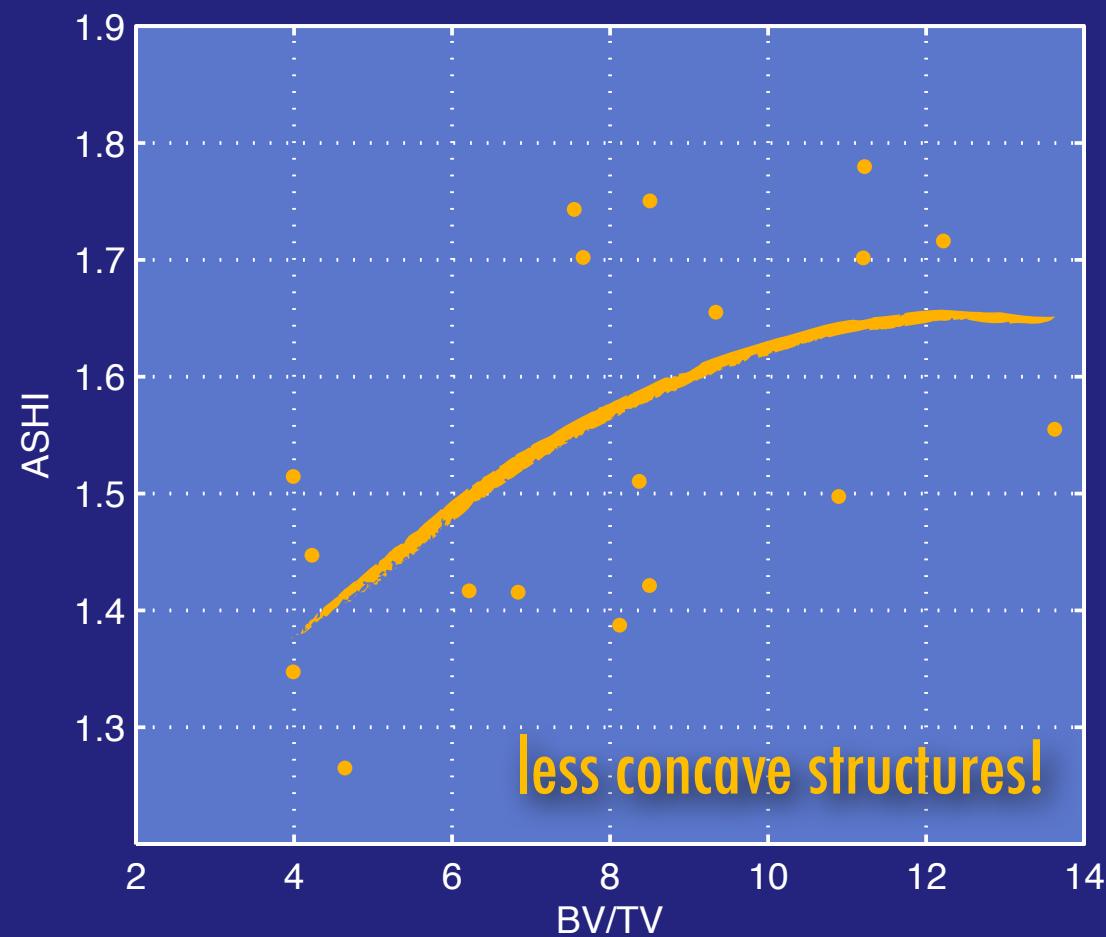
Conclusion

Conclusions

Conclusions

- measures of complexity for 3D image analysis

Conclusions

- measures of complexity for 3D image analysis

- quantify 3D micro-structure of trabecular bone

Conclusions

- measures of complexity for 3D image analysis

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- bone loss (proximal tibia):

Conclusions

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  - complexity of bone surface decreases

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  - amount of concave structures decreases

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

Conclusions

- potential applications:

Conclusions

- potential applications:
  - > quantification of bone loss in micro-gravity

Conclusions

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

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

Montag, 3. März 2014