An Innovative Approach for the Assessment of 3D Structures in Trabecular Bone

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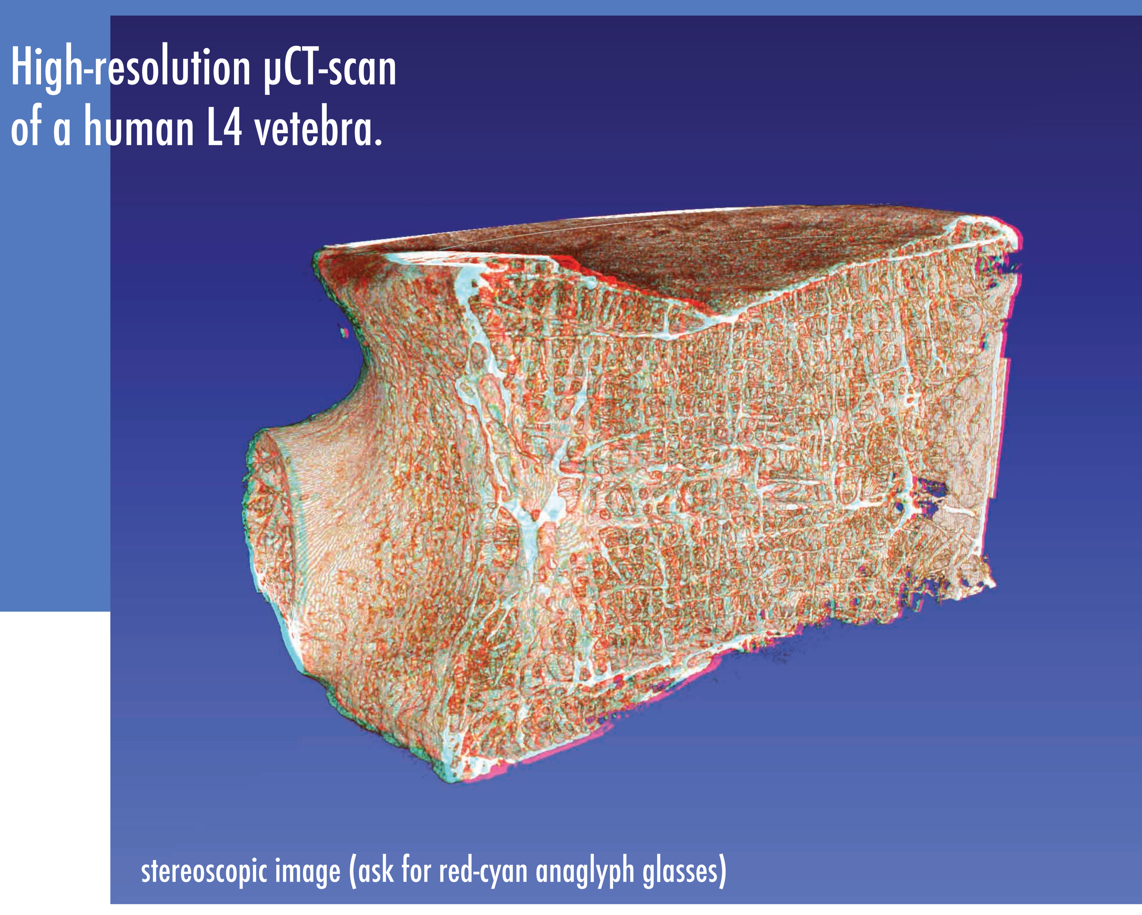


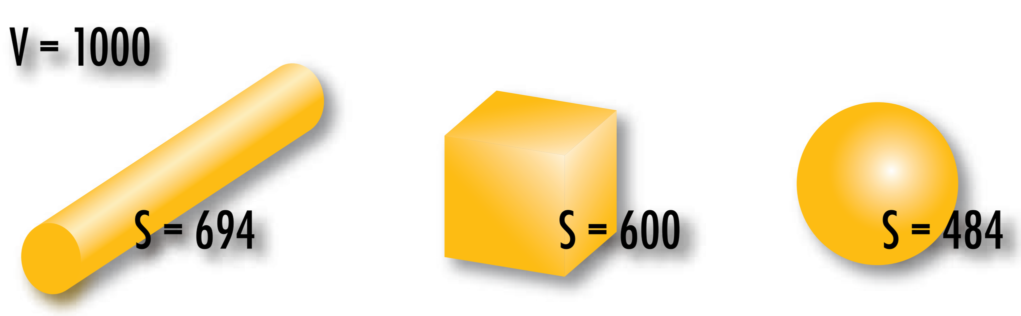
stereoscopic image (ask for red-cyan anaglyph glasses)

Changes in trabecular bone composition during the development of osteoporosis are used as a model of bone loss in microgravity. The structural changes of trabecular bone have received more attention in the last years as bone densitometry alone cannot explain all variation in bone strength. The rapid progress in high resolution 3D microCT imaging facilitates the development of new 3D structural measures of complexity, which should be able to assess the spatial architecture of trabecular bone.

In the present project, several new approaches for quantification of bone micro-architecture were developed. They comprise measures basing on symbol-encoding, curvatures, auto-correlation or translational invariance. Here we present an approach based on the shape of trabecular structures and their construction with geometrical objects and apply them on μCT data from proximal tibia (28 samples, 20 μm voxel size) and lumbar vertebra (L4, 24 samples, 40 μm voxel size).

Shape related measures

A first approach is based on the fact that the surface of 3D objects with same volume varies for different shapes.



S - surface, V - volume

Local shape index

ratio between bone surface and minimal surface possible from the corresponding bone volume in a moving box

$$ASHI = \left\langle \frac{S_{loc}}{\sqrt[3]{36\pi V_{loc}^2}} \right\rangle_{VOI}$$

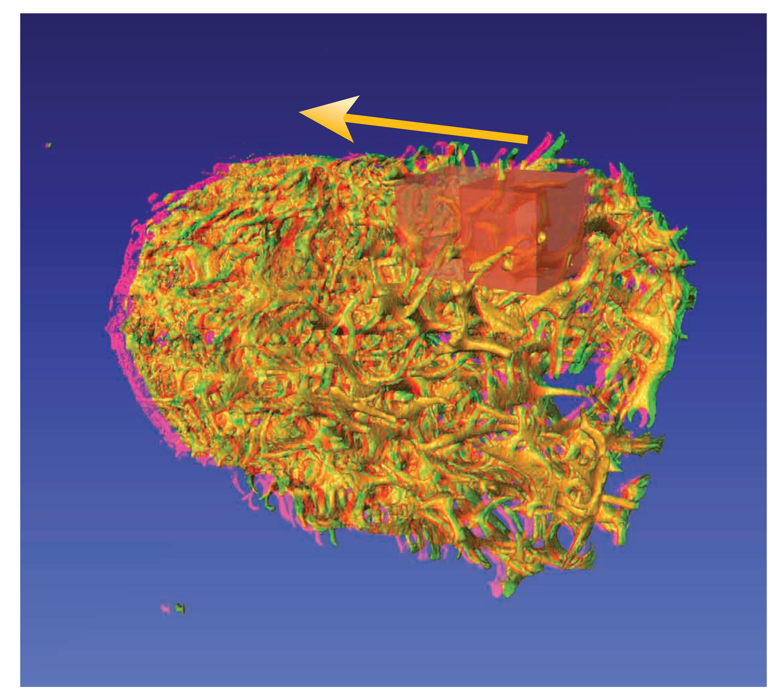
Surface of a sphere

Shape complexity

conditional entropy of joint distribution of bone surface and bone volume

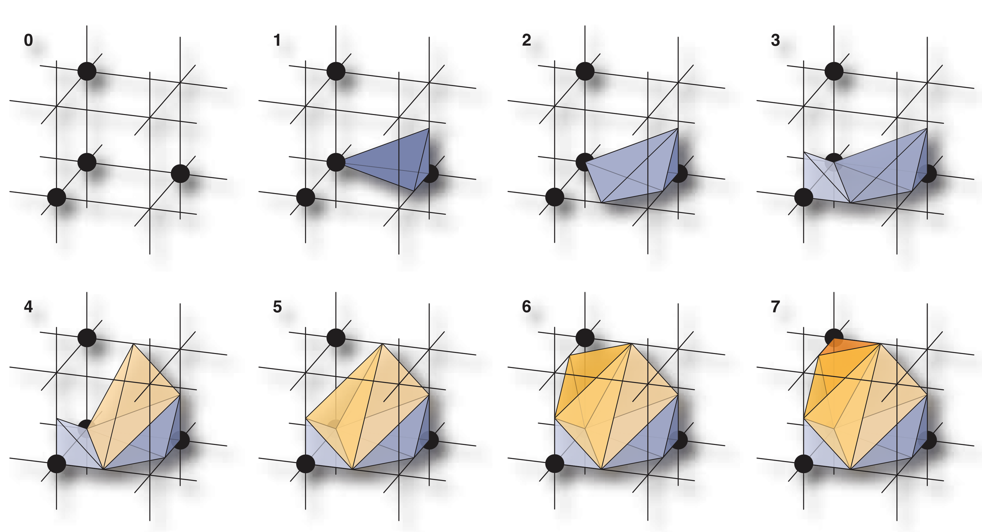
$$SHC = -\sum p(S_{loc}, V_{loc}) \log \frac{p(S_{loc}, V_{loc})}{p(V_{loc})}$$

ASHI quantifies the shape and differentiates between concave and convex structures. SHC measures the complexity of occurring local structures or shapes (e.g. rods or plates)



Surface and volume is determined within a cubic box,moving through the entire bone.

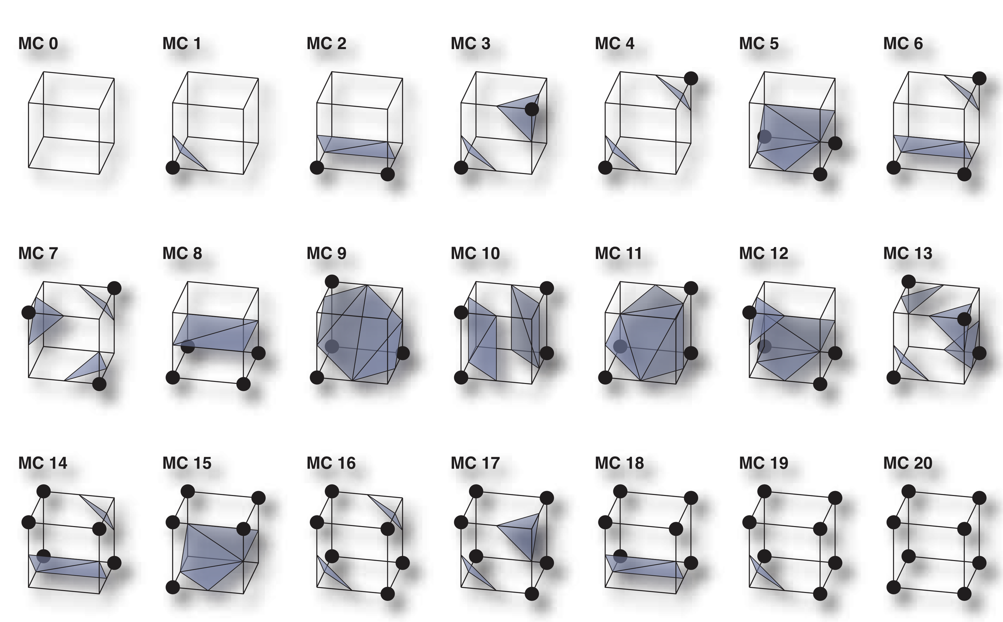
Surface and volume estimation is based on the marching cubes algorithm (Lorensen, SIGGRAPH Comp. Graph., 21, 1987)



A marching cube (MC) consists of eight neighbouring voxels, sitting at the corbers of a cube. MCs are used for the construction of iso-surfaces, e.g., in rendering 3D data. The surface is constructed by a set of triangles, and the volume is represented by set of tetrahedrons.

Marching cubes based measures

Considering some symmetry, we have 21 basic marching cube cases.



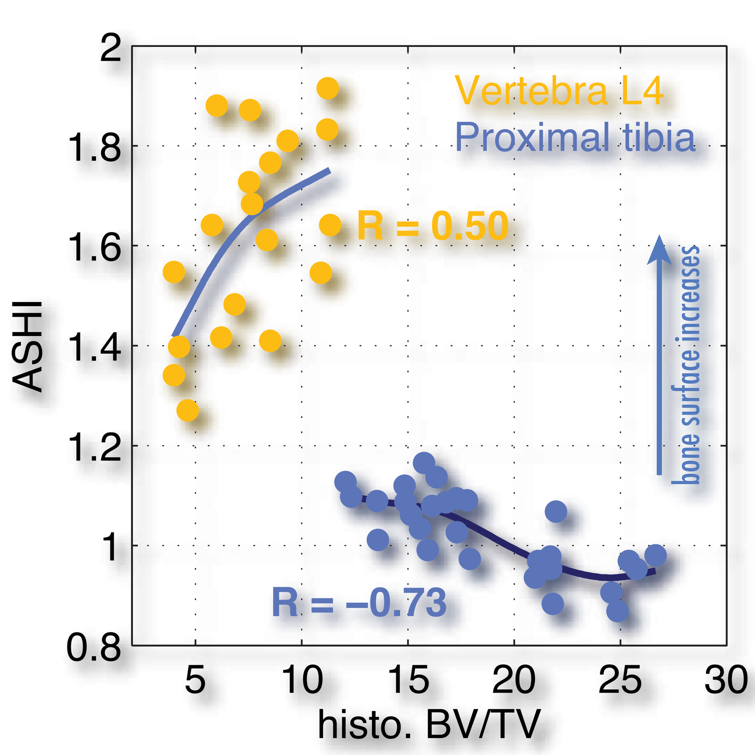
Marching cubes complexity

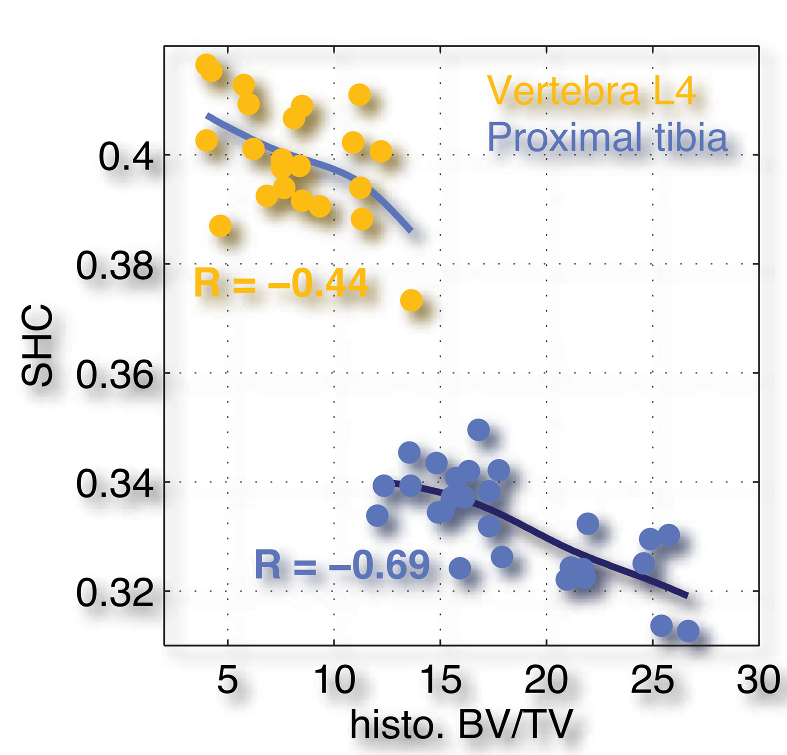
entropy of the distribution of found marching cubes

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

MCE measures the complexity of the bone surface and is related with its curvature.

Results

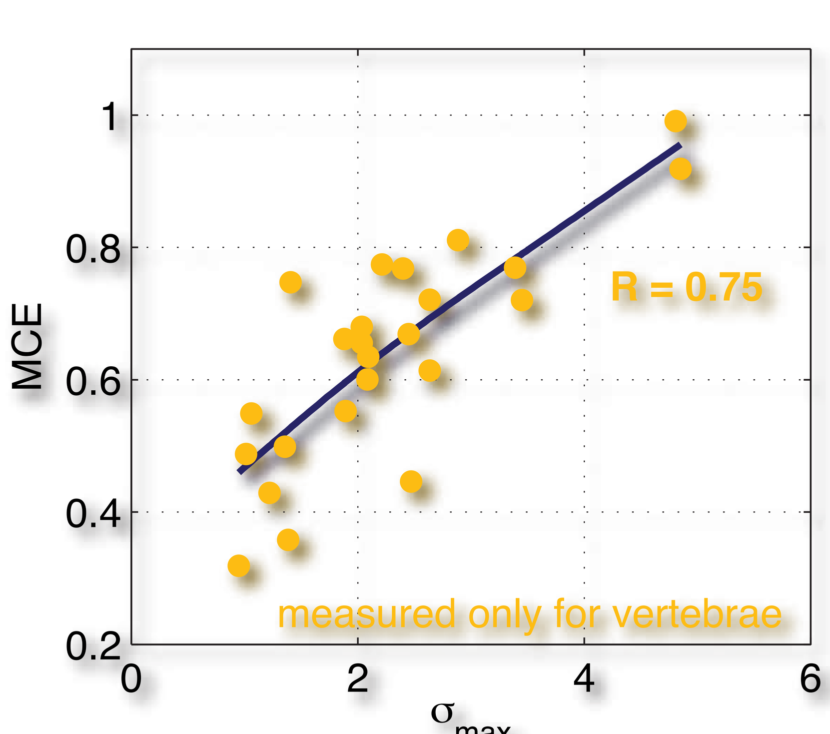


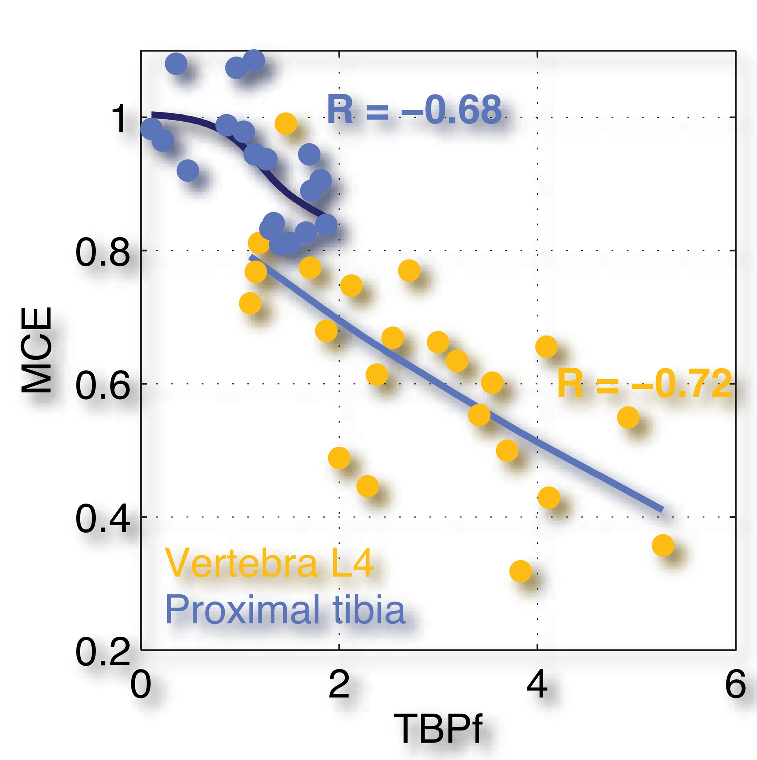


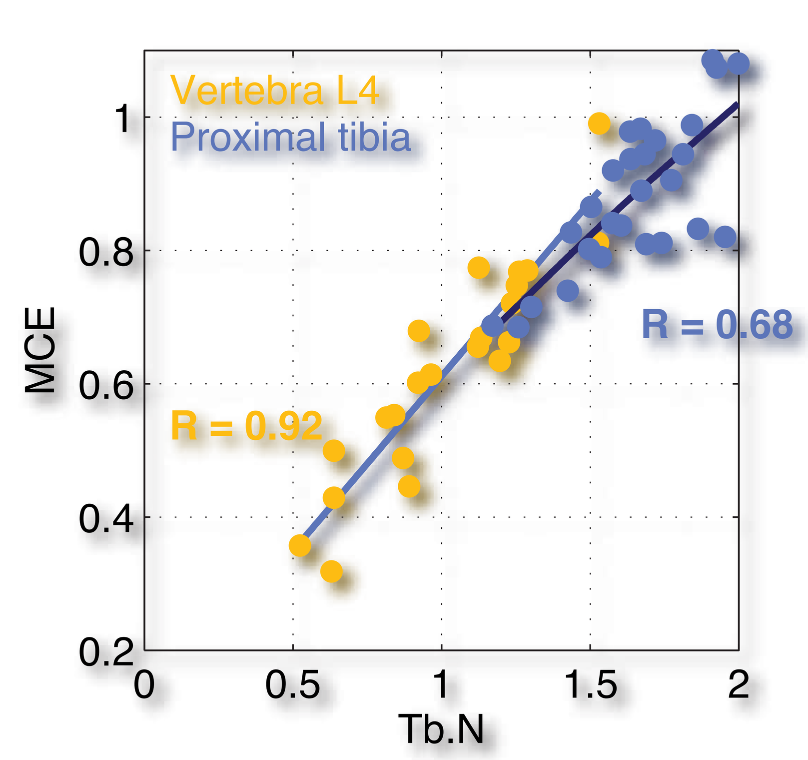
The averaged shape index reveals significant differences between proximal tibia and vertebrae: whereas in proximal tibia the amount of concave structures decreases with bone loss, we cannot give a similar statement for the vertebrae. However, it indicates a change from plate-like structures (which have a larger surface) to rod-like structures (which have less surface).

The shape complexity reveals an increasing amount of different shapes and structures during bone loss. Lossof bone results in a series of different trabecular structures.

R - Spearman's rank correlation







The marching cubes entropy index reveals similar results for proximal tibia and vertebra: during bone loss the complexity of the trabecular bone surface decreases. MCE correlates well with histomorphometrical measures, such as trabecular bone pattern factor and trabecular number. The more complex the surface of the trabecular bone, the stronger the bone.

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