AN INNOVATIVE APPROACH FOR THE ASSESSMENT OF 3D STRUCTURES IN TRABECULAR BONE

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ABSTRACT

A series of new structural measures of complexity were introduced in order to quantify the micro-architecture of trabecular bone from 3D micro Computed Tomography (μCT) data sets. The application of these measures on μCT data acquired from proximal tibia and lumbar vertebra illustrates their ability to quantify structures in trabecular bone.

1. INTRODUCTION

Structural changes of trabecular bone have received more attention in the last years as bone densitometry alone cannot explain all variation in bone strength. We have previously successfully developed and applied a set of measures of complexity, which quantify the trabecular bone architecture using 2D Computed Tomography (CT) images [1]. The rapid progress in high resolution μCT facilitates the development of new 3D measures of complexity, which should be able to assess the spatial architecture of trabecular bone in 3D.

2. MEASURES OF COMPLEXITY

2.1. Shape related measures

The idea behind quantification of a geometrical shape is based on the fact that different 3D objects of the same volume will have different surfaces, depending on their geometrical shape. For example, a long cylinder (length is much larger than radius) has a larger surface than a cube of the same volume, whereas a sphere of the same volume would have the smallest surface.

Using this relationship, we introduced structural measures based on bone surface and bone volume, locally estimated within a small cubic box moving through the entire volume of interest (VOI). Firstly, the *averaged shape index* is defined as

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

which is the ratio between the bone surface and the smallest possible surface for the same bone volume (i.e. the surface of a sphere). This index is related to the shape of the trabeculae and is sensitive to the amount of convex and concave trabecular structures.

The *shape complexity*

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

is the conditional entropy of the joint-distribution of local (within the moving cube) bone surface and volume in respect of a given bone volume. This measure quantifies the complexity or amount of different trabecular shapes.

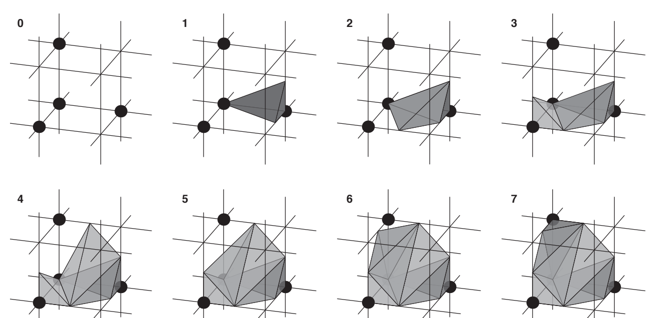

Fig. 1. Marching cube (MC) example for four bone voxels, demonstrating the filling of the MC with tetrahedrons. The surface is constructed by a set of triangles.

Bone surfaces and volumes were estimated using an improved *marching cubes* algorithm, which was initially introduced to form iso-surfaces for rendering 3D images [2]. A marching cube (MC) consists of eight neighbouring voxels, sitting on the eight corners of a cube (Fig. 1).

2.2. Marching cubes based measures

Depending on the position of the bone voxels in a MC, there are 256 different cases; however, due to rotational symmetry, there are only 21 pseudo-unique MC cases.

A specific MC case corresponds to a specific bone surface configuration and, hence, it is related to the complexity of the bone surface. Using the distribution of MC cases, we define the *marching cubes entropy index*

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

which quantifies the complexity of the bone surface.

3. MATERIALS

We have applied the introduced measures on 3D μCT scans of entire human lumbar vertebrae (L4, 23 samples) and of human proximal tibia biopsies taken 17 mm distal of the tibial plateau (28 samples). The central axial, horizontal, cuboidal VOI applied to the vertebrae has a size of 25×15×10 mm^3. The tibial biopsies were 8 mm in diameter and 10 mm long. The voxel size was 40 μm (vertebra) and 20 μm (tibia).

In order to validate the developed measures the results of the purposed 3D data evaluation were compared against conventional bone histomorphometry [3].

4. RESULTS AND CONCLUSIONS

The averaged shape index reveals significant differences in trabecular architecture between proximal tibia and vertebra (Fig. 2): in contrast to vertebra, the amount of concave structures decreases with bone loss at the proximal tibia. However, in vertebra *ASHI* indicates a change from plate-like structures (which have a larger surface) to rod-like structures (which have less surface).

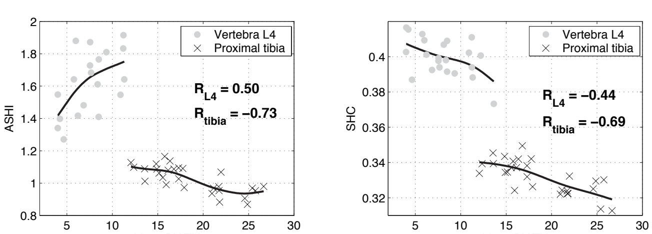

Fig. 2. Averaged shape index and shape complexity reveal differences in the micro-architecture of proximal tibia and vertebra (*R* – Spearman's rank correlation).

The shape complexity reveals an increasing amount of different shapes and structures during bone loss (Fig. 2). Loss of bone results in a series of different trabecular structures.

The marching cubes entropy index reveals similar results for proximal tibia and vertebra: during bone loss the complexity of the trabecular bone surface decreases. The structural measures of complexity correlate well with histomorphometrical measures, such as trabecular bone pattern factor TBPf and trabecular number Tb.N (Fig. 3).

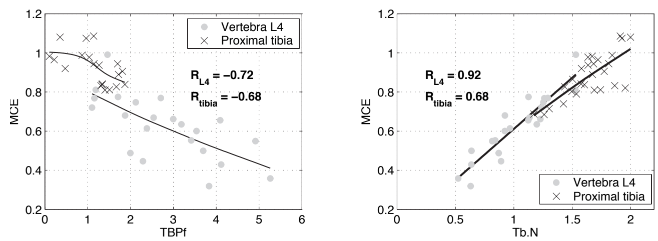

Fig. 3. Marching cubes entropy index reveals a relationship with histomorphometrical measures.

From these findings we infer, that the introduced new measures of complexity are able to quantify structural changes in trabecular bone. Moreover, the shape related measures are able to detect significant differences between the trabecular structure of proximal tibia and lumbar vertebra.

5. REFERENCES

1. Saparin P.I., Gowin W., Kurths J., Felsenberg D.: Quantification of cancellous bone structure using symbolic dynamics and measures of complexity. *Phys. Rev. E* 58 (5), 6449, 1998.

2. Lorensen W.E., Cline H.E., Marching cubes: A high resolution 3D surface construction algorithm. *SIGGRAPH Comput. Graph.* 21 (4), 163-169, 1987.

3. Thomsen J.S., Ebbesen E.N., Mosekilde Li.: A new method of comprehensive static histomorphometry applied on human lumbar vertebral cancellous bone. *Bone* 27 (1), 129-138, 2000.

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