Quantification of changes in human bone structure at different skeletal locations using measures of complexity*

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Abstract

The aim of the study was to assess and to compare the structural composition and deterioration of human bone tissue in osteoporosis at seven different skeletal sites. We applied measures of complexity to assess quantitatively the structural composition of bone tissue. The complexity of the bone architecture at the different locations was compared with each other.

High-resolution 2D CT-images (pixel size 0.2 x 0.2 mm, slice thickness 1 mm) were acquired from the following skeletal regions of 29 human cadavers: proximal tibia, vertebral body L3, distal radius, midshaft humerus, femoral neck, femoral head, and calcaneus.

Our 2D technique consists of three stages: image segmentation, encoding of the image by symbols, and quantification of symbol-encoded structure by measures of complexity. 1. For each skeletal site, an originally developed image segmentation procedure provides two standardized regions of interest: the trabecular bone and the whole bone. 2. The segmented image was encoded using a mixture of three static and two dynamical symbols. 3. The spatial arrangement of symbols representing the bone structural composition was assessed by six structural parameters based on measures of complexity and symbolic dynamics: Structure Complexity Index (SCI) expresses the complexity and homogeneity of the architecture. Structure Disorder Index (SDI) assesses the degree of order or disorder within the architecture. Trabecular Net Index (TNI) informs about the richness of the trabeculae and its interactions with each other. Index of Global Ensemble (IGE) evaluates the dynamics of the assembly of structural element. Size of maximal L-block and Average Size of L-block measure the bone element replacement by marrow tissue. In addition, bone mineral density was calculated for every region.

We analyzed the relation between the amount of bone mass and the quantification of bone architecture by using bone density vs. bone structure diagrams. It was found that the structural composition responds to a loss of bone mass differently and with a different rate at each skeletal site. Skeletal locations can be distinguished from each other by both their BMD and their architecture assessed by the complexity measures. Despite the same BMD, bones from different skeletal locations have different complexities and different degrees of disorder. The rate of complexity change depends on the skeletal location as well. Rank-Order correlation coefficients were used to compare different skeletal sites. The strongest correlation is found between the bones of the same upper and lower extremities. The lowest correlation is found between the vertebra and peripheral bones. The correlation between all skeletal sites of the whole bone is stronger than the trabecular bone alone.

The quantification of bone structure in 3D is a work in progress within this project. Preliminary results of the 3D evaluation confirm the 2D results that the complexity of the bone structure decreases during bone loss. It is also found that beyond a certain amount of bone material loss, the probabilities of symbols representing the internal bone voxels and the surface voxels decrease at different rates, thus capturing the difference in bone architecture.

The proposed technique is able to quantify to a high degree the structural loss of the bone tissue and may help to diagnose and to monitor changes in bone structure of patients on Earth as well as of the space-flying personnel.

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