High-Resolution CT Images Yield Accurate Microstructural Information if Processed by 3-D Extensions of Standard Histomorphometric Analysis or Fuzzy Segmentation Approaches

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Abstract: In vivo assessment of trabecular bone microstructure is limited by image quality and radiation exposure. We investigated whether microstructural information can be accurately extracted from High Resolution CT (HRCT) images of human vertebrae.
Microstructural variables can be defined by 3-D adaptation of 2-D stereological methods used in histomorphometry. However, binarization of bone structures is affected by image resolution and image noise. Fuzzy segmentation approaches may overcome these limitations. For *bone* voxels exceeding a minimum gray level, a minimal weighted distance to the *bone marrow* background, named fuzzy distance, is calculated as measure of local thickness. A complementary process based on the marrow phase yields a measure of trabecular separation. Both the stereologic and the fuzzy methods were implemented on Structural*Insight*, our imaging software developed in house and yield estimates of microstructural variables, defined analogously to histomorphometry, including bone volume fraction (BV/TV), trabecular thickness (Tb.Th), and trabecular separation (Tb.Sp).
16 vertebral biopsies of 8mm diameter (Set 1, training) and 8 whole vertebrae (Set 2, validation) embedded in PMMA were measured by HRCT (Siemens Somatom 16, 120 kV, 360 mAs, pixel size 156 x 156 μm^2, slice thickness 400 μm) inside a CIRS abdomen phantom to emulate in vivo conditions. Reference measurements on micro-CT systems were obtained on a Scanco μCT40 (voxel size $24^3 \mu m^3$) for Set 1 and a Scanco Xtreme CT (voxel size $82^3 \mu m^3$) for Set 2.
The table lists residual root-means-square (RMS) errors (in% of the reference mean) and coefficients of determination for regression of reference systems against HRCT.

Reference results [mean±SD(in mm, %)]		BV/TV 0.08 ± 0.02 (26%)	Tb.Th 0.12 ± 0.02 (17%)	Tb.Sp 0.94 ± 0.13 (14%)
Set 1	Stereol.	19%, r^2=0.48	13%, r^2=0.45	13% , r^2=0.20
	Fuzzy	16%, r^2=0.61	11%, r^2=0.63	9%, r^2=0.61
Reference results [mean±SD(in mm, %)]		BV/TV 0.33 ± 0.08 (25%)	Tb.Th 0.37 ± 0.04 (12%)	Th.Sp 0.79 ± 0.21 (27%)
Set 2	Stereol.	17%, r^2=0.58	8%, r^2=0.66	20%, r^2=0.55
	Fuzzy	21%, r^2=0.40	5%, r^2=0.88	21%, r^2=0.49

Both methods estimate structural variables with RMS-errors substantially smaller than the sample SD,

demonstrating that microstructural information could be extracted from the HRCT images with acceptable residual accuracy errors of 5-21% under in vivo like conditions. HRCT has value for the assessment of vertebral microstructure in patients.