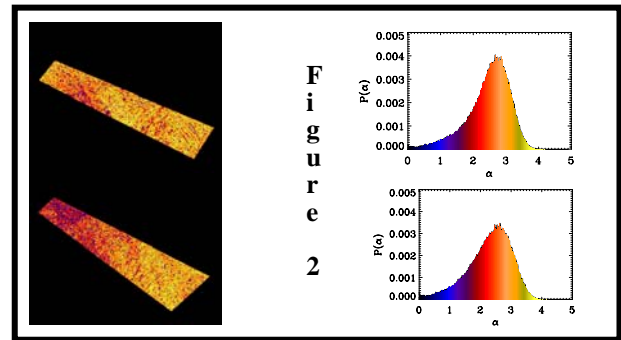
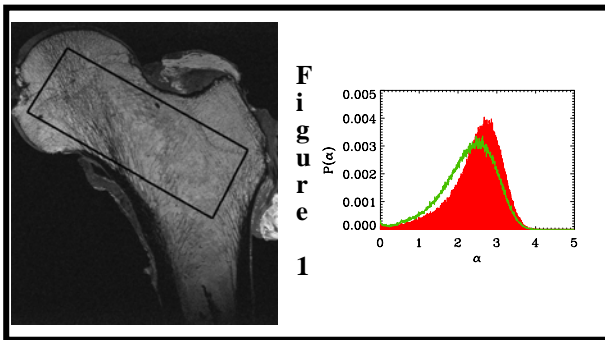




We introduce the scaling vector method (SVM): a technique to obtain local non-linear structural information from data sets suitable in cases where anisotropy plays an important role. We apply the SVM to High Resolution Magnetic Resonance Images (HRMRI) of human proximal femur specimens IN VITRO. By means of the SVM, we extract a 3D non-linear local anisotropic texture measure which we use to compare with similar isotropic texture measures, bone mineral density (BMD) and standard isotropic 2D (linear) morphometric parameters in the prediction of the biomechanical properties of the trabecular bone.

Proximal femur fractures are the most severe complications of osteoporosis. The structure characterization methods must account for the textural properties of proximal femur images which contain a large portion of bone tissue forming a mineralized trabecular network oriented along the major stress lines. 15 human proximal femur specimens were analyzed. Coronal HRMRI's were obtained using a 1.5 T scanner using a 3D-spin-echo sequence. A matrix of 384 x 512 was applied with a field of view of 75 x 100 mm, yielding a pixel size of 0.195 x 0.195 mm². Nineteen 0.9 mm thick sections were acquired. BMD (g/cm²) of the femoral neck was determined using DXA. Bone strength was determined in compression. The maximum compressive strength (*Sm*) ranged from 3.20 to 16.95 kN. Only one of the fractures was a pertrochanteric fracture and the remaining 14 were neck fractures. For all specimens, central coronal femur images were selected where a rectangular ROI was chosen to evaluate the morphological parameters bone volume/total volume (*BV/TV*), trabecular separation (*Tb.Sp*), trabecular thickness (*Tb.Th*), and trabecular number (*Tb.N*). Consider a grey scale tomographic image $g=G(x,y,z)$. Each pixel contains space and gray value information that can be encompassed in a four dimensional vector $p=[x,y,z,G(x,y,z)]$ which defines a 4D point distribution. The SVM characterizes the structural information of the images via the estimation



of local scaling properties of the above mentioned point distribution. We define a local weighted cumulative point distribution $\rho: \rho(p_i, L) = \sum_j e^{-(d_{ij}/L)^2}$ where L is the scaling range and d_{ij} a generalized quadratic distance

$$d_{ij}^2 = \lambda_x(x \cos \theta + y \sin \theta)^2 + \lambda_y(x \sin \theta - y \cos \theta)^2 + \lambda_z z^2 + \lambda_g g^2$$

where λ_i are the weighting factors of the different directions and θ is the rotation angle. Note that $\lambda_x = \lambda_y$ corresponds to the isotropic case. The weighted scaling vectors α_i are obtained by calculating the logarithmic derivative of ρ with respect to L . The frequency distribution of scaling vectors $P(\alpha)$ characterizes the bone structure. We perform a correlation analysis based on a filtering procedure applied to the $P(\alpha)$ spectrum which considers two sliding windows of variable width. We call α -fraction to the fraction of pixels $\Delta P(\alpha)$ with scaling-vector values within the sliding window. We use the following structure measure $m^d = \Delta_{w_1} P(\alpha) / \Delta_{w_2} P(\alpha)$. The window position and width were chosen to achieve optimal correlation between m^d and Sm . Figure 1 shows a HRMRI of the proximal femur where the black square limits a section of the 3D ROI. On the right, the $P(\alpha)$ spectra for two femur specimens (Red: $Sm = 4.25$ kN Green: $Sm = 13.6$ kN). Note that weaker bones lead to spectra shifted to higher α -values. Figure 2 shows two different color-coded femur α -images and the corresponding spectra. Different α -images can be located on the images.

	m_{ani}^d vs Sm	m_{iso}^d vs Sm	BMD vs Sm	BV/TV vs Sm	Tb.N vs Sm
Correl. Coeff.	0.91	0.85	0.72	0.6	0.52

Conclusions: The results suggest that 3D local non-linear anisotropic structural parameters has a superior performance in the prediction of biomechanical strength in cases where directional properties play a relevant role.

References:

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