Trabecular Bone Analysis: Correlation of 3D Structural Features with 3D Texture Analysis

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Introduction:

Osteoporosis, defined by loss of bone, affects both men and women of all ages. Currently, screening risk of fractures from osteoporosis is performed by measuring Bone Mineral Density (BMD) in vivo either by quantitative Computed Tomography (CT) or Dual Energy X-Ray Absorptiometry (DEXA). But in addition to BMD being a predictor of fracture risk, bone architecture also significantly contributes to the bone strength [1,2]. Other studies have shown that 64% of the overall strength of the trabecular bone can be explained by bone density alone and with architectural measures combined, 94% of its overall strength can be explained [3]. Texture defined as the characterization of the distribution of the gray tones in an image, may be meaningfully calculated at any resolution. Some studies indicate that measures of texture including fractal signature, co-occurrence-based texture analysis and the gray level run length method are useful in obtaining information about bone strength from clinical images [4]. In this paper, we explore the correlation of 3D texture obtained at different resolutions with conventional 3D structural indices at a higher resolution.

Material and Method:

MR images of 4 male subjects were acquired at 3.0 T (Magnetom Trio®, Siemens) with a wrist coil, using a phase-cycled truFISP constructive interference in steady state (CISS) sequence with sagittal slices. Imaging parameters for TE/TR/ FA/Matrix/FOV/Averages were 4.66 ms/10.55 ms/60^0/448 x 448/90 mm/2 respectively, with a total scan time of 12 minutes. Fig. 1a shows a representative sagittal image slice from the acquired study; a circular region of interest (ROI) is shown in red with zoomed-in resolution and post-processing in Fig. 1b. Post-processing included thresholding and binarizing, inversion of the color map to obtain an image that is similar to radiograph contrast; and skeletonizing to obtain 1-pixel wide representation of the trabecular structure. The threshold was determined by Otsu thresholding in which the histogram is divided into two classes and the inter-class variance is minimized.

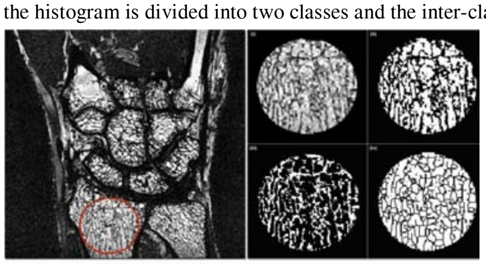

Figure 1: **(a)** Sagittal slice through the distal radius with the region of interest (ROI), shown in the circle. **(b)** The selected ROI is shown after different stages of post-processing, with (i) the original image region, (ii) the region binarized using an automatically determined threshold, (iii) the binarized image with an inverted lookup table, and (iv) the inverted image skeletonized.

3D structural parameters: 3D structural parameters such as Bone Volume (BV/TV), Apparent Trabecular Number (Tb.N), Apparent Trabecular Thickness (Tb.Th) and Apparent Trabecular Spacing (Tb.Sp) analogous to bone histomorphometry, were extracted from the thresholded image using the mean intercept length (MIL) methods from the plate model [5].

Texture Features: 3D statistical texture features were also derived from the original grey scale images using a cylindrical volume of interest over a consecutive set of thirty image slices with the region defined in Fig. 1a/b. The 3D co-occurrence-based texture measures investigated in this study is an extension of established 2D techniques described by Haralick [6]. Ten different texture features were calculated from the co-occurrence matrices which include cluster tendency (f_1), contrast (f_2), correlation (f_3), energy (f_4), sum entropy (f_5), homogeneity (f_6), inverse difference moment (f_7), maximum probability (f_8), sum mean (f_9) and variance (f_{10}). Texture features were also determined from images sub-sampled from the original images at 3 different lower resolutions.

Structural parameters	**1.5T MRI**	**3.0T MRI**		
	Range (SD)	***Range (SD)***	***Mean***	***Median***
BV/TV	0.26-0.34 (0.03)	0.28-0.31 (0.013)	0.296	0.293
Tb.N (mm^{-1})	1.21-1.53 (0.13)	1.12-1.25 (0.062)	1.182	1.178
Tb.Sp (mm)	0.44-0.61 (0.07)	0.55-0.63 (0.036)	0.597	0.606
Tb.Th (mm)	0.21-0.22 (0.004)	0.24-0.27 (0.013)	0.251	0.250

Table 1. Descriptive statistics for BV/TV (bone density), Tb.Sp (trabecular spacing), Tb.N (trabecular number), Tb.Th (trabecular thickness)

Statistical Analysis: Single-predictor linear regression model was used to determine if there was a relationship between any of the texture features and the structural indices. The texture features were used as an independent variable in the regression model.

Results and Discussion:

Table 1 lists the structural parameters obtained as the average of measurements in four normal volunteers; the typical region of interest is shown in Fig. 1a/b. The values obtained at 3.0T are in close agreement with the values reported in the literature at 1.5T. Table 2 lists some of the texture parameters obtained as the average of measurements in four normal volunteers in the original and in the sub-sampled images. For the single-predictor model, the texture features that had the largest R^2 value for a given structural index, calculated for a set of sub sampled images (voxel size = 0.2 mm), are presented in Table 3. The values in Table 3 indicate that numbers of texture features are highly correlated with the structural indices. Features f_3, f_4, f_6, f_7 and f_9 are highly correlated to BV/TV. Features f_3, f_6 and f_9 show strong correlation with Tb.Sp. Feature f_3 is also strongly correlated to Tb.N. The texture features sub-sampled to 0.30, 0.45 and 0.6 mm also showed correlations to structural indices as follows. Features f_1, f_2, f_3, f_9 and f_{10} showed strong correlation with Tb.Sp. Features f_2, f_4, f_5, f_7 and f_8 were correlated with BV/TV and f_1, f_3 and f_9 are correlated with Tb.N. We observed that for all sets of images none of the features show strong correlation with Tb.Th.

Voxel size	**0.20 mm**	**0.30 mm**	**0.45 mm**	**0.60 mm**
Texture	***Mean/SD***	***Mean/SD***	***Mean/SD***	***Mean/SD***
f_3	0.17/0.06	0.78/0.07	0.87/0.04	0.92/0.03
f_4	0.54/0.16	0.54/0.13	0.56/0.13	0.58/0.13
f_6	0.78/0.09	0.80/0.08	0.83/0.07	0.85/0.06
f_7	0.76/0.10	0.78/0.08	0.81/0.08	0.83/0.07

Table 2. Descriptive statistics for some representative texture features

R/R^2 Values				
Texture feat	***BV/TV***	***Tb.Th***	***Tb.Sp***	***Tb.N***
f_3	0.817/0.67	0.140/0.02	0.922/0.85	0.813/0.66
f_4	0.969/0.94	0.184/0.03	0.771/0.59	0.578/0.33
f_6	0.973/0.95	0.145/0.02	0.791/0.63	0.599/0.36
f_7	0.975/0.95	0.179/0.03	0.773/0.60	0.578/0.33
f_9	0.957/0.92	0.06/0.004	0.830/0.69	0.648/0.42

Table 3. Correlation between trabecular structural parameters and the mean texture features. R and R^2 values for single-predictor linear regression model ($p<0.005$) for voxel resolution 200 microns isotropic.

Conclusion:

Regression analysis shows that texture features are correlated not only to BV/TV but also Tb.Sp and Tb.N. This indicates that texture features provide information about bone micro-architecture which is not already accounted for by bone density. Further, the study shows the feasibility of using texture from lower resolution images as a surrogate marker of trabecular bone architecture

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