ABSTRACT

Estimation of mechanical strength of bones is an essential component in assessment of onset and progress of osteoporosis and fracture. Analyses of bone mineral density and soft bone architecture of femur are considered clinically important in explaining the mechanical variability of bone and in determining fracture risk and bone disorders. Trabecular bone is a highly complex anisotropic material that exhibits varying magnitudes of strength in compression and tension. Trabecular microstructure is typically oriented, such that it is organized along the lines of the mechanical forces applied to bone. This microstructural directionality contributes to trabecular bone anisotropy. Alteration of trabecular architecture due to pathology manifest as loss of trabecular plates and connection and results in alterations of structural anisotropy. An understanding of anisotropy of bone is important for diagnosis of osteoporosis like bone disorders.

In this work, anisotropy of compressive and tensile strength regions of femur trabecular bone is analyzed using spectral and multiscale spatial methods. The normal and abnormal femur trabecular bone radiographic images are considered for this study. The sub-anatomic regions, which include compressive and tensile regions, are delineated using pre-processing procedures. The apparent porosity, which is a key representative of trabecular architecture, is derived as a ratio of void area to total area of delineated strength regions. The anisotropy of trabecular architecture is investigated using various image processing techniques such as spectral and multiscale spatial methods. The spectral methods include wavelets, Gabor wavelet,

quaternion wavelets and quaternion Hilbert transform and multiscale spatial methods include structure tensor, lacunarity and succolarity.

The strength regions of normal and abnormal images are subjected to Daubechies5, Haar and coif5 wavelets at three levels of decomposition to derive approximation and detail coefficients. Similarly, the strength regions are also subjected to Gabor wavelet, quaternion wavelet transform and quaternion Hilbert transforms. Statistical parameters are derived from the transformed images and are correlated with apparent porosity. Further, anisotropy is calculated from these parameters and are analyzed. The results show that the values of energy derived from approximation coefficient using Haar wavelets show higher degrees of correlation with apparent porosity in both compressive and tensile strength regions. The anisotropy values derived from energy of Haar and Gabor wavelets appear to be distinct for normal and abnormal samples with high statistical significance. Similarly, the anisotropy derived from second and third phase components of quaternion wavelet transform and directional information of quaternion Hilbert transform could differentiate normal and abnormal subjects with high statistical significance. This could be attributed to sensitivity of adopted methods to the architectural changes and discontinuities in regional distribution of trabecular pattern in compressive and tensile region.

The strength regions of normal and abnormal images are also analyzed using piecewise and pixelwise structure tensor, lacunarity and succolarity methods. The anisotropy derived from structure tensor show distinct variation in normal and abnormal samples in tensile region than compressive region. Fractional anisotropy parameter derived using piecewise structure tensor method has high correlation with apparent porosity. This parameter is able to differentiate normal and abnormal subjects with high statistical significance. The lacunarity show higher variations in both the strength regions at smaller box size. Also the values are found to be uniform for higher box sizes. The distinct variation between normals and abnormal samples is observed in tensile region. This may be due to the presence of heterogeneous patterns in this region. Similarly, there is distinct variation in succolarity values between normal and abnormal subjects. The values of succolarity are found to have better correlation with apparent porosity.

The most significant twenty parameters from all the above analysis are selected using principal component analysis. The significant parameters derived from compressive and tensile strength regions are given as inputs to extreme learning machines classifier. The classification accuracy is found to be high in compressive region for all the activation functions. The sine and RBF activation function yield high and stable accuracy for compressive and tensile regions respectively. Sine function shows 99% of classification accuracy in compressive region and radial basis function yields 81% of classification accuracy in tensile region. It appears that anisotropy derived using various methods could be a useful index in analyzing trabecular structure and to classify normal and abnormal femur bones. Hence this methods of analysis helps in establishing biomarkers of osteoporosis like bone disorders.