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Improving Femoral Bone Strength Prediction through Characterization of Trabecular Micro-architecture with Anisotropic Minkowski Functionals and Quantitative Anisotropy Measures

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PURPOSE

Osteoporosis is characterized by changes to the trabecular bone micro-architecture in addition to reduction in bone mineral density (BMD). This study proposes using anisotropic Minkowski Functionals (AMF) for characterizing trabecular bone micro-architecture and evaluates their ability at predicting bone strength when analyzed with support vector regression (SVR).

METHOD AND MATERIALS

Axial images were acquired from 50 proximal femur specimens using 16-row MDCT scanner along with a calibration phantom. The specimens were then subject to biomechanical tests on the greater trochanter region and the failure load of each specimen was recorded. A spherical volume of interest (VOI) was fit into the femoral head region for further BMD value conversion and subsequent extraction of mean BMD and AMF-derived topological features. The computation of AMF feature vectors involved quantifying both the magnitude and direction of anisotropy in bone structure for all four Minkowski Functionals, i.e., volume, surface, mean breadth and Euler characteristic. All features were subsequently analyzed using multi-regression and support vector regression (SVR) to predict femoral failure load and prediction performance was evaluated with root-mean-square-error (RMSE). A Wilcoxon signed-rank test was used to compare RMSE distributions from different features and test for statistically significant differences in performance.

RESULTS

The best prediction performance was achieved for the feature vector encoding the magnitude of anisotropy, as derived from AMF Euler Characteristic (RMSE = 1.01 ± 0.13). This was significantly better than MDCT-derived mean BMD (RMSE = 1.12 ± 0.16, $p<0.05$). Finally, we also noted that all AMF feature sets outperformed MDCT-derived mean BMD.

CONCLUSION

Our results demonstrate that high-dimensional AMF features, when used in combination with SVR, can significantly improve bone strength prediction in the proximal femur. The improved performance likely stems from inclusion of anisotropic properties in trabecular bone characterization which are not accounted for in conventional BMD measures.

CLINICAL RELEVANCE/APPLICATION

Characterization of trabecular bone micro-architecture with anisotropic Minkowski Functionals for bone strength prediction can assist in osteoporosis diagnosis and monitoring of disease progression.

Cite This Abstract

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