Automated 3D trabecular bone structure analysis of the proximal femur--prediction of biomechanical strength by CT and DXA.

Abstract:
The standard diagnostic technique for assessing osteoporosis is dual X-ray absorptiometry (DXA) measuring bone mass parameters. In this study, a combination of DXA and trabecular structure parameters (acquired by computed tomography [CT]) most accurately predicted the biomechanical strength of the proximal femur and allowed for a better prediction than DXA alone. An automated 3D segmentation algorithm was applied to determine specific structure parameters of the trabecular bone in CT images of the proximal femur. This was done to evaluate the ability of these parameters for predicting biomechanical femoral bone strength in comparison with bone mineral content (BMC) and bone mineral density (BMD) acquired by DXA as standard diagnostic technique. One hundred eighty-seven proximal femur specimens were harvested from formalin-fixed human cadavers. BMC and BMD were determined by DXA. Structure parameters of the trabecular bone (i.e., morphometry, fuzzy logic, Minkowski functionals, and the scaling index method [SIM]) were computed from CT images. Absolute femoral bone strength was assessed with a biomechanical side-impact test measuring failure load (FL). Adjusted FL parameters for appraisal of relative bone strength were calculated by
dividing FL by influencing variables such as body height, weight, or femoral head diameter. The best single parameter predicting FL and adjusted FL parameters was apparent trabecular separation (morphometry) or DXA-derived BMC or BMD with correlations up to $r = 0.802$. In combination with DXA, structure parameters (most notably the SIM and morphometry) added in linear regression models significant information in predicting FL and all adjusted FL parameters (up to $R_{(adj)} = 0.872$) and allowed for a significant better prediction than DXA alone. A combination of bone mass (DXA) and structure parameters of the trabecular bone (linear and nonlinear, global and local) most accurately predicted absolute and relative femoral bone strength.