

PREDICTION OF SPINE AND HIP STRENGTH WITH BMD AND FE MODELS: INFLUENCE OF GENDER

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Introduction

Osteoporotic fractures of the central skeleton represent a major health problem. Quantitative computed tomography (QCT)-based finite element (hvFE) models can be used *in vivo* to estimate bone strength but need to be validated through accurate and reliable *in vitro* experiments. A recent study [1] found a different ability of subject specific FE models in predicting the risk of fracture in groups of males and females. In this context, the present study explores this issue in a substantial number of biomechanical tests quantifying vertebral and femoral strength *ex vivo* after measuring their bone mineral density (BMD). In particular, the effect of gender was studied when comparing the ability of densitometric variables (volumetric BMD and areal BMD, aBMD) and FE models in predicting bone strength.

Methods

Thirty-seven vertebral body sections and 36 proximal femora were dissected from cadaver donors and scanned together with a calibration phantom using QCT. The total volumetric BMD was estimated in each vertebral body and proximal femur. Each femur was scanned with a dual energy Xrays absorptiometry (DXA) to measure femoral neck aBMD and for each vertebra aBMD was computed by simulating a lateral DXA analysis from the 3D QCT images. Afterwards, the vertebral body sections [2] and proximal femora [3] were compressed quasi statically by means of a servo-hydraulic testing system to induce typical fractures observed in clinical practice. The QCT images were resampled (1.3 mm³ for vertebrae and 3.0 mm³ for femora) and the obtained voxels directly converted into hexahedral elements. Each element was considered as isotropic and heterogeneous and its material properties were determined as a function of its BMD. Material nonlinearities were based on the elastic-damage model developed by [4] and adapted as described in [3]. The applied boundary conditions reproduced the ones of the experiments. The failure load was computed for both experiments (Exp_Fu) and nonlinear hvFE (hvFE_Fu). The ability of the FE models and QCT BMD in predicting experimental bone fracture load for both females and males groups and for pooled data was investigated. Coefficients of determination (R²) are reported, but similar trends were found for standard error of the estimate.

Results

For pooled data, the FE models (femur, N=36: R²=0.85, vertebra, N=37: R²= 0.77) showed a better predictive ability compared to DXA aBMD (femur: R²=0.80, vertebra: R²=0.67) and QCT BMD (femur: R²=0.46, vertebra: R²=0.68). In particular, the predictions were systematically higher for the females groups compared to the males ones for FE (femur_M, N=17: R²=0.76, femur_F, N=19: R²=0.90, vertebra_M, N=24: R²=0.69, vertebra_F, N=13: R²=0.76), for DXA aBMD (femur_M: R²=0.71, femur_F: R²=0.84, vertebra_M: R²=0.57,

vertebra_F: $R^2=0.68$) and for QCT BMD (femur_M: $R^2=0.57$, femur_F: $R^2=0.71$, vertebra_M: $R^2=0.49$, vertebra_F: $R^2=0.70$).

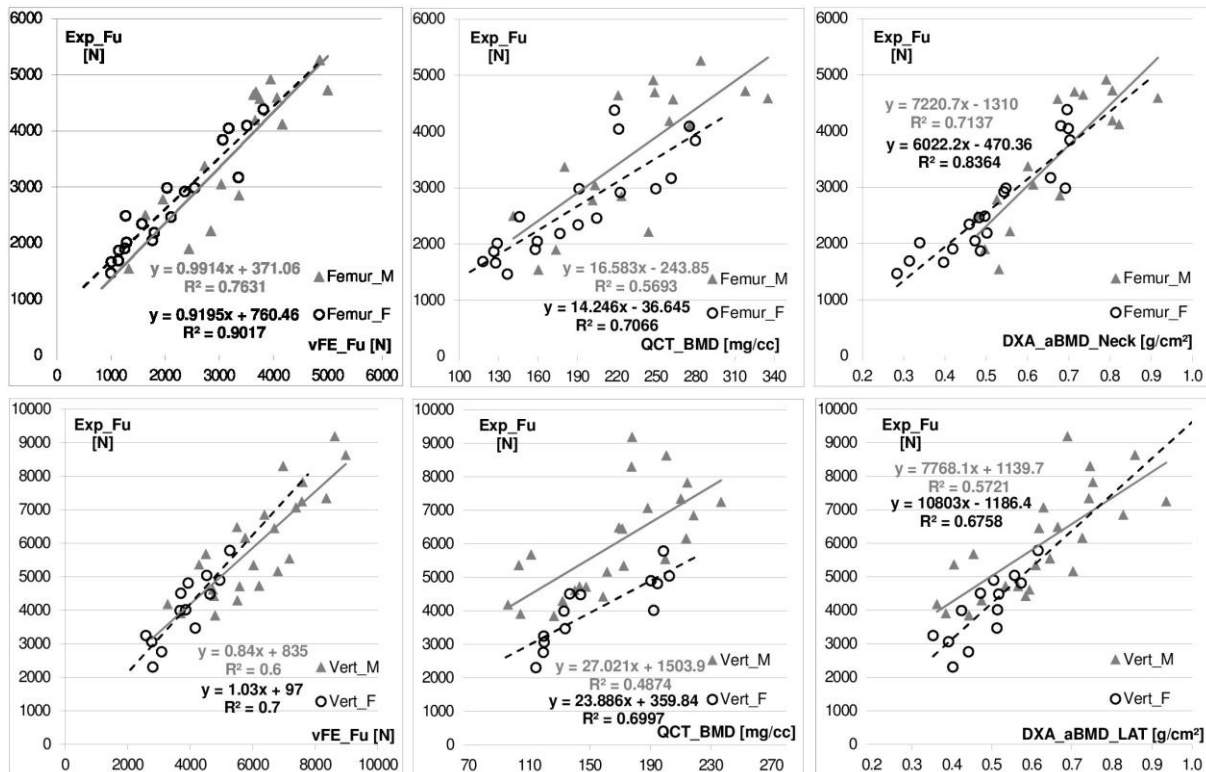


Figure 1: Predictions of experimental fracture load versus FE-computed (left), QCT BMD (centre) and DXA aBMD (right) for both vertebrae (below) and femora (above). The results are separated by females (F, open black circles) and males (closed grey triangles).

Discussion

The results of the present study show that the subject specific QCT-based hvFE model can predict vertebral and femoral fracture load with a fair accuracy also when separated for gender, and in particular, with a better accuracy compared to clinical BMD. The worse prediction of bone strength for male subjects suggests a possible dependency of the models to geometrical and dimensional bone properties. Therefore, this study underlines the importance of designing validation studies for a large sample size to evaluate possible effect of sample parameters.

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