Reliable p-FE analysis of the proximal femur validated by in-vitro experiments

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Abstract

Accurate methods for predicting and monitoring patient specific bone strength are of major importance in clinical applications but are nowadays very restricted. Numerous studies describe the generation of the femur's 3D model based on quantitative computerized tomography (QCT) scans with reasonable accuracy (but not satisfactory for clinical application). A novel high-order finite element method (p-FE) is suggested so that bone's geometry is represented by smooth surfaces accurately and the inhomogeneous elastic properties are evaluated according to a similar volume as the test specimens used for their estimation. For that purpose, the QCT data were processed following several steps, starting from bone borders detection at each CT slice, trough surface approximation, to solid body representation, and finally to mesh generation, see Figure 1.

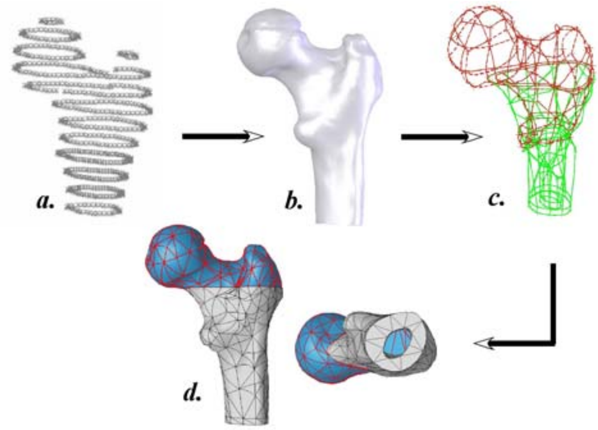

Fig. 1 The steps for generating the p-FE model: a. outer surface border points; b. approximated smooth surface; c. solid body having a cortical/trabecular separating surface; and d. meshed model with two different mesh regions.

An internal smooth surface is used to separate the cortical and trabecular regions upon which a p-FE auto-mesh is constructed. Within each region (cortical or trabecular) the QCT Hounsfield Units (HUs) are recalculated using a moving average method regardless of the FE mesh and inhomogeneous mechanical properties assigned by LMS approximations.

To validate the FE results (Figure 2) we performed mechanical in-vitro experiments on two freshly frozen femurs measuring head deflection and strains at several points – see Figure 3.

Two p-FE were created and their results were compared to the in-vitro experiments. Excellent correspondence was obtained between FE computed and measured strains and displacements. In Figure 4 we plot the strains and displacements computed by the FE model vs the ones measured in the experiments (each bone in a different graph). We performed a linear regression

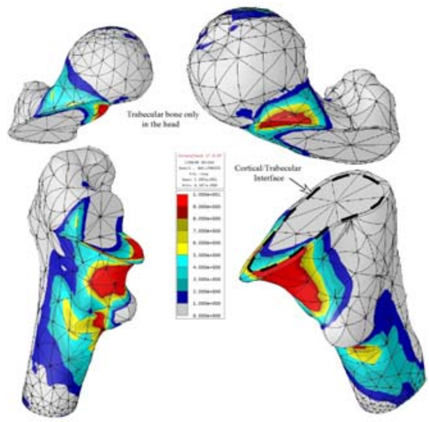

Fig. 2 von Mises stress [MPa] for a 1500 N load in one of the considered bone at 0 deg inclination angle which results in a slope of the regression line of about 0.94-0.95 (very close to one) and linear regression coefficient $R^2 = 0.97 - 0.98$ (the intercept is in percentage close to zero). The generation of the FE model, the isotropic and anisotropic material properties influence, and the comparison to the experimental observations will be presented [1,2].

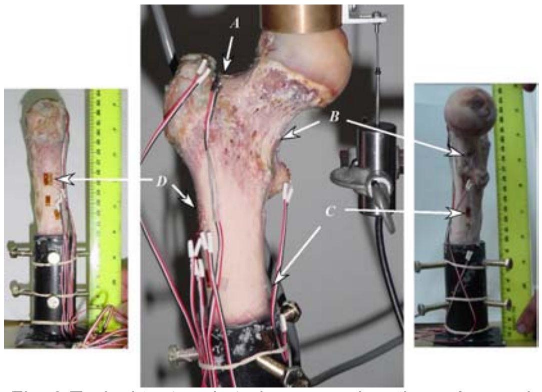

Fig. 3 Typical test and strain gauges locations: A. neck superior, B. neck inferior, C. shaft medial, and D. shaft lateral

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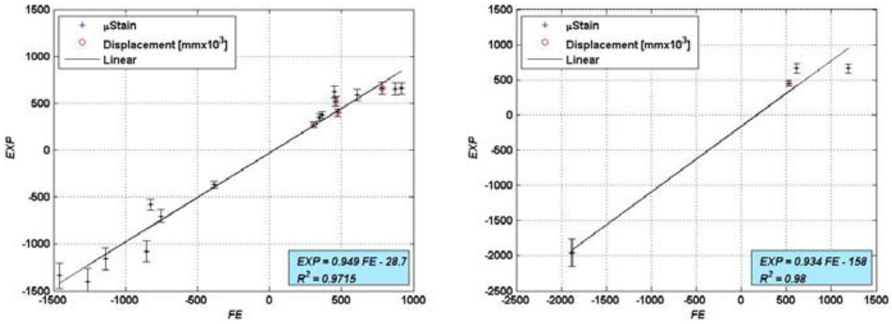

Fig. 4. Linear regression of predicted vs. measured displacement and strains for the two bones. Left and Right graphs represent two different human proximal femurs addressed.

References

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[2] Z. Yosibash, N. Trabelsi & C. Milgrom, "Reliable simulations of the human proximal femur by high-order finite element analysis validated by experimental observations", *J. Biomechanics,* to appear, 2007.