MIXED UNIFORM BOUNDARY CONDITIONS IMPROVE HOMOGENIZED FE MODELS OF BONE-SCREWS AND INVERSE REMODELLING

Dieter H. Pahr (1, 2), Sebastian Bachmann (1), Alexander Synek (1)

1. Institute of Lightweight Design and Structural Biomechanics, TU Wien, Vienna, AT
2. Division Biomechanics, Karl Landsteiner University of Health Sciences, Krems, AT

Introduction

In the field of numerical bone biomechanics, either micro finite element model (μFE) or homogenized FE models (hFE) are used. The latter requires a material law that translates the information on the micro level into effective material behavior on the macro level. Different trabecular bone material models can be used, including orthotropic and isotropic material derived from homogenization based on kinematic uniform boundary conditions (KUBC) as well as periodicity-compatible mixed uniform boundary conditions (PMUBC) [1]. There are a number of studies that have described both [2] for stiffness or bone strength predictions. This work focuses on the question which kind of boundary condition is better suited in case of screw-bone construct and inverse bone remodeling algorithms. The gold standard are μFE models of the same construct or bone.

Material and Methods

Screw-bone construct stiffness: 15 cylindrical bone specimens with 18 mm diameter were extracted from micro CT scans of human distal radii and a screw was virtually inserted (Fig. 1, top). In the hFE models, isotropic and orthotropic trabecular bone material models either from KUBC or PMUBC-derived homogenized were assigned and the constructs were loaded in three load configurations. Structural stiffness and the error between μFE and hFE was evaluated.

Inverse bone remodeling (IBR) of proximal femora: micro FE and hFE models were created based on micro-CT scans of 19 femoral bones (Fig. 2, top). In analogy to the screw-bone samples, trabecular bone material was assigned using ortho- or isotropic material either from KUBC or PMUBC-derived homogenization. hFE-based IBR [3] was then applied to predict the loading history, which was discretized using four unit load cases. μFE and hFE model predictions were compared using the relative root mean square error (RMSE).

Results

Screw-bone constructs: Stiffness was predicted most accurately using PMUBC-derived orthotropic material (error: -0.7±8.0%) and least accurately using KUBC-derived isotropic material (error: 23.1±24.4 %) (Fig. 1, bottom).

IBR of proximal femora: The loading history was predicted most accurately using PMUBC orthotropic (RMSE: 14.2±2.4%) and least accurately using KUBC orthotropic material (RMSE: 20.5±3%) (Fig 2., bottom).

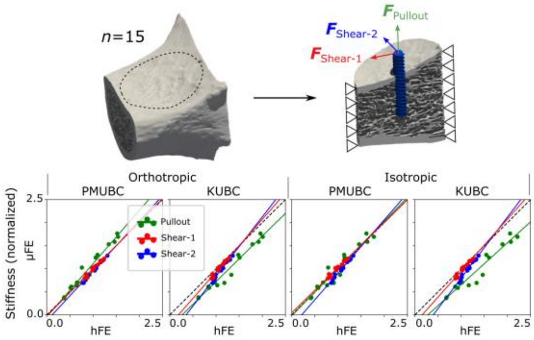

Figure 1: Screw-bone stiffness comparison.

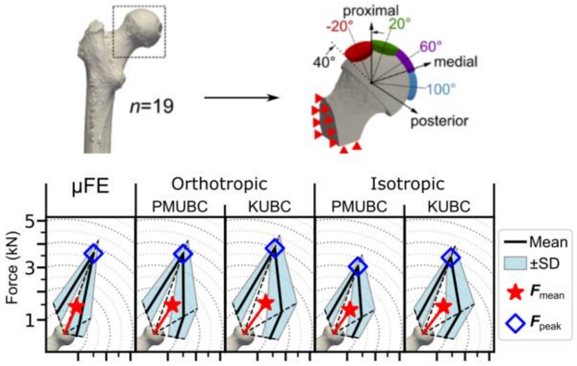

Figure 2: Inverse bone remodeling on proximal femur

Discussion

Both for screw-bone construct stiffness and hFE-based IBR, the results showed sensitivity towards the choice of boundary conditions used for homogenization. In both use cases, PMUBC-derived trabecular bone material properties showed better agreement with the μFE reference models, irrespective of material symmetry (iso-/orthotropy). This agrees with a previous study suggesting closer agreement of PMUBC-derived material properties with effective material properties [4]. Including orthotropy only slightly improved the predictions in both use cases. However, these results are not generally transferable and should be checked once for other hFE studies and models.

References

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