TOWARDS UNBIASED AND ACCURATE SIMULATIONS OF SCREW-BONE CONSTRUCTS WITH HOMOGENIZED FE MODELS

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Introduction

Homogenized finite element (hFE) models are increasingly used to investigate internal fixation of complex bone fractures with plates and screws. However, using hFE models for this purpose has also been criticized, especially if the screws are anchored in trabecular bone [1]. That is due to the many inherent simplifications, such as modelling trabecular bone as a continuum, and simplifying the screw thread geometry. Validating hFE models of screw-bone constructs based on experiments is challenging, as a lot of error sources are mixed and can hardly be separated (e.g. error due to homogenization, screw insertion damage, screw-bone contact). This might lead to biased models and could explain why some studies report good agreement with experimental results [2], while others do not [1]. In this study, we assessed hFE model accuracy using µFE models rather than experiments as a reference to delineate and control different error sources. As a first step, this study was limited to osseointegrated screws to exclude the effect of screw insertion damage and contact. hFE models were built based on "best evidence" without parameter tuning to avoid model bias.

Methods

15 cylindrical bone samples with 18 mm diameter were cut out of µCT scans (32.8µm voxel size) of human distal radii (Fig. 1, [3]) and a screw was virtually inserted. Linear elastic µFE models were created including the screw thread geometry, bone microstructure and a fully bonded screw-bone interface. hFE models were created by separating cortical and trabecular bone and replacing the screw with a smooth cylinder. Linear elastic material properties were mapped to the screw, cortex (density-dependent), and trabecular bone (density- and fabric-dependent). Material constants for trabecular bone were obtained from a previous study using µFE-based homogenization [4]. A force of 100N was applied to the screw to simulate three load cases (pullout, shear in two directions) (Fig. 1).

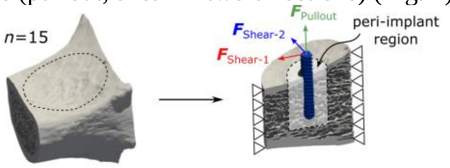

Figure 1: Sample extraction and boundary conditions.

Stiffness and average strain energy density (SED) in the peri-implant region were assessed. Accuracy between hFE and µFE was evaluated using the relative error and concordance correlation coefficient (*CCC*). To delineate error sources, additional comparisons were performed: 1) µFE models with vs. without screw threads 2) µFE vs. hFE models with homogeneous material.

Results

The stiffness predicted by the hFE models was in good agreement with µFE models (error: -0.7±8.0%; *CCC*: 0.98) (Fig. 2). Slightly lower accuracy was achieved for peri-implant average SED (error: +8.6±16.3%; *CCC*: 0.96) and SED distributions did not always match between µFE and hFE models (Fig. 2). The delineation of error sources showed low overall errors both for neglecting screw threads (mean: 1.3%) and µFE vs. hFE models with homogeneous material (mean: 1.3%).

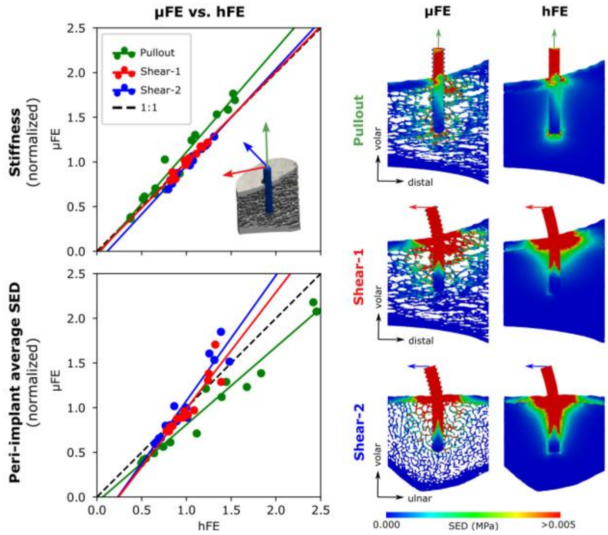

Figure 2: Correlation of hFE with µFE results (left) and SED distributions in one sample (right)

Discussion

This study showed that "best evidence" hFE models can provide reasonably accurate predictions of osseointegrated screw-bone construct stiffness relative to µFE models, even without parameter tuning. Averaged peri-implant SEDs were also captured with good accuracy, but the SED distribution could not be reproduced. Although this study has many limitations, the methodology could be extended step by step, e.g. by including material nonlinearity, contact and screw insertion damage separately into the models. Ultimately, this approach could provide a way towards unbiased and accurate hFE models of screw-bone constructs.

References

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