SIMPLIFIED SCREW-BONE INTERFACE MODELS FOR COMPUTATIONALLY EFFICIENT µFE SIMULATIONS

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Introduction

The realistic representation of the bone-screw interface is a challenging task and various approaches have been proposed. Computationally-intensive nonlinear µFE models [1] are able to model contact conditions including friction but are limited to small model sizes. Linear, computationally-efficient µFE models typically assume fully bonded screw-bone interfaces [2]. In order to realize contact in huge µFE models while maintaining computational efficiency, Steiner et al. [2] developed a simple technique which is based on the deletion of interface elements under tension. However, this technique may over-simplify the contact condition and has not been compared to general nonlinear contact µFE models. The goal of this study was to compare a well-known ABAQUS contact model to the Steiner model [2], a modified Steiner model, and a classical linear µFE model of a bone-screw.

Methods

Segmented µCT images of two human radius segments and a screw were used. The two specimens differed in their bone volume fraction (0.3 vs 0.17). Both specimens were cropped to a square cross section of ~9mm edge length and a height of ~15mm. The screw was digitally inserted with insertion depths of 50% and 100% of bone height (Fig. 1a). All images were resampled to 65.6µm resolution and voxel-based µFE models were generated. Three different loading scenarios were simulated (pull-out, compression and shear loading) by applying a displacement of 0.1mm to the top nodes of the screw (Fig. 1b). Linear-elastic, homogeneous material parameters were assigned to all materials. The reference model was a general contact model (hard contact with friction coeff. of 0.5, C) which was compared to fully bonded models (FB), tensionally-strained element deletion models (TED) from Steiner et al. [2] and a modification of TED (TED-M). The TED method involves deleting all bone-screw interface elements that experience positive volumetric strain in a single pre-simulation. TED-M allows for load redistribution of the interface elements by determining tensionally-strained interface elements in an iterative process prior to deletion. The forces at final displacement of FB, TED and TED-M were compared to those of C. All simulations were performed with ABAQUS Implicit (FB, TED, TED-M) and Explicit (C).

Results

For all load cases, all tested samples showed an overestimation of force when comparing FB to C (8% - 36%). For TED and TED-M the force difference to C was reduced and reached values between -8% and 8%. The mean force difference was slightly lower for TED-M (1.9%) than for TED (2.1%) (Fig. 2).

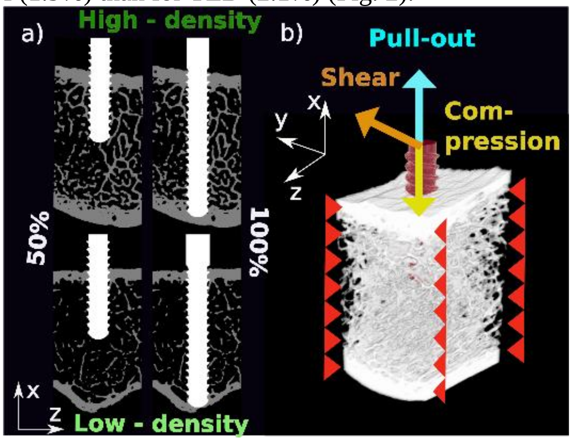

Figure 1: Evaluated samples (a) and load cases (b).

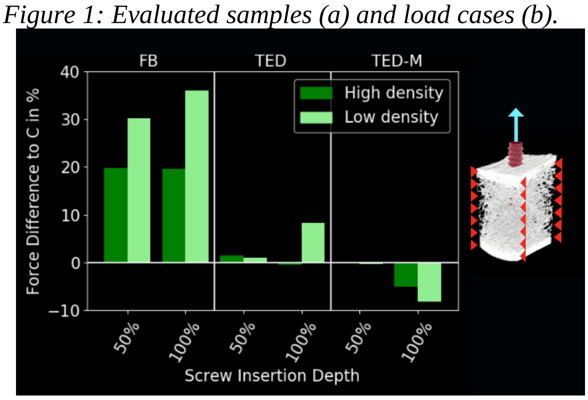

Figure 2: Comparison of force at final disp. for pull-out.

Conclusion

The use of the FB interface led to a considerable overestimation of the resultant force, indicating that contact modeling is important for accurate µFE simulations of bone-screw constructs. In order to reduce computational effort, simple algorithms (TED & TED-M) applied to linear µFE models can efficiently replicate contact with much less error. The iterative algorithm (TED-M) could only marginally improve the accuracy compared to the even more efficient TED. However, further research using larger or higher-resolution samples is needed to fully demonstrate the efficiency and accuracy of these algorithms. It is important to note that the findings of this study are based solely on computer simulations and still require experimental validation.

References

1. Ovesy et al, J Mech Behav Biomed Mater 126: 105002, 2022
2. Steiner et al, J Orthop Res 35:2415-2424, 2017