HOMOGENIZED FE MODELS CAN PREDICT HIP JOINT LOADING USING INVERSE BONE REMODELING AT THE FEMORAL HEAD

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Introduction

Physiological loading conditions are required for a multitude of problems, e.g., patient-specific finite element (FE) models can benefit from individualized and realistic loading conditions. Inverse bone remodeling (IBR) is a method to obtain such loading conditions by predicting the loading history directly from the bone microstructure. However, so far IBR required high-resolution CT images and micro-FE (µFE) models [1]. Thus, it was not applicable *in vivo* at most skeletal sites, time consuming, and the complexity of the models was limited given the constraints of specialized µFE solvers (e.g., no contact boundary conditions). To mitigate these shortcomings, we recently translated it to homogenized FE (hFE) [2], which works with clinical CT scans, reduces the computational effort and enables the use of standard FE solvers. The goal of this study was to replicate previous µFE-IBR hip joint loading predictions [3] using the new hFE-IBR method. Furthermore, our goal was to investigate how much material information is required in the hFE model for the loading history prediction.

Methods

In brief, IBR finds the loading history by using a finite set of unit-loads, that are combined and optimally scaled until a homogeneous tissue loading state is reached [1]. In this study, IBR was performed on a set of 19 femoral heads. Four unit-load cases were defined (Fig 1a), and µFE-IBR was applied, as described previously [3]. Additionally, hFE-IBR was performed on four model types with decreasing material information (Fig 1b): density- and fabric-dependent (ORTHO), density-dependent (INHOM), separate homogeneous cortical and trabecular material (HOM_HOM), and single homogeneous material (HOM). The new hFE-IBR algorithm was then used to predict the loading history, peak, and mean force. The root mean squared error (RMSE) of the loading history was calculated for each hFE model, using µFE-IBR as the baseline, and normalized by the µFE predicted peak force to get a relative RMSE.

Results

The average CPU-time for hFE-based predictions (50s) was considerably lower compared to µFE-based predictions (500h). The loading history converged towards the µFE model with increasing material information (Fig 1c). All hFE models except HOM were able to predict the same peak force direction as µFE (20°). The peak force magnitude decreased with decreasing material information. Mean force magnitude was relatively insensitive to the selected material model, but the angle tilted more and more towards the 60° load case with decreasing material information. The relative RMSE were: ORTHO 14.2±2.3%, INHOM 14.9±4.1%, HOM_HOM 32.3±4.4%, HOM 40.8±5.5 %.

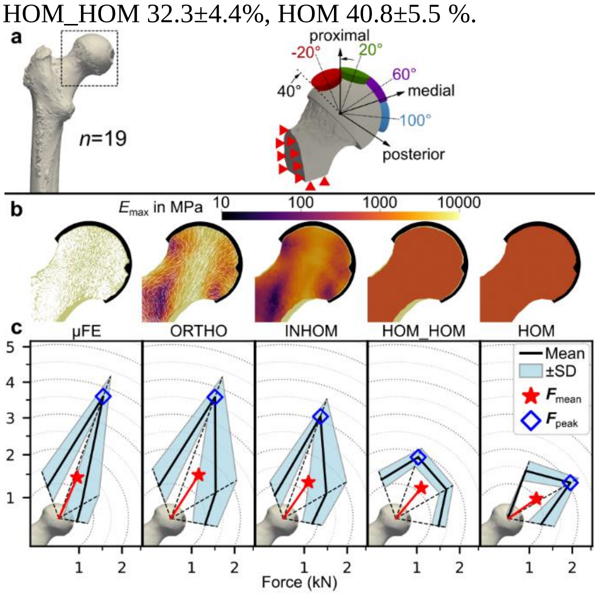

*Figure 1: (**a**) Model region and unit-load cases. (**b**) Material mapping. (**c**) Predicted loading history.*

Discussion

The loading history at the hip joint was successfully predicted using hFE-based IBR, with a mean relative RMSE of less than 15% compared to µFE-IBR and considerable reduction in computational effort. The usage of at least density-dependent material was essential for accurate predictions, whereas including fabric information improved the predictions only slightly. To summarize, hFE-IBR shows the ability for extremely fast loading history predictions at the price of a small error in the prediction. These results suggest that hFE-IBR can be used with clinically-available CT images and smooth meshes [4], which offer the application of realistic load cases (e.g., contact) in the future.

References

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