INFLUENCE OF LOADING CONDITION ON THE ABILITY TO PREDICT HUMERAL STRESS SHIELDING

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Introduction

Stress shielding around the humeral stem is a potential complication after total shoulder arthroplasty. Clinical studies have highlighted that a large relative stem size (RSS) tended to increase bone resorption [1,2]. In silico clinical trials (ISCT) have been proposed to enrich clinical data for device performance assessment. The aim of this study was to evaluate the influence of loading conditions on humeral stress shielding predictions for ISCT when compared to existing clinical data.

Materials and Methods

A benchtop validation of a similar model was performed per the ASME V&V40 to ensure that the physics were captured accurately. For ISCT, we added a clinical validation aiming to reproduce clinically reported cortical thinning in the superior lateral cortex with a larger RSS [1].

A cohort of 34 virtual humeri was taken from an internal 3D bone database, and virtual surgery was performed with the same implant as the clinical study (Bio-Modular shoulder stem, Zimmer Biomet) (Fig. 1A-C). To study the influence of RSS, a stem size matching the size of the humeral canal as well as one size larger was implanted. The implanted bones were imported to a finite element (FE) software for meshing, contacts definitions and application of boundary conditions representative of daily usage (Fig. 1D-F). Bone material properties were assigned from the CT-based bone density information (Fig. 1E). The loading included two different conditions: 1.) the “JRF-only” included the humeral joint reaction forces (JRF) at three different abduction angles; 2) the “full loading” additionally included the major muscles forces (Fig. 1F) [3,4].

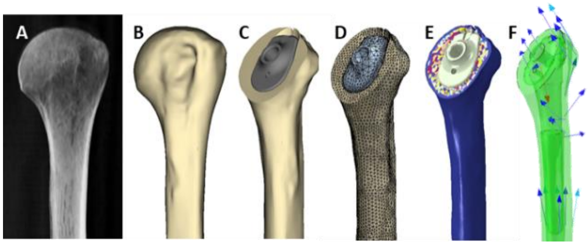

Figure 1: Steps for creation of FE models

Stress shielding was assessed by comparing the change in strain energy density (SED) between the intact and implanted bone in the same four regions of interest as in the clinical study [1] (i.e. lateral (L1 ($^1/_3$), L2 ($^2/_3$)) and medial (M1, M2) aspect of the humeral stem, Fig 2.A). The models were then divided into two groups with (S+) and without (S-) stress-shielding as in [1].

Results

In the group of patients with severe stress shielding (S+), the most cortical thinning was observed in the proximal lateral aspect of the humeral stem (L1) followed by the proximal medial aspect (M1) [1] (Fig. 2A). With the “full loading” boundary condition, the same trend was replicated with the highest reduction in SED observed in the locations L1 followed by M1 (Fig. 2B & Fig. 3), whereas the “JRF only” condition could not replicate the clinical finding, with the largest change in SED observed in the location M1 (Fig. 2C). For both loading conditions, the S+ group had larger RSS compared to the S- group, which agreed with the clinical study.

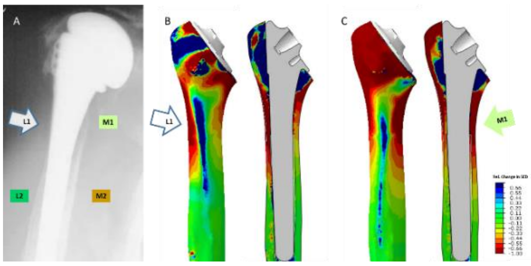

Figure 2: Examples of cortical thinning [1] (A) and change in SED with full loading (B) and JRF only (C).

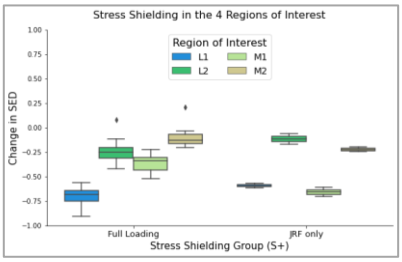

Figure 3: Change in SED in the stress shielding group (S+) with full loading and JRF only.

Discussion and Conclusions

The choice of loading conditions highly influenced the prediction of stress shielding. Applying “JRF-only” could not fully replicate the clinical findings. Including the muscle forces, the pattern of stress shielding around the humeral stem occurred in similar locations as observed clinically. Based on these findings, we consider our modelling approach appropriate for ISCT evaluations of stress shielding in the humerus.

References

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