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SENSITIVITY ANALYSIS OF A PATIENT-SPECIFIC FINITE ELEMENT MODEL OF SHOULDER ARTHROPLASTY

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Summary: Finite element models replicating total shoulder arthroplasty (TSA) are getting more and more sophisticated, with a clear tendency towards patient-specific modeling. This approach requires several steps, with specific uncertainties for each of them. Our objective was to investigate the sensitivity of a CT-based model replicating an 80-year-old female patient with glenohumeral osteoarthritis treated with TSA.

The sensitivity analysis focused on assumed uncertainties in the model creation process: 1) systematic error (-2%, 0, +2%) of CT numbers (in Hounsfield Units), 2) Gaussian filter parameter (0.1, 5, 20), 3) trabecular bone constitutive law (Keller's law [1], Zysset's law [2]). A full factorial design of experiment (DOE) method was used to investigate variations in bone octahedral shear strain, bone axial strain, cement von Mises stress, and cement axial strain. In total, 8 simulations and four DOE runs were performed. The DOE factors (DOEf) ranking the input parameters in order of importance were extracted.

Bone octahedral shear and axial strains were highly sensitive to constitutive law: DOEf = -30% and -18%, respectively. Bone strain was much less sensitive to Gaussian filter (DOEf <= 4%) and to CT number errors (DOEf <= 6%). For most tests, Zysset's law predicted lower bone strain values than Keller's. Cement stress was slightly altered by all parameters (DOEf <= 3%). Cement strain was mostly altered by the combination of constitutive law and CT number errors (DOEf <= 10%), as well as the combination of Gaussian filter and CT number errors (DOEf <= 10%). The analysis of variance performed with 95% confidence interval revealed significant results for bone octahedral shear strain ($p < 0.001$), bone axial strain ($p = 0.028$), cement stress ($p = 0.006$), but not significant for cement axial strain ($p = 0.22$).

The present work showed that the trabecular bone constitutive law had the largest impact on bone strain, while cement strain was nearly not altered. Our study helped identify sources of highest uncertainties in a multi-step patient-specific model generation. We conclude that the CT imaging process is sufficiently accurate, while efforts need to be focused towards a validated constitutive law of trabecular bone.

References

[1]Keller1994 [2]Latyopva 2016.JBiomech