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Determining Stress Relaxation of Trabecular Bone to Simulate Realistic Press-Fit Conditions of Cementless Implants

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Introduction

Accurate modeling of bone-implant interfaces and the primary stability of implants depend on accurate material properties. The trabecular bone is generally modelled as a linear elastic material, with the Young's modulus being related to the density of the bone. However, in reality the mechanical response of trabecular bone is time-dependent, displaying a distinct stress-relaxation response. Therefore, bone should be modelled as a viscoelastic material, with a response that varies with the strain level. To our knowledge, nonlinear stress relaxation of trabecular bone has not yet been quantified in relation to bone mineral density, which may influence the primary fixation of orthopaedic implants. In this abstract we present the preliminary results of stress relaxation experiments on bovine femoral bone.

Methods

Eight trabecular bone cylinders were harvested from distal bovine femora under 30 months of age. Before mechanical testing, computed tomography (CT) scans were made to determine the bone mineral density. Mechanical experiments were performed with a servo-hydraulic MTS. The samples were pre-conditioned at 0.1% strain for ten cycles, and were then allowed to recover for 30 minutes. Stress relaxation experiments were then conducted by applying a uniaxial compressive strain ranging from 0.2% to 0.8% for 24 hours. A water basin filled with physiological saline at 37°C was used to keep the specimens hydrated during the mechanical testing.

Results

After 24 hours, stress relaxation ranging from 43.3 to 66.5% was observed which can be seen in Figure 1. Large proportions of stress relaxation occurred in the first 10 minutes in which the maximal peak force decreased by 25.6 to 48.3% (Figure 2).

Conclusion

The initial results show that stress relaxation up to almost 50% already occurs after 10 minutes, which in clinical practice is still during surgery. This viscoelastic behavior can have implications for the primary fixation of press-fit implants, and the magnitude of the micromotions occurring at the implant-bone interface. We previously found that the initial mechanical conditions at the interface have a significant effect on interface micromotions. For instance, computational models using linear elastic bone material properties typically predict interface micromotions that are much smaller relative to experimental findings. Adding plasticity to the material model increases the micromotions, but still leads to an underestimation of the micromotions [1]. The addition of viscoelastic bone material response to the models may contribute to achieving a more realistic prediction and simulation of the primary fixation of press-fit implants.

We here present preliminary experimental results. Further testing will illuminate the relation between bone mineral density and viscoelastic response. The next step is to incorporate the viscoelastic behavior in finite element simulations of primary fixation of femoral and tibial total knee arthroplasty components to demonstrate the influence of bone relaxation on primary fixation, which may further optimize the implant design process.

References

[1]: S. Berahmani et al. J. Biomech. (2017), http://dx.doi.org/10.1016/j.jbiomech.2017.07.023

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Figures

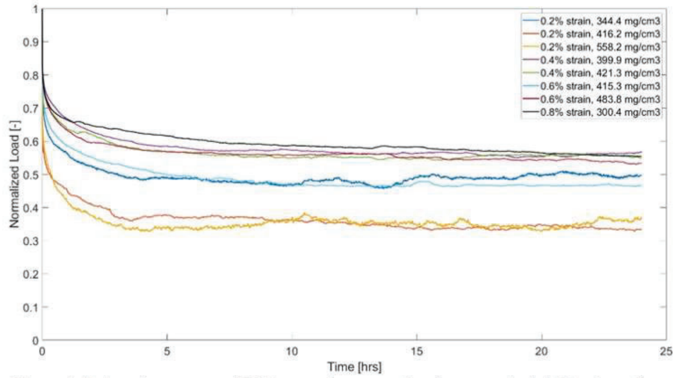

Figure 1: Relaxation curves of 24 hours, after normalization over the initial value of axial load, at different values of the preset strain.

Figure 1

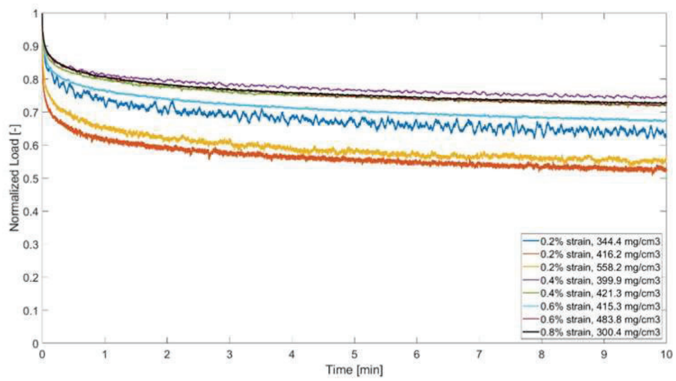

Figure 2: Relaxation curves of the first 10 minutes of the executed experiments, after normalization over the initial value of axial load, at different values of the preset strain.

Figure 2