DETERMINING STRESS RELAXATION OF TRABECULAR BONE TO SIMULATE PRESS-FIT CONDITIONS FOR CEMENTLESS IMPLANTS

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Introduction

Accurate modelling of bone-implant interfaces and the primary stability of implants depends on accurate material properties. The trabecular bone is generally modelled as a linear elastic material, while in reality the mechanical response of trabecular bone is time-dependent. Therefore, bone should be modelled as a viscoelastic material, with a response that varies with strain level. To our knowledge, nonlinear stress relaxation of trabecular bone has not yet been quantified in relation to bone mineral density (BMD), which may influence the primary fixation of orthopaedic implants. In this work, we present data of stress relaxation experiments of bovine bone.

Methods

34 Trabecular femoral bovine bone cylinders were harvested. Stress relaxation experiments on 16 samples were conducted by applying a uniaxial compressive strain (0.2 – 0.8%) for 24 hours to determine the test duration for the multiple stress relaxation experiments. The other samples were compressed with 0.2% strain for 30 minutes, after which they were stored to recover for 24 hours. This sequence was repeated on each sample for 0.4, 0.6, and 0.8% strain. Data of the 30 min experiments was extrapolated to 24 hours.

Results

After 24 hours, stress relaxation ranging from 41.0% to 68.7% was observed (Figure 1). Up to 52.9% of this stress relaxation occurred in the first 10 minutes. Extrapolating at different time points showed that accurate predictions could be made at 30 minutes, allowing for reduced experimental testing time.

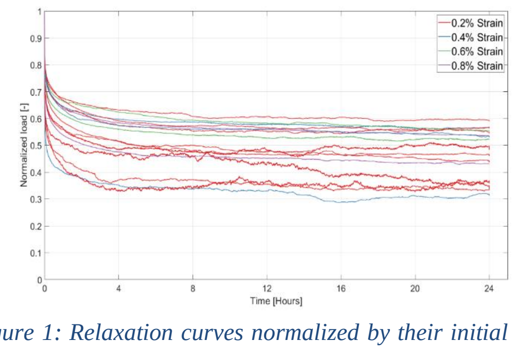

Figure 1: Relaxation curves normalized by their initial axial force, at different values of constant strain.

No relevant relation was found between BMD (ϕ) and time-dependent behaviour, which resulted in Equation 1, an adapted multiple superposition model (MSM).

The parameters in Table 1 originate from the repeated stress relaxation data.

$$\sigma(\phi, \varepsilon, t) = (A\varepsilon + (B * \phi^C + D)) * \varepsilon t^{E\varepsilon^F + G} \quad (1)$$

Parameters		
A = 4.34 x 10^4	D = 669.6	G = -0.039
B = -5.14 x 10^{10}	E = -3.63 x 10^{-6}	
C = -3.61	F = -1.35	

Table 1: Parameters for the stress function $\sigma(\phi, \varepsilon, t)$.

The use of Eq. 1 resulted in an average RMSE of 0.91 MPa and is displayed for one sample in Figure 2.

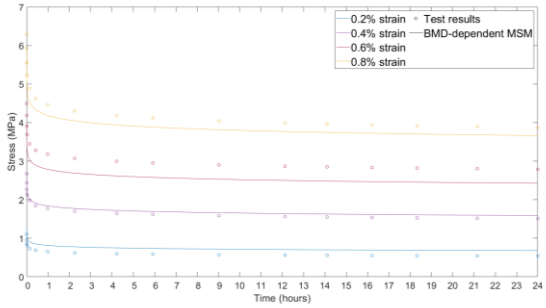

Figure 2: Experimental stress relaxation in comparison with predictions of Eq 1. Sample has a density of 375.3 mg/cm3.

Discussion

Most of the stress relaxation occurs within 10 minutes, which in clinical practice is still during surgery. However, stress relaxation continued even after 24 hours of testing. It is therefore important to model the viscoelastic behaviour up to 24 hours, which our newly developed viscoelastic model is capable of. The viscoelastic model is able to capture the nonlinear stress dependency and includes the influence of the BMD on the stiffness. BMD did not influence the time-dependent behaviour. Further testing will investigate the relation between BMD and the viscoelastic response for both bovine and human trabecular bone.

Incorporating this viscoelastic behaviour in simulations of primary fixation in arthroplasty components will establish the influence of bone relaxation on primary fixation.

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