# Trabecular bone shows more viscoelasticity than earlier reported; an experimental and finite element study

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## INTRODUCTION

Accurate modelling of the initial stability of cementless implants requires an accurate representation of the mechanical properties of the bone. While trabecular bone is commonly simulated as a linear elastic material, its mechanical response is actually time-dependent, displaying a distinct stress-relaxation response. Despite being often ignored, the viscoelastic behavior of bone could play a significant role in the analysis of the primary stability of cementless implants, as it affects the stresses at the implant-bone interface. In this study, experimental stress relaxation experiments were performed and replicated within a finite element modelling framework to demonstrate the effective integration of the viscoelastic behavior of trabecular bone.

## METHODS

31 Femoral and 33 tibial trabecular bone cylinders were harvested from 6 donor cadavers (5 female, age range: 53 – 90). The cylinders were compressed for 30 minutes at 0.2, 0.4, 0.6 and 0.8% strain. After each applied strain level, the samples were allowed to recover for 24 hours. A water basin filled with physiological saline at 37°C was used to keep the specimens hydrated during the mechanical testing. All experimental data was extrapolated to 24 hours, and a multiple superposition model was fit. Subsequently, the stress relaxation experiments were replicated within FE software (MSC.Marc/mentat 2023.1) in which the bone was simulated as viscoelastic, using a custom user subroutine. The stiffness of the individual elements was assigned based on the BMD obtained from calibrated CT scans of the bone samples.

## RESULTS

After extrapolation of the experimental data, an average stress relaxation of 54.0% (range 38.5% - 81.6%) was observed (Figure 1). Femoral and tibial samples showed similar levels of stress relaxation. The substantial degree of variability in the level of stress relaxation could not be explained by the applied strain level nor by the bone density of the specimens. Moreover, no correlation was found between the BMD and the stiffness of the bone specimens. The mean stress relaxation response was therefore integrated in sample-specific FE simulations, in which the stiffness was assigned based on equations by Keyak et al. [Keyak, 2005]. The implementation of stress relaxation is shown for one specific sample (strain 0.6%) in Figure 2. Figure 3 shows the experimental and simulated stress relaxation for all tested specimens, at all strain levels, with an implemented viscoelastic law that was based on the average stress relaxation as seen in the experiments.

## DISCUSSION

This study shows that the amount of stress relaxation occurring in human trabecular bone is more than earlier reported. Since we were unable to formulate a viscoelastic material law with strain and BMD dependency, an equation based on the mean level of stress relaxation derived from our experiments was combined with an existing well-established density-based model describing the bone stiffness. Although this caused an overestimation of the stiffness relative to the experiments, this combination proved successful in demonstrating stress relaxation in FE models and was able to capture the variability observed in the 64 femoral and tibial specimens.

Our next step is to implement the viscoelastic behavior of the trabecular bone in finite element simulations of the primary fixation of femoral and tibial arthroplasty components to demonstrate the influence of bone relaxation on the initial stability, thereby potentially refining the implant design process.

## SIGNIFICANCE/CLINICAL RELEVANCE

The current work contributes to improving analytical tools to study the initial stability of press-fit implants before ingrowth has occurred, with the ultimate goal of providing total joint replacement systems that last a lifetime, even for young and active patients.

## ACKNOWLEDGEMENTS

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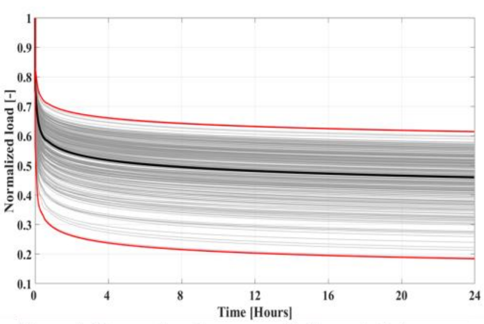


*Figure 1: Stress relaxation curves of all executed stress relaxation experiments. The black line indicates the average level of stress relaxation, while the red lines show the minimal and maximal stress relaxation curves.*

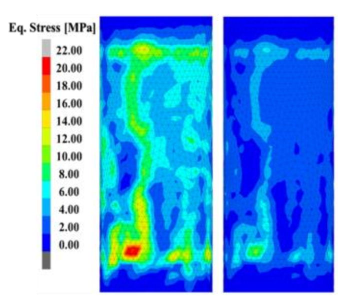


*Figure 2: Equivalent stress maps of a bone specimen that is compressed with 0.6% strain at T = 0 and after 24 hours of relaxation.*

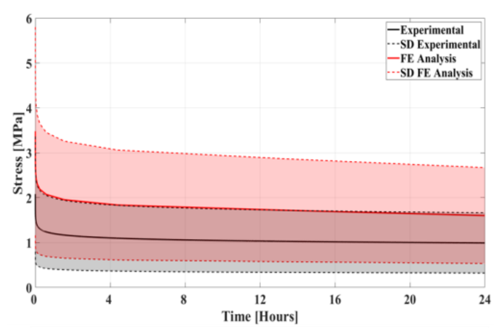


*Figure 3: Average stress relaxation behavior of the experimental data and data from the finite element simulations plotted with their corresponding standard deviation.*