INVESTIGATING THE INTERVERTEBRAL DISC'S CREEP BEHAVIOUR THROUGH MATHEMATICAL MODEL. AN IN VITRO STUDY

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Introduction

The intervertebral disc (IVD) is a complex biological structure due to its biphasic and viscoelastic properties that acts as a shock absorber allowing high loads and maintaining the spine mobility and flexibility. This involves relationships between external loads and the disc mechanobiology [1]. Nevertheless, although the viscoelastic properties of the IVD are a discussed topic, they are still not fully understood today. [2]. New insights are researched by modelling the IVD creep behavior. Investigating the biomechanical response of IVD to long-term loads is critical since it influences nutrient and water transport, i.e., hydration. The aim of this *in vitro* study is to describe the intermediate characteristics between solid and fluid of the IVD by using different mechanical constitutive models.

Methods

Eight human frozen lumbar segments (L4-5) with an average age of 48 years (range: 38-58) and with no signs of degeneration were used. The specimens were prepared and embedded in PMMA and then fixed in a universal spine tester [4]. A creep test was performed with an axial compression load of 500 N for 15 minutes. The disc height reduction (DHR) was evaluated by using different rheological models and Nutting's power law (Fig. 1) (Wolfram Mathematica v13.). A correlation analysis was performed between the model parameters and the maximum value of DHR (RStudio).

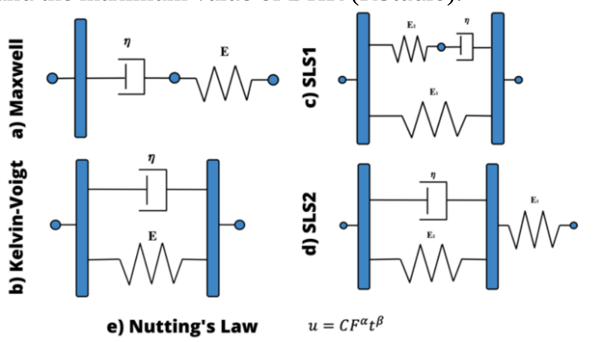

Figure 1. a) Maxwell: spring in series with dashpot; b) Kelvin-Voigt: spring in parallel with dashpot; c) SLS1: Kelvin-Voigt in series with spring; d) SLS2: Maxwell in parallel with spring; e) Nutting's Law

Results

An immediate reduction in IVD height from the initial values (mean value 0.94 mm) was observed from the creep curves. After 15 minutes of creep, the disc height decreased by an average of 1.14 mm (min: 0.91 mm and max: 1.44 mm). By fitting the data, it was found that the Maxwell and Kelvin-Voigt models do not fit the data, while the SLS1, SLS2 ones and Nutting's law seems to be the better fit (Fig. 2). Correlation matrices were calculated, identifying Pearson's significant values (r, $p < 0.05$). An important finding is the linear regression identified between stiffness and the maximum value of the DHR for the SLS1 model ($r = -0.93$, with $R^2 = 0.84$) and for the SLS2 ($r = -0.93$, with $R^2 = 0.97$).

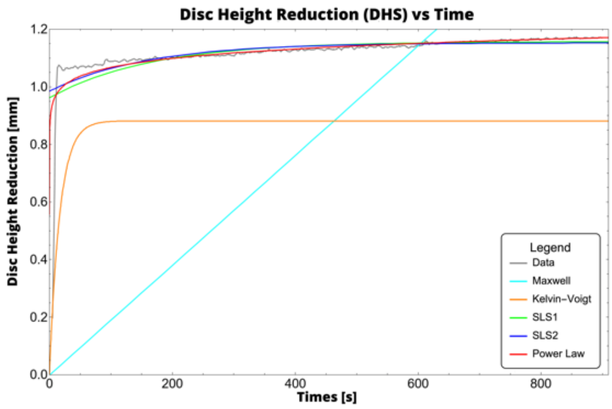

Figure 2. Example of fitting the creep curve. Legend: Raw data in Gray; Maxwell in Cyan; Kelvin-Voigt in Orange; SLS1 in Green curve; SLS2 in Blue; Nutting's Power law in Red.

Discussion

From the creep curves modelled with the rheological models and Nutting's law, it is clear that the link between DHR and time is not linear. SLS1 and SLS2 capture well the regime trend of data but not the upward ramp. The Nutting's law seems to be the best fitting because it captures the total creep curve, and its formulation considers the biphasic properties of IVD. However, the fitting is not always successful. Hence, a biphasic model should be designed considering the direct link between external loads and the mechanobiology of IVD. Limitations include the creep time, the lack of a histological study to assess the water content, and that these mathematical models do not consider the cellular aspects. This in vitro study shows how necessary it is to find a mathematical model for the creep behavior of the IVD so that its mathematical and mechanical link between the macroscopic and cellular levels can be assessed.

References

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