The influence of strain rate on the viscoelastic properties of duck oesophageal tissue

Karol Marcula[1,]*, Jarosław Filipiak[1]

[1]Department of Mechanics, Materials and Biomedical Engineering, Mechanical Faculty, Wrocław University of Science and Technology, Wroclaw, Poland
e-mail: karol.marcula@pwr.edu.pl

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The oesophagus is an organ with a complex tissue structure, exhibiting nonlinear and viscoelastic mechanical behaviour. This response arises from the presence of structural components with distinct properties and their mutual interactions. Understanding the stress relaxation behaviour of oesophageal tissue is of particular importance in the context of developing biomechanically justified elongation methods used in the treatment of long-gap oesophageal atresia.

The aim of this study was to experimentally characterise the stress relaxation behaviour of oesophageal tissue and to develop and validate a numerical model capable of reproducing its time-dependent mechanical response under different strain rates.

The study was conducted on oesophageal tissue obtained from Pekin ducks (n = 5 per strain rate). Specimens were subjected to stress relaxation tests at strain rates of 1, 2.5, 5, and 10%/s, with loading corresponding to a stress level of 0.5 MPa and a relaxation period of 1.3 h. The material behaviour was described using a Yeoh hyperelastic model combined with a three-term Prony series. The model parameters were identified based on fitting to experimental data and subsequently implemented in finite element simulations (ANSYS, Transient Structural). Two approaches were considered: a direct approach using parameters fitted independently for each strain rate, and a normalized approach in which the material parameters were defined as functions of strain rate.

A close agreement was observed between the experimental and numerical results for all analysed strain rates (Figure 1). The RMSE values ranged from 0.003 to 0.009 MPa, with NRMSE below 3.5%, and the coefficient of determination (R^2) exceeding 0.96. The normalized model, incorporating the strain rate dependence of the material parameters, also accurately reproduced the stress relaxation behaviour.

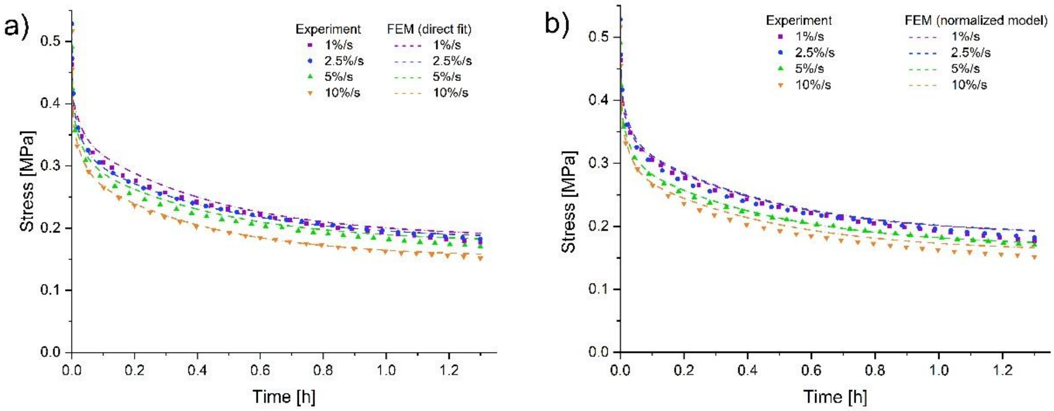

Figure 1. Comparison of experimental and numerical stress relaxation results: (a) direct model, (b) normalized model.