Modelling the apparent viscoelastic behaviour of passive muscle tissue under confined compression using a poroelastic framework

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Introduction Wound healing and prevention of chronic wounds are challenging issues in public health. Wounds result from prolonged, repetitive mechanical loads. A biomechanical approach to evaluate the soft tissue injury risk could be a solution towards a personalized estimate of this risk. Current approaches however often ignore the detailed biomechanical properties of compressed soft tissues and in particular muscle. In the literature, attempts to characterise muscle tissue generally assume a viscoelastic formulation, ignoring the underlying physical mechanisms that give rise to the time dependent stress-strain behaviour. Porous media models represent a promising approach. The aim of this study was to investigate the capability of poroelasticity to reproduce the apparent viscoelastic behaviour of passive muscle tissue under confined compression.

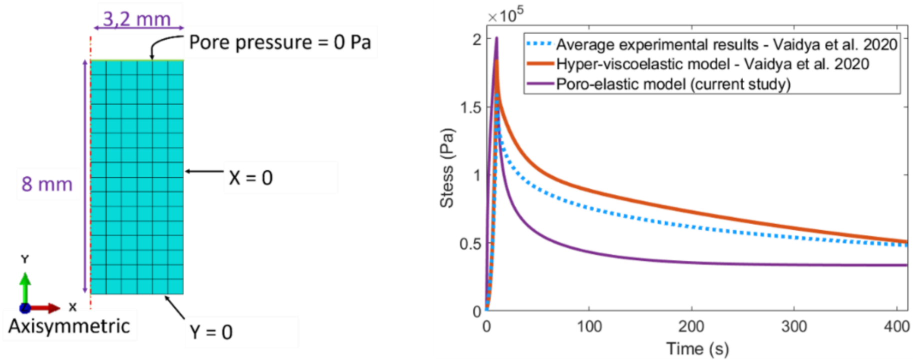
Methods Experimental stress-time relaxation curves of 31 cylindrical tibialis anterior porcine muscle samples previously tested in confined compression and previously reported in (Vaidya and Wheatley, 2020) were numerically reproduced. A poro-elastic axi-symmetric finite element model was developped in ABAQUS (Figure 1(a)). A one to one calibration was performed to fit the assumed quasi-incompressible, isotropic, poro-elastic constitutive model. The calibration procedure was gradient-based and the cost function was defined as the weighted sum of the peak stress error, the normalized Root Mean Square Error and the error on the derivative of the stress-time curve during the last 50s.

Results The peak stress, characteristic relaxation time and consolidated state were recovered for most of the samples (normalized Root Mean Square Error $\leq 0{,}03$). The toe-region of the curve did not follow the experimental curves. The stress-relaxation curve predicted by the poro-elastic model is given in Figure 1(b) for the average case. The mean experimental result and the result of the uncoupled Yeoh/Prony hyper-viscoelastic model calibrated by (Vaidya and Wheatley, 2020) are also superposed.

Discussion The strength of the proposed model of this contribution is its fewer number of variables with respect to visco-hyperelastic models generally assumed in the literature. This contribution provides an important step toward a mechanistic interpretation of passive muscle tissue under going compression in the context of prevention of chronic wounds. Poroelasticity also represents a promising approach for integrating multiscale/multiphysics data to probe biologically relevant phenomena at a smaller scale.

References

Vaidya, A.J., Wheatley, B.B., 2020. JMBBM. https://doi.org/10.1016/j.jmbbm.2019.103526


3,2 mm
Pore pressure = 0 Pa
8 mm
X = 0
Y
X
Axisymmetric
Y = 0
×10^5
2
1.5
1
0.5
0
Average experimental results - Vaidya et al. 2020
Hyper-viscoelastic model - Vaidya et al. 2020
Poro-elastic model (current study)
Stess (Pa)
0
100
200
300
400
Time (s)

(a) (b)