Ex-vivo human tongue muscle mechanical characterization

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Introduction

Mechanical characterization of human tongue has a great influence on modelling of its complex behaviour. The strong nonlinearity and also anisotropy make this characterization more difficult. The non-invasive methods like indentation or aspiration tests usually need a presumption of the underneath layers beneath the measurement probe. The elastography methods also suffer from small displacement assumption which is not sufficient for soft tissue accounting large deformations. Moreover, all of these methods cannot eliminate the effect of initial stresses in the tissues. For this reason, the invasive tests are preferred [1] which for living human subjects is implausible. For this purpose, a cadaver study (ex-vivo) is a step forward to have better identification of the mechanical properties of human tissues.

Method

Tongue of a human cadaver with signed consent of its donor was extracted in Lyon Hospital anatomy laboratory and transferred in zero-degree saline solution. Specimen from tongue musculature both along fibre direction and orthogonal to it were extracted. The specimens were installed in a warm bath with temperature set equal to 37^{o}C in uniaxial testing machine to simulate human body condition. After some loading and unloading cycles for preconditioning purpose, loading cycles were performed at different strain rates to measure viscoelastic properties as well. The last cycle continued up to complete rupture of samples.

Results

The elastic portion of the last loading cycle with a small strain rate were fitted with different hyperelastic models assuming isotropy and full incompressibility. Two linear regions connected with a middle toe region are observed, which is a typical behavior of soft materials (figure). The hyperelastic models range from low order ones such as 2 parameter Mooney-Rivlin to high order ones such as Ogden, Yeoh and Gent models. The fitted constitutive laws show significant differences (figure). None of them is able to follow the behavior for whole strain region simultaneously. By playing on the inclusion of the second or third order term in the Yeoh model strain energy density ($c_1 (I_1-3)+c_2 (I_1-3)^2+c_3 (I_1-3)^3$), it was possible to get flexibility to reach a satisfactory approximation of the toe region. The obtained results with the second order term: $c_1=0.357\ kPa$, $c_2=90.17\ kPa$ and with the third order term: $c_1=0.357\ kPa$, $c_3=409.05\ kPa$.

Discussion

Presumably due to the collagen straightening phenomenon in soft tissues the tensile force creates a toe region which usually gets fitted with a piecewise function. These types of functions confront the 3D modelling with the problem of convergence due to needed order of continuity between regions at different loading conditions. The results suffer from the lack of anisotropy assumption but they provide a good estimate for the mechanical properties of tongue muscle matrix [2].

References

[1] Yousefi, A.A.K., Nazari, M.A., Perrier, P., Panahi, M.S. and Payan, Y., 2018. A visco-hyperelastic constitutive model and its application in bovine tongue tissue. *Journal of biomechanics*, *71*, pp.190-198.

[2] Nazari, M.A., Perrier, P. and Payan, Y., 2013. The distributed lambda (λ) model (DLM): a 3-D, finite-element muscle model based on Feldman's λ model; assessment of orofacial gestures. *JASA.*