Investigation of Anisotropy in Passive Muscle Tissue

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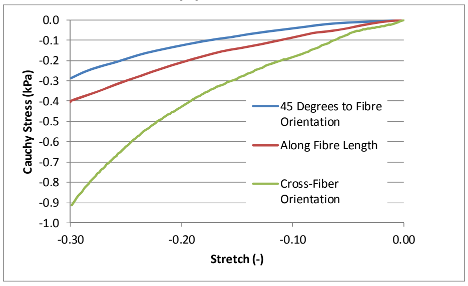
I. INTRODUCTION

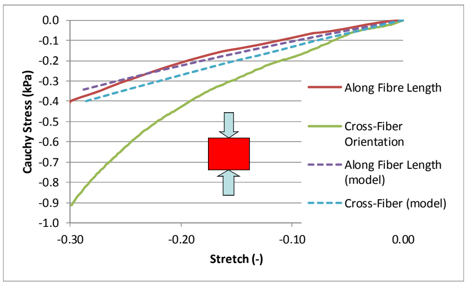
Muscle is the most abundant tissue by mass and volume in the human body, comprising water (80%), collagenous tissue (10%) and fat (3%) [1]. The structure of muscle tissue is hierarchical in nature including oriented fibers connected by the endomysium, fascicles connected by the perimysium, and surrounded by the epimysium. The directional properties of passive muscle tissue have been attributed to this structure.

In impact scenarios, muscle tissue provides the primary load transmission path, often loaded transverse to the fibers, so it is important to accurately characterize and model the mechanical response of this tissue for loading in different directions (Fig. 1) and at different strain rates [2]. This study is focused on investigating the anisotropic response in passive muscle [1] tissue at low rates using finite element methods, and eventually incorporating this into a continuum model for use in human body model impact and injury studies.

II. METHODS

A isotropic continuum model and continuum model with oriented fibers were investigated. The constitutive models were applied to solid continuum elements and compressed in the fiber, transverse and 45° directions.





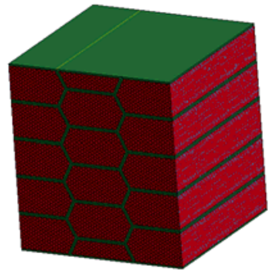


Fig. 1: Passive muscle tissue [1] Fig. 2: Single element simulation results Fig. 3: Proposed fiber-level model

III. INITIAL FINDINGS

The isotropic model did not capture the orientation effects, but did accurately model the shape of the individual curves. The oriented fiber model was able to demonstrate increased stiffness for transverse loading compared to fiber direction loading but did not predict the results for loading at 45°. To understand these limitations, a fiber-level model (Fig. 3) was developed including individual fibers modeled with three-dimensional continuum elements surrounded by a layer of membrane elements to represent the endomysium.

IV. DISCUSSION

Existing continuum treatments of muscle tissue properties are not adequate to represent different modes of loading. In particular, the decreased stiffness at 45° and the tension-compression asymmetry is not intuitive, but may be explained by the substructure and orientation of the fibers. This will be investigated at quasi-static and high deformation rates using a detailed fiber-level model.

V. REFERENCES

[1] van Loocke et al., JBiomech, 2008.

[2] Forbes et al., IJCrash, 2006.

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