Simulating musculotendon dynamics during active lengthening injury

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Summary

Vehicle and sporting accidents can result in chronic injury to the neck which is painful to individuals and costly to society. The musculature of the neck can develop large forces when activated and forced to undergo large length changes during the accident. It is not clear if existing models simulate active lengthening consistently and accurately. Here we simulate the forces developed by three muscle models in LS-DYNA (MAT_156, EHTM, and VEXAT models) during an extreme active lengthening event. Although the models have been fitted to the force-length-velocity properties of the same cat soleus, each model passes through the thresholds of injury at substantially different lengths. So that we can measure the accuracy of these models, we plan on making new experimental measurements of extreme active lengthening at the scale of muscle fibers, muscle bundles, and whole muscle.

Introduction

Human body models have been developed to simulate the movements of the neck during accidents [1] in an effort to better understand, and prevent, neck injury. While attention has been given to developing reflex controllers to activate the modelled muscles [2], less attention has been given to the accuracy of the musculature. Here we compare the forces developed by three muscle models available in LS-DYNA during extreme active lengthening [3]: MAT_156 [4], the extended Hill-type model (EHTM) [5], and the viscoelastic–cross-bridge active-titin (VEXAT) [6] model.

Methods

Prior to simulation, each of the models was fitted to represent the same cat soleus as closely as possible. While the architectural properties and initial path length of each model are identical, the nonlinear force-length-velocity properties have been fitted to reduce the squared errors in comparison to published data [7]. After fitting, each of the models is maximally activated close to ℓ_o^M and lengthened by 52 mm at a rate of 9 mm/s.

Results and Discussion

Each of the models passed through through the thresholds of injury [8] at substantially different lengths (Figure 1) despite having similar force-length-velocity characteristics. The VEXAT model's active titin element caused it to develop the highest forces. Although both the MAT_156 and EHTM are Hill-type models, the EHTM developed higher forces because of the exponential function it uses to describe its passive-force-length relation. Unfortunately, it is unclear which model most accurately captures the process of injury because limited experimental data exist. The data that do exist [9] have been measured from whole rabbit muscle, which are known to be much stiffer than human skeletal muscle [10].

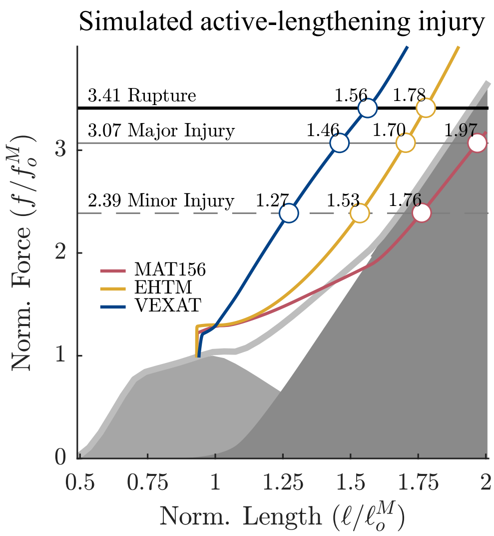

Figure 1: The normalized force-length profile produced by each of the models during the extreme lengthening event.

Conclusions

The muscle models available in LS-DYNA produce substantially different force-profiles during extreme active lengthening. Since experimental data of extreme lengthening is scarce, we plan on making new in-vitro experimental measurements of the extreme active lengthening to improve the accuracy of accident simulations.

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