Evaluating the performance of Hill-type and titin-clutch models in predicting in vivo muscle force during perturbed walking and running

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Abstract—Hill-type muscle models have been in widespread use for decades, and a new model based on a role for titin in active muscle is under development. We tested the two models using data from a previous study that measured muscle activation, fascicle length and force of the guinea fowl lateral gastrocnemius (LG) during obstacle-perturbed treadmill locomotion over a range of walking and running speeds (0.8 – 2.0 m/s). The models share some parameters, and the overall complexity and number of estimated parameters is similar. Both models tend to systematically underestimate muscle force. However, only the titin-inspired model captures length-dependence of activation dynamics in perturbed strides, a feature that is essential for forward prediction of force in wearable robotic devices.

Keywords—muscle mechanics, viscoelasticity, activation dynamics, muscle fascicle strain

I. DESCRIPTION OF THE MODELS

Hill-type muscle models (Fig. 1A) have been used to predict muscle force in a wide variety of contexts ranging from ex vivo experiments [1], to in vivo locomotion [2], to whole-body simulations using OpenSim [3]. A seven parameter Hill-type model [2] was used here with 3rd order activation dynamics (a system of differential equations with eight parameters), total 15 parameters.

The titin-clutch model (TCM, Fig. 1B), inspired by tunable viscoelastic properties of titin [4], is based on interactions of titin with actin [5]. The titin element wraps around a pulley, connected to a contractile element in both series and parallel. When CE force is greater than titin force, the pulley rotates in the counterclockwise direction, and vice versa. The translational position of the pulley is determined by the relationship between SE force and the sum of CE force and titin force. The pulley position influences the response of the model to activation. The muscle force depends on pulley position, given the same activation. The inherent length-dependence of activation in the model replaces the activation dynamics, thereby reducing the total number of estimated parameters to 7.

II. PRELIMINARY RESULTS

The TCM had a higher $R^2$ (0.65) than the Hill-type model (0.55) with fewer estimated parameters, and predicted greater stride-to-stride variability in force (Fig. 2, colored rectangles).

III. DISCUSSION & FUTURE WORK

These results demonstrate that the TCM predicts muscle force with higher accuracy than the Hill-type model without including activation dynamics. This suggests that the pulley successfully implements titin-actin interactions in active muscle, which can provide a simple algorithm for length-dependent activation dynamics. Nevertheless, the TCM explained only 65% of the stride-to-stride variation in muscle force (Fig. 2, shaded area) and future models should concentrate on how to better predict the intrinsic response of muscles to perturbations.

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V. REFERENCES