# Cross-Bridge vs. Hill-Type Muscle Models: Implications for Muscle and Joint-Level Postural Control

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## Summary

Muscle models are crucial for creating neuromechanical simulations of movement and postural control. However, the commonly used Hill-type muscle model fails to accurately describe the response of muscle to stretch. We hypothesize that cross-bridge-based models that more mechanistically describe muscle contraction processes will better capture transient behaviors such as balancing under perturbations than Hill-type models. To test this, we developed simulations using cross-bridge-based and Hill-type muscle models. Both models had identical force-length and force-velocity properties, but cross-bridge model generated greater resistive forces during sudden perturbations, leading to improved postural control in simulations of standing balance compared to the Hill-type models. Cross-bridge-based muscle models may allow for more versatile simulations across various movement scenarios.

## Introduction

Phenomenological models like Hill-type muscles are widely used in biomechanics, however, these models are based on steady-state forces and lack many transient properties of active muscle forces especially during rapid stretches [1]. Specifically, prior work showed that adding a phenomenological short-range stiffness model to the Hill-type model is important to capture instantaneous mechanical responses during perturbations to standing balance [2]. However, short-range stiffness is prescribed as a predefined force-length relationship specific to the experimental condition. We aimed to develop a generalizable mechanistic muscle model for motor control simulations and compare it to phenomenological models in both isolated muscle-level and joint-level simulations.

## Methods

We implemented a 3-state cross-bridge model simulation based on the open-access MATMyoSim code [3]. To assess the benefit of mechanistic cross-bridge simulations, we ensured that both muscle models had the same steady-state force-length and force-velocity profiles. To identify force-length and force-velocity relationships for the Hill-type muscle simulations, the isometric force of the cross-bridge-based model was simulated at various lengths, and isokinetic forces at different contractile velocities. We then compared the two muscle models in 1) muscle-level simulations assessing force responses to imposed muscle length change, and 2) joint-level standing balance simulations involved a pair of muscles actuating a one-degree-of-freedom inverted pendulum, initially balanced at upright angle. Muscles were activated at a constant sub-maximal level throughout the simulation, with a focus on their initial responses (<50ms) to acceleration perturbation.

## Results and Discussion

As expected, the cross-bridge based muscle model exhibited transient force response that is absent in a Hill-type muscle model. When subjected to length changes (Figure 1A), the Hill-type model produced constant isokinetic forces, while the cross-bridge-based model exhibited high transient forces at the onset of rapid stretches. Joint-level responses to perturbation were also different across models (Figure 1B). An inverted pendulum without muscles is unstable under perturbations, but both muscle models slow the fall. Cross-bridge-based models develop force more quickly than Hill-type models during sudden stretches, resulting in a smaller angle change. Therefore, mechanistic muscle models may better capture muscle contributions to postural stability.

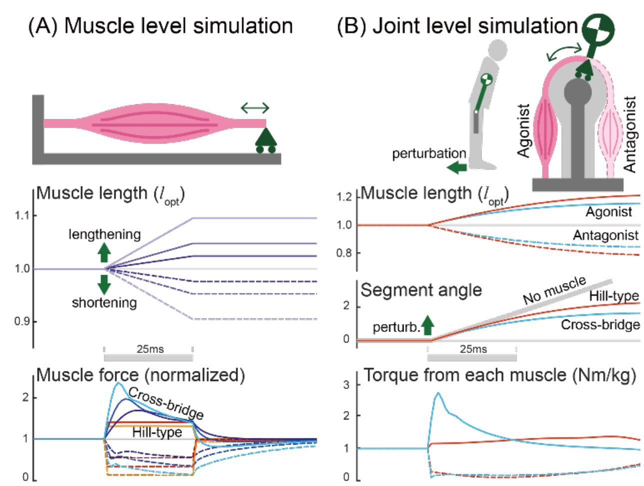


**Figure 1**: Hill-type and cross-bridge-based model simulations

## Conclusions

Cross-bridge-based models better capture transient muscle behaviors than widely used Hill-type muscle models, highlighting the importance of intrinsic muscle properties in early postural stabilization before reflex and feedback control engage.

## Acknowledgments

This research was supported by NIH NICHD R01HD090642

## References

[1] Rack PM, Westbury DR. (1974) *J. Physiol.* **240**
[2] De Groote F, Allen JL, Ting LH. (2017) *J. Biomech.* **55**
[3] Campbell KS. (2014) *J. Gen. Physiol.* **143**