Validation of the energetics of a Huxley muscle-tendon-complex model using experimental data obtained from mouse soleus muscle fibre bundles

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Summary

We have validated the energetics of a novel Huxley-type muscle-tendon-complex (MTC) model that includes series and parallel elasticity, force-length properties and activation dynamics. Data from dedicated experiments on fibre bundles of mouse Soleus muscle was used, in which oxygen consumption and mechanical behaviour were measured. Metabolic power for cross-bridge cycling and muscle activation were separated through the application of blebbistatin. Model parameter values were chosen to best describe the experimental data. This resulted in good correspondence between model-predicted and measured forces, and reasonably good correspondence between model-predicted and measured metabolic energy expenditure. This study opens up the possibility of using a Huxley-type MTC model in musculoskeletal simulations of human mechanical behaviour and metabolic energy expenditure, for applications in sports or rehabilitation.

Introduction

There is a lack of muscle models in musculoskeletal modeling that unify the description of mechanical behaviour and metabolic energy expenditure. In this work, we compared predictions of force and metabolic energy expenditure of a Huxley-type muscle-tendon-complex (MTC) model to experimental data.

Methods

The model consisted of a modified version of the classic Huxley model, to which force-length dependency, series elasticity and activation dynamics were added [1]. Metabolic energy expenditure was modelled as the weighted sum of the energetic cost of cross-bridge cycling and calcium pumping. Fibre bundles of 9 mouse soleus muscles were subjected to sinusoidal contractions while oxygen consumption and force at the tendon was measured [2]. Measurements were done both before and after addition of blebbistatin, a chemical cross-bridge blocker. Comparison of pre- and post-blebbistatin trials allowed separate estimation of the contributions of cross-bridge cycling and calcium pumping to total metabolic energy expenditure.

Parameter values pertaining to mechanical behaviour were fit to a subset of trials in which only force was measured. Using these, simulations of the trials during which oxygen consumption was measured were done, and the parameter values governing the modelled metabolic power were fit.

Results and Discussion

For all animals, there was good correspondence between simulated and measured forces (RMSE < 10% maximum isometric force). For the metabolic energy prediction, mean RMSE was 20.3% (SD 12.6%) of the measured average metabolic power, and results varied widely between animals (figure 1). High RMSE was largely due to high within-animal variability in the measurements, and thus we consider the model predictions of metabolic energy expenditure to be promising.

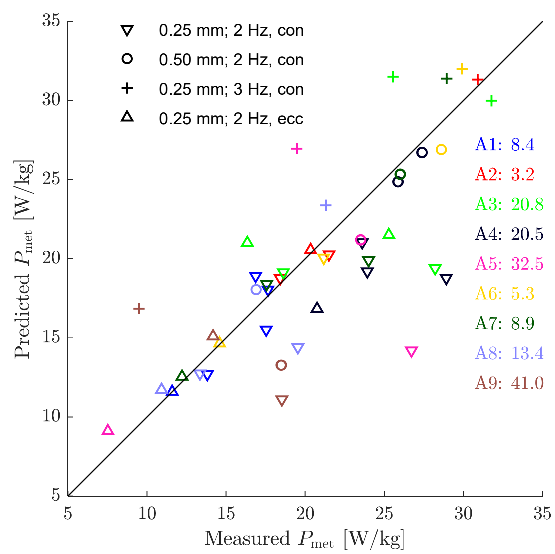

Figure 1: Predicted versus measured average metabolic power during sinusoidal contractions with amplitudes of 0.25 and 0.50 mm, and with stimulation during the concentric (con) or eccentric (ecc) phase of length change. Colors distinguish different animals (A1-A9), colored numbers refer to the root mean squared error per animal, expressed in percentage of the measured metabolic power.

Conclusions

Combined with our previous work, this study opens up the possibility of using a Huxley-type muscle-tendon-complex model in musculoskeletal simulations of human mechanical behaviour and metabolic energy expenditure, for applications in sports or rehabilitation.

References

[1] Lemaire KK et al. (2016). *J Exp Biol*, **219**:977-87.
[2] Lemaire KK et al. (2019). *Front Physiol*, **10**:760.