8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

Simulation of stretch-shortening cycles with two common hill-type muscle models

Tobias Siebert[1], Christian Rode[1], Olaf Till[1] and Reinhard Blickhan[1]

[1] Friedrich-Schiller-University
Institute of Motion Science, Seidelstr. 20, 07749 Jena, Germany
tobias.siebert@uni-jena.de http://www.biomechanik.uni-jena.de

Key Words: *Hill-type muscle model, simulation, stretch-shortening cycles, passive force.*

Phenomenological Hill-type models of skeletal muscle play an important role in the simulation of movement. The two most common models contain three components. In model [CC+SEC] the passive component (PEC) is in parallel with the contractile component (CC) and the series elastic component (SEC). In the other model [CC] the PEC is only in parallel to the CC. As soon as one of the components exhibits nonlinearities the two models are mechanically not equivalent and the deduced muscle properties differ [3]. For the cat soleus muscle the maximum isometric force is 10% higher, the optimal muscle length is shifted to longer muscle length and the PEC is much stiffer in model [CC] compared to model [CC+SEC] [2]. The aim of this study was to test if simple hill-type muscle models including passive forces (1) are sufficient for simulation of muscle contractions and (2) differ in the qualtity of the approximation of measured forces. Therfore we simulated stretch-shortening cycles applying model [CC+SEC] and model [CC] and compared the predicted forces and produced work with experimental data.

Experiments were performed on cat soleus muscle [3]. The work-loop technique [1] was used to impose cyclical sinusoidal length changes upon the muscle in length ranges with substantial passive forces (Fig. 1) while it was phasically stimulated. Cycle frequency (f), strain amplitude (a) and stimulus duration (d) were varied (Table 1). The stimulation began (t_{sim}=0.05/f) shortly before concentric part of the stretch-shortening cycle. Simulations of experimental stretch-shortening cycles were performed with both muscle models containing force-length and force-velocity relationship, excitation-contraction coupling and series and parallel elastic force-elongation relation. Realistic model [CC] parameters were determined beforehand [3]. In situations with negligible passive force, the SEC and force-velocity relation are equal for both models. For model [CC+SEC] the PEC-relation equals the measured passive muscle force-length relationship and the active force length-relation was adapted from the active model [CC] force-length relation.

Stretch-shortening simulations applying both muscle models resulted in almost similar force traces (Fig.1, grey lines) and small differences in work prediction per cycle (1.7% ± 2.4%, Table 1). Comparison of experimental and simulated force traces resulted in acceptable description of cyclical contractions for both models (Fig.1). The force traces agree across large ranges and the maximum deviation we found is less than 8 % maximum isometric force. Prediction of experimental work per cycle is 96% ± 13% and

97% ± 14 for model [CC+SEC] and model [CC], respectively (Table 1).

Table 1. Experimental (exp) and simulated (sim) stretch-shortening cycles.

frequency *f* [Hz]	2	1	1	0.5	0.5	0.25	0.25
strain amplitude *a* [mm]	2	6	4	8	2	8	6
stimulus duration *d* [s]	0.15	0.45	0.4	1	0.7	2	2
w_{exp} [mJ]	27.5	67.9	61.8	96.0	46.1	133.5	128.7
[CC] w_{sim_CC} [mJ]	23.9	58.6	50.5	105.8	43.0	156.4	137.1
[CC+SEC] w_{sim_CC+SEC} [mJ]	23.9	56.3	50.1	100.2	43.6	151.8	136.1
w_{sim_CC}/w_{exp} [%]	87%	86%	82%	110%	93%	117%	106%
w_{sim_CC+SEC}/w_{exp} [%]	87%	83%	81%	104%	95%	114%	106%

Experimental work output was overestimated in simulations with high work output (large amplitude, low frequency) and underestimated in simulations with low work output (less amplitude, high frequency) suggesting that experimental muscle force is more depressed in the first and less depressed in the second case. This effect can't be predicted by the models, where a mean force depression is accounted for by a depressed active force-length relation [3]. In conclusion, though model [CC] represents real muscle better [2,3], both models give acceptable predictions of stretch shortening cycles.

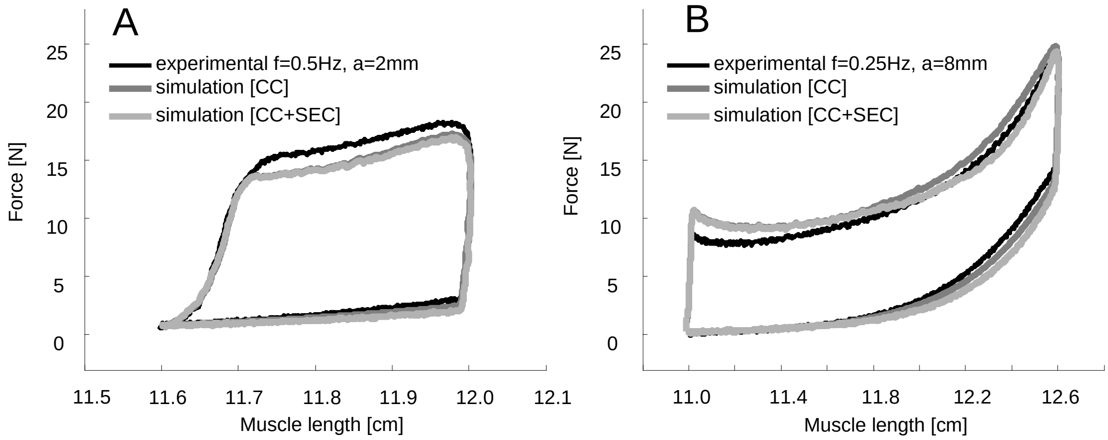

Fig. 1. Two examples of experimental and simulated stretch-shortening cycles.

Acknowledgement: We thank the German Science Foundation (DFG) grant Bl236/13-1 and Prof. Dr. W. Herzog for support.

REFERENCES

[1] R. K. Josephson, "Mechanical power output from striated muscle during cyclical contraction", *J Exp. Biol.*, Vol. **114**, pp. 493–512, (1985).

[2] C. Rode, T. Siebert, W. Herzog and R. Blickhan, "The effects of parallel and series elastic components on estimated active cat soleus muscle force", *Acta Physiol*, (submitted).

[3] T. Siebert, C. Rode, W. Herzog, O. Till and R. Blickhan, "Nonlinearities make a difference: comparison of two common Hill-type models with real muscle", *Biol. Cybern.* DOI 10.1007/s00422-007-0197-6