IMPACT OF VELOCITY ON MUSCLE FORCE GENERATION DURING LONG ECCENTRIC CONTRACTIONS

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Introduction

Eccentric muscle contractions are part of humans' everyday living. For example, they are functionally relevant during jumping, running, or accidents associated with long muscle stretches. So far, the mechanisms of eccentric force generation need to be fully understood. Several studies reported a drop in force (defined as *Give*, Flitney and Hirst 1978) after an initial force peak (Figure 1, f_p). Interestingly, muscle *Give* was followed by almost linear force redevelopment (Figure, $slope_2$) during extensive stretches (Tomalka et al. 2017). However, how the stretch velocity affects *Give* and force redevelopment remains largely unknown. This study examines the influence of stretch velocity on force generation in long (0.45 optimum fiber length (l_{opt})) stretches of skinned rat muscle fibers.

Methods

Extensor digitorum longus muscles were extracted from female Wistar rats (n=5). Muscle fiber preparation, permeabilization, and activation techniques were described in detail by Weidner et al. (2022). Skinned muscle fibers (n=39) were mounted in a fiber-test apparatus (600A, Aurora Scientific, Canada), which enabled measurement of fiber force and length. The sarcomere length was measured in the central segment of the fiber with an inverted microscope (Eclipse Ti-S, Nikon, Japan) and a high-speed video system (Aurora Scientific, 901B). Fibers were fully activated by calcium diffusion in the presence of ATP. After an isometric pre-contraction, the fibers were stretched from 0.85 to 1.3 l_{opt} at 1%, 10%, and 100% of the maximum shortening velocity (v_{max}).

Results

The force-length traces of the muscle fibers during isovelocity stretches did not reflect the changes in the slope of the underlying active isometric force-length relationship (Figure 1, dashed black line). Muscle fibers showed a steep initial increase in force (Figure 1, $slope_1$). $slope_1$ increased with stretch velocity by 85% (p<0.001). *Give* was absent (Figure 1, solid black line) in slow stretches (1% v_{max}). Moderate (10% v_{max}) and fast (100% v_{max}) stretches yielded a clear "*Give*" (Figure 1, blue and red line). *Give* tripled by increasing stretch velocity (10% to 100% v_{max}, $p < 0.001$). During the last half of the stretch (from 1.07 to 1.3 l_{opt}, which is within the range of the expected descending limb of the force-length relationship), $slope_2$ increased from 1% to 10% v_{max} by 180% ($p < 0.001$), from 10 to 100% v_{max} by 55% ($p < 0.001$), and from 1% to 100% v_{max} by more than 300% ($p < 0.001$).

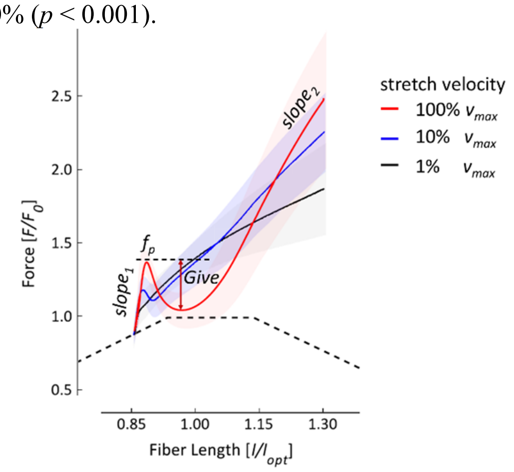

Figure 1: Mean forces (solid lines) and standard deviation (shaded areas) for different stretch velocities. Forces are plotted over measured relative fiber length (l/l_{opt}). For comparison, the active isometric force-sarcomere length relationship (dashed black line) of skinned EDL muscle fibers is shown. F_0: maximum isometric force; f_p: initial force peak.

Discussion

This study presents the first systematic in vitro investigation of the force response of mammalian muscle fibers subjected to long stretches (from 0.85 l_{opt} to 1.3 l_{opt}) at velocities across two orders of magnitude (1%, 10%, 100% v_{max}). Our results are compatible with forcible cross-bridge detachment, redevelopment of a cross-bridge distribution, and a viscoelastic titin contribution to fiber force during extensive stretches (Weidner et al. 2022). Results of this study regarding the velocity and length-dependency of *Give* can improve muscle models and alter predictions of multi-body models. The observed linear force increase during long stretches might stimulate the interest of biologists, physiologists, and engineers alike as it may contribute to the reduction of necessary neuromuscular control in biological and mechanical locomotion systems.

References

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