INTRODUCTION

Rack and Westbury (1969) measured the force-length properties for the cat soleus and found the plateau region of this relationship at sarcomere lengths of approximately 3.0µm, while the optimal length would be expected to occur between 2.3-2.5µm. However, they did not account for possible sarcomere shortening associated with force production and the corresponding stretching of series elastic components. This neglecting of series elasticity might be justified in cat soleus, as it is a virtually parallel fibred muscle with a rigid tendon (Barratta and Solomonow, 1990). The purpose of this study was to repeat Rack and Westbury’s (1969) study, while measuring fibre and average sarcomere lengths. We hypothesized that the plateau of the force-length relationship occurs at sarcomere lengths between 2.3-2.5µm, rather than 3.0µm, and that fibre length changes would be smaller than the corresponding muscle length changes.

METHODS AND PROCEDURES

Testing was performed on six soleus muscles of adult male cats. After anaesthesia and intubation, a nerve cuff stimulation electrode was fixed on the tibial nerve (Herzog & Leonard, 1997). Supramaximal electrical stimulation was applied with monopolar rectangular pulses (0.1 ms duration) at frequencies of 1, 2, 10, 30 and 100 Hz. The soleus muscle, its tendon and the calcaneus were carefully dissected and isolated from surrounding tissues. The tendon was cut with a remnant part of bone and fixed to a muscle puller. Force and excursion were measured continuously. Sonomicrometry crystals were implanted at the ends of a proximal and a distal fascicle and sutured fixed underneath the fascia. Optimal soleus length was defined as the length of maximal active isometric force at 100Hz stimulation and was designated as 0mm length. Isometric forces were measured for lengths ranging from approximately -20 to +20mm relative to the optimal length for all stimulation frequencies. Following testing soleus muscles were fixed in a 10% formalin solution and five fascicles were extracted from the medial, central and lateral part of the muscle. Fascicle lengths were measured using video analysis. Mean sarcomere lengths were obtained from six measurements along each fascicle by laser diffraction (Butterfield & Herzog, 2006). Sarcomere number was determined by dividing the fascicle length by the average sarcomere length. In situ sarcomere lengths were calculated from the fascicle lengths measured during the experiments and the known serial number of sarcomeres. For each stimulation frequency, the active peak force was obtained by subtracting the passive from the total force. In situ fascicle lengths were obtained from the sonomicrometry system and were synchronized with the corresponding force values.
RESULTS AND DISCUSSION

The sarcomere force-length relationship showed an ascending and descending part with a plateau between 2.0-2.3µm (Figure 1). Therefore, peak forces were obtained at smaller average sarcomere lengths than reported by Rack and Westbury (1969), and closer to the optimal sarcomere length based on sliding filament considerations. There was a decrease in the optimal sarcomere length with increasing stimulation frequencies. Optimal length was about 2.2 µm for 1-2 Hz and 2.1 µm for 30-100 Hz, respectively (Figure 2).

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**Figure 1.** Force (100 Hz) as a function of sarcomere length, fiber length, muscle length and joint angle.

Fibre lengths increased with increasing muscle lengths and decreased with increasing forces at a given muscle length. For muscle length changes of 40mm, fibre lengths changed by 14mm or about 35% of the muscle length changes in the passive muscle and by about 24mm or 60% in the active muscle. Therefore, fibre length changes were substantially smaller than muscle length changes despite the small angle of pennation (6.4°; Spector et al., 1980) and virtually rigid tendon (Baratta and Solomonow, 1990) associated with the cat soleus. These substantial differences in fibre and muscle length changes are partly responsible for what we think was a vast overestimation of the optimal sarcomere length in the Rack and Westbury (1969) study. We conclude that optimal cat soleus length is associated with near optimal sarcomere lengths.

**Figure 2.** Optimal length as a function of stimulation frequency. Symbols indicate p<0.05 after a Friedman’s repeated measures analysis on ranks.

REFERENCES


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