Shortening velocity, power output and relaxation rate during fatigue of skeletal muscle of young rats

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Introduction

Muscle fatigue is usually assessed by the loss of isometric force, but in most daily activities skeletal muscles are used for movements and thus it is the maintenance of power which is important.

During sustained voluntary contractions muscle contractile properties change such that relaxation is slowed and contractions become more fused at lower frequencies. This acts to preserve force during isometric contractions (Bigland-Ritchie et al. 1972; Jones and Bigland-Ritchie 1986). It is not clear whether the slowing of relaxation also confers any advantageous effect on dynamic function. If the change in relaxation represents a prolongation of the active state due to slower reaccumulation of calcium into the sarcoplasmic reticulum, there is no obvious reason why this should affect the force-velocity characteristics of the whole muscle. If however the slowing is accompanied by a reduction in the rate of cross-bridge cycling, then a change in the force-velocity characteristics would be expected to result in lower force and therefore power output for a given velocity of shortening.

In the present investigation we have compared the loss of isometric force with that of maximal shortening velocity and power output during fatiguing contractions of rat medial gastrocnemius muscle. These changes occurring during fatigue have been related to changes in relaxation rate.

Methods

Young male Wistar rats (120 - 160g) were anaesthetized with pentobarbitone (60mg/kg; i.p.) and the medial head of the gastrocnemius was dissected free and distally attached to a force-transducer of an isovelocity measuring device (de Haan et al. 1989). Muscle temperature was maintained at 26°C by a water saturated airflow around the muscle. The most distal fibre bundle length was ~13mm and the length of the muscle belly ~25mm. The muscles were maximally stimulated (pulse heigh: 1mA; stimulation frequency: 60Hz) via the severed sciatic nerve.

The muscle was taken through a repeated cycle of alternative long (15s) and short (1s) contractions with 15min recovery after each long contraction and 5min after a short contraction. The muscle was first stretched to L_0 +2mm and then stimulated for either 1 or 15s. The muscle was released by 4mm at preset velocity, such that 0.3s before the end of stimulation the length was equal to L_0. To minimize the effect of elasticity we chose to measure the force attained after 3mm of release i.e. at L_0-1mm (F). F was expressed as a fraction of the isometric force immediately prior to release (F_0). The muscle was held at L_0-2mm while tension redeveloped until stimulation came to an end. The half time of relaxation was measured from the subsequent relaxation by taking the time needed for force to fall from one half to a quarter of the force reached at the end of stimulation.

A hyperbolic curve was fitted to the force and velocity data points using an iterative least squares method. The power-velocity curve was calculated from this fitted force-velocity curve.

Unloaded shortening velocity was determined using the "slack test" (Edman 1979). The sequence of events was similar to that used for the isovelocity releases, except that the amplitudes of the releases were 4, 5, 6, or 7mm at a nominal velocity of 500mm/s.

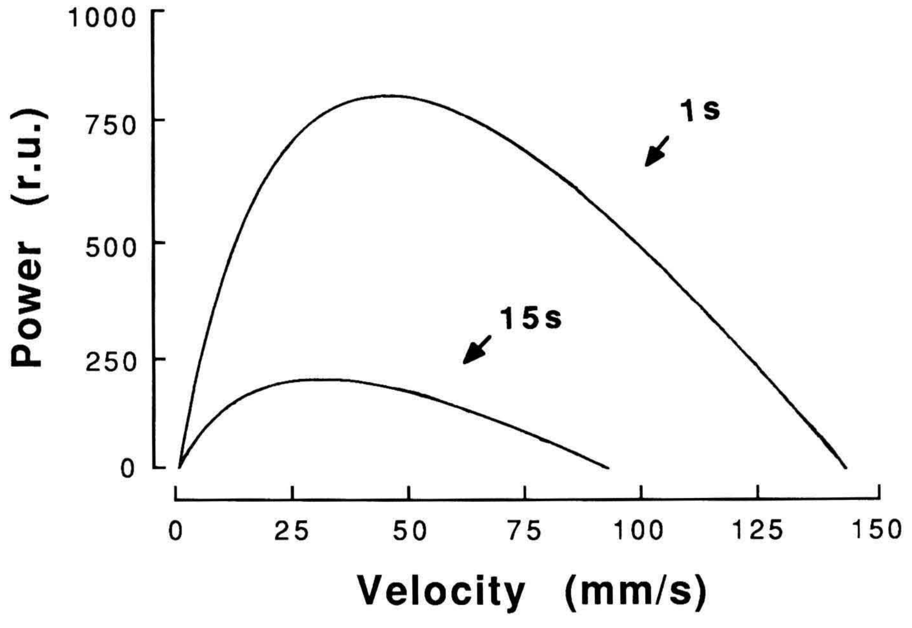

Figure 1. Power in relation to velocity for four muscles performing alternating long (15s) and short (1s) contractions. Power is given in relative units expressing force as a percentage of the peak isometric force attained in that contraction prior to shortening and velocity in mm/s for the complete muscle-tendon preparation.

Results and discussion

Following the 15s contraction the half time of relaxation was almost doubled and maximum shortening velocity reduced to ~64% compared to the 1s contractions. The data of the unloaded shortening velocity confirmed the reduction in maximal shortening velocity as estimated from extrapolation of the calculated force-velocity curve (Table 1; Fig.1).

Isometric force decreased to 48 ± 15% of the maximum during the fatiguing 15s contraction: However this reduction in isometric force greatly under-represented the loss of power. Due to the combination of reduced force and velocity of shortening, maximum power (at the velocity where power was greatest) decreased to ~24% following the 15s contraction. The reduction in power was even more pronounced at higher velocities (Fig.1).

The results are similar to those of Crow & Kushmerick (1983) and demonstrate that at a time when relaxation was slowed there was a change in the force-velocity relationship such that the normally fast medial gastrocnemius muscle assumed the characteristics of a slow muscle. The change in the force-velocity characteristics indicates a slower rate of cross-bridge turnover in fatigued muscles.

Thus the slowing of relaxation during fatigue can at least in part be attributed to a slowing of cross-bridge turnover. The results also demonstrate that isometric force may be a poor indicator of loss of performance in fatiguing exercise involving external work and power output.

Table 1. Summary of contractile properties of medial gastrocenemius muscles at the end of short and long contractions

	Short (1s) contractions	**Long (15s) contractions**
Unloaded shortening velocity.(mm/s)	143 (8)	88 (13)
Maximal shortenening velocity (mm/s)	145	93
Maximum power (relative units)	816	195
Velocity with maximum power (mm/s)	44.8	30.6
Half time of relaxation (ms)	11.9 (1.3)	20.6 (3.9)

Unloaded shortening velocity is given as the mean (SD) for 5 muscles.
The values for maximum shortening velocity, maximal power and velocity with maximum power are from the fitted curve in Fig. 1. Half time of relaxation is from the total number of contractions (24) from four muscles.

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