Tension and Structure in Crustacean Fast and Slow Muscle Fibres

The sliding filament hypothesis of muscle contraction[1] rests on the premise that tension is generated by formation of cross bridges between thick (myosin) and thin (actin) filaments where they overlap within the sarcomere. The hypothesis predicts that the tension within a sarcomere is a function of the extent of overlap of the thick and thin filaments, and this has been substantiated by recent work on the length-tension relationship of single frog muscle fibres[2].

Two other predictions of the sliding filament hypothesis which apply to muscle fibres of different resting sarcomere length are as follows: (1) Muscle fibres with long sarcomeres should develop more tension per unit area of cross-section than fibres with short sarcomeres, due to more extensive overlap between the 2 sets of myofilaments within the longer sarcomere. (2) More rapid contraction would be expected in fibres with short sarcomeres, since they possess more sarcomeres in series per unit length of muscle fibre[1]. Validation of these predictions would require that the long and short sarcomeres under consideration contain myofilaments with equivalent numbers of similar cross bridges per unit length.

Materials and methods. In the present work, these predictions were tested on the abdominal extensor muscles of the crayfish and lobster[3]. Tension of individual fibres was recorded isometrically by means of an RCA 5734 transducer while current for direct stimulation of the fibre was applied intracellularly with a microelectrode[4].

Results and discussion. The 'deep' extensor muscles possess much shorter sarcomeres (2–4.5 μ) than the 'superficial' extensor muscles (6–10 μ). Overlap between thick and thin filaments is about 3 μ per sarcomere in a lobster deep extensor fibre of 4.3 μ sarcomere length, compared with an overlap of about 6 μ per sarcomere in a superficial muscle fibre of 9 μ sarcomere length (determined by electron microscopy). The sarcoplasmic reticulum is similar in amount in the 2 types of fibre, and diadic contacts between elements of the sarcoplasmic reticulum and T-tubules are roughly equivalent in terms of the number per sarcomere[5].

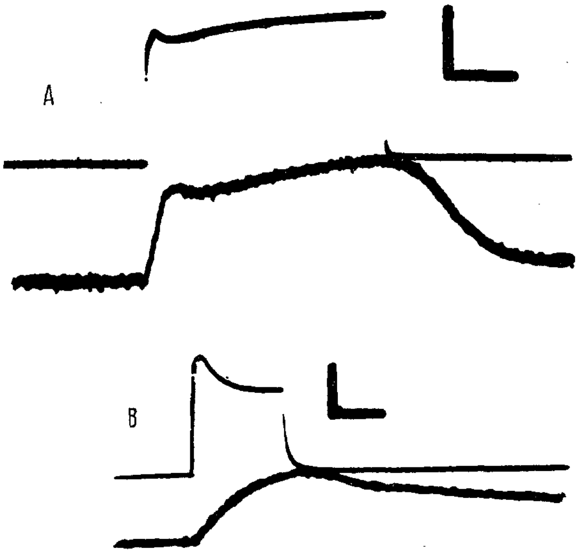
Tension development and relaxation were always much slower in the superficial (long sarcomere) fibres (Figure). Thus, the relationship between speed of contraction and length of sarcomere holds for these fibres, as in certain other crustacean muscles[3,4,6].

Peak isometric tension of single muscle fibres in response to direct stimulation was compared after treatment with solutions containing tetraethylammonium chloride (TEA), a compound which facilitates production of prolonged, overshooting spikes in crustacean muscle fibres[7]. Although the TEA spikes were more prolonged in the fast fibres, the calculated tension per unit area of fibre cross-section was always greater in the slow fibres. Values ranged from 0.8–1.4 kg/cm^2 in fast fibres, and from 5.0 to over 10 kg/cm^2 in slow fibres.

In other tests, tension of the 2 types of fibre was compared during application of contracture-producing agents (Table). For each treatment, the slow fibres developed more tension than the fast fibres. Indeed, the latter failed to develop measurable tension in high potassium unless a pre-treatment with caffeine was included.

Treatment	Fast muscle tension (kg/cm^2)	Slow muscle tension (kg/cm^2)
Excess K^+ (200 mM)	0	Mean 1.50 ($N = 3$) S.E. ±0.26
Caffeine (30 mM)	Mean 0.22^{a} ($N = 4$) S.E. ±0.08	Mean 1.10^{a} ($N = 3$) S.E. ±0.31
Excess K^+ (400 mM) and caffeine (30 mM)	Mean 0.84^{b} ($N = 3$) S.E. ±0.15	Mean 4.40^{b} ($N = 4$) S.E. ±0.76

[a] T-test: Means differ significantly (P 0.05). [b] T-test: Means differ significantly (P 0.01).



Contraction of a deep extensor muscle fibre (A) and of a superficial extensor muscle fibre (B) in response to direct stimulation applied intracellularly by microelectrode. The top traces in each figure show the muscle fibre membrane responses; in neither case does a spike appear. Tension (bottom traces) develops and relaxes much more slowly in B. Calibrations: Horizontal (time), 0.2 sec (A), 0.4 sec (B); vertical (voltage), 10 mV; tension, 50 mg.

The present results are in qualitative agreement with the predictions of the sliding filament hypothesis. Further quantitative evaluation would require information about the numbers of cross bridges per unit length of the myofilaments[8].

Résumé. Les fibres de l'abdomen du homard pourvues de longues striations ont développé une plus grande tension par unité de surface, en coupe transversale, que les fibres munies de striations courtes.

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