MAMMALIAN MUSCLE CONTRACTION AND PERFORMANCE EXAMINED BY TEMPERATURE PERTURBATION

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It is well known that skeletal muscle contraction is temperature sensitive; in mammalian muscle, both the active force and shortening velocity decrease in cooling from 35 ºC to 10 ºC so that the maximal mechanical power output of muscle is reduced to ~5% at 10 ºC (Ranatunga, 1984; 1998). In order to identify the underlying mechanism(s) of the force increase on warming, rapid temperature-jump (T-jump) technique has been used; the experiments showed that isometric muscle force is endothermic, i.e. force increases as heat is absorbed in warming (see references in Davis, 1998; Kawai, 2003; Coupland & Ranatunga, 2003). The main findings from these isometric studies are the following.

Firstly, whereas the rigor force decreases linearly, the active force in muscle increases ~two-fold when the temperature is raised from ~10 ºC to high physiological (>30 ºC) temperatures (Ranatunga, 1994). The active force versus reciprocal absolute temperature is sigmoidal (see references in Coupland & Ranatunga, 2003) with indication of saturation at the physiological temperatures. *Secondly*, the increase of active force on heating is not accompanied by a concomitant increase of stiffness (Goldman *et al*, 1987) and, hence, it is not due to an increase in the fraction of attached crossbridges. *Thirdly,* a rapid temperature-jump (T-jump, 3-5˚ in <0.2 ms) induces a bi-exponential rise (labelled phase 2b and phase 3) in force to a level as expected from steady state experiments; the (faster) phase 2b is identified as "endothermic force generation" in attached crossbridges (Davis & Harrington, 1987; Goldman et al, 1987; Bershitsky & Tsaturyan, 1992; Ranatunga, 1996). *Finally*, on the basis of its sensitivity to inorganic phosphate (P_i), the endothermic force generation has been identified as a molecular step before P_i-release (i.e. a transition between two AM.ADP.P_i states) in the AM-ATPase cycle (Ranatunga, 1999); with kinetic modelling, the effects of [MgADP] can also be accommodated in such a scheme (Coupland et al, 2005).

The active muscle force decreases below the isometric level during shortening whereas the force increases above the isometric level during lengthening, in a velocity dependent manner. Therefore, in a recent study (Ranatunga et al, 2007), we examined the endothermic force generation induced by a T-jump in shortening and lengthening muscle fibres. Experiments were done on ~2 mm (L_o) segments of single skinned fibres from rabbit psoas muscle. A fibre was maximally Ca-activated at ~10 ºC and ramp shortening / lengthening of different velocities applied; when the force reached a steady level, a 0.2 ms laser pulse (λ = 1.32μ) induced a T-jump of ~3 ºC in the fibre and bathing fluid (see Ranatunga, 1996). The experiments showed that the amplitude and the rate of force generation induced by the T-jump increase as the shortening velocity is increased (up to ~0.2 L_o / s); conversely, the amplitude of T-jump tension rise is near zero (i.e. no net tension rise) during lengthening. Thus, endothermic crossbridge force generation is enhanced during muscle shortening but

inhibited during lengthening. The lack of a net tension rise to a T-jump in lengthening muscle supports the view that increased force in lengthening muscle is due to increase of strain in crossbridge states before force generation (Pinniger et al, 2006) and not associated with the A-M ATPase reaction; this would account for the well known Fenn effect that energy liberation in muscle is enhanced during shortening and inhibited during lengthening.

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