The force-length relationship in vivo: a simulation study

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The force-length relationship of muscle is a fundamental mechanical property of muscle and an important determinant of resultant joint moments. In vivo a muscle may operate over all or only part (ascending limb, descending limb or plateau region) of the force-length curve for physiologically realistic ranges of motion. There are several possible sources of this variability, for example anatomical and architectural differences and differences in muscle-tendon mechanical properties. Such features are reflected in the parameters usually included in muscle models. Reported values for these parameters typically vary between different muscles and vary between subjects for a given muscle. The purpose of this study was to determine the effect of these parameters on the section of the force-length relationship that a muscle operates over. A generalised model of a mono-articular muscle-tendon complex operating over a 90 degree joint range of motion was formulated and variables were systematically varied. The parameters investigated were: ratio of tendon resting length to muscle fibre optimum length (L_{TR} / Lf_{OPT}) (varied from 0.5 to 11.5), ratio of muscle fibre optimum length to average moment arm (Lf_{OPT} / r) (0.5 to 5), normalised tendon strain at maximum isometric force (c) (0 to 8%), muscle fibre pennation angle (θ_{PENN}) (0 to 45 degrees). The joint angle at which the optimum muscle fibre length occurred (θ_{REF}) was varied throughout

the 90 degree range of motion. The values for each parameter were based on reported ranges for five mono-articular muscles with different functional roles. It was shown that L_{TR} / Lf_{OPT} was important in determining the section of the force-length relationship that a muscle operated over. The effect of this ratio was modulated by Lf_{OPT} / r. The muscle operated over only one limb at intermediate values of these two ratios (L_{TR} / Lf_{OPT}=5; Lf_{OPT} / r=3), whether this was the ascending or descending limb was determined by the precise relative values of c, θ_{PENN}, θ_{REF}, and L_{TR} / Lf_{OPT}. At higher values of the two ratios the whole force-length relationship was used, at lower values only a small section of one limb was used. It was concluded that that inter-individual variability in the expressed section of the force-length relationship is possible, particularly for muscles with intermediate values of Lf_{OPT} / r and L_{TR} / Lf_{OPT} such as the brachialis and vastus lateralis. These results have implications for understanding the training adaptations of muscles for sport.