Experimental investigation of passive and active forces of m.triceps

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Introduction

The m. triceps brachii of small mammals (Rattus norvegicus, Galea musteloides) is well investigated with respect to kinematics, inverse dynamics, EMG mapping during locomotion and histochemical analysis of fiber spectrum by cooperating research groups (von Mering 1999; Biedermann, Schumann et al. 2000; Schilling 2001; Witte 2001).

Investigations at the Institute of Systematic Zoology and Evolutinary Biology, Jena (unpublished) revealed similar behavior in forelimb kinematics of Rattus norvegicus and Galea musteloides in the stance phase. This is characterized by extension in elbow joint and flexion in shoulder joint. M. triceps brachii is extensor at the elbow joint and with it’s biarticular head flexor in shoulder joint. In locomotion of small mammals the m. triceps serves as anti gravity and anti flexor muscle (Fischer 1998). Different fiber types (Gorb, unpublished), different activation (Cohen and Gans 1975; Biedermann, et al. 2000) and different alignment of the three heads indicate a functional partition. Presumably, monoarticular muscles are primarily responsible for generation of force and work, whereas the bifunctional muscles control the direction of external forces by regulating the distribution of the net moments across the joints (van Ingen Schenau, et al. 1994).

This study examines muscle properties of the m. triceps brachii (Rattus norvegicus) in relation to locomotion. The working range of muscle during stance phase, the importance of passive forces in locomotion, the optimum contaction velocity as well as the hypothesis that the caput longum is mainly responsible for kinematics in stance phase will be addressed.

Methods

Muscle architecture of m.triceps brachii, preparations and experimental setup are described previously (Siebert, et al. 2001). Stimuli were delivered by a computer controlled stimulation system. Torque and angle were measured and driven by an Aurora Scientific 305B-LR Dual-Mode Lever Arm system. The experimental setup allows the static and dynamic investigation of torque and angles generated by the whole muscle at the elbow joint with and without supramaximal nerval stimulation. Torque produced by the m. triceps was measured at the separated olecranon driven by the motor unit aligned with the rotational axis of the elbow joint. The system is able to drive and measure dynamically within a range of 39°. This is sufficient to reproduce motion during stance phase in elbow joint. All physiological shoulder joint angels can be adjusted by rotation of the turning table.

Passive and active isometric torque-angle relations of the whole muscle in dependency of shoulder (65°, 75°, 85°, 95°) and elbow joint angles (65°, 75°, 85°, 95°, 105°, 115°) are estimated by performing 24 isometric measurements (Rattus norvegicus m=516g). Isometrical stimulation was by fusion frequency of 120Hz, a pulse width of 100 µs and an amplitude of 8 V for 500 ms. In a second set of experiments torques produced by a supramaximally stimulated m.triceps were measured during different isokinetic movements (within 66° and 104°) in the elbow joint. The angular velocities (from 100°/s to 1600°/s) result in contraction of the caput longum similar to stance. The shoulder joint angle was fixed at 75°. In a third experiment the passive dynamic torque-angle relation in dependency of angle velocity was measured. The muscle was sinusoidally lengthened at the elbow joint with various frequencies (0.5 to 6Hz) for 4s. Movement in the elbow joint (outer angle 85° ± 19°) was in the range of motion in stance phase.
**Results & Discussion**

Torque produced by the isometric muscle decreased over the whole range of the stance phase with a small plateau at the beginning (Fig.1a). The muscle works in the ascending limb of the length-tension curve. In this section the force depression after shortening is not present (Morgan, et al. 2000)(own measurements). The avoidance of instability (sarcomere non-uniformity) during locomotion is therefore a system property of the triceps muscle.

![Fig.1: Active isometric (a,b) and passive (b) torque. (a) thin lines: torque in Nm, thick line: change in elbow (outer EJA) and shoulder (SJA) angle during the stance phase, arrows: direction of motion, s=compression of leg, e=elongation of leg, dark plane in fig (b): passive torque. c: Interpolated torques for the whole muscle and force of c.longum under assumption that other parts do not contribute.](image)

High moments at the elbow joint which are calculated from inverse dynamics (Witte 2001) occur within the first phase of stance and there maximum torques can be developed (torque-angle curve). In addition monopolar EMG recording (Scholle, unpublished) during trot document high activity in this phase. During compression (Fig.1a, arrow s) and elongation of the leg the biarticular caput longum shortens (Fig.2a). Fig 1c shows the calculated isometric forces for the caput longum. The influence of the monoarticular parts was neglected due to cross sectional area, architecture and lever arm.

![Fig.2: a: Length changes during stance phase of the three muscle parts, in assumption that model origin is located at the midpoint of fleshy origin (caput mediale, caput longum). b:Angle velocity calculated from contraction velocity of biarticular caput longum under the assumtion of a fixed shoulder joint angle. c: Power output of m.triceps brachii in dependence of angle velocity. (b) and (c): thick lines mark the range of maximal power output](image)

Isokinetic measurements with different angular velocities result in optimum contraction velocities with maximum power production of the triceps muscle within the range of 300-600°/s (Fig.2c). This corresponds with contraction velocities of the caput longum in the range of 23.8-47.7mm/s. Optimum contraction velocity
for rat m. gastrocnemius medialis were found to be 30mm/s (Ettema, et al. 1990) and for mice EDL 18.8
mm/s (Brooks, et al. 1991). Nearly all fibers in the caput longum are typ II fibers (Sullivan and Armstrong
1978; von Mering 1999) whereas the smaller caput mediale consists mainly of typ I fibers. Kinematic
analysis show that contraction velocities of caput longom during stance phase locomotion (Fig.2b) are in the
range of maximum power production. Higher contraction velocities combined with high tension values from
the length-tension curve as well as following optimum contraction velocities enable the muscle to produce
high power about a wide range. Lower contraction velocities (Fig.2b), decreasing force values (Fig.1c) and
decreased activation at the end of stance (Scholle, unpublished)(Cohen and Gans 1975) correspond with
decreasing moments in elbow joint estimated from inverse dynamics.

The contribution of passive force is between −1% and 1% of the measured isometric force during stance
(Fig.1b, dark plane). Minimum contribution is −11% at outer EJA=65° and SJA=65° (max. compression of
muscle). Maximum is about 6% at outer EJA=115° and SJA=115° (max. lengthening of muscle). Both
situations do not occur during locomotion. During early swing phase even negative passive stress values
occur. The m. triceps contributes passive to the swing movement. The contribution of passive properties to
the torque developed at the elbow joint can reach 8 %. Similar to observations at the hind limb (Perry et al,
1988) about 25 % of the cross-section is recruited during trotting.

Torque produced by m. triceps during trotting are unexpectedly high, if we suppose that the average force
produced in vivo is 60% of maximum isometric force. Thus there seems to be only a small range of force
reserves for faster gaits, such as gallop or jump.

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