ROLE OF PASSIVE MOMENTS IN THE MECHANICS AND ENERGETICS OF LIMB SWING

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INTRODUCTION

A growing body of data indicates that limb-swing is not passive, but requires considerable mechanical and metabolic energy[1,2]. We have recently explored the mechanical determinants of the energy cost of limb swing by combining mechanical measurements from inverse dynamics and metabolic measurements of individual muscles using a blood flow technique in a bipedal animal model (*Numida meleagris*; guinea fowl)[3]. These experiments show that the mechanical work at the joints required to accelerate the limb segments do not explain the metabolic cost of limb swing.

Passive moments are not incorporated in conventional mechanical work analyses, but may alter the active mechanical work required of muscles during gait, and may thus hold clues to the mechanical determinants of limb-swing cost. Here we explore the role of passive moments in walking and running gaits and their contribution to limb-swing energetics using the guinea fowl as a model. Although all joints are analyzed, we focus primarily at the ankle given that it permits the estimate of the efficiency of a single muscle, the tibialis cranialis (ankle flexor).

METHODS

We measured passive joints moments in non-survival surgeries on deeply anesthetized guinea fowl. Complete muscle relaxation was achieved by blocking nerve conduction proximally in the major nerve trunks entering the limb. Adjacent joints were fixed by externally applied fixation devices attached via bone screws. The joint was flexed and extended by applying an external force to a bone-embedded force-transducer (Kistler) at a know distanc from the moving joint. The force transducer was free to rotate around the axis of the bone screw. Joint positions and the orientation of the externally-applied force vector were tracked by applying reflective markers and videoing the movements with a digital video camera (field rate 60 Hz). Inverse dynamic calculations were used to measure the passive moments across the joints' range of motion.

Because the passive moment at one joint is affected by the position of adjacent joints (due to two-joint muscles), we performed experiments at each joint under 11 different combinations of fixed adjacent joint angles. The data from these experiments were fitted with a double exponential function that predicted the passive moment for a given joint based on its angle and the angle of its adjacent joints. These predictive equations were used to compute the passive joint moments across limb swing during walking and running. Active muscle moments, power and work were computed by subtracting the passive moment from the net joint moments during limb swing, and the efficiency of the active muscle work was estimated by incorporating the muscle's rate of energy expenditure [2].

RESULTS AND DISCUSSION

The passive limb-swing moments have a major influence on the predicted active muscle moments, especially at the ankle during walking (Fig. 1a). For most of limb swing, ankle flexion results in a large passive extension moment that must be countered by a muscle flexion moment (Fig. 1a). When taking into account the passive joint moments, the mechanical work required by active muscles at the ankle increases considerably during walking, but not running. As a result, the predicted efficiency of the tibialis cranialis during ankle flexion in walking increases by a factor of two when incorporating the passive joint moment, but changes negligibly from the efficiency calculated from inverse dynamics alone at faster running speeds (Fig. 1b).

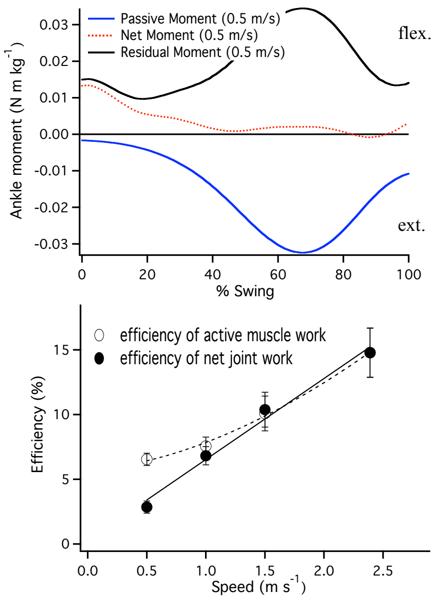

Figure 1: (**a**) net, passive and active joint moments and (**b**) the predicted efficiency of the tibialis cranialis muscle (±SD)

CONCLUSIONS

Passive joint moments have a major impact on the mechanical function predicted for limb-swing muscles, especially during walking. Passive moments increase the required active muscle work at the ankle during limb swing. This additional work incurs a substantial metabolic cost and explains, in part, the previous low efficiencies predicted for the tibialis cranialis muscle from inverse dynamics [3].

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