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DEVELOPMENT OF A MUSCULOSKELETAL MODEL OF THE NEW ZEALAND WHITE RABBIT HINDLIMB: JOINT POWER AND WORK DURING HOPPING AND JUMPING

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SUMMARY

This project describes the development of a musculoskeletal model of the left hind limb of the New Zealand White rabbit that can be applied to the study of movement and musculoskeletal mechanics. The model was then used for an initial analysis of the joint power and work performed during steady speed hopping and vertical jumping to 30 and 45 cm. The total work increased by over 300% from hopping to jumping to the 45 cm box with the ankle joint accounting for approximately 80% of the work performed in all conditions. Surprisingly, these data indicate that the compliant muscles acting about the ankle joint (e.g. gastrocnemius, soleus) may be equally well suited for both energy storage and return (hopping) and positive power generation (jumping).

INTRODUCTION

The rabbit is among the most commonly used animal models of disease. The motivation for using the rabbit models is to induce disease and/or to make invasive experimental measurements that are infeasible in humans. The development of a New Zealand White rabbit musculoskeletal model would permit integration of animal experimental procedures with the analytical potential offered by computational neuromuscular modeling.

Bridging the experimental and computational domains will allow for validation of computational predictions of variables such as muscle force and tendon strain. In addition, the development of a computational model of this commonly used animal will hopefully decrease the number of animals needed for animal-based mechanics studies.

METHODS

Kinematics and kinetics

Three dimensional motion capture and ground reaction forces during normal hopping and vertical jumping onto boxes 30 and 45 cm high of a New Zealand white rabbit were recorded using a 6 camera Vicon MX system (Vicon, Oxford, UK) and small animal force plates (AMTI, Watertown, MA, USA).

Musculoskeletal model development

A musculoskeletal model of the New Zealand white rabbit left hind limb was developed with 42 muscle lines of action (Fig. 1). Bone geometry was based on CT data. Muscle and tendon paths were digitized using a commercial digitizing arm (Microscribe 3DX, Immersion, San Jose, CA, USA). Muscle fiber lengths and pennation angles and tendon slack length were measured on fixed specimens. Sarcomere lengths were measured using laser diffraction [1] and used to calculate optimal fiber lengths.

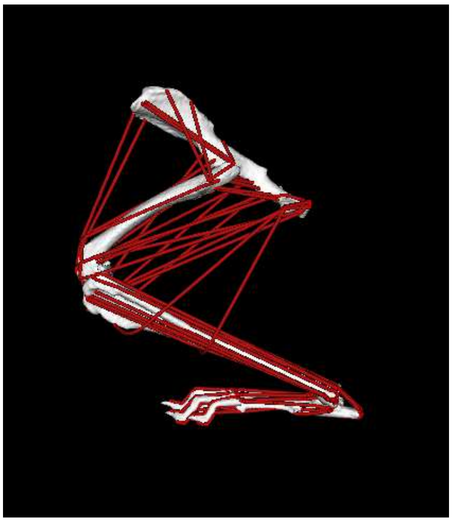

Figure 1: Musculoskeletal model of the left hind limb of the New Zealand White rabbit.

Musculoskeletal simulations

Torques at each joint in the left hind limb during normal hopping and jumping were determined using the inverse kinematic and inverse dynamics tool in OpenSim [2]. Joint power and work were then calculated for the hip, knee, and ankle joints.

RESULTS AND DISCUSSION

The power generated increased from hopping to jumping with the majority of the power being generated by the ankle joint (Fig. 2). As can be seen in Fig. 2a, when hopping at steady speed the rabbits power generation nearly mirrored power absorption indicative of a spring-mass system and storage/return of mechanical energy. However, the required power increased about 5 fold from normal hopping to jumping to a height of 45 cm with minimal negative work preceeding power generation.

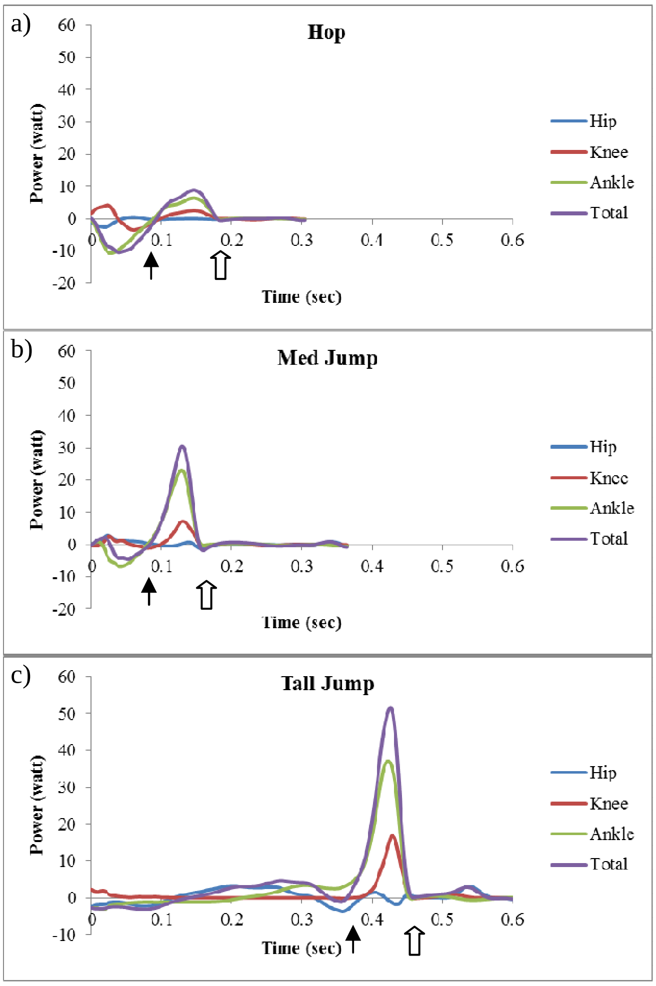

Figure 2: Power generated in the joints of the left hind limb during normal hopping (a) and jumping to a height of 30 cm (b) and 45 cm (c). Toe on (time 0), mid-stance (solid arrow), toe off (open arrow).

The total work increased by over 300% from hopping to jumping to a height of 45 cm (Table 1). Most of the work was done by the ankle joint which accounted for approximately 80% of the work whether hopping or jumping.

Table 1: Work (Joules) done by the left hind limb during hopping and jumping to a height of 30 cm (Med) and 45 cm (Tall). Calculated for area between solid and open arrow in Fig. 2.

	Hip	Knee	Ankle	Total
Hop	-0.01036	0.123913	0.363051	0.476603
Med	-0.00645	0.195734	0.848782	1.038061
Tall	-0.07766	0.495965	1.603998	2.022303

CONCLUSIONS

Power and work increased from steady speed hopping to jumping with the majority occurring at the ankle joint. Interestingly, the anatomy of the ankle muscle-tendon units, and the storage capabilities of the Achilles tendon in particular, appear to be well suited to both energy storage and return during steady-speed hopping and explosive positive power generation in jumping. These findings are surprising given the different mechanical demands of these locomotor tasks.

The continued development of the New Zealand White rabbit hind limb musculoskeletal model will allow for more complex measurements such as muscle activation as well as muscle and tendon force to be determined in the future. These parameters can be important in assessing normal vs. diseased muscle function and establishing minimum requirements for tendon repairs.

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