Effects of size and muscle properties om primate vertical jump height

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Summary

A human athlete may jump about 40 cm high, whereas a marmoset, a small primate, jumps about 45 cm high. How should we compare these two performances? Here we studied the effect of size and muscle properties on jump height. Isometric downscaling of a human musculoskeletal model to the size of a marmoset caused jump height to drop from 40 cm to 10 cm. The higher percentage of fast twitch fibers and lower curvature of the force-velocity relationship in marmosets could only partially compensate for this drop in jump height, raising jump height from 10 to 18 cm. Obviously, a real marmoset is not an isometrically downscaled human. In order to explain why marmosets jump higher than humans, it seems necessary to make a model representing actual marmoset anatomy and muscle properties.

Introduction

Jump height, defined as vertical displacement of the center of mass from takeoff to the apex of the jump, has been abundantly studied in various species. A 70 kg human athlete may jump about 40 cm high, whereas a small primate such as a marmoset (*Callithrix jacchus*) with a mass of about 0.365 kg) jumps about 45 cm high [1]. It has been shown that isometric downscaling of a human musculoskeletal model leads to a reduction in jump height [2]. How, then, can a marmoset jump higher than a human athlete? The percentage of fast twitch fibers in leg muscles is greater in marmosets (around 100%) than in humans (around 50%) [3]. Furthermore, the force-velocity relationship of marmoset muscles is less curved than that of human muscles [3]. Here we studied to what extent these factors compensate for the negative effects of isometric downscaling on jump height.

Methods

Vertical squat jumps were simulated using a planar forward dynamic simulation model of the musculoskeletal system [2]. The model had foot, shank and thigh segments, as well as a head-arms-trunk segment, and was actuated by muscle-tendon complexes of m. soleus, m. gastrocnemius, monoarticular vasti, m. rectus femoris, glutei and hamstrings. Each muscle-tendon complex was modeled as a Hill-type unit. The model calculated the segmental motions resulting from stimulation (STIM) input to the muscles. Initial STIM levels were chosen such that equilibrium initial conditions were achieved. Subsequently, STIM-time histories of the muscles were optimized using jump height as criterion. To downscale the human model, we decreased length scale factor L from 1.0 to 0.16. All body segment lengths, distances of segmental mass centers to segment ends, and muscle moment arms, were scaled by L, all masses by L^3, and all moments of inertia by L^5. Lengths of contractile and elastic elements were scaled by L and their forces, which depend on physiological cross-sectional areas, by L^2. Properties of fast twitch and slow twitch muscle fibers were taken from Hatze [4].

Results and Discussion

When the human model with 50% of fast twitch muscle fibers was isometrically downscaled to the size of a marmoset, jump height dropped from 40 cm to 10 cm (Fig. 1). In the downscaled model, joint angular velocities reached higher values, but the vertical velocity at takeoff was smaller because the segments were shorter. Due to higher shortening velocities associated with the higher angular velocities, the force-velocity relationship was the dominant performance-limiting factor in the downscaled model. Increasing the percentage of fast twitch fibers in the downscaled model to 100% raised jump height from 10 to 16 cm, and additionally reducing the curvature of the force-velocity relationship to that measured in marmoset muscle fibers raised it from 16 to 18 cm. However, 18 cm is still far below the actual marmoset jump height of 45 cm [1]. Obviously, the isometrically downscaled model does not represent an actual marmoset. Given the fact that the force-velocity relationship was a dominant limiting factor in the downscaled model, we reduced muscle moment arms by 50% to reduce shortening velocities, and this raised the jump height of the downscaled model from 18 to 27 cm. This suggests that in trying to explain why marmosets jump higher than humans, we need to take into account not only muscle properties but also marmoset-specific anatomical properties.

Conclusions

Isometric downscaling of a human musculoskeletal model to the size of a marmoset causes jump height to drop from 40 to 10 cm. The higher percentage of fast twitch fibers and lower curvature of the force-velocity relation in marmosets only partially compensated for this drop in jump height. To explain why marmosets jump higher than humans, it seems necessary to make a model representing actual marmoset anatomy and muscle properties.

References

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