Dynamic Compensations in the Gait of a Patient with Quadriceps Weakness

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INTRODUCTION

Because the human musculoskeletal system acts as a set of interconnected segments, forces produced by muscles or connective tissues crossing a joint will induce accelerations at all other joints (Zajac and Gordon 1989). Traditional gait analysis methods have not been able to measure these induced accelerations and thus are limited in explaining how a person with musculoskeletal deficiencies can compensate to produce effective gait. In this paper, a model is presented that estimates the individual contributions of the joint torques to the acceleration of the body. The model is then applied to understand how a patient with quadriceps femoris weakness compensates during gait.

REVIEW AND THEORY

Zajac and Gordon (1989) used a musculoskeletal model to demonstrate that torques produced by muscle forces about a joint will generate accelerations about all joints, including those not spanned by the muscle. Meglan (1992) used these principles in conjunction with traditional inverse dynamics methods to show that the joint torques produced during gait significantly affect the accelerations at other joints. These induced accelerations can be calculated by setting **C**, **G**, **F** and all but one joint torque equal to zero in the equation of motion

$$\mathbf{q} = \mathbf{M}^{-1}\mathbf{T} + \mathbf{M}^{-1}\mathbf{C} + \mathbf{M}^{-1}\mathbf{G} + \mathbf{M}^{-1}\mathbf{F}$$

(**q** is the matrix of accelerations, $\mathbf{M}^{-1}$ is the inverted mass matrix, **C** is the matrix of Coriolis terms, **G** is the matrix of gravitational terms, **F** is the matrix of external forces and **T** is the matrix of joint torques.)

This paper extends Meglan's model by accounting for closed kinetic chain effects and by examining the effect of the net torques on the acceleration of the trunk. The model is then applied to further understand the adaptive behavior of a patient with quadriceps femoris weakness.

PROCEDURES

The subject of this study was a 40 year old male with left quadriceps femoris weakness due to polymyositis. Gait data were collected using a six camera Vicon system with two AMTI force plates and were evaluated during single limb support.

The data were input into a model consisting of two feet, two legs, two thighs and a single head arm trunk (HAT) segment. The ankles and knees were pin joints and the hips were spherical joints. The foot/ground interface was modeled as a pin joint located at either the metatarsal head or at the calcaneus. The location was selected based on the constraint that the foot was not allowed to rotate into the floor. If neither pin location met this constraint, the foot was considered fixed.

ADAMS/ANDROID software was used to solve for the translational accelerations at the HAT segment induced by the joint torques. The induced vertical accelerations were assumed to reflect the role of the joint torques in supporting the body and the anterior accelerations were assumed to reflect the role of the joint torques in forward progression.

RESULTS

During the first half of single limb support, the vertical accelerations induced by the joint torques were clearly different for the normal and weak limbs. On the normal side, the joint torques were active in supporting and controlling the acceleration of the HAT segment (Fig. 1a). The extensor torques at the knee joint were primarily responsible for this activity. On the weak limb, where knee extensor strength was limited, very little support was induced (Fig. 1b).

During the second half of single limb support, the joint torques were responsible for both supporting and propelling the body forward (Figs. 1-2). Further examination of the joints contributing to propulsion (Fig. 3) showed similar mechanisms were used on both sides. This was an expected result because propulsion was found to be generated by active plantar flexion on the stance limb and the deceleration of the swing limb by the hip extensors.

Discussion

The most striking compensations in the subject's gait were exhibited during the early part of single limb support. On the normal side, the vertical HAT segment acceleration closely followed the induced accelerations, indicating the subject actively controlled the center of gravity to absorb shock. On the weak side, the subject's knee was near full extension, allowing him to passively use the limb to raise the center of gravity. This use of the straight limb increases knee joint stability (Siegel et al. 1994), but does not allow the limb to control the accelerations of the center of gravity in order to absorb shock.

Of additional significance is the ability of the current technique to determine which joints contribute to the subject's forward progression. The use of the hip extensors to decelerate the swing leg were found to assist in forward propulsion. This mechanism could not have been determined using traditional approaches and illustrates the important role dynamic link models can play in the study of human gait.

References

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Acknowledgment

The authors thank Mechanical Dynamics Inc. for their support of this work.

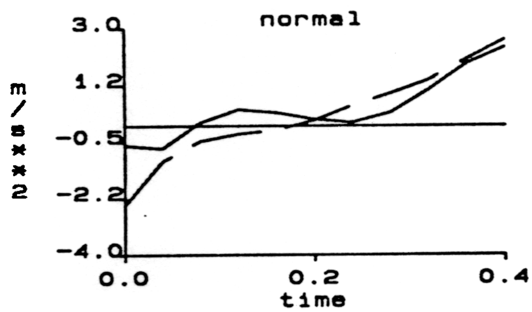

Figure 1a-b. Anterior(+)/posterior(-) acceleration of the HAT induced from the joint torques (solid line) compared to the Vicon measured values (dashed line).

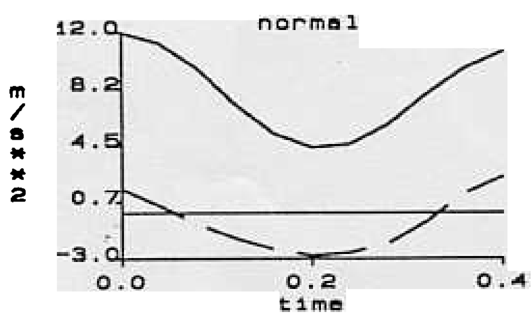

Figure 2a-b. Vertical acceleration of the HAT induced from the joint torques (solid line) compared to the Vicon measured values (dashed line).

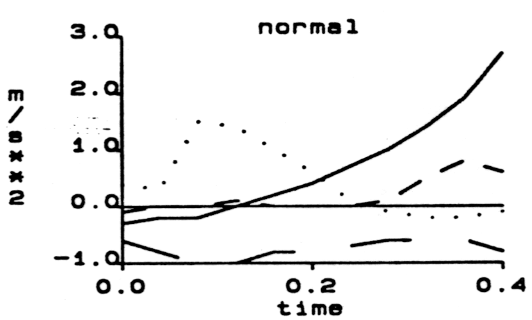

Figure 3a-b. Contributions of the joint toques to induced acceleration in the anterior/posterior direction. Ankle (solid line), Knee (dotted line), Stance hip (long dashed line), Swing Hip (short dashed line)