

CROUCHED GAIT POSTURES REDUCE THE CAPACITY OF UNI-ARTICULAR MUSCLES TO EXTEND THE HIP AND KNEE JOINTS

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INTRODUCTION

Many children with cerebral palsy (CP) walk with a crouched posture during the stance phase of the gait cycle, exhibiting excess knee flexion, hip flexion, and internal hip rotation. This pathological gait pattern increases the energy cost of walking and can lead to chronic knee pain and joint degeneration if left uncorrected. Further, without intervention, crouch gait typically worsens over time (Bell et al., 2002).

Understanding the impact of a crouched gait posture on muscle function may shed light on the progression of the pathology and improve the efficacy of corrective and preventative treatments. The goal of this study was to determine the effect of crouch gait on the capacity of the major limb extensor muscles to accelerate the hip and knee joint during the single limb support phase of the gait cycle.

METHODS

We assessed the effect of crouched gait postures on the capacity of muscles to extend the joints using a modeling technique known as an induced acceleration analysis (e.g. Zajac and Gordon, 1989). In this analysis, a model of the musculoskeletal system is positioned with joint angles corresponding to a given gait cycle. The model's equations of motion are then used to calculate the capacity of the muscles to accelerate each of the joints.

We used a 3D, 15-segment, 23 degree-of-freedom model of the musculoskeletal system (Delp et al., 1990). This model was positioned using four distinct gait patterns: normal, mild crouch, moderate crouch and severe crouch (Figure 1). The normal gait pattern was based on the averaged gait kinematics of 83 able-bodied children. The crouch gait patterns were based on averaged gait kinematics from subjects with CP, classified based on their knee flexion

angle at initial contact. Mild crouch subjects had between 20° and 30° of knee flexion at initial contact (N=103), moderate crouch between 30° and 40° (N=171), and severe crouch over 40° (N=197). All gait data was collected using a 3D motion capture system at Gillette Children's Specialty Healthcare.

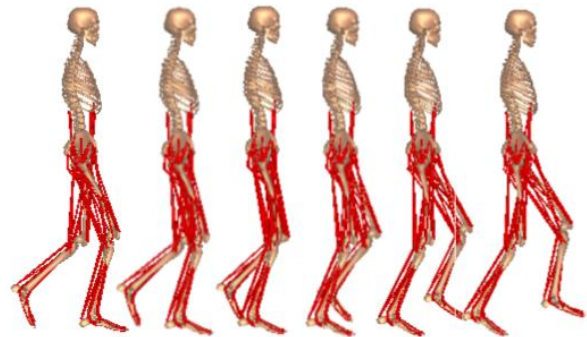


Figure 1: The musculoskeletal model in postures corresponding to the single limb support phase of moderate crouch gait.

For all four gait patterns, the capacity of the major limb extensors to accelerate the hip and knee joints toward extension was calculated for every 2% of single limb support (14-50% of the gait cycle). First, the contribution of each muscle to the ground reaction force was determined using an approach developed by Anderson and Pandy (2001): five contact points were distributed over the sole of the foot, a unit muscle force was applied to the model, and the resulting ground reaction force was determined by solving for the minimum force that would constrain the acceleration of each contact point to be zero. Second, a unit muscle force plus its contribution to the ground reaction force were applied to the model. The resulting accelerations of the hip and knee were then calculated using the model's equations of motion. This quantity represents the capacity of a muscle to accelerate the joint at that pose of the gait cycle, per unit muscle force.

RESULTS AND DISCUSSION

Major limb extensors were defined as the muscles that had an average extension capacity of at least $5^{\circ}/s^2/N$ and are active during normal single limb support (Perry, 1992). Of these muscles, the gluteus maximus was found to have the greatest potential to extend both the hip and knee joints (Figure 2). The bi-articular hamstrings was found to have an extension capacity at both the hip and knee. Vasti, soleus, and the posterior gluteus maximus also had significant hip and knee extension potentials.

When walking with a crouched gait posture, the extension capacities of almost all muscles were markedly reduced (Figure 2). The more severe the crouch gait pattern, the larger the impact on muscle extension capacity. For moderate crouch, the capacities of the limb extensors to accelerate the knee joint were reduced by 25-70%. At the hip joint, the capacities of the gluteal muscles, vasti and soleus were reduced by 15-50% for moderate crouch. The lone exception was the bi-articular hamstrings: the capacity of hamstrings to extend the hip *increased* slightly with crouch gait.

Two major factors must be considered when interpreting the results of this analysis. First, the actual angular acceleration of a joint induced by a muscle depends on the muscle's activation level as well as its force-generating capacity, which depends in turn on the muscle's physiological cross-sectional area and the muscle's length and velocity during the movement. Second, the results of this analysis depend on the musculoskeletal geometry and inertial properties of the model, which are variable, especially in children with CP.

The results of this analysis provide several valuable insights into muscle function during crouch gait. First, as crouch gait worsens, muscle extension capacities are further reduced in a negative cycle. This is consistent with the clinically observed worsening of crouch gait over time. Conversely, small improvements in hip or knee flexion may help reverse the process, especially if intervention occurs early in the progression of crouch gait. The only muscle whose extension capacity was not reduced by a

crouched posture, at least at the hip joint, was the hamstrings. Over-activity of hamstrings is common in patients with crouch, which may be related to this maintenance of extension capacity in a crouched posture.

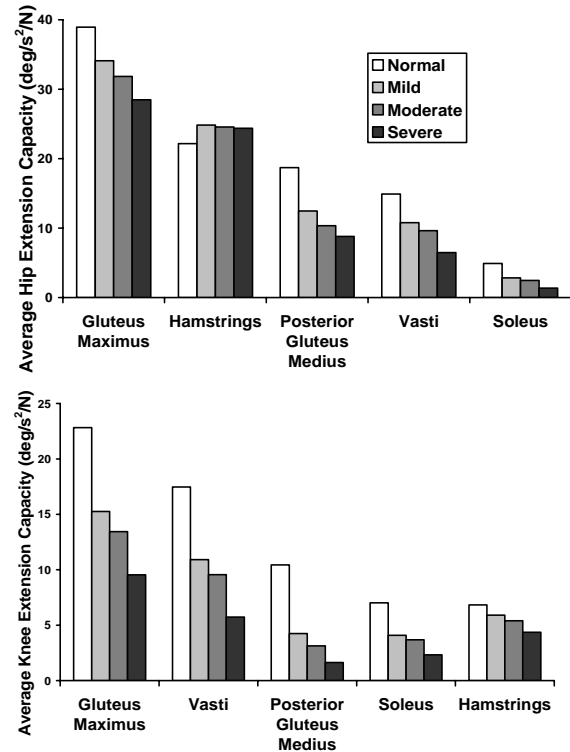


Figure 2: Effect of crouch gait on the average capacity of the major limb extensors to accelerate the hip (top) and knee (bottom) towards extension during single limb support.

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ACKNOWLEDGEMENTS

The authors thank Clay Anderson, Allison Arnold, and the staff of the Gillette Gait Lab. Supported by the NSF and NIH Roadmap for Medical Research, Grant U54 GM072970 and through NIH Grants HD33929 and HD04681