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MECHANICAL ADVANTAGE OF CROUCH GAIT

Jeffrey A. Reinbolt[1], Ajay Seth[1], Jennifer L. Hicks[2], and Scott L. Delp[1,2]

Departments of [1]Bioengineering and [2]Mechanical Engineering, Stanford University
Email: reinbolt@stanford.edu, Web: www.stanford.edu/group/nmbl

INTRODUCTION

Crouch gait is a prevalent and troublesome movement abnormality among children with cerebral palsy [1]. Crouch gait is characterized by excessive knee flexion during stance, which substantially increases the energy requirements of walking [2] and can lead to knee pain and joint degeneration [3].

Although the disadvantages of crouch gait are well documented, it is difficult to elucidate mechanisms that lead to a crouched posture. Muscle tightness, weakness, and spasticity, skeletal deformities, and motor control deficits are factors that have been associated with the development of crouch gait. Despite being studied for decades, it remains unclear whether these factors are the reason for adopting a crouched posture or instead a consequence of walking with a crouch gait. One theory deserving further exploration is that there may be unrecognized benefits to a crouched posture.

In this study, we used musculoskeletal modeling and optimization to examine one possible benefit of a crouch gait. Our goal was to determine if walking in a crouched posture increases the capacity of muscles to generate ground reaction forces in the transverse plane during midstance. We hypothesized that a crouch posture has a larger force-generation profile compared with an upright one (Figure 1).

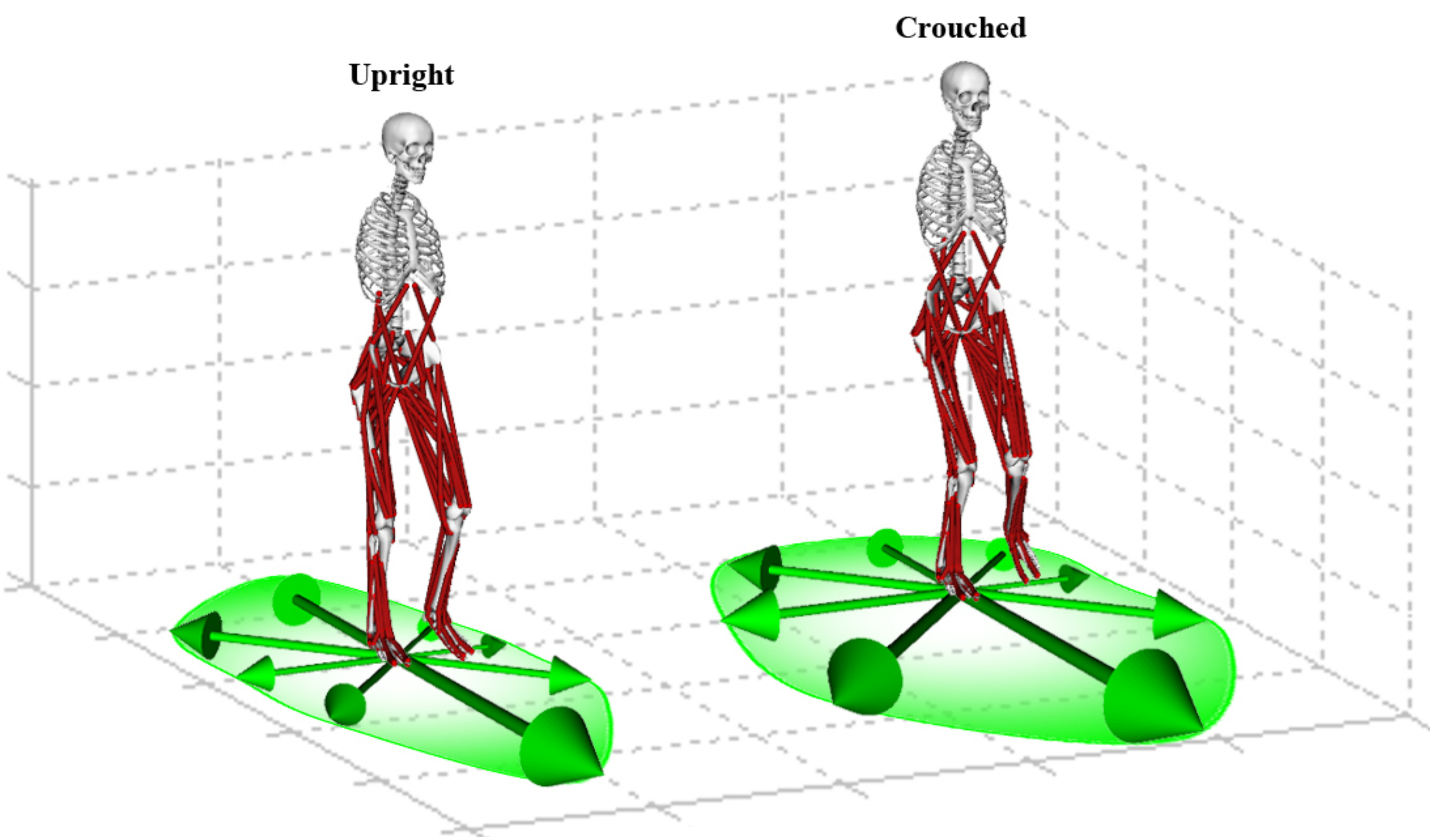

Figure 1. Three-dimensional musculoskeletal model placed in the upright (left) and crouched (right) postures during midstance at 32% of the gait cycle and maximum ground reaction force profiles in the transverse plane.

METHODS

A three-dimensional musculoskeletal model with 15 degrees of freedom and 92 muscle-tendon actuators was created in OpenSim [4]. The stance foot was welded to the ground. The lower extremity joints were modeled as follows: each subtalar and ankle joint was a revolute joint, each knee was a planar joint, and each hip was a ball-and-socket joint. The head, arms, and torso were represented as a rigid segment connected to the pelvis by a ball-and-socket joint.

The musculoskeletal model was separately placed into crouched and upright postures during midstance at 32% of the gait cycle (Figure 1). The crouched posture was defined by mean kinematics for 100 subjects with cerebral palsy who walked in a severe crouch gait [5]. The upright posture was defined by mean kinematics for 83 able-bodied subjects [5].

For the crouched and upright postures, a series of optimizations were performed using IPOpt. For each of 8 points on the compass, separated by 45º, we maximized the ground reaction forces in the transverse plane by modifying the muscle forces acting on the model. Each optimization was subject to a set of constraints requiring the center of pressure to remain under the stance foot and the vertical ground reaction force to remain greater than or equal to zero.

We evaluated our hypothesis regarding the force-generation profile of a crouched posture by comparing the maximum ground reaction forces and force profile plots of this posture to those of the upright posture (Figure 1).

RESULTS AND DISCUSSION

The crouched posture had, on average, 22% larger maximum ground reaction forces during midstance compared with an upright posture (Figure 1, Table 1). The increase was largest (304 N, 66%) in the lateral, anterior direction. There was one direction (posterior) with a decrease (-286 N, -27%) in the maximum force generated for the crouched posture compared with the upright one. The overall larger force-generation profile is the result of a mechanical advantage of crouch gait. One benefit to adopting a crouched posture is increased potential of muscles to generate new movements which may compensate for impairments, such as muscle weakness and motor control deficits, associated with cerebral palsy.

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Table 1. Maximum ground reaction forces in the transverse plane for the upright and crouched postures during midstance at 32% of the gait cycle.

Direction	Upright		Crouch		Increase	
	Anterior force (N)	Lateral force (N)	Anterior force (N)	Lateral force (N)	Anterior force (%)	Lateral force (%)
1: lateral	0	577	0	827	0	43
2: lateral, anterior	463	463	767	767	66	66
3: anterior	1134	0	1299	0	15	0
4: anterior, medial	462	-462	584	-584	26	26
5: medial	0	-436	0	-523	0	20
6: medial, posterior	-352	-352	-462	-462	31	31
7: posterior	-1052	0	-766	0	-27	0
8: posterior, lateral	-596	596	-613	613	3	3