TELESCOPING ACTION IMPROVES THE FIDELITY OF AN INVERTED PENDULUM MODEL IN HEMIPLEGIC CEREBRAL PALSY GAIT

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INTRODUCTION

An inverted pendulum (IP) model of human gait can be used to understand the interplay between gravity and joint powers in propulsion. Dynamic walking models have shown that human-like gait can be achieved on downward slopes through gravity alone [1,2]; yet, additional sources of propulsion are needed for level gait [3,4]. Such an analytical finding was supported by inverse dynamics of a telescoping IP directly applied to normal gait [5]. Here, pendulum radial kinematics (telescoping) improved the prediction of both horizontal and vertical ground reaction forces (GRF). Without telescoping, GRF predictions deviated significantly from actual values, during sagittal power bursts at the hip, knee, and ankle joints. We hypothesized that these findings would extend to patients with hemiplegic cerebral palsy, despite a range of mobility disabilities and prior treatment.

CLINICAL SIGNIFICANCE

In combination with detailed physical examination findings, joint power patterns have been a useful adjunct to guide therapeutic and surgical interventions for children with cerebral palsy. If the IP model proves inadequate to predict GRF in these patients, this would strengthen the justification for treatment recommendations based in part upon these joint power patterns.

METHODS

After informed consent approved by the local human subjects committee, seven pediatric patients (mean age, height, mass: 11.6 yr, 1.4 m, 36.1 kg), diagnosed with hemiplegic cerebral palsy, were enrolled in the study. They presented as Winters Type I, II, and IV (n = 3, 1, 3, respectively). Five patients had prior heelcord lengthenings, one had concurrent hip adductor and iliopsoas lengthenings, one had gastrocnemius BOTOX injections, one had no prior treatment. Kinematic data were collected at 120 Hz using a ten camera Vicon 612 system. A thirteen-segment, full-body model was implemented in Visual3D (C-Motion Inc.), and the instantaneous full-body center-of-mass (COM) was calculated. Horizontal and vertical GRF (*Fh*, *Fv*) were collected at 1560 Hz using three AMTI force plates. Subtracting average center-of-pressure (COP) coordinates from those of the instantaneous COM provided an IP with optional telescoping action [5]. Affected-side inverse dynamics in Visual3D provided lower extremity joint powers. Five repeated measures ANOVAs with Tukey HSD *post hoc* tests detected differences ($P \leq 0.05$) among actual and predicted minima and maxima in *Fh* and *Fv*, with and without telescoping. Root mean square (RMS) errors quantified differences between actual and predicted *Fh* and *Fv*.

RESULTS

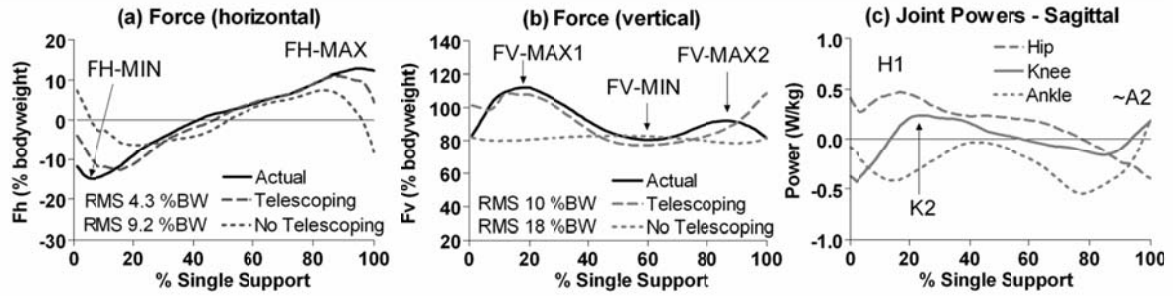

Figure. Ground reaction forces and joint powers. For all panels, one walking trial for each of seven hemiplegic cerebral palsy patients were averaged across single support. Panels (a) and (b) include actual (solid), predicted with telescoping (dashed, average length change 2.1 cm), and predicted without telescoping (stippled) horizontal and vertical ground reaction forces; RMS errors are % bodyweight. Panel (c) includes mean sagittal joint powers at the hip, knee, and ankle. Power bursts H1, K2, A2 are after Winter [3].

Table. Repeated measures ANOVAs, with Tukey Honest Significant Difference (HSD) *post hoc* tests.

							***P* values**		
Variable	**ACT**		**TEL1**		**TEL0**		**ACT-TEL1**	**ACT-TEL0**	**TEL1-TEL0**
Fh-min	-16.1	(6.1)	-7.1	(3.8)	3.8	(5.6)	**0.009068***	**0.000195***	**0.002520***
Fh-max	14.1	(3.8)	11.0	(3.5)	2.1	(4.9)	0.126156	**0.000193***	**0.000311***
Fv-max1	114.5	(16.4)	109.4	(10.8)	80.7	(5.3)	0.602355	**0.000254***	**0.000494***
Fv-min	65.6	(17.8)	83.7	(21.3)	83.7	(4.4)	0.160792	0.161860	0.999991
Fv-max2	97.2	(10.4)	93.2	(11.2)	80.7	(5.3)	0.560949	**0.002796***	**0.017227***

For each kinetic variable (% bodyweight), maxima and minima in actual data were compared with inverse dynamics data predicted after Buczek et al. [5] at the same relative time (i.e., percent of single support). ACT = actual data, TEL1 = inverse dynamics with telescoping, TEL0 = inverse dynamics without telescoping, Data are means and (standard deviations) with n = 7. (*) indicates significant at $P \leq 0.05$.

DISCUSSION

Telescoping improved the fidelity of *Fh* and *Fv* during single support, as compared to the non-telescoping action. Movement strategies varied across patients, but for three, sagittal hip powers occurred simultaneously with the onset of a positive *Fh* near mid single support. Results suggest these joint powers contributed to propulsion for some, but not all, patients.

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DISCLOSURE STATEMENT

NIOSH currently supports a simplified acquisition contract to C-Motion. The opinions expressed in this abstract are those of the authors and may not reflect the views of NIOSH.

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