KNEE EXTENSION AT TERMINAL SWING: A MISSING CRITICAL GAIT EVENT FOR CHILDREN WITH SPASTIC CEREBRAL PALSY

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Summary/conclusions
In a series of 175 children (276 legs) with spastic cerebral palsy (SCP) undergoing routine gait analysis, 87% of the legs demonstrated a limitation in peak knee extension at terminal swing (PKETSW) of 10° or greater. The degree of limitation in PKETSW was significantly different among three distinct patterns of initial foot contact, and significant relationships were detected between the knee extension limitation and kinematic variables linked to critical precursor events.

Introduction
Sufficient knee extension at terminal swing has been identified as a critical gait event because its existence positions the foot for weight acceptance [1]. Normal knee kinematics in swing reflect the behavior of the thigh and shank as a compound pendulum. Knee flexion in initial swing is promoted by factors that accelerate the thigh and flex the hip during limb advancement, but the sequence begins in terminal stance and preswing with ankle and hip power generation. Knee extension later in swing, is promoted by factors that decelerate the thigh at midswing and other complementary factors that grade the movement of the knee into extension [2, 3]. Symptoms of spasticity and impairments in selective motor control limit the precursor gait events that are required for normal PKETSW in children with SCP [3, 4]. The purposes of this retrospective study were to: 1) assess the prevalence of limitations in PKETSW, 2) examine the relationship of these limitations to pattern of foot contact; and 3) examine the association of kinematic variables that are linked to precursor events in the gait cycle to the limitations in PKETSW.

Statement of clinical significance
Limitations in PKETSW in children with SPC are highly prevalent, affect foot position at initial contact, and are linked to precursor critical events that may be limited by impairments in motor control. These findings may be useful in planning gait interventions for children with SPC and measuring the outcomes of the interventions.

Methods
Permission to conduct this retrospective study, under exempt status, was granted by the local institutional review board. Sagittal plane kinematic data from the initial gait analyses of all individuals with SPC, ages 5-21 years, conducted at the CGMA from June, 1999 to May, 2005 were entered into a database. About 58% of the samples were from children between 5 and 10 years of age; 27%, between 10 and 14 years; and 15%, between 16 and 21. The kinematic data were collected at 120 Hz using a 6-camera Vicon 512 motion capture system. Each leg constituted one sample. From the original 366 samples, 276 affected legs were maintained for analysis. Samples were omitted according to the following exclusion criteria: unaffected leg of a subject with spastic hemiplegia; use of assistive device during the gait trials; true equinus gait pattern, or crouch gait pattern. In true equinus and crouch gait, knee displacement are predictably constrained by the ankle or hip. Statistical analyses applied to the data are outlined in Table 1.

Table 1. Guiding Questions and Statistical Analyses

Guiding Questions	Statistical Analysis
Prevalence of PKETSW	Frequency analysis; Descriptive Statistics
Effects of foot contact on degree of limitation in PKETSW	Analysis of Covariance (ANCOVA), with adjustment for peak ankle dorsiflexion in swing.
Relationship of kinematic variables to limitations in PKETSW	Univariate analysis (Pearson r correlation coefficients) to detect relationships of PKETSW with 17 relevant kinematic variables including peak values, % gait cycle and slope at hip, knee and ankle in swing period on ipsilateral side and in stance period on ipsilateral and contralateral sides. Multiple regression analysis of variables with Pearson r correlation coefficients > 0.30 (variables with fair-moderate associations), to assess their simultaneous effects on PKETSW

Results

Prevalence: Mean limitation in PKETSW, relative to normal (4° of flexion) was 21.35°±SD. Limitations in PKETSW of at least 10° relative to normal range were observed in 87.32 % of 276 samples. Of the 276 sampled, 12.68% demonstrated less than 10° of limitation; 35.14 %, a mild limitation (10°-20°); 33.70 %, a moderate limitation (20°-30°); and 18.48 %, a severe limitation (> 30°).

Effects of degree of limitation on pattern of foot contact: ANCOVA identified a significant effect of pattern of initial foot contact (forefoot, foot flat, or heel contact), with peak ankle dorsiflexion in swing accounted for ($p < 0.0001$). Post-hoc analysis identified significant differences ($p \leq 0.0065$) in PKETSW among all three foot contact patterns.

Relationships of kinematic variables: The multiple regression model accounted for 58% of the variance. Multiple regression analysis identified the following significant relationships: peak hip flexion in swing ($p < 0.0001$), slope of knee extension in swing ($p < 0.0001$), interaction of % gait cycle of peak knee flexion in swing with slope of knee extension ($p < 0.0001$) and with % gait cycle peak ankle dorsiflexion in stance ($p = 0.0006$).

Discussion

The kinematic variables and interactions that are significantly related to limitations in PKETSW, identified in the multivariate model, can be linked to three precursor gait events that affect knee behavior in swing; onset of plantarflexion in stance, control of forward thigh movement, and knee extension angular velocity at terminal swing. First, the onset of plantarflexion in stance is linked since timing of peak dorsiflexion interacts significantly with the timing of peak knee flexion in swing. Second, the control of forward thigh movement in midswing is implicated because of the significant relationship of peak hip flexion in swing and terminal knee extension limitations. Finally, the link to knee extension angular velocity at terminal swing is established by the significant relationship of the *slope* of knee extension and the excessive knee flexion just prior to initial contact, as well as the interaction of the slope with the timing of peak knee flexion in swing. Impairments associated with SCP may limit the motor control mechanisms required for performance of these precursor events at any stage prior to initial contact, which adversely affects foot placement. This analysis is the foundation for further investigation which will integrates kinematic with kinetic and clinical variables. The long-term objectives are to identify patterns among these variables and investigate causal relationships that will guide clinical decision making.

References

[1] Perry J, (1992), Gait Analysis: Normal and Pathological Function, 235-239.
[2] Davis RB & Ounpuu S, (2004), in Gage, The treatment of gait problems in cerebral palsy, 120-133.
[3] Carollo JJ, (2002), Phys Med & Rehabil Clin of N Amer, 13, 949-977.
[4] Cooney KM et al., (2006), Clin Biomech, 21, 59-66.