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ORIGINAL ARTICLE

Prevalence of Specific Gait Abnormalities in Children With Cerebral Palsy

Influence of Cerebral Palsy Subtype, Age, and Previous Surgery

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Abstract: The authors retrospectively reviewed a series of 492 consecutive cerebral palsy patients undergoing computerized motion analysis. The prevalence of 14 specific gait abnormalities was evaluated and compared based on involvement (hemiplegia, diplegia, or quadriplegia), age, and history of previous surgery (lower extremity orthopaedic surgery or rhizotomy). Stiff knee in swing, equinus, and intoeing were all seen in more than 50% of the subjects in each of the hemiplegic, diplegic, and quadriplegic groups. Increased hip flexion and crouch were also present in more than 50% of the subjects in the diplegic and quadriplegic groups, and hip adduction occurred in more than 50% of the quadriplegic subjects. The likelihood of having stiff knee in swing, out-toeing, calcaneus deformity, and crouch increased with prior surgery. The likelihood of having rotational malalignment of the leg (internal hip rotation with out-toeing), calcaneus, out-toeing, varus and valgus foot deformities, and hip internal rotation increased with age. These findings provide important information for counseling ambulatory children with cerebral palsy and their families.

Key Words: gait analysis, cerebral palsy, natural history, surgery

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Objective data are lacking regarding the prevalence and distribution of gait deviations and joint deformities limiting function in children with cerebral palsy (CP). Although many reports describe certain gait problems, such as equinus or crouch gait, as the most common in CP,[3,5,7,13] these are empirical judgments not based on evidence in the literature. Objective data are needed for several reasons. Knowledge of the most common gait problems in patients seeking treatment will help researchers and clinicians focus their efforts in areas that will have the greatest impact on quality of care. These data may also be helpful when counseling patients and parents about the natural history of CP and the potential ramifications for their child. In addition, it is important to understand what problems are being corrected and what problems are potentially being caused or exacerbated when surgery is performed.

This study examines the prevalence of 14 specific gait abnormalities in almost 500 children with CP who were referred to our laboratory for computerized gait analysis. The purposes of this study were to document the prevalence of each gait abnormality in children with CP and to determine the influence of CP subtype, age, and previous surgery on the likelihood of having each of these gait abnormalities.

MATERIALS AND METHODS

Gait analysis data were reviewed for all patients with CP under 25 years of age who underwent pretreatment gait analysis testing in our laboratory between October 1992 and January 2003. Four hundred ninety-two subjects were studied: 291 with diplegia, 76 with quadriplegia, 115 with hemiplegia, 5 with triplegia, and 5 with athetosis (Table 1). Diplegia was defined as lower extremity involvement with minimal to no upper extremity dysfunction and quadriplegia as upper extremity involvement similar in degree to that seen in the lower extremities. The average age of subjects was 9.6 ± 4.0 years (range 3.1–24.4). Two hundred seventy (55%) of the patients were male, and 222 (45%) were female. Two hundred seven of the patients (42%) had undergone previous surgery that could affect lower extremity function, including orthopaedic surgery and selective dorsal rhizotomy (Table 2).

All subjects had undergone gait analysis testing at our institution. The gait analysis used a seven-camera VICON (Oxford Metrics, Oxford, UK) three-dimensional motion analysis system. This system uses a set of 15 to 19 passive retroreflective markers attached over specific bony landmarks of the pelvis and lower extremities. Subjects made several passes down a 15-meter path with the markers in place. Kinematic data from at least three trials were averaged, and the averaged data were included in the gait analysis report. An experienced gait laboratory physical therapist reviewed the gait data for all 492 subjects. Gait abnormalities were identified using the definitions in Table 3, and the percentage of subjects with each gait abnormality (prevalence) was calculated. The five triplegic and five athetoid subjects were included in the analysis of the group as a whole but were excluded from the CP subtype analyses. For the diplegic, quadriplegic, and hemiplegic subjects,

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TABLE 1. Patient Demographics

Type of CP	# Subjects	Percent	Age (yr) (mean ± SD)
Hemiplegic	115	23%	9.5 ± 4.0
Diplegic	291	59%	9.5 ± 4.0
Quadriplegic	76	15%	9.7 ± 3.8
Triplegic	5	1%	7.1 ± 1.8
Athetoid	5	1%	14.5 ± 3.3
All CP	492	100%	9.6 ± 4.0

univariate analysis was performed to examine whether the likelihood of having each abnormality was affected by CP subtype, age, or previous surgery. Logistic regression was then performed to adjust for covariates. The significance level was set at $P < 0.05$. For the comparisons between CP subtypes, the significance level was $P < 0.017$ based on the Bonferroni adjustment for multiple comparisons.

RESULTS

The most common gait problem in the group as a whole was stiff knee in swing (80%), followed by crouch (69%), excessive hip flexion (65%), intoeing (64%), and equinus (61%) (Fig. 1). The most common gait problems in diplegic subjects (seen in >50% of subjects) were stiff knee (88%), crouch (74%), excessive hip flexion (66%), intoeing (66%), and equinus (58%) (see Fig. 1).

The most common gait problems in quadriplegic subjects (seen in >50% of subjects) were stiff knee (93%), crouch (88%), excessive hip flexion (78%), intoeing (70%), equinus (68%), and excessive hip adduction (63%) (see Fig. 1). Controlling for age and previous surgery, quadriplegics had a greater likelihood of having crouch, scissoring, excessive hip adduction, and valgus compared with diplegics ($P < 0.017$). The likelihood of having equinus, calcaneus, varus, recurvatum, stiff knee, intoeing, out-toeing, excessive hip flexion, excessive hip internal rotation, and rotational malalignment did not differ between quadriplegics and diplegics.

The most common gait problems in hemiplegic subjects (seen in >40% of subjects) were equinus (64%), stiff knee (56%), intoeing (54%), excessive hip flexion (48%), and crouch (47%) (see Fig. 1). Controlling for age and previous surgery, hemiplegics were more likely to have ankle varus and less likely to have calcaneus, valgus, crouch, stiff knee, intoeing, excessive hip flexion, excessive hip adduction, and excessive hip internal rotation compared with both diplegics and quadriplegics ($P < 0.017$). The likelihood of having equinus, recurvatum, scissoring, out-toeing, and rotational malalignment did not differ between hemiplegics and either diplegics or quadriplegics.

Controlling for previous surgery and CP subtype, the likelihood of having rotational malalignment, calcaneus, out-toeing, varus, valgus, and hip internal rotation increased with age, while the likelihood of having equinus, recurvatum, and intoeing decreased with age (Fig. 2). The likelihood of having crouch, excessive hip adduction, excessive hip flexion, scissoring, and stiff knee did not change with age.

Controlling for age and CP subtype, the likelihood of having stiff knee, out-toeing, calcaneus, and crouch was higher in subjects who had previous surgery, while the likelihood of having varus, intoeing, and equinus was lower in subjects who had previous surgery (Fig. 3). The likelihood of having rotational malalignment, valgus, excessive hip flexion, recurvatum, excessive hip adduction, hip internal rotation, and scissoring did not change with previous surgery. The gait deviations are ranked in order of prevalence for subjects with and without previous surgery in Tables 4, 5, and 6.

DISCUSSION

The current study is the first to quantify the prevalence of specific gait problems in CP using three-dimensional kinematics. The results differ in some respects from common perceptions, suggesting that the gait problems cited as "most common" in the literature may, in reality, simply be the most obvious or visually apparent. Equinus has been described as the gait deviation that receives the most attention from surgeons and therapists because it is the most noticeable.[2,6] However, stiff knee in swing was the most common gait deviation in the current series. A stiff knee was more common than equinus for both operated and unoperated children with diplegia and quadriplegia as well as for previously operated children with hemiplegia. Only in those with hemiplegia and no previous surgery was equinus more common than a stiff knee. This type of discrepancy illustrates the difficulty in accurately assessing complex gait patterns with the unaided eye. In fact, stiff knee gait was first identified[12] and its treatment, distal rectus femoris transfer, was optimized with the aid of gait analysis technology.[11]

The gait problems identified in this study for the three subtypes of spastic CP differ from the characteristic patterns described previously. Hemiplegic gait consisted of equinus and intoeing with crouch (increased knee flexion on the hemiplegic side) in stance and a stiff knee in swing in

TABLE 2. Comparison of Mean Age Between Subjects With and Without Prior Surgery by Type of CP

	No Previous Surgery			Previous Surgery			
Type of CP	# Subjects	%	Age (yr) (mean ± SD)	# Subjects	%	Age (yr) (mean ± SD)	*P* Value
Hemiplegic	84	73%	8.9 ± 4.0	31	27%	11.0 ± 3.5	0.0101
Diplegic	158	54%	7.7 ± 3.2	133	46%	11.7 ± 3.8	<0.0001
Quadriplegic	36	47%	8.1 ± 3.0	40	53%	11.2 ± 3.9	0.0002

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TABLE 3. Definition of Gait Abnormalities Studied

Gait Abnormality	Definition
Equinus	Ankle plantarflexion >1 standard deviation (SD) below the mean for normal during stance phase, with or without hindfoot and/or forefoot varus or valgus
Calcaneus	Dorsiflexion >1 SD above the mean for normal for a significant portion of stance phase (>50% of stance)
Ankle varus	Hindfoot and/or forefoot varus/supination in stance or swing, with or without equinus
Ankle valgus	Hindfoot and/or forefoot valgus/pronation or midfoot break in stance or swing, with or without equinus
Crouch	Knee flexion >1 SD above the mean for normal in a significant portion of stance phase
Recurvatum	Knee extension in stance beyond 0°
Stiff knee	Decreased arc of knee motion from maximum knee extension in stance to peak knee flexion in swing, and/or delay in peak swing knee flexion to mid- or terminal swing, hindering foot clearance
Scissoring	Leg crossing in swing causing problems with foot clearance
Intoeing	Internal foot progression >1 SD more than mean for normal
Out-toeing	External foot progression >1 SD more than mean for normal
Excessive hip flexion	Hip flexed >0° in terminal stance
Excessive hip adduction	Hip adducted >1 SD above normal for significant portion of stance
Excessive internal hip rotation	Internal hip rotation >1 SD more than mean for normal for significant portion of stance
Rotational malalighment	Excessive internal hip rotation with excessive external foot progression (>1 SD more than mean for normal, regardless of cause, tibial torsion versus foot deformity)

approximately half of the subjects in this study. Although Bleck[2] states that "varus is usual" in hemiplegic subjects, ankle varus was present in only 31% of hemiplegic subjects referred for gait analysis in the current study. Winters et al[14] reported four types of hemiplegic gait patterns characterized by equinus, stiff knee, hip flexor tightness, and adductor involvement, increasing in proximal involvement with greater severity. In addition to these problems, the current study found intoeing and excessive stance-phase knee flexion in approximately 50% of hemiplegic subjects. Diplegic gait can be characterized as stiff-kneed, crouched, and intoed, with excessive hip flexion and equinus. Quadriplegic gait is very similar, with the addition of excessive hip adduction, scissoring, and a higher prevalence of crouch and ankle valgus than in diplegic subjects.

Changes in the likelihood of having specific gait deviations with age may reflect the course of CP over time. Previous authors have reported deleterious effects of time on the walking ability of children with CP.[1,8,9] Johnson et al reported the deterioration of static range of motion, sagittal kinematic parameters, and gait stability with time in a longitudinal study of 18 subjects followed for a mean of 32 months.[8] Bell et al more recently noted longitudinal deterioration in stride parameters, static range of motion, and sagittal kinematics in a series of 28 children with CP studied with computerized motion analysis with a mean of 4.4 years between studies.[1]

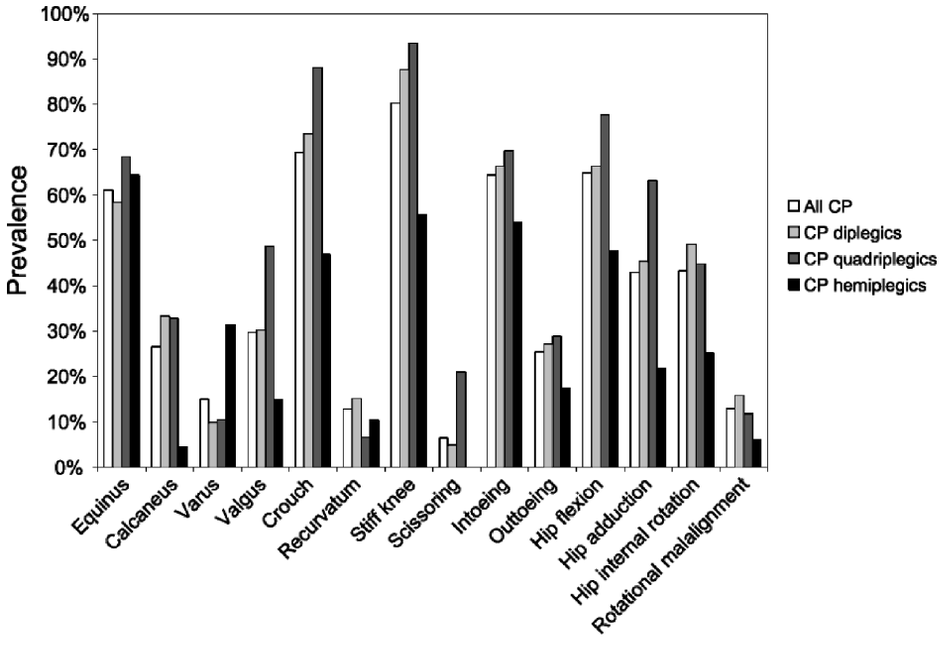

FIGURE 1. Prevalence of gait abnormalities in CP patients referred for gait analysis.

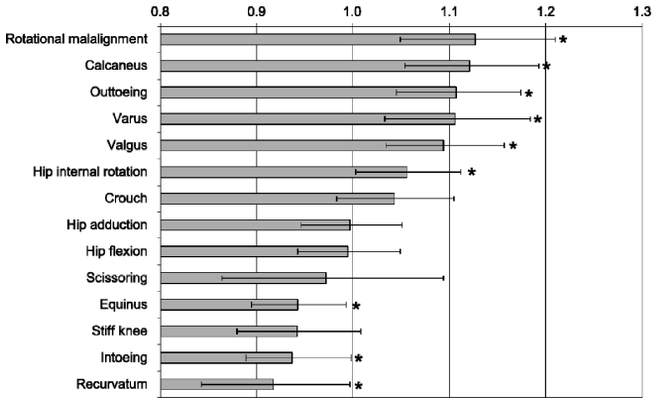

FIGURE 2. Adjusted odds ratios for gait abnormalities per year in age (adjusted for CP subtype and previous surgery). Ratio of 2.0 indicates doubling of the likelihood of having the abnormality per year of age; odds ratio of 0.5 indicates halving of the likelihood of having the abnormality per year of age. Asterisk indicates that the ratio differs significantly from 1.0.

In the current series, the most significant finding in older subjects was an increasing likelihood of rotational malalignment between the femur and tibia (with correspondingly increased chances of having internal hip rotation and out-toeing with age). This increase in rotational malalignment with age suggests that failure to address rotational problems in younger children with CP may lead to progressive rotational deformity with time. The fact that Bell et al did not note a significant change in hip rotation in their series may be due to small sample size.[1]

Another important finding of this study was the increased odds of having calcaneus deformity and decreased odds of having equinus over time, even without previous surgery. This suggests that overly aggressive treatment of equinus should be avoided. Although there was no significant

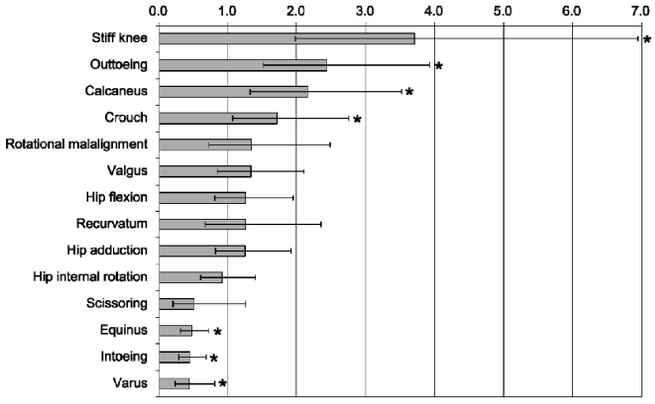

FIGURE 3. Adjusted odds ratios for gait abnormalities with previous surgery (adjusted for CP subtype and age). Ratio of 2.0 indicates doubling of the likelihood of having the abnormality if previous surgery was done; odds ratio of 0.5 indicates halving of the likelihood of having the abnormality if previous surgery was done. Asterisk indicates that the ratio differs significantly from 1.0.

TABLE 4. Most Prevalent Gait Problems for CP Diplegics With and Without Previous Surgery

Rank	No Previous Surgery (n = 158)		Previous Surgery (n = 133)	
1	Stiff knee	82%	Stiff knee	94%
2	Intoeing	78%	Crouch	76%
3	Crouch	72%	Excessive hip flexion	68%
4	Equinus	69%	Intoeing	52%
5	Excessive hip flexion	65%	Calcaneus	49%
			Internal hip rotation	49%
6	Internal hip rotation	49%	Equinus	46%

Calcaneus was present in 20% of subjects with no previous surgery. More than one problem per subject possible.

increase in the likelihood of crouch with age for the group as a whole, when the CP subtypes were analyzed separately, the odds of having crouch increased significantly with age for diplegic subjects, as expected (adjusted odds ratio 1.14; 95% confidence interval 1.05–1.24; $P = 0.003$), while remaining stable in the other two groups. Bell et al previously noted more of a tendency toward crouch (with excessive knee flexion and excessive ankle dorsiflexion) at follow-up in their subgroup of "less functional" children.[1]

Changes in the likelihood of having specific gait deviations after previous surgery illustrate the impact surgery may have on patients. Surgery appears to be effective in reducing the odds of having equinus, intoeing, and ankle varus but appears to increase the odds of having crouched gait, stiff knee gait, calcaneus gait, and out-toeing. These findings may reflect the impact of overlengthening the triceps surae on crouched gait, as well as the result of correcting femoral anteversion without attention to compensatory external tibial torsion and/or pes valgus. Even in the hemiplegic group, crouch was seen in 74% of children who had undergone previous surgery in comparison to 37% who had not. In addition, of 207 patients who had previous surgery, only 9 (4%) had undergone rectus femoris release or transfer, while 98 (47%) had undergone hamstring lengthening without rectus femoris procedures. The nearly fourfold increase in the odds of having stiff knee gait with previous surgery suggests the unmasking effect of rectus femoris dysfunction after isolated hamstring

TABLE 5. Most Common Gait Problems for CP Quadriplegics With and Without Previous Surgery

Rank	No Previous Surgery (n = 36)		Previous Surgery (n = 40)	
1	Stiff knee	89%	Stiff knee	98%
2	Excessive hip flexion	86%	Crouch	95%
3	Crouch	81%	Excessive hip flexion	70%
			Excessive hip adduction	70%
4	Intoeing	78%	Intoeing	63%
	Equinus	78%		
5	Excessive hip adduction	56%	Equinus	60%
			Ankle valgus	60%

Ankle valgus was present in 36% of subjects with no previous surgery. More than one problem per subject possible.

TABLE 6. Most Prevalent Gait Problems for CP Hemiplegics (Deviations on Hemi Side) With and Without Previous Surgery

Rank	No Previous Surgery (n = 84)		Previous Surgery (n = 31)	
1	Equinus	70%	Crouch	74%
2	Intoeing	58%	Stiff knee	71%
3	Stiff knee	50%	Excessive hip flexion	58%
4	Excessive hip flexion	44%	Equinus	48%
5	Crouch	37%	Intoeing	42%

More than one problem per subject possible.

lengthening[4] and supports the consideration for concomitant rectus femoris transfer in appropriate patients.[10]

The current study included only ambulatory subjects with gait problems severe enough to be considered for surgical or other treatment intervention. Therefore, the results may not be applicable to the CP population as a whole. Nevertheless, to the best of our knowledge, this is the first study to document the prevalence of specific gait abnormalities in a large sample of children with CP. The results should be useful for clinicians and researchers who treat and study this patient population.

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