Relationship of Strength, Weight, Age, and Function in Ambulatory Children With Cerebral Palsy

Jon R. Davids, MD, Donna J. Oeffinger, PhD,† Anita M. Bagley, PhD,* Mitell Sison-Williamson, MS,* and George Gorton, MS‡*

Background: The natural history of ambulatory function in individuals with cerebral palsy (CP) consists of deterioration over time. This is thought to be due, in part, to the relationship between strength and weight, which is postulated to become less favorable for ambulation with age.

Methods: The study design was prospective, case series of 255 subjects, aged 8 to 19 years, with diplegic type of CP. The data analyzed for the study were cross-sectional. Linear regression was used to predict the rate of change in lower extremity muscle strength, body weight, and strength normalized to weight (STR-N) with age. The cohort was analyzed as a whole and in groups based on functional impairment as reflected by Gross Motor Function Classification System (GMFCS) level.

Results: Strength increased significantly over time for the entire cohort at a rate of 20.83 N/y ($P = 0.01$). Weight increased significantly over time for the entire cohort at a rate of 3.5 kg/y ($P < 0.0001$). Lower extremity STR-N decreased significantly over time for the entire cohort at a rate of 0.84 N/kg/y ($P < 0.0001$). The rate of decline in STR-N (N/kg/y) was comparable among age groups of the children in the study group. There were no significant differences in the rate of decline of STR-N (N/kg/y) among GMFCS levels. There was a 90% chance of independent ambulation (GMFCS levels I and II) when STR-N was 21 N/kg (49% predicted relative to typically developing children).

Discussion: The results of this study support the longstanding clinically based observation that STR-N decreases with age in children with CP. This decrease occurs throughout the growing years, and across GMFCS levels I to III. Independent ambulation becomes less likely as STR-N decreases. This information can be used to support the rationale, and provide guidelines, for a range of interventions designed to promote ambulation in children with CP.

Key Words: cerebral palsy, strength, weight, age, ambulation

(*J Pediatr Orthop* 2015;35:523–529)

From the *Shriners Hospital for Children, Sacramento, CA; †Shriners Hospital for Children, Lexington, KY; and ‡Shriners Hospital for Children, Springfield, MA.

Supported by the Shriners Hospitals for Children Grant No. 9158.

The authors declare no conflicts of interest.

Reprints: Jon R. Davids, MD, Shriners Hospital for Children, 2425 Stockton Boulevard, Sacramento, CA 95817. E-mail: jdavids@shrinenet.org.

The natural history of ambulatory ability in individuals with cerebral palsy (CP) is not well documented. Previous studies have focused on gait changes during childhood and adolescence.[1–7] Additional studies have focused on changes in ambulatory ability and motor function during adult life in individuals with CP.[3,8–13] Although the nature of the injury (acquired, congenital, or developmental) to the central nervous system is thought to be static in the majority of subjects with CP, it seems clear that deterioration in ambulatory ability and motor function occurs in a quarter to a half of individuals with CP during adolescent and young adult life. Previous investigators have speculated that this deterioration may be the consequence of disrupted balance function, progressive joint contractures, impaired motor control, pain, diminished strength, increased spasticity, increased weight, over use (chronic fatigue), and under use (chronic immobility).[2,8,11,12,14–18]

Classic teaching suggests that the relationship between strength and weight becomes less favorable for ambulation during adolescent and young adult life.[2,19,20] This is thought to be a consequence of the fact that strength is related to physiological cross-sectional area of skeletal muscle, which is a squared function of growth; whereas weight is related to body volume, which is a cubed function of growth.[17] During growth, development of muscle strength may not keep pace with gains in weight, increasing the risk of diminished ambulatory ability with age. This concept has not, to our knowledge, been objectively studied in children with CP.

The current study investigated the interrelationship between strength, weight, and function in a large cohort of ambulatory children and adolescents with CP. It was hypothesized that (1) total lower extremity strength normalized to weight (STR-N) declines with increasing age; (2) the rate of decline of STR-N is greater in adolescents than young children; (3) the decline in STR-N is more pronounced in subjects with greater functional impairment as reflected by Gross Motor Function Classification System (GMFCS) level; and (4) the relationship between STR-N and GMFCS level can be used to determine the probability of independent ambulation (ie, GMFCS I and II vs. III).

METHODS

The study design was a prospective, case series, resulting in level III evidence. The data were part of a prospective, multicenter study that was approved by the

Institutional Review Boards of all participating sites. Subjects were recruited at 7 pediatric orthopaedic specialty hospitals. Written informed consent, assent, and Health Insurance Portability and Accountability Act authorizations were obtained from children who participated and their parents or guardians, as appropriate. Inclusion criteria consisted of individuals between the ages of 8 and 19 years with a diagnosis of spastic diplegic type CP, ability to walk 15 feet without resting for a minimum of 3 times, ability to follow simple commands, and tolerate application of adhesive markers to the skin. Individuals were excluded if they were unable to follow instructions to a degree that precluded accurate physical examination assessment, had lower extremity orthopaedic surgery within the prior year, botulinum toxin injections within the prior 4 months, or a currently implanted and functioning baclofen pump.

Each participant assessment included determination of GMFCS level by a site-specific assessor who had undergone standardized training before initiation of the study; patient clinical history; standing height and weight per hospital grade calibrated scales; lower extremity muscle strength utilizing a standardized protocol; body composition; and measures of body function, activity, and participation. For the few children who could not stand with hips and knees fully extended, height was measured supine.

Results from the latter 4 data domains have been reported in previous publications.[21–24]

Maximum isometric muscle strength of 8 lower extremity muscle groups (hip flexors, extensors, adductors, and abductors; knee flexors and extensors, with the knee flexed to 30 degrees; and ankle dorsiflexors and plantar flexors) was obtained using a hand-held dynamometer (JTECH PowerTrack II Commander, Salt Lake City, UT). Evaluators were trained to administer this test following a protocol that had been previously validated for the measurement of muscle strength in children with CP.[14,15,18,25,26] Individual muscle group strength scores were calculated by taking the maximum score of 3 trials of each muscle group and averaging across the right and left sides. Total lower extremity strength (STR) was calculated as the sum of the strength scores for the 8 muscle groups and was intended to reflect overall strength. STR-N was calculated as the sum of the strength scores for the 8 muscle groups divided by the participants' body weight. Normative values were derived from applying the current study methods to normative data published using the same hand-held dynamometer protocol.[26] Total lower extremity strength from the published data was calculated, and the strength data from the current study were divided by this calculated value to generate a percentage of normal.

Statistical Analyses

Linear regression was used to determine the rate of change in STR, weight, and STR-N with age. Separate linear regressions were done for the entire cohort, and for subjects stratified by GMFCS levels (I to III). Additional linear regressions were used to determine the rate of change in STR-N among 3 age groups (8 to 10 y of age, 11 to 14 y of age, and 15 to 19 y of age). Standardized β-coefficients were used to compare the rate of change in STR with age to rate of change in weight with age. The independent variable with the largest absolute standardized β-coefficient was determined to have the strongest effect. Rule of thumb test was used to determine if group means were statistically significantly different from each other when confidence intervals (CI) overlapped.[27] Finally, logistic regression was performed to determine the relation between independent ambulation ability (predictor variable defined as GMFCS I and II levels) and STR-N. Cut points were calculated to establish optimal sensitivity and specificity for STR-N as a predictor of independent ambulation.

RESULTS

Cohort Demographics

There were 255 subjects who met the inclusion criteria, and their demographics are summarized in Tables 1 and 2. There were 90 girls and 165 boys in the study group. Mean age was 13 years (8.1 to 19.0 y, SD = 2.6 y).

Distribution of number of subjects; sex distribution; and mean age, height, and weight overall and among GMFCS levels I to III are shown in Table 1. The only significant differences found among GMFCS levels was for height ($P < 0.0008$). GMFCS levels I and II were significantly taller than III ($P = 0.0002$ and $P = 0.0124$, respectively).

Distribution of number of subjects, sex distribution, and mean height and weight among age groups are shown in Table 2. There were significant differences for height

TABLE 1. Subject Demographics for All Subjects and by GMFCS Levels

	All Subjects	GMFCS I	GMFCS II	GMFCS III
No. subjects	255	65	125	65
No. females	90	21	39	30
No. males	165	44	86	35
Mean age (SD) (y)	13.0 (2.6)	13.4 (2.7)	12.9 (2.7)	12.9 (2.5)
Mean height (SD) (cm)*	148.3 (14.3)	152.6 (14.1)	148.7 (14)	143.4 (13.5)
Mean weight (SD) (kg)	45.6 (16.2)	47.6 (18.1)	45.3 (15.8)	44.3 (14.9)

*There were significant statistical differences for standing height across GMFCS levels ($P < 0.0008$). Groups 1 versus 3 ($P < 0.0002$) and groups 2 versus 3 ($P = 0.0124$), no significant differences in groups 1 versus 2 ($P = 0.0672$).
GMFCS indicates Gross Motor Function Classification System.

TABLE 2. Subject Demographics for Subjects by Age Group

	All Subjects	Age 8-10	Age 11-14	Age 15-19
No. subjects	255	60	96	99
No. females	90	23	32	35
No. males	165	37	64	64
Mean height (SD) (cm)*	148.3 (14.3)	131.4 (7.7)	147.5 (10.0)	159.4 (9.8)
Mean weight (SD) (kg)+	45.6 (16.2)	31.5 (8.8)	44.6 (13.7)	55.3 (15.3)

*Height—significant statistical differences across age groups ($P < 0.0001$). Group 1 versus 2 ($P < 0.0001$), groups 1 versus 3 ($P < 0.0001$), groups 2 versus 3 ($P < 0.0001$).

+Weight—significant statistical differences across age groups ($P < 0.0001$). Group 1 versus 2 ($P < 0.0001$), groups 1 versus 3 ($P < 0.0001$), groups 2 versus 3 ($P < 0.0001$).

and weight among age groups ($P < 0.0001$). The youngest age group was significantly shorter and lighter than each of the older age groups, and the intermediate age group was shorter and lighter than the oldest age group ($P < 0.0001$ for each comparison).

Strength, Weight, and Age

Fit plots for STR, weight, and STR-N versus age are shown in Figures 1A to C. The mean STR for the entire study group was 685.6 N (±343.7 N). The mean weight for the entire study group was 45.6 kg (±16.2 kg). The mean STR-N for the entire study group was 15.99 N/kg (±8.19 N/kg).

Rates of change in STR, weight, and STR-N with age across age groups are summarized in Table 3. STR increased for the entire cohort at a rate of 20.83 N/y, and this rate of increase was significant ($P = 0.01$; 95% CI, 4.89-36.76). Within the age groups assessed, the rate of change of STR with age was not significant (ie, the STR/y slopes were not significantly different than zero in each age group). Weight increased for the entire cohort at a rate of 3.5 kg/y, and this rate of increase was significant ($P < 0.0001$; 95% CI, 2.92-4.08). The rate of weight gain with age was significant within each age group. However, no differences among age groups for the slopes were appreciated via rule of thumb analysis. STR-N decreased for the entire cohort at a rate of 0.84 N/kg/y, and this rate of decrease was significant ($P < 0.0001$; 95% CI, −1.21, −0.47). Within the age groups assessed, the rate of change of STR-N with age was not significant (ie, the STR-N/y slopes were not significantly different than zero in each age group). For all subjects, the β-coefficient for the rate of change in weight (0.58) was greater than that for the rate of change in strength (0.16), implying a stronger effect for changes in weight than changes in strength in the model.

Rates of change in STR, weight, and STR-N by age across functional groups (GMFCS) are summarized in Table 4. Within each GMFCS level, the rate of change of STR with age was not significant (ie, the STR/y slopes were not significantly different than zero in each GMFCS level). There were significant increases in weight with age within each GMFCS level. However, the rule of thumb test (performed due to overlapping CIs) showed no significant difference in the rate of weight increase among GMFCS levels. There were significant decreases in STR-N with age within each GMFCS level. However, the rule of thumb test (performed due to overlapping CIs) showed no significant difference in the rate of normalized strength decrease (N/kg/y) among GMFCS levels.

The probability of independent ambulation using no assistive devices based upon STR-N is shown in Figure 2. There was a 90% chance of independent ambulation (GMFCS levels I and II) when STR-N was 21 N/kg (49% predicted relative to typically developing children), a 75% chance of independent ambulation when STR-N was 14 N/kg (33% predicted relative to typically developing children), and a 50% chance of independent ambulation when STR-N was 7 N/kg (16% predicted relative to typically developing children).

DISCUSSION

The ambulatory ability of individuals with CP is widely presumed to deteriorate with age. Previous studies have focused on gait changes during childhood and adolescence.[1–7] Different means of assessing ambulatory ability and motor function, small sample sizes, and retrospective study design make it difficult to compare and contrast these studies. However, when ambulatory ability is characterized by the GMFCS, and motor function is characterized by the Gross Motor Function Measure, it appears that children with CP usually improve up to 6 or 7 years of age, then deteriorate during adolescence.[3,6,28] Longitudinal studies utilizing quantitative gait analysis have found deterioration in passive joint range of motion, time distance parameters, kinematics, and kinetics during adolescence.[2,4,5,7]

Additional studies have focused on changes in ambulatory ability and motor function during adult life in individuals with CP.[3,8–13] These studies have relied upon subject questionnaires and retrospective review of governmental databases to assess function and mobility in these subjects. Deterioration in ambulatory ability was found in 23% to 52% of individuals. Self-reported causes for this decline included musculoskeletal pain, fatigue, impaired balance, and lack of access to adaptive physical activity programs.[8,11,12] Loss of ambulatory ability has been correlated with intelligence quotient, topographical type of CP, severity of neurological impairment, presence of a seizure disorder, delayed age at first walking, and older age.[1,11] Cross-sectional study with quantitative gait

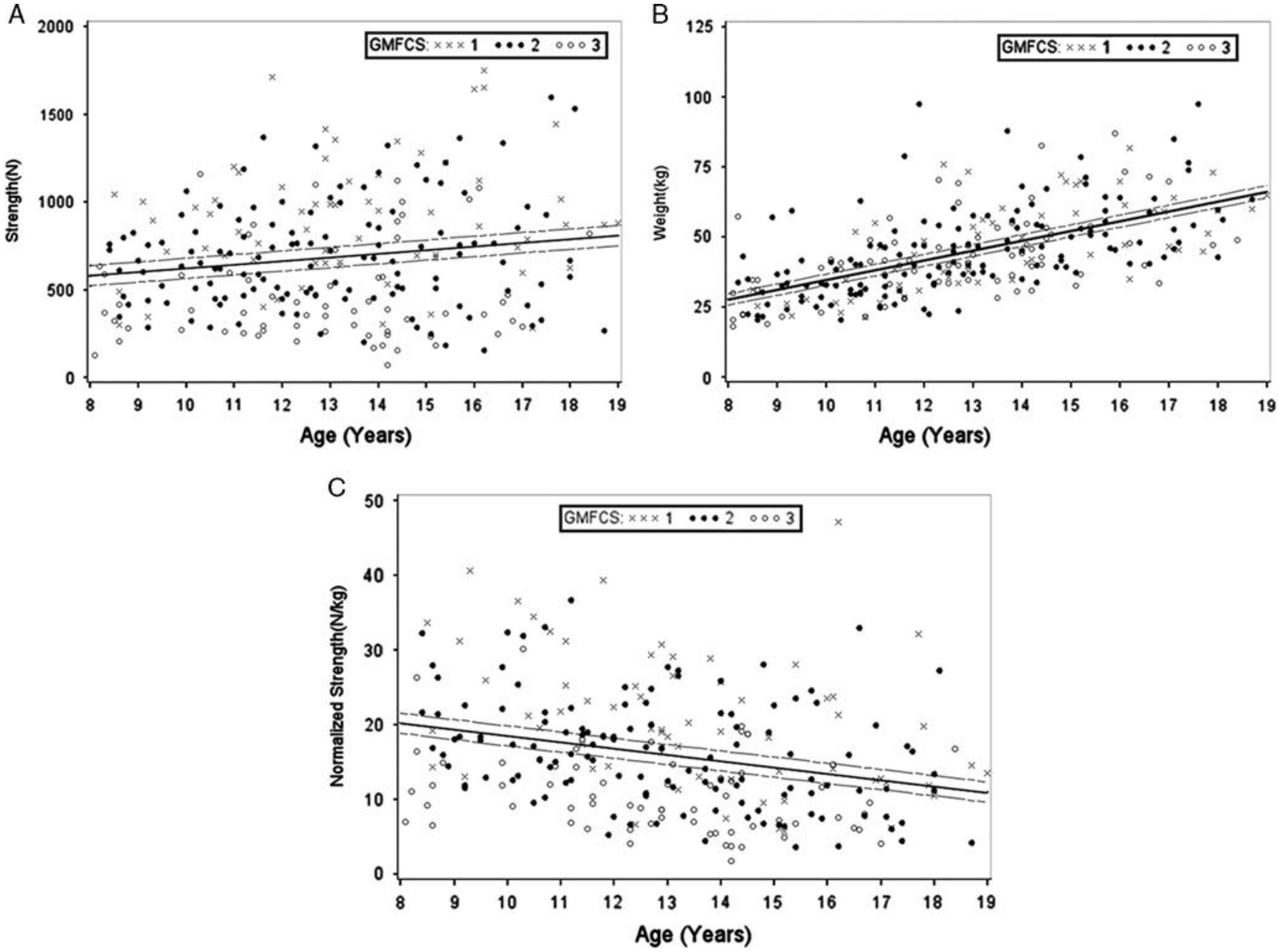

FIGURE 1. Fit plots for STR versus age (A), weight versus age (B), and strength normalized to weight (STR-N) versus age (C). The regression line is shown by the solid line. The boundaries of the 95% confidence interval are shown by the dashed lines. GMFCS indicates Gross Motor Function Classification System.

analysis was not able to characterize this deterioration in a small sample of adults with CP.[13]

There are significant technical and clinical challenges relating to the assessment of strength and weight in subjects with CP.[18,25,29,30] Study of muscle strength in children and adolescents with CP suggests that these subjects are weaker than typically developing peers, weakness is greater in distal (vs. proximal) muscle groups, and the strength difference between agonist and antagonist muscle groups is greater than in typically developing peers.[14,15,18,26] Strength has been correlated with ambulatory ability (as measured by the GMFCS) and motor

TABLE 3. Rates of Change in Strength, Weight, and Normalized Strength by Age Group

	Rate (*P*) [95% CI]			
	All Subjects	**8-10 y of Age**	**11-14 y of Age**	**>14 y of Age**
No. subjects	255	60	96	99
Strength (N/y)	20.83 ($P = 0.01$) [4.89, 36.76]	62.81 ($P = 0.09$) [−9.01, 134.63]	−14.44 ($P = 0.72$) [−93.56, 64.67]	29.14 ($P = 0.33$) [−30.02, 88.30]
Weight (kg/y)	3.5 ($P < 0.0001$) [2.92, 4.08]	2.8 ($P = 0.03$) [0.23,5.31]	4.0 ($P = 0.01$) [0.94, 6.99]	2.3 ($P = 0.04$) [0.167, 4.51]
Normalized strength (N/kg/y)	−0.84 ($P < 0.0001$) [−1.21, −0.47]	0.78 ($P = 0.53$) [−1.69, 3.26]	−1.58 ($P = 0.09$) [−3.38 0.23]	−0.01 ($P = 0.99$) [−1.19, 1.17]

CI indicates confidence interval.

TABLE 4. Rates of Change in Strength, Weight, and Normalized Strength by Functional Level

	Rate (P) [95% CI]			
	All Subjects	**GMFCS I**	**GMFCS II**	**GMFCS III**
No. subjects	255	65	125	65
Strength (N/y)	20.83 (P = 0.01) [4.89, 36.76]	20.88 (P = 0.19) [−10.93, 56.70]	15.70 (P = 0.12) [−4.41, 35.80]	13.02 (P = 0.35) [−14.67, 40.70]
Weight (kg/y)	3.5 (P < 0.0001) [2.92, 4.08]	4.1 (P < 0.0001) [2.82, 5.44]	3.4 (P < 0.001) [2.56, 4.19]	3.1 (P < 0.0001) [1.97, 4.18]
Normalized strength (N/kg/y)	−0.84 (P < 0.0001) [−1.21, −0.47]	−1.25 (P = 0.002) [−2.04, −0.56]	−0.96 (P < 0.0001) [−1.42, −0.50]	−0.56 (P = 0.04) [−1.09, −0.03]

CI indicates confidence interval; GMFCS, Gross Motor Function Classification System.

function (as measured by the Gross Motor Function Measure).[14,18,22,23,25,31]

Study of weight in children and adolescents with CP suggests that 16% to 33% of subjects who function at GMFCS levels I and II are overweight (as determined by body mass index), which is comparable with typically developed peers in the western world.[16,32–34] Cohorts with more severe motor impairment (GMFCS III, IV, and V) have progressively more subjects who are underweight (as determined by body mass index), which is presumably a consequence of increased metabolic cost related to spasticity and difficulty feeding (diminished caloric intake).[16]

The current study investigated the interrelationship between strength, weight, and function in a large cohort of ambulatory children and adolescents with CP; and considered 4 hypotheses. The data from the study support the first hypothesis, that *total lower extremity strength normalized to weight (STR-N) declines with increasing age (between 8 and 19 y)*. Although both STR and weight increase significantly with age, the rate of change in weight was greater than the rate of change in STR, implying a stronger effect for weight than STR, as reflected by the decrease in STR-N with age.

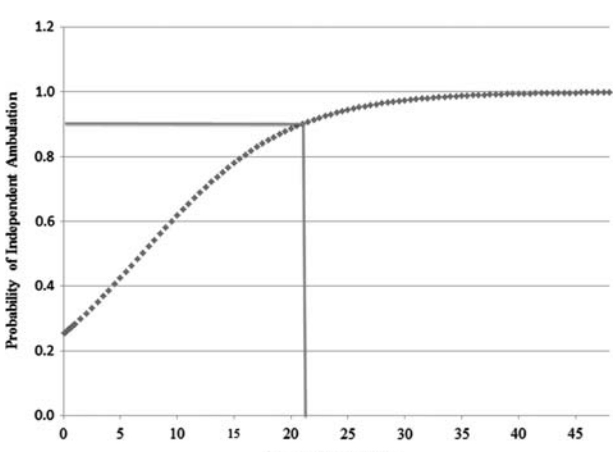

FIGURE 2. Probability of independent ambulation by strength normalized to weight (STR-N). There was a 90% chance of independent ambulation without assistive devices when STR-N was 21 N/kg, which was 50% of predicted relative to typically developing children.

The data from the study did not support the second hypothesis that *the rate of decline of STR-N is greater in adolescents than young children*. Weight was the only parameter that increased significantly within each of the 3 age groups, and none of the parameters changed significantly among age groups. There has been considerable study of strength and the effects of strength training on gait and other functional activities in subjects with CP.[14,15,18,25,26,30,31,35–38] To date there has been relatively little study of the prevalence of obesity and the relationship between weight and function in subjects with CP.[16,32–34]

The data from the study did not support the third hypothesis that *the decline in STR-N is more pronounced in subjects with greater functional impairment as reflected by GMFCS level*. Although the rate of change for weight and STR-N were significantly different within each GMFCS level, there were no significant differences for any of the parameters among GMFCS levels. Functional level (as described by GMFCS) was not discriminatory for changes in STR, weight, or STR-N. Although previous studies have related strength to function, it is clearly only one of multiple potentially significant variables that determine functional abilities in subjects with CP.

The data from the study support the fourth hypothesis that the relationship between STR-N and GMFCS level can be used to determine the probability of independent ambulation (ie, GMFCS I and II vs. III). A previous investigator determined that approximately 50% of predicted muscle strength (relative to typically developing children) was sufficient for walking without support.[14] This measure of strength was not normalized to weight, and a single cut-point value is of limited clinical utility. The current study suggests that independent ambulation is highly likely when STR-N is 49% of predicted (relative to typically developing children), probable when STR-N 33% of predicted, and highly unlikely when STR-N is of 1% predicted.

The results of this study provide support to several longstanding clinically based observations, which in turn support the rationale and provide guidelines for a range of interventions designed to promote ambulation, functional standing, and transfer ability in children with CP. Normalized strength (STR-N) decreases with age in children with CP. This decrease occurs throughout the growing years (not just during adolescence), and across GMFCS levels I to III. Independent ambulation without assistive devices becomes less likely as STR-N decreases. Children at the GMFCS I and II levels should receive aggressive, proactive management to promote ambulation. Normalized strength (STR-N) can be followed over time to establish a trend, and long-term interventions that maximize strength and minimize weight should be encouraged and implemented before the teenage years. Children at the GMFCS III level with STR-N values associated with a higher probability of independent ambulation or a positive trend of STR-N over time should also receive aggressive, proactive management to optimize ambulation. Conversely, children at the GMFCS III level with STR-N values associated with a low probability of independent ambulation or a negative trend in STR-N over time should be encouraged to focus on the use of assistive devices and receive surgical management designed to promote functional standing and transfer ability.

The principle limitation of the current study relates to its cross-sectional design, which, when used to predict changes over time, is subject to selection bias. A cross-sectional design is appropriate to initially investigate the longstanding clinically belief that strength normalized to body weight decreases with age. The study procedures were designed to limit selection bias and included participants from a broad geographic area. A longitudinal study design is preferred and would provide higher level evidence concerning changes in STR, weight, and STR-N with age. The next step is to investigate these findings using a longitudinal study. In addition, the accurate assessment of extremity muscle strength in children with CP is challenging due to a range of confounding variables, such as impaired selective voluntary motor control, and technical measurement issues, such as position dependency.[18,25,29,30] The study assessors were trained before the onset of the study in the protocol (specifically with respect to patient positioning and placement of the hand-held dynamometer) to decrease the interrater variability. The selected protocol was previously established by other researchers and had been shown to minimize potential for muscle activation synergies.[26,39] Muscle strength was graded as 0 if the subject was not able to isolate the movement. Future studies should focus on strength changes with age of individual muscle groups, to better understand the relation between strength and ambulation, and guide or focus interventions in children with CP. Finally, ambulatory function in children with CP is the consequence of the complex interplay between a wide range of physical, cognitive, psychological, and cultural variables. Strength is clearly an important factor, but its relative significance with respect to other impairment elements remains to be definitively determined and may be variable among individuals.

ACKNOWLEDGMENTS

The Functional Assessment Research Group acknowledges the contributions of Dick Kryscio, PhD, Department of Biostatistics at the University of Kentucky, study co-investigators Chester Tylkowski, MD (Shriners Hospitals for Children (SHC)-Lexington); Mark Romness, MD and Mark Abel, MD (University of Virginia); Sahar Hassani (SHC-Chicago); Barbara Johnson, PhD, PT (SHC-Salt Lake City); Sylvia Õunpuu, MS (Connecticut Children's Medical Center); and the research coordinators and motion analysis laboratory staff at all participating facilities for their roles in data collection, as well as the participants and their families.

REFERENCES

1. Beckung E, Hagberg G, Uldall P, et al. Probability of walking in children with cerebral palsy in Europe. *Pediatrics*. 2008;121: e187–e192.
2. Bell KJ, Ounpuu S, DeLuca PA, et al. Natural progression of gait in children with cerebral palsy. *J Pediatr Orthop*. 2002;22:677–682.
3. Day SM, Wu YW, Strauss DJ, et al. Change in ambulatory ability of adolescents and young adults with cerebral palsy. *Dev Med Child Neurol*. 2007;49:647–653.
4. Gough M, Eve LC, Robinson RO, et al. Short-term outcome of multilevel surgical intervention in spastic diplegic cerebral palsy compared with the natural history. *Dev Med Child Neurol*. 2004;46:91–97.
5. Gough M, Schneider P, Shortland AP. The outcome of surgical intervention for early deformity in young ambulant children with bilateral spastic cerebral palsy. *J Bone Joint Surg Br*. 2008;90: 946–951.
6. Hanna SE, Rosenbaum PL, Bartlett DJ, et al. Stability and decline in gross motor function among children and youth with cerebral palsy aged 2 to 21 years. *Dev Med Child Neurol*. 2009;51:295–302.
7. Rose GE, Lightbody KA, Ferguson RG, et al. Natural history of flexed knee gait in diplegic cerebral palsy evaluated by gait analysis in children who have not had surgery. *Gait Posture*. 2010;31: 351–354.
8. Andersson C, Mattsson E. Adults with cerebral palsy: a survey describing problems, needs, and resources, with special emphasis on locomotion. *Dev Med Child Neurol*. 2001;43:76–82.
9. Bottos M, Feliciangeli A, Sciuto L, et al. Functional status of adults with cerebral palsy and implications for treatment of children. *Dev Med Child Neurol*. 2001;43:516–528.
10. Haak P, Lenski M, Hidecker MJ, et al. Cerebral palsy and aging. *Dev Med Child Neurol*. 2009;51(suppl 4):16–23.
11. Jahnsen R, Villien L, Egeland T, et al. Locomotion skills in adults with cerebral palsy. *Clin Rehabil*. 2004;18:309–316.
12. Opheim A, Jahnsen R, Olsson E, et al. Walking function, pain, and fatigue in adults with cerebral palsy: a 7-year follow-up study. *Dev Med Child Neurol*. 2009;51:381–388.
13. Opheim A, McGinley JL, Olsson E, et al. Walking deterioration and gait analysis in adults with spastic bilateral cerebral palsy. *Gait Posture*. 2013;37:165–171.
14. Eek MN, Beckung E. Walking ability is related to muscle strength in children with cerebral palsy. *Gait Posture*. 2008;28:366–371.
15. Eek MN, Tranberg R, Beckung E. Muscle strength and kinetic gait pattern in children with bilateral spastic CP. *Gait Posture*. 2011; 33:333–337.
16. Hurvitz EA, Green LB, Hornyak JE, et al. Body mass index measures in children with cerebral palsy related to gross motor function classification: a clinic-based study. *Am J Phys Med Rehabil*. 2008;87:395–403.
17. Nene AV, Evans GA, Patrick JH. Simultaneous multiple operations for spastic diplegia. Outcome and functional assessment of walking in 18 patients. *J Bone Joint Surg Br*. 1993;75:488–494.
18. Thompson N, Stebbins J, Seniorou M, et al. Muscle strength and walking ability in diplegic cerebral palsy: implications for assessment and management. *Gait Posture*. 2011;33:321–325.
19. Bleck EE. *Orthopaedic Managment in Cerebal Palsy*. London: MacKeith Press; 1987.
20. Rang M, de la Garza J. Cerebral palsy. In: Lovell WW, Winter RB, eds. *Pediatric Orthopaedics*. 2nd ed. Philadelphia: J.B. Lippincott; 1986:345–396.

21. Bagley AM, Gorton G, Oeffinger D, et al. Outcome assessments in children with cerebral palsy, part II: discriminatory ability of outcome tools. *Dev Med Child Neurol*. 2007;49:181–186.
22. Flanagan A, Krzak J, Hassani S, et al. Relationship among strength, body composition, and measures of activity in ambulatory children with cerebral palsy: a cross-sectional study. *Crit Rev Phys Rehab Med*. 2011;23:15–29.
23. Hassani S, Krzak J, Flanagan A, et al. Assessment of strength and function in ambulatory children with cerebral palsy by GMFCS level and age: a cross-sectional study. *Crit Rev Phys Rehab Med*. 2011;23:1–14.
24. Oeffinger D, Gorton G, Bagley A, et al. Outcome assessments in children with cerebral palsy, part I: descriptive characteristics of GMFCS Levels I to III. *Dev Med Child Neurol*. 2007;49:172–180.
25. Ross SA, Engsberg JR. Relationships between spasticity, strength, gait, and the GMFM-66 in persons with spastic diplegia cerebral palsy. *Arch Phys Med Rehabil*. 2007;88:1114–1120.
26. Wiley ME, Damiano DL. Lower-extremity strength profiles in spastic cerebral palsy. *Dev Med Child Neurol*. 1998;40:100–107.
27. Wolfe R, Hanley J. If we're so different, why do we keep overlapping? When 1 plus 1 doesn't make 2. *CMAJ*. 2002;166:65–66.
28. Narayanan UG. Management of children with ambulatory cerebral palsy: an evidence-based review. *J Pediatr Orthop*. 2012;32(suppl 2):S172–S181.
29. Givon U. Muscle weakness in cerebral palsy. *Acta Orthop Traumatol Turc*. 2009;43:87–93. Beyin felcinde kas zayifligi.
30. Scianni A, Butler JM, Ada L, et al. Muscle strengthening is not effective in children and adolescents with cerebral palsy: a systematic review. *Aust J Physiother*. 2009;55:81–87.
31. Seniorou M, Thompson N, Harrington M, et al. Recovery of muscle strength following multi-level orthopaedic surgery in diplegic cerebral palsy. *Gait Posture*. 2007;26:475–481.
32. Kwon DG, Kang SC, Chung CY, et al. Prevalence of obesity in ambulatory patients with cerebral palsy in the Korean population: a single institution's experience. *Clin Orthop Surg*. 2011;3: 211–216.
33. Rimmer JH, Yamaki K, Davis BM, et al. Obesity and overweight prevalence among adolescents with disabilities. *Prev Chronic Dis*. 2011;8:1–6.
34. Rogozinski BM, Davids JR, Davis RB, et al. Prevalence of obesity in ambulatory children with cerebral palsy. *J Bone Joint Surg Am*. 2007;89:2421–2426.
35. Antilla H, Autti-Ramo I, Suoranta J, et al. Effectiveness of physical therapy interventions for children with cerebral palsy: a systematic review. *BMC Pediatr*. 2008;8:14–24.
36. Damiano DL, Abel MF. Functional outcomes of strength training in spastic cerebral palsy. *Arch Phys Med Rehabil*. 1998;79: 119–125.
37. Dodd KJ, Taylor NF, Damiano DL. A systematic review of the effectiveness of strength-training programs for people with cerebral palsy. *Arch Phys Med Rehabil*. 2002;83:1157–1164.
38. Scholtes VA, Becher JG, Janssen-Potten YJ, et al. Effectiveness of functional progressive resistance exercise training on walking ability in children with cerebral palsy: a randomized controlled trial. *Res Dev Disabil*. 2012;33:181–188.
39. Damiano DL, Dodd K, Taylor NF. Should we be testing and training muscle strength in cerebral palsy? *Dev Med Child Neurol*. 2002;44:68–72.