Preoperative and Postoperative Gait Evaluation in Cerebral Palsy

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• The purpose of the study was to evaluate objectively and quantitatively the possible effects of surgical correction for equinus deformity on the gait of children with cerebral palsy (CP). Evaluation criteria selected were based on time and distance parameters of stride during gait. Ten children with confirmed diagnoses of CP took part in the study. They were tested before surgery and after surgery at four-month intervals for a period of up to one year. Results were compared to published data obtained on able-bodied, growing children to determine whether progress after the operation was faster than that expected in normal growth. Gait improvement was demonstrated by a decrease in support time and an increase in walking speed and stride length. Overall improvement was sometimes preceded by an initial, temporary deterioration. Results indicate that the time and distance parameters of stride can provide reliable objective evaluation of gait improvement after tendo Archilles lengthening in children with CP.

KEY WORDS: Achilles tendon; Cerebral palsy; Equinus deformity; Gait

In treating musculoskeletal problems associated with cerebral palsy (CP), gait abnormalities are largely assessed by visual inspection and by examination of spasticity and/or contractures.[1] However, to assess the effects of therapeutic intervention such as surgery, casting, and physical therapy, more objective and quantitative methods of gait measurement would be desirable. To date, quantitative methods for clinical assessment of the effect of corrective surgery on children with CP has included electromyography of the lower limb muscles before and after surgery,[2-4] sometimes combined with kinematic and dynamic data.[5]

Methods of direct gait measurement of children with CP have included, among others, using electrogoniometers[6] and force plates. The latter method has been used for studying crouch gait in spastic diplegia.[7] More recently, computerized, high-speed cinematography was used to analyze the three-dimensional gait of able-bodied and CP children.[8] It was found that children with CP had greater intersubject variability than the able-bodied groups.

In spite of their ability to provide reliable quantitative information, the above methods are difficult to apply clinically due to the complexity of the experiments involved and the bulk of data obtained, requiring intensive processing. Thus, it would be essential to have a simpler experimental method from the standpoints of patient convenience, data collection, and processing.

A simple method meeting these requirements, in which the foot-fall parameters of walking subjects are monitored, has been suggested.[9-11] Measurements by this method are made on an instrumented walkway from which the stride parameters are easily measured. The method is especially suitable for patients with locomotor disorders as it requires only minimal cooperation, and it interferes to a very small extent with the natural gait of the patient. Furthermore, it can be applied in cases of supported gait.

The purpose of this study was to evaluate objectively and quantitatively the possible effects of surgical correction related to equinus deformity on the gait of CT children. Of special interest was identifying criteria which, when based on easily obtainable data, would enable us to assess the success of surgical treatment. The evaluation criteria selected were based on the foot-fall parameters obtained during gait.

METHODS

Subjects

Ten subjects, aged four to 11 years, with confirmed diagnoses of CP and described in table 1, participated in the study. Clinical findings were consistent with mild to moderate spastic diplegia in six cases, and mild to moderate spastic hemiplegia in the four other cases. Clinical evaluation of the patients was made with respect to their walking ability.[11,12] The scoring used for foot-to-ground contact during gait was as follows: 0 = full foot-to-ground contact; 1 = full contact in normal walking but toe contact in fast walking; 2 = full contact at rest; 3 = equinus in walking; 4 = equinus in all states. In some of the subjects a mild inversion of the ankle was noted in addition to the equinus deformity, with no observable influence on function. Passive ankle dorsiflexion was measured with the subject lying in a relaxed supine position and the knee extended.

All subjects studied were community ambulators with restrictions in walking speed and distance. Three of the subjects

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Table 1: Discription of Subjects

			Passive dorsiflexion angle				Foot-to-ground contact*			
			Before TAL†		After TAL		Before TAL		After TAL	
Subject	Age (yrs)	Diagnosis	L	R	L	R	L	R	L	R
1	9	Mil spastic diplegia	15	0‡	15	10	0	1	0	0
2	7	Spastic diplegia	−10	−5‡	−10	0	2	2	2	0
3	4	Spastic diplegia	10‡	−5‡	10	0	0	1	0	0
4	11	Rt. spastic hemiplegia	10	0‡	20	0	0	1	0	0
5	11	Rt. spastic hemiplegia	10	−15‖	10	5	0	3	0	0
6	9	Spastic diplegia	−20‖	−15‖	10	−5	3	3	0	1
7	6	Mild rt. hemiplegia	20	−10‡	20	0	0	2	0	1
8	6	Lt. spastic hemiplegia	−15‡	15	0	0	3	0	1	0
9	6	Spastic diplegia	0‡	−5‡	0	5	0	1	0	0
10	4	Mild spastic diplegia	5	−5‡	0	5	0	2	0	0

*Scores for foot-to-ground contact—0 = full foot-to-ground contact, 1 = full contact in normal walking but toe contact in fast walking, 2 = full contact at rest, 3 = equinus in walking, 4 = equinus in all states; †TAL = tendo Achilles lengthening; ‡ sliding technique; ‖Z = plasty technique

walked while being supported by a walker. None of the subjects used orthoses. The subjects were, therefore, candidates for surgery to elongate the Achilles tendon. This was done by using Z-plasty[13,14] or the sliding technique.[15,16]

The results obtained for the subjects were compared to published data on able-bodied, growing children in the same age range.[17-19] Four controls of different ages, but in the same age range (i.e, 5,9,10, and 12 years), were incorporated in this study; their walking parameters confirmed the data found in the literature and used as reference (fig 1).

Instrumentation

Time and distance parameters of stride were measured on a five-meter electric contact system. The walkway consisted of an open electric circuit, through which current flowed when shorted by the patients' shoes, which had self-adhesive conductive tape attached.[10] The current was proportional to the distance along the walkway and, after calibration, the following parameters could be measured: support time, double support time, swing time, stride time, and stride length, all separate but simultaneous for the left and right feet. Walking speed was calculated as the ratio between stride length and stride time. Time and distance symmetries were defined as the relative time or distance of one leg between two consecutive first foot contacts of the other leg. In an able-bodied person the first foot contact is normally the heel strike, and symmetry is nearly 0.5.[10]

The above parameters were calculated for every two consecutive steps, usually for five to 11 strides. All subjects wore well fitting shoes, and special care was taken to tighten them properly to the feet. This was necessary to avoid the possibility of the ankle remaining in slight plantar flexion while still obtaining heel contact of the shoe.

Procedures and Statistical Methods

The subjects were tested before the operation and four months after the operation. Subsequently, they were tested every four months for one year. Seven subjects were tested three times after the operation, and the remaining three were tested only once after the operation. During each testing session, at least two walking tests were made. The four controls were tested once, only using two gait samples for each.

For every subject, the mean and standard deviations of stride parameters obtained from each testing day were calculated. The means were plotted against time, and linear regressions were fitted for every subject. The slopes of these lines could then be compared to the slope corresponding to time variation of the gait parameters in the able-bodied population of the same age range (fig. 1). Comparison of the slope was made,

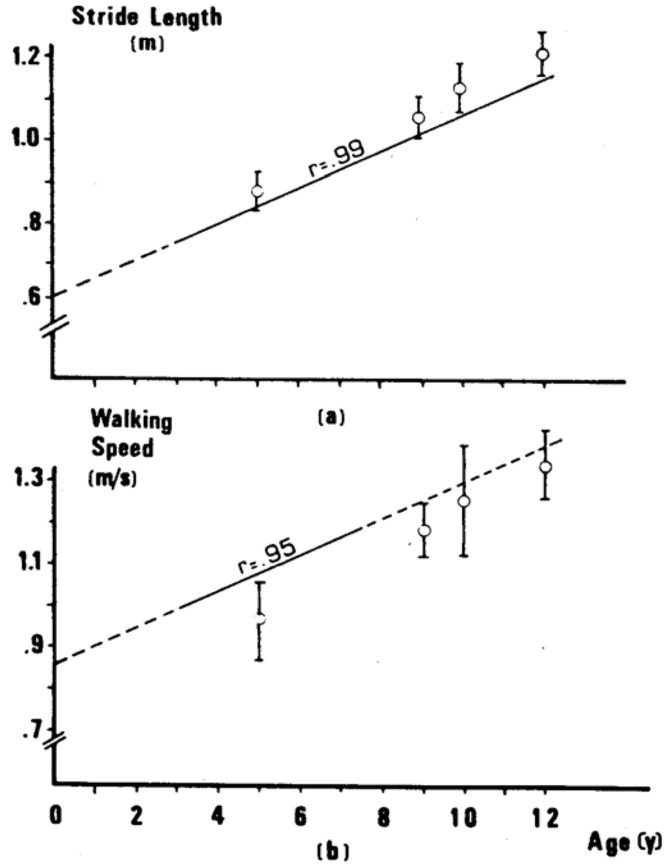

Fig. 1—The variation in walking parameters with increasing age, as represented by linear regressions from data taken from the literature: (a) (top) stride length[17]; (b) (bottom) walking speed.[19] The results (±1SD) obtained in this study on four subjects are shown by open circles.

Table 2: Support Times (Mean ± SD) for Both Legs of the Subjects Before and on Three Tests After Surgery

	Before surgery		After surgery					
			1		2		3	
Patient	L	R	L	R	L	R	L	R
1	0.57(0.05)	0.56(0.05)*	0.50(0.11)	0.53(0.07)	0.64(0.05)	0.36(0.02)	0.30(0.04)	0.25(0.03)
2	0.79(0.08)	0.80(0.08)*	1.01(0.19)	0.92(0.02)	1.04(0.08)	1.13(0.20)	0.87(0.09)	1.00(0.06)
3	0.80(0.09)*	0.71(0.08)*	0.75(0.12)	0.55(0.06)	0.70(0.07)	0.57(0.04)	0.71(0.11)	0.62(0.06)
4	0.64(0.03)	0.58(0.07)*	0.63(0.04)	0.65(0.04)	0.51(0.05)	0.43(0.04)	–	0.43(0.02)
5	0.79(0.10)	0.73(0.09)*	0.92(0.20)	0.67(0.08)	0.78(0.07)	0.59(0.07)	–	–
6	0.73(0.09)*	0.74(0.18)*	1.03(0.21)	0.92(0.27)	0.63(0.06)	0.69(0.06)	0.59(0.17)	0.46(0.09)
7	0.48(0.03)	0.48(0.06)*	0.51(0.04)	0.40(0.04)	0.58(0.17)	9.44(0.12)	0.54(0.04)	0.34(0.02)
8	0.68(0.06)*	0.73(0.70)	0.42(0.06)	0.58(0.02)	–	–	–	–
9	1.19(0.15)*	1.26(0.19)*	0.70(0.50)	0.71(0.09)	–	–	–	–
10	0.57(0.07)	0.57(0.09)*	0.53(0.08)	0.54(0.03)	–	–	–	–

*Surgery

using the paired t-test, to indicate whether progress after the operation was faster than expected for normal growth.

RESULTS

A summary of the clinical outcome after surgery, as compared to before surgery, is shown in table 1. All subjects had a marked improvement of equinus deformity and foot-to-ground contact during gait. The need for upper extremity walking aids did not change after surgery; the three subjects using walkers continued to do so after the operation. Significant improvements related to walking distance were not noted at the one-year follow-up.

The actual results of the gait parameters for all subjects are shown in the tables. Variation of the stance time, for each foot separately, is shown in table 2. This parameter decreased on the operated side after surgery in nine of the ten subjects tested. It should be mentioned, however, that in two of these subjects there was initially a temporary increase in the parameters from the first test after surgery. Subsequently, this turned out to be a total decrease in comparison to the preoperative state.

The variations in walking speed after surgery and during the follow-up are shown in fig. 2. The results, plotted for the ten subjects, show that in nine cases there was an overall increase in velocity. The average slope of increase, on linear regression, was significantly higher ($p<0.05$, paired t-test) than the slope expected to occur with normal growth (fig 1b). The actual walking speed values, however, were still generally lower in the children with CP than in the able-bodied children.

Variations in stride length for the operated subjects are shown in table 3. Nine of ten subjects demonstrated an overall increase in stride length. In four of these subjects, increase was preceded by an initial, temporary decrease. The average slope of increase in the subjects was obtained by linear regressions, and it was found to be significantly higher ($p<.05$, paired t-test) than the slope of stride length corresponding to normal growth (fig 1a).

Double support time, distance symmetry, and time symmetry did not yield any consistent preoperative and postoperative variations in the results obtained in this study.

Somewhat odd results were obtained for subject 2, who decreased postoperative gait velocity and minimally increased stride length on the third postoperative testing. This was a severe diplegic subject who was to be operated on both sides due to limitation of ankle dorsiflexion. However, because of an ulcer under the left metatarsal head, he was first operated on the right, less severe, side.

DISCUSSION

We attempted to quantify intrasubject variability by calculating selected gait parameters measured during several strides (five to 11) made on a five-meter walkway. The average values

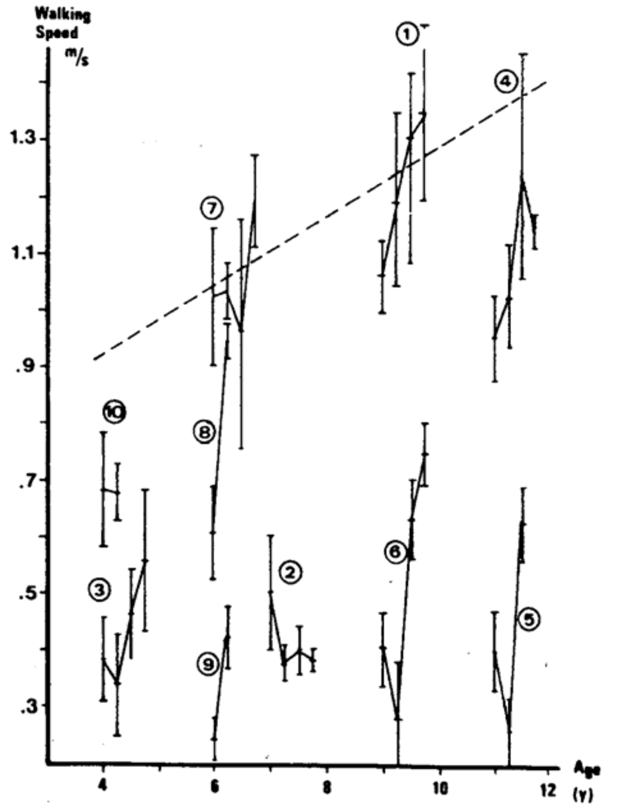

Fig. 2—Variation in walking speed during the follow-up period for experimental subjects (numbered 1 to 10). The first measurement for each subject corresponds to the preoperative test; subsequent measurements represent postoperative tests. Odd results were obtained in subject 2, who was an especially severe case, and subject 10, who was tested only once postoperatively. The dashed line represents the variation in walking speed with increasing age for the able-bodied population.

Table 3: Stride Length (cm, Mean±SD) of the Subjects Before and on Three Tests After Surgery

Patient	Before surgery	After surgery 1	2	3
1	107.7(5.2)	108.0 (5.5)	111.8 (9.8)	119.3 (4.1)
2	65.8(9.1)	68.3 (3.6)	74.7 (5.2)	69.4 (4.1)
3	43.0(7.0)	35.6 (6.6)	48.0 (5.9)	59.5(11.8)
4	103.8(7.9)	102.8(10.0)	108.5(14.1)	117.4 (6.1)
5	55.2(6.5)	35.0 (8.7)	80.2 (4.3)	–
6	51.2(6.8)	43.1(11.3)	65.5 (9.9)	68.7(12.7)
7	84.8(4.0)	82.0 (5.6)	80.8 (7.5)	96.8 (7.8)
8	66.7(6.4)	103.2 (2.0)	–	–
9	47.1(4.7)	52.1 (9.6)	–	–
10	69.1(8.0)	67.4 (4.2)	–	–

were taken to represent each parameter, and standard deviations indicated the variability. The latter factor was clearly observed in children with CP compared to standard deviations in controls (vertical bars on figs 1a and 1b). Standard deviations remained high after surgery also, and no significant variations were noted throughout the follow-up. A longer walkway, in which data are collected from more steps, should be expected to decrease the varability.

The three main parameters analyzed were stance time, stride length, and walking speed. These were considered of primary importance, and from them, two additional parameters, stride time and swing time, were calculated.

After surgery the support time became shorter relative to the total stride time on the operated side in the four subjects with hemiplegia. In the other six subjects with diplegia, with a total of nine operated legs, relative shortening of the support time was found in six legs. From the remaining operated legs, two were unchanged with respect to this parameter, and in only one leg was the support time increased. The shortening of support time after the operation implies that there is a transient plantar flexion weakness after tendo Achilles lengthening.

In the subjects where only one leg was operated, shortening of the support time was sometimes accompanied by a parallel, although somewhat smaller shortening of the same parameter in the opposite leg. Thus, overall improvement in gait performance did occur, although gait symmetry decreased. It should be noted that shortening of stance time occurs even though the operated leg, previously in equinus deformity, becomes more able to produce full contact with the ground. Thus, it could be expected that improvement in lower extremity control would be reflected by an increase in stance time, which, as mentioned, was not the case.

Sutherland and colleagues[20] and Lehmann and associates[21] found that weakness of the calf muscle in one leg can create a decrease in the stance time of both legs, with the shorter stance time in the weak leg. The same situation occurs after elongation of the Achilles tendon. Perry and coworkers[22] and Perry and Hoffer[3] found that correction of the equinus improved functional control of the leg, resulting in decreased stance phase and clonus of the triceps surae muscles. This indicates that the operation indeed improves the locomotor function of the triceps surae-ankle foot complex.

In the long range, stride length and walking speed parameters increased in most of the subjects after surgery. An initial, temporary decrease in these parameters was noted in three subjects. This may be attributed to immediate postoperative triceps surae weakness in those subjects. In fact, weakening of the ankle plantar flexors due to surgery and immobilization, mentioned earlier in connection with the support time parameter, occurs in many cases when it takes some time until the full benefit of tendo Achilles lengthening is achieved. Odd results were obtained in subject 2, who was an especially severe case, and in subject 10, who was tested postoperatively only once and whose long-range results were not available.

Total improvements in stride length and walking speed with time were judged by comparing the slopes of regression lines for every patient to the slope of age variation of these gait parameters in the able-bodied population. In most of the subjects tested, the slopes found were higher than expected as a result of growth. However, as demonstrated in fig 2 for walking speed, the actual parameter values were still generally lower in the subjects tested than in those of the able-bodied population. Of the different parameters studied, it is suggested that walking speed can serve as a good indicator of locomotor performance, since it combines both time and distance. Previous studies[10,23] have emphasized the importance of walking because it had the highest correlation with the clinical outcome.

Results obtained in this study indicate that the time and distance parameters of stride can provide reliable objective evaluation of locomotor improvement after tendo Achilles lengthening in children with CP.

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References

1. Samilson RL. Current concepts of surgical management of deformities of the lower extremities in cerebral palsy. Clin Orthop 1981; 158:99–107.
2. Hoffer MM, Reiswing JA, Garrett AM, Perry J. The split anterior tibial tendon transfer in the treatment of spastic varus hind foot of childhood. Orthop Clin North Am 1974;5:31–8.
3. Perry J, Hoffer MM. Preoperative and postoperative dynamic electromyography as an aid planning tendon transfer in children with cerebral palsy. J Bone Joint Surg [AM] 1977;59A:531–7.
4. Skinner SR, Lester DK. Gait electromyographic evaluation on long-toe flexors in children with spastic cerebral palsy. Clin Orthop 1986;207:70–3.
5. Winters TF, Gage JR, Hicks R. Gait patterns in spastic hemiplegia in children and young adults. J Bone Joint Surg [AM] 1987;69A:437–41.
6. De Bruin H, Russell DJ, Latter JE, and Sadler JST. Angle-angle diagram in monitoring and quantification of gait patterns for children with cerebral palsy. Am J Phys Med 1982;61:176–92.
7. Sutherland DH, Cooper L. The pathomechanics of progressive crouch gait in spastic diplegia. Orthop Clin North Amer 1978;9:143–54.
8. Skrotzky K. Gait analysis in cerebral palsied and nonhandicapped children. Arch Phys Med Rehabil 1983;64:291–5.
9. Grieve DW. The assessment of gait. Physiotherapy 1969;56:452–60.
10. Mizrahi J, Susak Z, Heller L, Najenson T. Objective expression of gait improvement of hemiplegics during rehabilitation by time-distance parameters of the stride. Med Biol Eng Comp 1982;20:628–34.
11. Goldkamp O. Treatment effectiveness in cerebral palsy. Arch Phys Med Rehabil 1984;65:232–4.

12. Trever S, Levai JP, Bleck EE. Les buts raisonnables que l'on peut fixer a un infirme moteur cerebral grevement handicape. Motricite Cerebral 1981;2:55–68.
13. Gaines RW, Ford TB. A system approach to the amount of Achilles tendon lengthening in cerebral palsy. J Pediatr Orthop 1984;4:448–51.
14. Graebe RP, Thompson P. Lengthening of the Achilles tendon in cerebral paresis. Basic principles and follow-up study. S Afr Med J 1979;56:993–6.
15. Banks HH, Green WT. The correction of equinus deformity in cerebral palsy. J Bone Joint Surg [AM] 1958;40A:1359–79.
16. White JW. Torsion of the Achilles tendon. Its surgical significance. Arch Surg 1943;46:784–7.
17. Beck RJ, Andriacchi TP, Kuo KN, Fermier RW, Galante JO. Changes in the gait patterns of growing children. J Bone Joint Surg [AM] 1981;16-A: 1452–7.
18. Rose-Jacobs R. Development of gait of slow, free, and fast speeds in 3- and 5-year-old children. Phys Ther 1983;63:1251–9.
19. Sutherland DH, Olshen R, Cooper L, Woo SL. The development of mature gait. J Bone Joint Surg [AM] 1980;62A:336–53.
20. Sutherland DH, Cooper L, Daniel D. The role of ankle plantar flexors in normal walking. J Bone Joint Surg [AM] 1980;62A:354–63.
21. Lehmann JF, Condon SM, de Lateur BJ, Price R. Gait abnormalities in peroneal nerve paralysis and their correction by orthoses: biomechanical study. Arch Phys Med Rehabil 1986;67:380–6.
22. Perry J, Hoffer MM, Giovan P, Antonelli D, Greenberg R. Gait analysis of triceps surae in cerebral palsy. A preoperative and postoperative clinical and electromyographic study. J Bone Joint Surg [AM] 1974;56A:511–20.
23. Andriacchi TP, Ogle JA, Galante JO. Walking speed as a basis for normal and abnormal gait measurement. J Biomech 1977;10:261–8.

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