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Wartenberg pendulum test: objective quantification of muscle tone in children with spastic diplegia undergoing selective dorsal rhizotomy

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The aim of this study was to investigate the reliability and sensitivity of the Wartenberg pendulum test for quantification of muscle tone in young children with spastic diplegia undergoing selective dorsal rhizotomy (SDR). Fourteen non-disabled children (mean age of 5.5 years, age range 2.3 to 8.8 years, one female and one male in each year) were tested twice. Twenty children with spastic diplegia (12 males, eight females; mean age of 4.3 years, age range 2.5 to 6.3 years) consecutively selected for SDR, were assessed before and 6 months after SDR. Parameters of the pendulum test: R2, R1, maximal velocity, and swing time were correlated with clinical assessments for spasticity (modified Ashworth scale, quadriceps reflex) and measurements of gross motor function: the Gross Motor Function Classification System and the Gross Motor Function Measure. The Wartenberg pendulum test was found to be an objective and sensitive method for quantifying spasticity in knee extensor muscles in children as young as 2.5 years old. The method was responsive to changes after SDR. The only correlation with clinical measurements of spasticity was between the R2 ratio and the quadriceps reflex. Swing time was the most reliable and sensitive variable; it showed a weak correlation with measurements for gross motor function.

Spasticity is a common motor impairment in children with cerebral palsy (CP). It is the result of an insult to the developing brain that produces a disorder of movement and posture that is permanent but not unchanging (Rang et al. 1989). Spasticity is characterized by a velocity-dependent increase in tonic stretch reflexes with exaggerated tendon reflexes resulting from hyperexcitability of the stretch reflex as one component of the upper motor neuron syndrome (Lance 1980). It is a disabling impairment, which interferes with the maintenance of posture and coordinated voluntary movements and may lead to contractures, deformities, and pain. It disrupts activities in daily living and limits the efficacy of physical therapy (Davies 1977). Most knowledge about spasticity is based on studies of adults with stroke, spinal cord injury, and multiple sclerosis (MS). Less is known about spasticity in children with CP.

The measurement of spasticity is a difficult and unresolved problem, partly due to its complex and multifactorial nature (Katz et al. 1992). Clinical, electrophysiological, and biomechanical techniques have been used in its assessment (Sehgal and McGuire 1998). In the clinical setting, spasticity is most often assessed subjectively by quantifying the muscle tendon reflexes and by the original Ashworth scale which grades resistance to passive movement across a relaxed joint on an ordinal scale of 0 to 4 (Ashworth 1964). This scale suffers from a clustering effect with most patients grouped in the middle grades, therefore modifications of the scale have been created by adding an intermediate grade (Katz and Rymer 1989). The modified Ashworth scale (Bohannon and Smith 1987) has been shown to have a high interrater reliability in adult patients with hemiplegia when testing elbow flexors. It is, however, unreliable for measuring tone in the plantar flexors (Lee et al. 1989, Sloan et al. 1992). Another reported disadvantage of the Ashworth scale, original as well as modified, is its inability to differentiate the components of muscle tone (viscoelastic properties versus reflex activation of the contractile elements). In addition, the testing can be performed at different velocities by different investigators which might affect the result (Sehgal and McGuire 1998). Reliability and validity of the Ashworth scale have never been studied in children with CP.

The assessment and management of spasticity in children with CP is a challenging task for clinicians as well as for researchers. New techniques to treat spasticity in children with CP, such as selective dorsal rhizotomy (SDR), botulinum toxin injections, intrathecal baclofen infusion, and peroral drug therapy require assessment tools to monitor their effectiveness (Hinderer and Gupta 1996, Forssberg and Tedroff 1997, Hesse and Mauritz 1997). In order to quantify spasticity in children with CP subjective quantification of muscle tendon reflexes and modifications of the Ashworth scale have been used (Peacock and Staudt 1991, Staudt et al. 1995, Steinbok et al. 1997, McLaughlin et al. 1998, Wright et al. 1998). A hand-held force transducer or myometer has been used to quantify resistance to passive motion (Staudt et al. 1995). Biomechanical measurements, such as the spasticity measurement system (SMS; Lehmann et al. 1989) have been used for quantification of the plantar flexors (Price et al.1991). The Kin-com dynamometer has been used for quantification of spasticity in hamstrings, dorsiflexors, and plantar flexors in children with CP (Engsberg et al. 1996, 1998, 1999). However, the authors commented that children who were not large enough to fit comfortably in the test equipment and who could not presumably cooperate had to be excluded (Engsberg et al. 1998).

The pendulum test was first described by Wartenberg as a simple and reliable clinical test to quantify lower-limb hypertonia in Parkinson disease (Wartenberg 1951). The test was subsequently extended to assess changes in tone in upper motor neuron disorders (Schwab 1964). The extended leg of a supine individual is allowed to fall freely from a fully extended position. Normally the leg swings smoothly with regular, gradually decreasing movements in the vertical plane, like a pendulum. In the spastic limb the swing is dampened by the viscoelastic properties and exaggerated stretch reflexes of the limb. The most commonly measured parameter is the relaxation index or R2 ratio, i.e. the amplitude of the first swing divided by the final angle of the knee (Boczko and Mumenthaler 1958, Bajd and Vodovnik 1984, Katz et al. 1992). In non-disabled elderly persons the R2 ratio is generally more than 1.6 (Brown et al. 1988a, 1988b; Katz et al. 1992). It has been shown to correlate well with the degree of spasticity, as quantified using a clinical assessment such as the Ashworth scale, in adults with MS (Leslie et al. 1992) and hemiparesis (Katz et al. 1992). A significant correlation between changes in the R2 ratio and the Ashworth scores in patients with MS having spasticity-reducing medication has also been shown (Emre et al. 1994).

Very few studies have been published on the Wartenberg pendulum test in children. Lin and collaborators measured the oscillations after eliciting a quadriceps tendon reflex in children with hemiplegia due to CP (Lin et al. 1994). This was, however, not a classical Wartenberg pendulum test. Recently, Fowler and collaborators showed that the test is sensitive in detecting spasticity in patients with CP of between 7 and 50 years old (Fowler et al. 2000). The sitting position was standardized and padded straps were secured around the patient's waist and distal thigh. They studied a number of parameters and found that the amplitude of the first swing was the best predictor of the degree of spasticity.

In our programme there is a need for a test that is objective and clinically useful in the selection of very young children (as young as 2.5 years of age) for spasticity reducing interventions and in monitoring their effects. The aim of this study was to investigate whether the Wartenberg pendulum test can be used in young children where a standardized sitting position is difficult to obtain. A reliability test was first performed in non-disabled children. Thereafter, children with spastic diplegia were tested before and after SDR. The parameters of the pendulum test were correlated with clinical assessments for spasticity and measurements of motor function.

Method

PARTICIPANTS

For comparison and test–retest reliability of the method, 14 non-disabled children (mean age of 5.5 years, age range 2.3 to 8.8 years; one female and one male in each year) were assessed. Their weight ranged between 14 and 35 kg, and height ranged between 91 and 139 cm. The interval between the two assessments was 1 to 2 weeks. Only the right leg was tested in the two youngest children as they could not be motivated to cooperate in a longer session. The study group included all children with spastic diplegia who were selected for SDR between March 1996 and September 1999. All 20 patients were evaluated pre- and 6 months postoperatively (Tables I and II). In one patient, only the right leg was tested both times. In a second patient, only the right leg was tested after the SDR, and in a third patient the postoperative data from the right leg could not be used due to an inability to relax. Children and their parents gave their informed consent before participating in the study, which was approved by the research ethics committee at Lund University, Sweden.

TEST PROCEDURES

Pendulum test

Children sat comfortably on a couch, with a belt fixed over the thighs and a parent behind them. The lower leg was hanging over the edge of the couch. Knee angle was measured with an electrogoniometer (Biometrics Ltd, Gwent, UK) attached to the lateral side of the knee. EMG was recorded simultaneously from the quadriceps and hamstring muscles. The children were encouraged to relax and close their eyes. The knee was fully extended when the leg was lifted and when no EMG activity could be recorded from the quadriceps and hamstring muscles, the leg was released to swing freely. The EMG and the knee angle were recorded and stored for further analysis with the LabVIEW program (National Instruments Corporation, Austin, Texas, USA). The pendulum test was repeated until at least three successful trials were obtained for each leg. The measurement variables were: (1) R2 ratio – the amplitude (in degrees) of the first swing (A) divided by the amplitude of the final position (C; Fig. 1a); (2) R1 ratio – the amplitude of the first swing (A) divided by the amplitude of the rebound angle (B; Bowman and Bajd 1981); (3) maximal velocity of the first swing (Vmax; °/s), and (4) the time between the peaks, i.e. swing time (s). Swing time is dependent on pendulum length. In non-disabled children, there was a strong correlation between height and swing time (Fig. 2). From these data, the equation ($y=0.0054x+0.2484$) was derived where y indicates expected swing time (s) and x height (cm). The recorded swing time was divided by the expected swing time and the obtained quotient was defined as relative swing time. Thus, the length dependence was eliminated and the relative swing time could be used for comparison between the two groups of children.

CLINICAL ASSESSMENTS OF SPASTICITY AND GROSS MOTOR FUNCTION

Clinical assessment of spastic hypertonia was made when the patient was resting supine. To avoid interexaminer variation, the same experienced physiotherapist examined all participants. The passive muscle tone in quadriceps was assessed by flexing the knee and graded (0 to 5) on a scale for spasticity made by Peacock and Staudt (1991) modified from those of Ashworth (1964) and Bohannon and Smith (1987; Table III). The quadriceps tendon reflex was assessed by an experienced paediatric neurologist and graded on an ordinal scale 0 to 4. Preoperatively, the children were classified according to the Gross Motor Function Classification System (GMFCS; Palisano et al. 1997). This is a five-level classification system based on self-initiated movement for children with CP, with particular emphasis on sitting (truncal control) and walking. Gross motor function was measured with the Gross Motor Function Measure (GMFM; Russell et al. 1989). Correlations between pendulum test parameters and the score for dimension E (walking, running, and jumping), goal score, and total score were tested.

STATISTICAL ANALYSIS

Mean values of the different parameters from the right and left leg were calculated separately as they cannot be considered as independent variables. However, for the correlations with functional tests a mean of the right and left leg was used. When testing reliability the results of the second test were expressed as percentage of the first test and then the coefficient of variation was calculated. Differences between pre- and postoperative values were calculated with a paired, two-tailed Student *t*-test. Differences between preoperative values in

Table I: Preoperative parameters in children with CP

Participant nr	*Age*	*Sex (y)*	*Height*	*GMFCS (cm)*	*GMFM t*	*GMFM e*	*Right leg*					
							Quadriceps reflex	*Modified Ashworth scale*	*R1*	*R2*	*Vmax (°/s)*	*Relative swing time (s)*
1	2.5	M	85	4	29	0	3	3	1.36	0.78	144	0.44
2	2.8	F	97	4	27	0	3	2	1.55	1.12	325	0.52
3	3.3	M	92	4	40	0	2	3	1.06	1.49	285	0.21
4	3.3	F	92	3	51	17	3	1	1.61	1.13	303	0.42
5	3.3	M	100	3	57	6	2.5	2	1.83	0.86	223	0.44
6	3.4	F	92	5	19	0	3	4	1.34	1.22	235	0.30
7	3.4	M	104	4	42	0	3	3	1.27	1.05	280	0.41
8	3.5	F	98	1	80	65	3	1	1.53	1.19	307	0.76
9	3.8	M	92	4	36	4	3	2	1.32	1.40	242	0.59
10	3.7	M	93	4	36	4	3.5	2	1.43	0.66	92	0.45
11	4	M	100	4	20	0	3	4	1.88	1.14	223	0.52
12	4.9	M	97	4	27	0	3	2	1.68	0.75	232	0.39
13	4.9	F	101	2	80	57	3	2	1.75	0.95	233	0.72
14	5.2	F	96	4	21	1	3.5	2	1.28	0.71	262	0.59
15	5.2	F	103	3	68	18	3.5	2	1.26	0.78	270	0.43
16	5.2	M	102	2	76	38	3	1	1.28	0.94	178	0.55
17	5.3	M	104	3	63	14	3	2	1.66	1.15	189	0.29
18	5.6	F	104	4	62	17	3.5	3	1.59	0.71	297	0.53
19	6	M	113	2	88	82	2.5	1	1.57	1.17	273	0.67
20	6.3	M	104	2	84	57	3	2	1.94	1.32	282	0.87
Mean	4.3	–	–	3	50	19	3	2.2	1.51	1.03	244	0.50
SD	1.1	–	–	–	–	–	–	–	0.24	0.25	58	0.16
Median	–	–	–	4	47	5	3	2	1.54	1.09	252	0.48

In participant 8, left leg was not investigated. GMFCS, Gross Motor Function Classification System; GMFM t, Gross Motor Function Measure total score; GMFM e, Gross Motor Function Measure, dimension E (walking, running, and jumping); R1, amplitude of first swing divided by amplitude of rebound angle; R2, amplitude of first swing divided by final angle of knee; Vmax, maximal velocity.

Table II: Measurements at first test for control children, and pre- and postoperatively for children with CP

Variables	*Control children (n=14)*				*CP preop (n=20)*				*CP preop–control*	
	n	*Mean*	*SD*	*Range*	*n*	*Mean*	*SD*	*Range*	*%*	p^a
R2 ratio										
Right	14	1.86	0.26	(1.37–2.24)	20	1.03	0.25	(0.66–1.49)	55	<0.001
Left	12	1.82	0.22	(1.35–2.13)	19	1.10	0.26	(0.72–1.54)	60	<0.001
R1 ratio										
Right	14	4.01	1.40	(1.83–6.95)	20	1.51	0.24	(1.06–1.94)	38	<0.001
Left	12	3.78	1.24	(1.93–6.11)	19	1.88	0.50	(1.15–3.17)	50	<0.001
Vmax (°/s)										
Right	14	388	77.5	(277–492)	20	244	58.0	(92–325)	63	<0.001
Left	12	392	39.8	(329–459)	19	260	60.0	(142–366)	66	<0.001
Relative swing time (s)										
Right	14	1.00	0.03	(0.96–1.07)	20	0.50	0.16	(0.20–0.79)	50	<0.001
Left	12	1.00	0.05	(0.90–1.06)	19	0.59	0.17	(0.30–0.85)	59	<0.001

%, mean preoperative values as a percentage of control group; *ns*=p>0.1.

[a] Differences between values of CP group preoperatively and control group, calculated with unpaired Student *t*-test, two-tailed *p* value.

[b] Differences between pre- and postoperative values calculated with paired Student *t*-test, two-tailed *p* value. R2, amplitude of first swing divided by final angle of knee; R1 ratio, amplitude of first swing divided by amplitude of rebound angle; Vmax, maximal velocity.

those with CP and unaffected children were calculated with unpaired, two-tailed Student *t*-test. The results from the pendulum test were compared with the clinical assessments for spasticity and function using non-parametric statistics, Spearman's rank correlation coefficient (r_S). The results from the pendulum test were correlated with age using parametric statistics, Pearson's correlation coefficient (r_P). Statistical significance was set at $p<0.01$

Table I continued

		Left leg			
Quadriceps reflex	*Ashworth scale*	*R1*	*R2*	*Vmax (°/s)*	*Relative swing time (s)*
3	2	1.94	1.14	185	0.48
3	2	1.34	0.93	241	0.53
2	3	2.5	1.34	239	0.49
2.5	2	2.07	1.42	346	0.85
2.5	3	1.87	1.12	248	0.49
3	4	1.33	1.02	264	0.35
3	2	1.74	1.11	366	0.47
–	–	–	–	–	–
3	2	2.33	1.54	264	0.89
3.5	2	1.35	0.93	178	0.48
3	4	1.79	1.08	223	0.54
3.5	2	1.94	0.8	292	0.59
3	2	1.93	1.04	299	0.73
3.5	2	1.41	0.69	242	0.50
3	2	1.15	0.85	238	0.34
3	1	1.85	1.27	220	0.70
3.5	2	2.08	1.5	339	0.62
3.5	2	3.17	0.72	298	0.50
3	1	1.43	0.93	142	0.68
2	2.5	2.43	1.41	325	0.89
3	2.2	1.88	1.10	260	0.58
–	–	0.50	0.26	60	0.17
3	2	1.87	1.08	248	0.53

Table II continued

CP postop (n=20)				CP post–pre	CP postop-ND
n	*Mean*	*SD*	*Range*	p^b	p^a
19	1.76	0.24	(1.50–2.35)	<0.001	*ns*
18	1.85	0.24	(1.62–2.52)	<0.001	*ns*
19	3.35	1.27	(1.26–6.41)	<0.001	*ns*
18	4.00	1.78	(2.42–9.85)	<0.001	*ns*
19	364	63.0	(243–456)	<0.001	*ns*
18	385	84.0	(247–544)	<0.001	*ns*
19	0.93	0.07	(0.76–1.03)	<0.001	<0.001
18	0.93	0.07	(0.78–1.07)	<0.001	<0.01

Results

PENDULUM TEST IN NON-DISABLED CHILDREN

An example of a typical pendulum test response in a non-disabled 5-year-old female is illustrated in Fig. 1a. The leg movement was characterized by a smooth swing with a low damping factor. The amplitude of the first swing (A) was much larger than that of the final position (C). The R2 ratio was 1.71, R1 3.11, Vmax 381°/s, and swing time 0.88 seconds. The expected swing time was 0.84 seconds. Hence the relative swing time was 1.04. The mean values of 14 right and 12 left legs in the non-disabled children are illustrated in Figures 3a to 3d and Table II. The two lowest R2 values were obtained in two of the youngest children. However, for the whole group, there was no correlation between R2 and age. Neither did R1 or maximal velocity show any correlation with age. The swing time, on the other hand, showed a strong correlation with age and height (see Fig. 2), which is to be expected as it is dependent on pendulum length. When corrected for this, by calculating the relative swing time, the age dependence was eliminated in order to facilitate the comparison between groups.

TEST–RETEST RELIABILITY IN NON-DISABLED CHILDREN

In order to test the reliability of the pendulum test, the mean values of the four parameters for each leg were calculated. The results from the second test were expressed as a percentage of the results from the first test and plotted against age in Figures 4a to 4d. No correlation with age was found. The reliability was expressed as the coefficient of variation (CV), i.e. the standard deviation as a percentage of the mean. The relative swing time displayed the lowest CV (4% and 3% in the right and left legs, respectively).

PENDULUM TEST IN CHILDREN WITH CP

A typical pendulum test in a 5-year-old female with spastic diplegia before SDR is illustrated in Fig 1b. EMG recordings from the quadriceps and hamstring muscles are also presented. The diagram differs from that for a normally developing child in a number of aspects. First, when the leg was

Table III: Scale for grading spasticity modified from those of Ashworth (1964) and Bohannon and Smith (1987) by Peacock and Staudt (1991)

Score	*Definition*
0	Hypotonic: less than normal muscle tone, floppy
1	Normal: no increase in muscle tone
2	Mild: slight increase in tone, 'catch' in limb movement or minimal resistance to movement through less than half of the range
3	Moderate: more marked increase in tone through most of the range of the motion but affected part is easily moved
4	Severe: considerable increase in tone, passive movement difficult
5	Extreme: affected part rigid in flexion or extension

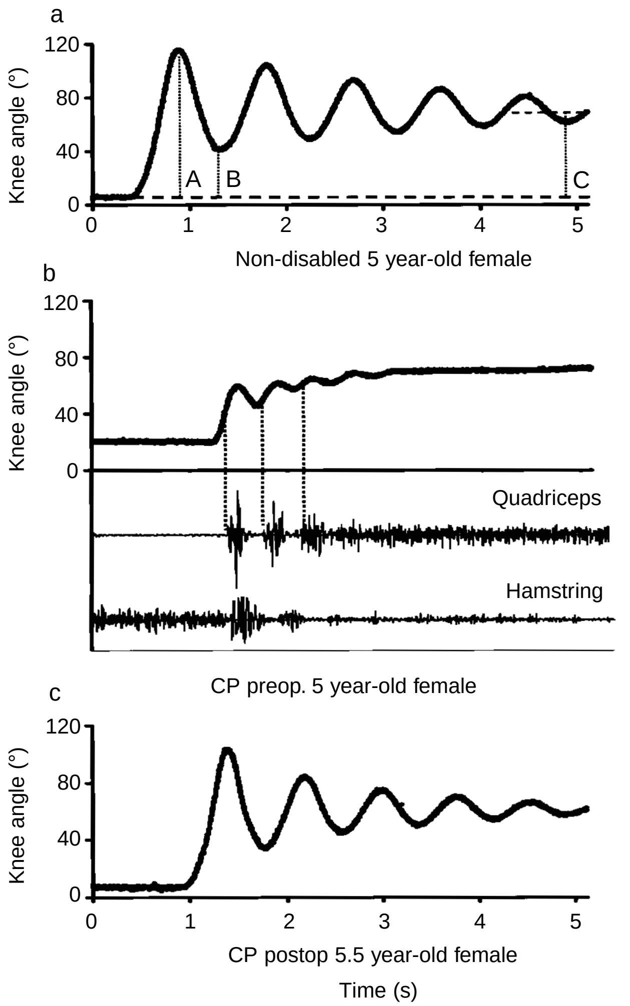

Figure 1: *Knee angle during pendulum test. Zero indicates full extension and positive values flexion. (a) non-disabled 5-year-old female; (b) five-year-old female with CP preoperatively. EMG recordings from the quadriceps and hamstring muscles; (c) same child 6 months after SDR.*

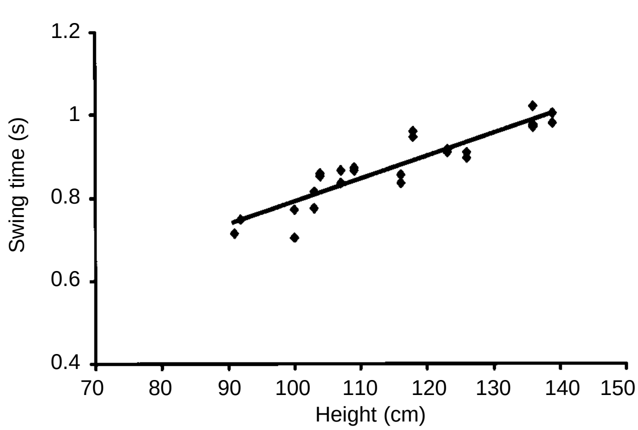

Figure 2: *Correlation between height (cm) and swing time (s) of both right and left legs in non-disabled children. Correlation coefficients were r_p=0.96 (right leg) and r_p=0.89 (left leg). In the two youngest children measurements were obtained from the right leg only.*

stretched, there was an extension deficit of 20 degrees, and a tonic stretch reflex was observed in the hamstrings. Second, when the leg was released the amplitude of the first swing was only 40 degrees, i.e. less than the final (vertical) position. As seen in the EMG recording, the quadriceps muscle was activated during flexion. This stretch reflex was strong enough to produce an extension before the lower leg had reached a vertical position, explaining the low R2 ratio (0.74). Also, during the second and third flexion movements, stretch reflexes were elicited in the quadriceps. At the end of the pendular movement when the knee was flexed, a tonic stretch reflex was observed in the quadriceps. Third, the peak velocity and swing time were low. In this leg the mean R1 ratio was 1.46, Vmax 270°/s, and swing time 0.40 s. The expected swing time was 0.85 s. Hence, the relative swing time was 0.46 s. This low value can be explained by the stretch reflexes in both quadriceps and hamstring muscles. All these values were considerably lower than in the control participant (see Fig. 1a). As seen in Figures 3a to 3d and Table II, there was a highly significant difference (p<0.001) between the group of normally developing children and those with spasticity, preoperatively. Mean values in the patient group were between 38 and 66% of those of the control group.

RESPONSIVENESS TO CHANGE

Six months after SDR, all parameters of the pendulum test were significantly improved (p<0.001) compared with preoperative values (Figs 1c and 3a to 3d). They were now similar to those of the control children. Only the relative swing time was still significantly lower (right leg, p=0.001 and left leg, p=0.01). EMG recordings revealed no reflexes postoperatively (not shown in Fig. 1c as in this patient, there was a large movement artifact during the initial part of the pendulum test).

CORRELATION WITH CLINICAL TESTS

For the children with diplegia, the preoperative R2 ratio showed a statistically significant correlation with the quadriceps reflex for the right leg, r_S=–0.626 (p=0.003) and nearly significant for the left leg, r_S=–0.566 (p=0.014). There was no significant correlation between the R2 ratio and Ashworth scale for either leg. For the variables R1, Vmax, and relative swing time there was no significant correlation with either of the clinical tests for spasticity.

No significant correlations were found between the R2, R1, and Vmax and the GMFCS and GMFM. However, statistically significant correlations were found between the relative swing time and these tests. The correlation between the relative swing time and the GMFCS was (r_S)=–0.584 (p=0.007). The correlation between the relative swing time and the GMFM dimension E, was (r_S)=0.614 (p=0.004).

Discussion

In the present study, the pendulum test variables could differentiate between the unaffected group and the group with spasticity and they responded to the decreased spasticity after SDR. The relative swing time was the most reliable parameter.

The pendulum test has been evaluated in non-disabled adults, and adults with either rigidity or spasticity. It has been demonstrated to be a practical and reproducible measure of spastic tone (Wartenberg 1951; Boczko and Mumenthaler 1958; Schwab 1964; Bajd and Bowman 1982; Brown et al. 1988a, b; Jamshidi and Smith 1996). There is only one report

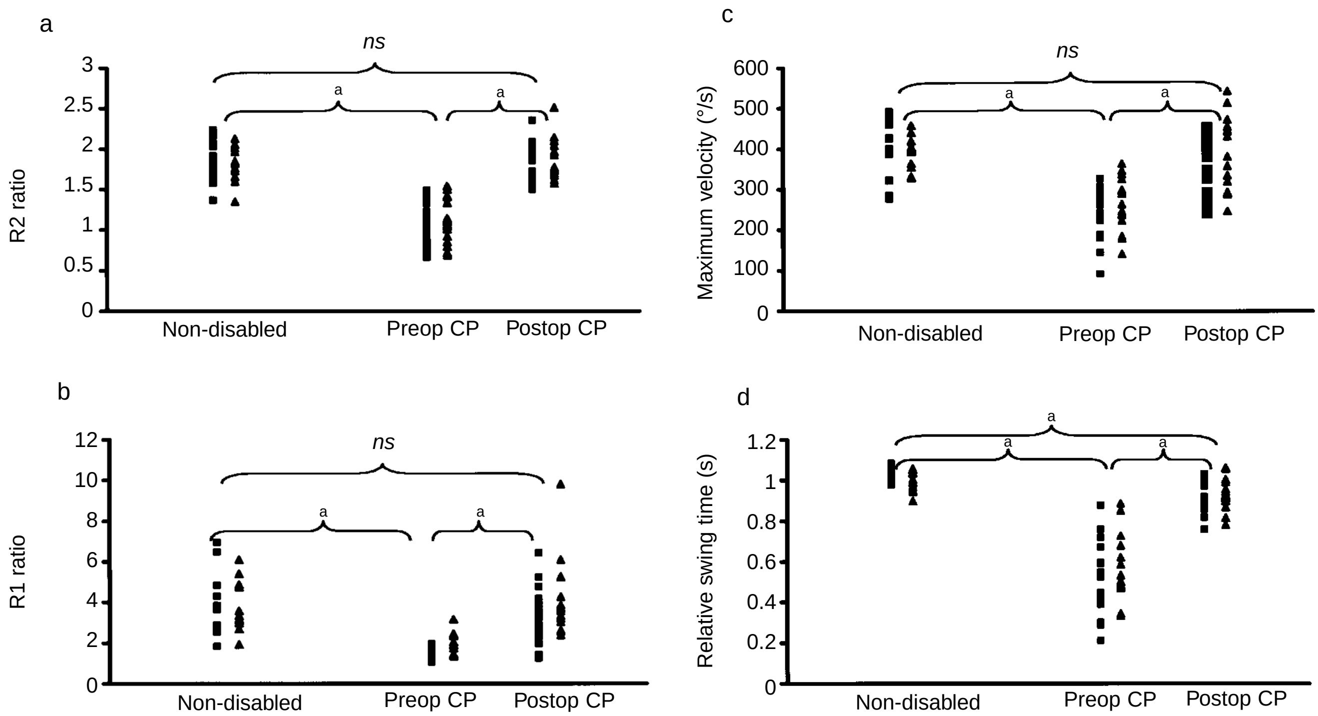

Figure 3: *Comparison of individual values and mean of right (■) and left (▲) legs in non-disabled children (14 right and 12 left legs), with children before (20 right and 19 left legs) and after SDR 9 right and 18 left legs). ns=p>0.1, $^{a}p<0.001$. (a) R2 ratio, (b) R1 ratio, (c) Maximal velocity (°/s), (d) Relative swing time (s).*

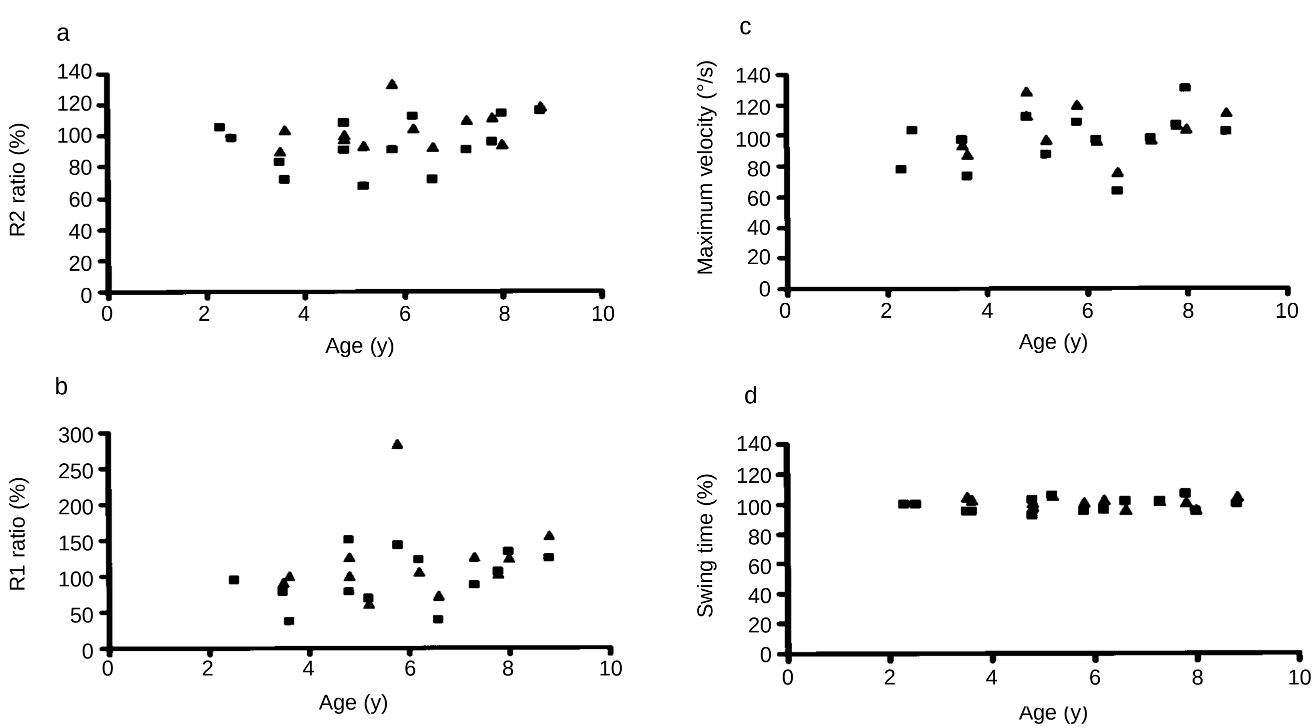

Figure 4: *Reliability of pendulum test parameters in control group. Results from second test are expressed as a percentage of those from first test and plotted versus age for right (■) and left (▲) legs. CV, coefficient of variation, expressed as standard deviation in percentage of mean. (a) R2 ratio, CV right leg 17% and left leg 13%; (b) R1 ratio, CV right leg 37% and left leg 47%; (c) Maximal velocity, Vmax (°/s), CV right leg 18% and left leg 14%; (d) Swing time (s), CV right leg 4%, and left leg 3%.*

on the sensitivity of the pendulum test in children with CP (Fowler et al. 2000). The authors concluded that it is a valid tool for assessing spasticity in persons with CP. However, the youngest children were 7 years old and the material includes patients up to 50 years old. The purpose of the present study was to determine if the Wartenberg pendulum test was applicable and useful in quantifying spasticity in children as young as 2.5 years.

In order to avoid the lower leg hitting the couch, the children had to sit so far forward that the distal part of the thigh had no support. As a consequence, the thigh was leaning down during the test and in the final position of the lower leg, the knee flexion was less than 90° (approximately 70°, see Fig. 1). This explains how the R2 ratio could attain values of 2 or more, which is impossible with a horizontal thigh and a final vertical position of 90°.

Our goal was to perform repeated measurements on all children, even the very young ones and children with impaired cognitive function. As the test relies on the participants being relaxed and not assisting or resisting the pendular movements, we chose a test position where the child was sitting relaxed and safely with one parent close behind. The advantage of this test position was that the children were comfortable and tolerated the test very well. The disadvantage was that the position was not quite standardized. This could have affected the results. However, in the choice between a standardized position and a relaxed child, we preferred the latter. It is most likely that the test results would have been more affected by inability to relax than by rather small differences in the sitting position. In addition, it would not have been possible to perform repeated measurements if the patients had felt uncomfortable. To minimize the error from voluntary activation of the investigated muscle we used EMG recordings to ensure that the children were relaxed when the test started.

Different test positions have been studied in adults: lying supine (Jamshidi and Smith 1996), semi-supine (Vodovnik et al. 1984, Leslie et al. 1992,) and sitting up (Katz et al. 1992). Brown and collaborators studied the importance of the test position in non-disabled elderly individuals and found that the position contributed very little to the total variability (Brown et al. 1988a). In a small group of non-disabled young adults this contribution was even smaller. In a recent study on non-disabled elderly individuals and those with hemiplegia, Fowler and collaborators (1998) tested the influence of quadriceps muscle length on the pendulum test. They reported that the angle of reversal was influenced by muscle length such that there was no difference between patients and non-disabled individuals when the difference in muscle length was taken into account. However, the peak velocity was much lower in the patients and this could not be explained by muscle-length difference. In the present study, all parameters were reduced to about the same extent in the patients (see Table II). Thus, variation in muscle length does not seem to have influenced the results. However, as there is no study on the influence of sitting position in children with CP, we cannot entirely exclude the possibility that some variation is due to this.

CORRELATION WITH CLINICAL TESTS OF SPASTICITY AND MOTOR FUNCTION MEASUREMENTS

Preoperatively, there was a negative correlation between the R2 ratio and the quadriceps reflex. As seen in Figure 1b, a stretch reflex was elicited in the quadriceps muscle during the flexion of the knee reducing the amplitude of the first swing, which leads to a low R2 ratio. Thus, such a correlation is expected to occur.

The lack of correlation between any of the pendulum test parameters and the modified Ashworth scale (Peacock and Staudt 1991) is not in accordance with previous studies that have shown a significant correlation between R2 and the Ashworth scale in adult patients (Katz et al.1992, Leslie et al. 1992). This might be explained partly by the clustering effect on the 6-point ordinal scale, with 14 of 20 patients grouped in grades 2 to 3 (see Table I). Other reasons that might have influenced our results could be the small sample size and the fact that the tests were performed in different positions and at different times on a given day. It should also be kept in mind that the validity and reliability of the Ashworth scale have not been tested in children with CP. Therefore, a lack of correlation between the pendulum test parameters and this method is rather non-informative.

There are few reports concerning the relation between spasticity and motor function. In the present study, swing time was the only variable which showed a significant correlation with GMFCS and the GMFM. The correlation was weak, which is to be expected as motor function is dependent on many factors of which spasticity is only one. It must also be kept in mind that the pendulum test can only measure the properties of one muscle group (i.e. the quadriceps) under passive conditions. Nevertheless, it has been shown that gross motor function is also improved after SDR and physical therapy (Steinbok et al. 1997, McLaughlin et al. 1998, Wright et al. 1998).

The finding that the different pendulum parameters correlate with different tests suggest that they reflect different aspects of the spastic muscle's resistance to passive movements. Further studies to elucidate the mechanisms affecting different variables will be necessary. Little attention has been paid, for example, to the potential effect of viscoelastic properties of the knee extensor muscles on the result of the pendulum test. The present observation that relative swing time was different between the non-disabled and the postoperative group, in whom there was no residual spasticity in the quadriceps, indicates that this parameter could also be sensitive to differences in viscoelastic properties.

New treatments of spasticity have been introduced in physiotherapy, pharmacology, and surgery. For future research it will be important to identify the mechanisms behind the motor impairment in patients with CP, such as spasticity, cocontraction, and weakness. To this end, there is need for reliable and sensitive tests to be developed that can determine the relative importance of these mechanisms in any patient. Only then can the optimal therapeutic intervention be chosen and its effects be assessed.

Conclusions

The Wartenberg pendulum test combined with EMG is an objective and sensitive method for quantifying spasticity in knee extensor muscles in children as young as 2.5 years. The method is responsive to changes after SDR. The only correlation with clinical measurements of spasticity was between the R2 ratio and the quadriceps reflex. Swing time was the most reliable and sensitive variable, which showed a weak correlation with measurements for gross motor function. Limitations of the test are mainly that it can be used only for one muscle group (quadriceps) and that it measures the properties under passive conditions.

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References

Ashworth B. (1964) Preliminary trial of carisoprodol in multiple sclerosis. *Practioner* **192:** 540–2.

Bajd T, Vodovnik L. (1984) Pendulum testing of spasticity. *Journal of Biomedical Engineering* **6:** 9–16.

Boczko M, Mumenthaler M. (1958) Modified pendulousness test to assess tonus of thigh muscles in spasticity. *Neurology* **8:** 846–51.

Bohannon RW, Smith MB. (1987) Interrater reliability of a modified Ashworth scale of muscle spasticity. *Physical Therapy* **67:** 206–7.

Bowman B, Bajd T. (1981) Influence of electrical stimulation on skeletal muscle spasticity. In: Popovic D, editor. *Proceedings of the Seventh International Symposium on External Control of Human Extremities*. Belgrade, Yugoslavia: Committee for Electronics and Automation. p 567–76.

Brown RA, Lawson DA, Leslie GC, Part NJ. (1988a) Observation on the applicability of the Wartenberg pendulum test to healthy, elderly subjects. *Journal of Neurology, Neurosurgery, and Psychiatry* **51:** 1171–7.

— Lawson DA, Leslie GC, MacArthur A, MacLennan WJ, MacMurdo MET, Mutch WJ, Part NJ. (1988b) Does the Wartenberg pendulum test differentiate quantitatively between spasticity and rigidity? A study in elderly stroke and Parkinsonian patients. *Journal of Neurology, Neurosurgery, and Psychiatry* **51:** 1178–86.

Davies PA, Drillien CM, Foley J, Bryant KM, Nash MI, Egan JM. (1977) Cerebral palsy. In: Drillian DC, Drummond MB, editors. *Neurodevelopmental Problems in Early Childhood*. Oxford: Blackwell Scientific.

Emre M, Leslie GC, Muir C, Part NJ, Pokorny R, Roberts RC. (1994) Correlations between dose, plasma concentrations, and antispastic action of tizanidine (Sirdalude). *Journal of Neurology, Neurosurgery, and Psychiatry* **57:** 1355–9.

Engsberg J, Olree KS, Ross SA, Park TS.(1998) Spasticity and strength changes as a function of selective dorsal rhizotomy. *Journal of Neurosurgery* **88:** 1020–6.

— Ross SA, Park TS. (1999) Changes in ankle spasticity and strength following selective dorsal rhizotomy and physical therapy for spastic cerebral palsy. *Journal of Neurosurgery* **91:** 727–32.

Engsberg JR, Olree KS, Ross SA, Park TS. (1996) Quantitative clinical measure of spasticity in children with cerebral palsy. *Archives of Physical Medicine and Rehabilitation* **77:** 594–9.

Forssberg H, Tedroff K. (1997) Botulinum toxin treatment in cerebral palsy: intervention with poor evaluation? *Developmental Medicine & Child Neurology* **39:** 635–40.

Fowler E, Nwigwe AI, Wong Ho T. (2000) Sensitivity of the pendulum test for assessing spasticity in persons with cerebral palsy. *Developmental Medicine & Child Neurology* **42:** 182–9.

Fowler V, Canning CG, Carr JH, Shepherd RB. (1998) Muscle length effect on the pendulum test. *Archives of Physical Medicine and Rehabilitation* **79:** 169–71.

Hesse S, Mauritz KH. (1997) Management of spasticity. *Current Opinion of Neurology* **10:** 498–501.

Hinderer SR, Gupta S. (1996) Functional outcome measures to assess interventions for spasticity. *Archives of Physical Medicine and Rehabilitation* **77:** 1083–5.

Jamshidi M, Smith AW. (1996) Clinical measurement of spasticity using the pendulum test: comparison of electrogoniometric and videotape analyses. *Archives of Physical Medicine and Rehabilitation* **77:** 1129–32.

Katz RT, Rymer WZ. (1989) Spastic hypertonia: mechanism and measurement. *Archives of Physical Medicine and Rehabilitation* **70:** 144–55.

— Rovai GP, Brait C, Rymer WZ. (1992) Objective quantification of spastic hypertonia: correlation with clinical findings. *Archives of Physical Medicine and Rehabilitation* **73:** 339–47.

Lance JW. (1980) Symposium synopsis. In: Feldman RG, Young RR, Koella WP, editors. *Spasticity: disordered motor control*. Chicago: Year Book Publications. p 45.

Lee KC, Carsin L, Kinnin E, Patterson V. (1989) The Ashworth scale: a reliable and reproducible method of measuring spasticity. *Journal of Neurology and Rehabilitation* **3:** 205–9.

Lehmann JF, Price R, de Lateur BJ, Hinderer S, Traynor C. (1989) Spasticity: quantitative measurements as a basis for assessing the effectiveness of therapeutic intervention. *Archives of Physical Medicine and Rehabilitation* **70:** 6–15.

Leslie GC, Muir C, Part NJ, Roberts RC. (1992) A comparison of the assessment of spasticity by the Wartenberg pendulum test and the Ashworth grading scale in patients with multiple sclerosis. *Clinical Rehabilitation* **6:** 41–8.

Lin J-P, Brown JK, Brotherstone R. (1994) Assessment of spasticity in hemiplegic cerebral palsy I: Proximal lower limb reflex excitability. *Developmental Medicine & Child Neurology* **36:** 116–29.

McLaughlin JF, Bjornson KF, Astley SJ, Graubert C, Hays RM, Roberts TS, Price R, Temkin N. (1998) Selective dorsal rhizotomy: efficacy and safety in an investigator-masked randomized clinical trial. *Developmental Medicine & Child Neurology* **40:** 220–32.

Palisano R, Rosenbaum P, Walter S, Russell D, Wood E, Galuppi B. (1997) Development and reliability of a system to classify gross motor function in children with cerebral palsy. *Developmental Medicine & Child Neurology* **39:** 214–23.

Peacock WJ, Staudt LA. (1991) Functional outcomes following selective posterior rhizotomy in children with cerebral palsy. *Journal of Neurosurgery* **74:** 380–5.

Price R, Bjornson KF, Lehmann JF, McLaughlin, Hays RM. (1991) Quantitative measurement of spasticity in children with cerebral palsy. *Developmental Medicine & Child Neurology* **33:** 585–95.

Rang M, Silver R, Ganza J. (1989) Cerebral Palsy. In: Lovell WW, Winter RB, editors. *Pediatric Orthopedics*, Philadelphia: JB Lippincott.

Russell DJ, Rosenbaum PL, Cadman DT, Gowland C, Hardy S, Jarvis S. (1989) The gross motor function measure: a means to evaluate the effects of physical therapy. *Developmental Medicine & Child Neurology* **31:** 341–52.

Schwab RS. (1964) Problems in the clinical estimation of rigidity (hypertonia). *Clinical Pharmacological Therapy* **5:** 942–6.

Sehgal N, McGuire JR. (1998) Beyond Ashworth, electrophysiologic quantification of spasticity. *Physical Medicine and Rehabilitation Clinics of North America* **9:** 949–79.

Sloan RL, Sinclair E, Thompson S, Taylor S, Pentland E. (1992) Interrater reliability of the modified Ashworth scale for spasticity in hemiplegic patients. *International Journal of Rehabilitation Research* **15:** 158–61.

Staudt L, Nuwer MR, Peacock WJ. (1995) Intraoperative monitoring during selective posterior rhizotomy: technique and patient outcome. *Electroencephalography and Clinical Neurophysiology* **97:** 296–309.

Steinbok P, Reiner AM, Beauchamp R, Armstrong RW, Cochrane DD. (1997) A randomized clinical trial to compare selective posterior rhizotomy plus physiotherapy with physiotherapy alone in children with spastic diplegic cerebral palsy. *Developmental Medicine & Child Neurology* **39:** 178–84.

Vodovnik L, Bowman BR, Hufford P. (1984) Effects of electrical stimulation on spinal spasticity. *Scandinavian Journal of Rehabilitation Medicine* **16:** 29–34.

Wartenberg R. (1951) Pendulousness of the legs as a diagnostic test. *Neurology* **1:** 18–24.

Wright V, Sheil E, Drake J,Wedges J, Naumann S. (1998) Evaluation of selective dorsal rhizotomy for the reduction of spasticity in cerebral palsy: a randomized controlled trial. *Developmental Medicine & Child Neurology* **40:** 239–47.