

The Effect of Hinged Ankle-Foot Orthoses on Sit-to-Stand Transfer in Children With Spastic Cerebral Palsy

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ABSTRACT. Park ES, Park CI, Chang HJ, Choi JE, Lee DS. The effect of hinged ankle-foot orthoses on sit-to-stand transfer in children with spastic cerebral palsy. *Arch Phys Med Rehabil* 2004;85:2053-7.

Objective: To investigate the effectiveness of the hinged ankle-foot orthosis (AFO) on sit-to-stand (STS) transfers in children with spastic cerebral palsy.

Design: Before-after trial.

Setting: University-affiliated hospital.

Participants: Nineteen spastic diplegic children (age range, 2–6y).

Interventions: Not applicable.

Main Outcome Measures: The transitional movement of STS was tested in random order with children while wearing the barefoot and hinged AFOs. The temporal, kinematic, and kinetic data during the task were collected by using a motion analyzer (with 6 infrared cameras). Statistical comparison between barefoot and hinged AFO was done with the Wilcoxon signed-rank test.

Results: Total duration of STS transfer was significantly shortened with the hinged AFO ($P < .05$). The initial knee flexion, the initial angle, and the final angle of ankle dorsiflexion were increased with the AFO, compared with when barefoot ($P < .05$). However, the increased pelvic tilt and hip flexion while barefoot was not reduced with the AFO. The maximal moment and power of hip and knee joints were significantly increased with the AFO ($P < .05$), whereas the maximal moment and power of the ankle joint were not significantly changed when wearing the AFO.

Conclusions: Although proximal compensatory strategy of increased pelvic tilt and hip flexion did not change with the hinged AFO, some improvements of temporal, kinematic, and kinetic parameters were identified during the task. These findings suggest that a hinged AFO is beneficial for STS transfer activity for children with spastic diplegia.

Key Words: Ankle; Cerebral palsy; Foot; Motion, Orthotic devices; Rehabilitation.

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CHILDREN WITH SPASTIC cerebral palsy (CP) are characterized by loss of selective muscle control, dependence on primitive reflex patterns for ambulation, abnormal muscle tone, relative imbalance between muscle agonist and antagonist, and deficient equilibrium reactions.¹ The sit-to-stand (STS) transfer activity, which is among the most commonly executed movements and a fundamental activity for upright mobility and daily living, is a mechanically demanding task that is often compromised by spastic CP. By using a motion analysis system, the pattern of STS transfer in spastic CP was systematically characterized in our previous study.² Compared with normally developed children, the patterns of STS transfer in spastic diplegia was characterized by slow speed, increased anterior pelvic tilt, early abrupt knee extension, decreased knee extensor moment, and decreased extensor power generation of the hip and knee joints.² Ankle-foot orthoses (AFOs) are frequently prescribed to correct skeletal malalignment in spastic CP, and their positive effect on gait has been documented previously.³⁻⁸ Hinged AFOs have more beneficial effect on gait^{3,4,9} and STS transfer activity¹⁰ than do solid AFOs and therefore are thought to be superior. The effect of hinged AFO on STS transfer has been documented only once to our knowledge.¹⁰ In that study, some children who could not stand up independently used a horizontal bar for STS transfer. Use of the upper extremities to provide propulsive forces when rising may influence the characteristics of kinetic and kinematic parameters. To clarify the effect of hinged AFOs, it may be that this bias be controlled. Limiting a study to include only children who can stand up independently could be a way to make this determination. Also, the change in the kinetic parameter of each joint of the lower limb during STS transfer activity provided by the hinged AFO has not been investigated; consequently, we believe it is worth studying.

Therefore, we used motion analysis to compare kinetic and kinematic data of spastic CP children wearing a hinged AFO and when going barefoot who were able to stand up independently to investigate the positive effect of the hinged AFO on STS transfer activity.

METHODS

Participants

Children with spastic diplegic CP were included in the study if they met the following criteria: (1) had neither a joint contracture nor fixed deformity, (2) had neither visual nor auditory problems, (3) could understand verbal commands, (4) could stand independently from a chair without support, and (5) were from 2 to 6 years old. Informed consent was obtained from the children's parents. Nineteen children were recruited; their mean age was 45.2 ± 13.3 months.

Study Design

A motion analysis system using a motion analyzer^a with 6 infrared cameras was used to evaluate the STS transfer task. The analysis was done with subjects barefoot and while wearing a hinged AFO. We followed the same technique used in our previous report, in which 2 forceplates were used.² The resting

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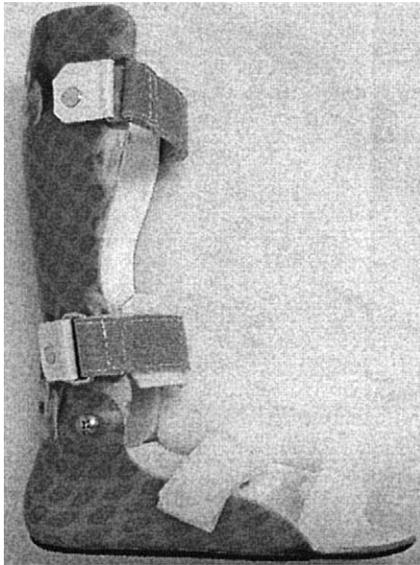


Fig 1. The hinged AFO.

period between 2 tests was at least 1 hour. Ten children were tested first while barefoot, whereas 9 children tested first wearing the hinged AFO. The upper part of the AFO extended to just below the knee and its flat footplate extended to the tips of the toes. The AFO material was 3-mm thick. The AFO blocked ankle plantarflexion but allowed free dorsiflexion through the hinge (fig 1). Kinetic and kinematic data from 38 limbs were obtained. The 6 transitional points, based on an analysis of kinematic data, were measured (T0, the initial point of STS was the point at which the sacral marker started to move; T1, the point of maximal hip flexion; T2, the point of abrupt transitory knee extension; T3, the point of maximal ankle dorsiflexion; T4, the point of standing with full extension of hip and knee; T5, the end point of STS as the point at which the motion of markers stopped) (fig 2).

The duration of 4 phases of STS from 6 transitional points (phase I, forward transfer of trunk; phase II, hip lifting off the chair and maximal hip flexion; phase III, transitory knee extension point to maximal ankle dorsiflexion; phase IV, maximal ankle dorsiflexion to point of standing up in nearly full

extension of knee and hip; phase V, stable standing) were also assessed with kinetic and kinematic variables.

We used the Wilcoxon signed-rank test for paired samples to test for statistical differences when barefoot and when wearing the hinged AFO. A statistically significant difference was accepted as *P* less than .05.

RESULTS

Changes of Temporal Parameters

The total duration of the STS transfer task was significantly reduced with the hinged AFO (2.34 ± 1.01 s), compared with being barefoot (3.42 ± 1.99 s). The durations of phases I, IV, and V were significantly shortened with the hinged AFO ($P < .05$). Phase III, which had been abnormally shortened in our previous report,² was lengthened with the hinged AFO ($P < .05$; table 1).

Changes in Angular Movement of Each Joint

The averaged kinematic curves of each joint in the lower limbs when barefoot and with the AFO are shown in figure 3. Pelvic and hip angular movement with the AFO did not differ significantly from that when subjects were barefoot. Initial angle of knee flexion was significantly increased, while the initial angle and final angle of ankle dorsiflexion were significantly increased with the AFO ($P < .05$; table 2).

Moment and Power of Each Joint

The maximum moment and power of hip extensor and knee extensor were significantly increased with the AFO ($P < .05$), but the maximal moment and power of ankle plantarflexor did not differ significantly when subjects were barefoot (table 3).

DISCUSSION

AFOs are frequently used to improve the gait children with spastic CP,³⁻⁸ to decrease muscle tone,¹¹⁻¹³ to improve standing balance,^{14,15} and to provide a stable base of support.^{11-13,16} However, studies of the effects of AFOs on STS transfer in children with CP have been limited. Previously, we showed some deviations in kinetic and kinematic data in the pattern of STS transfer activity in spastic diplegia, compared with normally developed children.² Our question was whether use of a hinged AFO could modify that pattern into a pattern exhibited by normally developed children. This study has revealed some

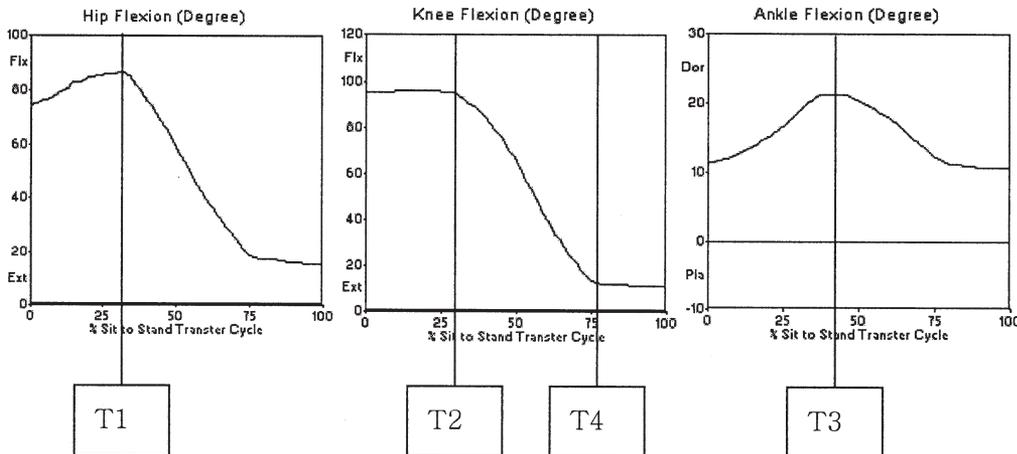


Fig 2. Transitional points from kinematic data. See Study Design section for definitions of T points. Abbreviations: Dor, dorsiflexion; Ext, extension; Flx, flexion; Pla, plantarflexion.

Table 1: Five Phases of STS Transfer

Phases	Normal Control [†] Time (s)	CP Diplegia			
		Barefoot		Hinged AFO	
		Time (s)		Time (s)	
		Mean ± SD	Median (Range)	Mean ± SD	Median (Range)
Phase I	.32±.08	1.03±0.67	0.92 (0.22–3.18)	0.75±0.40*	0.68 (0.24–1.45)
Phase II	.05±.07	0.14±0.30	0.07 (–0.27 to 1.04)	0.07±0.20	0.45 (–0.41 to 0.61)
Phase III	.10±.12	0.09±0.24	0.11 (–0.99 to 0.48)	0.13±0.14*	0.06 (–0.04 to 0.55)
Phase IV	.38±.14	1.48±0.97	1.29 (0.41–5.17)	1.03±0.48*	0.9 (0.39–2.03)
Phase V	.27±.06	0.72±0.51	0.52 (0.19–2.58)	0.43±0.20*	0.37 (0.15–0.90)

NOTE. See Study Design Section for definitions of phases.

Abbreviation: SD, standard deviation.

* $P < .05$, vs barefoot.

[†]Data from Park et al.²

positive effects in temporal parameters and also in kinematic and kinetic parameters.

In a previous study,¹⁰ the time needed to reach stable standing was shortened with the hinged AFO in children who were more than 1 standard deviation slower than non-CP children when barefoot. The speed of STS transfer was also faster using hinged AFOs in our study. The results suggest that hinged AFOs improve the efficiency of STS transfer activity in spastic diplegia. On the other hand, the duration of phase III, which represents vertical and forward movement of the center of mass, was significantly lengthened despite the overall shortening of total duration with the hinged AFO. A shortening of phase III, as compared with control subjects, was among the characteristics of children with spastic diplegia in our previous study.² Therefore, lengthening of phase III with the AFO may be considered a positive effect of the AFO.

Ankle and foot mobility during gait were improved with the hinged AFO.^{3,4,7} In this study, we found that the initial and final angle of the ankle joint with the AFO was significantly increased. The reduction of triceps surae spasticity resulting from stretching of the Achilles' tendon when wearing the

AFO¹⁷ may contribute to the changes of ankle joint movement during the STS task.

The effect of the AFO on proximal joints was not significant during gait.⁵ However, the effects on the proximal joints from AFOs have been documented during perturbed standing in spastic CP¹⁸ and also during standing up from the supine position in adults without disability.¹⁹ In our study, we observed an effect on angular movement of the proximal joint on the knee joint during the task with the AFO. The increased angle of initial ankle dorsiflexion by the hinged AFO seemed to result in better knee joint positioning for increased knee flexion at the initial point of the task. In contrast, the increased final angle of ankle dorsiflexion was not significantly affected by the final angle of the knee joint. The position of the knee when stable standing was achieved was already flexed on barefoot; thus, the AFO did not significantly increase the final knee angle.

Increased hip flexion and pelvic tilt during this activity was a compensatory strategy found in diplegia CP,² and also in patients with gross muscle weakness.²⁰ Still, increased pelvic

Table 2: Angular Movement During STS Activity

Joint Angle (deg)	Normal Control [†]	CP Diplegia			
		Barefoot		Hinged AFO	
		Mean ± SD	Median (Range)	Mean ± SD	Median (Range)
Pelvis tilt					
Initial angle	–4.4±6.5	–0.7±13.2	1.03 (–23.22 to 22.35)	–4.8±7.6	–4.86 (–25.22 to 8.21)
Maximal angle	24.1±5.7	32.3±10.1	30.07 (13.33–58.60)	32.3±7.8	33.80 (17.47–50.86)
Final angle	12.9±4.9	22.0±7.0	23.07 (4.21–33.17)	22.0±7.0	20.30 (9.57–35.26)
Hip flexion					
Initial angle	73.9±6.9	80.4±12.1	79.96 (56.03–105.92)	79.2±10.3	79.01 (60.54–104.82)
Maximal angle	87.5±6.2	97.2±10.5	96.38 (76.90–120.14)	95.5±9.8	94.92 (73.82–116.59)
Final angle	15.0±9.2	33.9±9.9	34.37 (10.64–60.96)	35.4±9.6	35.28 (16.83–52.97)
Knee flexion					
Initial point	91.2±8.0	87.5±15.8	86.23 (52.85–120.87)	92.3±12.5*	93.91 (61.94–119.20)
Transition point angle	89.2±7.6	90.5±23.0	93.06 (6.17–122.84)	90.4±22.3	93.16 (12.24–119.33)
Final angle	11.0±8.1	25.3±19.8	20.00 (–3.98 to 90.83)	24.3±10.9	21.48 (9.40–64.97)
Ankle dorsiflexion					
Initial angle	11.8±5.3	5.3±6.9	5.40 (–10.31 to 22.63)	9.9±4.6*	8.34 (1.98–17.51)
Maximal angle	21.9±5.4	17.0±8.1	17.88 (–0.98 to 32.68)	17.6±6.1	17.14 (4.94–31.72)
Final angle	9.3±6.4	4.7±8.9	5.10 (–21.55 to 22.05)	13.0±5.4*	11.71 (1.97–29.21)

* $P < .05$, vs barefoot.

[†]Data from Park et al.²

Table 3: Maximal Moment and Power

Moments and Power	Normal Control [†]	CP Diplegia			
		Barefoot		Hinged AFO	
		Mean ± SD	Median (Range)	Mean ± SD	Median (Range)
Hip extensor					
Maximal moment (Nm/kg)	0.68±0.34	0.44±0.26	0.46 (-0.61 to 0.86)	0.53±0.22*	0.52 (0.10-0.95)
Maximal power (W/kg)	1.28±0.82	0.44±0.30	0.35 (0.05-1.50)	0.57±0.33*	0.54 (0.11-1.48)
Knee extensor					
Maximal moment (Nm/kg)	0.39±0.26	0.14±0.08	0.14 (0.01-0.30)	0.17±0.09*	0.16 (0.02-0.40)
Maximal power (W/kg)	0.58±0.47	0.19±0.13	0.15 (0.02-0.52)	0.30±0.22*	0.24 (0.05-1.08)
Ankle plantarflexor					
Maximal moment (Nm/kg)	0.22±0.32	0.33±0.13	0.33 (0.03-0.59)	0.31±0.14	0.32 (0.06-0.68)
Maximal power (W/kg)	0.15±0.11	0.18±0.19	0.14 (0.01-0.98)	0.15±0.09	0.13 (0.01-0.35)

* $P < .05$, vs barefoot.

[†]Data from Park et al.²

tilt and hip flexion with the hinged AFO indicated that it did not modify the compensatory strategy.

The peak resultant joint torque increased when the speed of ascent increased.²¹ The fast speed realized with the AFO appeared to result in increased hip extensor momentum without significant change in the hip angular movement. The findings agree with the results of a previous study.²¹ The increased ankle moment while barefoot in spastic CP patients was not significantly reduced by the AFO. Compared with referent values, it was high both when subjects were barefoot or wearing the AFO. It may partly have resulted from a proximal compensatory strategy of increased pelvic tilt and hip flexion related to the increased ankle moment²² that was not significantly changed by the AFO. It might also be possible that the increased lever arm effect from increased ankle dorsiflexion with the AFO might be counterbalanced by the moment change

from increased speed, resulting in no significant change in ankle moment. In this study, there was an increase in the power of hip and knee joints during the task performed with the AFO. The increase in the speed with which the task was performed and in the moment of hip and knee joint flexion with the AFO appears to have contributed to these changes.

The reduction of spasticity in the triceps surae induced by stretching of the Achilles' tendon¹⁷ and the decreased disorganized muscle response pattern with the AFO¹⁸ may contribute to improvement of this activity. Postural stability is an important factor in achieving coordinated STS transfer.²³ The foot and ankle are more stable when the AFO is worn, which in turn enables postural control and alignment under more favorable physiologic conditions.²⁴ Although the exact mechanism by which hinged AFOs may help in this activity remains unclear, the positive effects produced by the hinged AFO may contribute the improvement of temporal, kinetic, and kinematic parameters during the STS task.

CONCLUSIONS

The total duration of the STS transfer was shortened when subjects wore the hinged AFO. The angular movements of ankle and knee joints were improved. Also, the moment and power of the hip and knee joints were also significantly increased, compared with when subjects were barefoot. However, the proximal compensatory patterns of increased pelvic tilt and hip flexion were not modified with the hinged AFO. These findings indicate that the hinged AFO has some beneficial effects on STS transfer activity in children with spastic diplegia.

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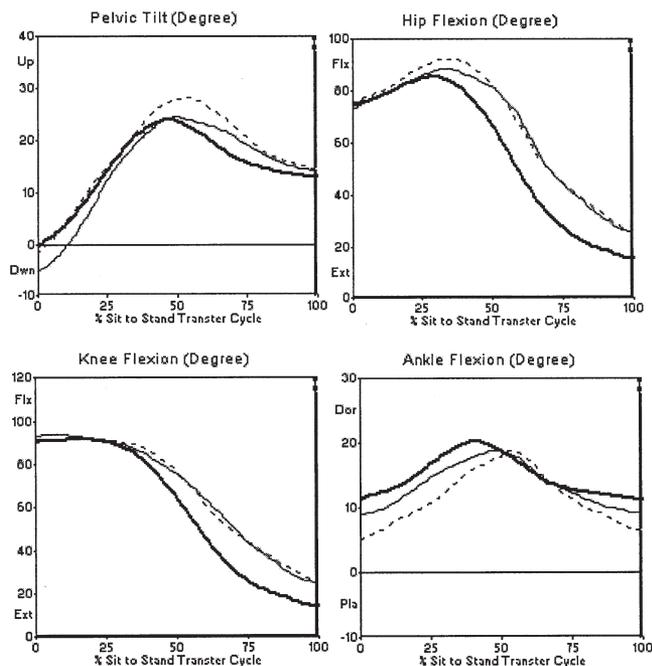


Fig 3. Averaged curves of kinematic data for barefoot (- -) and on hinged AFO (-) in spastic diplegia, compared with referent control (-) of the study by Park et al.² Abbreviation: Dwn, down.

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