Journal of Biomechanics 45 (2012) 2658–2661

Contents lists available at SciVerse ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Effects of ankle foot orthosis in stiff knee gait in adults with hemiplegia

Marcelo Andrés Gatti [a,*], Orestes Freixes [a], Sergio Anibal Fernández [a], Maria Elisa Rivas [a], Marcos Crespo [b], Silvina V. Waldman [c], Lisandro Emilio Olmos [c]

[a] Physical Therapy Unit, FLENI Rehabilitation Institute, Ruta 9 Km 52.5 Colectora Este, Escobar Buenos Aires, Argentina
[b] Gait Analysis Laboratory, FLENI Rehabilitation Institute, Buenos Aires, Argentina
[c] Department of Rehabilitation Medicine, FLENI Rehabilitation Institute, Buenos Aires, Argentina

ARTICLE INFO

Article history:
Accepted 9 August 2012

Keywords:
Stroke
AFO
Gait analysis
Hemiplegia
Stiff knee
Kinematic
Orthoses

ABSTRACT

Stroke survivors present a less efficient gait compared to healthy subjects due to abnormal knee flexion during the swing phase of gait, associated with spasticity of the rectus femoris muscle and overactivity of the ankle plantarflexors. It is relevant to understand the effect of the ankle foot orthosis (AFO) on gait in individuals with plantarflexor spasticity. The aim of this study was to compare the knee kinematics with an AFO/footwear combination and barefoot in post-stroke subjects with plantarflexor spasticity.

Ten subjects with chronic hemiplegia were measured. Two kinematic variables were assessed during the swing phase of the paretic limb: knee flexion angle at toeoff and peak knee flexion angle. We also analyzed gait speed and step length of the non-paretic limb. All variables were obtained with and without the orthosis. Kinematic data were acquired using a motion capture system (ELITE). Subjects wearing an AFO showed significant improvements in gait speed (0.62 m/s (0.08 SD) vs. 0.47 m/s (0.13 SD) (p=0.007)), step length of the non-paretic limb (42 cm (5.9 SD) vs. 33.5 cm (6.6 SD) (p=0.005)) and peak knee flexion angle during the swing phase: 30.7° (14.1° SD) vs. 26.3° (11.7° SD) p=0.005. No significant differences were obtained in the knee flexion angle at toeoff between no AFO and AFO conditions.

We described benefits with AFO/footwear use in the kinematics of the knee, the step length of the non-paretic limb, and the gait velocity in hemiplegic subjects after mild to moderate stroke. We conclude that the use of an AFO can improve the gait pattern and increase velocity in these subjects.

1. Introduction

People who suffer a stroke experience changes in strength, muscle tone and neuromuscular coordination (Neckel et al., 2008). It is estimated that two-thirds of stroke survivors will present an alteration in their walking ability (Jorgensen et al., 1995), and one-fifth will present with spastic drop foot (Burridge et al., 1997). For these reasons, ankle foot orthoses (AFOs) are widely used to provide mediolateral stability at the ankle in stance phase, facilitating the toe clearance in the swing phase, and promoting heel strike (Leung and Moseley 2003; Wang et al., 2005; Gök et al., 2003).

Still, the effect of the AFOs on spatial, temporal and biomechanic changes in gait parameters in stroke survivors is controversial (Cruz and Dhaher 2009; Simons et al., 2009). Van Peppen et al. (2004) concluded that no benefit in gait speed was found in subjects treated with AFOs after stroke. However, Leung and Moseley (2003) reported an immediate increase in gait speed, step length and gait pattern, in the hemiplegic adult treated with AFOs.

Stroke survivors present a less efficient gait, with an increase in the risk of falls, compared to a healthy population. This may be related to an alteration in the knee flexion during the swing phase (Robertson et al., 2009; Stoquart et al., 2008; Moore et al., 1993). This alteration in the flexibility is mainly associated with the spasticity of the rectus femoris muscle, weakness in the hip flexor muscles, and overactivity of the ankle plantarflexor at terminal stance (Robertson et al., 2009; Stoquart et al., 2008; Moore et al., 1993; Sung and Bang, 2000; Piazza and Delp, 1996; Lewek et al., 2007; Anderson et al., 2004; Goldberg et al., 2006).

However, studies that have evaluated the use of AFOs in subjects with a stiff knee on the affected side, did not demonstrate significant changes in knee kinematics during swing phase (Cruz and Dhaher, 2009; Fatone et al., 2009). It must be stated that there are no studies to our knowledge that evaluate a subset of subjects with plantarflexor spasticity and moderate motor impairment.

This conflicting information raises the need of new studies to understand the potential benefits of AFOs as part of the treatment in stroke survivors. It is relevant to understand the effects of AFOs on gait kinematics in individuals with plantarflexor spasticity.

The aim of this study is to compare knee kinematics during gait with use of an AFO/footwear combination as opposed to walking barefoot in post-stroke subjects with plantarflexor spasticity.

* Corresponding author. Tel./fax: +5411 5777 3200x7082.
E-mail address: marcelogatti@hotmail.com (M.A. Gatti).

0021-9290/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jbiomech.2012.08.015

2. Methods

2.1. Participants

We prospectively included ten subjects with chronic post-stroke hemiplegia. The study was accepted by the Ethics Committee, and every subject signed an informed consent for the study. The gait analysis was performed in the Gait Lab, between July and October 2010.

The diagnosis, age, sex, affected side and onset time of hemiparesis were obtained from patient interviews and medical charts. The inclusion criteria were: subjects 18 years old and older, with values of plantarflexor spasticity measured by the Modified Ashworth scale (Bohannon and Smith, 1987) between 1+/5 and 3/5, no limitation in the range of motion (ROM) in lower limbs. According to the Scandinavian Stroke scale (SSS) score for lower extremity motor strength (Lindenstrem et al., 1991), subjects had to have strength in lower limbs of at least 4, raise leg with flexion in knee (moderate paresis) to 5, raise leg straight but with reduced strength (mild paresis) (Table 1).

Subjects were excluded if they could not walk at least 10 m without external support, their gait speed was higher than 1 m/s, inability to provide informed consent, and significant cardiorespiratory or metabolic disease—including untreated cardiac failure, diabetes, or uncontrolled hypertension.

Subjects were then cast by an orthotist for a customized, polypropylene AFO with full length foot plate, set at 90°. Polypropylene of 4.8 mm thickness was used in the fabrication of all AFOs and a dorsal ankle strap was attached to them to maintain proper foot alignment. Footwear was standardized for subjects with hemiplegia, with each participant receiving a pair of shoes, with zero centimeter difference in the sole height from heel-to-forefoot.

2.2. Data collection

Kinematic data was acquired using a motion capture system ELITE (BTS Bioengineering, Italy) with 8 infrared cameras of 100 Hz frame rate. Retro reflective markers were placed following the gait analysis technique proposed by Davis et al. (1991). The studied variables were obtained with the software SMART BTS Analyzer 1.10 (BTS Bioengineering, Italy). Subjects were instructed to walk a distance of 10 m in which central part a capture volume of 4 m of length was configured, enough to complete two gait cycles. Six trials were performed by subjects for each condition, resulting in a total of 12 steps analyzed by side, divided into two sets three without the orthosis and three with the orthosis/footwear combination. The order of each set was randomly chosen. Prior to the acquisitions, practice walking trials were completed to allow familiarization with the orthosis, until subjects felt comfortable. The motion markers were localized in the outer side of the footwear. For orthosis, the marker on the forefoot was removed in order to put the orthosis and shoe. After that, the marker was placed again in the same place outside of the shoe, controlling the position by visual inspection. The ankle flexion/extension angle was re calibrated with a standing acquisition.

2.3. Outcome measures and statistics

Two kinematic variables were assessed in the swing phase in the paretic limb: knee flexion angle at toe off, and peak knee flexion angle. Spatial and temporal variables were calculated, including gait speed, and step length of the non-paretic limb. This measurement evaluates the effect of the use of AFO in the weight bearing of the affected limb. All variables were obtained with an AFO/footwear combination and barefoot. Data was analyzed for significant statistical differences on the Wilcoxon signed rank test. Statistical significance was set at a p value of $\leq .05$.

The spasticity of soleus, gastrocnemius and rectus femoris was also recorded as secondary outcome (Table 1).

3. Results

3.1. Participants

A sample of 10 participants (7 males; 3 females) met the inclusion criteria of the study. The mean age was 45.5 years (range 20–56) and the mean time since stroke was 40 months (range 12–120). Right hemiparesia was identified in 8 participants, whereas 2 presented left hemiparesia. Subject's characteristics are shown in Table 1.

3.2. Gait speed

A higher gait speed was observed in participants with AFO, compared to no AFO measurements. The average increase of speed was 0.15 m/s, which reflected the change from 0.62 m/s (0.08 SD) with AFO, compared to 0.47 m/s (0.13 SD) in the no AFO measurements, to $p=0.007$ (Table 2).

3.3. Non-paretic step length

Significant differences were observed in the step length of the non-paretic limb, which was significantly longer when the AFO was used: AFO 42 cm (5.9 SD) versus no AFO 33.5 cm (6.6 SD) $p=0.005$ (Table 2).

3.4. Knee flexion angle

No significant differences were obtained in the knee flexion angle at toe off, in the sagital plane between no AFO and AFO conditions (Table 2).

3.5. Peak knee flexion angle

Significant differences were observed in the knee flexion angle in participants with and without AFO (Table 2). Fig. 1 shows an increase in the peak knee flexion angle during the swing phase when the AFO was used: 30.7° (14.1° SD) vs. 26.3° (11.7° SD) $p=0.005$. These results were consistent across all subjects (Fig. 2).

4. Discussion

In this study we analyzed stiff knee gait in post-stroke subjects with spasticity. We measured the effects of the AFO use in the kinematics of the paretic knee in the sagital plane, the gait speed, and the step length of the non-paretic limb.

Table 1
Subject characteristics.

Subject	Sex	Age (yrs)	Time since stroke (months)	Daily wearing AFO	Affected hemisphere	Stroke type	Modified Ashworth scale			SSS
							Soleus	Gastrocnemius	Rectus Femoris	
1	M	53	18	Partially	Left	Ischemic	1+	2	1	4
2	F	52	120	Partially	Left	Ischemic	2	3	1+	4
3	M	48	43	No	Left	Ischemic	2	2	1+	4
4	M	49	21	Partially	Left	Ischemic	2	3	1+	5
5	M	54	12	No	Left	Hemorrhagic	1+	2	0	5
6	M	56	120	Partially	Left	Hemorrhagic	2	3	1+	4
7	M	40	24	Constantly	Left	Hemorrhagic	2	3	2	4
8	M	39	14	Partially	Right	Hemorrhagic	1+	2	2	4
9	F	20	13	Partially	Left	Hemorrhagic	2	3	1+	5
10	F	44	18	Constantly	Right	Hemorrhagic	1+	2	1	4

Table 2
Functional tests with and without AFO.

	Velocity (m/s)		Non-paretic step length (cm)		Knee flexion angle[a] (deg.)		Peak knee flexion angle (deg.)	
	With AFO	Without AFO	With AFO	Without AFO	With AFO	Without AFO	With AFO	Without AFO
Mean (SD)	0,627 (0,08)	0,476 (0,14)	420,8 (59,5)	335,2 (66,28)	18,644 (10,1)	17,224 (8,73)	30,785 (14,18)	26,316 (11,76)
Minimun score	0.51	0.21	336.00	245.00	−0.96	−1.70	3.85	1.67
Maximun score	0.78	0.71	536.00	428.00	36.32	26.30	55.04	37.62
p-Value Wilcoxon	0.007*	0.005*	0.508	0.005*				

p-Value with Wilcoxon signed ranks test.

* Significance level set at $p<0.05$.

[a] Calculated at toeoff.

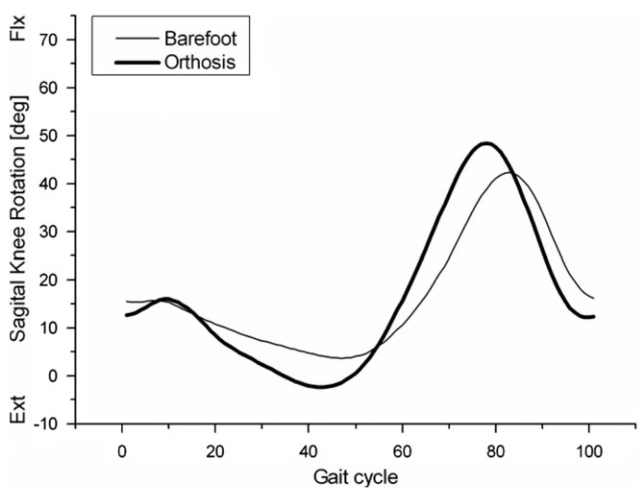

Fig. 1. Knee sagital plane angle of the paretic limb with and without AFO.

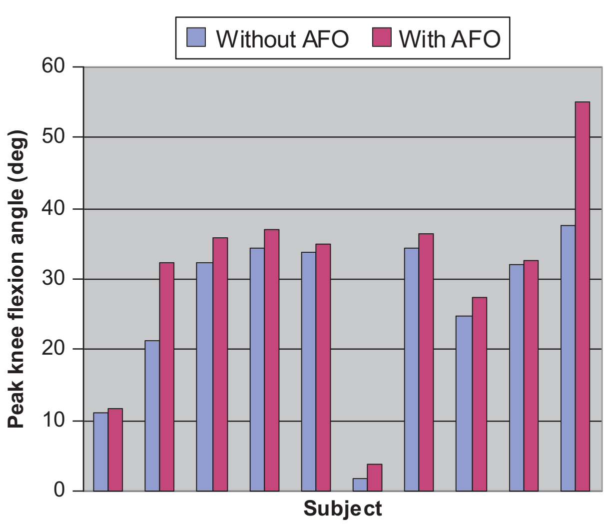

Fig. 2. Peak knee flexion with and without AFO.

A significant increase in the peak knee flexion angle was observed during the swing phase with the use of AFO. The vast majority of post-stroke subjects present an abnormal knee flexion pattern during the swing phase. Pre swing events are plausible causes of knee flexion limitation (Moore et al., 1993). According to different authors (Robertson et al., 2009; Moore et al., 1993; Piazza and Delp, 1996), an increase of the extensor moment and a decrease in the toeoff velocity are responsible for this gait pattern. This is due to an overactivity of the rectus femoris and the triceps surae in the stance phase. Two electromyography studies reported that the marked premature gastrocnemius activity of some patients was even reduced when they were wearing the AFO (Hesse et al., 1999; Perry et al., 1978), which could explain the improvement in the knee flexion angle.

The improvement in the peak knee flexion during the swing phase can be associated with a reduction in the walking energy cost. Similar results were obtained by Stoquart et al. (Leung and Moseley, 2003) when botulinum toxin was injected in the rectus femoris (5.4 ± 1.6–$4.6\pm$J kg^{-1} m^{-1} ($p=0.006$)).

Previous studies (Cruz and Dhaher, 2009; Fatone et al., 2009) have shown that the swing phase kinematic in the sagital plane at the knee joint was unaffected by removal of the AFO. This discrepancy between these studies and our results may be due to differences in the participants′ impairments.

An increase in the step length of the non-paretic leg in subjects with AFO was observed. According to previous studies (Hesse et al., 1999; Tyson and Thornton, 2001; Fatone and Hansen, 2007; Pohl and Mehrholz, 2006), the AFO may give a sense of safety with an increase in the weight bearing during the stance phase of the paretic limb. In addition, the AFO increases the ankle center of pressure excursion.

A number of studies (Leung and Moseley, 2003; Wang et al., 2005; Gök et al., 2003; Tyson and Thornton, 2001; Nolan et al., 2010; Nolan and Yarossi, 2011) reported an increase in gait speed with the use of an orthosis. We obtained similar findings with the AFO condition, which could be related with a diminished double support time (Nolan et al., 2010). In our study, the subjects present adverse conditions for the stance phase, such as hyperactivity and hypertone of the paretic lower limb, that act as a braking force during the double support. The use of AFO reduces the braking force, preserving the first ankle rocker, and creates a more efficient weight bearing capacity in the affected limb (Nolan and Yarossi, 2011).

There are limitations to this study. In clinical settings AFOs may be assessed against barefoot gait or whilst the patients wears footwear. However, since an AFO can only be used in conjunction with existing footwear (the plastic sole of the AFO offers little grip with the floor) the relative contribution of the footwear in this type of comparison is neglected (Churchill et al., 2003). In our study, the footwear was standarized to reduce the effects of the shoes, with each participant receiving a pair of extra shoes with 0 cm heel-to-forefoot sole thickness difference to avoid the effect of anteriorly tilting the tibia (Fatone and Hansen 2007).

The use of AFO is limited in the daily practice for rehabilitation of post-stroke subjects, mainly due to insufficient information regarding the muscle activity with and without the use of an orthosis, as well as the fear of creating a dependency of the orthosis by the subjects. However, the AFOs may lead to immediate kinematic and temporal improvements in gait in selected hemiplegic patients (Leung and Moseley, 2003).

5. Conclusion

In this study we describe benefits with AFO/footwear use in the kinematics of the knee, the step length of the non-paretic limb, and the gait velocity in hemiplegic subjects after mild to moderate stroke with plantarflexor spasticity. We conclude that the use of an AFO can improve the gait pattern and increase velocity in these subjects.

Conflict of interest

None.

References

Anderson, F.C., Goldberg, S.R., Pandy, M.G., Delp, S.L., 2004. Contributions of muscle forces and toe off kinematics to peak knee flexion during the swing phase of normal gait: an induced position analysis. Journal of Biomechanics 37, 731–737.

Bohannon, R.W., Smith, M.B., 1987. Interrater reliability of a modified Ashworth spastic scale of muscle spasticity. Physical Therapy 67, 206–207.

Burridge, J.H., Taylor, P.N., Hagan, S.A., Wood, D.E., Swain, I.D., 1997. The effects of common peroneal stimulation on the effort and speed of walking: a randomized controlled trial with chronic hemiplegic patients. Clinical Rehabilitation 11, 201–210.

Churchill, A.J., Halligan, P.W., Wade, D.T., 2003. Relative contribution of footwear to the efficacy of ankle–foot orthoses. Clinical Rehabilitation 17, 553–557.

Cruz, T.H., Dhaher, Y.Y., 2009. Impact of ankle foot orthosis on frontal plane behaviors post stroke. Gait & Posture 30, 312–316.

Davis, R.B., Õunpuu, S., Tyburski, D.T., Gage, J.R., 1991. A gait analysis data collection and reduction technique. Human Movement Science 10, 575–588.

Fatone, S., Hansen, A.H., 2007. Effect of ankle–foot orthosis on roll-over shape in adults with hemiplegia. Journal of Rehabilitation Research and Development 44, 11–20.

Fatone, S., Gard, S., Malas, B.S., 2009. Effect of ankle foot orthosis alignment and foot plate length on the gait of adults with post stroke hemiplegia. Archives of Physical Medicine and Rehabilitation 90, 810–818.

Gök, H., Küçükdeveci, A., Altinkaynak, H., Yavuzer, G., Ergin, S., 2003. Effects of ankle–foot orthoses on hemiparetic gait. Clinical Rehabilitation 17, 137–139.

Goldberg, S.R., Õunpuu, S., Arnold, A.S., Gage, J.R., Delp, S., 2006. Kinematic and kinetic factors that correlate with improved knee flexion following treatment for stiff knee gait. Journal of Biomechanics 39, 689–698.

Hesse, S., Werner, C., Matthias, K., Stephen, K., Berteanu, M., 1999. Non velocity related effects of a rigid double stopped ankle foot orthosis on gait and lower limb muscle activity of hemiparetic subjects with an equinovarus deformity. Stroke 30, 1855–1861.

Jorgensen, H.S., Nakayama, H., Raaschou, H.O., Olsen, T.S., 1995. Recovery of walking function in stroke patients: the Copenhagen stroke study. Archives of Physical Medicine and Rehabilitation 76, 27–32.

Leung, J., Moseley, A., 2003. Impact of ankle foot orthoses on gait on gait and leg muscle activity in adults with hemiplegia. Physiotherapy 89, 39–55.

Lewek, M.D., Hornby, T.G., Dhaher, Y.Y., Schmit, B.D., 2007. Prolonged quadriceps activity following imposed hip extension: a neurophysiological mechanism for stiff knee gait? Journal of Neurophysiology 98, 3153–3162.

Lindenstrem, E., Boysen, G., Christiansen, L.W., Hansen, B.R., Nielsen, P.W., 1991. Reliability of Scandinavian Neurological Stroke Scale. Cerebrovascular Diseases 1, 103–107.

Moore, S., Schurr, K., Wales, A., Hebert, R., 1993. Observation and analysis of hemiplegic gait: swing phase. The Australian Journal of Physiotherapy 39, 271–278.

Neckel, N.D., Blonien, N., Nichols, D., Hidler, J., 2008. Abnormal joint torque patterns exhibited by chronic stroke subjects while walking with a prescribed physiological gait pattern. Journal of Neuroengineering and Rehabilitation 5, 19.

Nolan, K.J., Yarossi, M., 2011. Preservation of the first rocker is related to increases in gait speed in individuals with hemiplegia and AFO. Clinical Biomechanics 26, 655–660.

Nolan, K.J., Savalia, K.K., Yarossi, M., Elovic, E.P., 2010. Evaluation of a dynamic ankle foot orthosis in hemiplegic gait: a case report. Neurorehabilitation 27, 343–350.

Perry, J., Walters, R.L., Perrin, T., 1978. Electromyographic analysis of equinovarus following stroke. Clinical Orthopaedics 131, 47–53.

Piazza, S.J., Delp, S.L., 1996. The influence of muscles on knee flexion during the swing phase of gait. Journal of Biomechanics 29, 723–733.

Pohl, M., Mehrholz, J., 2006. Immediate effects of an individually designed functional ankle–foot orthosis on stance and gait in hemiparetic patients. Clinical Rehabilitation 20, 324–330.

Robertson, J.V.G., Pradon, D., Bensmail, D., Fermanian, C., Bussel, B., Roche, N., 2009. Relevance of botulinum toxin injection and nerve block of rectus femoris to kinematic and functional parameters of stiff knee gait in hemiplegic adults. Gait & Posture 29, 108–112.

Simons, C.D., Van Asseldonk, E.H., Van der Kooij, H., Geurts, A.C., Buurke, J.H., 2009. Ankle–foot orthoses in stroke: effects on functional balance, weight-bearing asymmetry and the contribution of each lower limb to balance control. Clinical Biomechanics 24, 769–775.

Stoquart, G.G., Dtrembleur, C., Palumbo, S., Deltombe, T., Lejeune, T.M., 2008. Effect of botulinum toxin injection in the rectus femoris on stiff knee gait in people with stroke: a prospective observational study. Archives of Physical Medicine and Rehabilitation 89, 56–61.

Sung, D.H., Bang, H.J., 2000. Motor branch block of the rectus femoris: its effectiveness in stiff legged gait in spastic paresis. Archives of Physical Medicine and Rehabilitation 81, 910–915.

Tyson, S.F., Thornton, H.A., 2001. The effect of a hinged ankle foot orthosis on hemiplegic gait: objective measures and user's opinions. Clinical Rehabilitation 15, 53–58.

Van Peppen, R.P., Kwakkel, G., Wood-Dauphinee, S., Hendriks, H.J., Van der Wees, P.J., Dekker, J., 2004. The impact of physical therapy on functional outcomes after stroke: what's the evidence? Clinical Rehabilitation 18, 833–862.

Wang, R.Y., Yen, L., Lee, C.C., Lin, P.Y., Wang, M.F., Yang, Y.R., 2005. Effects of an ankle–foot orthosis on balance performance in patients with hemiparesis of different durations. Clinical Rehabilitation 19, 37–44.