J Rehabil Med 2004; 36: 165–168

Taylor & Francis healthsciences

ENERGY EXPENDITURE IN STROKE SUBJECTS WALKING WITH A CARBON COMPOSITE ANKLE FOOT ORTHOSIS

Anna Danielsson and Katharina Stibrant Sunnerhagen

From the Department of Clinical Neuroscience – Rehabilitation Medicine, The Sahlgrenska Academy, Göteborg University, Göteborg, Sweden

Objective: **To measure walking speed and energy cost in patients with prior stroke with and without a carbon composite ankle foot orthosis.**

Design: **Within-group comparisons of 2 walking conditions.**

Participants: **Convenience sample of 10 hemiparetic patients with a stroke at least 6 months earlier (average age 52 years) habituated to a carbon composite ankle foot orthosis.**

Methods: **Subjects walked on a treadmill at self-selected speed both with and without ankle foot orthosis for 5 minutes on each occasion. Energy expenditure was measured by breath-by-breath analysis and electrocardiography. Main outcome measures were walking speed, oxygen consumption, heart rate and energy cost per metre.**

Results: **Walking speed: without ankle foot orthosis 0.27 (SEM $\pm$ 0.03) m/s, with 0.34 ($\pm$0.06) m/s, difference 20%. Oxygen consumption: without ankle foot orthosis 8.6 ($\pm$0.4) ml/kg/min, with 8.8 ($\pm$0.5) ml/kg/min. Energy cost: without ankle foot orthosis 0.58 ($\pm$0.07) ml/kg/m, with 0.51 ($\pm$0.06) ml/kg/m, difference 12%.**

Conclusion: **Use of a carbon composite ankle foot orthosis in patients with stroke may increase speed and decrease energy cost during walking.**

Key words: cerebrovascular accident, energy expenditure, walking, ankle foot orthosis.

J Rehabil Med 2004; 36: 165–168

Correspondence address: Anna Danielsson, Department of Clinical Neuroscience – Rehabilitation Medicine, University of Göteborg, Sahlgrenska Hospital, Guldhedsgatan 19, SE-413 45, Göteborg, Sweden. E-mail: anna.danielsson@vgregion.se

Submitted July 2, 2003; Accepted November 28, 2003

INTRODUCTION

After stroke, around 80% of patients regain walking function within 11 weeks (1) although residual hemiparesis often involves an asymmetrical gait pattern (2, 3). A physiologically functional movement pattern is a significant component of efficient gait and an important goal in stroke rehabilitation. Different leg orthoses can partially correct the movement pattern and compensate for the loss of motor function. Most prevalent in stroke rehabilitation is the use of an ankle foot orthosis (AFO). In 1 study (4) 22% of the patients with stroke at a rehabilitation unit were discharged with an AFO. By supporting dorsiflexion and stopping excessive plantar flexion, the AFO prevents the paretic foot from dropping or the toes from dragging during the swing phase, facilitates heel contact and provides mediolateral stability during stance. Various designs, features and materials of AFOs exist (5). Depending on the construction of the AFO, plantar flexor activity and knee stability can be affected (6–8). Improvements with an AFO concerning kinematical, kinetic, temporal and distance gait parameters as well as muscular activation patterns, have earlier been described in patients with stroke (9–11).

After stroke, the self-selected walking speed is significantly decreased (12). Persons with a disturbed movement pattern have a higher energy cost than normal in walking (13). The rate of oxygen consumption can, due to low walking speed, be at the same level as in able-bodied persons. Calculated per distance walked, the energy cost is increased several times compared with values in able-bodied persons (12).

In children with spastic diplegia (cerebral palsy), wearing AFOs lowered the energy expenditure during walking (14, 15). Wearing AFOs reduced oxygen consumption in addition to improvements in other gait variables in a study of children with spina bifida (16). In a recently published study increased walking speed and reduced energy cost were measured in 9 hemiplegic subjects walking with an AFO (17). One study on 15 adult hemiparetic subjects wearing either a plastic or a metal short leg brace showed lower oxygen consumption with AFOs compared with unbraced walking, but showed no difference between the 2 types of AFOs (18). Walking speed was not altered by the AFO in another study of 19 hemiplegic patients (19). The impact on energy expenditure of a carbon composite AFO, which today is the most frequently used orthosis in our clinic, has not been investigated in any earlier published work.

This study aimed to compare walking with and without a carbon composite AFO with respect to self-selected gait velocity and energy expenditure in persons with hemiparesis due to stroke. Our hypothesis was that the AFO decreases energy demands.

MATERIAL AND METHODS

Subjects

Inclusion criteria were a stroke diagnosis, according to WHO criteria (20), at least 6 months prior to the study, hemiparesis, walking ability for

 ISSN 1650–1977
DOI 10.1080/16501970410025126

Table I. *Characteristics of the subjects, time since stroke and motor function*

Subject/ Sex	Age (years)	Weight (kg)	Height (cm)	Time since stroke (months)	Motor function (FMA)
1/M	48	75	178	22	19
2/M	30	87	178	15	21
3/M	49	90	182	7	19
4/M	53	63	178	10	18
5/M	60	69	165	14	22
6/M	59	80	179	19	20
7/M	47	73	183	24	23
8/M	59	73	188	17	16
9/F	53	80	170	8	22
10/F	63	66	161	96	19

FMA = Fugl-Meyer Sensorimotor Assessment, leg section, maximum 34.

at least 5 minutes without personal assistance (a walking aid was permitted) and habituated to walking with a carbon composite AFO. Exclusion criteria were severe heart disease, leg wounds, pain or other than stroke-induced gait disability or inability to follow instructions.

The study group consisted of a convenience sample of persons from the patient list at a rehabilitation department, who fulfilled the criteria and were willing to participate. The ethics committee of Göteborg University had approved the study. Eight men and 2 women (mean age 52 years, range 30–63 years) gave their informed consent (Table I). Median time since stroke onset was 16 months (7–96). Five subjects had suffered from an intracerebral infarction, 3 from an intracerebral haemorrhage and 2 from a subarachnoidal haemorrhage. Five had right-side and 5 had left-side hemiparesis. Leg motor function on the Fugl-Meyer Sensorimotor Assessment (FMA) (21), which has a maximum score of 34 points, scored median 20 (16–23). Sensory function in the paretic leg was impaired in 5 cases. All subjects had increased muscle tone in the plantarflexors, median 4 (2–4) on the 6-point Modified Ashworth Scale (22). They had been using their AFOs for a median time of 12 months (4–21). Seven of the subjects walked with a cane and 3 walked unsupported. Most of the subjects had previous experience of treadmill walking. Three were on beta-blocker medication.

Equipment

The walking tests were performed on a motorized treadmill (TR Spacetrainer, TR Equipment, Tranås, Sweden) 0.5 metres × 1.6 m with eligible speeds of 0–2 m/s and a handlebar for balance support in front of the subject. The subjects wore their own comfortable walking or training shoes. Each subject's individually fitted standard carbon composite AFO (Toe-off, Camp Scandinavia AB, Helsingborg, Sweden) was used (Fig. 1).

Data collection was carried out by a stationary, computerized system for breath-by-breath analysis and electrocardiography (Medical Graphics Cardiopulmonary Exercise Testing System, St Paul, Minneapolis, MN, USA). A face mask covering the subject's nose and mouth was used. The rate of oxygen consumption (VO_2), carbon dioxide output (VCO_2), respiratory exchange ratio (RER), ventilation and heartbeat rate (HR) in beats per minute (bpm) were continuously monitored. The reliability of the method in this patient population has been established in a previous study (23). The energy cost per walked metre was calculated as VO_2 divided by walking speed. The perceived exertion was rated on the 10-point Borg Category Ratio Scale (CR10) (24).

Procedure

Before application of the measurement equipment the subjects were accustomed to walking on the treadmill for 5 minutes. At the first session, each subject's self-selected speed for walking without (speed I) and with (speed II) the AFO, were determined on the treadmill prior to the measurement procedure. The speed was chosen during walking on the treadmill, the subject was asked to tell when he or she felt that it was comfortable.

Ten minutes of seated rest preceded each walking trial. The subject was habituated to the face mask for 7 minutes followed by 3 minutes of baseline registrations. Data were collected during 5 minutes of walking, first without and then with AFO, or reversed order. The speed selected without AFO was used in the trials without AFO and the speed selected with AFO in the trials with AFO. Measurements were repeated on another day, within 1 week, with the trials in reverse order. The mean values from the fourth and fifth minute of the 2 walking trials from both sessions were calculated and used for further analysis.

Data analysis

Wilcoxons' sign rank test processed by the StatView program was used for the testing of differences between the first and second session as well as walking speeds, VO_2, RER, HR, energy cost and perceived exertion with and without AFO, respectively. The significance level was set at $p < 0.05$. A difference of 20% was regarded clinically significant.

RESULTS

The self-selected treadmill speeds for the different individuals are shown in Fig. 2. Without AFO the mean speed (I), was 0.27 m/s (SEM ± 0.03) and with AFO the mean speed (II) was 0.34 m/s (±0.06) which was 20% higher ($p = 0.027$) and considered to be clinically significant.

Mean rate of O_2 consumption in each of the 2 trials is illustrated in Fig. 3. Without AFO (speed I) it was 8.6 (±0.4) ml/kg/min and with AFO (speed II) 8.8 (±0.5) ml/kg/min. This

Fig. 1. The carbon composite ankle foot orthosis used by the subjects.

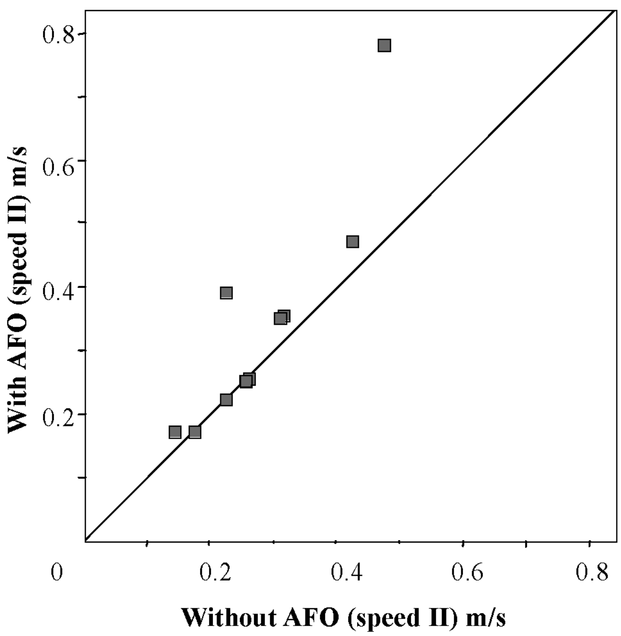

Fig. 2. Individual self-selected walking speeds with and without ankle foot orthosis (AFO).

difference was not significant. The energy cost (Fig. 4) without AFO (speed I) was 0.58 (±0.07) ml/kg/m and with AFO (speed II) 0.51 (±0.06) ml/kg/m which was significantly lower ($p = 0.024$), a difference of 12%. HR did not differ between the 2 conditions; means were 84.8 (±3.8) bpm without AFO and 84.8 (±3.9) bpm with AFO. RER without AFO was 0.82 (±0.01) and with AFO 0.83 (±0.01). The ratings of perceived exertion on CR10 had a median value of 2 in all trials; 3 subjects rated walking with AFO 1 point lower than without AFO.

DISCUSSION

The hypothesis that the carbon fibre AFO decreases the energy cost in stroke subjects during walking was supported by our study, although the sample size was small. We choose to use both statistical and clinical significance, with the latter requiring a difference of 20%. Therefore, in our study, the energy cost was reduced significantly but not clinically. Similar results concerning energy reduction in subjects with stroke were published recently (17), although the type of AFO was not described, nor the clinical significance. Lower energy cost with AFO was also reported in an older study (18) on stroke patients where a metal and a plastic orthosis were compared. In our study no comparisons to other types of AFOs were made, since we considered it important for relevant results that the subjects were well habituated to their orthosis. Besides, no measurements were performed before introducing the orthosis. It could be of interest to measure the energy cost before and after a training period with the orthosis in a prospective study.

The mean self-selected walking speed in our study group was very low, only about 20% of reference values for the age group (25). Published data on walking velocity in subjects with stroke vary in different studies (11, 12) probably due to different levels of motor function. Most of our subjects had experience of treadmill walking, although some might have chosen too low a speed due to feeling unsafe. The HR was low, as were the ratings of perceived exertion, indicating that the work in this study was quite light. For safety reasons, no measurements at maximum speed were performed.

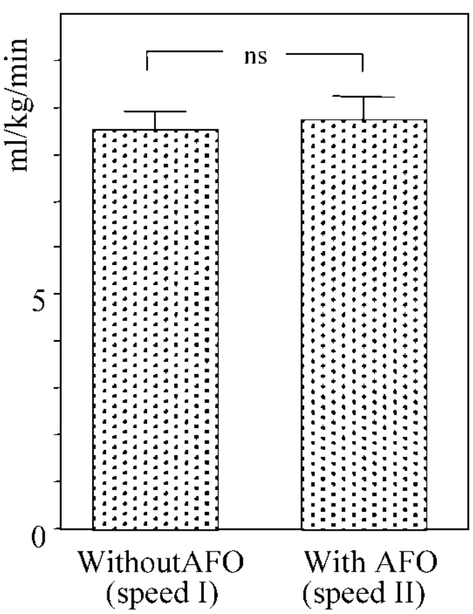

Fig. 3. Rate of oxygen consumption with and without ankle foot orthosis (AFO). Mean values with SEM. ns: not significant.

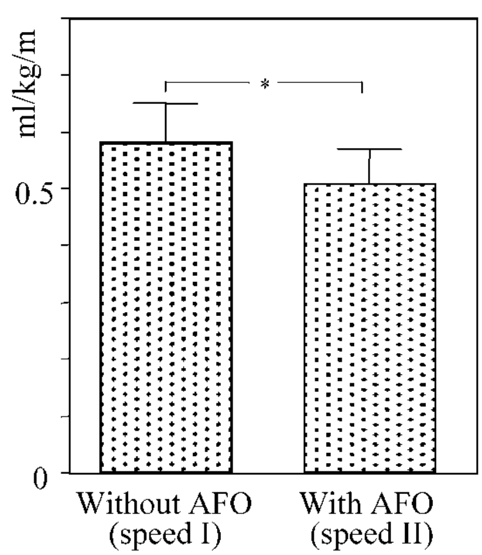

Fig. 4. Oxygen cost per metre with and without ankle foot orthosis (AFO). Mean values with SEM. $*p < 0.05$.

The low walking speed resulted in a low rate of VO_2, the mean level in our group was slightly above standard values for slow walking (26) and lower than able-bodied persons walking at their self-selected speed (12). The energy cost calculated per distance gives a measure of physiological work and gait efficiency. An elevation in energy cost can be caused by either an increased rate of VO_2 or by low walking speed. However, the energy cost per distance walked was more than 3 times higher in our study group than in a healthy group (12), which could be a limitation in daily life. A major finding in our study, which was not expected, was that the AFO made it possible for the subjects with stroke to increase their self-selected walking speed by 20%, which has to be considered clinically significant. Since these subjects walked very slowly the real increase is small, but might be important for gait efficiency. The possibility of walking at a higher speed results in lower net oxygen cost per distance, which was confirmed in our study, where the energy cost was 12% lower in walking with the AFO. This might lead to an increased walking endurance. In a study with another type of AFO (27), patients with stroke considered fast walking more important than quality of movement and they also experienced increased safety and confidence in addition to gait effectiveness. A feeling of increased safety with an AFO is often described by patients although this has not been studied systematically concerning the carbon composite AFO used in the present work. Future studies addressed to investigation of walking distance, walking capacity on uneven ground and balance function with and without AFO are needed.

In conclusion, we found that the use of a carbon composite AFO in patients with stroke may decrease the energy cost during walking and increase the walking speed. In addition to improvements of gait variables shown in other studies, a decrease in energy cost supports the use of an AFO in this patient group where the energy demands during walking are increased due to a disturbed movement pattern.

ACKNOWLEDGEMENTS

This study was financed by grants from the Swedish Association of Neurologically Disabled, Axel Linder's Foundation and the Swedish Medical Society (Hööks Foundation).

The authors acknowledge assistance from biomedical analyst Gull-Britt Henning for collection and processing of data.

REFERENCES

1. Jorgensen HS, Nakayama H, Raaschou HO, Olsen TS. Recovery of walking function in stroke patients: the Copenhagen Stroke Study. Arch Phys Med Rehabil 1995; 76: 27–32.
2. Knutsson E, Richards C. Different types of disturbed motor control in gait of hemiparetic patients. Brain 1979; 102: 405–430.
3. Woolley S. Characteristics of gait in hemiplegia. Top Stroke Rehabil 2001; 7: 1–18.
4. Teasell RW, McRae MP, Foley N, Bhardwaj A. Physical and functional correlations of ankle-foot orthosis use in the rehabilitation of stroke patients. Arch Phys Med Rehabil 2001; 82: 1047–1049.
5. Malas B, Kacen M. Orthotic management in patients with stroke. Top Stroke Rehabil 2001; 7: 38–45.
6. Lehmann JF, Esselman PC, Ko MJ, Smith JC, deLateur BJ, Dralle AJ. Plastic ankle-foot orthoses: evaluation of function. Arch Phys Med Rehabil 1983; 64: 402–407.
7. Lehmann JF. Push-off and propulsion of the body in normal and abnormal gait. Correction by ankle-foot orthoses. Clin Orthop 1993; (288): 97–108.
8. Miyazaki S, Yamamoto S, Kubota T. Effect of ankle-foot orthosis on active ankle moment in patients with hemiparesis. Med Biol Eng Comput 1997; 35: 381–385.
9. Lehmann JF, Condon SM, Price R, deLateur BJ. Gait abnormalities in hemiplegia: their correction by ankle-foot orthoses. Arch Phys Med Rehabil 1987; 68: 763–771.
10. Chen CL, Yeung KT, Wang CH, Chu HT, Yeh CY. Anterior ankle-foot orthosis effects on postural stability in hemiplegic patients. Arch Phys Med Rehabil 1999; 80: 1587–1592.
11. Hesse S, Werner C, Matthias K, Stephen K, Berteanu M. 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 1999; 30: 1855–1861.
12. Waters RL, Mulroy S. The energy expenditure of normal and pathologic gait. Gait Posture 1999; 9: 207–231.
13. Zamparo P, Francescato MP, De Luca G, Lovati L, di Prampero PE. The energy cost of level walking in patients with hemiplegia. Scand J Med Sci Sports 1995; 5: 348–352.
14. Mossberg KA, Linton KA, Friske K. Ankle-foot orthoses: effect on energy expenditure of gait in spastic diplegic children. Arch Phys Med Rehabil 1990; 71: 490–494.
15. Maltais D, Bar-Or O, Galea V, Pierrynowski M. Use of orthoses lowers the O_2 cost of walking in children with spastic cerebral palsy. Med Sci Sports Exerc 2001; 33: 320–325.
16. Duffy CM, Graham HK, Cosgrove AP. The influence of ankle-foot orthoses on gait and energy expenditure in spina bifida. J Pediatr Orthop 2000; 20: 356–361.
17. Franceschini M, Massucci M, Ferrari L, Agosti M, Paroli C. Effects of an ankle-foot orthosis on spatiotemporal parameters and energy cost of hemiparetic gait. Clin Rehabil 2003; 17: 368–372.
18. Corcoran PJ, Jebsen RH, Brengelmann GL, Simons BC. Effects of plastic and metal leg braces on speed and energy cost of hemiparetic ambulation. Arch Phys Med Rehabil 1970; 51: 69–77.
19. Burdett RG, Borello-France D, Blatchly C, Potter C. Gait comparison of subjects with hemiplegia walking unbraced, with ankle-foot orthosis, and with Air-Stirrup brace. Phys Ther 1988; 68: 1197–1203.
20. World Health Organisation. Stroke-1989. Recommendations on stroke prevention, diagnosis, and therapy. Report of the WHO Task Force on stroke and other cerebrovascular disorders. Stroke 1989; 20: 1407–1431.
21. Fugl-Meyer AR, Jaasko L, Leyman I, Olsson S, Steglind S. The post-stroke hemiplegic patient. 1. A method for evaluation of physical performance. Scand J Rehabil Med 1975; 7: 13–31.
22. Wade DT. Modified Ashworth scale for grading spasticity. In: Wade DT. Measurement in neurological rehabilitation. Oxford: Oxford University Press; 1992, p. 162.
23. Danielsson A, Sunnerhagen KS. Oxygen consumption during treadmill walking with and without body weight support in patients with hemiparesis after stroke and in healthy subjects. Arch Phys Med Rehabil 2000; 81: 953–957.
24. Borg GA. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 1982; 14: 377–381.
25. Sunnerhagen KS, Hedberg M, Henning GB, Cider A, Svantesson U. Muscle performance in an urban population sample of 40- to 79-year-old men and women. Scand J Rehabil Med 2000; 32: 159–167.
26. Waters RL, Lunsford BR, Perry J, Byrd R. Energy-speed relationship of walking: standard tables. J Orthop Res 1988; 6: 215–222.
27. Tyson SF, Thornton HA. The effect of a hinged ankle foot orthosis on hemiplegic gait: objective measures and users' opinions. Clin Rehabil 2001; 15: 53–58.