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

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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 ± 0.03) m/s, with 0.34 (±0.06) m/s, difference 20%. Oxygen consumption: without ankle foot orthosis 8.6 (±0.4) ml/kg/min, with 8.8 (±0.5) ml/kg/min. Energy cost: without ankle foot orthosis 0.58 (±0.07) ml/kg/m, with 0.51 (±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.

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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...
The rate of oxygen consumption ($\text{V}O_2$), carbon dioxide output ($\text{V}CO_2$), 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 $\text{O}_2$ divided by walking speed. The perceived exertion was rated on the 10-point Borg Category Ratio Scale (CR10) (24).

### 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 ($\text{SEM} \pm 0.03$) and with AFO the mean speed (II) was 0.34 m/s ($\pm 0.06$) which was 20% higher ($p = 0.027$) and considered to be clinically significant.

Mean rate of $\text{O}_2$ consumption in each of the 2 trials is illustrated in Fig. 3. Without AFO (speed I) it was 8.6 ($\pm 0.4$) ml/kg/min and with AFO (speed II) 8.8 ($\pm 0.5$) ml/kg/min. This 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

Wilcoxon’s 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, $\text{VO}_2$, 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.

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

<table>
<thead>
<tr>
<th>Subject/</th>
<th>Age (years)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>Time since stroke (months)</th>
<th>Motor function (FMA)</th>
</tr>
</thead>
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<tr>
<td>1/M</td>
<td>48</td>
<td>75</td>
<td>178</td>
<td>22</td>
<td>19</td>
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<tr>
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<td>30</td>
<td>87</td>
<td>178</td>
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<td>21</td>
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<tr>
<td>3/M</td>
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<td>90</td>
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<td>4/M</td>
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<td>63</td>
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<tr>
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<td>69</td>
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<td>179</td>
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<tr>
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<td>47</td>
<td>73</td>
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<td>59</td>
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<td>188</td>
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<tr>
<td>9/F</td>
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<td>80</td>
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<td>8</td>
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<tr>
<td>10/F</td>
<td>63</td>
<td>66</td>
<td>161</td>
<td>96</td>
<td>19</td>
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</tbody>
</table>

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

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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 ($\text{VO}_2$), carbon dioxide output ($\text{VCO}_2$), 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 $\text{O}_2$ divided by walking speed. The perceived exertion was rated on the 10-point Borg Category Ratio Scale (CR10) (24).
The 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. 2. Individual self-selected walking speeds with and without ankle foot orthosis (AFO).](image)

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

![Fig. 4. Oxygen cost per metre with and without ankle foot orthosis (AFO). Mean values with SEM. *$p < 0.05$.](image)
The low walking speed resulted in a low rate of \( \text{VO}_2 \), 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 \( \text{VO}_2 \) 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 effective ness. 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.

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REFERENCES