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Effects of an ankle-foot orthosis on spatiotemporal parameters and energy cost of hemiparetic gait

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Objective: To assess the effect of an ankle-foot orthosis on the gait and energy parameters of walking in chronic hemiparetic subjects.
Design: With/without group comparison.
Setting: Consecutive patients recruited from the gait analysis laboratory of our rehabilitation department.
Subjects: A group of nine chronic hemiparetic patients, with the same gait pattern alteration, were evaluated during walking at free speed with and without the use of an orthosis.
Outcome measures: Gait analysis and study of energy cost.
Results and conclusion: The orthosis significantly improved self-selected speed (15.47 versus 21.39 m/min), stride cycle (2.33 versus 2.08 s), stance (1.83 versus 1.48 s) and double support (1.55 versus 1.16 s) and reduced energy cost (0.76 versus 0.49 ml O_2/kg/m) of walking without affecting cardiorespiratory response. Moreover, a significant correlation was found between the improvement of double support and the reduction of energy cost.

Introduction

In hemiplegic patients spatiotemporal parameters are significantly different from those of healthy subjects: speed is lower, the rate and length of steps are lower, the swing phase of the affected limb is shorter, and the stance phase of the uninvolved leg is longer.[1–3] Hemiplegic gait implies fatigue and higher energy cost compared with normal walking.[4,5] Orthoses can limit kinesiological problems of the foot–ankle complex, improve the stride's spatiotemporal parameters,[6] and lower the energy cost of walking.[7] The aim of this study was to assess the effect of an ankle-foot orthosis (AFO) on the gait and energy parameters of walking in a group of chronic hemiparetic individuals.

Materials and methods

Nine consecutive hemiplegic subjects referred to the gait analysis laboratory of our rehabilitation

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department were enrolled in the study. All had completed an intensive rehabilitation programme, were able to walk independently for at least 6 min, with or without walking aids, and shared a similar kinesiological foot–ankle disorder with a swing phase characterized by hypertonic equinus. None had any symptoms indicating a cardiopulmonary disorder. Six were men and three women. Three suffered from right hemiparesis and six from left hemiparesis. The mean age was 66.5 ± 16.4 years. The duration of hemiplegia varied from two months to 244 months. (median 39). Three patients used a cane. Each individual used a foot-ankle orthosis adjusted to his or her kinesiological disorder.

The BTS telemetric system (BTS, Italy) was used for gait analysis. The patient was asked to walk 10 metres in a straight line at self-selected speed. At least three measurements were made for each patient. The measurements were: stride time, stance time, swing time, single and double support time. These parameters were also expressed as a percentage of the stride cycle time.

Metabolic parameters of gait were measured with miniature telemetry equipment (Cosmed K2) described in detail elsewhere.[8] This system simultaneously analysed oxygen concentration of the exhaled air and cardiorespiratory parameters. The system is user-friendly, accurate and reliable compared with standard breath to breath systems.[9] Each test was performed in the morning 3 hours after breakfast, 1 hour after the gait analysis.

The experimental procedure was as follows: 3 min in sitting position and 6 min of continuous walking at a comfortable self-selected speed. Patients walked along a hospital corridor of known length. The average speed was calculated dividing the distance covered by the 6 min of walking. The cardiorespiratory parameters analysed were: ventilation per minute (VE), heart rate (HR), respiratory rate (RR) and oxygen uptake. We use the term energy consumption per kilogram mass per minute to indicate the oxygen uptake divided by the patient's weight. Dividing this value by the speed, the energy cost per kilogram per unit of distance covered is obtained.

The comparison between parameters was performed using nonparametric statistics (Wilcoxon test) as well as the tests of correlation between variables (Pearson's rho correlation index).

Results

There was a significant reduction in the duration of the stride cycle in the gait with an orthosis (respectively 2.33 versus 2.08 s, $p < 0.016$ and 2.34 versus 2.08 s, $p < 0.016$), the duration of the stance phase (respectively: 1.83 versus 1.48 s, $p < 0.016$ and 2.06 versus 1.76 s, $p < 0.011$) and the duration of double support (respectively: 1.55 versus 1.16 s, $p < 0.011$ and 1.55 versus 1.17 s, $p < 0.011$ respectively). The orthosis led to a significant increase in the self-selected speed ($p < 0.001$) and a significant reduction in energy cost of walking ($p < 0.01$), but did not significantly affect energy consumption and cardiorespiratory parameters (Table 1).

Statistical correlation shows an inverse relation between energy cost and walking speed without ($r = -0.80$, $p = 0.008$) and with ($r = -0.82$, $p = 0.006$) the orthosis. No significant correlation exists between energy cost and double support in walking without an orthosis for the healthy and

Table 1 Effects of orthosis on energy cost and functionality of walking

	Without orthosis		With orthosis		
	Average	SD	Average	SD	*p*-value
Energy cost (ml O_2/kg/m)	0.76	0.41	0.49	0.20	<0.01
Energy consumption (ml O_2/kg/min)	9.87	1.92	9.42	1.62	NS
Speed (m/min)	15.47	6.95	21.39	7.30	<0.001
HR (beats/min)	89.14	13.36	87.88	13.43	NS
RR (breaths/min)	22.25	3.27	23.31	4.25	NS

SD, standard deviation; HR, heart rate; RR, respiratory rate

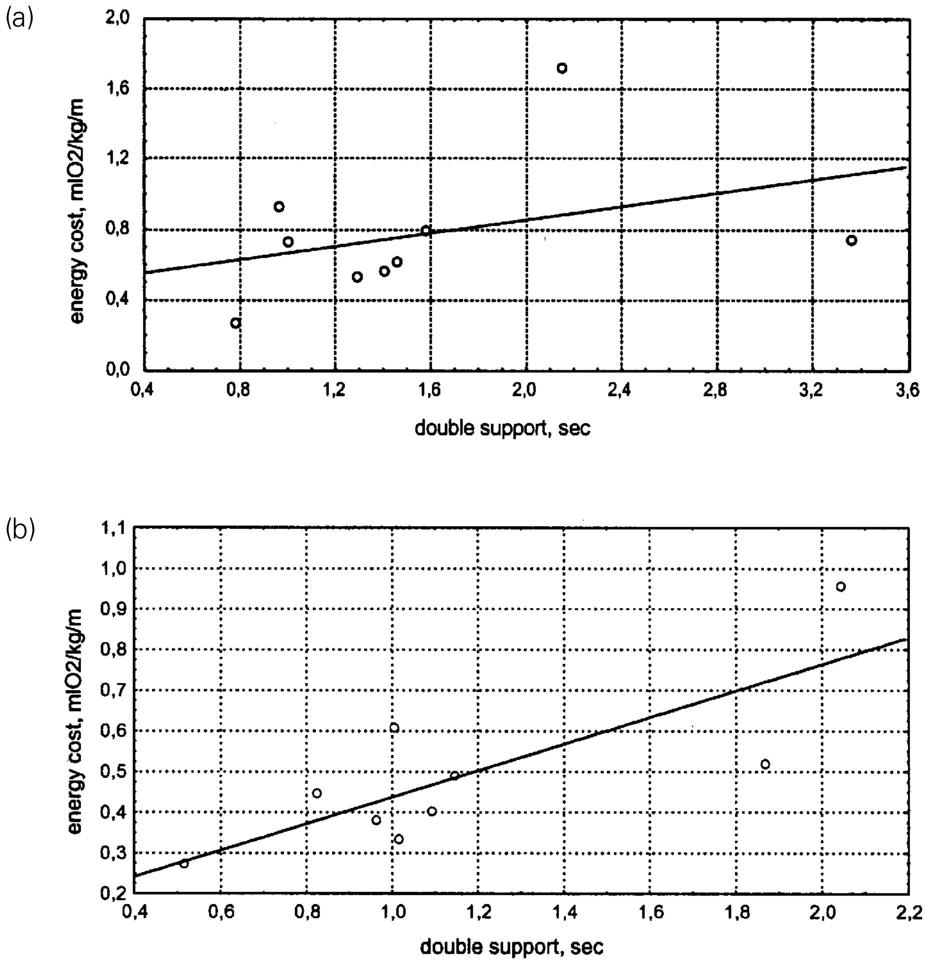

Figure 1 Correlation between energy cost and double support (a) without orthosis (Pearson's correlation $r = 0.36$, $p =$ NS) and (b) with orthosis (Pearson's correlation $r = 0.78$, $p < 0.05$).

the weak side ($r = 0.36$, in both cases). Such a correlation is instead present in the walking with the orthosis ($r = 0.78$, $p < 0.05$ for the healthy and the plegic side) (Figure 1a,b).

Discussion

An AFO or other intervention may improve both energetic[7,10–13] and spatiotemporal[6,14–16] parameters of the stride. Besides confirming this, our study also showed improved energy efficiency.

The speed/energy cost ratio of gait, intended as

Clinical messages

- An ankle-foot orthosis in chronic hemiplegic subjects may correct the pattern of gait and significantly improve the functionality of walking and spatiotemporal parameters.
- This may be because an AFO reduces the energy cost of gait, without affecting energy consumption or cardiorespiratory response.

oxygen consumption per kilogram body weight per metre walked, is curvilinear, both in healthy and hemiplegic individuals.[17] The energy consumption of gait, as oxygen consumption per kilogram body weight per minute, increases proportionally to the increase of the workload (i.e., of speed).[18]

The reduction in energy cost of gait with the orthosis detected by our study may stem from the biomechanical effectiveness of the AFO or from the speed increase itself. Though it is clear that only a comparison of gait with and without an orthosis at the same speed would provide a definitive answer, our data may indirectly suggest that the first hypothesis is not to be ruled out because, even though the speed is higher when patients use AFO, energy consumption and cardiorespiratory parameters do not increase implying that the body's workload does not increase in spite of the higher speed. This is probably due to a facilitating biomechanical effect of the orthosis.

The double support's duration seems to be the parameter that best represents the benefit provided by the orthosis in terms of energy. The double support in fact correlates significantly with energy cost only in gait with AFO. Free speed, as expected, will instead correlate with energy cost both with and without an orthosis. Improvement in the stride's energy and time parameters with the use of an orthosis could also be linked to an improvement in the stride pattern.[19,20] An orthosis can improve an abnormal base of support and limb instability during the stance phase and improve the limb clearance and limb advancement during the swing phase.[21] The orthosis clearly leads to a substantial change in the locomotor pattern which provides greater stability to the plegic side in the stance phase.[6,15,16]

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