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Technical note

A medial linkage orthosis to assist ambulation after spinal cord injury

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Abstract

A "proof of concept" prototype of a new device to link bilateral knee-ankle-foot orthoses, the Mooring Medial Linkage Orthosis (Moorong MLO), is presented. The device consists of an arcuate sliding link centred on the hip joints with rolling element bearings to minimise friction. A single repeated-measures case study is reported in which a woman with an incomplete C6 tetraplegia ambulated over different surfaces and gradients using both the Moorong MLO and the Walkabout orthosis. Results demonstrated a slight increase in gait velocity in the Moorong MLO (between 0.36-1.02m/min faster) and a consistently lower oxygen cost across all conditions (between 18-61% reduction) compared to the Walkabout orthosis. The reduction was most noticeable on sloping surfaces. These preliminary results suggest an improved efficiency of ambulation in this new device.

Introduction

Ambulation for paraplegic individuals wearing knee-ankle-foot orthoses (KAFOs) has been recognised as impractical for all, except those with very low level or incomplete spinal cord lesions, due to the high energy costs and cardiorespiratory stresses involved (Gordon and Vanderwalde, 1956; Clinkingbeard *et al.*, 1964; Huang *et al.*, 1979; Merkel *et al.*, 1984).

Better stabilisation of the trunk and hips provided by incorporating a thoraco-lumbar support and lateral hip joints into different types of hip-knee-ankle-foot orthoses (HKAFO) has resulted in an improvement in the mechanical efficiency of paraplegic gait, as well as a reduction in the energy cost of ambulation (Nene and Patrick, 1989; Hirokawa *et al.*, 1990; Winchester *et al.*, 1993; Bernardi *et al.*, 1995). Commonly prescribed HKAFOs have included the Hip Guidance Orthosis (HGO) (Rose, 1979), the Louisiana State University-Reciprocating Gait Orthosis (LSU-RGO) (Douglas *et al.*, 1983), the Advanced Reciprocating Gait Orthosis (ARGO) (Hugh Steeper Ltd., London, UK) (Lissens *et al.*, 1992), the modified Douglas RGO (Isakov *et al.*, 1992) and the Isocentric-RGO (I-RGO) (Motloch, 1992).

More recently, the Walkabout orthosis (Kirtley, 1992) which employs a medially-mounted hinge joint to link two KAFOs, has provided an alternative device for paraplegic ambulation. It was originally hoped that the Walkabout modular medial-linkage orthosis would be more compatible with wheelchair use and offer practical and cosmetic advantages over existing orthotic devices, which were seen as cumbersome, difficult to apply and incompatible with routine daily tasks such as transfers and toileting (Kirtley, 1992). Several recent studies, however, have questioned the functional advantages of the Walkabout orthosis (Harvey *et al.*, 1997; Middleton *et al.*, 1997).

Medial-linkage of KAFOs has been shown to signficantly reduce the energy cost of ambulation compared to KAFOs alone (Cliquet *et al.*, 1989; Saitoh *et al.*, 1996). However, Harvey *et al.* (1988) found that with the Walkabout orthosis subjects ambulated

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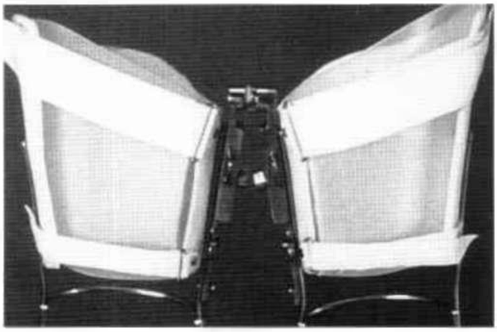


Fig. 1. The Walkabout device shown medially linking a pair of KAFOs.

significantly slower and with a 2½ fold increase in the energy cost of a gait compared with the I-RGO.

Description of the Moorong Medial Linkage Orthosis

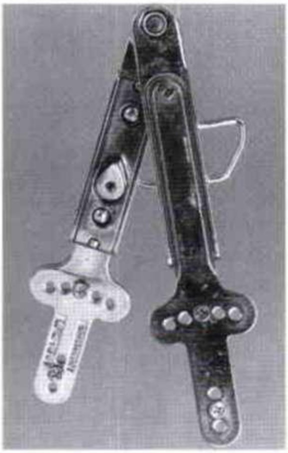
The Moorong Medial Linkage Orthosis (Moorong MLO) is an evolution of medial linkage orthotic devices designed to improve the function of separate KAFOs or HKAFOs. This concept was proposed by Cliquet *et al.* (1989) and realised as a device by Kirtley and McKay (1992).

Kirtley and McKay's Walkabout device (Figs. 1 and 2a) links the medial uprights of a pair of KAFOs to control adduction and abduction of the lower limbs during ambulation. Specifically, the linkage prevents abduction of the swing-through leg while the body is tilted to create ground clearance for the swinging leg and, at the same time, prevents abduction of the stance leg under body weight. The Walkabout orthosis employs a simple hinge mechanism which, being placed below the perineum, is not aligned with the centres of the hip joints, the discrepancy being 100 mm to 150 mm. Kirtley (1992) points out that due to the lengths of the limbs and the limited angle of hip movement required for effective ambulation, only a small amount of soft tissue distortion is needed to accommodate the discrepancy between the hip joints and the hinge axis of the Walkabout orthosis. It is the authors' contention that this discrepancy does in fact create a significant impediment to ambulation by increasing resistance to movement of the legs.

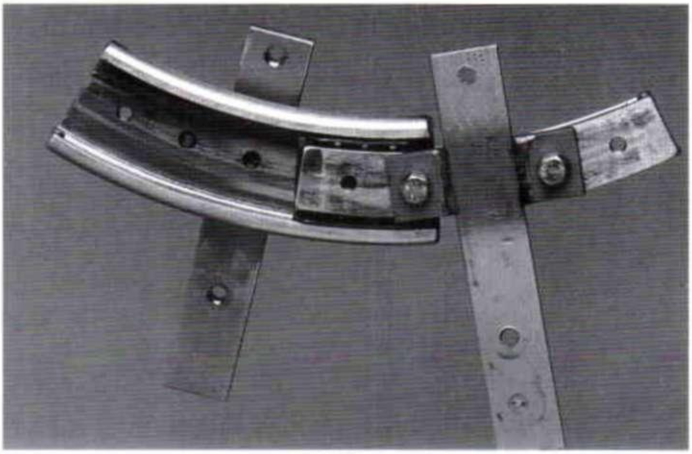
The main objective in designing an improved orthotic device was to provide controlled guidance of the legs for ambulation while minimising unnecessary constraints. To this end, it was decided to extend the MLO concept by minimising the distance between the hip joint centres and the hinge axis of the MLO. This was achieved by fabricating an arcuate sliding link centred on the hip joints and using rolling element bearings to minimise friction (Fig. 2b). The Moorong MLO is a "proof of concept" prototype and this report comprises a single repeated-measures case study.

Case history

A 25 year old woman with an incomplete C6



(a)



(b)

Fig. 2. (a) The single hinge mechanism of the Walkabout device not allowing alignment with the hip joints. (b) The Moorong MLO with an arcuate sliding linkage centred on the hip joints.

tetraplegia (ASIA Impairment Classification C with spared proprioception) was investigated whilst ambulating over several different gradients and terrain surfaces in the Walkabout orthosis and the Moorong MLO.

Her spinal cord injury resulted from a horse riding accident in July, 1991. Following vertebrectomy, bone graft and internal fixation of a burst fracture of the C5 vertebra, she underwent a multidisciplinary inpatient rehabilitation programme. This included muscle strengthening and stretching exercises, hydrotherapy, electrical stimulation of lower limb and trunk muscles and standing supported in backslab splints, in preparation for gait training. She was fitted with KAFOs and commenced gait training with the aid of a rollator frame during admission which she later continued as an outpatient using Canadian crutches.

Due to severe neurological impairment of her hip musculature (Table 1), she ambulated very slowly in unlinked KAFOs experiencing considerable difficulty swinging her legs through. Her gait improved markedly when the Walkabout device was attached to medially link the KAFOs. Several months after discharge she also tried a RGO, which she found very restricting and difficult to use. Ultimately, she preferred the Walkabout orthosis for cosmetic and functional reasons.

Over the last 5 years, the subject has regularly utilised the Walkabout orthosis, initially 3 times per week but more recently, due to the demands of full-time employment, once or twice per week. She requires some assistance to apply the orthosis and transfer from sitting to standing and *vice versa*. She describes the benefits gained from using the Walkabout as improved exercise tolerance, enhanced psychological well-being from assuming an upright posture and a reduction in time to evacuate her bowels if she had walked the previous day. When using the Walkabout orthosis, she normally walked outside the house over different surfaces and gradients.

As an experienced Walkabout user, the authors believed her to be an ideal subject to assess the new Moorong MLO.

Table 1. Muscle chart for subject.

Muscle group	Strength	
	Left	Right
Elbow flexors	5	4+
Wrist extensors	5-	4
Elbow extensors	2	2
Finger flexors	1	1
Finger abductors	1	1
Trunk flexors	2	2
Trunk extensors	4	4-
Hip flexors	0	0
Hip adductors	2-	2-
Hip abductors	0	0
Hip extensors	2	2
Knee extensors	4	4
Knee flexors	0	0
Ankle dorsiflexors	1	0
Ankle plantarflexors	3	3

NB. Strength graded out of a maximum of 5 according to MRC guidelines.

Method

Assessment of the energy expenditure and cardiorespiratory demands of using the Moorong MLO in comparison to the Walkabout orthosis was undertaken during a continuous outdoor walk over several different gradients and terrain surfaces. The overall distance of the course was 148m comprising; (i) a 33m level concrete footpath, (ii) a 22m gentle grass-covered slope (2.5° decline, 2.3° cross-slope down to the right), (iii) a 43m downhill concrete footpath (3.7° decline), and (iv) a 50m uphill ashpalt roadway (slope variable, average 4.2° incline). The subject was allowed two walking sessions to familiarise herself in the new device prior to testing. She was first tested with the Moorong MLO and then with the Walkabout orthosis. Testing was performed at the same time on two separate days. The ambient environmental conditions were unremarkable (20-26°C, 25-50% relative humidity).

Before commencement of testing, the subject sat quietly for 3 minutes to establish baseline heart rate (HR) and oxygen uptake (VO_2) measurements at rest. Energy expenditure data were collected via open circuit spirometry (KB1-C Portable Metabolic System; AeroSport Ltd, Minneapolis, USA) and heart rate was derived from chest leads to the portable system. The KB1-C portable system is carried on the front and back of the subject's chest and weighs less than 1 kilogram. The KB1-C portable system was previously validated against an open

Table 2. Data summary of heart rate and oxygen uptake at rest and during and testing over different surfaces and gradients in each device.

Condition	Orthosis	Heart rate (b/min)	O_2 uptake (l/min)
Rest	Walkabout	78 ± 2	0.22 ± 0.01
	Moorong MLO	73 ± 1	0.17 ± 0.01
Level footpath	Walkabout	155 ± 2	0.55 ± 0.02
	Moorong MLO	164 ± 1	0.49 ± 0.02
Grass (slope -2.5°/ camber 2.3°)	Walkabout	136 ± 2	0.51 ± 0.02
	Moorong MLO	160 ± 2	0.42 ± 0.02
Footpath (slope -3.7°)	Walkabout	142 ± 2	0.52 ± 0.01
	Moorong MLO	155 ± 2	0.29 ± 0.01
Road (slope +4.2°)	Walkabout	157 ± 2	0.73 ± 0.01
	Moorong MLO	154 ± 3	0.48 ± 0.03

NB: Data are means ± SEM derived over 6 20-second measurements in steady state.

circuit laboratory system (Sensormedics 2900, Loma Linda, USA) and shown to be accurate (>96%) and reliable.

Data collected every 20 seconds during the testing period included heart rate (b/min), VO_2(1/min), VCO_2 (1/min) and expired ventilation (1/min). An average velocity of walking (m/min) was calculated from the time taken to walk the measured distance of each section. Physical Cost Index (PCI) (MacGregor, 1981) and oxygen cost of gait (O_2 cost) were calculated by averaging the last 2 minutes of physiological data (six 20s data points) in each section of the course as follows:

$$\text{PCI (b/m)} = \frac{\text{HRsteadystate} - \text{HRrest}}{\text{Average Velocity}}$$

$$O_2\,\text{cost (ml/min/kg)} = \frac{VO_2\text{steadystate} - VO_2\text{rest}}{\text{Average Velocity}}$$

Inspection of the raw data confirmed that a physiological steady state had been reached in the last 2 minutes of each section of the course, when measured and derived variables were collected.

Results

Heart rate and energy expenditure measurements, at rest in sitting and during gait for each test condition, are displayed for both orthotic devices in Table 2.

Walking at a self-selected pace in each device, the time to complete the total course in the Moorong MLO (22:37 minutes) was less than with the Walkabout orthosis (24:20 minutes). In terms of velocity, ambulation with the Moorong MLO was 0.36 to 1.02m/min faster than with the Walkabout orthosis. Gait velocities for individual sections of the course in each device are shown in Figure 3a. With respect to daily function, however, the velocity of ambulation was slow in both orthoses.

The PCIs for all conditions showed little difference between orthoses, except during ambulation over the grassy cross-slope where the heart rate in the Moorong MLO was markedly higher (Fig. 3b). However, on all surfaces the calculated oxygen cost of gait was less when ambulating in the Moorong MLO by between 18-61% (mean 39%) compared with the Walkabout orthosis (Fig. 3c). This reduction was most noticeable on sloping surfaces.

Discussion

These results show lower energy expenditure with the Moorong MLO, suggesting improved overall efficiency of ambulation with this device. Visual observation of subjects ambulating in the Moorong MLO and the Walkabout orthosis suggested greater freedom and range of leg movement associated with using the Moorong MLO. It is not clear if this is due to the better alignment of orthotic and anatomical joints in the Moorong MLO or its low friction characteristics.

The subject generally ambulated somewhat faster using the Moorong MLO and with a consistently lower oxygen cost across all conditions compared to the Walkabout orthosis. It appears that, in this single case study, the

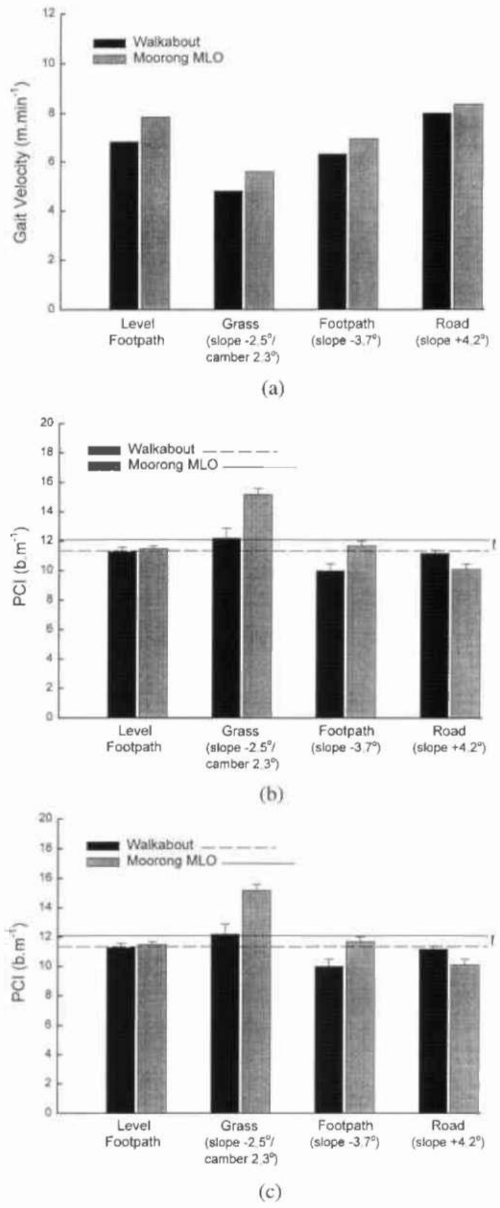


Fig. 3. Results of (a) gait velocity, (b) PCI, and (c) oxygen cost during ambulation over different surfaces and gradients in the Moorong MLO compared to the Walkabout orthosis.

speed of ambulation was not limited by energy expenditure, since it was observed that ambulation in both orthoses was fastest when negotiating a moderate incline. The subject identified a feeling of insecurity, associated with her upper limb weakness, as the major limiting factor in her speed of ambulation. This may also help to explain why she was best to able to control ambulation when ascending a slope.

An interesting and unexpected finding was that the Moorong MLO induced a marked increase in heart rate and greater PCI (compared with the Walkabout) when walking on the grassy cross-slope; the marginal increase in speed (with the Moorong MLO) seems an unlikely explanation for this finding. It seems more likely that, compared with other walking surfaces, greater upper limb forces were required on the uneven and cross-sloping grassy surface to stabilise the additional freedom of the hips provided by the Moorong MLO. The authors speculate that the additional upper limb effort required to stabilise the trunk with higher isometric muscle loading contributed to a higher heart rate without significantly elevating systemic VO_2.

In setting up the Walkabout, a fairly wide separation of the feet (250 mm between the heels in this subject) was necessary to ensure clearance between the release knobs on the medial face of the KAFO clamps. The set-up of the Moorong MLO (which can be fitted with a smaller lateral separation of the feet than the Walkabout) was intended to duplicate that of the Walkabout orthosis, but the actual separation between the heels was a little less, about 225 mm. Medial linkage ambulatory orthoses need to be set up with a wider separation of the feet than normal in order to reduce the degree of lateral tilting necessary for ground clearance on swing through. While it seems likely that a reduction in the energy cost of ambulation could be achieved by reducing the lateral separation between the feet, this strategy is obviously limited by the need to maintain adequate ground clearance. As a strategy for reducing the energy cost of ambulation, it is likely that greater benefit would be obtained by shortening of the "leg length" in swing phase, by knee flexion or other means. This seems to have been clearly established by Yano *et al.* (1997) who used a novel powered mechanism under the foot to alter leg length and allow clearance for swing through without needing a wide gait and body tilt.

Further orthotic development planned for the Moorong MLO includes provision of some freedom for the legs to rotate about the long axis of the limb. The idea that this extra freedom may be helpful was suggested by examining wear patterns on the prototypes of the Moorong MLO and by the authors and others trialing the Moorong MLO and the Walkabout orthosis in order to experience the sensations of freedom and constraint imposed by the orthoses. An underlying (though untested) assumption in providing this extra freedom is that it will reduce resistance to movement of the hip; in addition, loads on the orthosis may be reduced.

Conclusion

This case report comparing a new prototypic medial linkage device (an arcuate sliding joint) to the Walkabout hinge device has presented some encouraging preliminary results suggesting improved efficiency of orthosis-assisted ambulation in this new device. Further investigation is currently underway to assess the biomechanical efficiency and energy expenditure of ambulation using the Moorong MLO in comparison with the I-RGO for individuals with complete paraplegia.

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