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REVIEW

The efficiency of orthotic interventions on energy consumption in paraplegic patients: a literature review

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Study design: This is a systematic literature review.
Objectives: Different types of orthoses have been developed to enable and facilitate ambulation in individuals with paraplegia. However, their effect on energy consumption while ambulating is not clear. The objective of this review was to compare the energy expenditure required to walk with these devices.
Methods: Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method, and based on selected keywords and their composition according to the Population Intervention Comparison Outcome (PICO) method, a search was performed in Science Direct, Google Scholar, Scopus, Web of Knowledge and PubMed databases. The searches were restricted to papers published in the English language and were conducted during February 2014; the last access to the database was on 25 February 2014. A total of 24 articles were chosen for final evaluation.
Results: Hybrid orthoses reduce energy consumption compared with mechanical orthoses when used for walking by paraplegic patients. The isocentric reciprocating gait orthosis has been shown to be more effective than other reciprocating orthoses in reducing energy consumption. Energy consumption when walking with powered orthoses (PO) and hybrid orthoses was also reduced compared with when walking with conventional orthoses.
Conclusions: The hybrid orthoses and PO could be effective alternatives in rehabilitation for spinal cord injury patients to help improve the energy consumption.
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INTRODUCTION

The ability to ambulate produces positive physiological and psychological effects for people with paraplegia.[1] Reduced incidence of osteoporosis, fractures, bedsores, spasticity, contractures and infection, as well as increased blood circulation, bowel and bladder performance, self-esteem, independence and more effective communication with people in society, are all examples of therapeutic reasons why paraplegic subjects should be able to walk.[2,3]

Different types of mechanical orthoses have been developed to help individuals with paraplegia to ambulate,[4] such as hip–knee–ankle–foot orthoses (HKAFOs), reciprocating gait orthoses (RGOs), the hip guidance orthosis (HGO) and also medial linkage orthoses.[1] However, the use of mechanical orthoses is reducing because of high rejection rates owing to the high loads applied to upper limb joints and the high rate of energy expenditure experienced.[5]

PO (which comprise a combination of mechanical orthoses and external actuators) and hybrid orthoses (a combination of mechanical orthoses and functional electrical stimulation) have been developed to improve walking and to reduce the effort required to ambulate by paraplegic subjects.[5] The use of external actuators and electrical stimulation of paralysed muscles has the potential to reduce energy consumption in paraplegic individuals during ambulation.[6]

Arazpour *et al.*,[1] when comparing the influence of PGOs, HGOs and mechanical orthoses (for example, RGOs and HGOs) in walking parameters and the energy efficiency of walking by spinal cord injury (SCI) patients, concluded that there was not enough evidence to show any superiority of currently developed PO over mechanical orthoses in improving walking parameters in SCI patients. Nene *et al.*[7] stated that mechanical orthoses and hybrid orthoses were only used by paraplegic subjects for exercise purposes and only worn for a few hours per week because of the high rate of energy consumption experienced when walking with them. Waters and Mulroy[8] in a review of energy expenditure of normal and pathologic gait reported that walking speed and energy consumption improved between 0 and 10% when using hybrid orthoses compared with mechanical orthoses in SCI patients. The supportive structure of an orthoses around the lower extremity can cause a reduction of upper limb joint loads and a reduction in energy consumption.[8] Karimi in a comparison between mechanical orthoses and hybrid orthoses reported that mechanical orthoses were more effective in providing stability and reducing energy consumption during walking in paraplegic patients.[9]

The overall analysis of orthotic devices (for example, mechanical orthoses, hybrid orthoses and PO) on energy consumption is therefore unclear. The objectives of this review were to compare the energy

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Table 1 Comparative effects of hybrid orthosis on energy expenditure experienced by SCI patients

Author/year	*No. of subjects and injury level*	*Quality of assessment physiotherapy evidence database scale*	*Orthoses tested or compared*	*Energy expenditure*							
				O_2 cost ($ml\,kg^{-1}\,m^{-1}$)	*O_2 consumption ($ml\,kg^{-1}\,min^{-1}$)*	*PCI (beat per m)*	*HR (beats per min)*	*O_2 uptake ($l\,min^{-1}$)*	*VO_2 ($l\,min^{-1}$)*	*VO_2 consumption $Ml\,kg^{-1}\,min^{-1}$*	*Walking speed ($m\,s^{-1}$)*
Nene *et al.*[7]	Three subjects with complete paraplegia with lesion level ranging from T5 toT7	2	Parawalker+FES	10.95	—	—	—	—	—		0.231
			Parawalker	11.78	—	—	—	—	—		0.216
Stallared *et al.*	Five paraplegic patients with lesion level ranging from T8 to L1	2	Parawalker	—	—	1.4	—	—	—		—
			Parawalker+FES	—	—	0.98	—	—	—		—
Beillot *et al.*[14]	14 patients with spastic complete paraplegia injury levels ranged from T2 to T12	3	RGOII +FES ($n=4$)				121 ± 6		0.76 ± 0.13		0. 1
							165 ± 14		1.33 ± 0.13		0.23–0.50
			RGOII ($n=4$)				147 ± 20		0.73 ± 0.29		0.1
							175 ± 12		1.11 ± 0.21		0.23–0.50
Sykes[15]	Five spinal cord lesions ranging from C2 to T6 (incomplete)	3	RGO	13.519	2.331	—	—	—	—		0.2252
			RGO+FES	13.699	2.58	—	—	—	—		0.25
Merati *et al.*[18]	24 paraplegic patients with lesion level C7 ± T11	4	(PW), $n=4$	—	—	—	150 ± 13	—	—	13.4 ± 3.0	1.72 ± 0.6
			(RGO), $n=6$	—	—	—	131 ± 21	—	—	13.8 ± 3.5	1.5 ± 0.36
			RGO+FNS ($n=4$)	—	—	—	155 ± 23	—	—	17.2 ± 4.8	1.44 ± 0.44
Spadone *et al.*[16]	One parapelegic patient with lesion level T5 ± T6	3	Wheelchair	—	—	—	133	—	0.90		3.35 Self-chosen
			ARGO	—	—	—	142	—	0.79		0.52
			ARGO+ FES	—	—	—	108	—	0.94		0.53
			Para step	—	—	—	124	—	1.33		0.20
Goldfarb *et al.*[17]	Four subjects with paraplegia	3	Control brake orthosis	—	—	—	—	—	—		0.060
			Controlled-brake orthosis+four channel FES- aided	—	—	—	—	—	—		0.054

Abbreviations: ARGO, advanced reciprocating gait orthoses; FES, functional electrical stimulation; FNS, functional neuromuscular stimulation; HR, heart rate; PCI, physiological cost index; PW, Para walker; RGO, reciprocating gait orthose; SCI, spinal cord injury T, thoracic; VO_2, oxygen uptake.

Table 2 Comparative effects of powered orthoses on energy expenditure experienced by SCI patients

Author(s)	Number of subjects and injury level	Quality of assessment physiotherapy evidence database scale	Orthoses tested or compared	Energy expenditure				
				O_2 consumption ($ml\,kg^{-1}\,min^{-1}$)	PCI (beats per min)	HR (beats per min)	VO_2 ($ml\,kg^{-1}\,min^{-1}$)	Walking speed ($m\,min^{-1}$)
Kawashima *et al.*[22]	SCI patients withT8 to T12 level of spinal injury ($n=4$)	2	The weight-bearing control (WBC) orthosis	0.25	—	147.3±10.94	16.08±1.93	0.31
Arazpour *et al.*[1]	Five subjects (two female, three male) with T6–T12 level of spinal injury	2	Powered gait orthosis	—	0.92±0.25	—	—	0.35
			IRGO	—	1.93±0.40	—	—	0.25
			HKAFO	—	1.97±0.17	—	—	0.23
Tanabe *et al.*[21]	Paraplegic patients with T6-T12 level of spinal cord injury ($n=4$)	2	The wearable power-assist locomotor	—	1.3	116	—	0.203
			Prime walk	—	3.4	151	-	0.07

Abbreviations: HR, heart rate; HKAFOs, hip–knee–ankle–foot orthoses; IRGO, isocentric reciprocating gait orthosis; PCI, physiological cost index; SCI, spinal cord injury; T, thoracic; VO_2, oxygen uptake.

expenditure of people with paraplegia when using these types of orthoses.

MATERIALS AND METHODS

Search strategy

A search was performed using the Population Intervention Comparison Outcome (PICO) method, based on selected keywords and their composition. By using the words 'OR', 'AND' and 'NOT' between the considered keywords, studies were identified electronically in the Science Direct, Google Scholar, Scopus, Web of Knowledge and PubMed databases. Studies were selected by hand-searching the reference lists of the electronically identified studies. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method was used to report the results. Assessment of the quality of all articles was performed on the basis of the Physiotherapy Evidence Database (PEDro) scale. The searches were restricted to papers published in the English language and were conducted during February 2014; the last access to the database was on 25 February 2014. All relevant full-text articles were retrieved for detailed assessment by three reviewers (MA, MAB and MM), and those papers that met the exclusion criteria were rejected. Studies that analysed the chosen outcome measures were included in the final review. According to the chosen inclusion and exclusion criteria, 24 articles were subsequently selected for final evaluation.

Inclusion and exclusion criteria

Studies that were considered for inclusion were randomised clinical trial, case–control trials, cohort studies, case series studies and single-case studies. Language or year of publication was not considered as restrictions. Studies reporting the effect of all types of mechanical orthoses HKAFOs, KAFOs, the Louisiana State University RGO, the advanced RGO (ARGO), the isocentric RGO (IRGO), the parawalker, the HGO, the primewalk orthosis, the walkabout orthosis (WO), the Moorong and the Araz medial linkage orthosis (medial linkage orthoses) designs, as well as hybrid orthoses and powered orthoses (POs), on paraplegic ambulation were selected for further analysis. The primary outcome measures selected were energy consumption and energy expenditure. Studies with alternative outcome measures, studies using 'body weight support systems with robot-assisted gait' and papers related to the effect of 'powered ankle foot orthoses' on alternative outcome keywords and measures were excluded from the study. The abstracts and full text of all of the studies found in all databases were compared with the inclusion criteria by two independent reviewers.

RESULTS

The studies identified for those with SCI are either individual case reports or individual subject data from a multiple case series and are therefore classified as poor-quality papers (Tables 1–3). PEDro scores ranged from 1 to 4 across studies, with a median value of 2.

The effect of hybrid orthoses (mechanical orthoses and FES) on energy consumption in paraplegic patients

Table 1 demonstrates studies that evaluated the use of Hybrid orthoses (mechanical orthoses and effect of hybrid orthoses (FES)) on energy consumption in paraplegic patients.

Four studies with a low level of evidence according to PEDro score (2/10) included here in this group that evaluated the effect of hybrid orthoses on energy consumption in paraplegic subjects. Nene and Patrick[10] estimated the crutch-type walking aid impulse and energy expenditure of reciprocal locomotion when walking with the Parawalker orthosis augmented by surface electrical stimulation of the stance-side gluteal muscles in three subjects. They found that the mean energy cost without FES was $11.78\,J\,kg^{-1}\,m^{-1}$ and with FES augmentation it was $10.95\,J\,kg^{-1}\,m^{-1}$ (a 7.1% reduction), as well as a considerable reduction in the vertical crutch impulse values (mean 21%).[10]

Table 3 Comparative effects of mechanical orthoses on energy expenditure experienced by SCI patients

Author(s)	*No. of subjects and injury level*	*Quality of assessment physiotherapy evidence database scale*	*Orthoses tested or compared*	*Energy expenditure*							
				O_2 cost ($ml\,kg^{-1}m^{-1}$)	*O_2 consumption ($ml\,kg^{-1}min^{-1}$)*	*PCI (beats per min)*	*RER (VCO_2/O_2)*	*HR (beats per min)*	*O_2 uptake ($l\,min^{-1}$)*	*VO_2 ($ml\,kg^{-1}$)*	*Walking speed ($m\,s^{-1}$)*
Nene and Patrick[10]	*n*=10 (injury levels: T4–T9)	2	Parawalker	16	3.1	—	—	—	—	—	0.214
			HKAFO	—	—	—	—	—	—	—	
Nene and Patrick[12]	*n*=16	2	Parawalker	—	—	3.11	—	—	—	—	0.28
Winchester *et al.*[25]	*n*=4 (injury levels: T3–T12)	3	IRGO	13	1	2.6	1.2	144	—	—	0.22
			RGO	14.2	1.1	3.6	1.1	145	—	—	0.21
Muszkat *et al.*[31]	*n*=1 (injury level: C6)	1	HKAFO	—	1.16	—	0.9	—	—	—	—
			ARGO	—	1.31	—	0.82	—	—	—	—
Saitoh *et al.*[27]	*n*=5 (injury levels: T5–L1)	3	WA	9.61	—	—	—	—	—	—	0.33
Ijzerman *et al.*[35]	*n*=6 (injury levels: T4–T12)	3	ARGO	—	1.55	5.4	0.99	136.3	0.316	—	0.24
			NRO	—	1.63	5.8	0.97	136.4	0.302	—	0.23
Middleton *et al.*[30]	*n*=1 (injury level: C6)	1	Moorong MLO	—	—	11.5	—	155	0.55	—	0.13
			WA	—	—	11.5	—	164	0.49	—	0.11
Harvey *et al.*[23]	*n*=10 (injury levels: T9–12)	4	IRGO	—	1.65–1.8	4.3–4.9	—	120–140	—	1.06–1.33	0.19
			WA	—	3.9–4.9	8.4–10.3	—	119–133	—	1.05–1.43	0.09
Massucci *et al.*[28]	*n*=6 (injury levels: T3–12)	3	ARGO	13.79	1.28	—	—	156.5	0.45	—	0.16
Abe[29]	*n*=2 (subject A: female, subject B: male) injury levels at T9 and T12	2	KAFO	Subject A: 15.2 subject B: 18.8	—	—	—	—	—	—	Subject A: 0.07 subject B: 0.04
			WO	Subject A: 13.4 subject B: 15.5	—	—	—	—	—	—	Subject A: 0.10 subject B: 0.06
			RGO	Subject A: 11.5 subject B: 14.9	—	—	—	—	—	—	Subject A: 0.10 subject B: 0.07
Leung *et al.*[24]	*n*=6 (injury levels: T12–L1)	4	IRGO	—	—	—	2.8	—	—	—	0.17
			KAFO	—	—	—	6.7	—	—	—	0.09

Abbreviations: ARGO, advanced reciprocating gait orthosis, HKAFOs, hip–knee–ankle–foot orthoses; HR, heart rate, IRGO, isocentric reciprocating gait orthosis; KAFO, knee–ankle–foot orthoses; MLO, medial linkage orthosis; NRO, non reciprocally linked orthosis; PCI, physiological cost index; RGO, reciprocating gait orthosis, RER, respiratory exchange ratio; T, thoracic; VCO_2, carbon dioxide production; VO_2, oxygen uptake; WA, walkabout; WO, walkabout orthosis.

In a case series study, Hirokawa *et al.*[11] compared the energy consumption of six paraplegic persons with injuries at the thoracic level when wearing an RGO with and without FES, a long leg brace and the HGO. The lowest energy costs ($Kcal\,kg^{-1}\,min^{-1}$) were associated with the RGO and FES, followed by the RGO, HGO, long leg brace and FES for walking speeds below $28\,m\,s^{-1}$. During walking speeds higher than $28\,m\,s^{-1}$, the HGO demonstrated the lowest energy cost followed by the RGO and FES, RGO, FES and long leg brace. At the end of a 30 m walk, patients using the RGO and FES had a mean heart rate (HR) that was 12 beats per min less than the RGO without FES, 31 beats per min less than the HR when using the long leg brace and 42 beats per min less than the HR when using FES only.[11]

Nene and Patrick[12] evaluated the oxygen consumption and energy cost ($J\,kg^{-1}\,m^{-1}$), as well as energy consumption ($J\,kg^{-1}\,s^{-1}$), demonstrated by five paraplegic subjects when walking with the Parawalker with simultaneous electrical stimulation of the stance-side gluteal muscles. They reported that with this 'hybrid' orthosis three subjects increased their walking speed (10.92, 7.85 and 9.27%) and two reduced it (4.49 and 9.36%). Energy cost was reduced in four subjects (6.47, 7.93, 6.92 and 7.97%) but remained the same for the fifth subject (mean 7.32%). In addition, energy consumption was reduced in four subjects (0.82, 11.06, 0.38 and 10.28%) and increased in one subject (4.19%); (mean -5.35%).[12]

Stallard and Major[13] investigated the influence of orthosis stiffness on five paraplegics when ambulating, and its implications for FES walking systems. In their study, physiological cost index (PCI) was significantly reduced in each case when using the Parawalker, and the average decrease in PCI was 0.42—a reduction of 30%. They also demonstrated that in four out of the five subjects a decrease in energy cost of between 6 and 9% was seen, and in the fifth subject no change in energy cost was noted.[13]

There were four studies with PEDro score 3/10 in this group that analysed the influence of using hybrid orthoses on energy consumption on paraplegia patients. Beillot *et al.*[14] evaluated the energy cost of walking when using an RGOII orthosis with FES applied in 14 patients with complete paraplegia. They reported that, at maximal speed with the RGO, VO_2 was 91% of LVO_2 peak, mean HR reached 96% and mean blood lactate concentration was only 52% of the maximal values measured during the laboratory test. Four of the subjects also repeated the tests without using FES and at a speed of $0.1\,m\,s^{-1}$, and in these cases VO_2 represented 47% of LVO_2 peak and the mean HR was 137 beats per min.[14]

Sykes *et al.*[15] compared ambulatory energy expenditure in adult subjects ($n=5$) with spinal cord lesions ranging from C2 (incomplete) to T6 when using the RGO with and without FES applied to the thigh muscles at self-selected walking speeds. They found that energy consumption when walking with the RGO alone ranged from $1.429\,j\,kg^{-1}\,s^{-1}$ to $3.469\,j\,kg^{-1}\,s^{-1}$ (mean $=2.071\,j\,kg^{-1}\,s^{-1}$) and from $1.720\,j\,kg^{-1}\,s^{-1}$ to $3.327\,j\,kg^{-1}\,s^{-1}$ (mean $=2.588\,j\,kg^{-1}\,s^{-1}$) when using FES. The four subjects who increased their walking speed with FES also increased their energy consumption. The associated energy cost varied from $3.558\,j\,kg^{-1}\,m^{-1}$ to $17.642\,j\,kg^{-1}\,m^{-1}$ (median $=13.519\,j\,kg^{-1}\,m^{-1}$) when walking with the RGO alone and from $3.800\,l\,kg^{-1}\,m^{-1}$ to $17.06\,1l\,kg^{-1}\,m^{-1}$ (mean $=13.699\,j\,kg^{-1}\,m^{-1}$) when using the hybrid system.

In a case study, Spadone *et al.*[16] compared the energy expenditure during ambulation with the ARGO, with and without FES, and with the Parastep system (Sigmedics Inc., Northfield, IL, USA) in a single subject (lesion level T5 ± T6). They indicated that, compared with wheelchair locomotion, the slope of HR/VO_2 curves with the ARGO was higher, with the ARGO+FES it was similar and with Parastep it was smaller; HR increased linearly with all locomotion systems, but it did not rise above 125 beats per min with the Parastep, and the cost of locomotion was higher with Parastep than with the ARGO (with and without FES), tested at each velocity. The VO_2 values were 0.36, 0.35 and 0.62 l per min during standing with orthosis and 0.79, 0.94 and 1.33 l per min during locomotion at the self-selected speed with ARGO, ARGO+FES and Para step, respectively. The slope difference Δ_{s1} HR/VO_2 [bl^{-1}] refers to the increase in heart beats per litre of O_2 consumed when changing from wheelchair to orthosis ambulation: the higher values were observed from the ARGO locomotion.[16]

Goldfarb *et al.*[17] evaluated a hybrid controlled brake orthosis (CBO) and compared it with conventional four-channel FES-aided gait in four subjects with paraplegia. In comparison between FES and CBO in speed of walking, there were no significant differences between them in this study. The average speed for all subjects was $0.054\,m\,s^{-1}$ in using FES and $0.060\,m\,s^{-1}$ in using the CBO. Percent increase in HR was reported in this study. The mean of the percent increase in HR for walking with FES was 56, whereas in using CBO this percent was 45. Therefore, the CBO provided better result in this parameter compared with FES-only gait.[17]

Merati *et al.*[18] compared the energy cost of locomotion demonstrated by 14 SCI patients (lesion level C7 ± T11) during ambulation with different orthoses (the HGO, Parawalker; RGO, and RGO+FES). They observed that during locomotion at maximal speed HR peak values were 160 ± 16, 155 ± 31 and 154 ± 31 beats per min and VO_2 $l\,kg^{-1}$ peak values were 18.0 ± 6.1, 18.5 ± 5.4 and 19.1 ± 7.2 for PW, RGO and RGO+FNS, respectively. During orthosis-assisted locomotion at maximal speed, HR peak values were 150 ± 13, 131 ± 21 and 155 ± 23 beats per min, and VO_2 $l\,kg^{-1}$ peak values were 13.4 ± 3.0, 13.8 ± 3.5 and 17.2 ± 4.8 for PW, RGO and RGO+FNS, respectively. They also reported that maximal ventilations at VO_2 peak were 63.8 ± 24.0, 68.9 ± 27.1 and 67.6 ± 23.91 $l\,min^{-1}$ during wheelchair ambulation, and 71.8 ± 7.3, 76.5 ± 21.3 and 72.3 ± 12.2 $m\,kg^{-1}\,min^{-1}$ during orthosis locomotion for PW, RGO and RGO+FNS, respectively.[18] The PEDro score for this study was 4/10, which equals the highest score assigned in this group.

The effect of powered orthosis on energy consumption in paraplegic patients

Table 2 demonstrates the results of studies that evaluated the effect of PO on energy consumption in paraplegic patients.

Three papers with a low level of evidence according to the PEDro score (2/10) included here compare PO with mechanical orthosis on energy consumption in paraplegic subjects. Kawashima *et al.*,[19] in evaluation of the weight-bearing control orthoses on energy consumption, stated that the energy consumption of walking has been quoted as being $5.41\,J\,kg^{-1}s^{-1}$ for SCI persons, whereas the mean of this parameter was reported to be $0.176\,ml\,kg^{-1}\,m^{-1}$ in non-paraplegic subjects.[20] A comparison between mechanical orthoses (HKAFOs and IRGOs) and powered gait orthoses (PGOs) reported that a PGO can improve walking speed and walking distance and that the PCI of walking decreased in walking with a PGO compared with mechanical orthoses. The activated movements of the lower limb joints may be the mechanism to provide these results.[6] In a comparison between the wearable power-assist locomotor and prime-walk orthoses on energy consumption in four people with paraplegia, Tanabe *et al.*[21] reported that the PCI exhibited was reduced when the wearable power-assist locomotor was used. The effort of walking has been shown to be reduced when using a powered motorised ARGO compared with mechanical ARGO in SCI patients.[22] On the basis of

limited studies in the evaluation of PGOs on energy consumption in paraplegic patients, a further understanding of this parameter is therefore required for patients with SCI when using PGOs.

The effect of mechanical orthoses on energy consumption in paraplegic patients

Although this grouping contains the largest number of studies by far, 11 in all, no randomised clinical trials have been reported among these to evaluate the efficacy of mechanical orthoses on energy consumption in paraplegic patients. Table 3 demonstrates studies that evaluated the effect of walking with mechanical orthoses on energy consumption in paraplegic patients.

Harvey *et al.*[23] in a comparison between the WO and IRGOs in 6 SCI subjects (T4–T12) demonstrated that energy expenditure during ambulation was twice that of the IRGO when used in SCI patients (4.3 versus 8.4). The limited trunk stability of SCI patients to maintain upright stance and no reciprocating gait system when using WO was thought to have caused the additional effort demonstrated. In other study, Leung *et al.*[24] in a comparison between the IRGO and HKAFO in 6 (T12-L1)SCI subjects announced that the mean of this parameter in using the IRGO was significantly less than when using a KAFO (2.8 versus 6.7). The PEDro score for these studies was 4/10, which equals the highest score assigned in this review.

There were four studies with PEDro score 3/10 in this group that evaluated mechanical orthoses on energy consumption on paraplegia patients. Winchester *et al.*[25] in an evaluation of two different orthoses on gait parameters demonstrated by four SCI subjects (T3–12) showed that PCI was improved when using the IRGO (2.6 beat per m), compared with when walking with the RGO (3.6 beat per m). SCI subjects had less fatigue during ambulation with the IRGO. Ijzerman *et al.*[26] in a comparison between ARGOs with and without a connector cable demonstrated that using a connector cable in ARGOs reduced energy consumption compared with an ARGO without a cable (5.4 beat per m versus 5.8 beat per m), but not significantly. The ARGO with a reciprocating gait system helped SCI patients to maintain posture, and this point was beneficial for patients with high levels of injury compared with those with lower levels of injury. Saitoh *et al.*[27] in an evaluation of WO on 5 (T5-L1) SCI subject announced that the mean of O_2 consumption as an indicator of energy expenditure was 9.61($ml\,kg^{-1}\,min^{-1}$). However, Massucci *et al.*[28] in an evaluation of the ARGO on six subjects with SCI at levels (T3-12) reported that O_2 consumption and O_2 cost were 13.79 ($ml\,kg^{-1}\,min^{-1}$) and 1.28 ($ml\,kg^{-1}\,m^{-1}$), respectively.

The three-low level studies (PEDro score 2/10) included here compares different types of mechanical orthoses on energy consumption in SCI patients. Nene *et al.* in evaluation of Parawalker on 16 SCI subjects demonstrated that the mean of PCI as indicator of energy consumption was 3.11. In another study in comparison of the Parawalker and HKAFO on 10 (T4–9) SCI subjects, Nene and Patrick[10] reported that the O2 consumption was 3.1 and 16 $j\,kg^{-1}\,s^{-1}$, respectively. Abe[29] in comparison between KAFO, WO and RGO on 2 (T9, T12) SCI subjects demonstrated that the mean of O_2 cost were 17, 14.45 and 13.2 ($ml\,kg^{-1}\,m^{-1}$), respectively.

The two poor-quality studies in this group according to PEDro scale (1/10) performed by Middleton *et al.*[30] and Muszkat *et al.*[31] Middleton *et al.*[30] in a comparison between different types of medial linkage orthoses on one SCI subject from C6 level of injury showed that there was no significant difference between the Moorong and WO in PCI values when walking along a level surface (11.5 beat per m); however, the Moorong orthosis provided increased speed of walking compared with WO during ambulation. Muszkat *et al.*[31] in a comparison between ARGOs and HKAFOs in one SCI subject with C6 level of injury reported that the ARGO needed less energy expenditure during ambulation (0.9 versus 0.82).

DISCUSSION

Different methods of evaluating energy expenditure in SCI patients when using mechanical orthoses for ambulation have been used in publications. The O_2 cost ($ml\,kg^{-1}\,m^{-1}$), O_2 consumption ($ml\,kg^{-1}\,min^{-1}$), the PCI (beat per m), HR (beat per min), O_2 uptake ($l\,min^{-1}$) and the respiratory exchange ratio are all approaches used to measure this parameter.[4]

With regard to assistive devices (hybrid, mechanical and PO), the use of hybrid orthoses has been shown to produce reduced energy consumption compared with mechanical orthoses during walking in paraplegic patients. The IRGO has been shown to be a more effective orthoses compared with other mechanical orthoses such as the RGO and the WO in reducing energy consumption during ambulation in SCI subjects. Consequently, this present review advises that the energy consumption during walking with PO and hybrid orthoses has been shown to be better than the values given in walking with conventional orthoses (for example, HGO, RGO and ARGO) for paraplegic patients.

Different factors affect energy consumption during walking with orthoses in SCI patients: the level of injury, duration of orthoses use, gait velocity and the type of orthoses. Injury and addition injury in each segment of the spinal cord (not level of spine) influence walking ability and consequently energy consumption in SCI patients. The neurological and bone injury levels could have totally different outcomes on ambulation. The level of lesion (paraplegia versus tetraplegia) and degree of neurological impairment (complete versus incomplete) influence the activities of daily living and function ability. Ambulatory tetraplegic patients have significantly higher lower-extremity motor scores (lower-extremity muscle strength) compared with ambulatory paraplegic patients. (38.4 versus 27.3 points).[32] Different degrees of upper-extremity paralysis and disability of the upper extremities, which are needed to hold assistive devices, are responsible for these high-energy consumption levels.[33] The energy consumption of SCI patients has not been evaluated between complete and incomplete kinds, and therefore an analysis of energy expenditure between these groups will be beneficial in this field.

The mean of gait velocity has been reported to be 0.214, 0.16,0.24 and 0.22 $m\,s^{-1}$ when using the different types of mechanical orthosis during ambulation by SCI patients(10), (28),[24,25,34,35] When using a hybrid orthosis and PGO, this parameter is not altered and has not shown any significant difference between them. As there is a vice versa relationship between energy consumption and gait velocity, it is assumed that an increase in the speed of walking can cause a reduction of energy expenditure during walking with these orthoses by SCI patients.

It is assumed that patients with incomplete SCI injury have less energy consumption compared with those with complete SCI, but this has not been conclusively evaluated, and further research is therefore needed. SCI patients with different levels of injury have different walking abilities and walking parameters when walking with orthoses. It is anticipated that patients with an upper (higher) level of injury will have higher energy consumption compared with SCI patients with a lower level of injury.

The level and severity of injury, and the age of SCI patients, are other important factors in influencing the ability to walk with orthoses. In a comparison between patients with different levels of injury, it was demonstrated that SCI patients with a lower level of

injury had better gait parameters compared with SCI patients with upper (higher) levels of injury.[36] Patients with lesions above T9 or above do not use orthoses for ambulation owing to the high rate of energy consumption experienced. From an age point of view, it has been demonstrated that younger patients prefer to wear orthoses for walking, whereas elderly SCI patients prefer to use wheelchairs for ambulation and activities of daily living.[37]

SCI patients have difficulty in obtaining orthotic gait training in the early stages of their rehabilitation,[38] but after 6–8 weeks of gait training they show improvement in walking independently and reciprocally.[28,39,40] It seems that after appropriate gait training with orthoses and after gaining the ability to walk and stand with an orthoses SCI patients may use less energy consumption during orthotic ambulation compared with without one. However, no study was found that evaluated energy consumption before and after orthotic gait training, and therefore a study with this aim would be beneficial.

Orthoses have a positive effect on physiological aspects. SCI patients do not use orthoses for ambulation and reject them owing to the high rate of energy consumption experienced. It is well-reported that SCI patients have significantly decreased VO_2 peak rates according to the reduction in the daily activity levels.[41] Physical status and activity daily living (ADL) levels have been related to orthoses use in SCI patients, and therefore it seems that these two parameters (physical status and ADL level) are reduced in SCI patients. This effect has not been fully evaluated in these patients; a future study in this field will therefore also be beneficial. SCI patients prefer wheelchairs more than orthoses for ambulation. Therefore, SCI patients should facilitate their own ADLs, not only with wheelchair use but also by walking with orthoses. Conventional mechanical orthoses require a very high energy expenditure that usually leads to exhaustion within a few minutes of walking. PO and hybrid orthoses have shown to produce better results in reduction of energy consumption. Although commercial types of these orthoses are rare, future developments in orthosis design should prove beneficial for the rehabilitation of SCI patients.

Although the effect of orthoses on walking in SCI patients has been reported,[22,42–44] few publications have analysed the efficacy of PO compared with mechanical orthoses on energy expenditure in SCI subjects. PO were designed with the concept of providing active lower-extremity motion for SCI patient ambulation, especially those who are unable to swing their leg voluntarily,[45,46] and it has been demonstrated that temporal spatial parameters of walking can be improved with this type of orthosis compared with mechanical orthoses by providing active joint motions.

A person's individual perception of the exertion associated with walking using an orthotic device can be related to the energy cost, as well as having a significant impact on whether they might choose to use this device on a regular basis. According to previous studies in this field, only one study (Spadone *et al.*[16]) evaluated the perceived exertion associated with the energy consumption when using the Parastep orthosis during walking by SCI patients. Ferguson *et al.*[47] and Hardin *et al.*[49] both demonstrated that perceived exertion in using a bracing system with functional electrical stimulation was 'easier' than without stimulation. On using parastep during walking in SCI patients, Ferguson *et al.*,[47] Marsolais *et al.*[48] and Hardin *et al.*[49] demonstrated that perceived exertion in using the bracing system with functional electrical stimulation was 'easier' than without stimulation. The perceived exertion during walking in SCI patients was measured with the Borg scale and Perceived exertion Scale.

CONCLUSION

It is therefore concluded that the hybrid orthoses and PO could be an effective alternative in rehabilitation for SCI patients to help promote their best walking performance. To prove this, it would be beneficial to perform the following:

- As there are few commercial types of powered orthoses and hybrid orthoses available, it is seems that the development of these kinds of orthoses is essential.
- Evaluation of these types of orthoses on energy consumption and studies designed to find a solution as to how to reduce energy consumption during walking by people with SCI is essential in the rehabilitation of paraplegic patients.
- According to gait training, evaluation of the energy consumption before and after orthotic gait training with mechanical orthoses and powered and hybrid orthoses will be beneficial.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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