Influence of Reciprocating Link When Using an Isocentric Reciprocating Gait Orthosis (IRGO) on Walking in Patients with Spinal Cord Injury: A Pilot Study

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Background: Studies collectively imply that the reciprocal link has no effect on walking when using reciprocating gait orthoses (RGOs). There may be differences between the 2 configurations of the RGO (eg, isocentric reciprocating gait orthosis [IRGO] and IRGO without reciprocating link), but the specific benefits and problems encountered in their use must be understood. **Purpose:** To highlight more evidence for the mechanical function of the reciprocal link in RGOs used for walking by individuals with spinal cord injury (SCI). **Methods:** Nine people with SCI participated in this study. Gait analysis was performed in 2 conditions (walking with IRGO and walking with IRGO without reciprocating link) in a random order. The Vicon digital capture system was used to obtain kinematic data. **Results:** There were significant differences between each orthotic configuration in terms of speed of walking ($p = .029$), step length ($p = .048$), hip joint range of motion (ROM) ($p \leq .001$), and lateral and vertical compensatory motions ($p \leq .001$). There was no significant difference between each orthotic configuration in cadence ($p = .162$). **Conclusion:** The reciprocating link in IRGO improved the walking parameters in SCI patients. **Key words:** *isocentric reciprocating gait orthosis, orthotic gait training, reciprocal link, spinal cord injury, walking*

Introduction

Standing and walking have been associated with many physiological and psychological benefits. Some of the physiological benefits include reduction of spasticity, improvement in bone mineral density, prevention of pressure sores, and improvement in blood circulation and bladder and bowel functions.[1] The psychological benefits may include improvement in self-esteem and communication and better interaction with able-bodied people in the society.[2]

However, standing and walking disability is the main complication after spinal cord injury (SCI).[3] From the orthotic rehabilitation perspective, various types of orthoses can be used for helping SCI patients in standing and walking. Conventional hip-knee-ankle-foot orthoses (HKAFO), hip guidance orthosis, reciprocal gait orthoses (RGO) (eg, advanced RGO, isocentric RGO [IRGO]), and medial linkage orthoses (MLO) are common mechanical orthoses options in this field.[4,5] Studies have demonstrated that RGOs cause superior improvement in energy consumption compared to HKAFO and Walkabout MLO.[6] RGOs are easier to use and permit a more energy-efficient gait compared to other mechanical orthoses[4,5]; they are, hence, routinely used for walking and ambulation in SCI patients. However, some patients discontinue the use of these orthoses because of fatigue or inconvenience in use.[7,8]

One of the main differences between RGOs and other mechanical orthoses is the reciprocally linked hip joints. The function of the reciprocal link in RGOs can be evaluated using 2 methods (ie, direct and indirect methods).[9] Ijzerman et al[10] analyzed the reciprocal link function indirectly by comparing the energy expenditure of subjects in the advanced reciprocating gait orthosis (ARGO)

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group and those with the same ARGO but with disconnected cable. They reported that there was no sufficient evidence to draw general conclusions about the difference in energy expenditure between both orthoses, but they demonstrated a difference in energy consumption between participants with low- and high-level paraplegia. Patients with low-level lesions may benefit from removing the reciprocal cable linkage in ARGO because oxygen cost was lower.[10] Baardman et al[11] evaluated both configurations in ARGO and NRO in terms of standing stability and the function of a functional hand task during standing. They reported that there were no significant differences with respect to standing performance for the 2 orthosis configurations. They further suggested that the reciprocal hip joint link in the ARGO can decrease the upper body effort needed for standing under functional conditions. Dall et al[12] directly analyzed the function of the reciprocal link using RGOs and reported that the cable was not being used at all during gait in 3 out of 6 patients. The maximum torque produced in the cable was 0 Nm. Furthermore, Johnson et al[13] calculated the hip joint torque for extension and reported it to be between 0 and 0.3 Nm kg in spina bifida children who participated in their study.[13] Therefore, Dall et al,[12] Johnson et al,[13] and Ijzerman et al[10] collectively implied that the reciprocal link has no effect on walking, but there appear to be differences between the 2 configurations of the RGOs.

When using RGOs, the provided force via trunk muscle contractions associated with compensatory motions caused leg swing based on the paralysis of the trunk muscles and muscles around the hip joint.[14] Therefore, the contraction of the trunk muscles and compensatory motions play the main role for providing hip flexion in SCI individuals who can produce high loads on wrist and shoulder joints during orthotic ambulation with a mechanical orthosis.[15,16] Although previous studies demonstrated that the reciprocal link has no effect on walking, the effect of the reciprocal link in RGO must be understood. Therefore, the purpose of this study is to highlight more evidence for the mechanical function of the reciprocal link in RGOs used for walking by individuals with SCI.

Method

Subjects

Nine SCI patients (3 women and 6 men; age, 39.88 ± 8.97 years; weight, 57.55 ± 16.21 kg; height, 168.33 ± 7.76 cm) volunteered to participate in this study. The level of injury in these subjects was as follows: T12 (3 subjects), T10 (4 subjects), T8 (1 subject), and T6 (1 subject). The time since injury was 22 ± 14 months. Seven subjects presented with an incomplete T level lesion (level B), and 2 subjects presented with a complete T level lesion (level A) based on the American Spinal Injury Association Impairment Scale (AIS). All the patients were referred to receive IRGO. The inclusion criteria in this study were no evidence of cardiovascular or pulmonary diseases, contractures, severe spasticity, obesity, or asymmetric hip positions. Informed consent to participate in this study was received from all the patients. Ethical approval was obtained from the Human Ethics Committee of University of Social Welfare and Rehabilitation Sciences (USWR).

Orthosis

Two types of IRGO were used in this study (original IRGO and IRGO without link condition [**Figure 1**]). The orthoses were constructed according to lower limb casting. In the original version, the orthosis had a reciprocating mechanism while the hip flexion of one side caused extension of the other side via a pivot reciprocating link and vice versa. Dropped locked knee joints and ankle joints without mobility were used in all IRGOs for this study. In the IRGO without reciprocating link, the reciprocal link in the IRGO was removed at the subjects' first visit to the unit.

Orthotic gait training

The subjects received 2 hours of gait training for 5 days per week over a 2-week period. All gait training was applied by a physiotherapist with expertise in walking and standing by patients with paraplegia. The gait training program included passive stretching of the lower limb and upper limb and balance training with the orthosis

Figure 1. Isocentric reciprocating gait orthosis overall view used in this study.

while standing and walking. The participants performed upper and lower limb stretching exercises for 30 minutes, and a further 30 minutes were required for balance training. In the orthotic gait training, the orthosis must be used with a walker for functional ambulation. The volunteer SCI subjects walked with a walker for stability and safety. The height of the walker handles was adjusted to the preferred height for each subject. The technique of gait training with the IRGO was taught to the participants as illustrated in **Table 1**.

Gait analysis and procedure

Gait analysis was performed for 2 conditions (walking with IRGO and walking with IRGO without reciprocating link) in a random order. Each subject walked with both types of orthoses. The kinematic data were collected using the Vicon digital capture system (Oxford Metrics, UK, 640) in the floor of a 6-m walkway. All the SCI patients were asked to walk along a 6-m walkway in a gait laboratory at least 3 times at their self-selected walking speed. A walking frame (walker) with the wheels anteriorly positioned was used during the ambulation with the orthosis. A total of 18 retro-reflective markers were placed bilaterally on the position of the anterior superior iliac spur (ASIS), greater trochanter, the lateral condyle of the femur, the head and lateral malleolus of the fibula, the second metatarsal, calcaneus, over the jugular notch, the spinous process of the seventh cervical vertebrae, and the acromio-clavicular joints. The markers were positioned on the trunk of the patients and on the orthosis as close as possible to the positions on the subject's skin. The marker setup was the same for the 2 conditions.

In this present study, lateral compensatory motion and vertical compensatory motion were defined as the lateral and vertical trunk excursion in the frontal plane during walking. Walking was defined as a translator motion in the global vertical and horizontal axes. Increased lateral trunk motion results in a greater laterally deviated trunk over the limb at midstance. Lateral and vertical compensatory motions were calculated by analyzing the motions of the ASIS, seventh cervical vertebral, and acromion clavicular markers. These motions are needed for orthotic ambulation to move the trunk from side to side in paraplegic patients. This pattern of walking provides increased loads on the upper limbs joints (eg, wrist and shoulders) in SCI individuals.

A custom program (MATLAB; The Math Works, Inc., Natick, MA) was used to calculate the kinematics of the joints. The speed of walking, cadence, step length, hip joint kinematic, lateral compensatory motion, and vertical compensatory motion were evaluated from the motion analysis information. These calculations were based on a link segment model in which each body segment (thigh, foot, shank, etc) was represented as a rigid link between 2 adjacent joints. The temporal-spatial parameters were determined based on the marker data obtained from the marker attached to the calcaneus.

Table 1. Content of stages, training activity, training details, and training time for orthotic gait rehabilitation in this study

Stages	Training activity	Training details	Training time
Stage 1	Passive stretching of the lower extremities	Passive stretching of the hip, knee, and ankle joints in sagittal plane	15 minutes
Stage 2	Passive stretching of upper limb	Passive stretching of the shoulder, elbow, and wrist joints in sagittal plane	15 minutes
Stage 3	Balance training with the orthosis while standing	All subjects learned sit-to-stand and stand-to-sit in the orthoses. While standing, the subjects learned to balance with one hand lifted for 30 s, and then with both hands lifted for about 10 s. The participants also learned to use the walker to prevent a fall in the forward, backward, and diagonal directions by moving walkers simultaneously to stop the fall. The subjects were educated in trunk extension and postural control in standing with orthosis associated with walker.	10 minutes
Stage 4	Balance training with the orthosis while walking	Participants also learned to use the walker to prevent a fall in the forward, backward, and diagonal directions by moving walkers simultaneously to stop the fall during walking with IRGO.	20 minutes
Stage 5	Standing and walking with orthosis	Subjects learned to shift their weight completely on one lower leg (eg, right side) and have trunk lateral bending on the weight-bearing side to permit the orthoses to provide forward ambulation. These movements are necessary to provide sufficient foot-ground clearance. Subjects learned to shift their weight completely on other lower leg (left side) and have trunk lateral bending on the weight-bearing side to permit the orthoses to provide forward ambulation. The volunteer SCI subject walked with a walker for stability and safety.	60 minutes

Note: IRGO = isocentric reciprocating gait orthosis.

Statistical analysis

The Kolmogorov-Smirnov test was used to detect the normality of all variables ($p < .05$ proposing a significant deviation from normality) as well as visual inspection of Q-Q plots of each variable (eg, speed of walking) (**Figure 2**). A paired *t* test was used to analyze each of the parameters. IBM SPSS version 16 (IBM Corp., Armonk, NY) was used for data analysis, and a significance level was set at $p < .05$.

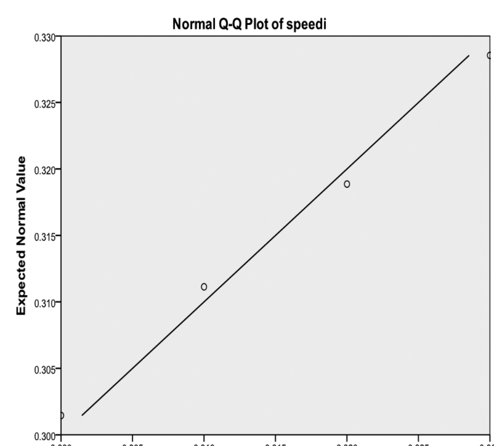

Figure 2. Visual inspection of Q-Q plots of speed of walking.

Results

Temporal-spatial parameters

Table 2 demonstrates the mean and *SD* of the temporal-spatial and kinematic parameters during walking with 2 orthotic configurations in this study. The mean speed of walking was 0.33 ± 0.046 and 0.30 ± 0.021 m/s during walking with IRGO and IRGO without reciprocating link, respectively. There was a significant difference between orthotics conditions ($p = .029$). The mean value for step length was 34 ± 2.23 cm and 31.66 ± 2.12 cm when walking with IRGO and IRGO without reciprocating link, respectively ($p = .048$). This observation was the same for the speed of walking. There was a significant difference between orthotics configurations ($p = .048$). No significant difference was found between the 2 orthosis configurations in terms of cadence (**Table 2**).

Table 2. Mean ± *SD* of hip joint range of motion (ROM) and spatial-temporal gait parameters in walking with 2 orthotic configurations

	Speed of walking, m/s	Cadence, steps/min	Step length, cm	Hip ROM, degrees	Lateral compensatory motions, cm	Vertical compensatory motions, cm
Walking with IRGOs	0.33±0.046	56±3.96	34±2.23	14 ±1.5	21.55±1.66	9.11±1.16
Walking with IRGOs without reciprocating link	0.30±0.021	54±1.53	31.66±2.12	7±1.11	24.88±1.69	13.11±1.76
P value	0.029	0.162	0.048	0.000	0.000	0.000

Note: IRGO = isocentric reciprocating gait orthosis.

Kinematics

Lateral and vertical compensatory motions

In this study, the mean of lateral compensatory motion during walking trails was 21.55 ± 1.66 cm and 24.88 ± 1.69 cm when using IRGO and IRGO without reciprocating link, respectively. This indicates that the lateral compensatory motion in using IRGO was significantly less compared to IRGO without reciprocating link.

The mean of vertical compensatory motion during walking trials was 9.11 ± 1.16 cm and 13.11 ± 1.76 cm in using IRGO and IRGO without reciprocating link, respectively. The use of IRGO demonstrated significantly less vertical compensatory motion compared to the other walking condition in this study.

Hip joints

An IRGO with drop lock knee joints that were attached to solid ankle-foot orthoses was used in this study; therefore we did not evaluate the kinematics of the ankle and knee joints. The mean of the hip joint range of motion during walking trials in this study was 14° ± 1.5° and 7° ± 1.11° in using IRGO and IRGO without reciprocating link, respectively. The use of IRGO with the reciprocal link demonstrated significantly better hip joint ROM compared to the other walking condition.

Power calculation and effect size

By using a power analysis, the following results were obtained: walking speed, 49.9; step length, 88.3; cadence, 32.8; hip joint ROM, 100; lateral compensatory motion, 100; and vertical compensatory motion, 100.

The following results were obtained for effect size: speed, 0.83; step length, 1.07; cadence, 0.66; hip joint ROM, 5.30; lateral compensatory motion, 1.98; and vertical compensatory motion, 2.68. The magnitudes for effect size based on Cohen's criteria were found to be large.[17]

Discussion

The aim of this study was to analyze the effect of a reciprocating link of an IRGO in temporal-spatial parameters, lateral and vertical compensatory motions, and hip joint kinematics in SCI patients during ambulation. There were significant differences in speed of walking, step length, hip joint ROM, and lateral and vertical compensatory motions between the 2 orthotics conditions. The results from this present study demonstrate that there was no significant difference in cadence between walking IRGO and IRGO without reciprocating link.

The speed of walking in normal able-bodied subjects was 1.22 ± 0.09 m/s.[18] This rate in normal able-bodied subjects was reported to be 0.87 ± 0.04 m/s when using a custom-powered IRGO.[18] The mean of this parameter was 0.33 m/s and 0.30 m/s when using IRGO and IRGO without reciprocating link. Previous studies in this field have demonstrated similar results for this parameter.[8,10,14,19-23] Ijzerman et al[10] noted that SCI patients with lesions ranging from T4 to T12 demonstrated a walking speed of 0.24 and 0.23 m/s when walking with ARGO and NRO, respectively. The use of a reciprocating link had a significant effect at this point. The speed of walking is related to the swing of hip flexion and step length. Since the use of the reciprocating link had a significant influence in the improvement of step length, the significant improvement in speed of walking is justifiable.

Lateral and vertical compensatory motions were reduced significantly with the use of IRGO because the reciprocal link induced flexion and extension of the hip joint. Instead of the patients using trunk muscle, the reciprocating link assisted them in swinging the paralyzed lower limbs, which may have been responsible for the reduction in compensatory motions and reduction in the effort required to walk. In using the IRGO with the reciprocal link disconnected, the patients were forced to use lateral bending to provide propulsion. This action caused high lateral and vertical compensatory motions. A reduction in these parameters was observed when participants used IRGO with a reciprocating link. The reciprocal link seems to be responsible for this point. Compensatory motions were related to energy consumption. Arazpour et al[14] suggested that a custom-powered IRGO had a positive effect in the reduction of lateral and vertical compensatory motions compared to IRGO. In another study that used the physiological cost index (PCI), Arazpour et al[19] showed that use of a custom-powered IRGO in SCI patients reduced PCI. The reduction in these parameters can influence energy consumption in SCI patients.

The maximum hip joint ROM in the IRGO and IRGO without reciprocating link were 14° and 7°, respectively. These values in walking with IRGO were also less than that of the normal human gait, but the overall hip ROM increased when IRGO was used compared to IRGO without the link system. Hip joint ROM influenced the step length and speeds of walking. The speed of walking and step length were similar in the 2 walking conditions; it seemed that the SCI subjects with lateral bending and rotational compensatory motions provided the same speed and step length, although the hip joint ROM was reduced in the IRGO without the reciprocating link.

The patients in this study had different levels of injuries; therefore, future studies should determine the influence of the injuries of the same level. In this study, only the kinematics and temporal-spatial parameters of walking were evaluated in the SCI patients. The analysis of energy consumption, lower limb muscle activity, and kinetics of walking will be beneficial in this field. Since applied forces on the upper limb joints (eg, shoulder and wrist) is one of the main reasons for the rejection of orthosis use in SCI patients, the evaluation of these points seems to be necessary. Small sample size was the main limitation of this study that can influence the generality of the results of the study.

Conclusion

This study demonstrated that the use of an IRGO had statistically significant differences in terms of speed of walking, step length, hip joint ROM, and lateral and vertical compensatory motions compared to an IRGO without a reciprocating link in SCI patients. Based on these findings, it appears that the reciprocating link of the IRGO had a positive effect on the improvement of walking parameters in SCI patients. Further research is required to explore the effects over a longer and sustained period.

Acknowledgments

The authors declare no conflicts of interest.

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