Effect of Orthotic Gait Training with Isocentric Reciprocating Gait Orthosis on Walking in Children with Myelomeningocele

Mokhtar Arazpour,^{1,2} Farin Soleimani,¹ Firoozeh Sajedi,¹ Roshanak Vameghi,¹
Monireh Ahmadi Bani,² Masoud Gharib,³ and Mohammad Samadian⁴

¹Pediatric Neurorehabilitation Research Center, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran; ²Department of Orthotics and Prosthetics, University of Social Welfare and Rehabilitation Science, Tehran, Iran; ³Department of Occupational Therapy, Faculty of Para-medical Sciences, Mazandaran University of Medical Sciences, Sari, Iran; ⁴Loghman Hakim Hospital, Shahid Beheshti University of Medical Sciences, Department of Neurosurgery, Tehran, Iran

Background: Mechanical orthoses are used to assist in standing and walking after neurological injury in children with myelomeningocele (MMC). **Objectives:** To evaluate the influence of orthotic gait training with an isocentric reciprocating gait orthosis (IRGO) on the kinematics and temporal-spatial parameters of walking in children with MMC. **Methods:** Five children with MMC were fitted with an IRGO. They walked at their own comfortable cadence using the orthosis. The hip joint angle, spatial temporal parameters, and compensatory motions were measured and analyzed. **Results:** Significant increases in walking speed and step length were demonstrated following orthotic gait training during walking with the IRGO. The sagittal plane hip range of motion was also significantly increased; however, the vertical and horizontal compensatory motions were significantly decreased. **Conclusion:** This study evaluated the influence of gait training with an IRGO on the kinematics and temporal spatial parameters in MMC children. The findings showed that orthotic gait training improved hip joint range of motion, increased walking speed and step length, and decreased lateral and vertical compensatory motions during level-ground walking trials. **Key words:** gait analysis, gait training, myelomeningocele, reciprocating gait orthosis

Introduction

Myelomeningocele (MMC), one of the most common and severe forms of spina bifida, is a condition in which a part of the vertebral column fails to form and close around the spinal cord. This condition causes the meninges and spinal cord to protrude in a sac containing cerebral spinal fluid, resulting in varying degrees of permanent disability.^{1,2} The prevalence of MMC is 3 per 10,000 births in the United States.³ The level of bony defect and the extent of cord or nerve involvement in patients with MMC determine the level and severity of paralysis and bladder or bowel incontinence.^{4,5}

Factors like the level of neurologic lesion, grade of muscle strength, and patterns of functional muscle activity affect the walking and standing activities in children with MMC with the thoracic and high lumbar levels.^{6,7} The demonstrated

benefits of walking and standing have been related to independence, the ability to ambulate, and a reduced incidence of pressure sore development.⁸ Depending on the level of the lesion, various types of orthoses and assistive devices have been designed for standing and walking purposes; some of these devices include the swivel walker, parapodium, hip-guidance orthosis (or “parawalker”), static hip-knee-ankle-foot orthosis (HKAFO), and the reciprocating gait orthosis (RGO).⁹⁻¹² The RGO is one of the most commonly prescribed orthoses for these children due to its reciprocal action at the hips.¹³

In 1969, the RGO was first fabricated at the Ontario Crippled Children’s Centre in Toronto, Canada.¹⁴ The use of this orthosis enabled patients with a high-level injury and resultant paraplegia to walk in a reciprocal pattern. Further improvements were applied to this orthosis by

Corresponding author: Masoud Gharib, Department of Occupational Therapy, Faculty of Para-medical Sciences, Mazandaran University of Medical sciences, Sari, Iran; e-mail: gharib_masoud@yahoo.com

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Douglas when he constructed the Louisiana State University RGO (LSU-RGO) design in 1983.¹³ In 1992, the isocentric reciprocating gait orthosis (IRGO) was introduced as a cable-less device¹⁵ for assisting walking in individuals with little or no control of their lower extremities (eg, spina bifida, traumatic paraplegia and muscular dystrophy). In terms of its design, the right and left hip joints were connected via a rocker bar reciprocator link. The flexion of one side caused the extension of the other side and vice versa. The positive effects of using an RGO have been demonstrated by previous studies.¹⁶⁻¹⁹ Qualitative or quantitative differences in walking with an RGO have been documented²⁰⁻²³; however, limited information exists on the energy consumption and walking speed of children with MMC when using an RGO or HKAFO.^{21,24,25} Posture, forces acting on the walking aids, and the action of the reciprocal link were reported to be the factors that contributed to the high energy consumption during walking with an IRGO in MMC children.²⁶

The use of an RGO was reportedly rejected by a majority of MMC patients^{9,27} due to the high loads on the upper limb joints and excessive energy consumption when using the orthosis.^{28,29} Orthotic gait training is a critical component of walking rehabilitation in individuals with paraplegia.³⁰ Arazpour et al evaluated orthotic gait training with a powered hip orthosis (PHO) in 4 spinal cord injury (SCI) patients and showed that gait kinematics and temporal-spatial parameters were improved following a period of gait training.³¹ In another study, Samadian et al demonstrated the value of a 12-week orthotic gait training program with an IRGO on 6 SCI participants. They found that walking speed and the distance walked increased and the physiological

cost index of walking decreased when compared with the baseline.³² The IRGO seemed particularly promising but is yet to be tested for orthotic gait training in MMC children. Therefore, the aim of this study was to evaluate the effects of the orthosis on the kinematics and temporal spatial parameters (speed of walking, cadence, and step length) when orthotic gait training was provided for children with MMC.

Methods

Subjects

Five children (2 girls and 3 boys) with MMC, aged 7 to 12 years, participated in this study (**Table 1**). The neurologic lesion levels of the participants were T12 (2 subjects), L2 (2 subjects), and L3 (1 subject). As expected, the participants had a wide variety of foot and ankle deformities. Radiographs showed no dislocation of the hip in these children. The participants had active hip flexion, and one child had scoliosis spinal deformity. To be candidates for this study, youth could have mild equinus deformities that could be accommodated easily with heel wedges, knee flexion contracture less than 20°, hip flexion contracture 30° or less, age older than 6 years so as to better understand the gait-training programs, family support, high patient motivation, and good upper extremity strength. Spasticity or other involuntary activity of lower limbs muscles that reduced the passive range of motion in lower limb joints and obesity were considered as exclusion criteria.³³ The body mass index (BMI) of each child was calculated and compared with the BMI-for-age growth chart. By using the growth chart, each child's percentile was determined. The BMI-for-age 95th percentile

Table 1. Demographics of the participants

Subject no.	Sex	Age, years	Weight, kg	Height, cm	Lesion level	Assistive device
1	F	7	18	93	T12	Crutches
2	M	8	19	95	T12	Crutches
3	F	8	17	100	L2	Crutches
4	F	1	26	109	L2	Crutches
5	M	1	34	124	L3	Crutches

or above was considered as obese. The University of Social Welfare and Rehabilitation Sciences approved this study, and informed consent was obtained from each child and family before participation.

Orthosis

Each child was fitted with an IRGO with reciprocating hip joints and ring-locking drop lock orthotic knee joints. The solid ankle-foot orthosis (AFO) portion of the IRGO was custom molded to the patient's lower limbs. **Figure 1** shows an IRGO that was used in this study.

After providing the orthoses, the children received 2 hours of gait training per day for 5 days per week, over an 8-week period. The gait training

program also included passive stretching of the lower extremities, upper limb strengthening, and balance training with the orthosis while standing and walking. All gait training was performed by the same therapist with expertise in walking and standing in children with paraplegia. Thirty minutes were needed for the stretching exercises, and upper limb strengthening was conducted for 30 minutes; balance training was performed for another 30 minutes per day. Each subject was discharged from the clinic and asked to return to the gait analysis laboratory for data gathering. Approximately 1 hour of the 2-hour gait training session was typically taken up by the walking and standing activities. Once each child achieved a satisfactory level of standing ability (ie, safe and stable), gait training with the IRGO was initiated (**Table 2**).

Gait analysis

For each participant, the gait was analyzed twice – at baseline and after 8 weeks of gait training. The children had no ability to walk without orthosis; therefore, the gait analysis without orthosis condition was not possible with the MMC participants in this study. The baseline data was gathered after the IRGO was fitted for MMC participants without any orthotic gait training. Therefore for evaluation the effect of the orthotic gait training effect, walking with orthosis without gait training was considered as the baseline condition.

Temporal-spatial and kinematic data were collected for each child in a gait laboratory when he or she was walking with the IRGO and the respective walking aids (**Table 3**). Gait information was obtained by using the Vicon digital motion capture system (Oxford Metrics, UK, 640), using 6 cameras (Vicon, Infrared) at a frequency of 100 HZ and 2 force platforms (Kistler 9286BA, Switzerland). Markers were placed on the orthosis for the lower limb sections and on the child's torso at the following positions: bilaterally over the position of anterior superior iliac spine (ASIS), the greater trochanter, the lateral condyle of the femur, the head and lateral malleolus of the fibula, the second metatarsal, calcaneus, and over the jugular notch, the spinous process of the seventh cervical vertebrae, and the acromio-clavicular

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

Table 2. Content of overground training program for orthotic gait rehabilitation

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 MMC subjects learned sit-to-stand and stand-to-sit with the IRGO. While standing, the subjects learned to balance with one hand lifted for 30 seconds, and then with both hands lifted for about 10 seconds. The participants also learned to use the walker (first to second week of gait training period) and crutches (third to eighth weeks of gait training time) to prevent a fall in the forward, backward, and diagonal directions by moving both crutches and walkers simultaneously to stop the fall. The subjects were educated in trunk extension and postural control in standing with orthosis associated with walker or crutches.	10 minutes
Stage 4	Balance training with the orthosis while walking	Participants also learned to use the walker and crutches to prevent a fall in the forward, backward, and diagonal directions by moving both crutches and 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 (for example 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 subjects walked with orthosis associated with a walker in the first and second week of gait training period. Once the subjects were trained in using IRGO and walker, walking with IRGO and crutch was started. All subjects walked with a crutch for the gait analyses.	60 minutes

Note: MMC = myelomeningocele; IRGO = isocentric reciprocating gait orthosis.

Table 3. Hip joint range of motion (ROM) and spatial-temporal gait parameters in MMC children walking with orthosis at baseline and after gait training with IRGO

		Walking with orthosis at baseline				Walking with orthosis after gait training with IRGO				<i>p</i> value
		Mean $\pm$ SD	Median	Max	Min	Mean $\pm$ SD	Median	Max	Min	
Walking speed, m/s		0.28 $\pm$ 0.03	0.29	0.32	0.25	0.32 $\pm$ 0.03	0.32	0.37	0.29	.042
Step length, cm		29.06 $\pm$ 1.70	30	30.40	26.40	32.90 $\pm$ 2.23	32.40	35.70	30.20	.043
Cadence, steps/min		58.20 $\pm$ 9.36	59	72	49	59 $\pm$ 9.06	53	73	53	.498
Hip ROM, degrees		7.40 $\pm$ 3.91	8.30	10.50	0.60	11.6 $\pm$ 1.7	11.40	14.20	9.80	.043
Compensatory motion, mm	Lateral	18.80 $\pm$ 2.16	20	21	16	16.4 $\pm$ 1.81	17	18	14	.038
	Vertical	14.40 $\pm$ 0.89	15	15	13	11.4 $\pm$ 1.14	11	13	10	.041

joints. A trial included 3 to 6 complete gait cycles of the MMC children walking along the walkway in a straight path. Depending on the participant's preparedness, each participant had 3 to 5 practice

walks along the walkway for conditioning before the actual trials were performed. For gait analysis purpose, 3 trials were collected for each child when walking with the IRGO. The MMC participants

reported no fatigue during data collection time with the orthosis. The compensatory motions were analyzed by measuring the maximum horizontal excursions of the shoulders and the maximum vertical excursion of the C7 vertebral body using markers placed on these positions.³⁴

Statistics

Due to the small sample size in this study, the Wilcoxon signed rank test as nonparametric test was used for comparing means of parameters. The SPSS statistical software was used for analysis of the data. The level of significance was set at .05.

Results

Table 3 shows the mean and *SD* of temporal spatial data in MMC children walking with orthosis at baseline and after 8 weeks of gait training with IRGO. All MMC participants walked at a comfortable speed, which was about one-third of the typical speed reported by healthy children.²⁶ The speed of walking with the IRGO was significantly greater after gait training compared to baseline, 0.32 m/s versus 0.28 m/s, respectively ($p = .042$). The mean of step length and cadence increased significantly in MMC children when compared to the baseline (**Table 3**). The mean hip joint range of motion during walking was $7.40^\circ \pm 3.91^\circ$ and $11.6^\circ \pm 1.7^\circ$ with IRGO at baseline and after 8 weeks, which was significantly different ($p = .043$). The participants had high compensatory motions in walking with IRGO at baseline that significantly improved 8 weeks after gait training (**Table 3**).

Discussion

The walking ability in MMC patients is related to the neurological level and severity.³⁵ Factors like sufficient upper limb strength, spinal stability, present active hip and trunk movement, and adequate ability to raise pelvis affected the walking ability in MMC children.³⁶ Dall et al suggested that the reciprocal link is minimally important in leg swing when RGOs were used for walking in paraplegic patients.³⁷ In addition Johnson et al demonstrated that the use of orthoses and assistive

devices alone has limited effects on the improvement walking parameters in children with MMC. In the paraplegic patients, trunk and pelvis motion contributes more to leg swing than elements of the orthosis such as the reciprocal link in the ARGO and IRGO.²⁶ It seems that orthotic gait training has an important role in walking rehabilitation in children with MMC. The main purpose of this study was to determine the influence of gait training with an IRGO on the improvement in walking speed, step length, cadence, compensatory motion, and lower limb joint range of motions in children with MMC who presented with lower limb paralysis.

The mean speed of walking and step length were found to be reduced when compared to the typically developed children at baseline and following training.²⁶ The speed of walking and step length can be affected by the hip joint range of motions. Our results demonstrated that all patients had small hip flexion and extension ranges of motion at baseline, but these parameters demonstrated significant improvement after 8 weeks of orthotic gait training. The hip joint movement that is created is assumed to be the result of hip flexors contraction, trunk movement, and compensatory motions. The rocker bar reciprocator link may have less effect on providing joint movement in walking, whereas trunk and pelvic movements contribute more to the leg swing. Dall et al reported that the reciprocal link has a minimal effect on leg swing.³⁷

In the present study, at baseline, the compensatory motions were high when walking with the IRGO, but a significant improvement in these parameters was found after 8 weeks of gait training. The children with MMC used their trunk muscles to ambulate with the IRGO. In this way, the vertical and lateral compensatory motions can be produced by excessive lateral bending of the trunk. Gait training for 8 weeks with the IRGO decreased these compensatory motions compared to baseline. Orthotic gait training with a powered hip orthosis in SCI subjects has demonstrated similar results.³⁸ Mechanically improving RGOs may further reduce the energy consumption of walking with an orthosis by reducing their weight and design of hip joint with maximal rigidity in the coronal plane.^{18,23} The use of a powered gait orthosis can be considered as one solution to this problem.^{39,40} Ohta et al³⁹ and Arazpour et al⁴⁰

reported positive effects of powered orthosis on the improvement of compensatory motion in SCI patients. Using actuators to provide active motions in hip joints to prepare leg swing could be a solution for this problem. Powered lower limb orthoses are an advanced approach in the rehabilitation and walking in paraplegic patients.³⁸ Using custom-powered IRGO compared to mechanical IRGO had a better improvement on walking parameters in SCI patients.⁴⁰ However, the efficacy of this type of assistive device on walking in MMC has not been reported. The use of a powered gait orthosis in the rehabilitation of walking in MMC patients could potentially be beneficial and should be considered as a future area of research in this field.

Comparison with other studies

The results of our study showed that the selected gait parameters after 8 weeks of gait training with an IRGO were better than that reported in previous studies with mechanical orthosis in MMC children. The literature demonstrates that energy consumption is less with IRGOs compared to HKAFO and other RGOs.⁴¹ The positive effect of the IRGO compared to an HKAFO has been demonstrated previously in children with MMC.²⁴ Although no previous literature exists on the influence of orthotic gait rehabilitation in walking in children with MMC, many researchers have demonstrated a positive effect of orthotic gait training with PHO and IRGO in SCI patients.^{31,32}

Despite the perceived advantages of standing and walking and the more cosmetic gait provided by RGOs, noncompliance with this particular device is high; 61% to 90% in children with MMC discontinue use of their RGOs.^{9,27} RGO users considered their orthosis to be exercise equipment.^{9,27} Orthotic gait training with associated improvement of walking parameters and less energy consumption may improve compliance with continued use of their RGOs.

Similar to many previous studies on walking with an RGO, a limitation of this study was the small and heterogeneous sample. Having patients with different levels of injuries can produce different muscle strengths, passive range of motions of the joints, degrees of spasticity, and levels of sensation. Future studies with larger sample sizes

of MMC patients walking with orthosis would be beneficial. In addition, the analysis of injured level on the walking parameters during orthotic gait in the MMC subjects will be beneficial in this field. Because the participants in the study were all new users of the RGO, we would not assume that 8 weeks of training would improve gait parameters simply because they had never been trained before. Another comparative study will be beneficial in this field.

The results of this study suggest that more studies are needed to further increase our knowledge about walking with RGO in children with MMC. Studies should also further investigate the effects of IRGO on posture, arm loading, and energy expenditure. This additional data may improve the RGOs' design or the walking pattern of patients and therefore result in more efficient walking with RGOs. Improvement of walking has the potential to increase the quality of daily life in these children, and further studies in this area will be beneficial to the neurological and rehabilitation fields.

An IRGO cannot be a totally suitable replacement for wheelchairs in paraplegic patients for ambulation.⁴² In our study, gait training with an IRGO improved the walking parameters compared with baseline in the MMC subjects. Their effect probably could be due to the increased endurance with the use of orthosis.

Conclusion

Gait training with orthosis can influence the walking ability and walking parameters in children with MMC. This study demonstrated that orthotic gait training improved hip joint range of motions, increased walking speed and step length, and decreased lateral and vertical compensatory motions during level-ground walking trials.

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