The Influence of Rocker Bar Ankle Foot Orthosis on Gait in Patients with Chronic Hemiplegia

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Background: This study aimed to evaluate the effect of rocker bar ankle foot orthosis (RAFO) on the spatiotemporal characteristics of gait in chronic hemiplegic patients compared with the effect of solid ankle foot orthosis (SAFO). *Methods:* Following ethical approval, 18 patients with chronic hemiplegia, at least 6 months post stroke, were investigated in barefoot condition, with SAFO and RAFO in random sequences. Their spatiotemporal characteristics were examined by 2 force platforms and a Vicon motion analysis system. *Results:* There were significant changes in spatiotemporal outcome measures between barefoot condition and using SAFO and RAFO ($P < .05$). Compared with SAFO, RAFO resulted in significantly more step length, faster gait velocity, and less preswing time ($P < .05$), although no significant differences were seen regarding step width and cadence ($P > .05$). Furthermore, RAFO led to significant increases in hip extension and knee flexion at toe-off, whereas SAFO did not change these parameters ($P < .05$). *Conclusion:* Findings of the present study showed that RAFO further improves gait abilities in chronic hemiplegic patients compared with SAFO, which could be due to the positive effect of added rocker bar on push-off function during the late stance phase of gait. **Key Words:** Rocker bar ankle foot orthosis—gait—patients—hemiplegia.

Introduction

Stroke is a main cause of disability worldwide.[1] Hemiplegia secondary to stroke may lead to functional difficulties in standing and walking.[2] Hemiplegic patients usually suffer from impaired and uncoordinated limb movements. Weak muscles, abnormal synergic movements, and spasticity contribute to poor balance, impaired gait, and enhanced energy consumption in stroke patients during gait.[3] Generally, a gait cycle starts when 1 foot contacts the ground and terminates when the same foot contacts the ground again, and includes 2 phases: the stance phase, which is approximately 60% of the gait cycle, and the swing phase, which includes about 40% of the gait cycle. Stance is a part of the gait cycle that the foot is in contact with the ground, and swing is the part that the foot is in the air.[4] Insufficient dorsiflexion at the ankle during swing, mediolateral ankle instability during swing and stance, and inappropriate push-off at late stance negatively change the gait pattern and lead to decreased speed,

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diminished cadence, shorter steps, and lack of sufficient toe clearance.[5]

Ankle foot orthosis (AFO) is mostly prescribed for hemiplegic patients to improve their balance and walking ability.[6,7] Generally, an AFO is utilized to provide mediolateral ankle stability during the stance phase, to facilitate foot clearance during swing phase, and to improve initial contact at early stance.[8]

Regarding walking, Perry and Burnfield[4] have described normal function of the foot and ankle as the combination of 3 sequential rockers: the first rocker (heel rocker), the second rocker (ankle rocker), and the third rocker (forefoot rocker). Hemiplegia damages the ankle–foot complex, and therefore, all of these 3 rockers are disrupted.[3] Previous research has mainly focused on evaluating the biomechanical, physiological, or musculoskeletal effect of AFOs on gait among people suffering from hemiplegia secondary to stroke. However, there have been some studies that have investigated the mechanisms of the AFO effectiveness. These studies have shown that a suitable AFO could successfully improve the first and the second rockers in hemiplegic patients during walking, while it has no positive effect on the third rocker or push-off.[9-11]

Thus, as improving push-off is an important function of the rocker bar modification in orthoses and prostheses,[12,13] it could be assumed that an AFO modified with a rocker bar is potentially able to improve push-off and to transfer body weight from the affected limb to the unaffected one. Consequently, the objective of the present study was to investigate the effect of rocker bar ankle foot orthosis (RAFO) on spatiotemporal characteristics of gait in patients suffering from chronic hemiplegia secondary to stroke compared with the effect of solid ankle foot orthosis (SAFO).

Materials and Methods

Patients

Table 1 shows the demographic and clinical characteristics of the patients. Eighteen chronic hemiplegic patients secondary to stroke (at least 6 months since onset) referred to rehabilitation centers, at the age of 40-70 (both men and women), voluntarily participated in the present study. All participants were able to walk independently for at least 10 m without assistive device. The spasticity in their calf muscles including gastrocnemius and soleus was maximally 2 according to the Modified Ashworth Scale. The participants had no history of surgery in their lower limbs, no deformities except for equinovarus in their affected limb that resulted from hemiplegia, and no severe cardiorespiratory or cognitive problems that negatively influence the participants' ability to perform instructed tasks. The patients were assessed for hemiparesis according to the Brunnstrom stage of lower limbs. The level of mobility of the patients was defined according to the Functional Ambulation Category.

Table 1. *Demographic and clinical characteristics of the patients (N = 18)*

Gender	Age (year), mean ± SD	Type of stroke	Weight (kg), mean ± SD	Height	Affected side	Site of the stroke lesion	Ankle joint passive ROM, (degree)	The type of AFO daily used	Sensory impairment (NIHSS score)	Months after stroke, mean ± SD	Br.s stage of lower limbs	FAC of the patients
Male: 10	57.86 ± 10.44	13 ps: Isch	72.95 ± 13	168.66 ± 13.21	L: 11	18 ps:	18	13 ps: solid	+1	25.31 ± 16	15 ps: IV	16 ps: IV
Female: 8		5 ps: Hem			R: 7	Hemisph.		5ps: hinged			3 ps: V	2 ps: V

Abbreviations: AFO, ankle foot orthosis; Br.s, Brunnstrom stage; FAC, Functional Ambulation Category; Hem, hemorrhagic; Hemisph., hemispheres; Isch, ischemic; L, left; NIHSS, National Institutes of Health Stroke Scale; ps, patients; R, right; ROM, range of motion; SD, standard deviation.

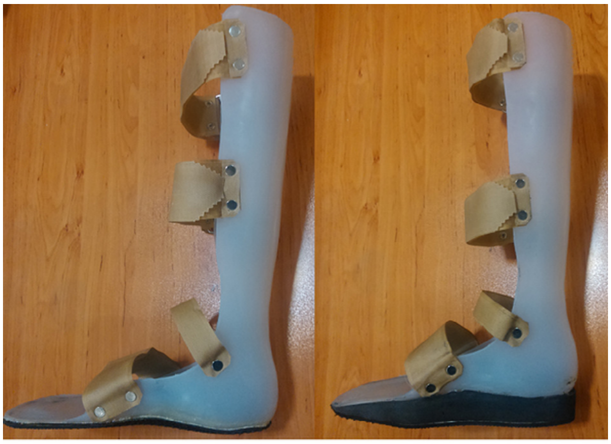

Figure 1. *(a) SAFO. (b) RAFO. Abbreviations: RAFO, rocker bar ankle foot orthosis; SAFO, solid ankle foot orthosis.*

Intervention

A custom-made SAFO and RAFO (Fig 1) were prepared by an expert orthotist for all participants. To provide SAFO, the patients' involved limb was cast while sitting on a chair. The orthosis kept the foot and ankle at 90° to the lower leg (neutral plantigrade position), and both dorsi- and plantar-flexion movements were restricted. AFOs were made from a 3-mm-thick polypropylene sheet. The foot plate was full length, extending from the heel to the tip of the toes. In order for the foot and ankle to be in a secured position, 4 straps, which tightly held the ankle–foot complex in the AFO, were used. A rocker modification was attached to the inferior portion of the SAFO to prepare RAFO, which was made of ethylene vinyl acetate rubber with standard hardness (shore-A 30-40) for the midsole and a rough hard rubber (shore-A 50-60) for the outsole. The same rough hard antislipping rubber (shore-A 50-60) with 2-mm thickness was attached to the sole of the SAFO to prevent slipping in the SAFO utilizing condition. The rocker modification attached to the SAFO to prepare RAFO was 2-cm thick, and its angle was 15° starting slightly from the proximal to the metatarsal heads (almost 65% of the foot length relative to the back of the heel). Also, the thickness of the foot part of the AFOs and rocker modification were compensated with a matched footwear worn by the uninvolved limb.

Procedure

Spatiotemporal characteristics of the participants' gait using 2 force platforms (Kistler 9286BA, Winterthur, Switzerland) and a Vicon motion analysis system with 6 infrared cameras (Oxford Metrics, Oxford, United Kingdom) were examined. Step length (centimeter) from the paretic to the nonparetic side, which was normalized to body height, cadence (step per minute), and gait velocity (meter per minute), was measured as a basic parameter to evaluate the effect of SAFO and RAFO on the patients' overall gait ability. Also, as a rocker bar added to the forefoot portion of the AFO was hypothesized to improve patients' gait characteristics in the late stance phase of gait (push-off), hip extension (degree), knee flexion (degree) at toe-off, and preswing time (seconds) were examined as well. The data were processed at a sampling frequency of 100 Hz with Vicon Bodybuilder (Oxford Metrics) using the standard model of the lower limbs. Obtained data were analyzed using MATLAB (MathWorks, Natick, MA). In total, 18 markers were utilized and placed bilaterally on the acromion process, the anterior superior iliac spine, the greater trochanter, the lateral condyle of the femur, the head and lateral malleolus of the fibula, the second metatarsal, the calcaneus, over the jugular notch, and the spinous process of the seventh vertebrae. The participants were examined barefoot, with SAFO and RAFO in random sequences. They were instructed to walk at their self-selected (comfortable) speed. At least 3 trials were performed by the participants in each condition, and the average data of the trials was considered for final evaluation. Means and standard deviations were calculated for data analysis. There was a 5-minute rest time between each trial and each test. All the tests were performed on the same day. All participants signed an informed consent prior to performing the tests. Furthermore, the current study received ethical approval from the Medical Ethics Board at the University of Social Welfare and Rehabilitation Sciences.

Data Analysis

Repeated measures analysis of variance test was utilized to investigate the differences among outcome measures. Also, Tukey's honestly significance difference post hoc tests were used to identify specific differences between the 2 groups. SPSS statistical software version 16.0 (SPSS Inc., Chicago, IL) was utilized for the data analysis. The level of significance was set at $\alpha = .05$.

Results

Table 2 gives information with regard to the spatiotemporal parameters of the patients walking in the following 3 conditions: barefoot, with SAFO, and with RAFO. There were significant differences between barefoot condition and using SAFO and RAFO in spatiotemporal parameters. SAFO and RAFO resulted in significant increases in gait velocity, cadence, and step length of the patients during walking ($P < .05$). Step width significantly decreased when the patients utilized SAFO and RAFO ($P < .05$). No significant difference was seen between barefoot condition and using SAFO with regard to hip extension and knee flexion at toe-off ($P > .05$), whereas RAFO enhanced hip extension and knee flexion at toe-off ($P < .05$). SAFO and RAFO significantly diminished preswing time in the late stance ($P < .05$). Regarding

Table 2. *The mean ± SD of gait parameters in 3 conditions: barefoot, with SAFO, and with RAFO*

Parameters	Barefoot	SAFO	RAFO	P1	P2	P3
Gait velocity (m/s)	.35 ± .11	.44 ± .14	.50 ± .17	.034	.010	.039
Cadence (step/min)	57.44 ± 9.18	63.38 ± 7.33	65.22 ± 8.46	.031	.026	.194
Step length (cm)	35.21 ± 7.60	41.97 ± 8.39	45.56 ± 8.55	.037	.018	.047
Step width (cm)	17.77 ± 6.12	14.50 ± 5.34	15.08 ± 6.91	.028	.041	.294
Hip extension at toe-off (degree)*	+13.50 ± 11.81	+11.36 ± 8.02	+3.41 ± 6.22	.563	.007	.019
Knee flexion at toe-off (degree)†	+9.1 ± 5.62	+10.73 ± 7.29	+18.75 ± 9.10	.632	.005	.017
Preswing time (s)	.68 ± .24	.54 ± .15	.35 ± .18	.035	.002	.014

Abbreviations: P1, comparison between barefoot condition and SAFO; P2, comparison between barefoot condition and RAFO; P3, comparison between SAFO and RAFO; RAFO, rocker bar ankle foot orthosis; SAFO, solid ankle foot orthosis; SD, standard deviation.
*Negative (−): hip or knee extension.
†Positive (+): hip or knee flexion.

comparison between SAFO and RAFO, the patients experienced a significantly faster gait velocity and increased step lengths utilizing RAFO compared with SAFO ($P < .05$). However, no significant difference was seen in cadence and step width between using SAFO and RAFO ($P > .05$). Also, RAFO led to significantly more hip extension and knee flexion at toe-off compared with SAFO ($P < .05$). Preswing time significantly decreased with RAFO compared with SAFO ($P < .05$).

Discussion

The present study aimed to evaluate the influence of RAFO compared with SAFO on spatiotemporal characteristics of patients with chronic hemiplegia. Several studies have indicated that different AFOs could potentially improve kinetics, kinematics, and spatiotemporal parameters of gait in these patients.[7,14] Similarly, in the present study, SAFO resulted in faster gait velocity and increased step length and cadence during hemiplegic gait compared with barefoot condition. Also, when SAFO was modified with rocker bar, compared to barefoot condition, spatiotemporal parameters were significantly improved.

Both SAFO and RAFO resulted in increasing gait stability through decreasing step width during the stance phase of gait. According to the obtained data, adding rocker modification to the SAFO led to no change on patients' gait stability. Previous studies have shown that AFOs have the ability to enhance stability of walking in poststroke hemiplegic patients.[6,15]

In the current study, as a result of increasing step length, gait velocity enhanced with RAFO compared to SAFO in spite of unchanged cadence. It seems that rocker modification added to SAFO had a positive effect on spatiotemporal characteristics and resulted in obtained improvements. Previously, it had been indicated that modifying orthoses with rocker bars could positively influence walking ability in neurologically disabled patients, which is consistent with the finding of the present study.[16,17] Rocker bar modification, in addition to removing forces from special parts of the foot, improved weight transferring and increased progressive forces during the stance phase of gait, and consequently could potentially influence knee–ankle–foot function.[12,13,16,17] In the present study, when participants used RAFO, preswing time in the stance phase of gait was significantly less than when they used SAFO or were barefoot. This finding is consistent with previous research which has indicated that rocker bar modification contributes to improve rocker function of the foot and ankle, which is necessary for push-off.[6,9,13,16]

Furthermore, our results showed that hemiplegic patients had less hip extension and knee flexion at toe-off compared with healthy people. Also, SAFO did not change the mentioned parameters significantly during walking. Our findings were consistent with previous studies which concluded that SAFO does not have a positive influence on forefoot rocker.[10,11] However, RAFO increased hip extension and knee flexion by 10° and 9°, respectively, at toe-off compared with barefoot condition. These results were similar to that of previous research,[17] and emphasized more on the probability of the positive effectiveness of forefoot rocker modification on improving push-off in hemiplegic patients using AFO.

It seems that RAFO resulted in more knee flexion, helped to shorten the lower limb, and consequently resulted in better toe-off. These results were consistent with previous studies too.[9,12] However, in the present study, only the immediate effect of RAFO was investigated, and authors of the present study suggest that gait training could better show the efficacy of rocker modification added to the AFO on walking abilities in patients with hemiplegia secondary to stroke.

The findings of the current study indicated that RAFO increased spatiotemporal parameters in poststroke hemiplegic patients. The results of the present study can provide hemiplegic patients secondary to stroke and rehabilitation professionals with valuable data regarding the effect of AFO with rocker modification on gait abilities. According to the results of the present study, RAFO may provide further improvement in hemiplegic gait compared to SAFO.

The first limitation of the present study that should be taken into consideration is the addition of 2-cm height to the sole of the AFO, which could potentially affect the gait parameters, although this measurement may be small. Thus, it is suggested that in the next studies, to eliminate the effect of sole height, the rocker bar be added to the sole of the shoes, and the effect of AFOs be evaluated while patients are wearing same-height shoes in all conditions.

The second limitation of the present study was having only 2 force platforms and recording only 1 step of the patient's gait. Examining only the immediate effect of the orthoses was the third limitation of the present study. Thus, evaluation of long-term effectiveness of RAFO should be done in further research. The small number of patients was the last limitation in our study. Therefore, the authors of the present study suggest evaluation of the RAFO in studies with larger sample sizes and different gait assessment parameters.

Finally, it is concluded that a RAFO could improve gait abilities in poststroke hemiplegic patients and has the potential to be an alternative for SAFO, although more studies need to be conducted to prove this finding.

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