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Comparison of the Effects of Pneumatic Ankle-foot Orthosis and Posterior Leaf Spring Ankle-foot Orthosis on Spatiotemporal Parameters of Gait and Ankle Range of Motion in Patients with Stroke: A Preliminary Study

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ABSTRACT

Background: Chronic stroke patients face impairment due to ankle dorsiflexor weakness that can influence their ankle kinematics and gait. The objective of this study was to compare the effects of a pneumonic ankle-foot orthosis (AFO) with those of a posterior leaf spring (PLS) AFO on the spatiotemporal parameters of gait and ankle range of motion in hemiplegic stroke patients.
Methods: In this cross-sectional study, 5 participants with chronic stroke were tested during one session under three conditions: without orthosis, with pneumatic AFO, and with PLS-AFO. Spatiotemporal gait parameters and ankle joint range of motion were measured with a motion analysis system.
Results: The results indicated that the pneumatic orthosis can improve gait speed in comparison with no orthotics (P=0.04). No significant difference was seen regarding other evaluated spatiotemporal parameters and ankle range of motion under different orthotic conditions.
Conclusion: The comparison of the immediate effects of the pneumatic ankle-foot orthosis and those of the posterior leaf spring ankle-foot orthosis showed that in comparison with no orthosis or with PLS-AFO, the pneumatic orthosis could improve gait speed, but had no effect on cadence, step length, or ankle range of motion in chronic stroke patients.

Introduction

Stroke is a neurovascular disorder that leads to brain damage. It can be caused by blockage of the blood supply to the brain (ischemic) or rupture of the cerebral artery that destroys brain tissue (hemorrhagic) [1, 2]. Stroke is the third leading cause of death in the world, and the risk of stroke increases with age [3]. Stroke patients face problems such as decreased muscle strength, spasticity, reduced joint movement, reduced reflex and sensation, and abnormalities in walking [3-5].

It is expected that stroke patients will be able to continue their normal daily activities with the least support after completing the rehabilitation process [4, 6]. One of the most important goals in stroke rehabilitation is to improve and increase the patient's walking abilities. Weakness in the ankle dorsiflexors, such as the tibialis anterior muscle, is a common disorder in stroke patients [7-9], and it can result in the toes being thrown to the ground upon initial contact and pulled to the ground during swing phases of the gait [10].

Under normal conditions, weight transfer is done in two stages: first in heel contact, and second in the preswing [6]. In stroke patients, weight tolerance in the

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involved leg is decreased, which may lead to instability and increased extra movement. Moreover, the weight from one leg is not transferred properly to the other leg, which can disrupt the gait's rockers and increase the risk of falling [11]. In addition, wider step width, increased double support time, and single support time of the unaffected side in stroke patients could reportedly reduce walking speed and lead to an asymmetrical gait [2].

One common rehabilitation intervention for improving the walking abilities of stroke patients is the use of assistive devices, especially ankle-foot orthosis (AFO). In cases of anterior tibialis muscle weakness, an AFO can help the patient by placing the ankle in a neutral position in the stance and swing phase, restore toe clearance and protect the toe from the ground in the swing phase, and prevent abnormal rotations in the ankle when the heel is put on the ground [12-14].

Another goal in prescribing different AFOs is to restore gait rockers. The first rocker actually has the braking role, and the third rocker has a progressive role that accelerates the patient's walking. Orthoses are modified to reduce the normal rocker speed by decreasing the role of the first rocker brake and increasing the role of the third rocker. The resistance to plantar flexion and dorsiflexion moment of the ankle is reduced, and thus, the heel contact with the ground is more stable [15-17].

The AFOs usually used to restore various gait requirements in stroke patients are passive (non-articulate or articulated) and active types (with actuator, sensor, and control system) [10]. Passive AFOs provide support to the plantar aspect of the foot, facilitate shock absorption, and provide some assistive force for propulsion. Some types of non-articulate AFOs, such as posterior leaf spring (PLS) AFOs, can integrate energy storage and assist elements into its structure [18].

Among the articulated systems, the dorsiflexion assist controlled by spring (DACS) AFO and the PneumaFlex AFO rely on a passive mechanism operating with compressed air and elastic springs, respectively, to apply a dorsiflexor torque. The DACS-AFO has two thermoformable plastic pieces that connect with joints on the medial and lateral sides of the ankle [19]. An embedded spring on the dorsal side of the shank provides a dorsiflexor toque. The PneumaFlex used pneumatic springs in place of mechanical springs to more easily modulate the stiffness of the passive element for patient-specific tuning [20]. To the best of the authors' knowledge, no published works documenting the performance of such design or comparing their benefits to other designs exist. The aim of the current study, therefore, was to investigate the immediate effects of the pneumatic AFO and compare it with those of the PLS-AFO on the spatiotemporal gait parameters and ankle range of motion in stroke patients.

Methods

This cross-sectional observational study was performed on hemiplegic stroke patients selected from among those who referred to rehabilitation centers affiliated with Isfahan University of Medical Sciences (IUMS). The protocol of the study was approved by the Ethics Committee of Isfahan University of Medical Sciences (ethics code: IRMUI.EC.1397.30.20).

Four men and one woman were recruited based on the inclusion criteria: 18 years of age or older [21], at least six months have passed since the stroke [17, 21], able to walk about 20 meters independently without any assistive devise [5, 22], no post-traumatic surgery [11, 16], able to follow individual instructions and use training aids [2,15], and able to stand and transfer weight without auxiliary equipment [5, 16, 22]. Patients with the following conditions were excluded: wheelchair-bound [16], lower limb fixation or spasticity [10, 17, 21], knee or hip contractures [23], lower extremity, neuromuscular, or neurological disease [24], history of recurrent stroke, or surgery in the past 6 months [23, 24].

All participants signed a consent form which was approved by the Ethics Committee of IUMS. The demographic information of each patient was recorded on a questionnaire designed for this purpose. Table 1 shows the demographic characteristics of the participants.

Patients were evaluated in three orthotics conditions: with no orthosis, with PLS, and with pneumatic AFO. The PLS is a thermoplastic, non-articulated flexible ankle-foot orthosis that stabilizes the ankle and acts as a spring due to its flexible posterior position (Figure 1).

The pneumatic AFO has a basic structure consisting of a calf and a foot section attached posteriorly with a pneumatic-mechanical jack (Figure 2). The jack creates freedom of movement for the patient's ankle joint and was semi-compressed relative to its lever length at the middle. The back of the leg and the back of the ankle were tied together so that the orthosis was adjusted to 25 degrees of ankle flexion. The pneumatic AFO controls plantar flexion and prevents drop foot by placing the foot in dorsiflexion. It also improves the rocker in the gait cycle by creating a slight gradual flexion in the static phase [23].

The patients walked on a 3-meter pathway in the laboratory. The force data was calculated by Kistler force

Table 1: Demographic characteristics of participants

Patients	Age (years)	Height (cm)	Weight (kg)	Affected side
1	46	158	70	Right foot
2	55	168	68	Left foot
3	65	142	58	Right foot
4	46	162	78	Right foot
5	40	180	78	Right foot
Mean	50.4	162	70.4	NA
SD	9.76	13.92	8.29	NA

SD: standard deviation, NA: not applicable

Figure 1: Posterior leaf spring ankle foot orthosis

Figure 2: Pneumatic ankle foot orthosis

Table 2: Mean (standard deviation) of ankle joint range of motion and spatiotemporal gait parameters of patients in various orthotic conditions

	No orthosis	PLS AFO	Pneumatic AFO	F statistic	P value
Ankle joint ROM (degree)	23.67 (8.36)	19.55 (3.22)	18.55 (5.36)	0.70	0.52
Cadence (steps/min)	31.4 (0.23)	31.6 (0.26)	29.6 (0.15)	0.25	0.74
Speed	0.47 (0.20)	0.48 (0.19)	0.61 (0.27)	8.79	0.04*
Step length	17.0 (12.0)	18.6 (10.0)	32.8 (18.7)	1.89	0.21

AFO: Ankle foot orthosis, ROM: Range of motion, *Significant differences are set at P<0.05.

plate (model; 9260AA6), and spatiotemporal parameters were collected by the Qualisys motion capture system. Visual 3D software was used to create biomechanical models. Information such as walking speed, cadence, step length, and ankle joint kinematics were measured for each individual. Each test was repeated 3 times to ensure the accuracy of the test. To avoid the negative effect of fatigue on the test process, a 10-minute rest period was considered between conditions.

For data analysis, the SPSS software (version 21; SPSS, Inc., Chicago, IL) was used. Mean, standard deviation, and standard error rate were used to describe the data. To assess differences among the three conditions, the repeated measure ANOVA statistical method was used. A P value less than 0.05 was considered as the significance level.

Results

Findings of repeated measures ANOVA showed no significant difference in ankle joint range of motion in the sagittal plane when using the PLS AFO, pneumatic AFO, or no orthosis (P=0.52). The patients' cadence in the 3 orthotic conditions was not significantly different (P=0.79). There were some differences in walking speed between the orthotics conditions, and statistical analysis showed that the pneumatic AFO had a significant effect on the participants (P=0.04). No significant effect of orthotics was seen during the walk on the stride length of evaluated patients (P=0.210). Table 2 shows the results of the comparison of various orthotic conditions.

Discussion

The results of the current study indicated that the immediate use of the pneumatic AFO significantly improved gait speed in comparison with no orthosis in stroke patients, although the pneumatic AFO used herein could not improve ankle ROM, cadence, or step length in these patients. The findings also showed no improvement in the evaluated parameters with the immediate use of the PLS-AFO compared to no orthosis. In addition, higher gait speeds were obtained using the pneumatic AFO than with the PLS-AFO.

Because the effects of pneumatic AFOs on stroke patients have not been previously investigated, the comparison of the current results with those of other studies is difficult. Taiar et al. investigated the effects of the MecaFlex orthosis, an orthosis with a spring cylinder, on 7 patients with different pathologies [25]. The MecaFlex orthosis used a similar mechanism as the pneumatic orthosis investigated in the present study. Similar to the current study, Taiar et al. found that the AFO can increase step length and step velocity. They concluded that by improving gait frequency and amplitude (step length), the orthosis could enhance the patients' stability, balance, and weight distribution.

The current results are also in line with those of Yamamoto et al. [19], who investigated the effects of the DACS-AFO on the gait of hemiplegic patients. Their results showed improvement in walking speeds and smoother gaits. The DACS-AFO has a similar mechanism for controlling ankle ROM as the current pneumatic AFO. In this AFO, an embedded spring on the dorsal side of the shank provides dorsiflexion toque that prevents an uncontrolled deceleration of the foot.

In the present study, no improvement in ankle ROM by using the pneumatic AFO was observed. This is in contrast with the results of a previous study that showed improvement in ankle ROM with the use of a pneumatically inactive operator AFO in the static phase of the gait [26]. This controversial result may be due to different action mechanisms of the pneumatic structures that were used in these two studies.

Regarding the effects of the PLS-AFO, no significant difference was found for ankle ROM, cadence, walking speed, or step length in comparison to the no-orthosis condition. These results are in line with those of Lewallen et al., who investigated the effects of solid, PLS, and articulated AFOs on the gaits of patients with cerebral vascular accident [27]. They reported no improvement in step length, single support time, or speed in patients using these orthoses. In contrast, Gok Haydar et al. showed that plastic and metal AFOs improved ankle dorsiflexion, velocity, cadence, and step length in stroke patients [28]. These improvements were not supported by the present results.

The current study was faced with some limitations. Primarily, a small sample size was selected for the current study; increasing the number of participants may provide better insight into the assessment of the effects of such devices. Secondly, only the immediate effects of the orthoses were investigated; kinetic gait parameters were not considered in this study. Further studies should evaluate the long-term effects of these AFOs considering both kinetic and kinematic parameters.

Conclusion

The comparison of the immediate effects of a pneumatic ankle-foot orthosis with those of a posterior leaf spring ankle-foot orthosis showed that the use of the pneumatic AFO compared to no orthosis or the use of a PLS-AFO could improve gait speed, but had no effect on cadence, step length, or ankle range of motion in chronic stroke patients.

Conflict of Interest: None declared.

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