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A Comparison the spatiotemporal efficiency of two designs of Posterior Leaf Spring (PLS) and pneumatic damper ankle-foot orthoses (AFO) in drop foot

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Abstract

Background: Drop foot syndrome is a disorder with foot slapping after the initial contact and foot-dragging during the swing phase. Passive and hybrid passive ankle foot orthoses (AFOs) are often prescribed in these patients. Although, the effects of these AFO designs on spatiotemporal parameters during gait in passive ankle foot orthoses were investigated in many studies, the effect of different types of hybrid passives of these AFOs in these parameters seem unclear.

The aim of current study was to compare the efficiency of newly designed pneumatic damper ankle-foot orthoses (PD-AFO) with posterior leaf spring ankle-foot orthoses (PLS AFO) in drop foot.

Methods: For this reason, ten drop foot patients were recruited for this study, walked at self-selected comfortable speed and three dimensional motion analysis systems were used to obtain spatiotemporal gait parameters.

Results: Pneumatic damper AFOs were showed significantly increase in the speed, cadence, step width, percent of single support time, percent of double support time, step and stride time on the paretic side and step length ($p<0.005$).

Conclusion: This newly designed pneumatic damper AFO significantly improved spatiotemporal parameters than PLS AFO.

Keywords: Drop foot, Ankle foot orthosis, spatiotemporal parameters, Gait

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Introduction

Drop foot syndrome is recognized as a disorder, in which the ability for raising the foot from the floor is disrupted during the swing phase, and would lead to reduce in speed, step length and leg propulsion [1, 2].

Conventional passive AFOs, such as the posterior leaf spring AFO, are almost rigid to immobilize the ankle joint at a near right angle [3]. This design allows few degrees of plantar flexion at the loading response, which is not ideal for providing enough resistive mechanisms to reduce the speed of the foot slap at the beginning of the stance phase, preventing excessive knee flexion moment during loading response, reduce pre-tibial muscles activities, and muscle

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↑***What is "already known" in this topic:***
Using conventional passive AFOs in drop foot with extra elements like springs, dampers, wires or different types of pneumatic and hydraulic dampers were developed.

→***What this article adds:***
A newly designed hybrid passive AFO with pneumatic damper AFO has disadvantage like dorsiflexion during the swing phase and plantar flexion during the mid-stance loading response.

atrophy [4, 5].

To respond these challenges, extra elements like springs, dampers, wires or different types of pneumatic and hydraulic dampers were added to AFOs [4, 6]. These elements worked to obtain near normal walking and provide enough toe clearance at the swing phase [6, 7].

This study presented a newly designed hybrid passive AFO with pneumatic damper AFO to cope with some of the previous designed hybrid passive AFO disadvantage like dorsiflexion during the swing phase and plantar flexion during the mid-stance loading response.

Therefore, the aim of our study was to compare the spatiotemporal efficiency of two designs of Posterior Leaf Spring (PLS) and pneumatic damper design ankle-foot orthoses (AFOs) in drop foot patients.

Methods

Subjects

The study sample included ten right side drop foot patients (7 men; 3 women), recruited from Occupational Therapy Center, Rehabilitation School of Iran University of Medical Sciences with the mean age of 65.18 (SD: 12.56). The average time after diagnosis was 23.84 months and central and peripheral nervous system damages were confirmed by magnetic resonance imaging (MRI), for the onset and diagnosis.

Prior to the clinical trial, subject's sex, age, mass, height, and self-selected gait speed were listed. All patients completed and signed informed consent forms prior to the start of this study, and the study protocol was approved by the Medical Ethics Committee of Iran University of Medical Sciences. Each participant had a confirmed diagnosis of drop foot with any reason of central and peripheral nervous system.

The inclusion criteria were a clinically observed unilateral drop-foot, ability to walk 10 m in 50 s without contact assistance which is indicated by the absence or delayed heel rise in terminal stance and problems with toe clearance at initial swing, more than -3 manual muscle test in pretibial muscle and more than >2 the Modified Ashworth Scale (MAS).

Exclusion criteria consisted of significant cardio-respiratory or metabolic disease (untreated cardiac failure, diabetes, or hypertension, and a history of abnormalities in visual/vestibular functions, emotional instability, and if they had severe peripheral poly neuropathy or a history of musculoskeletal fracture with difficulty in walking, absence of strongly manifesting spasms and contractures in lower extremity joints.

Procedures

Hybrid hydro pneumatic Ankle-Foot Orthosis: The newly designed ankle foot-orthosis is composed of a closed cycle hydra pneumatic cylinder in which the housed piston was used as an actuator. Two 10 cm bore tubes were used; air and oil were supplied to ensure air pressure did not buckle the overall mechanism, converted the air and oil power into nonlinear tension force.

This mechanism was used as a dorsiflexion actuator, resisted plantar flexion for the rest of gait sub-phases function; it converted the air and oil power into nonlinear tension force. Overall length of the actuator is much less than a traditional cylinder with a rigid rod. The bottoms of the two-foot support brackets are fused to a molded polypropylene foot support that transfers the moment to the user's foot.

The Hydra pneumatic actuator operated at pressures above 400 psi to achieve enough power density. The overall weight of this system was 450 grams. Hydra pneumatic cylinders are often used for low velocity and large linear force generation. The tuning of the Hydra pneumatic power supply was based on the required pressures and flow rates that correspond to the gait dynamics A pneumatic damper AFOs were tested in this study: made from a poly propylene with pneumatic damper mechanical elements according to the individual needs of the patients [8].

This study was performed in two visits, in the first visit with PLS and pneumatic damper AFOs, then patients wore pneumatic damper AFO for 3 weeks. The second with pneumatic damper was at least in 3 weeks intervals for adaptation with pneumatic damper AFO.

Patient were asked to walk at their comfortable, self-selected speed across ten meters walkway with selected AFOs and their own shoes at the beginning of each visits for at least 5 min to become familiar with the laboratory [9].

Six cameras motion capture system (Motion Analysis, CA, and 120 Hz) with 15 retro reflective markers affixed on the posterior sacrum, the bilateral ASIS, medial and lateral femoral condyles, medial and lateral malleoli, posterior heel counter of the shoe, and dorsally over the second metatarsal head, according to modified Helen Hayes markers setting.

Outcomes

Spatio-temporal and Kinematic were measured in participants with PLS and pneumatic damper AFOs [10-12]. Patient characteristics and descriptive outcome measures were collected.

The data were processed at 100 Hz with Qualysis Workstation [13, 14] using the standard model of the lower limbs included with the software [14, 15, 16].

Statistical analysis

Paired t-test was applied to recognize the difference between two conditions of using PLS and pneumatic damper AFOs. SPSS software statistical analysis (version 19) was used.

Results

The mean ages of participants were 65.18 years and mean times from onset of drop foot for the total group were ±23.84 months. The mean dorsiflexion in active and passive sitting were 88.10 (3.12) and 94.29 (3.00) degrees, respectively.

Outcome measures for pneumatic damper and PLS AFO

According to Table 1 significant differences were observed in the spatiotemporal parameters of pneumatic

Table 1. Results of the spatiotemporal parameters at self selected speed with PLS and pneumatic damper AFOs

Spatiotemporal parameters	With PLS AFO	With pneumatic damper AFO	sig
Cadence (steps/min)	84.3 (1.41)	96.63 (2.15)	0.000
Step length%	0.58 (.00)	0.58 (0.02)	0.738
Step width %	0.71 (0.21)	0.47 (0.11)	0.000
Stride length%	1.22 (0.154)	1.24 (0.10)	0.372
speed (m/s)	1.07 (0.106)	1.21 (0.073)	0.001

damper and PLS AFO. We have observed increases in speed ($p<0.01$), cadence ($p<0.01$) and step width in pneumatic damper design than PLS AFO ($p<0.05$). Furthermore, no significant differences were shown in for step length and stride length with pneumatic damper than PLS AFO ($p>0.05$).

Discussion

This study was aimed to compare the spatiotemporal efficiency of two designs of Posterior Leaf Spring (PLS) and pneumatic damper design ankle-foot orthoses (AFOs) in drop foot patients.

According to our study the pneumatic damper AFO significantly improved the cadence, step width, speed in drop foot patients. The results of this research was supported other studies in which wearing AFOs were significantly affected on the gait spatiotemporal parameters The importance of improvement in the spatio-temporal parameters in these patients were help to predict the likelihood of improved walking, to enhance the dynamic stability and forward propulsion in these patients, to improve the ankle joint stability with AFO, to improve balance weight bearing and to improve walking symmetry with closer step length and duration on both sides [8].

In line with some studies, wearing pneumatic damper AFO did not show significantly improved in the steps and stride length ($p>0.05$) at the self-selected speed [12, 17] in drop foot patients (8). Furthermore, while drop foot patients wear AFOs significantly increases in walking speed [18] [11, 19, 20] [21, 22], cadence [11, 18-20], step width [11, 18, 19, 23], stride length [17, 19, 20] were observed.

The possible cause of increase in these parameters can be attributed to improved dynamic stability, increased forward thrust and, consequently, an inequality in walking using inactive hybrid orthoses, especially new orthoses, in these patients. This improvements lead improvement in joint stability on the affected limb and corrected the ankle joint alignment [11, 24-27], which have reported by prior studies [11, 12, 28-30].

Speed improvement may be the result of increased in cadence and increased in the limb extension angle at toe off [11, 18, 19, 23, 31].

The following interpretations on the effects of pneumatic damper AFO on spatiotemporal parameters were showed this AFO design provided better ankle stability and step length of the non-paretic leg [11, 18-20], which leads to decrease the step length symmetry by using a pneumatic damper AFO.

The authors acknowledge some limitations for this study. One of the limitations was small population of patients. Furthermore, this study was not considering the middle to long time use of this AFO and future research should be used to examine the variability and symmetry of other walking characteristics, such as kinematics, kinetics. A one degree of freedom of articulation prevents natural ankle foot complex movement. The hydro pneumatic actuator was not adjustable.

Further research is needed to define best practice for the use of custom-fabricated pneumatic damper AFO and other traditional prefabricated AFOs like carbon fiber ones. Larger, randomized clinical trials are necessary to examine the impact of custom-fabricated spring damper AFO on gait kinetic parameters for individuals with drop foot. Further research can help to identify the best candidates for custom-fabricated spring damper AFO by allowing for motor learning in these patients. Finally, further research is needed to quantify the energy storing capabilities and impact of elements, design and fabrication techniques on the effectiveness of custom-fabricated spring damper AFO.

Conclusion

Hydro pneumatic AFO was improved spatio-temporal of foot drop patients in order to cope with different aspects of these patients and provide a chain of improvement within the ankle.

Conflict of Interests

The authors declare that they have no competing interests.

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مقایسه کارآیی مکانی–زمانی دو نوع ارتوز پوستریور لیف اسپرینگ و ارتوز با دمپر نیوماتیک در مبتلایان به افتادگی پا

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چکیده

مقدمه: سندرم افتادگی پا ضایعه‌ای است، که با برخورد ضربه‌ای پا بعد از تماس اولیه پاشنه پا با زمین و کشیده شدن سرانگشتان پا در فاز نوسان شناخته‌می‌شود. تجویز غالب در اکثر این بیماران، ارتوزهای مچ- پایی غیر فعال و هیبرید غیر فعال است. هرچند، پارامترهای مکانی زمانی در ارتوزهای غیر فعال در مطالعات بسیاری مورد بررسی قرار گرفته، تأثیر ارتوزهای هیبرید غیر فعال بر این پارامترها نامعلوم است. هدف این مطالعه مقایسه کارآیی ارتوز جدید با دمپر مکانیکی با ارتوز پوستریور لیف اسپرینگ است.

روش‌ها: به همین منظور ۱۰ بیمار مبتلا به افتادگی پا وارد مطالعه شدند، که با سرعت انتخابی در محیط آزمایشگاه راه رفتند. از سیستم آنالیز حرکت سه بعدی برای به دست آوردن پارامترهای مکانی زمانی استفاده شد.

یافته‌ها: ارتوز با دمپر نیوماتیک باعث تغییر معنی‌دار در پارامترهای زمانی مکانی سرعت، کادنس، عرض قدم، درصد مدت زمان ساپرت بر یک پا، درصد مدت زمان ساپرت بر دو پا، زمان قدم و گام و طول قدم شد (p<۰/۰۰۰).

نتیجه‌گیری: این ارتوز جدید توانست به صورت معنی‌دار باعث بهبود پارامترهای زمانی مکانی نسبت به ارتوز پوستریور لیف اسپرینگ شود.

کلیدواژه‌ها: افتادگی پا، ارتوز مچ- پایی، پارامترهای زمانی-مکانی، گیت

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