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The effect of articulated AFO with hydra pneumatic damper in biomechanical characteristic of drop foot: A pilot study

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Abstract

Background: Ankle Foot Orthosis (AFOs) are frequently prescribed in the management of drop-foot patients. However, few studies have examined the benefits of different design of Ankle Foot Orthosis with extra elements like dampers or springs. Therefore, the objective of this study was to investigate the efficacy of articulated Ankle Foot Orthosis with Hydra pneumatic damper, in kinetic, kinematic and spatiotemporal parameters of drop foot patients.

Methods: Ten drop foot patients were recruited for this study, walked at self-selected comfortable speed. A three-dimensional motion analysis, were used for obtaining kinetic, spatio-temporal and kinematic gait parameters.

Results: The articulated Ankle Foot Orthosis with Hydra pneumatic damper was significantly improved speed, cadence, step length of walking ($p<0.005$). Furthermore, the peak and mean of moment, push off velocity and energy storing/returning were significantly improved by articulated Ankle Foot Orthosis with Hydra pneumatic damper ($p<0.005$).

Conclusion: The newly designed articulated Ankle Foot Orthosis with Hydra pneumatic damper improved the ankle moment in at the loading response, power generation and the ankle range in drop foot patient.

Keywords: Drop foot, Ankle foot orthosis, Kinetic, Kinematic, Hydro pneumatic

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Introduction

Drop foot syndrome is a disordercharacterized by decrease in the capacity to raise the foot from the floor during the swing phase due to weakness or lack of voluntary control in the ankle dorsi-flexor muscles, which cause foot slap during each steps (1-4).Furthermore, steppage gait as a compensatory strategy was used in these patients by increasing the knee and hip flexion to improve the balance at the lower limbs (3, 5).

Passive AFOsare the most common non-surgical intervention, that enable these patients to walk closer to normal (6).

These AFOs were used to maintain the ankle joint in the neutral positionwithout dorsi or plantar flexion position to prevent toe dragging in the swing phase. Conventional passive AFOs, like posterior leaf spring AFO, with fixed ankle position, provide the ankle joint stability during walking while deformed. However, these AFOs cause excessive knee flexion moment during loading response and did not reduce the speed of the foot slap at the beginning of the stance phase (5, 7, 8).

To improve these parameters, extra elements such as springs, dampers, wires, or different types of pneumatic and

↑What is "already known" in this topic:
Ankle foot orthosis (AFOs) are frequently prescribed in the management of drop foot patients, with some kinetic and kinematic drawbacks.

→What this article adds:
This pilot study on hydra pneumatic AFO was performed to improve kinetics and kinematics closer to normal.

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hydraulic mechanismswere added (8).These elements were utilized to resist plantar flexion at the early stance (7, 8) and provide enough toe clearance at the swing phase (7, 9). However, these AFOs had some disadvantages came from inappropriate timing and control of elements, which inhibited the desirable motion and sufficient moment during the gait cycle (7, 10-13).

With regard to these disadvantages and different need of drop foot because of variety of reason leaded to drop foot, design and examine new AFOs seem necessary.

Thus, the aim of the current study was investigate the effect of articulated AFO with Hydra pneumatic damper in biomechanical characteristic of drop foot patients.

Therefore, we aimed to investigate the efficacy of articulated AFO with HPD (HPD AFO)in kinetic, kinematic, and spatiotemporal parameters of drop foot patients.

Methods

Participants

The study samples were included ten right drop feet 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 7.4 years for the onset of 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.

The inclusion criteria were a clinically observed unilateral drop-foot with at least six months post stroke, ability to walk independently without assistive devices at least 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 pre-tibial 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.

Instruments

Fifteen retro-reflective spherical markers were set according to the biomechanical model of Helen Hayes at the anatomical landmarks on the posterior sacrum, the bilateral ASIS, the medial and lateral femoral condyles. This markers help to ensure that six infrared cameras of the motion capture (Qualisys workstation AB, Gothenburg, Sweden 2013) were tracked the joint angles correctly at a sampling rate of 100 Hz. To determine the ground reaction force (GRF), force plates (Kistler Holding AG, Winterthur, Switzerland, Model 9286B) were employed at a sampling rate of 1000 Hz. This force plate was synchronized to the motion capture system (10, 11).

Procedure

At the beginning of the test session, patients were asked to walk at least for 20 min with their own shoes and pneumatic damper AFO/own shoes at their self-selected comfortable speed(13). Then, in each condition retro-reflective spherical markers were set at the anatomical landmarks according to Helen Hayes's model. Each patient walked with his/her own shoes and new AFOs for 10 meters walk away to track the motions with the motion capture system. Then, the patients rested for 2 min to record each set of data. Every trial was repeated three times.

Intervention

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 is 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.

This mechanism was used as a dorsiflexion actuator, resisted plantar flexion for the rest of gait sub-phases function, and converted the air and oil power into nonlinear tension force. The overall length of the actuator is much less than a traditional cylinder with a rigid rod. The bottoms of the 2-foot support brackets are fused to a moulded polypropylene foot support that transfers the moment to the users' foot (Fig. 1).

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 pistons are often used to provide large linear force generation with low velocity (20).

Data reduction

*Data analysis and instruments:*All the kinematic analyses were performed with three-dimensional QTM (Qualisys workstation AB, Gothenburg, Sweden 2013) in which, retro-reflective marker trajectory data were interpolated with a cubic polynomial, and GRF marker trajectory data were low-pass filtered using a 4th-order Butterworth filter with cutoff frequencies of 50 and 6 Hz, respectively.

For all conditions, the following parameters were recorded: cadence (steps/min), stride length (m), step width (m),

Fig. 1. The hydra pneumatic AFO

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walking speed (m/s), double limb support (%), push off (%), gait cycle (GC), loading response (%), single limb support (%), step length (m), step time (s), stride time (s), swing time (s). The spatiotemporal parameters for the two groups were compared using non-parametric Mann–Whitney comparison tests.

The analysis was conducted for the kinetic and kinematic parameters in two conditions of HPD AFO and shoe only included. Maximum power absorption (W/kg), Maximum power generation (W/kg), Mean Power (W/kg), Push off velocity ankle(m/s), Peak ankle angle at (0-20)% (°), Peak ankle angle at swing (°) and energy storing and return (W/kg) (1, 3)

Statistical analysis

Statistical analysis was performed using Statistic 19.0, with a significance level set at 0.05. The data were tested for normal distribution using the Kolmogorov–Smirnov test. If distributions of the data are normal, then the kinetic, kinematic and spatiotemporal variables can be expressed by mean and standard deviation. The statistical differences between the conditions were tested by an ANOVA for repeated measures with a post hoc paired t test after a Bonferroni correction. The statistical differences of precision between the methods were tested with a nonparametric Wilcoxon test. The significance threshold in all tests was ($p<0.05$).

Results

The use of the articulated AFO with HPD significantly improved kinetic, kinematic, and spatiotemporal parameters of walking than base line shoes only.

According to Table 1, kinematic and kinetic parameters were compared in 3 the baseline shoes only and AFO.

At the ankle joint, a significant increase was shown at the maximum power absorption, the maximum power generation, the mean power, and the peak moment, push off velocity at the ankle, the peak ankle angle at (0-20) %, the peak ankle angle at swing in AFO than base line shoes only. Also, the peak moment ankle at (60%-100%) was observed with AFO than the baseline ($p<0.05$).

Spatiotemporal parameters of walking included double limb support percent, single limb support percent, push off percent, and gait cycle percent. Also, loading response percent of AFO was shown to be significantly increased than base line shoes only ($p<0.05$).

For all conditions, cadence (steps/min), stride length (m), step width (m), walking speed (m/s), step length (m), step time (s), and stride time (s) were significantly increased with AFO than base line shoes only ($p<0.05$) (Table 2).

Discussion

The aim of this study was to compare the effect of the articulated AFO with HPD by using kinetic, kinematic, and spatiotemporal parameters in drop foot patients.

According to our findings, spatiotemporal parameters were significantly improved by AFO than the baseline shoes only, indicating improvement in gait performance and better ankle stability (21-23). Also, the use of AFO increases the duration of time spent in the stance phase and decreases the swing phase in the affected side, which prevents uncontrolled fall and excessive energy consumption (3, 24).

Significant changes were observed in the kinematic parameters at AFOs conditions than the base line shoes only, which included peak angle at the early stance, peak angle at the swing, push off angular velocity, and ankle ROM, which were significantly increased with the articulated AFO with HPD in our study. A significant increase in push off angular velocity at the ankle joint with hybrid hydra

Table 1. Comparison of the kinetic and kinematic parameters in the baseline of shoes only, with the articulated AFO with HPD in the affected side

Parameters		Baseline with shoes only	Affected side HPD	Sig
Ankle	Maximum power absorption (W/Kg)	-1.57 (0.08)	-1.01 (0.007)	0. 01
	Maximum power generation (W/Kg)	1.67 (0.19)	1.37 (0.083)	0. 03
	Mean Power (W/Kg)	0.85 (0.056)	1.01 (0.20)	0. 01
	Push off velocity ankle (m/s)	-2.00 (0.00)	-1.18 (0.98)	0. 00
	Peak ankle angle at (0-20) % (degree)	-7.690 (1.63)	-1.79 (1.68)	0. 00
	Peak ankle angle at swing (degree)	14.01 (0.71)	14.69 (0.38)	0.05
	Energy store (J)	-7.66 (0.99)	-7.34 (1.65)	0.10
	Energy return (J)	13.86 (1.45)	7.68 (1.19)	0.00

Table2 .Spatiotemporal parameters in the base line of shoe only, with pneumatic

Parameters	Baseline with shoes only	With HPD	Sig
Cadence (step/min)	82.0 (1.58)	91.20 (1.92)	0.001
Step length (m)	0.56 (.04)	0.63 (0.05)	0.005
Step width (m)	1.24 (0.11)	0.56 (0.11)	0.000
Stride length (m)	1.06 (0.16)	1.32 (0.08)	0.007
Speed (m/s)	0.81 (0.07)	1.16 (0.06)	0.000
DLS (%)	22.80 (1.41)	20.16 (0.26)	0.010
SLS (%)	32.04 (2.54)	36.94 (1.62)	0.005
ROM (degree)	24.02(1.74)	24.54 (0.78)	0.100
Push off (%)	57.96 (0.64)	58.66 (0.70)	0.020
Gait cycle (%)	1.41 (0.13)	1.17 (0.05)	0.019
LR (%)	13.80 (0.83)	12.62 (0.48)	0.020
Pre swing (%)	17.66 (0.35)	16.46 (0.25)	0.090
Step time (s)	51.14 (1.00)	49.70 (0.61)	0.000
Stride time (s)	1.42 (0.07)	1.27 (0.10)	0.000

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pneumatic AFO during mid-swing helped energy storing in this AFO.

Due to dorsiflexor weakness in the affected limb, the overall ROM was decreased during the early through terminal stance, and articulated hybrid hydra pneumatic AFO significantly increased the peak dorsiflexion angle and overall ROM than base line shoes only. Improvement in ROM leads to better engagement of the AFOs in the strut of the AFOs to bend over the foot plate component until peak ROM, which might indicate a critical value of AFOs deflection required for plantar flexor power production. (3, 25-27).

In the base line shoes only, the ankle was in the plantar flexion position, the shock absorption was lost, and the foot slapped the ground quickly, which were significantly improved with AFO. This increase is due to the position of the ankle in neutral position or the predetermined dorsi-flexion at the end of previous swing phase with HPD AFO (3, 28).

AFO significantly decreased the peak of plantar flexion at the LR sub phase than shoes only. Dorsi-flexor muscle weakness and increased fatigue in contracted plantar flexors caused uncontrolled plantar flexion with increased peak in drop foot patients and rapid foot fall in 10% of the gait cycle, which led to an unstable, no harmonic, and no symmetric walking pattern (1, 29).

According to the results of this study, the peak of plantar flexion in the pre swing phase (50%-60%) was significantly increased and led to better propulsion of the limb into the swing phase (19). Pneumatic mechanism in this AFO absorbed power during the early to late mid-stance for generating power at push off, which was significantly increased compared to the shoes only (25, 30), which was in line with the findings of other studies in which new AFO designs augmented the ankle power absorption and generation than baseline shoes only. However, various types of AFOs showed different ankle power values (25, 31).

At last, energy storing and restoring were significantly increased with articulated AFO with HPD than shoes only, which led to assisting push off power generation (25) and probably mimicking the effect of the plantar flexor and Achilles tendon in producing push off power (25, 32).

This maximum joint power almost corresponds with the power generation of the plantar flexors required for the lower limb to propel the body forward toward toe-off. According to our finding, energy storing and restoring were significantly increased with AFOs. All of the above mentioned results in muscle weakness and kinematic chain failure resulted in an abnormal motor pattern in these patients without AFO (1, 3).

Conclusion

In conclusion, hydro pneumatic AFO improves kinetic and kinematic of foot drop patients and provides a chain of improvement within the ankle.

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

Conflict of Interests

The authors declare that they have no competing interests.

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