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Original Article

Effects of Articulated & Static Ankle Foot Orthotics on Gait Kinematics: Foot Drop Patients Perspective

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ABSTRACT

Foot drop is a common occurrence following stroke. Ankle foot orthotics (AFO) are used to correct drop foot deformity with several AFOs available to choose from. Literature suggests research on the impact of articulated AFO on gait. **Objective:** To determine the impact of static/rigid and articulated AFO on gait kinematics in foot drop cases. **Methods:** This cross-sectional study involved 100 unilateral drop foot cases from the PIPOS Rehabilitation Services Program from September 2019 to February 2020. The sample included both genders aged 2-15 years. Gait Lab data were used to compare the results while wearing static AFO and articulated AFO and analyzed using SPSS version 21. T-test was used to see difference between groups with p-value <0.05 considered significant. **Results:** Articulated AFO is significantly ($p<0.001$) better than rigid AFO in terms of step length, stride time, and cadence. Articulated AFO is significantly better at initial contact ($p<0.001$), mid stance (Hip $p=0.006$, Knee & ankle $p<0.001$) and terminal stance ($p<0.001$) than rigid AFO. For Initial Swing, there was a significant ($p<0001$) difference between AFOs for extension at knee and ankle joint. At mid-swing articulated AFO provided significantly ($p<0.001$) better flexion at hip and knee joint. At terminal swing articulated AFO provided significantly ($p<0.001$) better flexion at the hip and required extension at the knee. **Conclusions:** This study identified that Articulated AFO was superior to rigid AFO in improving functional mobility and gait consistency & lowering the risk of falling. Articulated AFOs were significantly better in terms of step length, stride time, and cadence.

INTRODUCTION

Cerebrovascular accident is considered to be the leading cause of permanent motor disability globally [1]. Though quite common in the aged population, it is now also affecting an increasing number of working-age group population [2]. Stroke causes several impairments including hemiplegia which significantly reduces gait performance with walking being affected varying from total dependence to normal walking [3]. Walking is a very complex neuro-musculoskeletal coordinated phenomenon and is taken for granted by individuals with good health. Stroke patients lose their postural control and encounter a detained muscle and kinetic response to exterior perturbations leading to post-stroke falls with around 14 to 65 percent cases during hospitalization while a higher number of 37 to 73 percent fall within 6 months of discharge [4]. Stroke hampers motor function resulting in gait disorders resulting from weakness of the plantar flexor and dorsiflexor muscles affecting the normal gait cycle

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which includes a stance phase and a swing phase. Weakness of dorsal muscles results in inability to raise the foot appropriately in the mid-swing resulting in reduced walking speed, toe dragging, short step length, and increased risk of tripping which can occur in different phases of walking [5].The normal gait velocity of a human being is approximately 1.3 m/s while a person suffering from hemiparesis has a gait velocity ranging from 0.23 to 0.73 m/s [6]. Foot drop occurs due to reduced muscle activity at the ankle with the inability to lift the foot [7]. To correct drop foot deformity AFO are used. AFO is an external device that is used to stabilize joints, especially the ankle joint with the aim to control motion and correct deformity and to provide suitable gait on lower limb. These can be prescribed for varying periods according to an individual's need or evolution and may be substituted or changed [8]. It is commonly used to help patients with drop foot or spasticity issues. Different types of AFOs are available to choose from including articulated, rigid, dynamic, posterior leaf spring, Carbon fiber, Ground Reaction, etc., with the flexibility of the joint used to label AFO's as rigid which has a joint which is fixed, while flexible rigid has a rather flexible joint. On the other hand, articulated AFO possesses freely rotatable ankle joint with its mechanical properties more controllable compared to the remaining two [9]. Literature reveals that AFOs help stabilize gait and walk including speed, length of steps, stride, and cadence [10]. Literature reveals irregular manifestation during gait caused by sural triceps spasticity especially knee hyperextension during the support stage can be improved by AFO practice by decreasing sural triceps' hyperactivity by counterbalancing the foot and cooperating in the improvement of equinus deformity and knee hyperextension with custom made AFOs having better results compared to pre-fabricated devices [11]. A study comparing static and dynamic AFOs for the maintenance of balance revealed better response obtained for dynamic compared to static AFO [12]. Since stroke results in difficulty for the patient to perform and maintain the required level of physical activity and walking, individually tailored rehabilitation for the post-stroke patients group may result in better activity and walking [13]. AFOs have been shown to have a positive impact on gait abnormalities of stroke patients with resistance to plantar flexion put-up by AFO being considered important in these patients, however, evidence of this effect is limited [14]. Literature suggests further research into parameters for analysis of gait in cases with foot drop hemiplegia and impact of AFO structure (stiffness and alignment) on the effectiveness of AFO [15] and also changing resistance in AFO utilizing triple action joints affects ankle and knee kinematics in foot drop cases with stroke hence further research is recommended on the impact of articulated AFO on gait [16].

Hence, the current study was conceived to determine the impact of a static/rigid AFO and articulated AFO on gait kinematics in foot drop cases with chronic stroke. The current study is important since there is a lack of consensus on the effective model of AFO for the treatment of stroke sequelae. Further, it will help clinicians better manage cases because determining the type of AFO which is more appropriate for the disability of drop foot, findings of this study will contribute to clinical practice.

METHODS

This cross-sectional study recruited 100 patients with unilateral foot drop using non-probability convenient sampling from all centers of the Pakistan Institute of Prosthetic and Orthotic Sciences (PIPOS) Rehabilitation Services Program (PRSP), across Khyber Pakhtunkhwa over 6 months from 1st September 2019 to 28th February 2020. The sample included both genders aged 2 to 15 years. Cases with any other pathology or deformity were excluded from the study.

Sample size of n=100 was taken following calculation of sample size of n=97, with α=0.05, DEFF=1, 95% level of significance and prevalence proportion 0.067 & 5 percent precision using the formula:

$$N = \frac{z_{\alpha/2}^2 * p * (1-p) * DEFF}{d^2}$$

This study was conducted after the ethical approval of the institutional research board of Isra Institute of Rehabilitation Sciences, ISRA University vide approval No 1709-M.Phil P&O-008 dated 17th June 2019 and informed consent of participants. After selection, each patient was contacted through a phone call to come and participate in the study. Data of participants using static and dynamic AFOs was collected through analysis of their gait using Gait Lab and comparing the effectiveness of both designs and recording the scores at two occasions including with i) static AFO and iii) articulated AFO. Data were compiled utilizing formulas as follows:

Walking speed (m/s) = distance (m)/time(s)

Cadence (footfalls /min) = footfalls counted x 60(s) / time(s)

Stride time (sec) = stride length (m)/ walking speed (m/s)

Standard gait motion data were used as input to the biomechanical model in the adopted protocol.

Following data collection, SPSS version 21.0 was used to analyze data. Statistical analysis was conducted using descriptive statistics. A t-test was utilized to assess the difference between groups and p<0.05 was considered significant.

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RESULTS

A sample of 100 drop foot patients was incorporated in the study to establish the difference between the impact of dynamic and static AFO on person's gait. Findings revealed significantly (p<0.001) higher mean step length (51.88±8.09) for dynamic AFO compared to static/ rigid AFO shown in table 1. However as regards the impact of static and dynamic AFOs on stride indicated that changing the orthosis type revealed no significant difference with p=0.161, however, stride time i.e., number of strides per second, revealed a significant (p<0.001) difference with higher scores (1.43±0.09) for rigid AFO, hence stride time has increased by using articulated AFO resulting in smoother and efficient gait. As regards cadence of gait, a significant difference (p<0.001) was noted with a higher mean score (71.39±11.62) with articulated AFO.

Table 1: Paired sample t-test for Step length, Stride, Cadence, Stride time with different Orthosis (N=100)

Position / Movement	Paired Samples Statistics		t, p-value
	AFO Type	Mean ± SD	
Step Length	Rigid	48.01±7.52	-24.29,.000
	Articulated	51.88±8.09	
Stride	Rigid	103.97±14.89	-1.41,.161
	Articulated	119.52±111.29	
Cadence	Rigid AFO	68.18±8.90	-44.07,0.000
	Articulated AFO	71.39±11.62	
Stride time	Rigid AFO	1.43±0.09	16.99,0.000
	Articulated AFO	1.22±0.13	

Table 2 shows that at Initial Contact there was a significant difference (p<0.001) among different AFOs to bring the angle at the hip to normal with a lesser mean score (20.83±2.30) for articulated AFO at initial contact. Hence, the flexion angle at initial contact was brought to normal. Similarly, the flexion angle at the knee joint at initial contact was brought to normal using articulated AFO with a lower mean score (5.94±2.01) with a significant difference (p<0.001) between different AFOs. To determine performance at mid-stance, the t-test revealed a significant difference (p=0.006) with articulated AFO with a mean score of (2.74±3.33) indicating that the flexion angle at the hip joint was almost 0o. Similarly, at knee joint articulated AFO performed significantly (p<0.001) better with flexion angle at 0o and better stability. . Also significant difference (p<0.001) was present among different AFOs with better planter flexion at the ankle joint with articulated AFO. As regards movements at terminal stance, the angle at the hip joint with different AFOs revealed no significant (p=0.075) difference, however, the mean score was less for articulated AFO indicating flexion at the hip reduced more to normal compared to static AFO and thus controlled drag of toe. However, at the knee joint the flexion angle was kept at 0 degrees and more stabilized compared to static AFO and the difference was significant (p<0.001). Also at the ankle joint the difference between AFOs was significant (p<0.001) and articulated AFO use resulted in the provision of necessary planter flexion resulting in smooth gait. At Initial Swing, articulated AFOs provided better extension at the hip joint, however, the difference was not significant (p=0.075). Similarly, at the knee joint articulated AFOs provided better extension and stability than static AFOs, and resulted in a smooth sinusoidal path of the center of gravity, and the difference was significant (p<0.001). Similarly, a significant difference (p<0.001) between different AFOs was present with articulated ones providing better dorsiflexion at the ankle so that the patient was able to clear ground and avoid toe dragging. At Mid-Swing, articulated AFOs use resulted in significantly (p<0.001) better flexion at the hip and also significantly (p<0.001) better-required flexion (65 degrees) at the knee compared to static AFOs. At Terminal Swing, articulated AFOs provided significantly (P<0.001) better flexion i.e., 15 degrees, and also provided significantly better (p<0.001) required extension at the knee joint hence preparing the extremity for the next contact of the heal.

Table 2: Paired sample statistics and correlation between different positions (N=100)

Position	Pair	Paired Samples Statistics		Paired Samples Correlation		t-test
		AFO Type	Mean ± SD	Correlation	p-value	t, p-value
Initial Contact	Hip	Rigid	22.48±3.27	0.827	0.000	8.77, .000
		Articulated	20.83±2.30			
	Knee	Rigid	7.48±2.90	0.871	0.000	10.13, .000
		Articulated	5.94±2.01			
	Ankle	Rigid	.00a	-	-	-
		Articulated	.00a			
Mid-Stance	Hip	Rigid	3.49±3.73	0.717	0.000	2.79, .006
		Articulated	2.74±3.33			
	Knee	Rigid	6.55±2.28	0.796	0.000	8.49, .000
		Articulated	5.32±1.38			
	Ankle	Rigid	0.08±0.58	0.173	0.085	-11.03, .000
		Articulated	2.15±1.89			
Terminal Stance	Hip	Rigid	14.11±2.41	0.585	0.000	-4.16, .000
		Articulated	15.06±2.59			
	Knee	Rigid	6.25±1.87	0.386	0.000	6.54, 0.000
		Articulated	5.12±0.67			
	Ankle	Rigid	0.05±0.5	0.469	0.000	-31.35, 0.000
		Articulated	6.53±2.25			
Initial Swing	Hip	Rigid	11.67±2.23	0.207	0.039	1.79, 0.075
		Articulated	10.73±5.21			
	Knee	Rigid	60.56±3.26	0.186	0.064	4.52, 0.000
		Articulated	57.01±7.76			
	Ankle	Rigid	90.06±0.42	-0.022	0.832	-24.35, 0.000
		Articulated	3.18±1.20			
Mid-Swing	Hip	Rigid	24.91±2.42	0.83	0.000	6.23, 0.000
		Articulated	3.78±3.21			
	Knee	Rigid	24.85±3.186	0.678	0.000	5.44, 0.000
		Articulated	23.19±4.11			

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	Ankle	Rigid	0	-	-	-1,0.32
		Articulated	0.05±0.5			
Terminal Swing	Hip	Rigid AFO	20.72±1.56	0.459	0.000	5.87, 0.000
		Articulated AFO	19.64±1.92			
	Knee	Rigid AFO	6.19±1.73	0.759	0.000	8.50, 0.000
		Articulated AFO	5.22±1.14			
	Ankle	Rigid AFO	.00a	-	-	-
		Articulated AFO	.00a			

DISCUSSION

A sample of 100 drop foot patients was incorporated in the current study to establish a difference between impacts of articulated and static/ rigid AFO on persons' gait. Though Literature suggests that AFOs use results in longer the step and stride length than without AFO [17], however a study by Kobayashi et al. involving articulated AFOs revealed that adjusting resistance using triple action joints impacts ankle and knee kinematics [16]. In compliance current study revealed a significantly (p<0.001) higher mean step length for articulated AFO, however, there was no significant (P=0.161) difference for stride. However, stride time was significantly (p<0.001) higher for articulated AFO resulting in a smoother and efficient gait. Similarly, the cadence of gait revealed significantly (p<0.001) higher mean score with articulated AFO. A comparative study by Arazpour et al. revealed a mean step length of 31.3±17.27 vs 28.5±15.86, the mean cadence of 50.94±22.36 vs 56.25.24.44 steps per minute for solid and articulated/hinged AFO respectively [18]. In a study by Kobayashi et al. the articulated AFO was reported to be effective with better joint kinematics of lower limb and gait in post-stroke cases and the gait analysis revealed that the angle and movements of ankle and knee responded to settings of AFO joint with the angle at ankle changed from initial contact mean of -0.86 degree to 0.91 degrees for planter flexion resistance and from -1.48 to 4.45o for dorsiflexion resistance [19]. In compliance current study revealed a significant difference (p<0.001) at Initial contact among rigid and articulated AFOs to bring the angle at the hip to normal with articulated AFO, similarly, the flexion angle at the knee joint at initial contact was brought to normal using articulated AFO. The current study revealed that at mid-stance articulated AFO was significantly better (p<0.001) and brought the flexion angle at the hip joint to almost 0o. Similarly, at knee joint flexion angle was 0o and with better stability as well as better planter flexion at the ankle joint with articulated AFO. Similarly, at terminal stance, the angle at the hip joint with different AFOs revealed a significant (p<0.001)) difference, with the mean score is less for articulated AFO indicating flexion at the hip reduced more to normal compared to static AFO and thus controlled drag of toe. Similarly, the difference was significant (p<0.001) with articulated AFO at the knee joint the flexion angle was kept at 0 degrees and more stabilized & at the ankle joint articulated AFO use resulted in the provision of necessary planter flexion resulting in smooth gait. In contrast, a study by Radtka et al. revealed that compared to rigid AFO, hinged AFO give increased normal dorsiflexion during terminal stance as well as more ankle power during Pre-swing in cerebral palsy children with spastic diplegia [20]. In contrast, a study by Zollo et al. reported using gait analysis to compare static and dynamic AFO revealed that spatiotemporal parameters did not reveal significant difference and both reduced the range of motion of ankle dorsi-planter flexion during stance compared to without an AFO and reduced asymmetry between two limbs, however rigid AFO resulted in higher co-contraction of muscles involved in gait [21]. Literature using 3-D gait analysis reveals that AFOs are useful in toe clearance and limb shortening in hemi-paretic [22]. The current study revealed that at the Initial Swing, articulated AFOs provided better non-significant (P=0.075) extension at the hip joint. Similarly, at the knee joint articulated AFOs provided significant (p<0.05) better extension and stability and resulted in a smooth sinusoidal path of the center of gravity and also provided better dorsiflexion at the ankle so that the patient was able to clear the ground and avoid toe dragging. At Mid-Swing, articulated AFOs use resulted in significantly (p<0.001) better flexion at the hip and better-required flexion (65 degrees) at the knee compared to static AFOs. At Terminal Swing articulated AFOs provided significantly (P<0.001) better flexion i.e., 15 degrees, and required extension at the knee joint hence preparing the extremity for the next contact of heal. Similarly, the literature reveals that drop foot gait in cases with Cerebrovascular accident cases suffer dorsiflexion deficiency during swing with problems like foot slap at time of loading and toe-dragging during the swing which needs to be catered to with an articulated AFO with characteristics of being light in weight, compact and efficient [5]. In contrast according to Mulroy et al., rigid static AFOs tend to stop dorsiflexion in stance as well as knee flexion in swing in cases with planter flexion contracture. In contrast, those without contracture are benefit from AFOs allowing dorsiflexion mobility [23]. Literature reveals increased knee flexion, increased shock absorption, decreased knee flexion moment, and decreased heel pressure (concerning planter flexed orientation) during loading response can be shown by post-stroke individuals placed in 5o dorsiflexion [24], indicating that articulated AFO may be more beneficial. According to Alam M et al., the design and mechanism involved in an articulated AFO are important, hence AFO should be compact, light in weight, produce low novice, and efficient

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[5]. Also, the literature suggests no influence of timing of AFO provision with positive effects on cadence, stride time, and single limb support duration [25]. Since the study was conducted in only one part of Pakistan, and on a small sample size, hence its results are not generalizable.

CONCLUSIONS

Articulated Ankle Foot Orthosis when used for foot drop is significantly better than rigid AFO in terms of step length, stride time, and cadence is not different from rigid AFO as regards stride. Articulated AFO is significantly better at initial contact, mid stance, and terminal stance than rigid AFO and brings hip knee, and ankle angles to normal including flexion. For Initial Swing, there was no significant difference between AFOs for an extension at the hip joint, however, at the knee and ankle joint the difference was significant with better extension and stability at the knee and dorsiflexion at the ankle. At mid-swing articulated AFO provided better flexion at hip and knee joints, however no significant difference was noted at the ankle joint. At terminal swing articulated AFO provided significantly better flexion at the hip and required extension at the knee. Hence articulated AFO proves superior to rigid AFO for drop cases to improve their functional mobility and gait consistency while also lowering the risk of falling.

Authors Contribution

Conceptualization: AAK, IH,
Methodology: AK, AAK, MK
Formal analysis: AK, WK
Writing-review and editing: MK, GS

All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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