

Effect of Ankle-Foot Orthosis on Ankle Kinematics & Dynamics of Foot Drop Patients

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Abstract—Ankle-foot orthoses are the devices that are used to support the ankle-foot joint and are effective in many pathologies, mainly the ones that cause the foot drop. Foot drop is caused by a deficiency in the ankle joint in which results in the weakness of ankle and toe dorsiflexion. Many causes of foot drop include neurological conditions such as stroke, muscle weakness and injury to the peroneal nerve. In this study, the effect of AFO has been analysed on the ankle in terms of kinematic and dynamic parameters. The motion data of six foot drop patients was acquired in the Gait lab facility at the Department of Physical and Rehabilitation Medicine, PGIMER, Chandigarh. The data acquired was then imported into OpenSim and a dynamic musculoskeletal simulation was run to obtain the results of ankle angle and ankle moment. The results found that the use of AFO significantly improved the ankle angle and moment in foot drop patients.

Keywords— Kinematics, Dynamics, Drop foot, Musculoskeletal Modelling, OpenSim

I. INTRODUCTION

Ankle Foot Orthoses (AFOs) are external devices that are employed in the lower extremity of the leg. AFOs have been found to correct and control the bending and any defect in human movement. These devices have been primarily known to control the foot drop, which is the inability to lift the front part of the foot during walking. This inability primarily arises due to a) paralysis of anterior muscles of the lower leg b) inability to dorsiflex at the ankles and toes. Foot drop causes the toes to drag along the ground while walking. It can happen to one or both feet at the same time and can happen at any age. This pathology may be temporary as well as permanent.

The common causes of foot drop may include neurological conditions such as stroke, multiple sclerosis, cerebral palsy, Charcot-Marie-tooth disease etc. In addition to these, foot drop may be also caused due to the conditions that cause the muscles to progressively weaken, such as, rupture of tibialis anterior, fracture of the fibula, compartment syndrome, diabetes, alcohol abuse etc. The injury to the peroneal nerve is also the commonly occurring cause of the foot drop. This may occur due to an injury sustained in sports, hip or knee replacement surgery and childbirth.

There are mainly two types of AFOs known to reduce gait pathologies: Static and Dynamic. Static devices restrict the movement in all planes, providing rigid stability and control of the ankle and subtalar joints. To improve the forward progression, dynamic AFOs permit limited motion in the sagittal plane, restricting plantar flexion during the stance phase.

Foot drop affects kinematics, kinetics, power, energy and stability of gait. The gait speed has reported as the simplest methods to diagnose ankle disorder. There have been many methods to collect data about human gait, both normal and pathological. The more traditional methods include the utilization of electro goniometry, accelerometer. The more modern and contemporary methods applied in human motion analysis employ computer vision based automated tracking systems.

Traditional experimental methods of measurement of gait kinematics and dynamics do not give us the computational abilities of some biomechanical data. It is through simulation of the data that we can achieve this flexibility. Through simulation, we can give feedback from the measurement of the data to the model and the model setup can be changed easily without changing the measurement setup each time. The computational simulation of biomechanics is evidently cheaper and faster as well as equally effective and accurate as the experimental methods. Computer modelling and simulation have grown to new heights in past years mainly due to the growing belief that these methods can provide more comprehensive and quantitative explanations as to how the neuromuscular and musculoskeletal systems work together to produce movement. This interest in using models to study human movement has been fuelled by the increasing performance of computers and the availability of powerful and fast software.

In this work, a dynamic musculoskeletal model in OpenSim has been used to analyse the effect of an AFO on the ankle of foot drop patients. It is hypothesized that the use of an AFO reduces the effort put in by the ankle in terms of angles and moments generated while walking.

II. METHODOLOGY

The methodology followed to carry out this work is divided into the following sections:

A. Experimental Protocol

The motion data of the foot drop patients were taken in two phases in the GAIT Lab at the Department of Physical & Rehabilitation Medicine, PGIMER, Chandigarh. The data was acquired with AFO and without AFO, both in static as well as normal walking conditions. The data was acquired with the help of BTS Smart- Clinic software which worked with infrared cameras capturing the movement of the patients and 16 force plates capturing the ground reaction forces while walking.

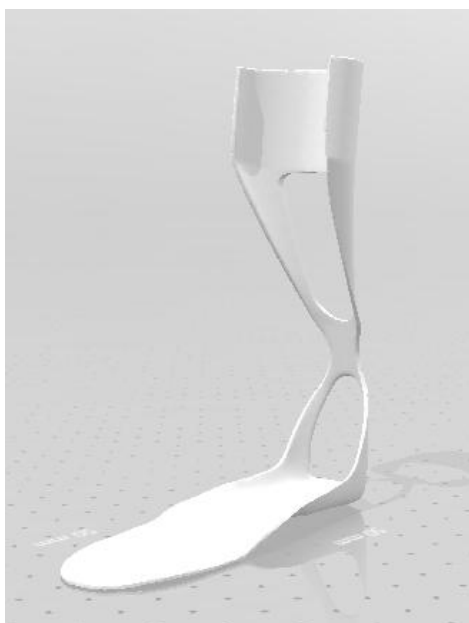


Fig. 1 The AFO used in the study

The anthropometric data of the patients were also gathered to be used with the BTS Smart- Clinic for accurate motion data acquisition. Table I shows the anthropometric data of the patients under experimentation.

TABLE I

Anthropometric data of foot drop patients

Anthropometric Parameters	P-1	P-2	P-3	P-4	P-5	P-6
Age (yrs)	40	43	35	40	45	44
Leg length (cm)	92	92	94	90	94	92
Knee diameter (cm)	10	10	10	10	10	11
Ankle diameter (cm)	8	8	6	7	6	7
Height (cm)	184	182	170	176	178	168
Body weight (kg)	72	88	69	73	88	61
ASIS breadth (cm)	30	30	26	26	28	26.5
Pelvis depth (cm)	8	8	6	6	7	6

The data capturing was done with the help of 6 infrared cameras capturing the position of the body, for which markers were placed on the patient’s body at specific points according to the Helen Hayes marker protocol. Fig. 2 shows the marker placement on the patient’s body.

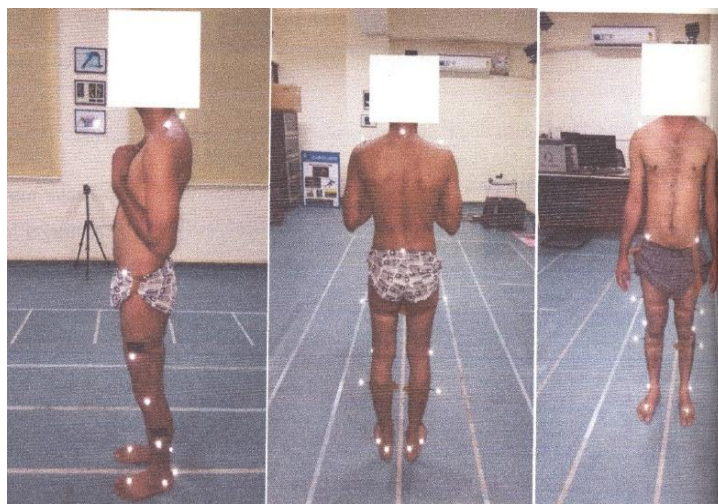


Fig. 2 Marker placement according to Halen Hayes Protocol

After the marker placement, the motion data of the patients were captured in both conditions as described above and the data was acquired in the .c3d file format which comprises of the motion data as well as the ground reaction data from the motion analysis system.

B. Simulation Protocol

After the data acquisition from the motion analysis system, the data obtained was converted into the formats recognizable by OpenSim. The tools used for this purpose comprised of a Matlab interface which extracts the required data i.e. marker trajectories and ground reaction data separately from the .c3d files. After successful extraction and conversion of the data into the marker trajectory files (.trc) and motion files (.mot), the model selection, on which the simulation was performed, was carried out. Since we are simulating the motions of the foot drop patients with AFO and without AFO in this work we have a focus on the lower extremity of the human body. In this regard, we have chosen to work with the “gait10dof18musc” model contained within OpenSim to simulate our desired scenario. It consists of the trunk, leg and pelvis segments. It has 10 degrees of freedom and has 18 muscles of the lower extremity. Fig. 3 shows the model selected for the simulation.



Fig. 3 “gait10dof18musc” model

Followed by model selection, scaling of the model was done to alter its anthropometry to match the patient as closely as possible. Scaling was also performed on the model in accordance with the data obtained for the two scenarios i.e. with AFO and without AFO. The scaled model according to the patient anthropometry is shown in Fig. 4.

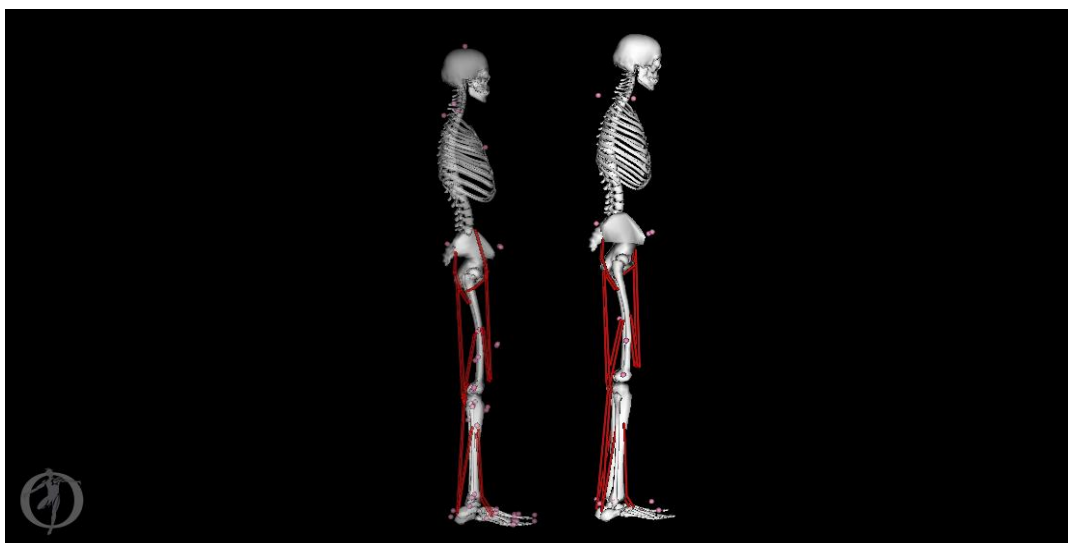


Fig. 4 Scaled model (right) and original model (left)

Scaling of the model was followed by the inverse kinematics, which is a tool that steps through each time frame of the experimental data and alters the position of the model to one that best matches the experimental marker and coordinate data for that time. The inverse kinematics was also carried out for the two conditions as scaling. The inverse kinematics gives the angular position of the model and the body parts at a particular time.

The results from the inverse kinematics were used to run the inverse dynamics tool that determines the generalized forces i.e. net forces and torques at each joint responsible for a given movement. It uses the kinematics describing the movement of the model and the external loads applied to the model (patient) to perform an inverse dynamics analysis.

III. RESULTS & DISCUSSION

After performing the inverse kinematics and inverse dynamics on the model according to the data obtained in two cases i.e. with AFO and without AFO, we obtained the ankle angle and the ankle moments in both these cases. Fig. 5 shows the mean ankle angle of six patients' affected leg, compared in both the cases i.e. with AFO and without AFO.

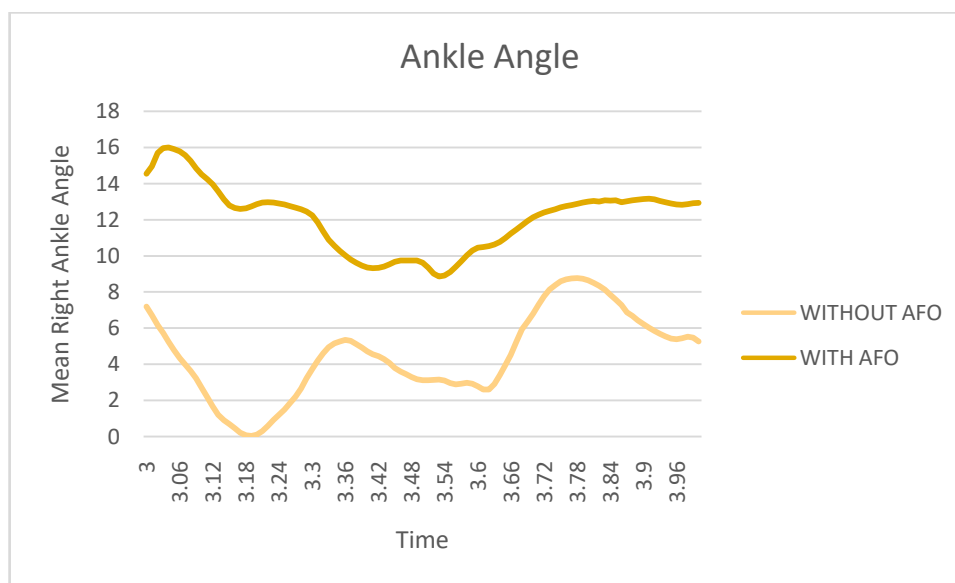


Fig. 5 Mean right ankle angle

In the normal gait, at heel strike, the dorsiflexors cause a controlled plantarflexion to prevent foot slap. In this state, the dorsiflexors act like a linear spring. At toe, off, dorsiflexor provides dorsiflexion to prevent foot drag. In this state and in swing phase, a position control is needed which provides external torque to push foot upwards.

When a person with drop foot walks, the affected foot slaps down onto the floor. Thus, it is natural for the person to compensate by raising the thigh excessively as if walking upstairs. It is evident from the Right Ankle Angle results that at the start of the cycle there is evident dorsiflexion of the right (affected) foot. An improved ankle angle in each case depicts that the AFO assists the drop foot patient in achieving healthy gait. The larger downward trend in the drop foot curve shows the patient's dorsiflexion failure.

Fig. 6 shows the mean ankle moment generated in the affected legs of the drop foot patients compared in the two conditions i.e. with AFO and without AFO.

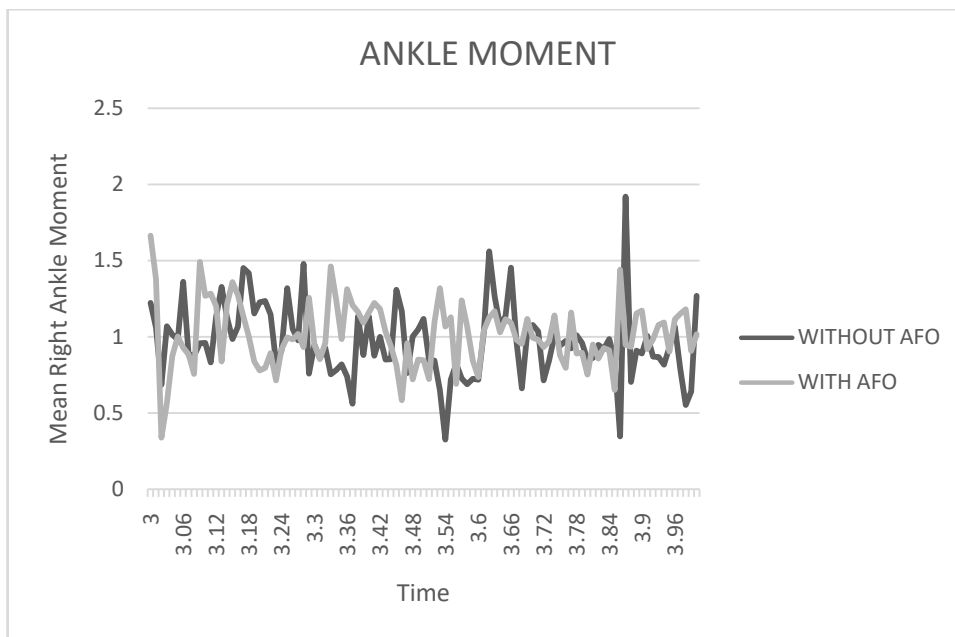


Fig. 5 Mean right ankle moment

The ground reaction force produced dorsiflexion moment during the first half of the stance phase and plantarflexion moment during the second half. Thus, the ankle torque underestimated the dorsiflexion moment just after heel contact and the plantar flexion moment at push off.

The extension of the hip is excessive which results in excessive dorsiflexion in the ankle. Moment of the ankle in drop foot patients also shows that ankle does not have required moment to provide dorsiflexion control. And thus, the Right Ankle Moment plots show that since the affected ankle cannot provide dorsiflexion, there are very few points of the negative moment in the cycle.

IV. CONCLUSIONS

The hypothesis that the use of an AFO by foot drop patients reduces the effort put in by the patients' ankle in terms of angle and torques generated was confirmed from the results of this work. It was found that there was a significant difference in the ankle kinematics and dynamics in both the cases i.e. with AFO and without AFO.

Future studies and analysis should focus on the effect of these results on other kinematic and dynamic parameters of knee and hip and also the individual muscle activations and forces generated in the muscles that are affected by the use of AFO thereby improving the gait of the foot drop patients.

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