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Analysis of the Applicability of an Ankle-Foot Orthosis during Gait in Poststroke Patients

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Abstract. [Purpose] The aim of this study was to develop and assess the applicability of an experimental ankle-foot orthosis during gait in patients with hemiparesis. [Subjects and Methods] This was a noncontrolled cross-sectional study. Ten adult patients with hemiparesis but who were capable of independent gait were included in the study. Gait assessment was performed using two platforms (EMG System do Brasil), an electromyograph (EMG System do Brasil),and a video camera. The experimental orthosis consisted of a single piece that fit over the foot and 1/3 of the distal tibia and had a steel spring. [Results] There was greater activation of the rectus femoris and vastus lateralis muscles in the stance and mid-stance phases with the use of the experimental ankle-foot orthosis in comparison with the use of a polypropylene ankle-foot orthosis and no orthosis. Regarding spatial and temporal gait parameters, the individuals achieved an increase in stride length with the use of the experimental ankle-foot orthosis in comparison with the use of a polypropylene ankle-foot orthosis. [Conclusion] The results of the present study demonstrate that individuals with hemiparesis achieved an improvement in the stance and mid-stance phases of gait with the use of the experimental ankle-foot orthosis.
Key words: Orthosis, Hemiparesis, Gait

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INTRODUCTION

Cerebral vascular accident (stroke) is a major cause of morbidity and mortality and is the third most common cause of death worldwide, following heart disease and cancer[1]. It is estimated that about 21.9 billion Euros are spent annually on this disease in European countries[2]. The worldwide prevalence in the general population is estimated to be 0.7% and in Brazil, the incidence of stroke is approximately 156 cases per 100,000 inhabitants[3].

Locomotion deficit is one of the main consequences of hemiparesis stemming from a stroke. Thus, gait rehabilitation constitutes important therapy for stroke victims[4]. The analysis of pathological gait patterns is performed with the aid of tools such as electromyography, which is used to capture the electrical signals of skeletal muscle activity, and force platforms, which are used to determine reaction forces on the ground[5–7].

The analysis of spatial and temporal gait parameters is important to understanding how gait pattern variables are changed due to a clinical condition. Gait speed and other parameters, such as cadence, stride length and step length, are important indicators of functional mobility and quality of life in poststroke patients[8]. Many hemiparetic patients use an ankle-foot orthosis as a treatment to compensate for poststroke changes in gait[9]. The use of an ankle-foot orthosis improves physiological function and aids this population in walking[10].

There are different types of orthoses with different therapeutic indications. A rigid ankle-foot orthosis is the most often employed and maintains the ankle in a neutral position, thereby avoiding plantar flexion deformities. However, articulated ankle-foot orthoses have received a growing number of recommendations and allow dorsiflexion movement, which promotes stretching of the posterior musculature and a consequent reduction in spasticity in this muscle group[11]. In clinical practice, however, a significant number of patients refuse to use a conventional AFO due to its weight and displeasing appearance, requiring the need for a larger shoe size or even rendering the use of shoes unviable. The decision not to employ this resource leads to impaired gait function. Thus, there is a need to develop a novel AFO aimed at the positioning of the ankle/foot and improved gait function with lesser weight and lower cost while also addressing esthetic issues.

The purpose of the present study was to assess the applicability of an experimental ankle-foot orthosis, compare it with a polypropylene ankle-foot orthosis during gait in poststroke patients and determine the simultaneous electromyographic activity of the tibialis anterior, rectus femoris, soleus and vastus lateralis muscles and spatial and temporal gait parameters (ground reaction force, velocity, stride length, step length and cadence) during gait with and without an orthosis.

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Table 1. Anthropometric data of the paticipants

	Individuals (n)	Age (years)		Body mass (kg)		Height (m)		Body mass Index (kg^2/m)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Subjects	10	52.85	12.60	65.22	13.70	1.66	0.06	22.10	8.48

n, number; kg, kilogram; m, meters; SD, standard deviation

SUBJECTS AND METHODS

A noncontrolled cross-sectional study was carried out at the Human Movement Biodynamics Laboratory of the Universidade Nove de Julho, São Paulo, Brazil.

Ten patients with hemiparesis (six men and four women) with a mean age of 52.85 ± 12.60 years, mean body mass of 65.22 ± 13.70 kg, and mean height of 1.66 ± 0.06 m participated in the study. Six patients in the sample had suffered ischemic stroke, and four had suffered hemorrhagic stroke. Six patients had right-side hemiparesis, and four had left-side hemiparesis. Mean time elapsed since stroke was 1.6 ± 0.94 years (Table 1). The study included patients who were capable of independent gait and exhibited passive mobility of the ankle, based on the functional ambulation scale adapted from that of Chen (2001)[12]. All patients agreed to participate in the study and signed a statement of informed consent.

The study received approval from the Human Research Ethics Committee of the Universidade Nove de Julho − UNINOVE in compliance with Resolution 196/96 of the Brazilian Health Ministry (research protocol regarding Conep Registration 25000.172928/2008-81, Process nº 126/2009).

The experimental ankle-foot orthosis (AFOe) was developed and patented during the study (protocol 018 090 022 818). The AFOe consists of a one-piece enclosure that is coupled directly to the foot and the distal third of the tibia. The device has a steel spring attached between the 3rd and 4th toes and the distal portion of the tibia of the affected lower limb, providing tension to assist in ankle dorsiflexion. This orthosis is lightweight, functional, and made primarily of leather, rubber, neoprene fabric, and rings (Fig. 1). Considering these materials are easy to access and handling, this AFO offers the advantages of low production and maintenance costs as well as satisfactory durability.

The polypropylene ankle-foot orthosis (AFOp) is rigid, non-articulated and inexpensive. Among the ten study participants, six owned and used an AFOp; their orthoses were tailored (moldable) rather than prefabricated orthoses. The four participants who did not use an AFOp had a medical indication for the use of an orthosis, but did not own one due to a lack of acceptance of the device on their part.

A Filizola mechanical scale was used to measure the body mass of the patients. The patients wore light clothing and stood barefoot with their feet positioned in the center of the weighing platform. Height was measured using a fixed wooden stadiometer; the participant's back was turned to the vertical surface of the device, with the upper limbs kept relaxed alongside the trunk, palms facing thighs, heels united, touching the vertical part of the stadiometer and medial edges apart. The mobile part of the stadiometer was moved until it reached the vertex, with compression of the hair.

Source: Author

Fig. 1. Experimental ankle-foot orthosis

A 16-channel electromyography (EMG System do Brasil) was used to evaluate the electromyographic (EMG) activity of the tibialis anterior (TA), rectus femoris (RF), soleus (SO), and vastus lateralis (VL) muscles during gait under three conditions (without an orthosis, with the AFOp, and with the AFOe). The electrodes were connected to a signal conditioning module, in which the analog signals (amplified 10 times) were amplified again with a common gain of 100 times, totaling a final gain of 1,000, and filtered with a band-pass filter of 10 to 500 Hz and a common-mode rejection ratio of > 120 dB. Four pairs of active bipolar surface electrodes were used, which were placed over the motor points of the RF, VL, TA, and SO muscles. To reach the innervation zone and reduce the risk of cross-talk, the electrodes were placed on the anatomic references recommended in the Surface Electromyography for the Non-Invasive Assessment of Muscles project[13] and attached using bandage tape to avoid slippage artifacts during data collection.

Two force platforms (EMG System do Brasil) were used to capture the curves of ground reaction force and determine precisely when the initial contact of the calcaneus and the propulsion phase occurred, thereby facilitating the analysis of spatiotemporal gait variables. A foots witch (EMG System do Brasil) was used in the shoes (heel region) and synchronized with the EMG and force platforms during data acquisition. The EMG signal and platform were synchronized in the signal conditioner. Synchronization between the foot switch and platform was established by the initial support phase of the gait cycle. This was accomplished using the EMG System Coleta software (EMG System do Brasil). A Sony camcorder (model DCR-HC15, with 640× digital zoom) was used to record stride length, step length, velocity, and pace of the individuals in all tests.

The camera was positioned on a tripod with a height of one meter at an angle that could record all trials performed. The participants walked on a catwalk measuring five meters in length, 1.5 meters wide, and 10 cm in height, which contained the two force platforms positioned in parallel. Distance was marked in centimeters to determine the temporal variables, such as gait speed.

After checking the motor points of the muscles evaluated, the area on which the electrodes were placed was cleaned to reduce bioimpedance according to the recommendations of the Surface Electromyography for the Non-Invasive Assessment of Muscles project (2000)[13, 14]. The active bipolar electrodes were placed at a distance of 20 mm (center to center) from each other. The electrodes and foots which were placed on the affected limb, with the participants sitting in a chair. The EMG signals of the RF, VL, TA, and SO muscles of the affected limb (right leg in six patients and left leg in four patients) were evaluated. Recording for the SO was performed at the distal portion of the gastrocnemius, where the SO signal prevails.

The ten hemiparetic patients walked on the catwalk six to ten times. The participants performed the test without an orthosis, with the AFOp, and with the AFOe. The order of the evaluations was defined randomly by lots. As only six individuals had an AFOp, these six patients performed three tests (without an orthosis, with the AFOp, and with the AFOe) and the other four patients performed only two tests (without and with the AFOe). The tests were performed with the patient wearing light clothing and footwear (shoes or sneakers worn daily by the patient). The EMG signals were analyzed in three phases: during the entire gait cycle, during initial contact and during the propulsion phase. The EMG signals, spatiotemporal gait variables (stride length, step length, gait speed, and cadence), and ground reaction force of all ten patients were evaluated.

The results were expressed as median values and interquartile interval. The data were tested by analysis of frequency distribution (Kolmogorov-Smirnov test). As the variables did not adhere to the Gaussian curve, a nonparametric test was used. The GraphPad InStat program (version 3.0; 1994–1999) was used for the data analysis. Friedman's test was used to compare the data for without an orthosis and the data for use of the AFOe and AFOp. A p-value < 0.05 was considered significant. The sample size was calculated using the GraphPad StatMate program (version 1.01).

RESULTS

The variation in EMG activity throughout the gait cycle in the muscles analyzed. The RF and VL muscles demonstrated increased EMG activity with the use of the AFOe in comparison with the AFOp ($p<0.05$). The activity of these muscles was also greater with the use of the AFOe in comparison with no orthosis, but this difference did not achieve statistical significance ($p>0.05$). The TA and SO muscles exhibited no significant variation with the use of the AFOs or without an orthosis.

Regarding the values of EMG activity in the muscles in the stance phase (initial contact), the TA muscle demonstrated a significant decrease in EMG activity when no orthosis was used in comparison with use of the AFOp ($p<0.05$) and AFOe ($p>0.05$). The other muscles exhibited no significant variations.

Regarding the values of EMG activity in the muscles in the propulsion phase (pre-swing) of gait, an decrease in EMG activity occurred in the SO muscle when no orthosis was used in comparison with use of the AFOp ($p<0.05$). The RF muscle demonstrated a decrease in activity when no orthosis was used in comparison to the use of the AFOp ($p>0.05$), but this difference did not achieve statistical significance.

Regarding the values for stride length during gait with and without an orthosis, an increase in stride length was found when using the AFOe in comparison with use of the AFOp ($p<0.05$). No significant differences were found in the other gait parameters (velocity, step length, and cadence) with and without the use of the orthoses ($p>0.05$).

The EMG activity curves for the muscles were evaluated. The RF and VL curves appeared to be more "physiological" with the use of the AFOe in comparison to the activity in these muscles without an orthosis and with use of the AFOp. The curves of the TA and SO muscles were nearly identical to one another.

DISCUSSION

AFOs are generally used by patients who have difficulty with dorsiflexion of the ankle. These devices improve the stability of the ankle during the stance phase of gait and assist in the swing phase of the paretic limb[15]. The use of an AFO reduces plantar flexion and assists in the swing phase, helping individuals with weak dorsiflexor muscles achieve a more physiological initial contact of the calcaneus[16].

Wilson et al.[17] reported that an articulated orthosis offers a better transition between sitting and standing. More complex tasks require a greater range of motion in the joints, which respond more efficiently when allowed to move freely. Thus, a rigid orthosis is more limiting for certain tasks. One may therefore conclude that there are no significant differences between articulated and rigid orthoses with regard to the parameters of simple locomotion, whereas an articulated orthosis achieves better results in more complex tasks.

AFOs alter EMG activity in lower limb muscles during the gait of hemiparetic patients. In the present study, there was an increase in EMG activity in the VL and RF muscles during the stance and mid-stance phases with the use of the AFOe in comparison with the AFOp and no orthosis. These results are in agreement with those described by Hesse et al. (1999)[18], who conducted a study involving 21 hemiparetic patients and found that EMG activity in the VL muscle was greater with an AFO during the stance and mid-stance phases in comparison with the activity without an orthosis. The AFOe was developed for hemiparetic patients with the aim of helping with dorsiflexion in both the stance and swing phases. According to Radtka et al.[19], the improvement in dorsiflexion achieved with an articulated orthosis (especially in the final support phase) in comparison to a rigid orthosis constitutes an important clinical benefit, as this type of orthosis allows a more functional gait pattern.

An improvement was found in the EMG signal curves of the RF and VL muscles during the stance and mid-stance phases with the use of the AFOe, possibly due to the greater activation of these muscles in these stages with the use of the orthosis. This alteration did not occur in the TA, indicating an increase in the function of this muscle, which is particularly important in the swing phase. The curve for these muscles in the stance phase were practically identical, which likely occurred due to interference from the steel spring during this phase, and so the activity occurring at this point in the curve was likely not due muscle activity but was more likely due to the steel spring.

Previous studies suggest that a change in muscle activity has an effect on ground reaction forces; thus, better action of the muscles results in a better gait pattern and less energy expenditure[17, 18]. Regarding ground reaction forces, the present study found that the first peak in the gait cycle curve (initial contact) was "more physiological" with the use of the AFOe in comparison with the use of the AFOp or no orthosis. Moreover, the curves for the mid-stance and propulsion phases were closer to normal. This did not occur with the use of the AFOp or no orthosis, for which there was a drop after the initial contact phase. These results were possibly due to the greater activation of the RF and VL muscles in the stance phase due to the assistance from the steel spring in this stage, allowing the heel to touch the ground in a more functional and physiological fashion[19].

In a study involving ten hemiparetic patients, Bleyenheuft et al.[20] compared and analyzed gait under three conditions: using a dynamic AFO (Chignon®), a prefabricated AFOp, and no AFO. They reported a significant improvement in walking speed with the use of the dynamic AFO in comparison with the prefabricated AFOp and no orthosis. In the present study, the hemiparetic patients experienced no improvement in speed, cadence, or step length with the use with the AFOe and AFOp, but exhibited a significant increase in stride length with the use of the AFOe in comparison to the AFOp. These results are in agreement with those reported by Fatone et al.[21] and can be explained by the fact that the present study was a cross-sectional study, i.e., the individuals used the AFOe only during the test. We believe that prolonged use of the AFOe would improve spatial and temporal gait parameters in the long term.

According to Patterson et al.[22], measurement of speed and other spatial and temporal parameters is often used to evaluate gait function in hemiparetic subjects. However, an increase in walking speed alone does not improve the gait pattern. In the present study, the entire data collection process was filmed, the results of which demonstrated an improvement in the gait pattern of the individuals analyzed, even though not all spatial and temporal gait parameters underwent an increase.

The sample was heterogeneous with regard to the time elapsed since injury, the degree of functional impairment, and age. These factors may account for the mixed responses of the patients between one another with the use of the orthosis. Another limitation was the absence of a kinematic evaluation of gait, as such an analysis would allow important information on possible alterations in gait pattern, especially regarding the mobility of the ankle. Moreover, there was no evaluation of spasticity of the triceps surae.

In an attempt to minimize alterations in gait pattern, individuals with hemiparesis stemming from a stroke make use of an ankle-foot orthosis. The present study describes a new, low-cost AFO made from light-weight material.

The results of the present study suggest that there was an improvement in gait pattern in the individuals analyzed, as evidenced by the significant changes in the values of the EMG signals.

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