Analysis of the Pressure Relief AFO in Individuals with Hemiparesis using Three Dimensional Gait Analysis

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Abstract

Application of an ankle foot orthosis has proven to be an effective means of improving functional ambulation in the hemiparetic individual. While many custom fabricated AFO designs are commonly used to improve different gait parameters, application of the Pressure Relief AFO (PRAFO) has empirically been shown to offer similar improvements in ambulatory potential in this patient population. Computerized gait analyses of 8 hemiparetic patients were conducted for barefoot ambulation and in the PRAFO to compare kinetic and kinematic changes when wearing the PRAFO as a functional orthosis. The data demonstrated statistically significant improvements in the sagittal plane ankle kinematics for all subjects who demonstrated excessive equinus during barefoot ambulation. Thus substantiating the observations that the PRAFO can provide effective control of the ankle foot complex during hemiparetic gait.

Key words: pressure relief AFO, computerized gait analysis, drop foot

Introduction

A normal gait cycle is characterized by a smooth advancement of the extremity from initial contact (heel strike) on one side to the subsequent (initial contact) on the same side. Four fundamental prerequisites are necessary for safe and energy efficient walking (Gage 1991). First, the stance limb must be stable and supportive in both the single and double support periods. Second, there must be adequate swing phase clearance to preclude a toe catch phenomenon during elevated limb advancement. Third, the foot must be properly pre-positioned to accept weight just prior to initial contact with the ground. Fourth, there must be adequate control and movement of the foot, knee and hip to enable efficient step length for functional ambulation to be realized. If any of these 4 prerequisites are severely compromised, the potential for optimal gait becomes adversely affected.

An individual who has sustained an injury to the central or peripheral nervous system often experiences difficulty with lower extremity control during the gait cycle. Depending upon the etiology and resultant clinical manifestations, deformity and pathomechanics may be present in the sagittal, coronal and transverse planes relative to the 3 joints of the lower extremity. One of the primary problems in this patient population is a “drop foot” or excessive equinus in swing. This compromises the second prerequisite of normal gait mentioned above. If uncompensated, excessive equinus will lead to poor clearance with associated increased incidence of tripping and ultimately falling in some individuals. Another issue related to excessive equinus in swing is inappropriate pre-positioning of the foot for initial contact (third prerequisite) with an associated toe initial contact gait. This is also leads to an unstable gait pattern and may ultimately result in ankle injuries or falling.

An excessive equinus in swing can be corrected for by an ankle foot orthosis that holds the ankle in a neutral position. The Pressure Relief ankle foot orthosis (PRAFO) was originally designed to minimize pressure on the heel for those persons with hemiplegia who have limited mobility and spend a majority of their time bed ridden. The PRAFO has a similar design to a typical AFO with the addition of rubber on the plantar surface to facilitate ambulation and eliminate the need for shoes during activities of daily living (Figure 1 – photo of a PRAFO). Visual observation suggests that this brace also provides the benefit of controlling ankle motion in swing and thus minimizing the risk of tripping and falling. It is therefore the purpose of this study to evaluate the effect of the PRAFO on ankle motion using three-dimensional gait analysis techniques.

Methodology

Following chart reviews, subjects were identified by the investigating orthotic practitioner and contacted by mail and follow-up telephone call. Patients meeting the inclusion criteria listed below were provided a detailed explanation of the study and afforded the opportunity to ask any questions of the investigator. A total of eight subjects were chosen for this study. All had unilateral involvement (left or right sided), and were able to ambulate functionally with or without a single assistive device (cane/crutch).

Inclusion Criteria

The subjects were selected according to the following inclusion criteria: 1) diagnosis of hemiparesis with known functional gait deficiencies, 2) passive dorsiflexion ROM at the ankle to 90° (neutral) or higher, 3) manual muscle test of at least 3/5 for knee extension and 3/5 for ankle plantar flexion and 4) documented excessive equinus in swing phase based upon visual assessment. Subjects were excluded from the study based on the following exclusion criteria: severe spasticity, ataxia or athetosis, 2) severe medial lateral instability/deformity at the ankle, and 3) poor balance precluded safe ambulation. All subjects were current patients of Hanger Prosthetics & Orthotics facilities in the greater Hartford area of Connecticut.

Testing

At the initial visit, subjects were examined and fit with an appropriate PRAFO given their relative weight, height and ambulating potential. Standard instructions were provided on fitting criteria, use, and care of the PRAFO. The subjects were then instructed to use the PRAFO daily over the period of one week (minimum) or longer. This provided an opportunity for the subject to acclimate their gait pattern with the PRAFO.

Gait Analysis

After the initial trial period with the PRAFO, each subject returned to the Center for Motion Analysis Laboratory at Connecticut Children's Medical Center for a complete gait analysis. A gait analysis included a full clinical examination, bi-planar video and acquisition of motion and kinetic data using three-dimensional gait analysis techniques (Davis and DeLuca 1996). Motion data was completed during barefoot walking and while wearing the PRAFO. Multiple trials were collected in each condition and a representative trial selected for analysis following routine protocols.

The clinical evaluation was completed by a physical therapist in the Center for Motion Analysis and included the following components: height, weight, passive joint range of motion, estimate of bony torsional measurements and manual muscle test. Motion analyses were then completed using the routine clinical procedures (Rose, Õunpuu et al. 1991; Davis and DeLuca 1996) as summarized below:

- Reflective markers were placed relative to bony landmarks on the lower extremities, pelvis and trunk (Figure 2).
- Each subject was instructed to walk at a self-selected pace along a designated walkway. Multiple trials were collected first from barefoot and then from PRAFO walking.
- The three-dimensional location of each reflective marker was determined using custom software and a VICON motion measurement system (Oxford Metrics Inc., Oxford, UK)
- Force plate data was collected simultaneously using three AMTI force plates (Advanced Medical Technologies Limited, Newton, MA) embedded into the walkway.
- Joint angles and joint moments were computed using Euler Angles and Inverse Dynamics (Winter 1990), respectively.

All gait analysis data was plotted and tabulated and descriptive statistical analyses were performed. A Student's T-test was used to determine if there were statistically significant differences between the barefoot and PRAFO walks. A probability of $p<0.05$ was considered statistically significant. All gait parameters were determined improved if they showed changes towards the normal reference data collected in the same laboratory (Õunpuu, Gage et al. 1991).

Results

A summary of the clinical examination findings for all subjects can be found in Table 1. Minor plantar flexor contractures were found in the 5 to 10 degree range in 3 subjects with the knee at 0 degrees. Two of the patients were unable to isolate dorsiflexion, which indicates a lack of voluntary control of this muscle group even though it may have antigravity strength.

Of the 8 subjects selected for the study, 3 were able to achieve normal dorsiflexion in the mid swing phase. The ankle joint kinematic and kinetic results for the 5 subjects that showed excessive equinus in swing are summarized in Table 2. The mean ankle dorsiflexion in mid swing for these subjects showed a significant excessive equinus, which was corrected with the PRAFO into a normal range of motion (Figure 3). The difference between the barefoot and PRAFO walk was significantly different ($p=0.029$). As would be expected, there was a significant drop in the peak plantar flexion in swing from –25 +/- 8 degrees to –8 +/- 3 degrees ($p<0.006$) with an associated significant ($p<0.006$) decrease in the sagittal plane range of motion of the ankle. With the PRAFO, there was a heel contact pattern noted with an associated dorsiflexor moment in first rocker (Figure 4). Power generation in terminal stance, was reduced with the PRAFO in comparison to barefoot walking. Also, of note there was a significant improvement in knee function with the PRAFO with an increase in knee flexion at toe off from 33 to 43 degrees ($p<0.037$) and an increase in sagittal plane knee motion from 60 to 65 degrees ($p<0.001$) (Figure 4). These subjects also showed a significant ($p<0.024$) improvement in their step length from 57 +/-7 to 63 +/-8 cm when using the PRAFO. There was a trend towards increased walking velocity with the PRAFO as compared to barefoot, however, this was not statistically significant.

The three patients that did not show excessive equinus in swing all had reduced peak knee flexion in swing and reduced knee extension at initial contact. An example of the barefoot versus PRAFO walk for the knee and ankle of one of these subjects is plotted in Figure 5. The abnormal knee position during barefoot walking changed the orientation of the foot with respect to the floor that is, the toe was pointing more downwards than normal. With the PRAFO the degree and timing of peak knee flexion in swing was improved.

Discussion

The purpose of this study was to evaluate the effect of the PRAFO on the motion of the ankle joint during gait. The kinematic data in those patients showing a drop foot in swing confirm that the PRAFO is capable of supporting the foot in swing and thus eliminating the excessive equinus in the swing phase. This has the benefit of improving clearance in swing with the associated risk of falling. The improved ankle positioning also extended to initial contact with the elimination of the excessive equinus and the associated ability to attain a heel contact gait. This was further substantiated by the increase in internal dorsiflexor moment at the ankle in the PRAFO during loading response as compared to barefoot walking. Again this will have a functional benefit in terms of the prerequisites of normal gait with improved stability associated with a heel contact pattern and normal first rocker (Perry 1992) during loading response.

The PRAFO also had an unexpected benefit at the knee. With the PRAFO, there was an increase in knee sagittal plane range of motion and a more normal knee flexion angle at toe off. The increase in knee range of motion was due in part to increased peak knee flexion in swing. This will also have an associated functional benefit of improving foot clearance in swing. This benefit was seen in both the patients that showed an excessive equinus in swing and those that did not and is consistent with previously published results (Õunpuu, Bell et al. 1996).

There were three subjects in this study that did not have an excessive equinus in swing during barefoot walking. Their sagittal plane ankle kinematics showed normal dorsiflexion in the swing phase on the involved side. Visually, however, their foot orientation was abnormal in that the toe was pointing down in swing. Further evaluation of the kinematic data showed that these subjects had abnormal knee motion in swing or more specifically reduced peak knee flexion in swing. This results in a change in orientation of the foot segment with a resulting visual drop foot. In these patients, it appears that clearance problems reported were a result of the knee joint and not the ankle joint. These three patients however, benefited from the PRAFO. This was possible through increased peak knee flexion in swing with the PRAFO in comparison to barefoot walking. Therefore, changes in knee function resulted in improved clearance in swing and the associated orientation of the foot segment. These findings indicate that the PRAFO has functional benefits that go beyond the ankle joint and would still be considered beneficial for patients with out excessive equinus. These findings also suggest that it is difficult to determine the presence of excessive equinus in swing (unless it is severe) from visual observation alone, the method used to recruit the subjects for this study. This points to the important role of three dimensional gait analysis in documenting human gait.

Summary

The results of this study show that the PRAFO provides sufficient support of the ankle in swing to prevent excessive equinus and allow for more normal pre-positioning of the foot for initial contact, both of these benefits are prerequisites of normal gait. As a result, these patients will be able to ambulate more safely when wearing the PRAFO as compared to barefoot walking. Of interest, those subjects that did not show an excessive drop foot in swing also showed a benefit due to the PRAFO. The increased peak knee flexion in swing seen in these subjects ultimately suggests improved function with respect to clearance in swing.

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