STRAIN ANALYSIS OF A COMPOSITE ANKLE-FOOT ORTHOSIS (AFO)

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Introduction

The HELIOS, an advanced composite AFO developed by Ortho Rehab Designs, aids patients with drop foot to improve gait. Foot drop is a common symptom of Charcot-Marie-Tooth (CMT) syndrome, which is a hereditary neuropathy disease [1]. Deformation of the AFO is analyzed with the use of strain gages while subjects walk over a floor mounted force plate in the Sports Injury Research Center (SIRC) at the University of Nevada, Las Vegas (UNLV). Two of the subjects are CMT patients and the third is a healthy individual not diagnosed with CMT. Informed consent was obtained for all participants. Since CMT affects individuals differently and is asymmetric [1], which means a single patient could have different degrees of degeneration in the left leg versus the right leg, this third 'normal' subject allows comparison between a healthy individual and one who has CMT.

Experimental

AFO Fabrication
Each HELIOS AFO brace is custom designed and fabricated at Ortho Rehab Designs. This customization allows for maximum correction of the patient's alignment for improved balance and joint stability, in addition to providing customized spring based on the patient's activity level and condition. An average brace is made from multiple layers of woven and braided carbon, kevlar, and/or fiberglass reinforcement vacuum formed with an epoxy matrix.

AFO Instrumentation
Affixed to each brace are a total of eight strain gages which are numbered and split evenly on the two struts of the brace as shown in Figure 1. The first gage is placed just below the top curve so it is positioned in the straight section of the strut. The second gage is placed approximately in the middle of the strut between the top and bottom. The third gage is placed in the straight section of the lower curve. The fourth gage is placed near the ankle and as close to the shoe line as possible without being placed in the shoe. All gages are placed in the center of the strut and run parallel to the strut direction. A 20-m cable suspended on an overhead guide-wire connects the gages, using D-sub 25 pin connectors mounted on the pretibial shell of each Helios brace, to the National Instruments data acquisition system.

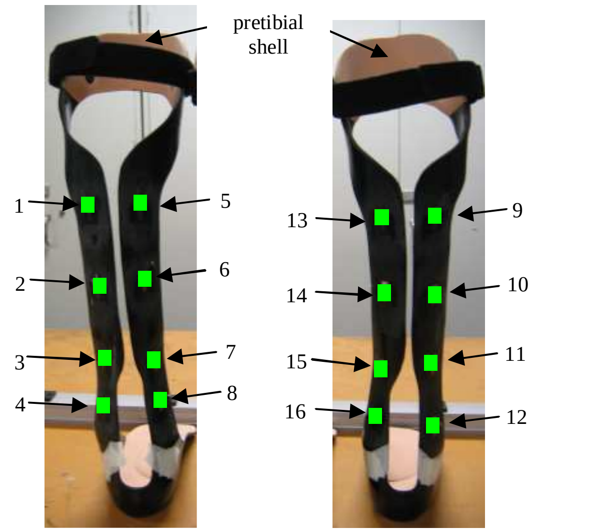

Fig 1: Gage placement on left and right HELIOS braces

Human Testing
All three subjects were asked to walk at a normal pace across two force plates in the UNLV Sports Injury Research Center (SIRC) laboratory (Fig 2). Each force plate records the vertical force (Fz), anterior/posterior force (Fy), and medial/lateral force (Fx) of one foot. Ten trials were collected for each subject. During these trials, data from all sixteen strain gages were collected via a LabView program. The raw strain data was filtered using a 4-pole Butterworth filter at 10 kHz.

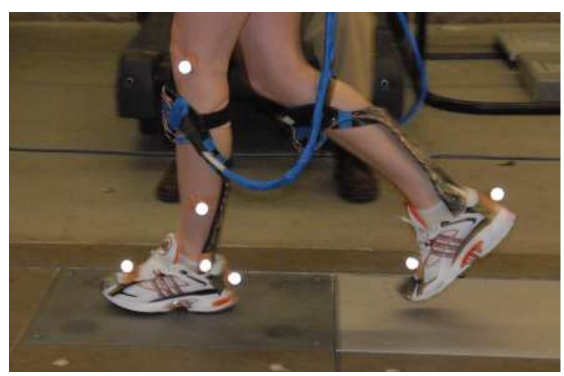
Fig 2: Subject walking across force plate

Results and Discussion

All raw force and strain data were analyzed using Matlab over the entire stance. Stance begins at 0 % with heel contact (HC) and ends at 100 % with toe off (TO). The data for each strain gage was then averaged for the ten trials of each subject. Shown in Fig 3, 4, and 5 are the average strain data for Subject 1, 2, and 3, respectively.

All three sets of graphs show compressive strain at the start of stance corresponding to a backwards bending of the struts. This is followed by tensile strain at the end of stance corresponding to the struts being bent forward.

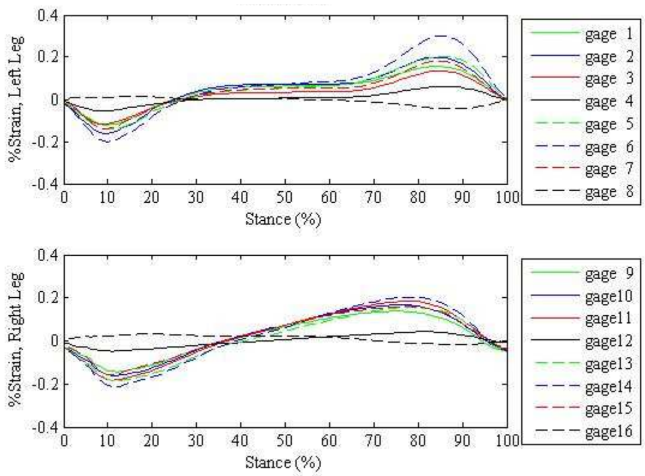

Fig 3: %Strain vs Stance (HC to TO) for CMT Subject 1

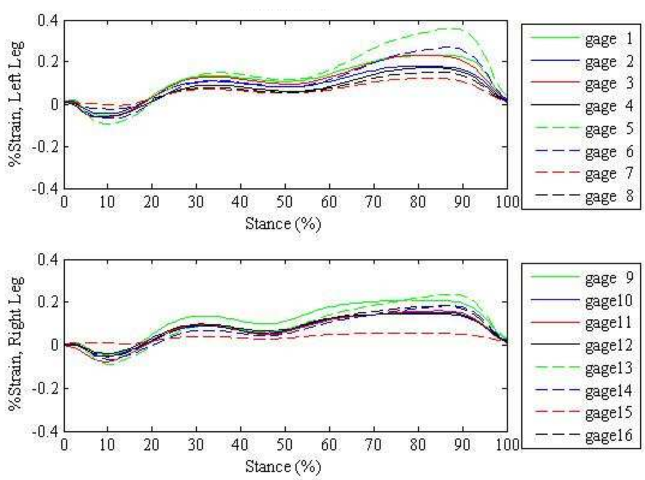

Fig 4: %Strain vs Stance (HC to TO) for CMT Subject 2

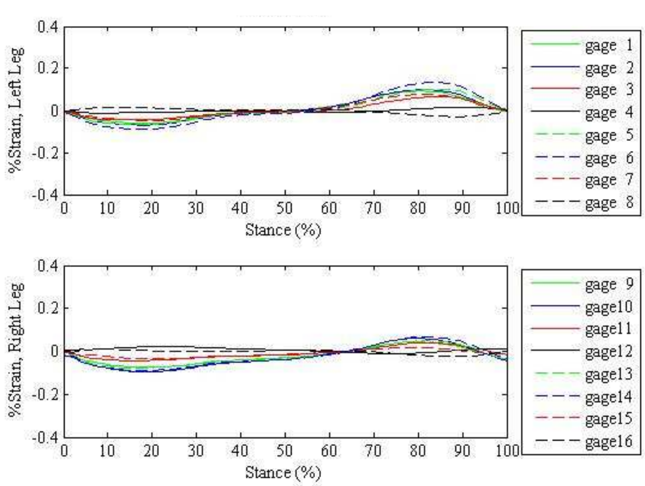

Fig 5: %Strain vs Stance (HC to TO) for Subject 3

Higher strains are seen in both CMT subjects as compared to the 'normal' subject. This could be due to the CMT subjects using the brace more during gait. The brace acts to absorb the impact during HC and prevent foot drop. The brace then supports the tibia at TO when the subject applies more pressure to the pretibial shell at the front of the brace before the swing phase.

Chu et. al. did extensive research on the stress measurement of a polyethylene brace using FEA and experimental testing. It was determined that the high stress location of a standard polypropylene brace would be in the middle-lower lateral neck region [2, 3]. This is not the case with the HELIOS brace, most likely due to differences in geometry. Subjects 1 and 3 show similar results with the highest strain seen in the middle of the struts (gage 2, 6, 10, and 14). Subject 2 shows a slightly different profile with the highest strain seen in the top of the struts (gage 1, 5, 9, and 13). CMT severity could alter the gait of Subject 2 yielding different deformation pattern from Subject 1 and 3.

A slight decrease in strain is seen in Subject 2 at around 50% stance that could be due to the CMT. It is possible that shortly after HC the subject falls into the brace hitting the tibia against the pretibial shell and then stabilizing before leaning into the pretibial shell again before TO.

Conclusion

Results show that the highest strains are seen in the middle or top of the strut during stance. The struts also experience both compression and tension to help absorb impact and stabilize the CMT subject during gait. A slightly different strain curve observed in Subject 2 has indicated that the severity of CMT in an individual might alter the behavior of the brace. A fourth subject is currently being evaluated to clearly determine if the brace is behaving differently for subjects that have different CMT severities.

References

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Acknowledgements

The authors would like to thank the Hereditary Neuropathy Foundation, UNLV, and Ortho Rehab Designs for their support.