The Effect of Cut-Line Location on the 3D Rotational Stiffness of an Ankle Foot Orthosis

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Introduction
An Ankle Foot Orthosis (AFO) is a brace used in the correction of many gait related problems, including dorsal or anterior nerve and musculature injury, mild cases of Charcot foot, neuropathy, spinal cord injury, and muscular dystrophy in children and adults. AFOs are tailored to individual patient needs, and can range from stiff and rigid to flexible and articulated, but are rarely quantified for functional measures of mechanical stiffness or range-of-motion. Changes in AFO stiffness can be achieved by cutting away more or less material during fabrication. A common challenge with the AFO is where to make the “cut line” in relation to the malleolus (or ankle) to achieve an appropriate stiffness for the patients needs. In this study, we have designed and used a bench-top AFO testing instrument to test the hypothesis that changes in AFO malleolus cut-lines will significantly affect resulting stiffness of AFOs in all 3 ankle motion planes.

Materials and Methods
A manual loading AFO testing instrument was designed and constructed for use in this study (Figure 1), to replicate the 3-DOF rotational axes of the ankle. The apparatus can replicate the key ranges of motion: dorsiflexion/plantarflexion (+20°-50°), inversion/eversion (±40°), and adduction/abduction (±40°), with the ability to isolate or combine these ranges of motion as desired. This instrument rigidly holds the calf portion of the AFO, while applying rotational torques about the ankle axes, inducing foot rotations through clinically relevant ranges of motion with a measured accuracy of ±0.01° and ±0.015 ft-lbs.

Four (n=4) lightweight, 3/16in thick copoly polypropylene, rigid AFOs were fabricated from an identical patients lower leg casting (patient age 15 years) by the Orthotics and Prosthetics Department of Shriners Hospital of Greenville, SC. All AFOs were tested serially for measures of rotational stiffness in three “cut” configurations: “Conservative”, “Moderate”, and “Aggressive” (Figure 2). Initially, “conservative” cuts measured approximately 110mm above the medial malleolus and 100mm above the lateral malleolus when measured at a 45° angle from the back of the heel (also known as a “cut-line”). “Moderate” and “Aggressive” cuts measured 91mm and 74mm, and 44mm and 54mm for medial and lateral malleolar cut-lines, respectively. For each iteration, each AFO was tested in dorsiflexion/plantarflexion (±4°), inversion/eversion (±7°), and adduction/abduction (±7°) ranges of motion five times to ensure reproducibility. Care was taken to ensure minimal damage and plastic deformation was inflected upon the AFO during serial testing. The stiffness of the AFOs about each rotational axis was calculated using LabVIEW by graphing the angle of rotation against the torque applied and fitting a linear slope to the curve. A student’s T-test with Bonferroni correction factor was used to determine the statistical difference between “conservative”, “moderate”, and “aggressive” cut AFOs at a level of p<0.016.

Results
Figure 3 shows the n=4 average rotational stiffness values for the three AFO cut-line configurations about each of the three ankle rotation axes. All stiffness measures were statistically significantly altered between all cuts (p<0.05, except in adduction/abduction between the “conservative” and “moderate” cuts). All stiffnesses changed dramatically between “conservative” and “aggressive” cuts, with a total 82.9% decrease in stiffness in dorsiflexion/plantarflexion, a total 65.0% decrease in stiffness in inversion/eversion, and a total 76.3% decrease in stiffness in adduction/abduction. Changes in dorsiflexion/plantarflexion were consistently affected the most by changes in cut-lines with 56.0% decrease and 61.1% decrease between the “conservative” to “moderate” and “moderate” to “aggressive” cut, respectively.

Discussion and Conclusion
In the clinical setting, AFO cut lines are modified for the individual patient’s needs in hopes to produce an AFO with proper support for the injury or illness. It is clear from this study, that the generic use of three cut-line configurations produces statistically significant changes in all measures of stiffness performance, and is perhaps too generic to be custom tailored for specific patient pathologies and functional demands. Information gathered in this study can be used to help develop a system for clinicians to determine the appropriate cut line for the patient before production of the AFO begins to help save time and money. The clinician would know the stiffness required for the patient then be able to identify the cut line required to replicate that stiffness. Future work for this study will include the effect of material thickness and footwear support on resulting AFO stiffness along with the development of a manufacturing algorithm which inputs the desired AFO clinical prescription, and outputs material type, cut-line location and 3D stiffness of the AFO.

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