THE EFFECTS OF STRUT LAYUP AND WIDTH ON CARBON FIBER AFO STIFFNESS

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INTRODUCTION

Carbon fiber is a resilient, lightweight material that can store and return energy (Hastings, et al., 2015). Carbon fiber AFOs have improved ankle range of motion, angular velocity, and power generation in patients with impaired plantar flexors (Desloovere, et al., 2005). The stiffness of a carbon fiber AFO must be appropriate for each patient in order for them to deflect the strut and see improved gait parameters (Hastings, et al., 2015; Arch, et al., 2016; Hawkins, 2010). Design of these AFOs affects their stiffness (Bartonek, et al., 2007; Hawkins, 2010; Hastings, et al., 2015; Wach, 2015). This study sought to determine the effects of strut layup and width on carbon fiber AFO stiffness. Strut width reductions might allow for post-fabrication stiffness adjustability.

METHOD

Apparatus: Computer-controlled motorized device (Danaher motion Inc., USA) with inline torque sensor (Transducer Tech Inc., USA) and optical encoder.

Procedures: Three carbon fiber AFOs were fabricated from the same average sized model with a height of 16 inches. The three AFOs differed only in the composition of the strut layup. Strut layups were comprised of 3, 5, and 7 layers of unidirectional carbon fiber between bidirectional twill carbon fiber. Each AFO was attached to the computer-controlled motorized device and moved into 20° dorsiflexion and 10° plantarflexion. Three, 60 second trials were completed for each strut width from 2.5 inches down to 1 inch. Templates of each strut width were used to decrease the strut width by 0.5 inches.

Data Analysis: Angular deformation and torque resistance data from the computer-controlled motorized device was digitally filtered. A two-way ANOVA with repetition and paired T-tests were performed to determine significance for layup and strut width in all conditions. The level of significance for this study was set at $p < 0.05$.

RESULTS

	Stiffness (Nm/°)		
Strut Width (in)	**3-Ply Layup**	**5-Ply Layup**	**7-Ply Layup**
2.5	3.06	5.91	7.02
2	2.43	5.86	7.61
1.5	3.56	5.49	7.97
1	2.39	4.86	6.73
Average	*2.86*	*5.53*	*7.33*

Table 1: Average stiffness of each carbon AFO layup and strut width condition.

Stiffness values were calculated as torque resistance over angular deformation. Table 1 shows average stiffness of the carbon fiber AFO for each condition. For each strut width, stiffness increases as the number of carbon layers in the strut layup increases. When looking at strut width, the 5-ply strut layup is the only layup that shows a linear decrease in stiffness for each strut width reduction. The 3-ply strut layup and 7-ply strut layup do not consistently decrease in stiffness with each strut width reduction.

A two-way ANOVA showed significance for layup, strut width, and interaction. Post hoc paired T-tests showed that stiffness of all conditions regarding layup were statistically significantly different, but only some conditions regarding strut width were significant.

DISCUSSION

The study demonstrated the impact of altering strut layup thickness. No overlap in stiffness values was found between the 3-ply, 5-ply, and 7-ply layups, regardless of strut width. Coincidentally, stiffness values averaged near the ply count for each orthosis. Clinicians might use this as a simple estimate of the stiffness of the AFO they would be providing. Future studies should consider in-between ply counts, such as 4-ply and 6-ply. Strut width reductions might then be effective in bridging gaps in stiffness between similar layups.

CONCLUSION

There was a significant difference in the stiffness of the three carbon fiber AFOs in regards to layup thickness. The data does support the importance of identifying an appropriate strut layup thickness to match the activity level, body type, and deficit of each patient. This study was not able to confirm whether strut width reductions could offer post-fabrication alteration to the stiffness of carbon fiber AFOs. These reductions were successful in only one of the three conditions tested. A range of stiffness values was achieved through layup alteration, supporting layup as the crucial component in the adjustability of these orthoses.

CLINICAL APPLICATIONS

Clinicians should carefully select a strut layup based on the patient's activity level, body type, and deficit because strut width reductions were not confirmed to offer post-fabrication adjustability of stiffness.

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