CAN PASSIVE DYNAMIC ANKLE FOOT ORTHOSES REPLICATE NATURAL ANKLE STIFFNESS?

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INTRODUCTION

A Passive Dynamic Ankle-foot Orthosis (PD-AFO) is a type of ankle brace that acts like a torsional spring [1]. PD-AFOs are prescribed to patients with weakened plantar flexors. PD-AFOs are designed to be effective by supporting the natural forward progression of the shank over the stance foot [2] (Figure1). Natural Ankle Stiffness (NAS) has been defined as the instantaneous slope of ankle moment plotted as a function of ankle angle [3]. The purpose of this study is to characterize NAS using an implied torsional spring PD-AFO model (PD-AFOm) as a basis.

METHODS

A video-based motion capture system (Oxford Metrics Inc., Oxford, UK) was used to capture the 3D lower extremity gait kinematics and barefoot stance phase kinetics (AMTI, Watertown, MA) of seven normal volunteers (age 26±5yr, body weight (BW) 608.2±78.5N, standing height (H) 1.77±.07m). Gait data were obtained from targeted walking velocity (Wvel) trials at 25%, 50%, 75%, 100%, 125% of normal walking velocity (.785 H/s) [4]. Net plantar/dorsiflexion ankle moments and corresponding ankle angles for three trials at each Wvel were calculated over the stance phase using Visual3D (C-Motion, Inc., Rockville, MD). The period of ankle dorsiflexion from foot flat (FF) to maximum ankle dorsiflexion (MD) was isolated and subdivided into regions R1 and R2 based on the ankle joint neutral reference position (NRP) (Figure 1). Visual inspections of existing PD-AFOs implied the resting position of the PD-AFOm should be aligned to NRP (0.0°) of the ankle obtained from a quiet standing trial. Ankle moment data were scaled by subject BW and H, and combined with angle data in R1 and R2, interpolated to 101 values and averaged for each of the five Wvels. A NAS value for each region was obtained from linear regression.

RESULTS AND DISCUSSION

Linear regression indicated that the PD-AFOm depicted NAS when evaluated in R1 and R2 (r^2>.940). R1 and R2 NAS each increased with Wvel, 12.3% and 19% respectively (Table 1). R2 averaged 58.4% stiffer than R1 over the range of Wvels. At 100% Wvel, the difference in NAS between R1 and R2 is 61%, and the difference in NAS in R2 between 100% Wvel and 25% Wvel is 47%. As R1 NAS increased, the x intercept angles decreased. The non-zero y intercepts of R2 indicated that the ankle was loaded in the NRP contradicting the assumption in the PD-AFOm. Unloading the PD-AFOm would require moving the NRP of the model by the suggested plantar flexion offsets derived from the Wvel dependent x intercept data changing the origin (NRP) of the model. Despite the origin aligned at the x intercept, patients with sufficiently impaired plantar flexors might never reach FF from heel strike (Figure 1). This data appears to isolate R2 as the dominant region for PD-AFOm fitting and potential enhancement of PD-AFOs by using suggested x intercept angles from R1 to optimize for a targeted Wvel (Table 1).

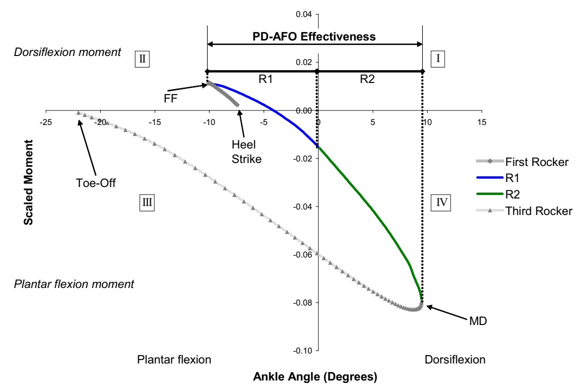

Figure 1: Mean NAS for 75% normal walking velocity

CONCLUSIONS

We have developed a novel method to characterize NAS using a PD-AFOm. Although the model indicated two regions for potential application, R1 does not seem feasible in supporting the natural forward progression of the shank over the stance foot (Figure 1). R2 NAS might be modified but supplementary study is needed to identify what adaptive movement control strategies may be necessary to overcome increased stiffness at the higher Wvels. Understanding normal and patient NAS along with robust PD-AFO modeling will be necessary to systematically enhance discrete regions of gait function where a PD-AFO could optimize human mobility.

REFERENCES

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Table 1: NAS across five walking velocities with corresponding x intercepts (x=degrees) and y intercepts (y=scaled moment)

NAS (1/BW*H)	Walking Velocity (% of 0.785 H/s)				
	25%	50%	75%	100%	125%
R1	-.00201 x=-7.34	-.00247 x=-6.06	-.00270 x=-4.98	-.00318 x=-3.23	-.00340 x=-2.2
R2	-.00433 y=-.0207	-.00542 y=-.0248	-.00627 y=-.023	-.00818 y=-.0164	-.00999 y=-.0212