Estimating the minimum stiffness of dynamic Ankle Foot Orthoses for people with foot drop: a gait-analysis based dynamic study

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Summary

Dynamic ankle foot orthoses (AFOs) are medical devices prescribed to patients with mild foot drop (FD), a condition characterized by weakness of the ankle dorsiflexor muscles. While rigid AFOs do not allow any movement to the ankle joint and are recommended in the most severe cases of FD, dynamic AFOs can flex and allow a more physiological foot and ankle movement throughout the gait cycle. Ideally, dynamic AFOs should prevent the foot from dropping in the swing phase while providing minimum hindrance to ankle motion in the stance phase. In this study, ankle joint dynamics and foot inertial parameters from skin-marker based gait analysis data were used to estimate the minimum stiffness of dynamic AFOs for patients with mild FD.

Introduction

Current 3D scanning and manufacturing technologies have enhanced the design and production of custom dynamic AFOs best fitting individual's foot and leg morphology [1]. However, no standard recommendation has been reported on the optimal mechanical properties of such devices. The aim of this study was to calculate the minimum stiffness of dynamic AFOs to support the foot and footwear in the swing phase of walking of individuals affected by mild FD.

Methods

Ten participants with unilateral FD were enrolled (8M, 2F; age = 65 ± 11 years; BMI = 26.2 ± 2.1 kg/m^2) and ethical approval was granted for the purposes of the study. For each participant, foot and ankle kinematics were obtained during three shod walking trials (footwear mass = 0.164 kg) at self-selected speed using a skin-marker based kinematic protocol [2]. Foot mass and inertial parameters were estimated according to anthropometric data [3, 4]. The maximum plantarflexion moments acting on the foot were calculated in static condition (the foot subjected to gravitational forces only) and during the swing phase of walking (Figure 1). The minimum stiffness of a dynamic AFO (N*m/deg) was calculated as the ratio between the maximum plantarflexion moment and the maximum ankle plantarflexion displacement allowed during swing.

Results and Discussion

Foot mass estimates, derived from anthropometric data obtained using skin markers, across the 10 participants were 1.15 ± 0.15 kg and 1.18 ± 0.16 kg and the moments of inertia at the ankle were 0.0133 ± 0.0026 kg*m^2 and 0.0141 ± 0.0035 kg*m^2 respectively for the affected and non-affected foot. The maximum plantarflexion moment at the ankle (N*m, median (25% 75%)) due to the gravitational forces (static condition) was 0.74 (0.01 0.46). In the swing phase of walking this was 1.66 (1.52 1.77) and 2.14 (1.46 2.58) respectively in the affected and non-affected foot. By setting a maximum angular displacement of the foot in swing to about 3 deg, the average minimum stiffness of the dynamic AFO to support the affected foot is about 0.6 N*m/deg.

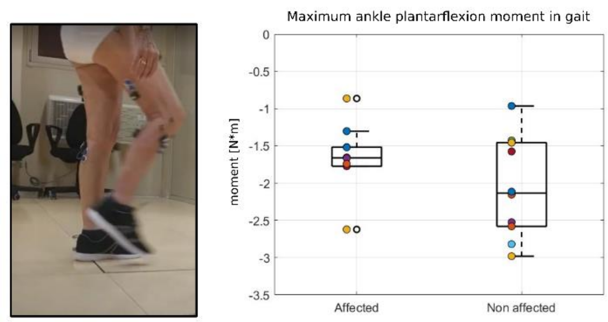

Figure 1: Left, one of the FD participants during the gait analysis. Right, boxplot of the maximum ankle maximum plantarflexion moment across all patients in gait, in the affected (left) and non-affected (right) foot.

Conclusions

While establishing the optimal stiffness of a custom dynamic AFO should include also data on the degree of ankle impairment, the type of footwear worn, and on the physical demand of the person affected by FD, this study provides useful quantitative information for the design and dimensioning of dynamic AFOs. A clinical trial on a larger FD population should be sought to assess the functional outcome of AFOs designed according to the minimum stiffness in plantarflexion as reported in this study.

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