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Short Communication

The effect of varying the plantarflexion resistance of an ankle-foot orthosis on knee joint kinematics in patients with stroke

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ABSTRACT

Ankle-foot orthoses (AFOs) can improve gait in patients with hemiplegia. However, it is anecdotally known that excessive plantarflexion resistance of an AFO could induce undesired knee flexion at early stance. The aim of this study was to systematically investigate the effect of varying the degrees of plantarflexion resistance of an AFO on knee flexion angles at early stance in five subjects with chronic stroke who demonstrated two clear knee flexion peaks at early stance and swing. Each subject wore an experimental AFO constructed with an oil-damper type ankle joint and was instructed to walk at their self-selected walking speed under five plantarflexion resistance conditions. The sagittal plane ankle and knee joint kinematics and gait speed were analyzed using a 3-D Motion Analysis System. A number of significant differences ($P < 0.005$) in maximum knee flexion angles at early stance amongst different plantarflexion resistance conditions were revealed. The knee flexion angle was 23.80 (3.25) degrees under the free hinge joint condition (condition 1), while that was 26.09 (3.79) degrees under the largest resistance condition (condition 5). It was therefore demonstrated that increasing the plantarflexion resistance of an AFO would induce more knee flexion at early stance phase in patients with stroke.

1. Introduction

Ankle-foot orthoses (AFOs) are frequently provided for patients with hemiplegia to assist their gait. They can improve temporal-spatial parameters, as well as kinematic and kinetic parameters of gait for this patient group [1]. A number of studies have compared the gait of patients walking in AFO and non-AFO conditions [2,3] or with different types of AFOs [4,5]. However, the design characteristics of the AFOs used, such as their resistance should also be studied systematically [6].

Sagittal plane resistance is one of the important design characteristics of an AFO, and therefore techniques to measure AFO resistance have been investigated for decades [7]. It has been demonstrated that AFO resistance can systematically affect ankle joint kinematics [8]. One of the important functions of an AFO is to enable patients with foot-drop to achieve heel strike. However, it is anecdotally known that excessive plantarflexion resistance provided by an AFO during early stance phase of gait could induce undesired knee flexion [9] although this has not been experimentally demonstrated by systematically changing the plantarflexion resistance of an AFO. The aim of this study was therefore to investigate the systematic effect of plantarflexion resistance of an AFO on knee flexion angles during early stance phase in patients with stroke. It was hypothesized that increased AFO plantarflexion resistance would induce significant increases in maximum knee flexion angles during loading response in early stance phase of gait.

2. Methods

2.1. Subjects

Five male community dwellers with stroke hemiplegia (53 (11) years old; with a period after the onset of 11 (5) years) who demonstrated two clear knee flexion peaks at early stance and swing phases of a gait cycle were included in this study. Their mean height was 1.65 (0.38) m, while their weight was 67.5 (4.3) kg. Their Brunnstrom stage ranged from 3 to 4. The study was approved by the Human Subjects Ethics Committee of The Hong Kong Polytechnic University, and the subjects gave informed consent to the work.

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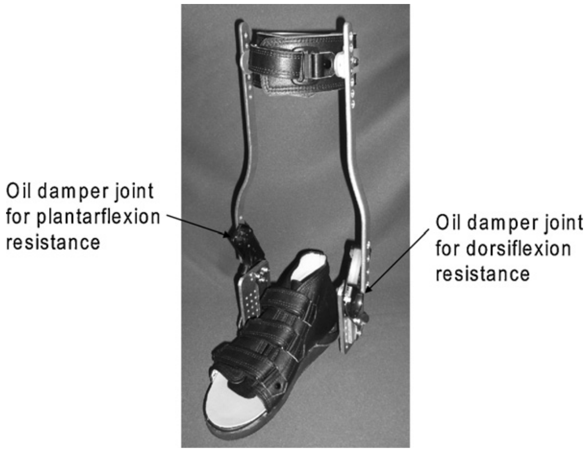

Fig. 1. Experimental ankle-foot orthosis (EAFO) [8].

2.2. Gait analysis

This study complements the results demonstrated in an earlier study which reported the systematic effect of AFO resistance on ankle joint kinematics using an experimental AFO (EAFO) with oil-damper type orthotic ankle joints (Fig. 1) [8]. The EAFO allows systematic adjustment of both dorsiflexion and plantarflexion resistance independently. The oil-damper joint allows stepless adjustment of resistance that ranges from 5 to14 Nm at 10° of plantarflexion measured at an angular velocity of 10 deg/s [10]. The sagittal plane ankle and knee joint kinematics were analyzed by placing reflective markers on the EAFO, knee and hip joints using a Vicon Nexus 3-D Motion Analysis System (Oxford Metrics, Ltd., Oxford, UK) with eight cameras (MX-F40). The sampling frequency of the cameras was set at 100 Hz.

Subjects walked at self-selected walking speed wearing the EAFO [8]. The effect of plantarflexion resistance was investigated by changing its resistance randomly from that designated at level 1 to level 4 (denoted as conditions 2–5) without any resistance contribution to dorsiflexion originating from the oil-damper unit. An additional gait test condition was conducted as a reference condition (denoted as condition 1) simulating a free hinge (i.e. a condition without any resistance contribution originated from the oil-damper unit in either direction). Kinematics of nine gait cycles and gait speed of three trials under each condition were analyzed for statistical analysis.

2.3. Statistical analysis

Due to the small number of subjects who were included in this study ($n = 5$), a non-parametric Friedman test ($P < 0.05$) was conducted to detect general difference amongst plantarflexion resistance conditions. A *post hoc* Wilcoxon Signed-Rank test was subsequently performed for multiple comparisons with a Bonferoni correction of *P*-value. Comparisons of ankle joint kinematics (maximum plantarflexion angle (MPA)), knee joint kinematics (knee flexion angle at early stance (FX1) and swing phase (FX2)) and gait speed amongst all test conditions were conducted to investigate the influence of plantarflexion resistance of the EAFO on these parameters of gait.

3. Results

The Friedman test demonstrated statistically significant differences ($P < 0.05$) in ankle joint (MPA) and knee joint kinematics at early stance (FX1), but not in knee joint kinematics at swing (FX2) or in gait velocity (Table 1). The *post hoc* analysis was subsequently performed on the kinematics (MPA and FX1) with the Bonferoni correction that resulted in a significance level set at $P < 0.005$. The results of comparisons amongst different plantarflexion resistance conditions are shown in Fig. 2.

4. Discussion

This is the first study that demonstrated the effect of a systematic increase of plantarflexion resistance of an AFO on knee flexion angles at early stance phase in patients with stroke. The results of this study supported the hypothesis of the study and coincided with the anecdotal knowledge that excessive plantarflexion resistance of an AFO could induce knee flexion [9].

The mechanisms of how plantarflexion resistance of an AFO affects knee flexion at early stance may be explained theoretically. When ankle plantarflexion resistance is too weak at initial contact, the forward rotation of the shank of the lower limb will not be achieved effectively and this would place a knee joint at more extended position. On the other hand, when the plantarflexion resistance is too strong at initial contact, the forward rotation of the shank will be induced abruptly and the knee joint will be pushed forward. This would place a knee joint at more flexed position and induce instability in gait. The results of this study suggested that knee joint flexion at early stance could potentially be controlled by individually tuning the plantarflexion resistance of an AFO. Therefore, the influence of varying AFO resistance on knee joint stability should be considered for the design of orthotic treatment for patients with stroke.

In conclusion, increases in the plantarflexion resistance of an AFO have been shown to induce more knee flexion at early stance phase in patients with stroke. This is a preliminary result, and a larger scale study is warranted to verify this effect in a more generalized stroke population.

Table 1
The mean knee flexion angles at early stance and swing phase, maximum plantarflexion angle and gait speed at each resistance condition.

	Condition 1	Condition 2	Condition 3	Condition 4	Condition 5	Friedman
FX1 (deg)	23.80 (3.25)	24.80 (3.75)	25.13 (3.93)	25.38 (3.14)	26.09 (3.79)	$P < 0.05$
FX2 (deg)	30.61 (10.64)	29.18 (9.62)	30.19 (11.06)	30.49 (10.33)	30.25 (10.54)	NS
MPA (deg)	−6.21 (2.20)	−2.56 (1.94)	−1.42 (2.43)	−0.17 (3.38)	1.98 (3.80)	$P < 0.05$
Speed (m/s)	0.54 (0.06)	0.55 (0.05)	0.54 (0.06)	0.56 (0.06)	0.53 (0.06)	NS

FX1, maximum knee flexion angles at early stance; FX2, maximum knee flexion angles at swing; MPA, maximum plantarflexion angle; NS, no significant difference.
Condition 1 = Free hinge joint condition.
Condition 2 = Level 1 of the oil-damper joint.
Condition 3 = Level 2 of the oil-damper joint.
Condition 4 = Level 3 of the oil-damper joint.
Condition 5 = Level 4 of the oil-damper joint.

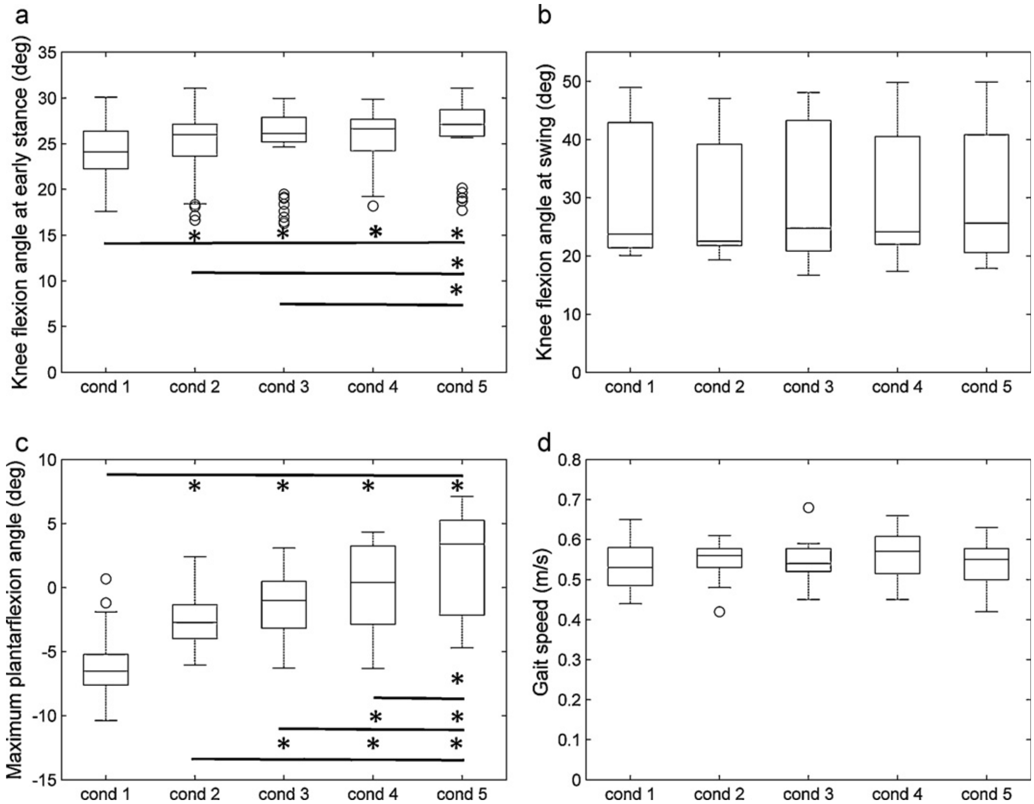

Fig. 2. A comparison of knee and ankle joint kinematics and gait speed amongst five plantarflexion resistance conditions of an EAFO. Boxes represent the central 50% of the distribution. Vertical whiskers extend to the values up to 1.5IQR (interquartile range). Outliers are plotted as an open circle. An asterisk (*) indicates a significant level of $P < 0.005$. (a) Effect of varying plantarflexion resistance on knee flexion angle at early stance, (b) effect of varying plantarflexion resistance on knee flexion angle at swing, (c) effect of varying plantarflexion resistance on maximum plantarflexion angle, (d) effect of varying plantarflexion resistance on gait speed.

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Conflict of interest statement

Authors declare no conflict of interest.

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