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Research Article

The effect and evaluation of stance control Knee Ankle Foot Orthosis on spatiotemporal parameters and kinematics in subjects with poliomyelitis

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ABSTRACT

Background: Subjects with lower limb paralysis or weakness could be ideal candidates for knee-ankle-foot orthoses (KASOs). Stance Control KAFOs (SCKAFOs) has the ability of providing stability in stance and knee flexion in swing phase of gait.
Purpose: The purpose of this study was design and evaluation of a SCKAFO on walking in subjects with poliomyelitis.
Methods: Spatiotemporal parameters and kinematics of walking were measured in 7 poliomyelitis subjects. Three conditions were tested: walking with locked knee KAFO, walking with SCKAFO without (initial knee flexion mode) IF and walking with SCKAFO with IF.
Results: Cadence and walking velocity were significantly increased when subjects used SCKAFO in comparison with locked KAFO. There was no significant difference in cadence and walking velocity between the SCKAFO without IF and SCKAFO with IF. Stance knee flexion was significantly increased when utilizing SCKAFO with IF compared to locked knee and SCKAFO without IF. Swing knee flexion was significantly increased when walking with SCKAFO in comparison with locked KAFO. Hip and pelvic ROM experienced a significant decrease walking with SCKAFO compared with locked KAFO. Hip flexion/extension ROM and pelvic tilt were significantly decreased using SCKAFO with IF compared to SCKAFO without IF.
Conclusion: Patients used SCKAFO with IF had a more normal walking pattern compared to who utilized locked knee KAFO and SCKAFO without IF.

Keywords: knee ankle foot Orthosis, stance control knee joint Orthosis, spatiotemporal parameters, kinematics

INTRODUCTION

Lower limb Orthosis are routinely used by patients suffering from lower limb paralysis and weakness. For example, those with poliomyelitis, Multiple Sclerosis, CVA, Cerebral Palsy or incomplete Spinal Cord Injury (SCI) use Knee Ankle Foot Orthosis (KAFO) that covers knee, ankle and foot [1-6]. Conventional KAFOs lock knee in full extension that provides stability during walking. Walking with knee locked in extension has shown to create a reduction of 24% in gait efficiency and abnormal and non-cosmetic gait patterns such as circumduction, vaulting and hip hicking[7]. These compensatory motions may lead to pain, soft tissue fatigue, joint dysfunction and a high rate of energy consumption in users [6, 8, 9]. For these reasons KAFOs historically have had a high rejection rate between 58% to 79% [10]. Development of stance control knee ankle foot orthoses (SCKAFO) has provided free knee motion during swing and locked knee in full extension in stance phase of gait [8]. Using SCKAFOs that allows initial knee flexion in stance phase of gait during pathologic gait is beneficial [11]. Initial knee flexion in stance enhances shock absorption, reduces load on lower limb tissues and joints and decreases the vertical displacement of the center of mass (COM) [12]. Therefore, the orthosis user does not have to compensate biomechanically for the functionally lengthened leg [10]. Researchers have reported that some SCKAFOs compared with conventional KAFOs provide a more symmetric gait, improve gait kinematics, enhance walking velocity and decrease energy consumption [2, 13]. The aims of this study was to designate and evaluate the effect of SC knee joint ,which provides initial knee flexion in stance and knee flexion in swing, on spatiotemporal parameters and kinematics of gait on patients with poliomyelitis and comparing with SC joint without initial knee flexion and traditional KAFO with locked knee.

METHOD

Design and components

This study consisted of three stages included design, fabrication and data collection. Components of new SC knee joint included powered actuator (model Faulhaber Hubble, Germany) coupled with planetary gearbox included two spur gears engaged together and moved by electromotor (12 volt, 450 rpm), a screw bush, optical encoders, a programmable controller. The electromotor was controlled by microcontroller. For detecting stance and swing phase of gait, two-foot pressure sensors were installed under the footplate. In swing, two gears in gearbox moved in opposite direction and accordingly moved the shaft of the joint that resulted in knee flexion. An exchangeable compressible bumper installed under the shaft for shock absorption and produced initial knee flexion in stance phase of gait (Figure1). The weight of SCKAFO is about 2.2kg. One rechargeable battery was used as a power source of electromotor energy, which was placed on the waist of user.

Figure1: stance Control KAFO (side view and front view)

Subjects

Sevensubjects (age=37.3±2.8years, weight=62.7±8.4kg and height=1.6±0.04meter) with poliomyelitis participated in this study. Table 1 demonstrates the demographic characteristics of the volunteered poliomyelitis subjects.

Table 1- the characteristics of the volunteered poliomyelitis subjects

Subjects	Sex	Age (year)	Height (cm)	Weight (kg)
A	F	34	157	65
B	F	38	157	55
C	F	39	155	49
D	M	35	159	60
E	M	42	165	72
F	M	35	162	68
G	M	38	164	70
Mean ± SD		37±3	160±4	63±8

Gait analysis

Gait analysis was performedby using Qualisys Track Manager System. These data were obtained by 7 cameras with 200 HZ frequency in six trials at the biomechanics laboratory. Subject was tested in three conditions included brace with locked knee, stance control knee joint without IF mode and stance control knee joint with IF mode.

Reflected markers were placed on anatomical parts of body included set on the trunk (left and right acromioclavicular joint, seventh cervical vertebrae and sixth thoracic vertebrae), the pelvis (right and left iliac crest and both ASIS), greater trochanters, right and left knees, ankles and foots with the technique of Visual 3D marker placement. The visual 3D was used to calculate joint angles and kinematic data. This information was filtered using fourth-ordered Butterworth filter. Cut-off frequency for data was 6. The experimental protocol for the study was approved by the Committee of Ethics in the University of Social Welfare and Rehabilitation Sciences (USWR).

Training

Subjects were trained to walk with stance control orthosis for 2-weeks in order for adaptation before being tested.

Statistical analysis

Normality of data was confirmed by using the Kolmogorov-Smirnov technique. One way ANOVA was used to compare the three test conditions. SPSS statistical software (JMP IN software, SAS Institute, Inc.) was used for analysis of the data. The level of significance was set at 0.05.

RESULTS

Spatiotemporal characteristics

Subjects improved spatiotemporal parameters walking with SCKAFO. Cadence and speed of walking were increased, but Stride length and percent of stance phase were decreased in subjects walking with SCKAFO compared with knee locked KAFO (table2). There was no significant difference in spatiotemporal parameters between the SCKAFO without IF and SCKAFO with IF (table4).

Table 2- Mean and Standard Deviation (SD) of the spatiotemporal parameters during walking in poliomyelitis subjects in three conditions

	Locked	Stance Control without IF	Stance Control with IF
Cadence	64.9±4	87.3±3	86±2
Speed of walking(m/s)	0.68±0.03	0.91±0.03	0.88±0.02
Stride length(cm)	76±4	66±3	69±3
Stance phase (%)	67±3	58±3	59±2

Kinematics

Subjects improved kinematics parameters when walking with SCKAFO (table3). There was significantly higher initial knee flexion in stance phase walking with SCKAFO with IF compared with locked knee KAFO and SCKAFO without IF (table 4) (figure 2a). Knee ROM increased in swing when patients walked with SCKAFO compared to locked knee (table 4) (figure 2a). Hip sagittal ROM was significantly higher walking with SCKAFO compared with locked knee. There was a significant decrease in hip sagittal ROM when walking with SCKAFO with IF compared with SCKAFO without IF (table 4) (figure 2b). Hip abduction ROM was significantly decreased when subjects walked with SCKAFO compared to knee locked condition (table 4) (figure 2c).

Pelvic tilt was significantly declined when used SCKAFO compared with locked knee. Also, it was significantly decreased when participants walked with SCKAFO with IF compared to SCKAFO without IF (table 4) (figure 2d).

Table 3- Mean and Standard Deviation (SD) of the kinematics during walking in poliomyelitis subjects in three conditions

	Locked	Stance Control without IF	Stance Control with IF
Initial knee flexion(K1)	1.14±0.2	0.84±0.2	9±1.4
Swing knee flexion(K2)	1±0.2	34.9±2	34.6±2.4
Hip sagittal ROM	22.86±1.7	35.43±1.4	28.29±1.6
Hip coronal ROM	30.57±1.3	9.14±1.1	7.79±1
Pelvic tilt ROM	15.14±1.03	11.64±1.25	9.86±0.95

Table 4- comparison of spatiotemporal parameters and kinematics walking in poliomyelitis subjects in three conditions

	Cadence	Speed of walking(m/s)	Stride length	Stance Phase	Knee flexion in stance (K1)	Knee flexion in swing (K3)	Hip flexion	Hip abduction	Pelvic tilt
P1	0.000	0.000	0.000	0.000	0.783	0.000	0.000	0.000	0.000
P2	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
P3	0.713	0.078	0.469	0.530	0.000	0.953	0.000	0.086	0.017

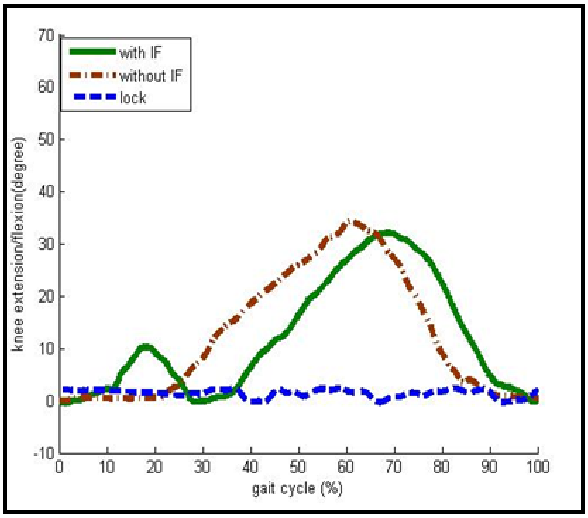
P1: Comparison between locked and SC without IF, P2: Comparison between locked and SC with IF, P3: Comparison between SC without IF and SC with IF

DISCUSSION

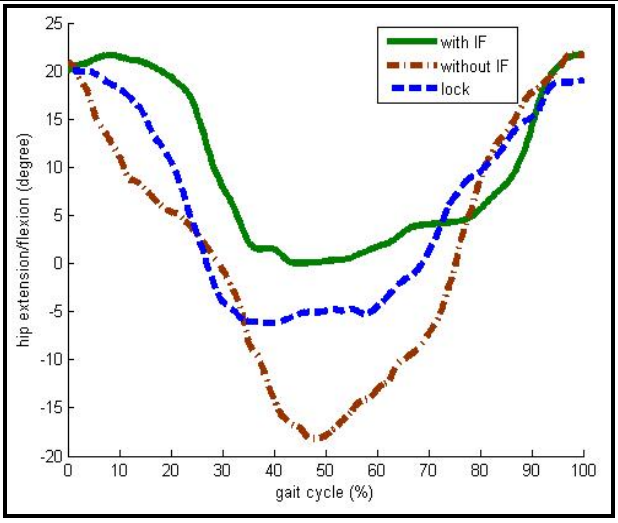
Patients with lower limb paralysis or weakness may require KAFO for stability in stance [14, 15]. SCKAFOs provide stability in stance and knee flexion during the swing period [3, 16, 17]. The aims of this study were to design and evaluate a stance control KAFO that provides initial knee flexion in stance and knee flexion in swing phase of gait. Data were collected in three conditions: locked knee, stance control without IF and stance control with IF. Kinematic gait analysis on subjects with poliomyelitis revealed that stance control offered controlled shock absorbing knee flexion in stance [18].

Compared to KAFO with knee locked in full extension, spatiotemporal parameters were improved when patients walked with SCKAFO. SCKAFO resulted in more cadence and gait speed compared with KAFO with locked knee. Stride length and percentage of stance phase were reduced when subjects used SCKAFO compared to when they used KAFO with locked knee. SCKAFO led to reduced compensatory movement because of the ability of knee flexion in swing phase of gait. These changes created more normal walking pattern and improved symmetry gait pattern. SCKAFO with IF had no significant effect on spatiotemporal parameters compared to the SCKAFO without IF.

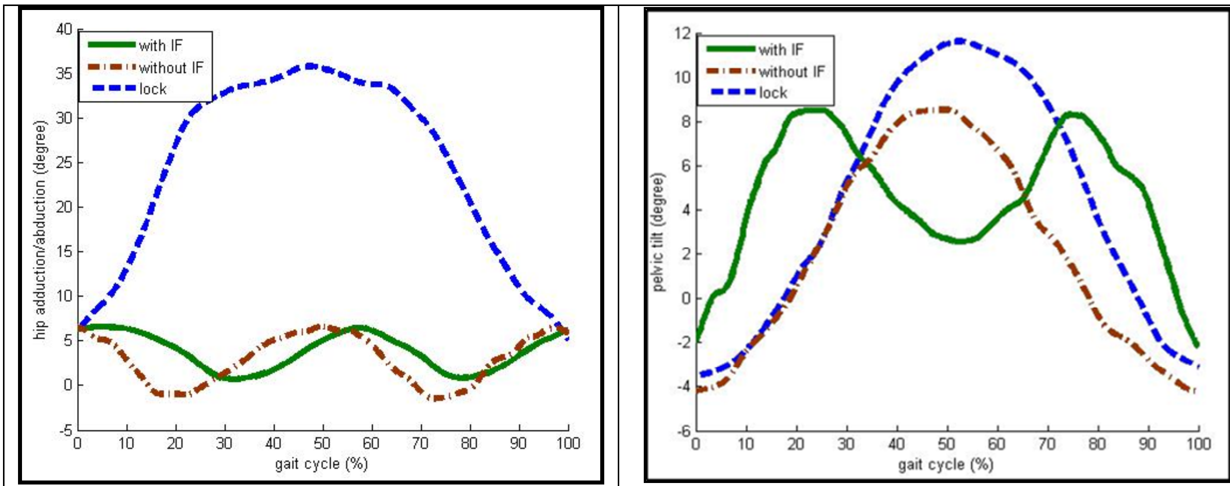
Kinematic gait analysis of subjects with poliomyelitis revealed increase in knee ROM and decrease in hip ROM and pelvic tilt using SCKAFO compared to KAFO with locked knee. SCKAFO provided initial knee flexion in stance phase, knee flexion in swing phase, and encouraged a more natural gait pattern compared with KAFO with locked knee. However, initial knee flexion in stance and knee flexion in swing reduced compensatory motions such as hip hiking or circumduction gait pattern and caused decreasing additional movement in segments of the body like hip abduction and pelvic tilt.



(a)



(b)



(c) (d)

Figure2- Kinematics of the joints (a) knee flexion/extension (b) hip flexion/extension (c) hip abduction/ adduction and (d) pelvic tilt ROM

In general, when participants used KAFO with locked knee the loss of knee flexion during stance and swing phases of gait was compensated through hip hiking and circumduction gait pattern to create toe clearance in swing [3]. Utilizing SCKAFO pelvic tilt was significantly reduced compared to locked KAFO. The pattern of knee, hip and pelvic motion in patients who used SCKAFO was more similar to normal that of those utilized KAFO with locked knee in full extension. SCKAFO with IF significantly increased initial knee flexion in stance phase and reduced pelvic tilt compared to the SCKAFO without IF, which indicates that the SCKAFO with IF allowed patients to walk with a more normal gait pattern and led to a reduced energy consumption during walking. A longer training period may be needed to adapt SCKAFO users to use new SCKAFO with IF. Further studies seem to be required in order to establish the effects of stance-control orthoses on persons with gait pathology.

CONCLUSION

In this study, new electromechanical stance control orthosis which could provide initial knee flexion in stance and knee flexion in swing was developed. The developed SCKAFO with IF could be useful in patients with poliomyelitis.

Additional gait training and more research are required to establish the effect of stance control knee joint with IF on subjects with gait pathology.

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