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# Development of a Prefabricated and User Friendly Stance-Control Orthosis

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**Abstract.** Patients with weak quadriceps have limited option to walk independently. Knee–ankle–foot orthosis (KAFO) are typically prescribed as walking assistive device. KAFOs keep the knee in full extension to provide knee stability during walking and keep knee straight throughout the gait cycle. Locked knee in the swing phase leads to an abnormal gait pattern. Stance control orthosis (SCO) is designed to release the lock during swing phase to allow free knee motion and lock it again during stance phase. It helps the user to walk more natural way by overcoming the limitations of KAFO. Usually SCOs are custom made for each patient. We have design and fabricated a prototype of prefabricated SCO. This prefabricated SCO is an off-the-shelf, compact and lighter design. It contains the adjustable features at shank and thigh side bars and cuffs. Therefore, it is adaptable for the patients of different height and size. This device is 50% lighter than commercially available prefabricated SCO. Lighter components and off-the-shelf design will increase the user acceptance. This new SCO offers three modes of operation; locked mode in entire gait cycle, stance control mode and free knee motion mode. The bio-mechanical performance test revealed this device is structurally strong and user friendly.

**Keywords:** knee-ankle-foot orthosis (KAFO), Stance-conrol orthosis (SCO), swing phase, stance phase.

## 1. Introduction

Rehabilitation researcher could discern the need of a device that would allow knee flexion for obtaining free knee motion during swing phase and provide adequate knee stability for weight bearing during stance phase of gait cycle. Extensive measures were implemented in the last three decades to develop such type of device [1]. Typically these assistive devices are referred as Stance Control Orthosis (SCO). SCOs are designed to lock automatically the knee joint that resists knee flexion during the stance phase and provides sufficient stability to support body weight. The knee actuation mechanism automatically unlocks the knee during the swing phase to allow free knee motion. Therefore, SCO allows more normal gait and greater cosmetic acceptance compared with the traditional fixed-knee KAFO [2]. SCO also improves gait efficiency, kinematics, and mobility. Another significant benefit is the reduction of the metallic energy expenditure of the user [3], [4].

KAFOs are having a hinge knee joint mechanism that provides knee stability for weight bearing by locking knee joint. But it prevents free knee motion in swing phase that leads to an unnatural gait pattern. Therefore, when a patient ambulates with KAFO and moves his leg forward he has to experience hip hiking in swing phase. In addition redeeming gait pattern comprises foot vaulting, lateral shake or oscillation of upper body and leg motility. Resisting knee flexion during swing phase causes sudden initial loading in stance phase and hinders balanced forward movement of center of mass of the user [5]. According to Waters et al. fixed knee motion can reduce 23-33% of gait efficiency of a patient and elevate center of mass position 65% vertically [4]. Unnatural gait pattern causes soft tissue, hip and knee joint dis-function and motion loss. It leads toward increase in lower limb muscular effort and elevate the energy expenditure during walking [6]. Since, flexed knee actively make shorter the leg in swing phase, thus, free knee motion increases the cadence.

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It allows the users to walk with more similar to normal gait pattern. Knee flexion is also very essential during stair climbing or slant and ambulation on inclined surface. There is great possibility of stumble with fully extended knee, since, KAFOs resists the leg flex to prevent fall. Hence, the SCO is a solution in this case, because it allows free knee motion during swing phase and resists knee flexion during stance to support weight bearing [5]. In addition some studies recommended free knee motion during swing phase improves walking efficiency and kinematics compare to using KAFO. Irby et al. [7] demonstrated a result of 14 patients using SCO. They had been using it for 6 month in an open enrolment clinical trial. Among those 14 patients seven were novice user and seven were experienced with traditional KAFO. The result exhibited significant enhancement of knee flexion and peak hip flexion for both types of patients. Walking velocity and stride length of novice users were increased substantially.

# 2. Methodology

## 2.1. Prototype description

The prototype is a prefabricated adjustable SCO. The design is compact, light and off-the-self. The main structure of the orthoses is made of aluminum-alloy 6061-T6. The thigh and shank cuffs, and foot section is made of carbon fiber-epoxy composite material. Commercially available stance control knee joint (SCKJ) and double action ankle joint of Becker Orthopedics were used. The knee to ankle side bars and thigh side bars contain adjustable features. Knee to ankle side bars allow eight adjustable positions and thigh bars allows four adjustable positions. Thigh and shank cuffs also contain adjustable slots. These cuffs are attached with main structure by bolt and easily adjustable by changing the bolt position through the grooves. Therefore, it is competent for wide range of patient in terms of height (153 cm to 183 cm) and weight. The knee locking and unlocking system is control cable operated and that is connected in between ankle and knee joint. The SCKJ keeps the knee locked throughout the stance phase. During the end of stance phase, maximum ankle dorsiflexion takes place and causes the control cable to pulls the lever of SCKJ that unlocks the knee joint. Hence, it keeps the knee unlocked throughout the swing phase. Before the heel strike, the knee extension causes the lever to reengage lock and locks the knee joint.

Fig. 1: Prototype of prefabricated SCO

## 2.2. Biomechanical performance analysis

Three healthy subjected were selected for the performance test of this new prefabricated SCO. The test was carried out in the gait motion analysis lab of University of Malaya. The knee joint angle and hip displacement were monitored by using seven camera motion capture system (Vicon Motion Systems; Los Angeles, California), Vicon Nexus 1.8.1 software (Vicon Motion Systems), and force plate (Kistler, Switzerland). After that all the data for every participant were imported in Microsoft Excel 2013.

## 3. Results

The mean knee flexion and extension angles of three able-bodied subjects in throughout the gait cycle were plotted while using drop locked knee joint KAFO and the prefabricated SCO (Fig. 2). All the participants had a higher knee flexion while using the prefabricated SCO. During swing phase the SCO allowed the maximum knee flexion of $40^0 \pm 1.3^0$, but the locked KAFO allowed a very small knee flexion of $4.1^0 \pm 0.5^0$. Throughout the swing phase the knee joint motion showed a very similar character with normal gait but a slightly lower value of angles. During stance phase the SCO allowed a very little knee flexion in compare to normal gait.

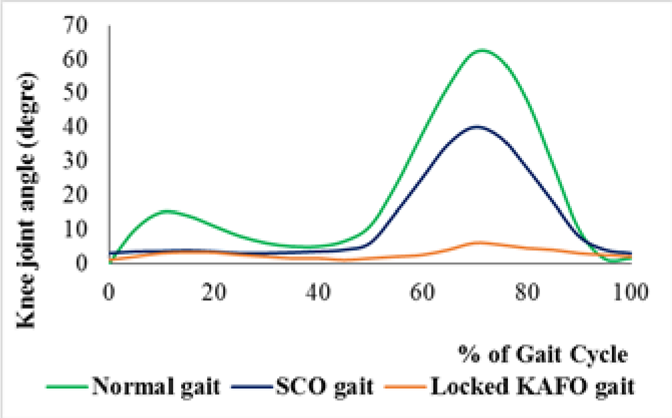


Fig. 2: Comparison of knee joint angle of normal gait, SCO gait and locked KAFO gait

Fig. 3 shows the hip hiking was significantly higher while using the conventional drop lock KAFO with compare to the gait with SCO. The overall prefabricated SCO gait pattern followed a very similar pattern to normal gait and didn't caused any higher hip hiking.

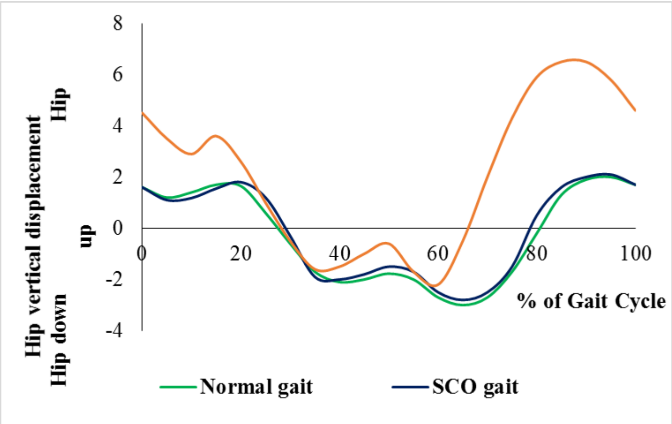


Fig. 3: Comparison of hip vertical displacement of normal gait, SCO gait and locked KAFO gait

## 4. Discussion

The investigated the gait performance of this adjustable SCO in healthy subjects compared to conventional drop lock KAFO and normal walking. Conventional KAFOs keep locked the knee joint throughout the gait cycle and causes higher hip hiking, those lead a user to walk an unnatural gait. The consequences of long time use of KAFO arise more complexity. The performance test of the device demonstrated a more knee flexion (40±1.30) during the swing phase compare to walking with conventional drop locked KAFO (Fig. 2). It also reduced the hip hiking significantly and leaded to a better hip compensatory motion (Fig. 3). The above results show, this prefabricated orthosis allows a more normal gait. According Lehmann et al. [8] it causes substantial reduction in energy requirement and oxygen consumption of users.

## 5. Conclusion

Impaired individuals with lower limb muscle weakness are very often prescribed to use KAFO for supporting the user body weight and assisting to work and stand. Since KAFOs resist free knee motion during swing phase and compel to walk with an abnormal gait pattern the rejection rate is about 58% to 79% [9], [10]. SCOs facilitate ambulation with a more natural gait. However, the success of commercially viable mechanical SCO designs is limited because of the weight, bulkiness, lack of enough cosmetic appeal, noise, and cost. This new prefabricated SCO is competent for patients from 5 feet to 6 feet in height. It contains adjustable features in thigh and shank heights and cuffs.

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## 7. References

[1] T. Yakimovich, J. Kofman and E. D. Lemaire. Design and evaluation of a stance-control knee-ankle-foot orthosis knee joint, IEEE T. Neur. Sys. Reh. 2006, **14** (3): 361-369.

[2] S. E. Irby, K. A. Bernhardt and K. R Kaufman. Gait of stance control orthosis users: the dynamic knee brace system, *Prosthet*. Orthot. Int. 2005, **29** (3): 269-282.

[3] S. E. Irby, K. R. Kaufman, J. W. Mathewson and D. H. Sutherland. Automatic control design for a dynamic knee-brace system, IEEE T. Rehabil. Eng. 1999, **7** (2): 135-139.

[4] R. L. Waters, J. Campbell, L. Thomas, L. Hugos and P. Davis. Energy cost of walking in lower extremity plaster casts, *J Bone Joint Surg*. 1982, **64**: 896–899.

[5] T. Yakimovich, E. D. Lemaire and J. Kofman. Engineering design review of stance-control knee-ankle-foot orthoses, *J. Rehabil. Res*. Dev. 2009, **46**(2): 257-267.

[6] A. G. McMillan, K. Kendrick, J. W. Michael, J. Aronson and G. W. Horton. Preliminary evidence for effectiveness of a stance control orthosis, *J. Prosthet. Orthot*. 2004, **16**(1): 6-13.

[7] S. E. Irby, K. A. Bernhardt and K.R. Kaufman. Gait changes over time in stance control orthosis users, *Prosthet*. Orthot. Int. 2007, **31**(4): 353-361.

[8] J. F. Lehmann and J. B. Stonebridge. Knee lock device for knee ankle orthoses for spinal cordinjured patients: An evaluation, *Arch. Phys*. Med. Rehab. 1978, **59**(5): 207-212.

[9] K. R. Kaufman, S. E. Irby, J. W. Mathewson, R.W. Wirta and D. H. Sutherland. Energy-efficient knee-ankle-foot orthosis: A case study, *J. Prosthet. Orthot*. 1996, **8**(3): 79-85.

[10] K. A. Bernhardt, S. E. Irby and K.R. Kaufman. Consumer opinions of a stance control knee orthosis, *Prosthet. Orthot*. Int. 2006, **30**(3): 246-256.