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ON THE BIOMECHANICAL DESIGN OF STANCE CONTROL KNEE ANKLE FOOT ORTHOSIS (SCKAFO)

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ABSTRACT

The main purpose of this research work is to design a dynamic Stance Control Knee-Ankle-Foot-Orthosis (SCKAFO) to support patients with gait disorders, namely for patients with muscular weakness and dystrophy in quadriceps femoris muscle group. Patients with quadriceps muscular weakness are regularly prescribed a Knee-Ankle-Foot-Orthosis (KAFO). A new type of orthosis, referred as Stance-Control-Knee-Ankle-Foot-Orthosis (SCKAFO), has recently emerged to allow knee flexion during the swing phase while providing controlled knee flexion in stance phase. The new orthotic device will allow a more natural gait pattern and consequently reducing metabolic cost. An improvement in this issue will be a huge effort in reducing the high rejection rate for these orthotic devices users.

HUMAN GAIT CYCLE

The gait cycle is divided into two periods for each foot, Stance and Swing phases. Stance is the time when the foot is on the ground, constituting nearly 58 to 61% of the gait cycle. Swing corresponds to the time when the foot is in the air, constituting the remaining 39 to 42% of the gait cycle time (Whittle 2007).
The gait cycle can be described in the phasic terms of initial contact, loading response, midstance, terminal stance, preswing, initial swing, midswing and terminal swing. Stance period consists of the first five phases, the remaining three ones correspond to swing period
The knee and ankle articulation are utmost significance in the management of the human giat. The knee plays a crucial role in the management of the flexion/extension motion during the human gait and anke The ankle is responsible for dorsiflexion/plantarflexion motion at the time of initial contact (Yakimovich et al. 2009).

DESCRIPTION OF KNEE-ANKLE-FOOT-ORTHOSIS (KAFO) AND STANCE CONTROL KNEE-ANKLE-FOOT-ORTHOSIS (SCKAFO)

Since last century, the Knee-Ankle-Foot Orthosis (KAFO) has been used for decades to overcome weakness and instability of the leg. Knee-Ankle-Foot-Orthosis (KAFO) is an orthotic device that locks the knee in the full extension during stance phase and remains locked during the swing phase. Due to the absence of knee flexion, the KAFO users must adopt abnormal gait patterns (Figure 1).
A new type of orthosis, referred as Stance-Control-Knee-Ankle-Foot-Orthosis (SCKAFO), has recently emerged to allow knee flexion during the swing phase while providing controlled knee flexion in stance phase for patients with *quadriceps femoris* muscle weakness with muscle grade at least 3 (Johnson et al. 2004). This particular type of muscular weakness of lower limb can be the result of different diseases, such as peripheral neurological diseases (poliomyelitis and post-polio syndrome, spina bifida, poly neuropathy), muscular diseases (Duchenne muscular dystrophy, Becker's muscular dystrophy, myasthenia gravis) and central neurological diseases (multiple sclerosis, cerebral palsy, Parkinson disease, brain injury, stroke and spinal cord injury (Whittle 2007; Johnson et al. 2004).
There are some disadvantages when the patients make use of these orthotic devices. The ankle and knee internal moments will increase because the patients have an extra weight in their leg. Most of the orthotic devices nowadays avaiable are heavy, bulky, noisy, expensive, unattractive and offers a limited locking position. It should be highlighted that some compensatory movements will take place such as hip elevation during phase (hip hiking), ankle plantarflexion of the contralateral foot (vaulting), increased upper-body lateral sway and leg circumduction (Kaufman et al. 1996). On the other hand, the prescription of these devices allow the patients to obtain a more symmetric gait, improved mobility, improved gait kinematics, reduced compensatory movements and energy

consumption. Overall, the SCKAFO orthosis promotes a more natural gait kinematics for orthosis users, compared to the conventional KAFO users, as Figure 2 shows (Johnson et al. 2004; Yakimovich et al. 2009).

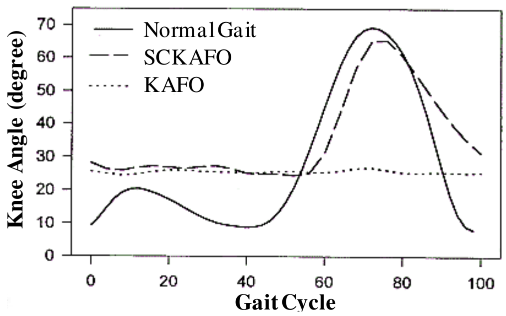

Figure 1: Knee angle during human gait: (1) without orthosis, (2) with SCKAFO and (3) with KAFO {adapted from (Kaufman et al. 1996)}

The first materials used in the KAFO conception were heavy metallic alloys, wood, leather and textile. The typical configuration of a KAFO consists of leather or thermoplastic thigh and calf bands attached to metal uprights joined by a footplate, as can be observe in Figure 2. For that reason the first orthoses were considered heavy and und unattractive.

During the last years, great improvements have been made in the cosmetic finish of the KAFO. New materials such as carbon fibers, thermoplastics and polymers are responsible not only for the weight reduction but also to turn the orthotic device more attractive (Johnson et al. 2004). More recently a new type of KAFO has emerged, namely the SCKAFO dynamic orthosis. Figure 2 depicts the evolution of different types of knee orthosis.

Figure 2: Historic evolution of knee orthotic devices from KAFO (left devices) to SCKAFO (right devices)

DESIGN GUIDELINES OF A NEW ELECTROMECHANICAL KNEE LOCKING SYSTEM

The requirements for a new electromechanical knee locking system can be established in order to approach the gait with a orthosis to a normal gait. If an external actuation system is going to be designed, it must be inspired in the functional actions of the musculo-skeletal system during the gait cycle. The main purpose is to do a reliable replication of the musculo-skeletal apparatus.

A design that exactly duplicates the dynamic behavior of the knee during the normal gait cycle is out of chance. First of all, during the stance phase the knee angle variation is quite small (Figure 1). In order to simplify the biomechanical design, a fixed angle during the stance phase is proposed. This characteristic simplifies the task of the electromechanical lock-ing system that will still locked during this stage (Bolton 2008).

Patients with muscular weakness in the quadriceps femoris muscle group do not have muscle control and the main objective is to assist extension.

In order to synchronize the locking and unlocking functions and actuation in the knee and ankle articulations, it will be necessary obtain biomechanical parameters that allow us to identify in which phase of gait the patient wearing the orthosis remains. This is the first step to control the actuation and locking system (Bolton 2008). These biomechanical parameters will be obtained using sensors. An actuator will be coupled to the RC servo motor in order to lock or unlock the knee electromechanical joint. The selection of the appropriate actuator for this application is still in study. This actuator could be mechanical (pawl, cam follower, pinion, pin), pneumatic or hydraulic.

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