A PNEUMATICALLY POWERED PORTABLE ANKLE-FOOT ORTHOSIS

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INTRODUCTION

Ankle foot orthoses (AFOs) are designed to improve function in individuals with lower limb gait deficiencies. Current powered orthotic technology is used for rehabilitation, diagnostic or training devices to assist walking function, direct measurement of joint motion and force, and to perturb gait in locomotion studies [1]. However, these powered AFOs are tethered to external power supplies and cannot be used outside the laboratory or clinic. Because orthoses are an integral part of rehabilitation, innovative technology, such as portable powered orthotic systems, offer a new treatment modality to improve the functional outcome of rehabilitation. We present a novel portable powered AFO (PPAFO) to provide untethered assistance for in-home rehabilitation of the ankle-foot complex [2].

METHODS

The PPAFO is designed to assist impaired gait by: (1) controlling forefoot velocity at heel strike to prevent foot-slap, i.e., eccentric dorsiflexor assistance, (2) providing modest assistive torque for propulsion and stability at the end of stance, i.e., concentric plantarflexor assistance, (3) supporting the foot in the neutral position during swing to prevent foot-drop, i.e., concentric dorsiflexor assistance, and (4) allowing free range-of-motion during the rest of the gait cycle.

The first generation prototype was made from mostly off-the-shelf components (Fig. 1). A 255 g portable compressed liquid CO2 bottle and pressure regulator (JacPac, Pipeline Inc., Waterloo) were used to power a dual-vane bidirectional rotary actuator (CRB2BW40; SMC, Noblesville, IN) at the ankle joint. The pressure regulator modulated plantarflexor torque for propulsion assistance. An additional pressure regulator (LRMA-QS-4; Festo, Hauppauge, NY) was used to modulate dorsiflexor torque for foot support during swing. The orthotic tibial and foot piece components are custom fabricated of carbon composite materials and serve as the structural elements of the system. A free motion ankle hinge joint connected the foot piece and tibial section on the medial aspect. Velcro straps secured the PPAFO to the leg and foot.

The direction of the torque could be switched between dorsiflexor and plantarflexor via two solenoid valves (VOVG; Festo, Hauppauge, NY). Switching control of the valves was selected based on specific events during the cycle. Event boundaries for loading response, mid stance, end of stance, and swing were determined using two force sensors (Interlink Electronics, Camarillo, CA) placed on the interface of the foot section under the heel and metatarsal heads. Onboard electronics (ez430-F2013 microcontroller; Texas Instruments, Dallas, TX) and the portable power source allowed the PPAFO to provide untethered powered assistance. The prototyped weighs 3.2 kg (power supply = 1.2 kg and AFO = 1.9 kg).
The function of the orthosis was demonstrated on healthy individuals during treadmill walking trials. Three experienced treadmill walkers (male, 25±5 yrs) walked at three speeds (self selected, self selected +25%, and self selected -25%) with five footwear conditions (running shoes, PPAFO: no assistance, 30 psi, 50 psi, and 90 psi assistance). Testing found that the 30, 50, and 90 psi pressures corresponded to 2.8 ± 0.02 (SD), 5 ± 0.02, and 9.2 ± 0.05 Nm, respectively. Each subject first walked in their shoes followed by randomized order of the four PPAFO conditions. A trial was 90s in duration. Walking speeds were conducted in the order given above for each footwear condition. To determine the longevity of the system, one subject also walked with a full CO2 bottle until it was empty. For this test, time and number of steps were recorded while wearing the PPAFO at the 30 psi condition.

Data were collected with a motion capture system at 150 Hz (Vicon, Oxford, UK Model 460), a split belt treadmill with embedded force plates at 1500 Hz (Bertec, Columbus, OH), two pressure transducers at 30 Hz (American Sensor Technology, Mt.Olive, NJ), and the PPAFO force sensors at 30 Hz.

RESULTS

The PPAFO provided functional assistance during the targeted phases of the gait cycle (Fig. 2A): (I) prevention of foot-slap during loading response, (II) free range-of-motion early in stance, (III) modest plantarflexor assistive torque for propulsion late in stance, and (IV) prevention of foot-drop during swing. The sensing capabilities of the PPAFO (Fig. 2B) were successfully used for event detection. The kinematics of the ankle joint were minimally impacted during assisted walking (Fig. 2C). Longevity trials showed that a full CO2 bottle (255g) lasted 37 min at 30 psi assistance level (~1800 steps).

DISCUSSION AND CONCLUSIONS

Experimental results demonstrated that the PPAFO is capable of providing appropriately timed untethered powered assistance during gait. Unlike other powered orthoses, the untethered nature of the PPAFO would allow for in-home rehabilitation use. The PPAFO provides portability combined with the flexibility to modulate the direction (dorsal or plantar), timing, and magnitude of the assistance. Such diversity allows the orthoses to meet an individual’s changing functional requirements, and offers promise as a clinical tool in many arenas of the rehabilitation process.

In the near term tests are planned on subjects with functional needs that would benefit from a powered orthoses. Additionally the performance and efficiency of the device will be improved through development of compact lightweight actuators and enhanced control schemes.

Figure 2: Averaged data (25 gait cycles) from a healthy walker at self-selected walking speed with a peak assistive torque of 4.4 Nm from an operating pressure of 50 psi. The data was normalized to stance and swing with toe off occurring at 60%.

REFERENCES

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