FOOT-PRESSURE DISTRIBUTIONS DURING THE GAIT OF PARAPLEGIC USING PGO

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Abstract

One of the main goals in the rehabilitation of SCI patients is to enable the patient to stand and walk themselves. We have developed high-thrust powered gait orthosis (PGO) using air muscle actuator (Shadow Robot Co., UK) to assist gait. From the experimental results, maximum hip flexion angle and angular velocity in the gait with RGO were 32.6±3.2° and 17±4.2°/sec respectively, and pelvic rotation angle was 11.27±2.23°. In the gait with PGO, maximum hip flexion angle and angular velocity were 35.4±2.1° and 30.8±2.5°/sec respectively and pelvic rotation angle was 6.48±1.9°. It was found that excessive pelvic rotation and hip flexion were reduced when using PGO and the gait with PGO becomes easier compared to the gait with an RGO. In the PGO gait, the movement of the COP is different from that the normal gait, however, the pressure distribution does not seem to affect the pressure ulcer and the deformation of the foot. Therefore, the proposed PGO can be a useful assistive device for the paraplegics to walk.

Key Words
Powered Gait Orthosis, Air muscle, pressure distribution

1. INTRODUCTION

It is a challenging task to make the paraplegic walk without the assist of the caregiver. RGO's (Reciprocating gait orthosis) have been introduced to assist the paraplegic to walk. An RGO is consisted of two KAFO's of which torso section on the top portion is a torso section including pelvic band. The patient wearing the RGO pushes the pelvic band backward with his/her trunk and one of leg braces moves forward. Thus he/she has to keep pushing the pelvic band in order to walk. Therefore during the gait with RGO, the energy expenditure is excessively great and the use of RGO is not widely accepted [1,2,3,4].

At KOREC, a prototype of a powered gait orthosis has been developed to reduce the energy consumption and the muscle fatigue.

Each hip joint of the PGO is flexed by an air muscle operated by pressurized air enabling the patient to walk. The air muscle behaves like a human muscle and connects one side of the torso section to the upper part of the same side of the brace. The role of artificial muscle is to assist hip flexion during swing phase. Therefore, the patient can walk with less energy expenditure by using a PGO than using an RGO. The PGO a modification of an RGO incorporating two pneumatic muscle actuators (PMA), a compressed air system, pressure and joint angle sensors. In this study, the gait study and foot pressure measurement of the paraplegic wearing the PGO was conducted to evaluate the performance of the PGO.

2. PGO system

The concept of the PGO driving system is to couple the right and left sides of the orthosis by specially designed hip joints and pelvic section.

The driving system of powered gait orthosis (PGO) consists of the orthosis, sensor, control system. An supply system is composed of an air compressor, 2-way solenoid valve (MAC, USA), accumulator, pressure sensor. Role of this system provide air muscle with the compressed air at hip joint constantly. According to output signal of foot switch sensor, air muscle assists the flexion of hip joint during PGO gait (Fig. 1).
3. CONTROL SYSTEM

The gait step table is composed by output signals obtained from foot switches with Fig. 2. Microprocessor by this table controls air flow rate that is supplied in air muscle using solenoid valve.

Role of two foot switches that is attached on fore and back of sole of a foot operates air muscle according to gait cycle. The foot switches are set metatarsal and calcaneus anatomically. The flexion/extension of hip joint with gait cycle was classified by 4 step. When the foot sensors of heel and metatarsal does not contact on floor, it is identified as swing phase of gait. The air muscle assists the flexion of hip joint by contract force. At heel contact, the hip joint become fully extension, release the air in air muscle.

4. Method

Three subjects (33.25±11.5 years) who were two adult normal male and one paraplegic male participated in this study. Subjects were recruited from the laboratory staffs and patient of the hospital. Their heights and weights ranged from 170±1.7 cm, 60.5±7.5kg, respectively. Subjects were performed the gait analysis five times per one month after gait training on PGO during about three months.

In order to identify any kinematic value of subjects, we were used six infrared CCD cameras and spheric reflective markers of 25mm in diameter. Seventeen spheric reflective markers were mounted in rigid arrays secured to each body segments: the anterior superior iliac spine, sacrum, great trochanter, medial thigh, knee joint and ankle joint, medial tibia, foot. The analog position signals of each body-fixed markers were converted to digital form, fed on line to a computer, and stored on a hard disc. The raw data of the marker positions were passed through a filter, and analyzed with the built-in software in the three-dimensional motion analyzer system (Vicon 370; Oxford Metrics Inc., UK).

To obtained kinetic data each lower limb joint of subjects, we measured ground reaction force using two force plate (900×600 mm, 600×400 mm in size; Kistler Co., Swiss). (Fig. 3)

Capacitance pressure sensor (Novel GmbH, Germany) were used to measure plantar pressure distributions during walking with PGO (Fig4).

5. RESULTS AND DISCUSSION

The aim of this study ultimately is verifying that PGO gait is more efficient than RGO for paraplegic, because the air muscle assists hip flexion power in heel off.

In figure 5 and 6 the gait characteristics of the paraplegic wearing PGO and RGO are compared with that of the normal person. At the heel contact in RGO and PGO gait, hip flexion angles are approximately 10 deg. while that of normal gait is approximately 30 deg. The smaller hip flexion angles of the PGO and RGO gait are due to the smaller step length. In normal gait, the duration of stance phase and swing phase are 60% and 40% of the total gait cycle respectively. In RGO gait, the duration of the swing phase is reduced since the hip joint is flexed by the rotation of the pelvic band. The hip flexion angle fluctuates during the stance phase as the movement of the body center is unstable. On the other hand, in the PGO gait since the hip joint is flexed by the air muscle and not by the rotation of the trunk, the movement of the center of the body appears to be more stable than that in the RGO gait.
The ratio of the duration of the swing phase in PGO gait is 68±8% showing improvement from the RGO gait in which the duration of the swing phase is 79±4%. The gait speed is 61±3 step/min for RGO gait and 77±2 step/min in PGO gait respectively. During gait, the pelvic tilt is normally related to the balance of the body and the amount of energy consumption. The pelvic tilt during the normal gait reduces the vertical movement of the hip joint and minimizes the vertical motion of the body center. In Figure 6, the pelvic tilts during the PGO and RGO gaits becomes larger than that of the normal gait. The reason is that since there are no knee flexion during the PGO/RGO gait, larger pelvic tilt than that of the normal gait is needed for toe off. The fact that pelvic tilt during the PGO gait is relatively smaller than that of the RGO gait means that the movement of the body center is more stable in PGO gait because of the air muscle.

As shown in figure 7, at the initial heel contact during the normal person’s level walking, the pressure distribution is concentrated on the part of heel and, at the terminal stance phase, heavy concentration of the pressure is found at the metatarsal part. As the mid stance the pressure distribution is almost even.

On the other hand, during the PGO gait, the pressure distribution conical shape concentrated on the heel and metatarsal at the initial heel center and through midstance. However at the terminal stance phase the pressure hill move back to the mid foot as the patients tries to change weight bearing to the other limb.
heel, metatarsal and toes. During the PGO gait, the peak pressure at the heel is more larger than normal gait.

(a) normal gait  
(b) PGO gait

Fig. 8. COP movement

6. CONCLUSION

In this paper a PGO using PMA's for SCI patients is proposed. As the hip flexion angle and the pelvic angle is decreased during the gait with PGO, the patient can walk faster. Foot pressure distributions in PGO gait were compared with those in the normal gait. In conclusion, PGO resulted in increases in pressure and force in the medial arch area and heel area. But in the PGO gait, the movement of the CoG is different from that the normal gait, however, the pressure distribution does not seem to affect the pressure ulcer and the deformation of the foot. Therefore, the proposed PGO can be a very useful assistive device for the paraplegics to walk.

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