Standing stability of the medial linkage KAFOs using functional electrical stimulation in complete paraplegia

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Abstract

A medial linkage device called Primewalk was developed by Saitoh et al. to connect two Knee-Ankle-Foot Orthoses (KAFOs). This device enabled to improve for paraplegic gait not only using orthosis but addition to functional electrical stimulation (FES). The purpose is to investigate the postural stability with the Primewalk device liked KAFOs in a paraplegic patient using FES. The complete T8 paraplegic patient, who has trained the gait for 7years using FES with medial linkage KAFOs participated in this study. The center of pressure (CoP) was measured during stance by force platform and calculated mean amplitude of sway and sway path. These parameter were evaluated under three conditions:(1) quiet standing, (2) pegs moving, and (3) plates staking. The results revealed that there were no significant differences between the Walkabout device and Primewalk one. The results suggested that the Primewalk provides the postural control as stable as the Walkabout during stance without upper limb support.

Introduction/Background

The application of the functional electrical stimulation (FES) to paralyzed muscles combined with medial linkage Knee-Ankle-Foot Orthoses (KAFOs) is useful for reconstruction of standing and ambulation for paraplegics. It enables easily don/doff, combining with the use of wheel chair. [1-2] Moreover, paraplegics can stand up from the wheel chair using FES with unlocked knee KAFOs. [3] The Walkabout device is a well-reported medial linked device that attaches to both KAFOs to form a medial linkage joint. [4] However, with the Walkabout device, the walking speed is considerably slower with shorter step length, because of height discrepancy between the axes of device and hip joint. [5] Saitoh et al. [2] invented the new device called Primewalk (Fig. 1-a, b) to solve this problem. The Primewalk device has a virtual axis near the hip joint height based on a sliding arc guide which attaches both KAFOs medially same as the Walkabout device. The Primewalk device improved walking speed and step length as compared with Walkabout device. Middleton et al. [1] investigated the postural control during stance in paraplegia using the Walkabout device medially linked KAFOs. In that report, quiet standing and two tasks, moving straws and plates were measured by force platform and the mean amplitude of sway and sway path of center of pressure (CoP) was evaluated.

The purpose of this study was to compare quiet standing and task during standing without upper limb support between the Walkabout device and the Primewalk device in a complete T8 paraplegic patient using FES with unlocked knee KAFOs.

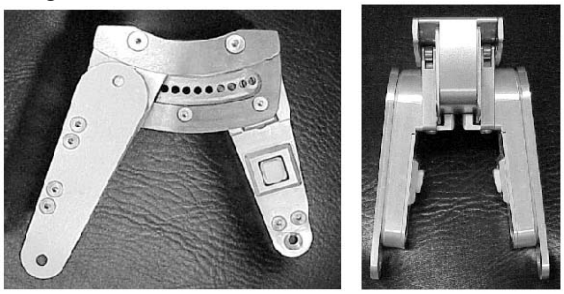

Fig. 1-a **Fig. 1-b**

Fig. 1 Primewalk
a: Lateral view
b: Anterior view

Methods

Subject: A 32-year-old male with complete T8 paraplegia participated in this study. The subject was implanted the electrodes for FES to the lower limb and trunk and training for ambulation with unlocked knee KAFOs using FES for 7 years. Although the Walkabout was used for medially linked device at first, the Primewalk has been alternatively used with the Walkabout since 1997. The subject could stand quietly for about 2 hours without knee buckling using constant FES with medial linkage KAFOs which was unlocked knee.

FES system: Akita Stimulator III (BIOTECH Ltd, Japan) was used for a stimulator to FES (Fig. 2). The points of electrical stimulation during standing were femoral nerve, gluteus maximus muscles and paravertebral muscles bilaterally. The rectangular pulse trains used consisted of a pulse width of 0.2 msec, a pulse interval of 50 msec and an output voltage modulated from 0 to –15V. The voltage of

each electrode was adjusted accordingly to standing without knee buckling.

Orthosis: The unlocked knee of KAFOs linked to the Walkabout or the Primewalk device medially was used in this study (Fig. 3-a, b).

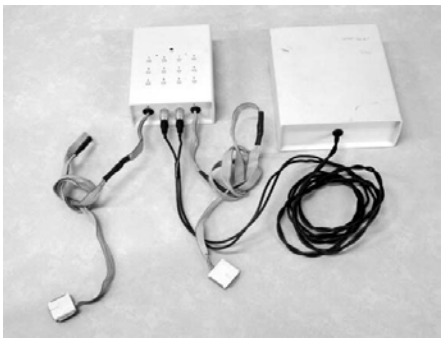

Fig. 2: The stimulator named Akita Stimulator III.

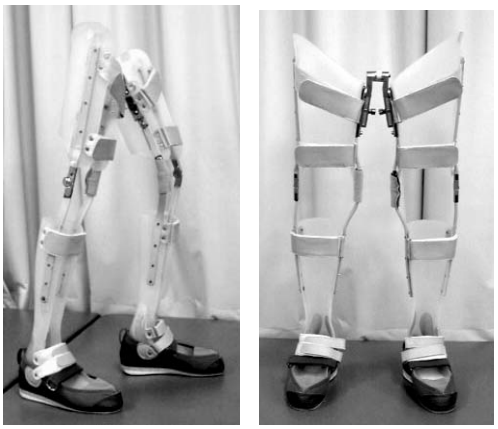

Fig. 3-a **Fig. 3-b**

Fig. 3 Unlocked knee KAFOs
a: Lateral view
b: Anterior view

Condition: The subject stood on the force platform with medial linkage KAFOs using FES in three conditions: (1) quiet standing (Fig. 4-a), (2) task of peg moving during standing without upper extremity support (Fig. 4-b), and (3) task of plate staking during standing without upper extremity support (Fig. 4-c). Peg moving was chosen to perturb stability in mediolateral (ML) direction. In peg moving task subject repeatedly moves a peg from one side of the table to the other between pairs of wells placed 30cm apart. Plate staking was chosen to perturb stability in anteroposterior (AP) direction. In plate staking task subject repeatedly stakes five plates one by one from the table to the shelf at a height of 20cm and return the plates from the shelf to the table.

Equipment: CoP data were measured by force platform (Type 9281B, Kistler, Switzerland) sampled at 50Hz for 30 seconds for all conditions.

Evaluation: Mean amplitude of sway was defined as the average distance from a set point which postural regulation occurred to the instantaneous position of the CoP. Sway path was defined as the total excursion of locus of the CoP. AP and ML directions were calculated respectively in each evaluations. The equations for the mean amplitude of sway and sway path were as follows:

Mean amplitude of sway

$$SP_{AP}\ (\text{mm}) = \frac{1}{n}\sum_{i=1}^{n}\sqrt{x_i^2}$$

$$SP_{ML}\ (\text{mm}) = \frac{1}{n}\sum_{i=1}^{n}\sqrt{y_i^2}$$

(The x_i and y_i are the distances between a set point which postural regulation occurred and instantaneous point of the CoP in the AP and the ML direction, respectively.)

Sway path

$$SP_{AL}\ (\text{m/min}) = c\sum_{i=1}^{n-1}\sqrt{\left(x_{i+1}-x_i\right)^2}$$

$$SP_{ML}\ (\text{m/min}) = c\sum_{i=1}^{n-1}\sqrt{\left(y_{i+1}-y_i\right)^2}$$

(The x_i is the instantaneous point of the CoP in the AP direction and the y_i is the instantaneous point of the CoP in the ML direction. In sway path, c = 2, a collection factor used to standardize to 1 minute.)

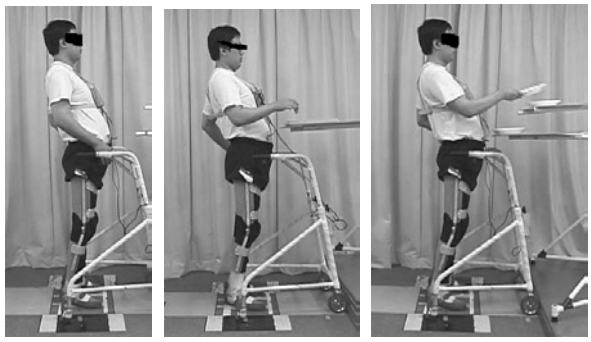

Fig. 4-a **Fig. 4-b** **Fig. 4-c**

Fig. 4-a: Quiet standing without upper limb support.
Fig. 4-b: Pegs moving between 30cm apart wells from side to side without upper limb support.
Fig. 4-c: Plates staking up and down between the table and the shelf without upper limb support.

Results

Student t-test was employed to compare these conditions between with the Walkabout device and with the Primewalk device. There were no significant differences between both Walkabout and Primewalk in quiet standing, peg moving task and plate staking task, respectively in mean amplitude of sway and sway path (Table. 1, 2).

Table. 1: Mean amplitude of sway (mm)

	Walkabout	Primewalk
AP		
Quiet standing	3.93 ± 2.80	5.03 ± 5.03
Moving pegs	7.78 ± 5.73	6.85 ± 4.29
Staking plates	11.07 ± 8.06	9.56 ± 5.94
ML		
Quiet standing	4.46 ± 2.90	3.32 ± 1.86

Discussion/Conclusions

Middleton [1] mentioned that the Walkabout device, because of its hinge that joins the legs proximally in an axis noncoincident with the hip joints, reduces some freedom of movement on the lower body thus providing a more stable base on which to stand. Saitoh studied several virtual axis height models of the Primewalk for paraplegics and reported that many paraplegics preferred the model which has still large discrepancy of about 70mm between axis of device and that of hip joint. Some paraplegics felt unstable on standing with higher axis model. Saitoh [2] reported that the discrepancy in hip axes would work resist joint rotation on standing. Since Primewalk seemed to reduce the postural stability during stance, the authors performed this study.

However, the results showed that there were no significant differences in both orthoses in terms of the mean amplitude of the sway and sway path at each condition. It revealed that the Primewalk provides same performances with regard to standing tasks without upper limb support as the Walkabout provides.

This study is in reference to the Middleton's report that investigated the postural control in standing with linked KAFOs in paraplegics. Low amplitude of sway indicates high postural stability, since the measurement showed how closely the average range of CoP movement was maintained to a set point about which dynamic balance occurred. [6] This view is limited to subjects who can control the body's balance with application of muscles. In case of complete paraplegics who have lost somatosensory information such as proprioception from the feet in contact with the support surface, the information is relied on visual and vestibular systems. Middleton interpreted that when the subjects perform a task requiring some movement, a stable posture is reflected in larger sway and sway path values.

To compare the results of this study to those reported by Middleton, the mean amplitude of sway and the sway path were relatively further in our study during moving peg and plate staking tasks.

The authors speculate that the FES has some effect on postural stability. Because the stimulation of femoral nerve generates the torque of knee extension and hip flexion simultaneously, the subject can afford to extend his hip joint to control postural balance than without FES.

Acknowledgments: The authors thank Prof. E. Saitoh who invented the Primewalk for providing it for us.

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