Restoration of gait with hybrid FES using knee unlocked Medially Linked Knee-Ankle-Foot Orthoses


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Abstract

The purpose of this study was to compare the effect of knee unlocked medially linked Knee-Ankle-Foot Orthoses (MLKAFO) to the conventional knee locked MLKAFO during walking by means of Functional Electrical Stimulation (FES). A 33-year-old male with complete T8 paraplegia participated in this study. The stimulator has two hand switches to change the stimulation pattern. When the switch was turned on, the femoral nerve and paravertebral muscles were stimulated. When the switch was turned off, the femoral nerve stimulation was stopped. Two different types of MLKAFO were prepared for that study namely the knee locked MLKAFO and the knee unlocked MLKAFO. The gaits were measured by three-dimensional analysis system. Trunk anterior tilt and swing leg time in initial swing phase and lateral aspect of gait were evaluated. The results revealed that trunk anterior tilt with knee unlocked MLKAFO was smaller than that of knee locked MLKAFO. Swing leg time in initial swing with knee unlocked MLKAFO was faster than that of knee locked MLKAFO. We concluded that the knee unlocked MLKAFO was provided better performances. The stance leg with knee flexed produced the weight bearing shift forward and the swing leg with knee flexed enabled to start swinging leg faster.

1. Introduction

MLKAFO was enabled the paraplegic patients to keep standing and walking than that of medially unlinked both Knee-Ankle-Foot Orthoses (KAFOs) [1]. MLKAFO stabilize both knee and ankle joints bilaterally by fixing both hip joints so as not to abduct and adduct by medial linkage which connected to both KAFOs.

Functional Electrical Stimulation (FES) utilizes several muscle groups for muscle power generation. For swinging leg action in terms of stimulation it utilizes the iliopsoas muscle, sartorius muscle, tensor fasciae latae. The stimulation of quadriceps, gluteus maximus and the hamstrings cause hip extension so as to stabilize the stance leg [2].

In our institution, when the reconstruction of gait was performed in paraplegics using FES with MLKAFO and L-walker, FES provided muscle power of swinging leg by stimulating hip flexor muscles. However, paraplegics achieved weight shift forward by bending over their trunk anteriorly and loading their weight to their upper extremity muscles. However, the paraplegics complain that the most principal factor of limitation of walking distance was fatigue of upper extremity muscles or wrist pain caused by overloading of their weight.

In general, the MLKAFO of knee joint were kept in a locked extension position. If paraplegics were able to reconstruct walking with a knee unlocked MLKAFO with FES which providing knee extension. Thus it was possible to assist weight shift and to reduce the loading of upper extremities.

The purpose of this study is to compare the effect of knee unlocked MLKAFO during walking by FES to that of the conventional knee locked MLKAFO.
2. Methods

A 33-year-old male with complete T8 paraplegia participated in this study. The patient’s gait has been reconstructed with MLKAFO by FES since 8 year ago.

The stimulator of FES named Akita stimulator III (BIOTEC Ltd., Japan) was used and this stimulator has two hand switches to control the stimulation pattern by turning on and off. When the stimulation was turned on, the femoral nerve and paravertebral muscles were being stimulated. When it was turned off, the femoral nerve stimulation was stopped and remained the stimulation of paravertebral muscles. Controlling this hand switches, the subject achieves reciprocal gait.

The MLKAFO was consisted of Walkabout device which connected medially to both of KAFOs below the perineum. This MLKAFO provides better medio-lateral stability to both hip joints. Two different types of MLKAFO were prepared for this study: one was a knee locked MLKAFO and the other was a knee unlocked MLKAFO (Fig. 1a, b). L-walker was used to reconstruct gait. The gaits were measured by three-dimensional analysis system (PEAK Motus, USA). The trial condition was set up as below: 5m walking distance with free walking which was performed and measured at least 5 times.

Trunk anterior tilt and swing leg time in initial swing phase were statistically compared by Student t-test. Each condition of gait were evaluated by the stick picture which was provided by three-dimensional analysis system.

3. Results

Trunk anterior tilt of knee unlocked MLKAFO was smaller than that of knee locked MLKAFO (Table 1). Swing leg time in initial swing phase with knee unlocked MLKAFO was faster than that of knee locked MLKAFO (Table 2).

Stick picture indicated that the knee flexion was occurred during the gait cycle. Especially, at the point of toe off most knee and trunk flexion were obtained (Fig. 2a, b). It indicated that most loading point to upper extremities was at the point of toe off. The stick picture of knee locked MLKAFO showed the bigger trunk anterior tilt of weight shifting to the forward limb. However, the trunk anterior tilt of knee unlocked MLKAFO was smaller than that of knee locked one. Knee joint was gradually extended from toe off to mid stance phase.

Table 1: Trunk anterior tilt (°)

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<th>Knee unlocked MLKAFO</th>
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<td>Trunk anterior tilt</td>
<td>20.4°±2.3</td>
<td>27.2°±2.7</td>
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Mean±S.D. (* p<0.05)

Table 2: Swing leg time (sec)

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<th>Knee unlocked MLKAFO</th>
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<tr>
<td>Swing leg time</td>
<td>0.32s±0.04</td>
<td>0.45s±0.07</td>
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Mean±S.D. (* p<0.05)
4. Discussion/Conclusions

Knee locked MLKAFO was provided the stability of knee joint during standing and waking in paraplegics. However, healthy subjects were performs knee flexion in both swing phase and stance phase. In case of extension contracture of the knee joint, the energy cost of walking was increased by the additional body maneuvers which required for floor clearance during swing [3]. We predicted that the gait in paraplegic patient with knee locked MLKAFO using FES were also performed additional body maneuvers which obtained for floor clearance. Thus we assumed that the knee flexion was available in paraplegic’s gait. With knee unlocked MLKAFO the knee joint was flexed a little due to weight shifts to the forward limb. The anterior weight shifts was occurred after the extension of knee joint at the point of toe off. Progressed body weight forward, the activation of quadriceps muscle were occurred which played a positive role of shifting the body more forward. As a result, the weight shift to forward limb was achieved regardless of small trunk anterior tilt.

In initial swing phase, the hand switch was turned off for swing leg was observed in both orthotic conditions. Swing leg time indicated that turning off in this phase was effective to start faster swinging leg.

These results suggested that knee flexion provide better performances in stance phase and in swing phase respectively. Thus in stance phase, knee flexion of stance leg assisted weight shift forward and it predicted that the load of upper extremities was more decreased. In swing phase, knee unlocked MAFO enabled to start swinging leg faster than that of knee locked one.

Controlling the knee joint using FES has the problem of muscle fatigue and knee buckling [4] [5]. However, in this study, muscle fatigue and knee buckling was not occurred even though the gait was reconstructed sequentially using FES for 2 hours, on contrary the muscle fatigue of upper extremities were observed [6].

References