The influence that the foot position and FES provides to the quiet standing balance


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Abstract

The hybrid FES using the Walkabout device that links the knee-ankle-foot-orthoses (KAFO) and C-posture provides lateral stability, however it had little effect on anteroposterior stability. The purpose of this study was to determine the influence that the foot position and FES provides to the quiet standing balance. A force platform was used to measure center of pressure (COP) while quite standing. Measurements were made as follows, 1) C-posture, 2) Unilateral foot forward, 3) Using the triangular stand, 4) Using the FES. In this study, to improve the balance in the anteroposterior direction, the unilateral lower extremity was contacted forward using a triangular stand with the FES. We concluded that the hybrid FES using the triangular stand provides standing stability on the anteroposterior for paraplegics.

1. Introduction

Balance is a generic term describing the dynamics of body posture used to prevent falling. Winter [1] reported that balance is related to the inertial forces acting on the body and the inertial characteristics of body segments. The slightest sway can unbalance every segment in the quiet standing [2]. Though paraplegic patients have insufficient muscle activity (which equals output source) and the somatosensory (which equals equilibrium maintenance function), they could maintain standing by FES and use of the several orthoses. The hybrid FES was conducted using the Walkabout (fig 1) to prevent muscle fatigue, reduce energy consumption, and enable better stability [3]. The medially linked knee-ankle-foot orthoses (KAFO) seemed to have many merits in the functions of standing and walking, wheelchair compatibility, cosmetics, and easy don-doff [4]. The first advantage of the medially linked KAFO is that it provides better lateral stability while standing, and it is rare to fall towards the mediolateral direction. However, the main problem is poor stability towards the anteroposterior direction, this can cause problems during activity of daily living while in the standing position. The purpose of this study was to determine the influence that the foot position and FES provides to the quiet standing balance.

2. Methods

Subjects

Subjects were 6 men with established traumatic paraplegia and a woman with paraplegia by neuroblastoma. Subjects had lesions between T4 and T12 levels, all patients had complete sensorimotor loss.

![Fig 1. Walkabout](image-url)
Two individuals were implanted with the electrodes for applying FES to the lower limb and trunk and given training for ambulation with the KAFO using FES 8 years and 2 years ago, respectively. The percutaneous intramuscular electrodes were implanted into the motor points of the paravertebral muscle, psoas major, vastus lateralis, vastus medialis, sartorius, tensor fasciae latae, gluteus maximus, gluteus medius, biceps femoris, adductor magnus and implanted near the femoral nerve and peroneal nerve.

**FES system**

The Akita stimulator III (BIOTEC, LTD, Japan) was used to restore the function of standing-up, standing and walking. The stimulator had 12 channels. The pulse amplitude was modulated from 0 to –15V. Rectangular pulse trains were used with a 200 microseconds pulse width and a pulse interval of 50ms.

**Procedure**

A force platform (9281B, Kistler) was used to measure center of pressure (COP) while quite standing in four methods. 1) C-posture: Usual standing position with hip hyperextension. 2) Forward: Unilateral foot was put forward 10cm. 3) Triangular stand: Unilateral foot was put forward 10cm and a triangular stand inserted between sole and floor. 4) FES: A quite standing using FES with a triangular stand. During the quiet standing, subjects were instructed to look straight ahead and stand as quietly as possible with arms by their side, not touching either their thighs or orthoses with their hands. During the quiet standing on a force platform, the COP digitized at a rate of 35Hz for 30 seconds. The total length of COP, the length of COP on the x-axis, and the length of COP on the y-axis were calculated from measured value variables.

3. Results

All measurements were performed satisfactorily. The standing with a triangle stand using FES was shortest in total length. The average total length is 5.89m/min in the C-posture, 2.98m/min in the forward, 0.57m/min using the triangular stand, and 0.39m/min using the triangular stand with FES (fig 2). There were no significant differences in the length on the x-axis between all measurements. The length on the y-axis was 5.20m/min in the C-posture, 1.86m/min in the forward, 0.98m/min using the triangular stand, 0.59m/min using the triangular stand with FES (fig 3).

4. Discussions

The equilibrium function is controlled by vision, the vestibular system, and the somatosensory. The complete paraplegic patient has to maintain the equilibrium function with the loss of muscle activities in the lower extremities.
and the somatosensory loss. According to Andrews and associates [5], if a subject leans slightly forward with hips and knees fully extended during standing, the floor reaction force passes in front of the knee joint and the leg is mechanically stable. This posture is often referred to as the C-posture which allows the patient to stand stably. While standing in the C-posture using the medially linked KAFO, the patient could maintain the standing position for long time. Middleton [6] described how the Walkabout device links the KAFO and C-posture, because the abduction foot position in the Walkabout, while increasing lateral stability, had little effect on anteroposterior stability. When his patients were moving in the standing position, they not only increased their C-posture, but often used contralateral arm movements, as well. They were necessary to prevent overbalancing forwards or backwards because of their inherent instability in the anteroposterior direction. Winter et al. [1] described that the relation between the COP and the center of gravity (COG) is important in the anteroposterior direction at quiet standing, it is controlled using an “ankle-strategy”. It is described how the position of COP and COG is sensed, and it is controlled by the muscle activity in the ankle due to changes in the position of COP. However, the paraplegic patient while in the standing position keeps the anteroposterior balance by using only the trunk and the upper extremity and they have to try to control their balance while maintaining the hip hyperextension. So, maintaining the balance in the anteroposterior direction is extremely difficult. In this study, to improve the balance in the anteroposterior direction, the unilateral lower extremity was contacted forward. However, the base of support becomes a triangle, instead of a parallelogram, because the ankle joint is fixed by orthoses and this only allows heel contact to occur with the unilateral lower extremity. This makes it difficult to provide adequate support using both lower extremities. The base of support becomes a parallelogram again by using a triangular stand under the sole and it is possible to recreate support by bilateral lower extremities. In addition, falling forward was decreased by the combination of a triangular stand and the rigidity of the ankle part of the posterior unilateral orthoses. However, it is necessary to realize that instability appears in the mediolateral direction when unilateral lower extremity contact is too far forward. Using FES, standing stability was improved. The reason for the improvement of the standing balance is that the stability of the lower trunk and the hip joint improved. Shimada et al [7] reported that the hybrid FES was superior in stability, reducing muscle fatigue, energy consumption. We concluded that hybrid FES, using the unilateral foot forward with the triangular stand, provided quiet standing stability for paraplegics. Finally, if the standing balance of paraplegic patients improves, their activity of daily living in the standing position will progress. However, not only the quiet standing evaluation but also dynamic standing evaluation should be further examined.

References