EFFECTS OF BIAS FES ON UPPER EXTREMITY FUNCTION IN C5/6 QUADRIPLEGIA

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ABSTRACT

Sustained electrical stimulation (Bias FES) to the paralyzed pronator of the forearm in combination with volitional supination is feasible for the restoration of rotational function in quadriplegic patients who lost pronating function of the forearm. This paper describes the effects of Bias FES on upper extremity function including the shoulder joint, the wrist joint and the hand in C5/6 quadriplegia. A C5/6 quadriplegic was required to abduct the shoulder joint for pronating the forearm in sitting posture while Bias FES to the pronator quadratus enabled the patient to rotate the forearm volitionally without shoulder abduction. As pronation progressed from supinating position by Bias FES in the patient, the angle of wrist dorsiflexion decreased, and thus, resulting in a decrease in grip force of the hand. In addition, EMG analysis of the wrist muscles during grip with constant force was performed in healthy subjects for investigating the role of the wrist muscles in forearm rotation. It was shown that the activity of the wrist extensors during grasp with constant force was significantly larger in pronation than those in supination ($p<0.05$). This result suggests that it is necessary to increase stimulus intensity for the wrist extensor in pronating position during Bias FES for obtaining constant grip force by FES. In the same patient, an increase in stimulus intensity to the extensor carpi radialis brevis resulted an increase in the angle of wrist dorsiflexion during forearm pronation which was followed by an increase in FES-induced grip force of the hand. Thus, adjustment of stimulus intensity to the wrist extensor is necessary to keep the grip force constant during forearm rotation controlled by Bias FES.

Key Words: Bias FES, grip force, dorsiflexion angle of the wrist joint, stimulus intensity

INTRODUCTION

Bias FES is a useful method to realize volitional bidirectional joint movement of the paralyzed upper extremity in cervical cord injury patients, which was achieved by volitional contraction of agonistic muscles in combination with tetanic contraction of the paralyzed antagonists activated by sustained electrical stimulation with constant intensity.

The research group in Cleveland reported restoration of the elbow and the forearm function through the continuous stimulation in cervical cord injury [1, 2]. We also reported that Bias FES to the pectoralis major and pronator quadratus provided a C5/6 quadriplegic with volitional abduction/adduction of the shoulder joint and supination/pronation of the forearm[3]. Simultaneous FES control of the wrist and the hand with Bias FES for the shoulder joint and the forearm provided the patient with upper extremity function for activities of daily living (ADL). The stimulus intensity for the control of the wrist and the hand was fixed to constant level in any rotational position of the forearm. In the study, we guessed that grip force induced by FES depended on rotational positions of the forearm during Bias FES.

In this study, we examined the effects of restoration of the rotational function in the forearm through Bias FES on the shoulder joint in a C5/6 quadriplegic. We also measured the grip force and dorsiflexion angle of the wrist joint under different rotational positions of the forearm during Bias FES. Furthermore, for creating a stimulation pattern for the wrist muscles, we investigated the role of the wrist muscles during grip in supination and pronation of the forearm from the EMG data in healthy subjects. In the patient using Bias FES we also measured grip force and dorsiflexion angle of the wrist joint when stimulus intensity for a key muscle, which was suggested from results of the EMG analysis of the normal wrist muscles, was changed.

METHODS

1. **CASE** The patient was 24 year-old-male who had been suffering from complete quadriplegia due to traumatic cervical cord injury. His disorder level was C_5-1-B at right side and C_6-2-A at left side according to Zancolli's classification. He received wire electrodes implantation five months after injury. The pronator quadratus was stimulated as Bias FES for the forearm function. The electrodes were also implanted to the extensor carpi radialis brevis (ECRB), the extensor carpi ulnaris (ECU), the flexor digitorum profundus, the flexor pollicis longus, the abductor pollicis brevis and the interosseous muscle for restoring the hand function.
2. For evaluation of the effects of Bias FES in the patient, we analyzed abduction angle of the shoulder joint and rotational angle of the forearm during feeding with only self-care device and those during feeding with Bias FES by a three dimensional motion analysis system (VICON, UK).
3. In the same patient grip force was measured under the different rotational positions of the forearm by a pressure sensor (Nitta, Japan) which was attached on a 0.2kg columnar wood block when using the Bias FES. The stimulation program during measurements was for drinking a cup of water that was provided by FES for cylindrical grip with wrist dorsiflexion and Bias FES for forearm rotation. The stimulus intensity for the wrist and finger muscles was fixed to constant value. In this examination dorsiflexion angle of the wrist joint and rotation angle of the forearm were measured simultaneously by the three dimensional motion analysis system.
4. Six normal volunteers (six males, aged from 27 to 36 years) performed the following activity, such as grip of an 1 kg object in three positions of the forearm, 60 degrees supination, 60 degrees pronation, and neutral position. Firstly the subjects were asked to grip the object with maximum force in the neutral position of the forearm and then they gripped it with 60% of the maximum grip force in the three positions of the forearm. EMG signals of the wrist muscles, such as the extensor carpi radialis longus (ECRL), ECRB, ECU, the flexor carpi radialis (FCR) and the flexsor carpi ulnaris (FCU), were detected through bipolar Teflon-coated stainless steel wire electrodes (AM system, USA). The EMG signals were recorded for 3000 msec, digitized at five kHz sampling rate with 12bit A/D converter (AD12-16U(98)EH, Contec, JAPAN). Also EMG signals were full-wave rectified and integrated (IEMG). IEMG values of the wrist muscles were normalized with the values in neutral position of the forearm.
5. In the same patient using Bias FES, stimulus intensity for ECRB was increased during forearm pronation, based on the results from the EMG analysis of the normal wrist muscles. Then we measured grip force and dorsiflexion angle of the wrist joint.

RESULTS

1. With respect to the feeding with self-care device, it was necessary to abduct the shoulder joint for pronating the forearm. Bias FES for forearm rotation contributed to minimize shoulder abduction that was used for pronating the forearm during feeding with self-care device.
2. When gripping an object using Bias FES with constant stimulus intensity for the wrist muscles in any forearm position, grip force of the hand induced by FES depended on rotational positions of the forearm. Namely, grip force was the largest in supination and it decreased as pronation progressed. The dorsiflexion angle of the wrist joint was smallar in pronation than in supination (Figure 2).
3. For normal subjects the normalized IEMG values of ECRL, ECRB, ECU and FCR in pronation were significantly larger than those in supination (P<0.05). The activity of FCR in pronation was three times as large as that in supination. There was no significant difference between the normalized IEMG value of FCU in supination and that in pronation (Figure 3).
4. In pronation of the forearm

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8. the dorsiflexion angle of the wrist joint and grip force reached to the values in supination as observed in Figure 2 with an increase in stimulus intensity for ECRB. When stimulus intensity was too high, however the forearm could not maintain in pronating position because of spillover of the stimulus current (Figure 4).

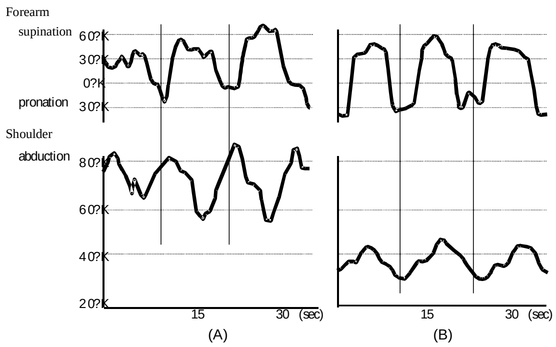

Fig. 1 The angle of forearm rotation and shoulder abduction measured during feeding ?@?@with self-care device (A) and that with Bias FES(B) for a C5/6 quadriplegic.
It was necessary to abduct the shoulder joint for pronating the forearm. Bias FES for forearm rotation contributed to minimize shoulder abduction.

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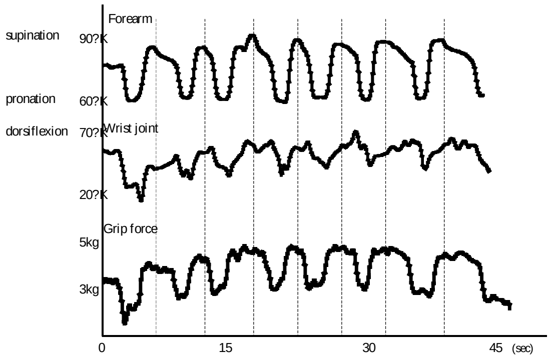

Fig. 2 Grip force and dorsiflexion angle of the wrist joint measured during rotation of the forearm via Bia FES in a C5/6 quadriplegic.
?@?@During the measurements, stimulus intensity for the wrist and finger muscles was fixed to a constant value.

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DISCUSSION

The forearm function was very important for achieving hand tasks provided via FES-controlled grip. Therefore we applied the sustained electrical stimulation to the pronator quadratus as Bias FES to restore forearm rotation in combination with volitional supinating of the forearm. As a result, the Bias FES was feasible because this method enabled the forearm to rotate with requested velocity and maintain in any requested rotational position volitionally without applying control command for pronation. Also Bias FES for forearm rotation contributed to minimize shoulder abduction that was used for pronating the forearm by

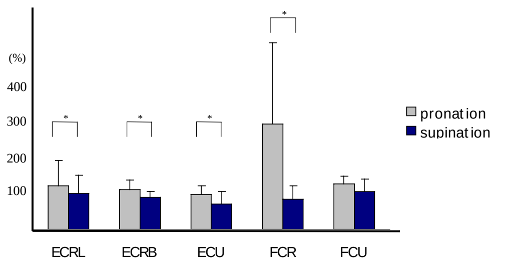

Fig. 3 IEMG values detected from the extensor carpi radialis longus (ECRL), the extensor carpi radialis brevis (ECRB), the extensor carpi ulnalis (ECU), the flexor carpi radialis (FCR), and the flexor carpi ulnalis (FCU) in supination and pronation of the forearm when healthy subjects gripped an object with 60% of maximum grip force in neutral position.
(n=6, *: P<0.05)

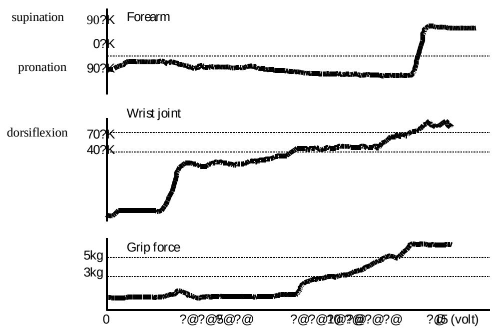

Fig. 4 In pronation of the forearm the angle of wrist dorsiflexion and grip force measured during increasing stimulus intensity for the extensor carpi radialis brevis.
The angle of wrist dorsiflexion and grip force reached to the values in supination as observed in Fig.2.

utilizing gravity in the patient with paralysis of the pronators. However, electrically obtained grip force was the smallest in pronation when stimulus intensity for the wrist muscles was fixed to a constant value. The grip force was affected by the tenodesis effect because dorsiflexion angle of the wrist joint was smaller in pronation than that in supination. Generally it is known that muscle force depend on muscle length according to the length-tension relationship. Therefore force of ECRB for wrist dorsiflexion depended on position of forearm rotation because the muscle length of ECRB is longer in forearm pronation as compared with in forearm supination. This phenomenon caused the problem that an object could not be gripped tightly during forearm pronation. It is necessary to solve this problem for the development of the Bias FES in the practical use for ADL.

We examined the characteristics of the activities of the wrist muscles by analyzing EMG signals of normal subjects. The experiment was performed to make an effective stimulation pattern for the wrist muscles to obtain constant grip force under the different rotational positions of the forearm. It is known in the normal wrist muscles that ECU affects ulnar deviation movement of the wrist joint during forearm pronation rather than dorsiflexion movement. This is because ECU has a shorter moment arm relative to the axis of dorsiflexion /palmer flexion of the wrist joint in pronation as compared with in supination. For ulnar deviation ECU has a longer moment arm relative to the axis of radial deviation /ulnar deviation in pronation as compared with in supination[4]. As a result, the progress of pronation during grip with constant wrist dorsiflexion caused an increase in the activities of ECRL and ECRB to compensate the decrease of the effect of ECU on wrist dorsiflexion. In addition, it was necessary to increase the activity of ECRL and FCR against the ulnar deviator, ECU, since they also act as radial deviators. Particularly the activity of FCR increased three times in pronation as compared with that in supination because muscle length of FCR is shorter in pronation. However this fact is negligible because force of FCR is extremely small when the wrist joint is dorsiflexed actively.

In the patient using Bias FES, the decrease of grip force in pronaiton was caused by a decrease in force of wrist dorsiflexion because of the constant stimulus intensity applied to the wrist extensor. Therefore in Bias FES it was necessary to activate ECRB or ECRL in pronation more than in supination for maintaining grip force of the hand and dorsiflexion angle of the wrist joint constant in any rotational position of the forearm. Practically we increased stimulus intensity for ECRB in pronation. When stimulus intensity for ECRB was increased, the dorsiflexion angle of the wrist joint and grip force in pronation increased to those in supination simultaneously with an increase in stimulus intensity for ECRB.

In a feed back loop system for upper extremity FES, it is likely that rotation angle of the forearm or dorsiflexion angle of the wrist joint can be used as a command of the stimulation for ECRB to obtain constant grip force.

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