Case Study

Integrated volitional control electrical stimulation for the paretic hand: a case report

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Abstract. [Purpose] Integrated volitional control electrical stimulation (IVES) is a type of electrical stimulation therapy that promotes agonist muscle contraction in limbs with motion paralysis. This case study describes the improvement in the paretic hand with stroke hemiplegia, eight years after the onset, with IVES for one month in the extrinsic and intrinsic muscles, including change of mode of stimulation based on the degree of improvement. [Participant and Methods] A 76 year-old male with hemiplegia for eight years. The patient was evaluated for two weeks and performed IVES in the right flexor pollicis brevis, abductor pollicis brevis, and extensor carpi ulnaris with the change of mode of IVES. [Results] The upper limb function improved in a short period of time. The hemiplegia test showed Brunnstrom stages II–III and II–IV for the right upper limb and right hand and fingers, respectively, 28 days after IVES initiation. [Conclusion] After one month of undergoing IVES, the patient showed improvement in hand and finger motor function, which was maintained even after IVES was completed. In this case, there was improvement with a short-term intervention using appropriately combined IVES modes.

Key words: Electrical stimulation, Integrated volitional control electrical stimulation (IVES), Hemiplegia

INTRODUCTION

Integrated Volitional-control Electrical Stimulation (IVES) is a type of electrical stimulation therapy that promotes agonist muscle contraction in limbs where motion paralysis, as in stroke hemiplegia, has occurred, resulting in an inhibition of the antagonist’s muscles to improve motor function.

The difference between IVES and conventional electrical stimulation therapy is that the device used in IVES (IVES device) provides a function for simultaneous myoelectric derivation and electrical stimulus output using the same electrode1, 2). Specifically, while conventional electrical stimulation therapies, such as therapeutic electrical stimulation (TES) and functional electrical stimulation (FES) only provide unilateral electrical stimulation, IVES has the advantage that it not only outputs an electrical stimulus from an electrode. It can also simultaneously detect myoelectricity from the same electrode and provide various stimuli, in which the timing and quantities are controlled, to locations other than myoelectricity derivation sites. Thus, with IVES, various myogenic potential input sites, stimulation sites, and controlled electrical stimulus combinations can be applied in accordance with the degree of recovery of the user, and various stimulus treatment methods can be adopted. In addition, because IVES can be performed at the same time as voluntary muscle contractions and the IVES device is compact, IVES can be combined with other therapies, such as exercise therapy and prosthetic therapy freely.
The developer, Muraoka et al.1, 2) also combined the use of IVES with a wrist hand orthosis in the first IVES device model, developed under the assumption that it would be equipped with finger extensor FES in the future.

There have been many previous reports indicating that IVES improves upper limb function. However, most of these reports are referring to the power assist mode (the mode in which an intense electrical stimulus is an output in proportion to the amount of the detected myoelectricity), the effects of IVES when combined with wrist hand splint eight hours daily for three weeks, and the effects of applying the extrinsic muscles of the wrist to targets. There are few reports of cases where various stimulus input methods according to myogenic potential input were used or reports in which both the extrinsic and intrinsic muscles of the wrist were stimulated together over the treatment period, as opposed to stimulating only the extrinsic or intrinsic muscles.

In patients with stroke hemiplegia, upper limb paralysis is generally more severe than lower limb paralysis, so ADL is greatly affected. Patients who do not recover upper limb function are forced to live their lives using the unilateral arm. Therefore, if the paralyzed arm is the dominant arm, ADL and QOL are significantly affected. Exercise therapy, such as conventional problem-oriented exercise therapy, combined with botulinum toxin to alleviate muscle tension, constraint-induced movement therapy, and electrical stimulation therapy have frequently been implemented to rehabilitate the upper limbs following stroke. These are frequently used during the acute phase and the recovery phase. These past reports showed that recovery of motion paralysis is very difficult in patients with stroke hemiplegia lasting more than six months3). Moreover, because Japanese health insurance is set up such that insurance points decrease after 180 days elapses from the onset, patients for whom an extended period of time has passed since disease onset do not receive sufficient rehabilitation and are forced to abandon motion paralysis recovery.

In the present report, IVES was performed for one month in the extrinsically and intrinsic muscles on the paralytic hand of a patient with stroke hemiplegia eight years after the onset of the disease. The report describes how marked improvement in upper limb function was observed in a short period of time by changing the mode of use of IVES according to the degree of improvement, and also discusses that motor function was maintained one year after IVES was completed.

**PARTICIPANT AND METHODS**

A right-handed 76 year-old male patient was diagnosed with a left-brain stem hemorrhage. He was 161.0 cm tall, had a body weight of 67.6 kg, his BMI was 25.8, and the Barthel Index was 35 points.

The disease occurred eight years prior. Inpatient treatment was completed eight months after the onset of the disease. Subsequently, the patient used an ambulatory rehabilitation facility five times per week through a nursing care insurance service. Individual training in ambulatory rehabilitation was performed 2–3 times weekly, and rehabilitation was performed for 20 minutes each time. Range of motion training was implemented mainly in the wrist to rehabilitate the right upper limb. The physical therapy that had been performed mainly was gait training using a T-cane. IVES was initiated during physical therapy because the patient strongly desired to be able to move his arm. None of the contraindications to electrical stimulation therapy applied, and he received regular medical examinations by a physician.

The patient was informed that the case report was to be written, and his written consent was obtained based on the Declaration of Helsinki. A physical therapist other than the therapist in charge handled the informed consent process not to prevent rejection of the patient participation.

A hemiplegia function test was performed to assess the patient’s physical function prior to starting IVES, and the results included upper-right limb Brunnstrom stage II, right hand and fingers II, and right lower limb I. The SIAS-Motor knee-mouth test was 1, and the finger-function was 1A. As for the movement of the upper limbs on the hemiplegic side, slight contraction of the extensors was observed in the right fingers 3–5, and abduction of the thumb was impossible since there was no voluntary finger movement (Fig. 1). The patient was also unable to dorsiflex his wrist. Muscle contraction occurred during palpation. The patient complained, “I have forgotten how to move my right hand because I haven’t tried to move it for a while.”

Muscle tension in the right elbow joint flexion muscles was 1+ on the Modified Ashworth Scale, and the right wrist joint flexion muscles were 1. Grip strength was 25.5 kg in the left hand (mean of 2 times) and could not be measured in the right hand, and almost no limitation in the range of motion of the right wrist joint was observed. The results of the sensory testing showed superficial sensation blunting that was moderate in the right palm (5/10) and mild in the forearm and upper arm (7/10) and deep sensation blunting that was severe in the right shoulder and elbow joints (2/5) and moderate in the wrist and index finger (3/5).

The patient scored 29/30 points on the Revised Hasegawa Dementia Scale (HDS-R) for higher-order brain functioning. In addition, no abnormalities were observed in the apraxia and agnosia tests. The Functional Independence Measure (FIM) score was 80 (required supervision when moving, such as when going to the bathroom), and the left upper limb was used to perform activities of daily living, such as eating meals or personal grooming, with the upper-right limb hardly being used at all.

As of 2019, there are 3 types of IVES devices: (1) IVES® (OG Wellness Technologies Co., Ltd., Okayama, Japan), (2) MURO Solution (Pacific Supply Co., Ltd., Osaka, Japan), and (3) WILMO® (SK-Electronics Co., Ltd., Kyoto, Japan) The IVES®, which was used in the present study, has 5 modes: A) normal mode (a pre-set electrical stimulus is output by an
electrode placed on the target muscle), B) power-assist mode (detects the myogenic potential obtained from the electrode placed on the target muscle and produces a proportional electrical stimulus from the same electrode), C) trigger mode (a set electrical stimulus is output from the electrode placed on the target muscle, triggered by the myogenic potential obtained from the same electrode), D) external trigger mode (a set electrical stimulus is output from the electrode placed on the target muscle, triggered by the myogenic potential obtained from an electrode placed at a separate site), and E) external assist mode (the myogenic potential obtained from an electrode placed at a separate site is detected, and a proportional electrical stimulus is an output by an electrode placed at the target muscle).

RESULTS

During 0–14 days after starting IVES (IVES performed 3 times weekly, 10 minutes each session), the modes used consisted of 1) normal mode and 2) external trigger mode; with a frequency was 50 Hz, the rising was 1.0 sec, falling was 1.0 sec, stimulus time was 10 minutes each, conduction time was 5.0 sec, and rest time was 5.0 sec. The following details were implemented. Figure 2 showed the normal mode on the intrinsic muscles of the hand. Muscle contractions in the intrinsic muscles of the hand were observed, but there was little muscle output for generating finger and hand motion. Therefore, normal mode stimulation of the right flexor pollicis brevis muscle and the right abductor pollicis brevis muscle was used to promote voluntary contraction. The target muscles for the stimulus sites included the right flexor pollicis brevis and the right abductor pollicis brevis. An electrode was cut out 15-mm in all four directions from its original size and attached to the belly of the muscle. The flexor pollicis brevis and abductor pollicis brevis attach to nearby sites, so it was difficult to distinguish them when stimulating at a surface electrode. So, it might be stimulated both muscles at the same time, Therefore, it is believed that they were stimulated simultaneously by a single electrode. Normal mode on the extrinsic muscles of the hand was executed. Although muscle contractions were observed in the extrinsic muscles of the hand (right extensor carpi ulnaris), right wrist joint dorsiflexion could not be performed, and muscle output was such that only extension was observed only slightly in the right fingers 3–5. Therefore, IVES was performed in normal mode to attach the electrode to the muscle belly and so wrist dorsiflexion could occur. Figure 3 showed the external trigger mode on the extrinsic muscles of the hand. Because the patient complained intensely, “I do not know how to move my right arm,” the external trigger mode was used since it can utilize movement on the non-paralyzed side. Myoelectric signals were acquired from the left extensor carpi ulnaris muscle, and an electrode was attached to the belly of the muscle. The right flexor pollicis brevis muscle was the target muscle for the stimulus site. IVES was performed while the patient visually confirmed the movement of the hands and fingers on both sides of the body.

Fourteen days after IVES initiation, voluntary extension in fingers 3–5 at approximately 5° occurred. Additionally, voluntary abduction of the right thumb was possible within a range of 0–15°.

During 14–28 days after IVES initiation, the following IVES was performed 3 times weekly for 10 minutes each. Power assist mode on the intrinsic muscles of the hand was executed to induce intentional movement (gripping action), IVES was performed on the intrinsic muscles of the hands in two different stimulus sites: one site targeting the right flexor pollicis brevis and the right abductor pollicis brevis from the functional limb position using a rod (Fig. 4), and one site targeting the 3rd lumbrical muscle to induce extensor movement in fingers 2–5 (Fig. 5). Each implementation time lasted 5 minutes. The stimulation mode was switched to 3) power assist mode because sufficient muscle contraction was observed. Figure 6 showed power assist mode to the extrinsic muscles of the hand. Because of the large myogenic potential that was observed in the dorsiflexors, myoelectricity was derived from the right extensor carpi ulnaris, and the power assist mode, which proportionally increases the electrical stimulus on the same muscle at the same time, was performed for the extrinsic muscles. Using feedback according to an electrical stimulus proportional to the derived myoelectricity, the patient has tried to grasp
Motor function evaluation 28 days after IVES initiation was that voluntary abduction of the right thumb and extension movement in fingers 2–5 was both possible 28 days after IVES initiation (Fig. 7). The hemiplegia test indicated Brunnstrom stage right upper limb III, right hand and fingers IV, and right lower limb II. The SIAS-Motor knee-mouth test was 2, and the finger-function changed to 1C. The results of the sensory testing showed superficial sensation blunting that was moderate in the right palm (5/10) and mild in the forearm and upper arm (8/10) and deep sensation blunting that was mild in the right shoulder joint and elbow joint (4/5) and Normal in the wrist and index finger (5/5). There were no changes in the other function evaluations. The patient’s impression was, “I was surprised because I did not think I would be able to move my hand.”

Follow-up evaluation 1 year after IVES was completed. The hemiplegia test showed right upper limb Brunnstrom stage right upper limb III, right hand and fingers IV, and right lower limb II. The SIAS-Motor knee-mouth test was 2, and the finger-function was 1C. There were no changes in the other function evaluations. Holding a pen and grasping a ball were possible; the patient was also able to open and close a clothespin (Fig. 8). Ambulatory rehabilitation via a nursing insurance service was used 5 times per week for 1 year. Ambulatory rehabilitation was performed 2–3 times weekly for 20 minutes per session. Intervention for both the rehabilitated upper and lower limbs that was centered on movements in daily life, and not specialized to the same fingers as prior to IVES implementation, was performed. IVES had not been used. At home, the patient practiced moving his right hand by himself.

**DISCUSSION**

After 1 month of receiving IVES on the hands, fingers, and wrist, the patient showed improvement in hand and finger motor function, which was maintained even after IVES was concluded. Conventionally, motor function recovery is hardly
observed 6 months or later after the onset of stroke hemiplegia. Therefore, the present case is believed to be important, since the improvement was observed in one month even though more than 8 months had passed since onset and the patient did not use the paralytic hand for an extended period of time. Nevertheless, the function was maintained and improved over a short period of time.

Fujiwara et al.4) reported improvement in the upper limbs of 20 patients (mean age, 49.7 years (SD 15.2), a mean of 17.5 months since onset (range, 5.3 to 32.5 months)), which was maintained for a period of three months as a result of implementing the power assist mode of IVES combined with the use of a brace for 8 hours a day, 5 days per week for 3 weeks. Similarly, Yamaguchi et al.5) reported significant improvement in wrist dorsiflexion myogenic potential in 10 patients (mean of 4.1 years elapsed since onset (range, 1.0 to 19.6 months) and mean age of 74.6 years (range, 67 to 86)) by implementing the power assist mode of IVES for 6 hours per day for 5 days. In the present case, various IVES modes were used, and an improvement was observed with one month of intervention, 20 minutes per day, 3 days per week, suggesting that upper limb function improvement can be expected even with short-term intervention by appropriately combining modes. In addition, that motor function was maintained for one year.

In terms of the positive factors regarding the improvement observed in this case, one reason why IVES was effective is believed to be that hand and finger ROM were hardly limited and the increase in muscle tension during movement was not marked. In addition, when using trigger mode, which was used in the initial 2-week period, muscle contractions of the non-paralyzed side occurred and electric stimulation was applied to the paralyzed side, enabling right/left symmetric movements to be generated. This was inferred to be an effect that was due to the same neurological mechanism as the mirror therapy proposed by Rizzolatti et al6). The input of an electrical stimulus triggered by the movement of the non-paralyzed side was believed to have generated pseudo-movement on the paralyzed side. The difference between the present IVES approach and mirror therapy is that an electrical stimulus was used to enable passive movement of the upper limb on the paralyzed side, resulting in motor sensation feedback. In addition, because the function was maintained and improved one year later suggests that if motor functions are reacquired once, they are maintained by repetitious movements.

Because improvement was observed with a nursing service, not an intensive medical service, despite the long period of time that had passed since onset, is believed to indicate that this was an important clinical study, even though it only involved a single case. In the future, we would like to propose useful ways to use IVES even as regional rehabilitation is promoted to meet the needs of the aging society. The present study has a few limitations. Firstly, the target was one person. Efficacy has not been shown for patients with different range of motion or muscle tone. Secondly, we didn’t take into account the effects of the differences in each mode and didn’t use each mode equally. These limitations should be overcome in future studies to test the universality of the effects of each mode combination.

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