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Case Study

Contralaterally-controlled functional electrical stimulation-induced muscle contraction for severe lower extremity paralysis

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Abstract. [Purpose] We describe a new method of functional electrical stimulation therapy for severe hemiparesis. Conventional functional electrical stimulation of the lower legs has limited applications. It is only suitable for patients who can monitor their muscle contractions, and it has complicated equipment installation procedures. [Participant and Methods] The participant was a male in his 40s with severe motor paralysis following brain surgery. We monitored the participant's healthy side using the external assist mode of an Integrated Volitional Control Electrical Stimulation (IVES® OG Giken, Okayama, Japan) system while forcibly contracting the paralyzed side. The participant received this new functional electrical stimulation therapy five times per week. [Results] Two weeks after initiation of therapy, paralysis was noticeably improved, and motor function was maintained for approximately 1 year. [Conclusion] The outcomes of this case suggest that the addition of forced contraction therapy, mirror therapy, and repetitive exercise therapy to regular physical therapy may be beneficial. This treatment method may also be useful in postoperative patients with central motor palsy and no muscle contraction ability.
Key words: Functional electrical stimulation, Contralaterally control rehabilitation, Central motor palsy

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INTRODUCTION

Functional electrical stimulation (FES) is a technique that uses electricity to activate the nerves that supply paralyzed muscles. FES therapy, through this nervous system-mediated activation is thought to forcibly promote muscle contraction, which disinhibits the cortical motor area via local inhibitory interneuron inhibition, thereby increasing cortical motor area excitability and changing synaptic plasticity[1)]. Integrated Volitional Control Electrical Stimulation (IVES® OG Giken, Okayama, Japan) is an FES device that elicits voluntary movements and outputs amplified electrical stimulation to different muscles by monitoring electromyograms[2)]. This device is used in clinical practice as a physical therapy technique to promote muscle contraction. IVES® has an external assist-mode setting that monitors the unaffected side and is effective even in cases where muscle contraction is not observed. In patients without upper extremity muscle contraction, the unaffected side was monitored, and stimulation was applied to the affected side[3–5)]. There have only been a few reports of this technique in the lower extremities. In our patient with prolonged motor paralysis after tumor resection, we monitored the unaffected side in the external assist mode of the IVES® and aimed to improve motor paralysis by forcibly contracting the muscle on the affected side (Fig. 1).

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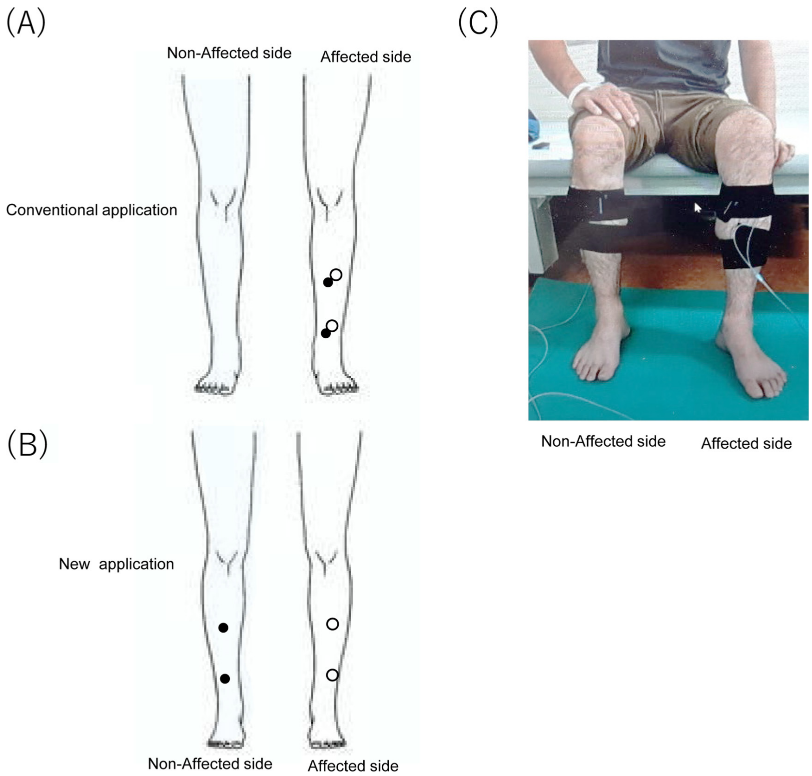

Fig. 1. Difference between conventional functional electrical stimulation application and the new application of Integrated Volitional Control Electrical Stimulation®.

(A) The conventional application of this device for motor paralysis is only direct stimulation, in which the lead-out and stimulation electrodes are placed on the same muscle. (B, C) In this new functional electrical stimulation, a lead-out electrode is placed on the unaffected side where the muscle is still capable of voluntary contraction, and this contraction is monitored. Subsequently, a stimulation electrode is placed on the affected side's muscle to induce muscle contraction.

PARTICIPANT AND METHODS

We designed this open-label feasibility clinical study to test this new method in patients with severe motor paralysis without muscle contraction. The main inclusion criteria were age ≥20 years and severe paralysis due to stroke or neuromuscular disease, and the main exclusion criteria were dementia or implanted internal metals, such as cardiac pacemakers or deep brain stimulation electrodes. A male in his 40s was diagnosed with a brain tumor in his right frontal lobe 6 years prior and was asymptomatic and under observation. One year ago, his left upper and lower extremities developed dyskinesia, which gradually worsened. Craniotomy was planned because the tumor interfered with his daily activities and driving. At his pre-operative evaluation, his Brunnstrom recovery stage (BRS) levels were: upper-left extremity III, finger III, and lower extremity IV. The total gross muscle strength test (GMT) revealed score of 5, for the upper-right extremity; 3, for the upper-left extremity; 5, for the lower-right flexor extremity; and 0, for the lower-left flexor extremity. The modified Ashworth scale was 1+ in the left upper extremity and 1+ in the left lower extremity, and his superficial sensation was normal. The pathological diagnosis was undifferentiated oligodendroglioma. After the craniotomy, the motor function of the left upper and lower extremities worsened, and rehabilitation treatment with physical and occupational therapy was initiated 2 days after the operation. At the start of treatment, BRS levels were: upper-left extremity III, finger II, and lower extremity I. GMT levels were: upper extremity 2, and lower-left extremity 0. Fugl-Meyer Assessment (FMA) lower-extremity item was 10, and severe superficial sensory paralysis was noted. His lower-left deep tendon reflexes improved, and Babinski's and Chaddoh's signs on the left side were positive. Ankle dorsiflexion limitation was pronounced at 0° during active movement, and no muscle contraction was observed. At 40 days post-operation, he received regular physical and occupational therapy, including neuromuscular re-education, strength training, and Activities of Daily Living training. There were still 10 FMA lower-extremity items, and muscle strength measurement with a handheld dynamometer (HHD) was not possible due to difficulty in voluntary movement of ankle dorsiflexion. We attempted FES of the tibialis anterior muscle; however, muscle contraction was difficult to monitor. This case report was approved by the Clinical Research Ethics Board of Nara Medical University (approval No. 3260).

Written and verbal consent was obtained from the patient for publication of the report and any accompanying images.

RESULTS

The tibialis anterior muscle was the target muscle for FES. The minimum stimulus intensity of the IVES device was set to 15%, maximum stimulus intensity to 50%, and sensitivity to 3.0. On postoperative day 65, the FMA lower extremity item improved to 24 points, and the BRS improved to lower extremity IV, GMT lower extremity 4, and MAS1. Muscle strength evaluation by HHD showed ankle dorsiflexion of 3.6 kg. In addition, automatic ankle dorsiflexion exercise to +6°was possible, improvement in motor paralysis and muscle strength was observed without increasing muscle tone, and the patient was discharged. At 149 days after surgery, the FMA lower limb item 30 points, BRS lower limb V, GMT lower limb 4+, MAS1, ankle dorsiflexion muscle strength 5.0 kg, and active ankle dorsiflexion motion recovered to +20° (Fig. 2). The patient was able to walk independently with a plastic ankle-foot brace even after discharge. Motor function was maintained one year after the operation, and no adverse events related to the FES were observed.

DISCUSSION

Earlier studies using electrical stimulation have reported that the combination of direct electrical stimulation monitoring of muscle contraction from the affected leg and voluntary movement improved motor paralysis. There are few reports on treatment methods that monitor the unaffected side of the affected lower limb without dysplasia[6]. This technology can also be applied to patients without muscle contraction in the acute phase and monitor the unaffected muscles and forcibly contracts the affected muscles, is expected to have effects similar to those of mirror therapy. The integrated function of a perceptual-motor loop is necessary when executing a movement, and the perceptual input of sight plays a significant role. Mirror therapy is thought to activate areas related to the corticospinal tract by evoking images of movement[7]. Exercise using the unaffected side of this technology not only activates the visual cortex and somatosensory cortex by visual feedback but also activates the motor cortex and related association cortex by projecting it to those areas. Repetitive exercise is also important for improving paralysis, and further strengthening of synaptic functional connections can be induced by repeating exercise as much as possible during the period when neural pathways are being rearranged. This technology increases exercise opportunities and the total amount of exercise that patients can perform. On the other hand, passive movement alone has negligible effect on central motor performance function and does not change the activity of cerebral cortical movement[8]. An increase in voluntary motor commands increases the efficiency of excitatory synaptic transmission and promotes synaptic integration[9]. It is hypothesized that the movement of the affected side can also lead to an improvement in synaptic efficiency owing to the repetition of the intended movement.

It is undeniable that the natural course of post-operative cerebral edema was also observed as part of the improvement process of motor paralysis especially when considering the effect on the pyramidal tract. No improvement in motor paralysis was observed until 40 days after surgery in this case. If motor paralysis is only due to post-operative edema, improvement in motor paralysis is expected approximately 2 weeks after surgery[10]. This should be accepted, and it is difficult to explain by the reduction in edema only. There is a high possibility that the tumor or pyramidal tract disorder associated with the surgical operation was present, and it is thought that FES therapy promoted the improvement of motor paralysis. This case showed the possibility of this FES being an effective treatment strategy.

This present case study has some limitations inherent to its design. The FES therapy used in this study was combined with 'regular' physical and occupational therapy and has not been shown to be effective alone. However, it may be effective when used in combination with conventional treatment. As there was no comparison with the natural course, a case-control study with a large number of cases is necessary to investigate this possibility. In addition, it is not yet known whether continued

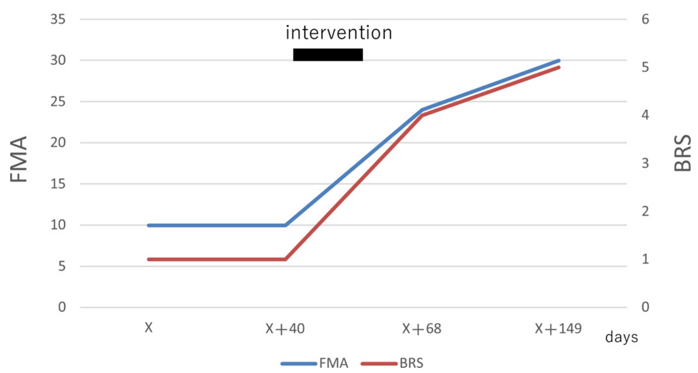

Fig. 2. The course of lower extremity function
FMA: Fugl-Meyer Assessment; BRS: Brunnstrom Recovery Stage.

use of this technique improves muscle function following paralysis. The main purpose of this method was to induce the initial muscle contraction, and it was therefore intended for short-term use. This study did not include objective evaluation of pyramidal tract symptoms such as motor-evoked potential monitoring before and after surgery, and could have brought us closer to elucidating their pathology.

We trialed FES therapy for a patient with decreased muscle output due to motor paralysis after brain tumor removal, with favorable one-year outcomes and no adverse events. Therefore, our new FES therapy may be safe and effective in postoperative patients with central motor palsy without muscle contraction.

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