

Clinical experience of functional electrical stimulation for restoration of tetraplegic hand function.

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Introduction

There are some Functional Electrical Stimulation (FES) systems that restore upper limb functions in tetraplegia. Surface electrodes [1], percutaneous intramuscular electrodes [2] and totally implantable electrodes [3] are used for stimulation in these neuroprostheses. The FESMATE system, developed by the Sendai FES Projects in Japan, is a portable multi-channel FES system with percutaneous electrodes [2]. We have been using the FESMATE system for restoring hand grasp in tetraplegia since 1991. The purpose of this study was to evaluate the improvement of hand grasp function in tetraplegia using the FESMATE system.

Methods

The subjects included four males and one female with tetraplegia caused by spinal cord injury of the cervical spine. Two subjects were incomplete C5 tetraplegia, two subjects were complete C6 tetraplegia and one subject was an incomplete C7 tetraplegia. The average patient age was 39 years (range, 19 – 69 years). The average time since injury was 1 year 2 months (range, 3 months to 1 year 10 months).

The FESMATE system is the only commercially available FES system in Japan. It consists of a system controller and a portable 30-channel stimulator. The system controller was used to compose and store the stimulation parameters that set the threshold voltages for each channel, and controlled the pulse shape and the individual pulse sequence. The stimulating data for restoring hand grasp of each patient was created in a system controller and transferred to a RAM of the portable multi-channel stimulator through a serial communication line. The patients usually wore the portable stimulator that was connected to percutaneous intramuscular electrodes. The indwelling electrode was formed as a helically wound Teflon-coated 19 strand stainless steel wire (Nippon Seisen Co. Ltd.). Electrodes were implanted percutaneously into the motor point of the muscles and nerves. Stimulation frequency was 20 Hz. Rectangular monophasic pulse waveforms were used. Pulse width was 0.2 msec, and the pulse amplitude was modulated from 0 to –15 volts.

Two hand grasp patterns (palmar grasp and lateral pinch) could be selected by the patients. We developed the original control unit consisting of three push buttons and a connector to the portable stimulator.

Results

The FESMATE system was implemented in four subjects. One patient (complete C6 tetraplegia) was excluded because the finger flexors showed no contraction during the pre-surgical test stimulation. The average follow-up period was 3 years (range, 9 months to 7 years 2 months). The average number of percutaneous electrodes was 16 (range, 9 – 20). The stimulated muscles and nerves were extensor digitorum, extensor indicis, flexor digitorum superficialis, flexor digitorum profundus, extensor pollicis longus, extensor pollicis brevis, abductor pollicis brevis, opponens pollicis, adductor pollicis, first dorsal interosseus, extensor carpi radialis, extensor carpi ulnaris, extensor carpi radialis, extensor carpi ulnaris and deep branch of the radial nerve. Tendon transfer

or joint fixation was unnecessary. Three patients (two incomplete C5 and one complete C6) had restored hand function. They showed an increased level of independence in eating, drinking, writing and self-care. One patient (incomplete C7) showed improvement with the hand function through therapeutic electrical stimulation and FES was not adopted.

Discussion

We could restore the hand function by the portable stimulator and percutaneous electrodes. There are some advantages in this neuroprosthesis. First, it can control many muscles simultaneously. The portable stimulator has 30 channels and can control 15 channels simultaneously. As a result, smooth and delicate hand-finger motion can be restored. Tendon transfer was not necessary to select the stimulation site in this study. Second, percutaneous intramuscular electrodes can stimulate deep and small muscles separately, especially dorsal interossei. Electrodes were implanted percutaneously into the motor point of the muscles through the small skin incision (2 – 3 mm), so surgical stress was small.

There are some further improvements in this system. First, the patients need to care for the body-entry point to prevent infection. In this study, there were no serious infections necessitating the removal of electrodes. In the FES study of complete paraplegia, Shimada and colleagues reported that the percentage of occurrence of the superficial infection as 6.0% and there were no deep infections [4]. Percutaneous intramuscular electrodes may be safe from serious deep infection. Completely implanted FES system is recommended for the further safety and releasing from self-care for the body-entry points. Second, the external control unit (switch) is still difficult to handle for some patients. Peckham and colleagues reported an implantable joint angle transducer for the controller [3]. The improvement of the control unit is also an important focus in the development of these neuroprosthesis.

References

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