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FES supported sitting-standing-sitting of completely paraplegic patient

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Paper describes successful achievement of sitting standing function for a completely paraplegic patient by using a newly developed four-channel FES stimulator. Microcontroller governs open loop control system for predefined and measured stimulation parameters. Surface electrodes are used to give stimulation.

Keywords: FES, FES stimulator, Paraplegics, Standing

Introduction

Functional electrical stimulation (FES) assisted sitting-standing for completely paraplegic patients incorporates elicited muscle movement into an every day activity, like standing, walking, reaching out etc[1]. It has great potential to provide both functional and therapeutic benefits to spinal cord Injury (SCI) patients. FES technique is promising to restore motor functions for paraplegic patients due to SCI, brachial plexus injury, stroke, multiple sclerosis, and traumatic brain injury[2]. FES can also be used to stimulate cardiac muscles and smooth muscles of human inner organs[3]. Some FES techniques provide bladder and bowel control, and improve sexual function in disease or after traumatic injury[4]. FES system at higher stimulation levels and with higher frequencies can be used for achieving functionalities in different levels of SCI patients[5,6]. Paraplegic patients with FES system are able to rise from a sitting to a standing position without braces and able to maintain standing position for a few minutes when stimulated[7].

FES system consists of a stimulator unit and electrodes (surface electrodes, intramuscular electrodes, cuff electrodes and intra-neural electrodes)[8,9]. There are clinical FES systems, which are programmable to provide better functionality and more users adaptive and these developed stimulators are open loop devices[10,11]. Study[12] based on activation patterns measured on healthy subjects proposes to apply open-loop stimulation patterns for standing-up in paraplegics. However, stimulated muscles tend to fatigue rapidly, thereby limiting role of FES in standing and walking. Improvements have been suggested to allow muscles to rest so as to prolong endurance, for example by posture switching or using a hybrid orthosis[13]. Some of the recent developments also used feedback of sensor information to intact neuromuscular system[14].

This study presents a microcontroller-based stimulator using surface electrodes for delivering stimulation pulses.

Materials and Methods

A multi-channel stimulator was developed using Atmel 89C51 microcontroller to give electrical stimulation pulses (Fig. 1). Patient controls stimulator with Stand/Sit buttons provided on the front panel of stimulator. Programmed microcontroller delivers pulse pattern. Developed system has multiple frequency (16 - 40Hz) having pulse width of 0.3 ms. Output voltage level can be controlled linearly (0 - 100 V) in steps of 12 V through selection switches depending on the amount of contraction required. Maximum current delivered from instrument is 100 mA at each channel. As the system was used for human clinical trials, all safety concerns related to medical equipment development are incorporated. All output channels are electrically isolated from each other. Before applying FES to patient, system was cutoff from mains supply. Carbon rubber surface electrodes (diam, 6 cm; thickness, 2 mm), used to give external stimulation, are

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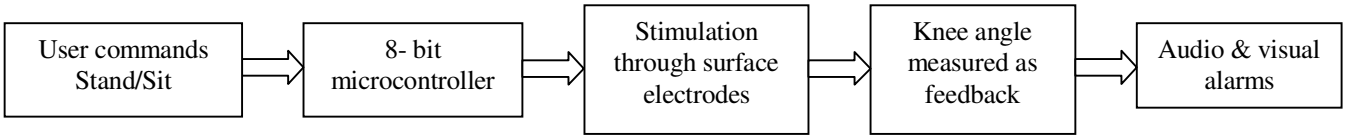

Fig. 1—System block diagram

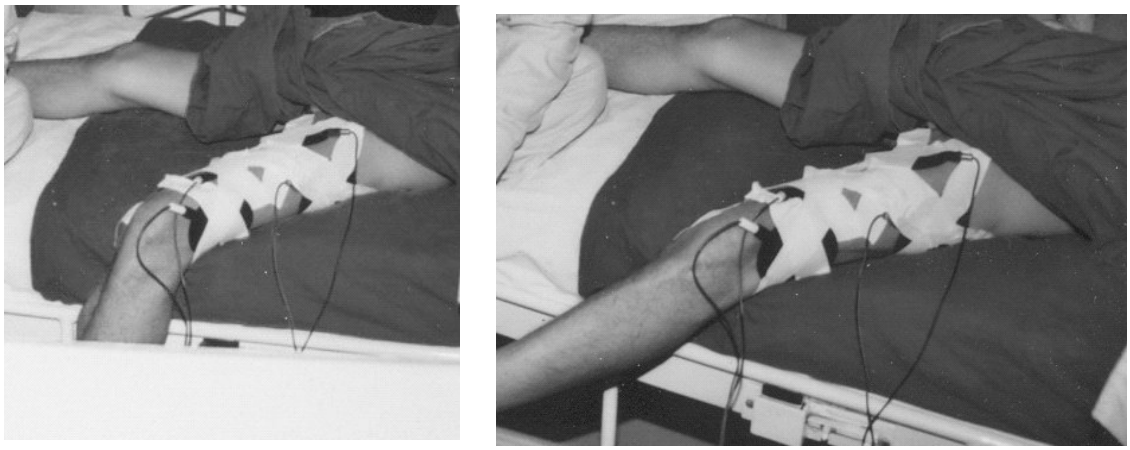

Fig. 2—Stimulation v/s muscle contraction: a) No stimulation, no contraction; b) Stimulation at 36V to quadriceps, Grade 2 contraction

cheap, safe, easy to handle, and suits Indian environment condition. Stimulator uses biofeedback signals for control. Some experiments for giving audio and visual alarms measuring knee angle with indigenously developed electro-goniometer as feedback signal is also reported[15].

All experiments were carried on a completely paraplegic patient (26 y old) with injury level between T4 and T5 in guidance of orthopedic surgeon and physiotherapist at GMCH with prior consent of patient. Stimulation was given to patient by identifying correct location of muscles through surface electrodes soaked with conducting gel. System delivers mono-phasic pulses of varying frequencies and amplitude levels[14,15]. Extensive trials of prototype have led to broad specifications of stimulator[16] as follows: multi channel, 4 channels; programmable, 4 programs; surface electrodes, carbon rubber electrodes; frequency, 16, 25, 40, 60 hz; pulse width, 0.3 m sec; pulse amplitude, up-to 100 ma; pulse waveform, rectangular mono-phasic; and programmability, parameter of each channel can be adjusted independently.

Results and Discussion

Mono-phasic pulses of varying frequencies and amplitude levels have been administered to a complete paraplegic patient with SCI level T-4. Tetnik contraction was observed after stimulation given to patient. Variation in isometric contraction grade depends on amplitude and frequency of applied stimulus. Variation in contraction grade achieved when pulse pattern of 0.3 ms @ 40Hz has been applied was as follows: 24 V, Grade 1; 36 V, Grade 2; 48 V, Grade 3; 60 V, Grade 4; 72 V, between Grade 4 & 5; and 84 V, Grade 5. Results were in accordance that high voltage and high frequency stimulation are required for FES assisted movement of any limb[16].

With no application of stimulation pulses, no FES activity or no movement or contraction was visible in the leg (Fig. 2a). Level of contraction grade achieved is Grade 2 by applying 36 V stimulation at quadriceps (Fig. 2b). It was observed that stimulation given at low voltage, low frequency contraction achieved is low and is of no use for FES activities and at high voltage, high frequency grade of contraction is higher but muscle fatigue is early.

While using developed FES system, ˜one of the challenging tasks for achieving standing function is that required muscles tend to fatigue rapidly. If a SCI patient does not perform any exercise or toning program then muscle loose its ability. This was overcome with long muscle training program for toning of muscles and to increase muscle fatigue time[17]. In present case, patient

has undergone a rigorous muscle-training programme, in which simulation at low voltage and low frequency was given for 1 h daily for 8 months continuously. During muscle training program, it was observed that number of muscle contraction episode at block (36 V, 40 Hz) was less as compared to block (36 V, 16 Hz), which was even lesser than number of contraction episodes achieved at block (24 V; 16 Hz)[16]. This confirms that stimulations at low voltage and low frequencies were very useful for muscle toning.

Successful achievement of sitting standing function was achieved and with stimulation of two muscles only using developed 4-channel stimulator. Stimulation was applied at quadriceps and glutei muscles for sitting standing at block (72V, 40 Hz), which achieved required grade 4-5 contraction. Glutei muscle provides support to spinal column to make standing posture and quadriceps muscle is required to perform standing flexion and extension. It was observed by stimulating just two muscles standing action was jerky. Patterned stimulation of calf muscle can make standing action smooth. A stimulator with higher number of channel can be useful for achieving smoother FES activity as more number of muscles can be stimulated simultaneously.

Conclusions

Unsupported sitting-standing-sitting function for a completely paraplegic patient is successfully achieved. In order to achieve FES function like standing, muscle-training programs are essential. Grade of contraction was related to different amplitude levels. More number of channels increases complexity but invariably it helps in smoothing muscle action.

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