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E Actitrode®: The New Selective Stimulation Interface for Functional Movements in Hemiplegic Patients

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Abstract: We describe the new multi-contact electrode-array for surface electrical stimulation, and the corresponding interface device that allows on-line selection of the conductive fields during the application of the system. This new device has a specific value for therapeutic applications of electrical stimulation since it allows effective generation of desired functional movements. The user-friendly interface also allows patients at home to select the optimal electrode array; thereby, to receive therapies out of the clinical environment. The electrode was tested in three post-stroke hemiplegic patients. The pilot experiments showed that system works sufficiently good for control of fingers during grasp and release functions without the interference of the wrist movement. The use of electrode is also envisioned for many other applications (foot-drop, fitness, shoulder subluxation, etc.).

Keywords: Stimulation, Hemiplegic Patients.

1 Introduction

Electrical stimulation of nerves and muscles by means of surface electrodes is now being used for various applications, including pain reduction, muscle strengthening, activation of paralysed muscles, spinal cord stimulation and training of sensory-motor mechanisms. Common to all uses of surface electrodes for stimulation is that it requires a great deal of skill and patience of the user and/or the therapist to place the electrodes in the optimal position for the function to be performed. It is impossible to know precisely the pathways of the electrical charge that should be delivered to sensory-motor systems under the skin. It is therefore difficult to predict precisely which anatomic structures will be activated for any given position and electrode configuration. Very often self-adhering electrodes are used, which must be taken off completely before they can be repositioned at a different location on the skin. This process is not only frustrating and time-consuming, but can also be painful and compromises the adhesion of the electrode to the skin, leading to an increased consumption of electrodes. Further, it is difficult to try many

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different electrode sizes, even if this may have an important effect on the function and subjective perception of the stimulation. For these reasons a non-optimal electrode position and electrode size are often chosen.

We address the problem of the effective use of surface electrodes within a neural prosthesis that is used for generating movement. We developed a prototype of a multiple contact surface stimulation electrode combined with an easy-to-use interface, which allows the user to rapidly emulate many different electrode sizes and positions, without actually removing the electrode from the skin during the process. A similar idea was recently presented [1,2]. The relation between the selectivity and the size of the conductive field were analysed in details, and the results suggested that the size of about 1cm^2 is optimal [1]. The size of the electrode and ability to select the array were tested with multiple individual electrodes positioned on the skin of the lower leg [2].

2 Methods

Apparatus

The new stimulation method comprises an array-electrode (Actitrode®, patent pending), and programmable stimulator (Actigrip CS®, patent pending). The Actitrode® provides a sensory or motor nerve interface comprising: 1) 24 conductive fields evenly distributed over the flexible substrate for application to the skin (Fig. 1, right), and 2) an user operable switch making and breaking electrical connection between the selected elements of the array and the stimulator (Fig. 1, left).

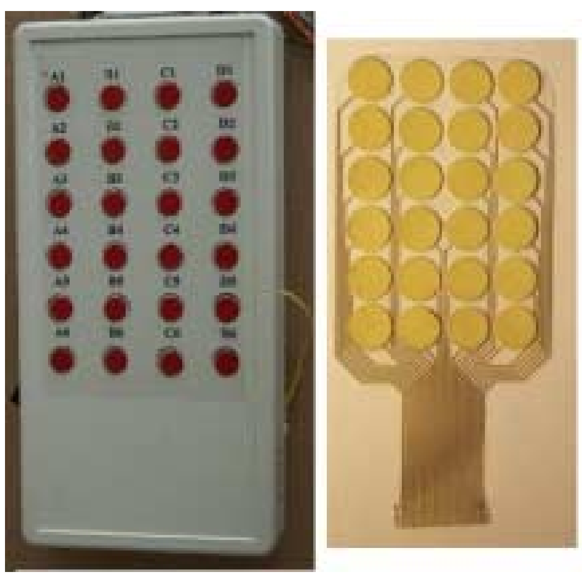

Fig. 1. - *24-field array-electrode (right) and the control box (left) of the Actitrode®.*

The impedance of the electrode when the electrode is positioned on the forearm and all fields are switched on is about $750\,\Omega$. The impedance of the electrode when only one field is switched on is about $1.6\,k\Omega$. The phase shift in both cases is less than $\pi/6$. This data was measured at $1\,kHz$. The size of the electrode was $5\,cm \times 8\,cm$, and the conducting fields had the diameter of $1\,cm$.

The control box comprises 24 buttons that match the layout of the conductive fields on the flexible substrate. The switches are marked with annotations $A1$ to $D6$. Sequential pressing of any buttons on the box controls transistor based switches that operate up to $\pm 100\,V$. Each button has a LED indicator showing when the switch is turned on or off. This indication is dedicated to the user at all times in order to allow him/her to change the layout if and when necessary.

Details about the Actigrip CS®* stimulator are described in details elsewhere [3].

Data Acquisition System (Fig. 2)

We fabricated a data glove by using Penny & Giles flexible goniometers (Biometrics, Gwent, U.K.), and the laboratory acquisition system based on Labview 6.1 program and NI DAQ 6024 for PCMCIA (National Instruments, Austin, Texas). The data glove recorded six joint angles: *Proximal Inter Phalangeal* – PIP, and *Meta Carpo Phalangeal* - MRP flexion and extension on the index and ring fingers, ulnar and radial deviation, and dorsal and volar wrist flexion. The sampling rate was 100 samples per second, and the resolution of the recording components ± 2 degrees. The data was off-line processed by using 4^{th} order Bessel filters.

Fig. 2 - *The data acquisition system for recording of joint angles during the emulation of functional grasp with the Actitrode®.*

* Actigrip CS® is a four-channel programmable stimulator designed for Functional Electrical Therapy (FET) of post-stroke hemiplegics available from Neurodan A/S, Aalborg, DK (http://www.neurdoan.dk).

Procedure

The Actigrip® was programmed to deliver stimulation at two channels. Two electrode arrays, used as cathodes, were positioned at the dorsal and volar sides of the forearm approximately at the midpoint between the elbow and wrist, and each electrode was connected to one of the stimulation channels. The stimulation parameters were set at $50\,\mathrm{Hz}$ current controlled compensated monophasic pulses with the duration of $250\,\mu\mathrm{s}$. The rectangular pulses had steep exponential rising edge. The pulse amplitude was changed to accommodate the needs of each specific measurement. The intensity was changed on-line by using the digital control built in the stimulator. The pulse amplitude was typically between 10 and $30\,\mathrm{mA}$. The anode was positioned over the carpal tunnel.

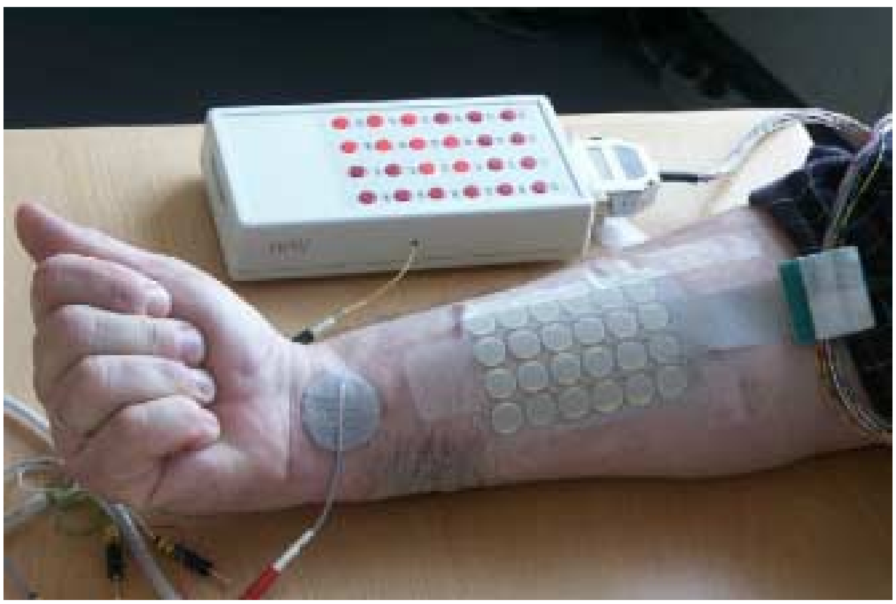

Fig. 3 - *The application of the Actitriode® in experiments.*
The round Pals Platinum electrode ($D = 3.2\,\mathrm{cm}$) was used as the anode over the carpal tunnel, and the Actitrode® (cathodes) were positioned on the dorsal and volar sides of the forearm.

The pilot measurements included three acute post-stroke hemiplegic patients (48 ± 5 years of age, more than 6 years post stroke) with no fingers function and limited wrist extension (bellow 10 degrees against the gravity); yet, with the response to electrical stimulation. In all three patients the muscles were noticeably atrophied, and the spasticity of the elbow joint was increased (Ashworth Scale grade > 2). Patients signed the consent form that was approved by the local ethics committee following the Declaration of Helsinki.

The task was to selectively provide functional finger flexion without the wrist flexion, and to provide functional finger extension without the wrist extension or radial/ulnar deviation. Palmar, lateral, and precision grasps were analysed in the experiments. The measurements included objects that require these grasps: little bottle, CD disk, and the pen respectively.

In this paper we present the results from the analysis of the palmar grasp. The testing object was the bottle with the diameter $D = 6\,\mathrm{cm}$, height $H = 15\,\mathrm{cm}$, and mass $m = 200\,\mathrm{g}$. The grasp was considered functional if the fingers could flex for more than 50 degrees, while the wrist ulnar/radial deviation and dorsal/volar flexion were less than 15 degrees. The opening of the hand was considered functional if the fingers could be brought to full extension with the wrist movements less than 15 degrees.

Three different position of the forearm were analysed: palm facing up, palm facing sideways, and palm facing down. The forearm was supported during the experiments.

An experienced therapist in the use of functional electrical stimulation was setting the conducting array by pressing the buttons on the control box. The experiments were repeated in each patient for each position at three different days during the same week. The initial combination at the first session followed the anatomical position of innervations points of the muscles that likely contribute to the desired movement. During the variation of the layout of the conducting fields the joint angles were recorded. The combination that resulted with the best functional grasp and release was recorded. The emulation of the best layout lasted at the beginning for about five minutes per electrode-array. The recorded layout in the first session was used for emulation of the layout at later sessions. The emulation time at second and third sessions was decreased to about one minute.

3 Results

Fig. 4 shows a typical example of the angles measured in the earlier listed joints in one of the three patients (Pt. C). Fig. 4 comprises four panels, each recorded for one array of conductive fields. The functionality was judged based on the range of movement at the finger joints vs. the range of movement at the wrist joint. The optimal layout of the conductive fields was the one in which this ratio was maximal. The top left panel shows functional grasp, while the remaining three panels show cases with the wrist deviation that compromised the grasp.

Fig. 5 shows the electrode array with the fields conductive being black, and the fields non-conducting being white. Fig. 5 shows the results for the palmar grasp for all three patients that participated in the pilot experiments. The position of the conductive fields on the skin is moving with respect the position of the sensory and motor nerves when the arm was pronated and supinated; therefore. We present the arrays for three positions of the forearm (palm facing up, sideways, and down) nicely showing this effect.

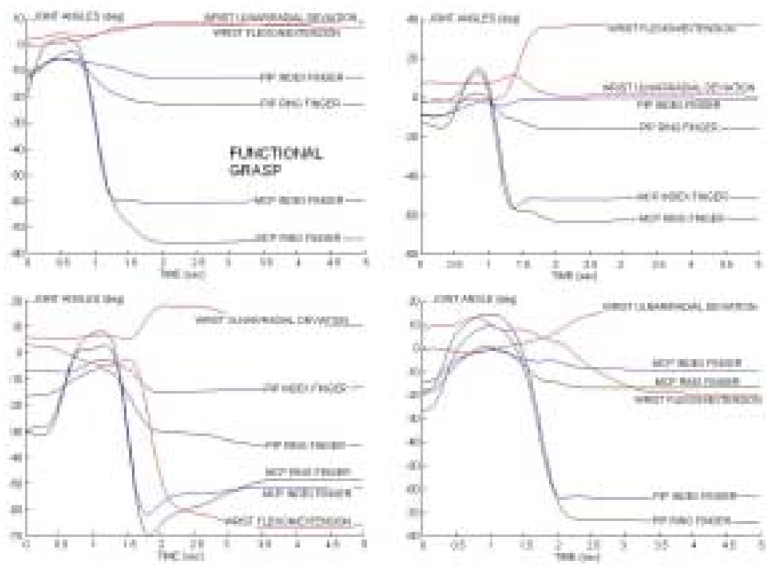

Fig. 4 - *Four examples of joint angles during the emulation of the optimal palmar grasp. The left top panel shows good grasp, while the remaining three cases present inappropriate wrist deviations that greatly interfere with the grasp.*

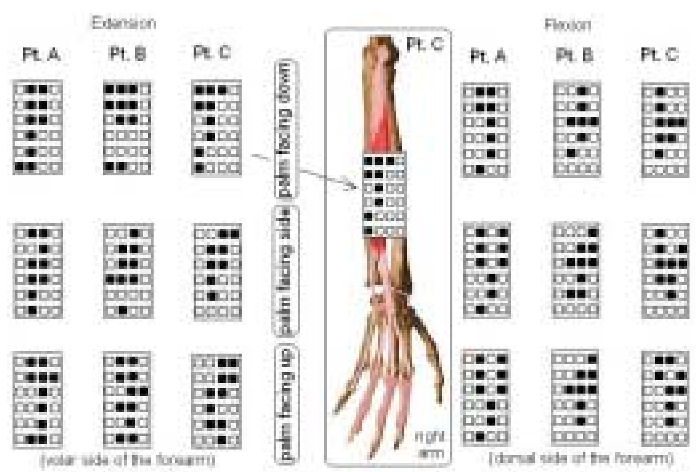

Fig. 5 - *The "conductive" fields (black dots) on the Actitrode® for hemiplegic patients Pt. A, Pt. B, and Pt. C. The top row are sketches indicating the array of conductive fields for the palm facing up, the middle row the arrays for the forearm when palm faces sideways, and the bottom row the position when the palm faces down. The middle panel indicates the muscles and the position of the electrode on the forearm.*

An important finding was that for the optimal position of conductive fields it was possible to increase the intensity of stimulation for about 20 percent, thereby strengthen the grasp or obtain hyperextension of fingers without the wrist movement interfering. For non-optimal positions small increase of the intensity of stimulation completely compromised the function.

The pilot experiment in three chronic post-stroke hemiplegic patients clearly proved that the flexible –electrode-array with 24 fields is very effective instrument for selective surface stimulation. It is important to notice that the layout of conductive fields (Fig. 5) had a branched pattern rather than oval or square form typical for all commercially available surface electrodes.

In parallel, the results indicated that during pronation and supination of the forearm the optimal branched pattern changed the size and form. This is important for future developments: electrode form has dynamically to fit the relative movement of the stimulated structures and the skin contact. This is of specific importance for functional electrical stimulation that is integrated in the intensive exercise based therapies [4,5].

The three independent sessions in pilot experiments clearly showed that once determined position of the conductive fields changes only little; hence, emulation of the optimal electrode becomes easy and fast after the first setup. This finding suggests that it is possible to design a template for a given patient after the first session. However, the difference between the optimal electrodes for three patients show that it is impossible to use a general template; it is necessary to emulate the array for every patient individually.

4 Conclusion

Actitrode® is a new instrument that allows simple and effective positioning of the stimulation electrodes for generating functional movements in patients having paresis or paralysis of extremities because of the injury/disease of the central nervous system. The selectivity of the new electrode is of value for therapeutic applications in post-stroke hemiplegic patients, especially for neurorehabilitation.

This paper only includes the presentation of the Actitrode® for grasp/release palmar grasp; yet, the system was tested for other functional movements (e.g., drop-foot). The Actitrode could be manufactured in forms and sizes appropriate for other body parts depending on the application.

The Actitrode® controller comprises programmable micro-computer; hence, it supports eventually the dynamic change of the stimulation array in order to match the relative movement of the electrode with respect the desired stimulation points.

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