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Efficacy of FES for restoring hand grasp in hemiplegia: Investigation using biosignals

Sehndkar C V, Mahadevappa M*.
School of Medical Science and Technology,
Indian Institute of Technology Kharagpur
Kharagpur, India
mmaha2@smst.iitkgp.ernet.in (*Corresponding Author),
shendkar.shekhar@gmail.com

Lenka P K, Kumar Ratnesh#, Biswas A
National Institute for the Orthopaedically Handicapped- Kolkata ((Under the Department Of Disability Affairs, Ministry of Social Justice & Empowerment, Govt. of India), # Former Director
prasanna.l@nic.in, ratneskumar@rediffmail.com, abhishekpmr@gmail.com

***Abstract*—Rational behind conducting this randomized trial was to examine the therapeutic effect of functional electrical stimulation (FES) in stroke survivors having hand grasp problem. For this we used novel approach of tracking the motor condition changes instead of traditional method of measuring functional assessment scores. In the study subjects less than 9 months of stroke history with hand grasp difficulty were allocated to FES group (FES stimulation and physiotherapy, n□=□10) and control group (only physiotherapy, n□=□10) and imparted respective therapy for 5 days in week for 12 weeks.**

Two bio-signals (grip force and surface electromyography - sEMG) were measured at baseline and after the 12-week therapy from the Flexor Capri Radialis (FCR) muscle of the affected limb. Analysis of grip force measure confirmed that the FES significantly improve grip force in FES group (3.7N±0.5, p=0.014) when compare to control group. Also, sEMG analysis of stimulated muscle showed significant increase in amplitude (14.3±2.3µV, p=0.031), mean power frequency (5.2Hz±0.7, p=0.022) and median power frequency (6.2Hz±0.76, p=0.020) in the FES group. The results revealed that FES therapy instigates increase activation of stimulated muscle and also improves muscle condition. So, we conclude that FES combined with physiotherapy is effective for hand grasp rehabilitation than conventional physiotherapy.

Keywords*— *Stroke rehabilitation , Functional Electrical Stimulation (FES), hand grasp, hemiplegic, Surface EMG, muscle force;

I. INTRODUCTION

Persons having stroke usually face hand grasping problem due to inability to planter-felx and dorsi-flex hand muscles. For improvement in hand grasp function, researches have recommended use of Functional electrical stimulation (FES) therapy to the Flexor Capri Radialis (FCR) and Extensor Capri Radialis (ECR) muscle of affected limb [1].

Till the date, researchers have evaluated efficacy of FES using various functional tests such as Modified Wolf Motor Function Test (WMFT), Ashworth Scale (MAS), Fugl–Meyer Assessment-Upper Eextremity (FMA-UE) score, range of motion (ROM), and Capabilities of Upper Extremity Test (CUE-T). These tests does not adequately justify how functional changes occurred. Few researchers claimed that FES causes some physiological changes and so has therapeutic effect [2-5]. Study of bio-physiological signals could put light on the cause of this improvement. Hence, we are with opinion that bio-signal such as grip force test and surface electromyograms (sEMGs) of stimulated muscles should be studied to understand FES effect on muscle condition along with traditional hand function tests. This could reveal reason behind functional improvements [6].

Our clinical study is an effort in this direction. While literature search we found that researchers started exploring FES effect on bio signals in healthy subjects. But, such study on stoke population is minimal. Our trial is conducted on clinically relevant populations (stroke affected individuals) rather than health subjects. In this study longer duration of FES intervention (3 months) was provided to the subjects. It is interesting to see the therapeutic effect of long term FES using multimodal signal analysis. For this we analyzed bio signals such as muscle force and surface EMG. This helped us to understand bio-physiological genesis of improvement in function via FES therapy in hand grasp condition.

II. MATERIAL AND METHOD

A. Subjects

Subjects having at least 3 months history of stroke were included in this study. Subjects having diabetes or skin disease were excluded. The experimental procedures involving human subjects described in this paper were approved by the Institutional Ethical Review Board of Indian Institute of Technology Kharagpur and the National Institute for the Orthopaedically Handicapped, Kolkata. Written informed consent of subjects were taken before interventions. A randomized controlled study design was used. Subjects were assigned randomly to the FES or control group. The study involved 28 subject with hand grasp problem equally divided into 2 equal groups-FES and control. No statistically significant differences was observed in both groups patients characteristics.

B.Intervention

The first group (FES) underwent FES therapy for 30 minutes and 30 minutes of conventional physiotherapy. Multichannel channel stimulator Mega XP (Cybermedic

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Corp., Korea) was used to apply the FES (Fig. 1b). The placement of stimulator unit, electrodes is shown in Fig. 1(a). Charge balanced stimulation waveform was used for applying stimulation. FES was delivered with pulses having pulse width of 0.18-millisecond, frequency of 40 Hz, stimulation intensity between 0 and 20 mA to cause appropriate flexion of hand muscles to produce hand grasping effect. Subjects assigned randomly in groups. Pysiotherapy and FES therapy was provided by certified physiotherapy and electrotherapist professionals. Conventional physiotherapy involving stretching, a range of motion enhancement exercise, muscle strengthening, and object grasping training was provided for 60 minutes to control group. Interventions for both groups were applied 5 days per week, for 12 weeks. Fig. 1a and 1b respectively depicts the placement of electrode for delivering FES and device used for delivering FES.

C. Measurements

Grip force and sEMG measurements were performed at baseline and after 12 weeks of FES intervention. Measurement were obtained sequentially. For grip force measurement a force sensor based bio-potential data acquisition system (PowerLab, AD Instruments, Bella Vista, NSW, Australia) was used. Fig. 1c shows the grip force acquisition device and measurement method used. The subject hold force sensor in their fist and produce maximum voluntary contraction (MVC) and till it reached 50 percent of MVC. This force was applied on sensor for at least 2 min duration. Average grip force was then calculated from acquired data. The details are given in Table 1. sEMG of the Flexor Capri Radialis (FCR) muscle of the affected limb was also recorded simultaneously while subject performed grasping of force sensor for muscle force data acquisition.

For sEMG acquisition, European recommendations (Surface Electromyography for the Non-Invasive Assessment of Muscles - SENIAM project) and the International Society of Electrophysiology and Kinesiology (ISEK) standards were followed [9]. Electrode position, sampling frequency, and filter parameters were set according to these international standards. A bio-potential data acquisition system (PowerLab, AD Instruments, Bella Vista, NSW, Australia) was used for capturing sEMG data. Electrode placement for the sEMG acquisition is shown in Fig. 1c. The subjects were asked to sit on a chair for performing grasping of force sensor. Subjects performed active flexion and extension with uniform contraction rate and force for 10 times during the 10 seconds of data recording. The FES device was turned off while capturing sEMG signal. While sEMG processing, isometric maximum voluntary contraction (MVC) was used as a sEMG normalization strategy.

D. Data processing

The grip force and sEMG signals were acquired two times. First, at baseline and second after intervention period. Typical grip force and sEMG signals obtained are displayed in Fig. 2a, and 2b respectively. Analysis was performed using MATLAB R2010b (Mathwork Inc. Natick, MA, USA) and the statistical analysis software SPSS (version 17.0, Chicago, IL, USA). SENIAM and ISEK standards were obeyed while processing the sEMG data and standards for reporting sEMG data was followed [9]. Segments of sEMG corresponding to hand flexion was used for analysis. Both temporal and spectral parameter information was analyzed.

E. Statistical analysis

Statistical analyses were performed with SPSS 17.0 software (SPSS Inc., Chicago, IL, USA). First, differences in the characteristics of the participants between the FES group and the control group were compared using Mann-Whitney U test and chi-square test. No statistically significant differences were observed in the characteristics between the 2 groups. Then, for evaluating the therapeutic effects of FES using bio-signals, 2-way analysis of variance (ANOVA) with repeated measures was used with time as the within-participant factor (baseline measurement versus post intervention measurement) and group as the between-participant factor (FES versus control). For those variables that showed significant group × time interaction in the ANOVA, independent t-tests were used to compare the change score between the two groups. After this, paired t-tests were used to examine changes over time in each group [10]. A p-value of <0.05 was considered statistically significant in change score and group × time interaction analysis. The significance level was adjusted to 0.025 for the post-hoc comparison of the pre-test and post-test scores for each group.

III. RESULTS

A. Grip Force

There was significant group × time interaction effect for grip force ($F=7.132$, $p=0.014$) (Table 1). Comparison of the change scores revealed that the FES group had significantly more changes in grip force (mean between-group difference = 3.7N±0.5, $p=0.014$) compared with the control.

B. sEMG Analysis

Significant group × time interaction effects were detected for RMS value ($F=6.681$, $p=0.020$), mean power frequency ($F=8.612$, $p=0.011$) and median power frequency ($F=6.946$, $p=0.016$) were statistically significant (Table 1). Post-hoc analysis showed change score showed significantly more improvements in root mean square value (mean between-group difference = 14.3±2.3, $p=0.031$), mean power frequency (5.2±0.7, $p=0.024$) and median power frequency (6.2±0.7, $p=0.022$) of the FCR muscle of affected limb compared with the control group. In rest of sEMG parameters there was no significant improvement observed. The spectral parameters of sEMG signals showed a significant shift in the mean and median power frequencies towards the higher frequencies. These indicate FES causes improvement in muscle fiber conduction velocity (MFCV).

C. Correlation between Grip force and sEMG

It has been found that there is positive correlation between grip force and sEMG signal. Post FES both signals shown positive improvements as seen in table 1.

Table 1. Changes in muscle force and sEMG parameters observed in within the FES and control groups and between the groups

Signal-Domain	Parameter	FES Group		$p^{\#}$	Control Group		$p^{\#}$	Group × Time interaction effect		Difference in change score	
		Baseline	*Post*		*Baseline*	*Post*		*F*	*P*	*Mean Diff. ± SD*	$P^{\wedge}$
Muscle force	Muscle force (N)	12.2±0.5	16.9±0.6	0.012	12.3±0.5	15.0±0.5	0.017	**7.132**	**0.014$**	3.7±0.5	**0.014^**
sEMG-Temporal	sEMG RMS value (µV)	102.1±15	121.1±16.1	0.023	110.1±12.1	116.1±14.4	0.032	**6.681**	**0.020$**	14.3±2.3	**0.031^**
sEMG-spectral	Mean power frequency(Hz)	78.1±11.0	91.4±10.2	0.021	83.6±9.0	89.1±8.2	0.043	**8.612**	**0.011$**	5.2±0.7	**0.022^**
	Median power frequency (Hz)	71.3 ±6.1	85.3±10.2	0.026	74.5±7.1	79.1±7.3	0.038	**6.946**	**0.016$**	6.2±0.7	**0.020^**

Mean ± standard deviation;
p-value for within-group comparison over time (paired t test, level of significance = 0.025);
$ Statistically significant difference in Group × time interaction (two-way repeated measures ANOVA, P<0.05);
^ Statistically significant between-group difference in change score (independent t test, P=0.05)

(a) (b) (c)

Fig 1. (a) Protocol for FES delivery (b) Multichannel FES machine used for stimulation (source- Cybermedic Corp. Korea) (c) Protocol for recording muscle Force using force sensor and corresponding sEMG recording of flexor muscle.

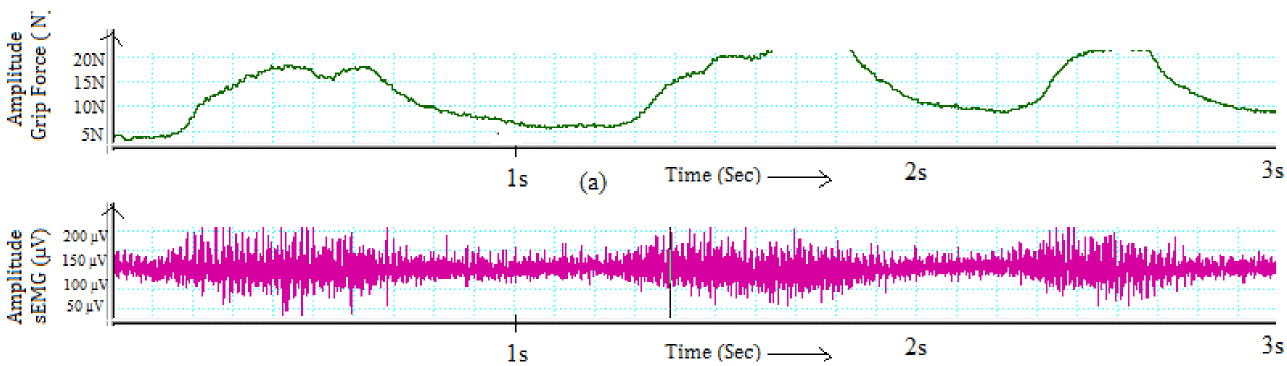

Fig 2. (a) Grip force applied by subject on force sensor with hemiplegic upper limb (b) Corresponding EMG signal as acquired from Flexor Capri Radialis (FCR) muscle.

IV. Discussion and Conclusion

As enumerated in table 1, results shows that FES causes significant change in grip force, sEMG temporal and spectral parameters. Group × time interaction effects and change score were detected for grip force, RMS value, mean power frequency and median power frequency.

Novelty of this study is in determining the relationship between FES instigated muscular force improvements and associated muscle condition changes after long term (3 months) therapeutic use of FES. For this grip force and sEMG of subject were evaluated at baseline and post FES therapy. We observed that hand grasping is improved due to functional changes which are result of physiological changes occurred due to FES therapy. sEMG analysis of FCR muscle revealed that FES program induced significant improvements in EMG amplitude (in RMS value), mean frequency and median frequency compared with the control group (Table 1). These changes are indicative of improved motor strength and muscle fiber conduction velocity following FES therapy [10,13]. Also, it has been found that there is correlation between grip force and sEMG signal improvements.

In conclusion, this study shows that long term FES intervention (3 month) produces significant therapeutic effects in hemiplegic patients having hand grasp problem. This effect is evident when post intervention bio-signals are analyzed.

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Ethical approval and clinical trial registration

The study is approved by ethical committee of IIT Kharagpur-India and NIOH Kolkata-India. The details of trial registration are available at www.ctri.gov.in [CTRI/2012/09/003019] and also at WHO's International Clinical Trial Registry Platform http://apps.who.int/trialsearch/Trial.aspx?TrialID=CTRI/2012/09/003019]

References

[1] M.R. Popovic, A. Curt, T, Keller, and V. Dietz, "Functional electrical stimulation for grasping and walking: indications and limitations,". Spinal Cord, vol. 39, issue 8, pp. 403-412, 2001.

[2] Vafadar, K. Amir, N. Julie, Côté, and S. Archambault Philippe, "Effectiveness of functional electrical stimulation in improving clinical outcomes in the upper arm following stroke: a systematic review and meta-analysis., BioMed Research International, 2014.

[3] T.A. Thrasher, V. Zivanovic, W. McIlroy,and M.R. Popovic, "Rehabilitation of reaching and grasping function in severe hemiplegic patients using functional electrical stimulation therapy," Neurorehabilitation and neural repair, vol. 22, issue 6, pp. 706-714, 2008

[4] P.G. Lindberg, N. Roche, J. Robertson, A. Roby-Brami, B. Bussel, and M.A. Maier, "Affected and unaffected quantitative aspects of grip force control in hemiparetic patients after stroke," Brain research, Vol. 1452, pp. 96-107, 2012.

[5] R. J. Marino, M. Patrick, W. Albright, B.E. Leiby, M.J. Mulcahey, M. Schmidt-Read,and S.B. Kern, "Development of an objective test of upper-limb function in tetraplegia: the capabilities of upper extremity test," American Journal of Physical Medicine & Rehabilitation, vol. 91 issue 6, pp. 478-486, 2012.

[6] G.I. Barsi, D.B. Popovic, I.M. Tarkka, T. Sinkjær, and M.J. Grey, "Cortical excitability changes following grasping exercise augmented with electrical stimulation," Experimental brain research, Vol 191, issue 1, pp. 57-66, 2008.

[7] M.R. Nuwer, G. Comi, R. Emerson, A. Fuglsang-Frederiksen, J.M. Guerit, H. Hinrichs, A. Ikeda, F. Luccas, and P. Rappelsberger, "IFCN standards for digital recording of clinical EEG. Recommendations for the Practice of Clinical Neurophysiology–Guidelines of the International Federation of Clinical Neurophysiology," EEG Suppl., vol. 52, pp. 11-14, 1999.

[8] C. Stippich, O. Henrik, and S. Klaus, "Somatotopic mapping of the human primary sensorimotor cortex during motor imagery and motor execution by functional magnetic resonance imaging," Neuroscience letters, vol. 331, pp. 50-54, 2002.

[9] R. Merletti, and P. Di Torino, "Standards for reporting EMG data," J Electromyogr Kinesiol, vol 9, pp. 3-4, 1999.

[10] C.V. Shendkar, P.K. Lenka, Abhishek Biswas, Ratnesh Kumar, and M. Mahadevappa, "Therapeutic effects of functional electrical stimulation on gait, motor recovery, and motor cortex in stroke survivors," Hong Kong Physiotherapy Journal, vol. 33, issue 1, pp. 10-20, 2015.

[11] E.A. Clancy, and N. Hogan, "Relating agonist-antagonist electromyograms to joint torque during isometric, quasi-isotonic, non fatiguing contractions," IEEE Trans. Biomed. Eng., vol. 44, pp. 1024-1028, 1997.

[12] G.R. Müller, C. Neuper, R. Rupp, C. Keinrath, H.J. Gerner, and G. Pfurtscheller, "Event-related beta EEG changes during wrist movements induced by functional electrical stimulation of forearm muscles in man," *Neuroscience Letters*, vol. *340, issue* 2, pp. 143-147, 2003.

[13] H.U. Kuriki, N. de Azevedo Raquel, C. de Carvalho Augusto, Mícolis de Azevedo Fábio, F. Rúben, Negrão-Filho, and A. Neri, "The surface electromyography analysis of the non-plegic upper limb of hemiplegic subjects," Arq Neuropsiquiatr, vol/ 68, issue 4, pp. 562-566, 2010.