Original Research

Effect of Power-Assisted Functional Electrical Stimulation (PAFES) and Occupational Exercise on Motor Unit Activity of *Extensor Digitorum Communis* and Hand Dexterity in Post-stroke Patient

Yusuf Roni[1*], Sri Mardjiati Mei Wulan[2], I Putu Alit Pawana[2]

[1]*Konawe Selatan Hospital, Southeast Sulawesi, Indonesia*

[2]*Departement of Physical Medicine and Rehabilitation, Faculty of Medicine, Universitas Airlangga, Surabaya, East Java, Indonesia*

*Corresponding Author:
Yusuf Roni. Konawe Selatan Hospital, South Konawe, Southeast Sulawesi, Indonesia
Email: rony_yusuf@yahoo.com

ABSTRACT

Background: Weakness of upper extremity can affect the ability to perform daily activities in post-stroke patients. Power-Assisted Functional Electrical Stimulation (PAFES) may give motor reeducation and sensory feedback to improve motor recovery through neuroplasticity.

Aim: To evaluate the effect of PAFES and occupational exercise on post-stroke patient hand dexterity and motor unit activity of *extensor digitorum communis* muscle.

Material and method: Twenty post-stroke patients enrolled in the study were divided into two groups (intervention group and control group). Intervention group received PAFES and occupational exercise, and control group received occupational exercise only. Each group underwent 30 minutes per session of treatment, 5 times a week, for 3 weeks. The Root Mean Square (RMS) for measuring motor unit activity of *extensor digitorum communis* muscle, Box and Block Test (BBT) and Nine Hole Peg Test (NHPT) for measuring hand dexterity were evaluated before and after intervention.

Result: There were significant improvements of RMS ($p<0.001$), BBT ($p<0.001$) and NHPT ($p=0.002$) in intervention group after receiving PAFES and occupational exercise. The improvement of BBT in intervention group was significant compared to the improvement in control group ($p=0.028$), but no significant improvement of NHPT was found between groups.

Conclusion: PAFES and occupational exercise could improve motor unit activity of the *extensor digitorum communis* muscle and hand dexterity in post-stroke patient.

Keywords: *power-asissted functional electrical stimulation, PAFES, stroke, hand dexterity, occupational exercise*.

 ***Recieved** : 27-01-2020*
How to cite this article : Roni Y, Wulan SMM, Pawana IPA. *Effect of Power-Assisted Functional Electrical Stimulation (PAFES) and Occupational Exercise on Motor Unit Activity of Extensor Digitorum Communis and Hand Dexterity in Post-stroke Patient*. SPMRJ. 2020;2(2):49-56

Introduction

Upper extremity hemiplegia is the primary impairment underlying stroke-induced disability. Upper extremity functional recovery has been documented mostly in the first month after stroke, only 20% of stroke survival had complete motor recovery in 3 months after stroke.[1] Around 50% stroke survivors may lose ability to control upper extremity due to a reduction in muscle strength, maximum voluntary force, and coordination. Other problems include a reduced ability to extend upper extremity, shoulder pain, and sensory deficit.[1,2]

Muscle weakness is reflected in the inability to generate normal level of muscle force or tension, despite maximal conscious voluntary movement. There was a 50% reduction in the number of functioning motor units in post stroke patient compared to normal control.[2] This reduction occur between the second and the sixth months after a stroke. From the sixth to approximately the nineteenth month, surviving motor units remained dysfunctional in that neurons failed to respond to the presence of denervation by axonal sprouting and collateral fiber innervation, as would be expected in normal motor neurons.[3]

In the upper extremities of patients who have had a stroke, a common course of hemiparetic recovery reveals the development of uncontrolled flexion synergy. Abnormal synergies constitute significant impairment that needs to be addressed by rehabilitation.[4] Grasping, holding, and manipulating objects are daily functions that remain deficient in 55% to 75% of patients 3 to 6 month post stroke.[2]

Stroke patients with unilateral upper extremity weakness rarely show improvements in arm and hand functions to the point of effective use in activities of daily living. Much of the improvement in function occurs due to compensation rather than true recovery of impairment, and this correlated with the ability to perform daily activities.[5]

One of the methods to improve post stroke motor function is by giving Functional Electrical Stimulation (FES) in daily activities or specific functional movement pattern. FES of upper limb muscles has been receiving increasing attention as a therapeutic modality in post-stroke rehabilitation.[1,3]

Power-Assisted Functional Electrical Stimulation (PAFES) is one of portable modality with EMG-Controlled FES system to improve coordinated movement that induce muscle contraction as well as voluntary muscle movement and give stimulation proportionally. Power-Assisted Functional Electrical Stimulation (PAFES) may give motor reeducation and sensory feedback to enhance afferent input and facilitate neuroplasticity.[4,6]

The aim of this study is to evaluate the effect of PAFES and occupational exercise on motor unit activity of the *extensor digitorum communis* (EDC) muscle and hand dexterity post stroke patients.

Material and Methods

The design of this study was non-randomized, pre-test and post-test group. Twenty post stroke patients were recruited in the study, divided into intervention group (PAFES group) and control group. Inclusion criteria were single unilateral stroke that occurred no less than 3 weeks and no more than 1 year prior to study commencement, age 30 to 70 years old, no clinical evidence of limited passive joint range of motion of the upper extremity, strength of the upper extremity ranging from 2 to 3 using Manual Muscle Testing (MMT) scoring, no cognitive disturbance (Mini Mental State Examination/MMSE score 24 to 30), able and willing to participate in a 3-week study and signed the informed consent form. Participants were excluded if they had spasticity of the upper extremity valued using Modified Ashworth Scale 3 to 4, pain with Visual Analogue Scale more than 4, apraxia, hemispatial neglect, implanted electronic pacing or defibrillation device, unstable vital signs, or potentially fatal cardiac arrhythmia. This study was approved by the ethical committee of Dr. Soetomo General Hospital, Indonesia.

Power-Assisted Functional Electrical Stimulation is a portable, 2-channel neuromuscular stimulator which works to promote wrist and finger extension movement during coordinated movement, but will not work when target muscles have no muscle contraction. This device induces greater muscle contraction by electrical stimulation in proportion to the voluntary integrated EMG signal picked up. The system comprises 2 instruments: a setting and input system and a stimulator (Figure 1). The portable stimulator is powered by very small batteries.[1,6]

Intervention group received PAFES and occupational exercise, and control group received occupational exercise only. Electrodes were placed on the extensor wrist group muscles and *extensor indicis proprius muscle* on the hemiparetic side. These muscles were stimulated simultaneously. Each group underwent treatment for 30 minutes, 5 times per week, for 3 weeks. Occupational exercises were grasping, moving and releasing cones as well as grasping and releasing blocks and balls, pinching, moving and releasing pegs and clothes pins. Cone size was 7 x 15 cm, block size was 3 x 3 cm, balls diameter was 2.5 and 5 cm (Figure 2). An occupational therapist supervised the participants throughout the exercise sessions.

Figure 1. PAFES instrument

Figure 2. Occupational exercises

Motor unit activity was evaluated using Root Mean Square (RMS) of EDC muscle from surface electromyography (sEMG). Hand was isolated with using wrist splint. Root mean square was measured with the wrist joint in the neutral position. Maximum isometric contractions during wrist and finger extension were sustained for 5 secs. The

EMG signal of the 5-sec period was analyzed with a sEMG apparatus.

Hand dexterity was evaluated before and after intervention by using the Box and Block Test (BBT) and the Nine Hole Peg Test (NHPT). The BBT test was repeated 3 times with the paretic hand, and the highest score achieved was the final outcome measure. The NHPT and test were repeated 3 times with the paretic hand, and the fastest scores achieved was the final outcome measure. The result was compared before and after intervention between the groups.

Result

The 20 patients recruited were divided into 2 groups. Ten participants were in the PAFES group, and 10 participants were in the control group. The participants were recruited from the outpatient clinic of the Physical and Rehabilitation department. The characteristics of the subjects showed normal distribution in both groups with $p<0.05$ (Table 1).

Table 2 showed the result of the RMS, BBT and NHPT. Both groups showed significant improvement. Improvement in the PAFES group was higher than the control group.

Table 1. Subject characteristic

Characteristic	PAFES group (Mean ± SD)	Control group (Mean ± SD)	*P value**
Age (years)	56.8 ± 6.0	56.9 ± 10.5	0.98
Sex			
Men	6 (54.5%)	7 (63.6%)	0.67
Women	5 (45.5%)	4 (36.4%)	0.67
Onset (months)	6.2 ± 3.7	5.9 ± 4.7	0.88
Stroke type			
Thrombotic	6 (54.5%)	8 (72.7%)	0.38
Hemorrhagic	5 (45.5%)	3 (27.3%)	0.8
Paretic side			
Right	4 (36.4%)	7 (63.6%)	0.2
Left	7 (63.6%)	4 (36.4%)	0.2
MMT fingers and wrist extensor	3 (2-3)	2 (2-3)	0.4
Hypoesthesia	4 (36.4%)	4 (36.4%)	1

***** Significant if p <0,05

Table 3 showed the mean values of RMS, BBT, and NHPT in the PAFES group compared to control group. There was significant difference of the mean value of RMS and BBT in PAFES group compared to the control groups, but no significant difference of the mean value of NHPT in PAFES group compared to control groups.

Tabel 2. Mean value RMS, BBT, and NHPT in both groups before and after intervention

Group	Before intervention (Mean ± SD)	After intervention (Mean ± SD)	*p value**
RMS			
PAFES	61.3 ± 24.7	102.3 ± 40.8	<0,001
Control	46.0 ± 22.7	71.5 ± 34.3	0,003
BBT score			
PAFES	13.8 ± 7.6	27.4 ± 9.8	<0.001
Control	12.9 ± 8.6	20.3 ± 15.2	0.01
NHPT score			
PAFES	111.5 ± 29.4	70.7 ± 18.6	0.002
Control	119.4 ± 33.6	77.4 ± 26.5	0.008

* Significant if *p*-value <0.05 with Paired Samples T test

Tabel 3. Mean value RMS, BBT, and NHPT between group before and after intervention

Outcome	PAFES group	Control group	*p value**
Delta RMS (Mean ± SD)	41,0 ± 23,8	25,5 ± 15,5	<0,0001
Delta BBT (Mean ± SD)	13.6 ± 3.4	7.4 ± 7.1	0.028
Delta NHPT (Mean ± SD)	- 40.8 ± 17.2	- 42.0 ± 19.0	0.913

* Significant if *p*-value <0.05 with Independent Samples T test

Discussion

The normal distribution of the subject characteristics showed homogeneity of age, severity of paresis, onset of stroke, and lesion type of the participants in both groups. The objective of this study was to evaluate PAFES effectiveness in the first year after stroke. According to some studies, around 80% motor recovery occurred in 6 weeks to 6 months after stroke, and can continue in the first year, even after several years by exercise-induces brain activation through the paretic hand, albeit slower after the first 6 months.[10.11]

The effect of stroke type for functional prognosis was diverse. Some studies showed various result in functional ability after stroke. Paolucci et al reported functional and neurologic prognosis after hemorrhagic stroke to be better than infarction stroke.[12] Kelly et al reported early impairment severity in hemorrhagic stroke poorer than infarction, but better functional recovery.[13] Meanwhile, another study reported no difference of neurological state and functional independence between hemorrhagic and infarction stroke in the first year.[14]

In this study, sensory deficit showed no significant difference between groups, however it may affect the outcome. Somatosensory impairment may reduce sensory feedback that is generated from PAFES, resulting decrease of sensory afferent input to the central nervous system, and thus affecting motor learning and motor planning. The existence of motor and sensory deficit may result in poorer rehabilitation outcome than motor deficit only.[15] There was a negative relationship between sensory impairment and motor function. Normal motion requires intact motor system and depend on sensory information to do effective motion.[16,17] The coordinated and effective motion also requires awareness of kinetic and somatosensory feedback for every movement and external environment change. Sensory feedback has important role for central nervous system to plan and execute smooth and controlled motion.[17,18]

Evaluation of hand dexterity in this study was done using BBT and NHPT. The BBT is a tool to assess gross dexterity. This study showed a significant result of BBT score before and after intervention in both groups, and significant improvement in the PAFES group compared to the control group. This is in accordance with previous studies which evaluated the effect of functional electrical stimulation on motor recovery of stroke survivors, despite using different method. Alon et al reported functional improvement of the upper extremity assessed using BBT in post stroke patients after given FES combined with task- oriented training.[2] Similar results were also reported by Lewinksi et al in their study using intensive EMG-triggered electro stimulation and daily task-oriented.[20] The improved hand dexterity in this study evaluated using BBT apparently was due to the combined effect of PAFES and spesific task through neuroplasticity. Cortical plasticity may be enhanced by cumulative excitation effect of motor and sensory cortex induced by FES and voluntary contraction, and this combination also may increase sensorimotor cortex blood flow than simple active movement or electrical stimulation.[21] This was in accordance with a postulate stating that therapeutic effect FES may facilitate neuroplasticity and motor learning by increasing afferent input synchronized with motor and sensory information.[22]

Another tool that we used in this study was NHPT, which is to assess fine dexterity. Based on the result displayed in Table 3, it showed a significant difference of BBT score before and after intervention in both groups, but no significant difference of BBT score between groups as displayed in Table 3. This result was different with previous studies. Hara et al reported a significant improvement of hand function coordination evaluated by using NHPT and Ten-Cup-Moving Test. Their study was using PAFES combined with phenol injection in chronic stroke.[4,6] Hand dexterity requires motor recovery, finger and hand control, and fingertip force for hand-object interaction. Many stroke survivors had impairment in finger discrimination to identify shape of object and finger coordination, although able to grasp and lift object.[23] Hand dexterity can be restored with exercise and repetitive task involving fingers coordination, and it is related to treatment frequency and duration. Repetitive task, visual and sensory feedback in kinetic motion may enhance neuromotor learning.[24,25] The NHPT result in this study might be influenced by the exercise of intervention not involving fingers precision, which fine dexterity requires complex stimulation of fingers coordination.

Our study was limited by the lack of sensory deficit not included in exclusion criteria so that might affect sensory feedback. All subjects in this study were from outpatient clinic, made it hard to control any activities or exercise besides the intervention.

Conclusion

This result showed affectivity of PAFES and occupational exercise in facilitating motor recovery and hand dexterity post stroke compared with occupational exercise only. Our result suggests that PAFES and occupational exercise may have a potential effect to improve hand dexterity in post stroke patients through neuroplasticity.

Acknowledgement

This research was supported by Dr. Soetomo Hospital and Department of Physical Medicine and Rehabilitation Dr. Soetomo Hospital - Universitas Airlangga. There is no funding for this research.

References

1. Hara Y. *Rehabilitation with functional electrical stimulation in stroke patients.* International Journal of Physical Medicine and Rehabilitation. 2013;1:6.
2. Alon G, Levitt AF, McCarthy PA. *Functional electrical stimulation enhancement of upper extremity functional recovery during stroke rehabilitation: A Pilot Study.* Neurorehabil Neural Repair. 2007;21:207–15.
3. Hara Y, Masakado Y, Chino N. *The physiological functional loss of single thenar motor units in the stroke patients; when does it occur? Does it progress?* Clinical Neurophysiology. 2004;115:97-103.
4. Hara Y. *Neurorehabilitation with new functional electrical stimulation for hemiparetic upper extremity in stroke patients.* Journal of Nippon Medical School. 2008;75:1.
5. Raghavan P. *The nature of hand motor impairment after stroke and its treatment.* Current Treatment Options in Cardiovascular Medicine. 2007;9:221–2.
6. Hara Y, Ogawa S, Muraoka Y. *Hybrid power-assisted functional electrical stimulation to improve hemiparetic upper-extremity funcyion.* American Journal of Physical Medicine and Rehabilitation. 2006;85:977-85.
7. Desrosiers J, Bravo G, Hebert R, Dutil E, Mercier L. *Validation of the Box and Block Test as a measure of dexterity of elderly people: reliability, validity and norms tudies.* Arch Phys Med Rehabil. 1994;75:751-5.
8. Mathiowetz V, Volland G, Kashman N, Weber K. *Adult norms for the Box and Block Test manual dexterity.* The American Journal of Occupational Therapy. 1985;3(6):39.
9. Mathiowetz V, Weber K, Kashman N, dan Volland G. *Adult norms for the Nine Hole Peg Test of finger dexterity.* The Occupational Therapy Journal of Research. 1985;5(1).
10. Johansson BB. *Brain plasticity and stroke rehabilitation: The Willis lecture.* Stroke. 2000;31:223-30.
11. Krakauer JW. *Arm function after stroke: from physiology to recovery.* Seminars in Neurology. 2005;24(4):384-95.
12. Paolucci S, Antonucci G, Grasso MG, Bragoni M, Coiro P, Angelis DD. *Functional outcome of ischemic and hemorrhagic stroke patients after inpatient rehabilitation: a matched comparison.* Stroke. 2003;34:2861-65.
13. Kelly PJ, Furie KL, Rallis N, Chang Y, Stein J. *Functional recovery following rehabilitation after hemorrhagic and ischemic stroke.* Arch Phys Med Rehabil. 2003;84:968-72.
14. Jorgensen HS, Reith J, Nakayama H, Raaschou HO, Olsen TS. *What determines good recovery in patients with the most severe stroke?.* Stroke. 1999;30:2008-12.
15. Aglioti S, Beltramello A., Bonazzi A, Corbetta M. *Thumb-pointing in humans after damage to somatic sensory cortex.* Experimental Brain Research. 1996;109:92-100.
16. Carey LM, Matyas T, OKE LE. *Sensory loss in stroke patients: effective training of tactile and proprioceptive discrimination.* Archive of Physical Medicine and Rehabilitation. 1993;74:602-11.
17. Nudo RJ, Friel KM, Delia WS. *Role of sensory deficits in motor impairments after injury to primary motor cortex.* Neuropharmacology. 2000;39:733-42.
18. Vaishnavi S, Calhoun J, Chatterjee A. *Crossmodal and sensorimotor integration in tactile awareness.* Neurology. 1999;53: 1596-8.
19. Terao S, Li M, Hashizume Y, Osano Y, Mitsuma T, Sobue G. *Upper motor neuron lesions in stroke patients do not induce anterograde transneuronal degeneration in*

spinal anterior horn cell. Stroke. 1997;28:2553-6.

20. Lewinski F, Hofer S, Kaus J, Rothkegel H, Liebetanz D, Frahm J, et al. *Efficacy of EMG- triggered electrical arm stimulation in chronic hemiparetic stroke patients.* Restorative Neurology and Neuroscience. 2009;27:189-97.
21. Joa KL, Han YH, Mun CW, Son KB, Lee CH, Shin YB, et al. *Evaluation of the brain activation induced by functional electrical stimulation and voluntary contraction using functional magnetic resonance imaging.* Journal of NeuroEngineering and Rehabilitation. 2012; 9:48.
22. Takeuchi N, Izumi SI. *Rehabilitation with poststroke motor recovery: a review with a focus on neural plasticity*. Stroke Research and Treatment. 2013/128641.
23. Raghavan P, Krakauer JW, Gordon AM. *Impaired anticipatory control of fingertip forces in patients with a pure motor or sensorimotor lacunar syndrome.* Brain. 2006; 129(6):1415–25.
24. Mirshoja MS, Pahlevanian AA, Khalili MA. *Comparison of fine motor skills in patients with chronic stroke in final stages of Bronestrum and healthy adults.* Middle East J Rehabil Health. 2015;2(4):e33274.
25. Kwakkel G, Kollen BJ, Van Der Grond J, Prevo AJ. *Probability of regaining dexterity in the flaccid upper limb: impact of severity of paresis and time since onset in acute stroke.* Stroke. 2003;34(9):2181-6.