Functional electrical stimulation of dorsiflexor muscle: Effects on dorsiflexor strength, plantarflexor spasticity, and motor recovery in stroke patients

Sukanta K. Sabut\textsuperscript{a,}\textsuperscript{*}, Chhanda Sikdar\textsuperscript{b}, Ratnesh Kumar\textsuperscript{b} and Manjunatha Mahadevappa\textsuperscript{a}

\textsuperscript{a}School of Medical Science & Technology, Indian Institute of Technology, Kharagpur, India
\textsuperscript{b}Department of Physical Medicine and Rehabilitation, National Institute for the Orthopaedically Handicapped, Kolkata, India

Abstract. Objectives: To evaluate the therapeutic effects of Functional Electrical Stimulation (FES) of the tibialis anterior muscle on plantarflexor spasticity, dorsiflexor strength, voluntary ankle dorsiflexion, and lower extremity motor recovery with stroke survivors.

Design: We conducted a prospective interventional study.

Setting: Rehabilitation ward, physiotherapy unit and gait analysis laboratory.

Participants: Fifty-one patients with foot drop resulting from stroke.

Intervention: The functional electrical stimulation (FES) group (\(n = 27\)) received 20–30 minutes of electrical stimulation to the peroneal nerve and anterior tibial muscle of the paretic limb along with conventional rehabilitation program (CRP). The control group (\(n = 24\)) treated with CRP only. The subjects were treated 1 hr per day, 5 days a week, for 12 weeks.

Main outcome measures: Plantarflexor spasticity measured by modified ashworth scale (MAS), dorsiflexor muscle strength measured by manual muscle test (MMT), active/passive ankle joint dorsiflexion range of motion, and lower-extremity motor recovery by Fugl-Meyer assessment (FMA) scale.

Results: After 12 weeks of treatment, there was a significant reduction in a plantarflexor spasticity by 38.3% in the FES group and 21.2% in control group (\(P < 0.05\)), between the beginning and end of the trial. Dorsiflexor muscle strength was increased significantly by 56.6% and 27.7% in the FES group and control group, respectively. Similarly, voluntary ankle dorsiflexion and lower-extremity motor function improved significantly in both the groups. No significant differences were found in the baseline measurements among groups. When compared with control group, a significant improvement (\(p < 0.05\)) was measured in all assessed parameters in the FES group at post-treatment assessment, thus FES therapy has better effect on recovery process in post-stroke rehabilitation.

Conclusions: Therapy combining FES and conventional rehabilitation program was superior to a conventional rehabilitation program alone, in terms of reducing spasticity, improving dorsiflexor strength and lower extremity motor recovery in stroke patients.

Keywords: Stroke, electrical stimulation, spasticity, foot-drop, motor recovery

1. Introduction

Stroke is a major global health problem. It is the second most common cause of mortality and a leading cause of serious, long-term disability in adults [1]. Fifteen million people suffer a stroke every year world-
wide, five million die and another five million are left with permanent disabled [3]. According to the World Health Organisation (WHO), by 2015 India will report 1.6 million cases of stroke annually, at least one-third of whom will be disabled [3]. Initially, some 80% of all patients with stroke experience motor impairments of the contralateral limbs, i.e., hemiparesis [4].

Hemiparesis induces ankle-control disturbances and equinovarus deformity, leading to difficult in walking. Motor weakness, poor motor control, and spasticity result in an altered gait pattern, poor balance, and risk of falls during walking [4,5]. Ineffective ankle dorsiflexion during swing (drop foot) and failure to achieve heel strike at initial contact are common problems that disturb gait pattern after stroke [7,8]. Drop foot after stroke is thought to be caused partly by poor active control of the anterior tibial muscle and by increased and inappropriate tone in the muscles of the leg, particularly the calf [9]. The calf spasticity disturbs walking in stroke patients; therefore its treatment is important to improve functional abilities [10].

Functional electric stimulation (FES) is the clinical application of electric current to the intact nerves of the body, in order to generate a muscle contraction. Since the 1961, FES has been used to correct foot drop in hemiplegics [11]. Researchers have reported that the FES system for the treatment of drop foot improves gait and effort of walking in stroke subjects [12]. The electrical stimulation to correct drop foot improved the physiological cost index (PCI) and walking speed [12, 13]. A clinical study has reported that the quality of life and range of motion are improved due to use of FES system [14]. They also have been claimed that spasticity reduction by FES is achieved without any muscle weakness or paralysis. Bakhtiary et al. [15] reported that the therapy combining Bobath inhibitory technique and electrical stimulation reduced plantarflexor spasticity effectively in stroke patients but no functional activity was assessed.

In this study, we hypothesized that repetitive dorsiflexion of the ankle by electrical stimulation may enhance lower limb motor function, and reduces plantarflexor spasticity in stroke patients. The purpose of this study was to investigate whether combining FES therapy with a conventional stroke rehabilitation program is more effective than a conventional program alone in reducing plantarflexor spasticity, improving dorsiflexor muscle strength, voluntary ankle dorsiflexion active, and facilitating recovery of lower-extremity motor functions in stroke patients.

2. Methods

2.1. Participants

The study included 51 consecutive stroke patients with spastic foot drop, ranging in age from 37 to 65 years. They were recruited from inpatient/outpatient department of National Institute for the Orthopaedically Handicapped, Kolkata and participated voluntarily in the study. The study protocol was approved by the Institute Ethical Committee (IEC), IIT Kharagpur. Participants gave their written informed consent before participation in the study. All patients were assessed for their suitability for treatment at an assessment clinic.

Patients were required to meet the following criteria for inclusion in the study: (1) unilateral drop foot due to stroke; (2) first episode of hemiplegia at least 3 months in duration as a result of a stroke with a stable neurology; (3) free from electrical life support device (e.g., cardiac pacemaker); (4) ability to understand and follow simple verbal instructions; (5) no medical contraindication to electric stimulation; (6) ability to walk at least 10 meters without assistance; and (7) participants were excluded for evidence of a fixed plantarflexion contracture, knee deformity, pregnancy and psychological disorders.

2.2. Study design

We conducted a prospective interventional study, where consecutive stroke patients were assigned alternatively either to the intervention group or to the control group (Fig. 1). Twenty-seven patients were assigned to the intervention group (CRP plus FES) and remaining twenty-four patients were assigned to the control group (CRP alone).

2.3. Interventions

All subjects received the same CRP including neurodevelopmental facilitation techniques, physiotherapy and occupational therapy, 1 hr per day, 5 days per week, for 12 weeks. In the FES group electrical stimulation was given for 20–30 minutes to the tibialis anterior muscle of the paretic limb. Transcutaneous FES was applied with the EMS stimulator (Johari Digital Healthcare Ltd., India). The stimulation current applied with 0.28 ms pulses, at 35 Hz in the constant mode within the subject’s tolerance level, via surface electrodes. The amplitude was adjusted to produce muscle contraction without affecting the patient’s com-
fort [14]. The electrodes were placed over the common peroneal nerve as it passes over the head of the fibula and the motor point of tibialis anterior or slightly lateral to this to elicit dorsiflexion and eversion of the foot during the swing phase of walking. The stimulation, timed to the gait cycle by using a heel switch placed in the shoe, causes ankle dorsiflexion in the swing phase of gait cycle [11]. The components of the movement may be varied by adjusting the electrode position and stimulation amplitude.

2.4. Outcome measures

At inclusion, clinical assessments were conducted with regard to plantarflexor tone by Modified Ashworth Scale (MAS), dorsiflexor muscle strength by the manual muscle test (MMT), voluntary ankle dorsiflexion range of motion (ROM) by using a hand-held goniometer, and lower-extremity motor function by Fugl-Meyer assessment (FMA).

2.4.1. Assessment of plantarflexor spasticity

The spastic plantarflexor muscles tone was measured on affected leg by using the Modified Ashworth Scale (MAS) [16]. Spasticity was graded according to MAS from 0 (No increase in muscle tone) to 5 (Affected part(s) rigid in flexion or extension) for ankle dorsiflexor. For test patients were sat in an upright position on a table that allowed free swinging of the lower leg against the upper leg.

Fig. 1. Flow diagram of study assignment.
2.4.2. Assessment of dorsiflexion strength

Ankle dorsiflexion is an important kinematic aspect of the swing and initial stance phase of the gait cycle. In clinical practice, muscle strength is most often evaluated using manual muscle strength testing using the Medical Research Council (MRC) grade. The ankle dorsiflexor strength was graded according to the MMT; graded from 0 (no contraction at all) to 5 (full range of movement against power and the same force as on the opposite side) for ankle dorsiflexor [17].

2.4.3. Assessment of ankle joint range of motion

The evaluation tests consisted of passive and active ankle joint ROM, measured in degrees using a handheld goniometer. Goniometry was performed with the subject in supine position with extended knees, and the measurement was made at the neutral position between dorsal flexion and plantar flexion, i.e. at 0° of dorsal flexion. The passive ROM was determined as the range that the experimenter was able to move the subject’s ankle beginning in maximum plantarflexion, to maximum dorsiflexion until any resistance was felt. Similarly the active range of motion (ROM) was measured by asking the participants to move joints maximally.

2.4.4. Assessment of lower extremity motor recovery

We assessed lower-extremity motor recovery using the Fugl-Meyer assessment score. The FMA is a stroke-specific, performance-based impairment index. It is designed to assess motor functioning, balance, sensation and joint functioning in hemiplegic post-stroke patients [18]. The FMA includes items dealing with the hip, knee, and ankle in the lower extremity. Fugl-Meyer assigned motor function scores to items that assessed motor function, the maximum score that can be attained is 34 for the lower extremity.

2.5. Statistical analysis

Baseline measurements were compared with those obtained at 12-week of post-treatment assessment. In the FES group the walking test was done without electrical stimulation. Paired t-test was performed to find any significant change within each group. Independent t-test was used to compare the baseline values and also the percentage changes of the recorded values between the two experimental groups. The percentage change between pre- and post-treatment data was calculated as 100 x [pre-treatment minus post-treatment]/pre-treatment. The significance level α was set at 0.05 for all tests. All statistical analyses were performed with SPSS version 11 for Windows.

3. Results

Initial and final evaluations were made 1 to 3 days before and after the 12-weeks of the treatment period. None of the patients missed more than 1 scheduled session during the study, and all completed the study. Table 1 shows the characteristics of the participants. Subject characteristics were all similar in both groups. Table 2 shows the measured parameters before intervention in both groups; no significant difference was found in the baseline values. The results also represented in Figs 2 and 3.
Table 1
Baseline characteristics of the two study groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>FES group (N = 27)</th>
<th>Control group (N = 24)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>49.1 ± 8.8</td>
<td>50.1 ± 10.4</td>
<td>0.63</td>
</tr>
<tr>
<td>Gender (Women/Men)</td>
<td>12/4</td>
<td>12/2</td>
<td>–</td>
</tr>
<tr>
<td>Paretic side (Right/Left)</td>
<td>9/18</td>
<td>16/8</td>
<td>–</td>
</tr>
<tr>
<td>Time since stroke (months)</td>
<td>17.3 ± 18.8</td>
<td>18.2 ± 11.8</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Note: Values are mean ± SD. or as indicated. p < 0.05: Statistical significance (independent t-test).

Table 2
Measured parameters at baseline in both the groups

<table>
<thead>
<tr>
<th>Measured parameters</th>
<th>FES group</th>
<th>Control group</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plantarflexor spasticity (MAS)</td>
<td>2.9 ± 0.67</td>
<td>2.6 ± 0.57</td>
<td>0.15</td>
</tr>
<tr>
<td>Dorsiflexor strength (MRC)</td>
<td>1.3 ± 0.93</td>
<td>1.4 ± 0.96</td>
<td>0.55</td>
</tr>
<tr>
<td>Active ankle dorsiflexion (degrees)</td>
<td>7.6 ± 1.5</td>
<td>7.9 ± 1.8</td>
<td>0.99</td>
</tr>
<tr>
<td>Passive ankle ROM (degrees)</td>
<td>37.7 ± 13.3</td>
<td>38.9 ± 10.4</td>
<td>0.73</td>
</tr>
<tr>
<td>Lower-extremity functional recovery (FMA) (maximum score is 34)</td>
<td>18.4 ± 4.5</td>
<td>19.3 ± 4.7</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Note: Values are mean ± SD. p < 0.05: Statistical significance (Independent t-test).

Abbreviation: Δ, percentage change between pre- and post-treatment.

Table 3
Measured parameters pre- and post-treatment in the both groups

<table>
<thead>
<tr>
<th>Measured parameters</th>
<th>FES group</th>
<th>Δ</th>
<th>Control group</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plantarflexor spasticity (MAS)</td>
<td>2.9 ± 0.67</td>
<td>1.8 ± 0.64</td>
<td>38.3*</td>
<td>2.6 ± 0.57</td>
</tr>
<tr>
<td>Dorsiflexor strength (MMT)</td>
<td>1.3 ± 0.91</td>
<td>2.2 ± 1.1</td>
<td>68.7*</td>
<td>1.4 ± 0.92</td>
</tr>
<tr>
<td>Active ankle dorsiflexion (degrees)</td>
<td>7.6 ± 8.2</td>
<td>11.1 ± 9.03</td>
<td>47.1*</td>
<td>7.9 ± 8.5</td>
</tr>
<tr>
<td>Passive ankle ROM (degrees)</td>
<td>37.7 ± 13.3</td>
<td>50.9 ± 13.6</td>
<td>35.1*</td>
<td>38.9 ± 10.4</td>
</tr>
<tr>
<td>Lower-extremity motor recovery (FMA score)</td>
<td>18.4 ± 4.5</td>
<td>23.7 ± 4.2</td>
<td>29.1*</td>
<td>19.3 ± 4.7</td>
</tr>
</tbody>
</table>

Note: Values are mean ± SD. p < 0.05: Statistical significance between pre- and post-test (Paired t-test).

Abbreviation: Δ, percentage change between pre- and post-treatment; MMT, manual muscle strength; ROM, range of motion.

3.1. Plantarflexor spasticity

After 12-weeks of treatment with FES based therapy, comparison between the MAS score showed significant decrease in the plantarflexor spasticity (p < 0.05) within both FES and control groups (Table 3). The calf spasticity was decreased by 37.5% in the FES group and 21.2% in the control group.

3.2. Ankle joint dorsiflexion ROM

The differences between the baselines mean scores ankle joint dorsiflexion ROM for the 2 groups were statistically nonsignificant. The active ankle ROM increased significantly in both groups, with an increase of 47.1% in FES group and 24.2% in control group as shown in Table 3. The difference between groups in terms of the percentage change, was found significant (p < 0.05), resulted better improvement in FES group than the control group. The passive movement of the ankle ROM also improved significantly by 35.1% in the FES group and 21.7% in the control group.

3.3. Dorsiflexor strength

The primary outcome parameter of this study was achievement of voluntary ankle dorsiflexion at the paretic side, representing selective motor control. Dorsiflexor strength was increased by 75.8% in the FES group, and 27.7% in the control group (Table 3).

3.4. Lower-extremity motor recovery

We evaluated with maximum lower-extremity score was 34. Comparison between the assessments of recovery of lower extremity motor recovery showed significant changes within both groups (Table 3). Fugl-Meyer lower-extremity score was increased by 32.8% and 11.6% in the FES and control group, respectively.
3.5. Comparison between groups

There were no significant differences among the subjects at the baseline values (Table 2). The between-group difference of percentage change was significant at post-treatment assessment in all measured parameters ($P < 0.05$) as presented in Table 4. The comparison of mean changes showed significantly lower plantarflexor spasticity ($P = 0.005$) in the FES group than in the control group. Statistically, higher dorsiflexion strength ($P = 0.001$) and active dorsiflexion ROM ($P = 0.007$) were found in the FES group. The change in lower-extremity motor recovery was significantly greater in the FES group than the control group ($P = 0.007$). This study result revealed that intervention group subjects improved better in measured parameters than the control group subjects.

4. Discussion

The aim of this study was to evaluate the therapeutic effects of neuromuscular electric stimulation of the tibialis anterior muscle on plantarflexor spasticity, dorsiflexor strength, ankle range of motion and lower extremity motor recovery in comparison with conventional rehabilitation treatment in stroke survivors with a drop foot. The present study showed that FES results in a significant improvement in measured parameters when used for a period of about 3 months as a treatment to correct foot drop in stroke patients.

Several studies have been designed to investigate the effect of electrical stimulation on walking speed, effort of walking and spasticity in stroke [19–22]. Hines et al. [23] reported that electrical stimulation does not have effect in reducing spasticity in hemiplegic patients. In a clinical study, Yan et al. [24] found a significantly increased in voluntary ankle dorsiflexion and integrated electromyographic signals of the FES than those of the control group Ankle dorsiflexion is an important kinematic aspect of the swing and initial stance phase of the gait cycle. Dobkin et al. [25] demonstrated that the supraspinal sensorimotor control of walking can be assessed indirectly by ankle dorsiflexion. The neuromuscular electrical stimulation may increase passive range of movement among children by reducing of muscle tone [26]. The primary outcome parameter of this study was achievement of voluntary ankle dorsiflexion at the paretic side, which represents selective motor control.

Previous studies have shown that FES has a positive orthotic effect on walking ability in chronic stroke subjects [9,13,24]. The application of electrical stimulation via surface electrodes restores motor functions, reduces muscle tonicity via the reduction of the stretching reflex, causing lower spasticity and allowing a larger range of motion [26–28] and preventing soft tissue stiffness and contracture [29]. A randomized clinical trial reported that the FES stimulation to dorsiflexors and plantar flexors combined with daily walking, improved the walking ability, muscle strength and spasticity in adult hemiplegics [30]. This study also revealed that the combination of FES therapy along with CRP was more effective in improving gait characteristics, effort of walking, improve in active/passive ankle joint range of motion, dorsiflexor strength, reduction of plantarflexor spasticity, and improving lower-extremity motor functions. The patients also experienced greater stability, improved the walking ability and confidence, while walking with the FES device. A recent study has reported that the contralaterally controlled neuromuscular electrical stimulation increased the active ankle dorsiflexion by 15 degrees and lower limb Fugl-Meyer score by 5 points in two chronic hemiplegic subjects [31]. This study has shown improvement in voluntary ankle dorsiflexion by 47.1% in FES group and 24.2% in control group. In this study, the 12-weeks supervised clinical-based rehabilitation program associated with FES therapy resulted improvement in both the experimental groups in measured parameters, but the FES group shown better recovery than the control group at post-treatment assessment. The electrical stimula-

### Table 4: Percentage change after treatment in the FES Group and the Control Group

<table>
<thead>
<tr>
<th>Measured parameters</th>
<th>FES group</th>
<th>Control group</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔPlantarflexor spasticity (MAS)</td>
<td>38.3</td>
<td>21.2</td>
<td>0.005</td>
</tr>
<tr>
<td>ΔDorsiflexor strength (MMT)</td>
<td>68.7</td>
<td>27.8</td>
<td>0.001</td>
</tr>
<tr>
<td>ΔAnkle joint active dorsiflexion (degrees)</td>
<td>47.1</td>
<td>24.2</td>
<td>0.007</td>
</tr>
<tr>
<td>ΔAnkle joint Passive ROM (degrees)</td>
<td>35.1</td>
<td>7.9</td>
<td>0.025</td>
</tr>
<tr>
<td>ΔLower-extremity motor recovery (FMA)</td>
<td>29.1</td>
<td>11.6</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Abbreviation: MAS, modified ashworth scale; ROM, range of motion; Δ, percentage change between pre- and post-treatment. $

p < 0.05$: Statistical significance (Independent t-test).

---

S.K. Sabut et al. / Functional electrical stimulation of dorsiflexor muscle
tion reduced spasticity more effectively and thereby improved muscle strength and sensorimotor functions.

5. Conclusions

This study shows that the clinical implementation of the neuromuscular electrical stimulation together with conventional rehabilitation program may reduce spasticity, improves joint voluntary movement, muscle strength and also provides better functional recovery in stroke patients. Low incidence of dropout from the treatment indicates that the electrical stimulation treatment is acceptable by the users. Therefore, it is recommended from these findings that electrical stimulation may be used as a standard therapeutic protocol along with conventional rehabilitation program to correct spastic foot drop in the rehabilitation practice in clinics and used by the patients at home.

Acknowledgments

We thank the clinicians, researchers, and therapists of National Institute for the Orthopaedically Handicapped, Kolkata for selection, and treatment of subjects. We would like to thank the participants for their support.

References

S.K. Sabut et al. / Functional electrical stimulation of dorsiflexor muscle


学霸图书馆
www.xuebalib.com

本文献由“学霸图书馆-文献云下载”收集自网络，仅供学习交流使用。

学霸图书馆（www.xuebalib.com）是一个“整合众多图书馆数据库资源，
提供一站式文献检索和下载服务”的24 小时在线不限IP 图书馆。
图书馆致力于便利、促进学习与科研，提供最强文献下载服务。

图书馆导航:
图书馆首页 文献云下载 图书馆入口 外文数据库大全 疑难文献辅助工具