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Effectiveness Of Antagonist Functional Electrical Stimulation Combined With Close Kinetic Chain Exercises On Plantar Flexor Spasticity, Heel Strike, And Motor Recovery In Patients With Stroke

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ABSTRACT

Background: Stroke is a significant neurological event leading to functional deficits and long-term disability. Restoring walking ability is essential for independence and quality of life. Functional electrical stimulation (FES) has recently emerged as an effective method for post-stroke gait rehabilitation. The present study aimed to evaluate the combined effect of antagonist functional electrical stimulation and closed kinetic chain exercises on plantar flexor spasticity, heel strike, and motor recovery in individuals with stroke.

Methodology: A pre- and post-experimental study was carried out on 60 stroke patients selected through simple random sampling based on defined inclusion and exclusion criteria. Participants were randomly allocated into two groups (n=30 each). Group A performed closed kinetic chain exercises alone, while Group B received a combination of functional electrical stimulation (FES) and closed kinetic chain exercises. The intervention was administered for 1 hour daily, 5 days a week, over a period of 8 weeks.

Outcome Measures: Plantar flexor spasticity was evaluated using the Modified Modified Ashworth Scale, ankle dorsiflexion range of motion was measured with a universal goniometer, and motor recovery of the lower limb was assessed using the Fugl-Meyer Assessment Scale.

Results: Post-intervention analysis revealed that Group B demonstrated significantly greater improvement compared to Group A. The experimental group showed a highly significant increase in active ankle dorsiflexion range of motion ($p<0.0001$) and a marked reduction in plantar flexor spasticity. Additionally, Group B exhibited enhanced motor recovery and better gait performance compared to the control group ($p<0.0001$).

Conclusion: The findings suggest that combining antagonist functional electrical stimulation with closed kinetic chain exercises produces superior outcomes in reducing plantar flexor spasticity, improving heel strike, and enhancing motor recovery in patients with hemiplegic gait following stroke.

KEYWORDS: Stroke, Functional Electrical Stimulation, Spasticity, Motor Recovery.

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INTRODUCTION

A stroke is a critical and potentially fatal neurological condition characterized by the sudden onset of focal neurological impairment within a specific vascular region, resulting from underlying cerebrovascular pathology that causes both neurological deficits and physical disability.[1] It ranks as the fourth leading cause of mortality and the second leading cause of long-term disability globally.[2] In India, the annual incidence of stroke is estimated to be between 105 and 152 per 100,000 population, while its prevalence ranges from 44.29 to 559 per 100,000 individuals.[3]

Stroke-related motor deficits impair mobility, daily functioning, social participation, and return to work, leading to reduced quality of life.[4] Even after regaining walking ability, many patients continue to exhibit lower-limb weakness and abnormal gait patterns.[5]

Following a stroke, reduced muscle strength is often attributed to physiological alterations in paretic muscles and their motor units, impaired activation of agonist muscles, and disrupted motor coordination. Abnormal motor control and atypical muscle activation contribute to irregular gait patterns, while factors such as increased muscle tone can further limit the generation of agonist and antagonist torque.

Common issues affecting gait pattern after stroke include ineffective ankle dorsiflexion, failure to achieve heel strike at initial contact, and plantar flexion during pre-swing. Dorsiflexor weakness, plantar flexor spasticity, motor weakness, and abnormal motor control, or a combination of all parameters, are signs of reduced ankle dorsiflexion leading to kinetic and kinematic deviations during the swing phase and stance phases of gait cycle.[6]

During daily activities, movement at one joint naturally influences adjacent joints. Closed kinetic chain (CKC) exercises replicate this coordinated movement by simultaneously engaging the hip, knee, and ankle joints, thereby enhancing proprioceptive and kinesthetic feedback.[7]

In everyday activities, movement at one joint causes movement at the other joints, and these movements preprovided by closed kinetic chain (CKC) exercises, which stimulate hip, knee, and ankle joints at the same time, lead to greater proprioceptive and kinesthetic feedback. [7]

Recently, transcutaneous electrical nerve stimulation (TENS), functional electrical stimulation (FES), and neuromuscular electrical stimulation (NMES) have been used to improve motor activity performance. [8] FES is used to strengthen weak foot dorsiflexor muscles, decrease spasticity in the plantar muscles.[9]

Long-term stroke management is currently gaining popularity. It is essential to know the possible effects of therapies like FES on gait parameters. Several studies have demonstrated the effects of therapeutic exercises on gait speed and spatiotemporal parameters. There is a paucity of studies showing the effect of therapeutic exercises on parameters of only the ankle joint, such as spasticity and voluntary control, leading to overall improvement in lower extremity motor recovery.

Regaining and improving walking skills are the key objectives of rehabilitation programs. In this background, the present study aims to compare effectiveness of functional electrical stimulation to antagonist muscles of the lower extremity combined with close kinetic chain exercises to facilitate and increase the recovery of motor function following stroke using universal goniometer, modified Ashworth scale and Fugl-Meyer lower extremity motor recovery scale in patients with stroke.

METHODOLOGY:

This experimental study was conducted over one year at a tertiary healthcare center in Karad. Sixty stroke patients aged 40–65 years, with Brunnstrom recovery stages 2–5, were included. Participants had stable vitals, clear consciousness, adequate communication ability, and absence of heel strike during gait due to hemiparesis.

Patients with active implants (e.g., pacemakers), peripheral neuropathy, pregnancy, contractures limiting ankle dorsiflexion, loss of proprioception, skin allergies, or psychological, visual, or auditory impairments were excluded.

The study was approved by the Institutional Ethics Committee of KIMSDU, Karad. After obtaining informed consent, eligible subjects were randomly assigned to two groups: Group A (control) received only closed kinetic chain (CKC) exercises, while Group B (experimental) underwent CKC exercises combined with functional electrical stimulation (FES).

FES was applied using surface electrodes over the common peroneal nerve and tibialis anterior motor point to produce dorsiflexion and eversion. Stimulation was synchronized with the swing phase of gait via a heel switch, using biphasic rectangular pulses (300 µs, 0–80 mA, 40 Hz) adjusted to generate near-normal ankle movement.

At beginning of each FES treatment session, the intensity of stimulation and the electrode positions were adjusted for required movement of the foot to clear the ground in the swing phase more easily.

Outcome measures were recorded at baseline and post-intervention. **ROM** was measured using a goniometer to assess passive and active movement.[11] **Spasticity** was evaluated with the Modified Modified Ashworth Scale (MAS). [12,13] **Motor recovery** was assessed using the Fugl-Meyer Assessment for lower extremities (FMA-LE), a validated tool for stroke rehabilitation.[14]

Both groups received one-hour sessions, five days a week for eight weeks. Post-test assessments were compared with baseline values, and statistical analysis was performed to determine study outcomes.

Statistical analysis: Data were analyzed using SPSS version 26.0. Within-group comparisons of ankle range of motion, plantar flexor spasticity, and Fugl-Meyer lower limb motor recovery were assessed using paired t-tests ($p < 0.0001$). Between-group differences were evaluated using independent t-tests, with significance set at $p < 0.05$.

RESULTS:

Table 1: Subjects characteristics

	Group A	Group B
Gender wise distribution	Male=19 Female=11	Male=21 Female=9
Age wise Distribution	Mean± SD=47.433±7.06	Mean± SD=48±7.469
Type of Stroke	Ischemic=18 Hemorrhagic=12	Ischemic=18 Hemorrhagic=12
Side involved	Right= 16 Left=14	Right= 18 Left=12
Brunnstrom stage of recovery	Stage 1=12 Stage 2=10 Stage 3=8	Stage 1=10 Stage 2=9 Stage 3=11

Table no 1, shows subject characteristics in the form of variable. This includes gender and age wise distribution, type of stroke, side involved and Brunnstrom stages of recovery.

Table 2: within group comparisons of all outcomes in group A

	Pre	**Post**	**P-value**
	Mean±SD	**Mean**	
AROM	**2.033± 0.135**	**3.86± 0.43**	**0.0813**
PROM	**9.04± 2.65**	**10.7±4.010**	**0.0025**
Plantar flexor Spasticity	**2.33±0.637**	**2.09±0.57**	**0.0001**
FMA-LE Score	**12.46±2.46**	**15.1±2.67**	**0.0054**

Table 2 presents within-group A comparisons for outcome measures. Active ankle dorsiflexion showed a slight improvement (mean difference 1.92±0.295; p=0.0813), while passive dorsiflexion improved significantly (1.66±1.3; p=0.0025). Plantar flexor spasticity decreased markedly (p=0.0001), and lower extremity motor recovery showed a modest improvement (2.64±0.21; p=0.0054).

Table 3: Within group comparisons of all outcomes in group B.

	Pre	**Post**	**P-value**
	Mean±SD	**Mean**	
AROM	**4.83± 0.120**	**12.566± 4.296**	**<0.0001**
PROM	**10.933± 4.52**	**20.7±5.39**	**<0.0001**
Plantar flexor Spasticity	**1.611±0.501**	**0. 633±0.12**	**<0.0001**
FMA-LE Score	**13.633±2.89**	**23.761±3.17**	**<0.0001**

Table no 3, shows comparison within group B for different outcome measures. There is significant improvement seen in active ankle dorsiflexion range of motion with mean difference of 7.736 ± 4.176, passive ankle dorsiflexion range of motion with mean difference of 9.80±0.87. There is noticeable Reduction in plantar flexor spasticity seen after post intervention than pre intervention with p value of <0.0001, also it shows that there is significant improvement in lower extremity motor recovery after post intervention in group B with mean difference of 10.128±0.38 with significant p value of <0.0001.

Table-4: Between group comparison of AROM

AROM	**Pre**	**Post**	**P-value**
	Mean±SD	**Mean**	
Group A	**2.033± 0.135**	**3.86± 0.43**	**<0.0001**
Group B	**4.83± 0.120**	**12.566± 4.296**	

In the table no.4, we compared the pre and post intervention scores for Active Range of Motion for Group A and Group B. Group B showed significant improvement, with score rising from 4.83± 0.120 to 12.566± 4.296 , with p value of <0.0001.

Table-5: Between group comparison of PROM

PROM	**Pre**	**Post**	**P-value**
	Mean±SD	**Mean**	
Group A	**9.04± 2.65**	**10.7±4.010**	**<0.0001**
Group B	**10.933± 4.52**	**20.7±5.39**	

In the table no.5, we compared the pre and post intervention scores for passive Range of Motion for Group A and Group B. Post intervention Passive range of motion showed more improvement in group B than group A ,with mean difference of 9.767±0.87, with p value of <0.0001.

Table-6: Between group comparison of plantar flexor Spasticity

Plantar flexor Spasticity	Pre	Post	P-value
	Mean±SD	Mean	
Group A	2.33±0.637	2.09±0.57	<0.0001
Group B	1.611±0.501	0. 633±0.12	

In the table no.6, we compared the pre and post intervention scores for plantar flexor spasticity for Group A and Group B. there is significant reduction in plantar flexor spasticity in Group B than in Group A with p value of <0.0001.

Table-7: Between group comparison of FMA-LE Score

FMA-LE Score	Pre	Post	P-value
	Mean±SD	Mean	
Group A	12.46±2.46	15.1±2.67	<0.0001
Group B	13.633±2.89	23.761±3.17	

In the table no.7, we compared the pre and post intervention scores for lower extremity motor recovery for Group A and Group B. Group B showed significant improvement in lower extremity motor recovery , with score increasing from 13.633±2.89 to 23.761±3.17, with p value of <0.0001.

DISCUSSION

A review of existing literature indicates that numerous stroke rehabilitation studies involve chronic stroke survivors, showing that functional improvements can occur even years after the event. Since many individuals continue to experience gait impairments in the chronic stage of recovery, identifying effective interventions for this group remains crucial. Therefore, this study aimed to evaluate the efficacy of applying functional electrical stimulation (FES) to the antagonist muscles of the lower limb as a therapeutic approach.

The result of the present study showed that at the end of 8 weeks, both Group A (control group which was given close kinematic chain exercises) and Group B (experimental group which was given close kinematic chain exercises along with functional electrical stimulation) experienced significant improvement but combined effect of close kinetic chain exercises with FES results in greater improvement in all measured parameters when used for 8 weeks as a treatment.

In this study there was improvement in Group A, who received close kinetic chain exercises. The success of this close kinetic chain exercises is consistent with previously published research. Insufficient activation of the gastrocnemius and tibialis anterior are often observed during the gait cycle in Stroke patients, and leads to an insufficient push off, toe clearance. Close kinetic chain exercises improve muscle activation of the gastrocnemius and tibialis anterior but they need more eccentric muscle activation for toe clearance. Na Kyung Lee et al, suggested that CKC exercise maybe used as proper training method for Stroke patients when used with different therapeutic interventions.[15]

Lee et al. evaluated the effects of open and closed kinetic chain exercises on lower limb muscle activity and balance in stroke patients. Their findings indicated that CKC exercises are more effective in improving muscle strength, balance, and functional mobility in chronic stroke patients. Although CKC exercises offer greater overall benefits, this study specifically focuses on enhancing ankle dorsiflexion; hence, exercises were tailored to target the ankle joint. [15]

Ankle dorsiflexion is an important kinetic aspect of heel strike in stance and swing phase of gait cycle. The primary outcome of this study was to achieve ankle dorsiflexion, which represents lower extremity motor control. Yan et al, found a significant increase in ankle ROM with integrated electromyographical signals of FES than those of control group.[16]

Our study found that the within-group comparison of Group B demonstrated a statistically significant improvement in all parameters. In present study we stimulated the peroneal nerve (which supplied the dorsiflexors and evertors of the ankle) with functional electrical stimulator, which showed significant improvement after intervention. Embrey et al. reported that stimulating both dorsiflexors and plantar flexors enhances gait by improving ankle control and forward propulsion. Stimulation during swing and loading phases produced a gait pattern closer to normal, though other studies did not confirm FES superiority over conventional gait training. [17]

Sukanta Sabut et al. reported that FES of plantar flexors and dorsiflexors, combined with daily walking, improved gait and foot clearance in hemiplegic adults. Over 12 weeks, FES also enhanced lower limb motor recovery, dorsiflexor strength, and reduced plantar flexor spasticity compared to conventional therapy.[18]

Bae YH et al. found that FES applied to dorsiflexors during pre-swing and swing phases is more effective than an ankle-foot orthosis, which limits ankle mobility. By mimicking natural gait, FES enhances motor learning, reduces spasticity, improves strength, and prevents muscle atrophy in stroke patients. [19]

Functional electrical stimulation to antagonist musculature of the lower extremity causes a reduction in spasticity of the agonist's muscles by reciprocal inhibition at the spinal cord level. facilitation of two sources of afferent stimulation on reflex motor activity, at the spinal or even at the supraspinal level under strong excitatory and inhibitory control from corticospinal tract fibers with the activity of antagonist muscles which leads to reduction of spasticity in agonist's muscles.[20]

Nudo et al. proposed that repetitive movement–induced afferent input enhances motor function recovery. Therefore, stimulation that triggers actual motor activity may be more beneficial than purely sensory input, as it engages cutaneous, muscular, and proprioceptive feedback. The therapeutic effect of FES is believed to result from the activation of alternative motor pathways that compensate for damaged efferent circuits. [21]

Similarly, Iftime-Nielsen et al. found that when neuromuscular stimulation is combined with voluntary effort, as in FES, it leads to greater cerebellar activation and reduced secondary somatosensory cortex activity compared to neuromuscular stimulation alone in healthy individuals. [22]

Within-group comparisons showed significant improvement across all outcome measures. The experimental group demonstrated greater gains in active and passive ankle range of motion, reduced plantar flexor spasticity, and superior lower limb motor recovery and gait performance compared to the control group, with a highly significant p-value < 0.0001.

The limitation of the study was subjects were not homogenous and it was limited to a small rural geographical area. The duration of the study was short and limited. Furthermore, research is required in a large population on early intervention among Stroke survivors.

Thus, the study provides us with a greater insight that close kinetic chain exercises combined with antagonist functional electrical stimulation shows more improvement on heel strike in stroke patients than close kinetic chain exercises.

CONCLUSION

The study finding concluded that combining antagonist functional electrical stimulation with close kinetic chain exercises produced significantly better results in Group B compared to Group A. The findings support that this combined approach effectively reduces plantar flexor spasticity, enhances ankle dorsiflexion range of motion, and improves lower limb motor recovery in stroke patients.

Author Contribution Statement

Dr. Manasi Prakash Chavarkar conducted literature review for this manuscript, developed an introduction section of manuscript, conducted the discussion of the study, findings, collected data and analyzed the data.
Dr. G Varadharajulu provided a description of the background information, analyzed the data and participated in prescription of the manuscript; all the authors read and approved the final manuscript.

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Ethical Committee

The study was approved by Institutional Ethical Committee of Krishna Institute of Medical Science Deemed to Be University, Karad, Maharashtra.

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Statement conflict of Interest

The authors claimed that there are no conflicts of interest concerning the content of the present study.

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