

ORIGINAL RESEARCH

REHABILITATION

Effectiveness of soft robotic gloves versus electrical muscle stimulation on hand function and quality of life in stroke survivors

Moin Yahya ¹, Qurba Kiran ², Ahsan Hanif ³, Junaid Saleem ⁴, Tayyba Majeed ⁵, Sanya Ashraf ⁶

Authors affiliations:

1. Moin Yahya, Superior University Lahore, Pakistan; Email: drmoinyahyapt@gmail.com
2. Qurba Kiran, Superior University Lahore, Pakistan; Email: qurbabutt8@gmail.com
3. Ahsan Hanif, Superior University Lahore, Pakistan; Email: ahsanhanif501@gmail.com
4. Junaid Saleem, Gulab Devi Hospital and Educational Complex Lahore, Pakistan; Email: docjunaid92@gmail.com
5. Tayyba Majeed, Superior University Lahore, Pakistan; Email: tayybamajeed36@gmail.com
6. Sanya Ashraf, Superior University Lahore, Pakistan; Email: drsanyaashrafpt@gmail.com

Correspondence: Qurba Kiran, Email; qurbabutt8@gmail.com Mobile: 92 3200486838

ABSTRACT

Background and Objective: Stroke is a cerebrovascular illness characterized by loss of brain blood flow that results in neurological dysfunction. Stroke ranks second globally in terms of cause of mortality. Study objective was to find effectiveness of soft robotic gloves versus electrical muscle stimulation (EMS) on hand function and quality of life in stroke survivors.

Methodology: This randomized control trial was conducted on 36 stroke survivors from May 2024 – Oct 2024. The study was conducted in Naseer Hospital Lahore. The data was collected through FMA-UE and Quick Dash scale. SPSS version 25 was used for statistical analysis.

Results: Group A (robotic gloves) had an FMA-UA score of 38.61 ± 9.79 (mean rank 20.39) versus Group B (EMS) had a score of 35.50 ± 6.85 (mean rank 16.61; $P = .280$); prior to intervention. Group A showed a substantial improvement 54.28 ± 8.67 ($P = .002$) after the intervention. Statistically the Quick-DASH scores were $p = .738$ among Group A participants, showing greater improvement post therapy (28.78 ± 5.90 vs. 37.00 ± 7.23 ; $P = .001$).

Conclusion: Results highlights the effectiveness of both interventions but robotic gloves was found to be more effective as compared to EMS.

Abbreviation: FMA-UE: Fugl-Meyer Assessment of Upper Extremity, Quick-DASH: Quick Disabilities of the Arm, Shoulder and Hand, EMS: Electrical muscle stimulation

Keywords: Cerebrovascular Accident; Stroke; Electrical Stimulation; Rehabilitation

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1. INTRODUCTION

Stroke is a cerebrovascular illness characterized by an abrupt loss of brain blood flow that results in neurological dysfunction.¹ According to estimates from

the World Health Organization (WHO), 15 million people worldwide suffer from strokes annually.² Stroke ranked third globally in terms of both mortality and The age-adjusted stroke mortality rate increased by 8.4% in the United States between 2011 and 2021, compared

disability combined (5.7%), it was the second most common cause of death (11.6%) worldwide in 2011.³ It was the second most common cause of death (11.6%) worldwide with a 26.3% increase in the actual number of stroke fatalities (from 128 932 to 162 890 deaths).⁴ Stroke is the most common cause of disability and the leading cause of death worldwide. Stroke and its consequences are a major cause of death worldwide, with a high incidence in Pakistan.⁵

The rehabilitation of hand function, in particular, has always been difficult and challenging for chronic stroke survivors because of the establishment of learned non-use in the impaired hand.⁶ Traditional stroke recovery interventions typically involve a series of intense, repetitive exercises that have been shown to effectively facilitate brain neuroplasticity during the recovery of gross motor function and daily functional skill. This helps stroke survivors regain better hand function.⁷ Rehabilitation robots can guarantee that patients with varying degrees of disability have access to extremely rigorous, accurate, and consistent training program.^{7, 8}

Robot-assisted treatment provides precise, automated movement control for the measurement of rehabilitation and an objective training approach through extremely repeated movements. Soft robotic gloves offer a transformative approach to rehabilitation for stroke patients, helping to restore hand function and improve overall quality of life.⁹ These innovative devices are designed to support and assist hand movements, making it easier for patients to perform repetitive exercises that are crucial for recovery.¹⁰ By providing tailored assistance, soft robotic gloves enable patients to engage in high-frequency and high-intensity practice, which is essential for motor learning and neural reorganization.¹¹

The outcomes demonstrated that the use of robot-assisted therapy significantly improved hand function and had a favorable effect on lowering motor impairment.¹² EMS, on the other hand, is a widely used technique in stroke rehabilitation that involves applying electrical impulses to the muscles, stimulating muscle contractions.¹³ By targeting specific muscles, EMS can enhance strength, improve muscle tone, and promote neuroplasticity. In stroke rehabilitation, EMS is often used to stimulate weakened muscles in the hand and forearm, helping restore voluntary control over movements.¹⁴ Studies show that EMS is particularly effective in improving motor function in patients with moderate to severe impairments. The repeated stimulation of hand muscles helps in the reactivation of dormant neural pathways, promoting recovery of motor control.¹⁵ Kottink et al. experimental study showed Grip strength ($P = 0.002$) and hand function ($P = 0.002$ on the Jebson-Taylor Hand Function Test and $p \leq 0.001$ on the Action Research Arm Test) both showed significant

improvements over the course of six using soft-robotic glove.¹⁶ Shi et al RCT suggested patients with weak grip showed significant improvement after using EMS for upper limb function.¹² Soft robotic gloves stand out as a safe and promising technology to enhance hand- and finger-related dexterity and functional performance.¹⁷

2. METHODOLOGY

Study design was randomized controlled trial. Naseer Hospital Lahore was study setting. 36 was sample size calculated through G power software by using FMA-UE as a variable and all the participants were distributed equally into two groups (18 in each).¹⁸

Simple random sampling method was utilized to ensure equal as well as unbiased selection. Assessor were blind in this study. Suitable participants were selected from a patient registry and received random numbers by employing a sealed-envelope technique. Sample was randomized into two groups A and B. Male and female participants, aged between 50 and 70 years; who had suffered an ischemic or hemorrhagic stroke in the last six months, and whose Mini-Mental State Examination (MMSE) score was more than 24 were included in this study. Participants having comorbid neurological diseases like Parkinson's disease, epilepsy, vertigo or any joint contracture that would restrict the application of a soft robotic glove were excluded. 2 study groups were made Group A: Received Soft robotic gloves stimulation 30-minute sessions, 5 times per week up to 8 week. Group B received electrical stimulation Frequency-80Hz, Pulse width- 250 micro second, Intensity-maximum tolerable. Fugl-Meyer Assessment of Upper Extremity (FMA-UE) Quick Disabilities of the Arm, Shoulder, and Hand (Quick DASH) were used as assessment tools. The data was analyzed using SPSS Version 25. All participants were analyzed pre and post treatment no subject was dropout.

3. RESULTS

In both groups majority of the patients were male. When considering the duration of stroke, 61.1% in Group A had a stroke duration of 1-3 months, while 38.9% experienced stroke symptoms for 4-6 months. In Group B, 66.7% (12) had a stroke duration of 1-3 months, and 33.3% (6) had a duration of 4-6 months. Regarding the side of paralysis, 33.3% in Group A had right-sided paralysis, and 66.7% had left-sided paralysis. Conversely, Group B had 66.7% with right-sided paralysis and 33.3% with left-sided paralysis. The mean age of patients in Group A was 60.611 ± 7.105 years, while in Group B, it was 57.667 ± 4.727 years had 59.140 ± 6.133 had mean age difference between groups. For cognitive function measured by the MMSE, Group A had a mean score of 24.833 ± 0.985 , and Group B had a

Table 1: Demographic data of the groups

Parameter		Group A	Group B	Total
Gender	Male	10 (55.6)	13 (72.2)	23 (63.9)
	Female	8 (44.4)	5 (27.8)	13 (36.1)
Duration of stroke	1-3 Months	11 (61.1)	12 (66.7)	23 (63.9)
	4-6 Months	7 (38.9)	6 (33.3)	13 (36.1)
Paralysis Side	Right	6 (33.3)	12 (66.7)	18 (50.0)
	Left	12 (66.7)	6 (33.3)	18 (50.0)
Type of stroke	Ischemic	15 (83.3)	12 (66.7)	27 (75.0)
	Hemorrhagic	3 (16.7)	6 (33.3)	9 (25.0)
Age (years)		60.611 ± 7.105	57.667 ± 4.727	59.140 ± 6.133
MMSE		24.833 ± .985	25.000 ± 1.084	24.923 ± 1.025
<i>Data presented as mean ± SD or n (%)</i>				

Table 2: Comparative Quick Dash using Mann Whitney U test:

Quick Dash	Groups	Mean ± SD	Mean Rank	Mann Whitney	P value
Quick Dash – Pre	Group A	57.273 ± 8.011	17.92	151.500	.738
	Group B	57.784 ± 8.553	19.08		
Quick Dash Post	Group A	28.777 ± 5.896	12.86	60.500	.001
	Group B	37.004 ± 7.225	24.14		
<i>P < 0.05 is considered as significant</i>					

mean score of 25.000 ± 1.084 had 24.923 ± 1.025 means difference between groups.

For comparing differences between two independent groups when the data were not normally distributed, the Mann-Whitney U test was utilized. It is a non-parametric test appropriate for ordinal or skewed data. Before the intervention, Group A and B had a mean rank of 19.08 (P = .738) indicating no significant difference between the groups at this stage.

However, after the intervention, there was a notable difference. Group A's Quick Dash score improved with a significant P value of .001, indicating a statistically significant improvement.

For the FMA wrist scores, Group A's pre-intervention mean was not significantly different to Group B's mean (P = .560). Post-intervention, Group A's wrist score improved to 7.444 ± 1.338 with a mean rank of 23.19, while Group B's score was 6.277 ± 0.826 with a mean rank of 13.81 (Mann-Whitney U = 77.500, P = .006), again showing significant improvement in Group A.

For the FMA hand scores, Group A had a pre-intervention mean of 8.055 ± 2.388 and a mean rank of

20.39, while Group B had a mean of 7.500 ± 1.581 and a mean rank of 16.61 (Mann-Whitney U = 128.000, P = .255). Post-intervention, Group A's hand score increased (P = .008), indicating a significant difference in favor of Group A.

For the FMA speed scores, Group A had a pre-intervention mean of 3.888 ± 1.078 and a mean rank of 21.28, while Group B had a mean of 3.222 ± 1.215 and a mean rank of

15.72 (Mann-Whitney U = 112.000, P = .097). Post-intervention, Group A's speed score increased to 5.555 ± 0.921 with a mean rank of 24.36, while Group B's mean was 4.055 ± 1.258 with a mean rank of 12.64 (Mann-Whitney U = 56.500, P = .001), indicating a significant improvement in Group A.

Lastly, the total FMA motor function (TMF) score in Group A was 38.611 ± 9.792 pre-intervention with a mean rank of 20.39, compared to Group B's mean of 35.500 ± 6.853 and a mean rank of 16.61 (Mann-Whitney U = 128.000, P = .280). Post-intervention, Group A's TMF score improved to 54.277 ± 8.669 with a mean rank of 24.03, while Group B's score was 43.833 ± 8.466 with a mean rank of 12.97 (Mann-Whitney U = 62.500, P = .002), showing a significant improvement in Group A.

4. DISCUSSION

Current RCT was conducted on 36 stroke patients. The results of the study showed prior to the intervention, there was no significant difference between Group A and Group B in their QuickDASH scores, as indicated by the Mann-Whitney U test (P = .738). This similarity in baseline scores suggests that both groups had

Table 3: Between Group Comparison of FMA Upper Extremity using Mann Whitney U test:

	Groups	Mean ± SD	Mean Rank	Mann Whitney	P value
Quick Dash – Pre	Group A	57.273 ± 8.011	17.92	151.500	.738
	Group B	57.784 ± 8.553	19.08		
Quick Dash Post	Group A	28.777 ± 5.896	12.86	60.500	.001*
	Group B	37.004 ± 7.225	24.14		
FMA UE Pre	Group A	21.111 ± 5.486	20.17	132.000	.336
	Group B	19.333 ± 5.810	16.83		
FMA UE Post	Group A	29.555 ± 5.271	23.22	77.00	.006*
	Group B	24.055 ± 6.601	13.78		
FMA Wrist Pre	Group A	5.555 ± 1.46	19.47	144.500	.560
	Group B	5.444 ± 1.149	17.53		
FMA Wrist Post	Group A	7.444 ± 1.338	23.19	77.500	.006*
	Group B	6.277 ± .826	13.81		
FMA Hand Pre	Group A	8.055 ± 2.388	20.39	128.000	.255
	Group B	7.500 ± 1.581	16.61		
FMA Hand Post	Group A	11.722 ± 2.515	23.08	79.500	.008*
	Group B	9.444 ± 1.854	13.92		
FMA Speed Pre	Group A	3.888 ± 1.078	21.28	112.000	.097
	Group B	3.222 ± 1.215	15.72		
FMA Speed Post	Group A	5.555 ± .921	24.36	56.500	.001*
	Group B	4.055 ± 1.258	12.64		
FMA TMF Pre	Group A	38.611 ± 9.792	20.39	128.000	.280
	Group B	35.500 ± 6.853	16.61		
FMA TMF Post	Group A	54.277 ± 8.669	24.03	62.500	.002*
	Group B	43.833 ± 8.466	12.97		

*Data presented as mean ± SD; P < 0.05 is considered as significant
Pre- an post-intervention data of Quick Dash and FMA is compared*

comparable levels of upper extremity disability. However, following the intervention, Group A showed a significant improvement in Quick DASH scores compared to Group B (P = .001). This indicates that the intervention used for Group A had a more substantial impact on reducing upper extremity disability. The finding aligns with previous Kottink et al. (2024) study conducted on stroke subjects to assess the therapeutic impact of a soft robotic glove with grip support as a home assistive tool for everyday tasks. Robotic glove-based QuickDASH scores revealed P < .001. Hand function (P = 0.002 on the Jebson-Taylor Hand Function Test and P ≤ 0.001 on the Action Research Arm Test)¹⁶ and grip strength (P = 0.002) provide evidence of the effectiveness of intensive, function-specific therapies in

lowering disability and enhancing motor function in upper extremity ailments.

Both Group A and Group B showed significant within-group improvements in QuickDASH scores post-treatment (P < .001 for both groups). This suggests that the interventions used in both groups were effective in reducing disability. The improvements observed in Group A were more pronounced, as reflected by the greater reduction in mean QuickDASH scores. This highlights the importance of tailored therapeutic approaches to maximize functional recovery. These results were in accordance to Proulx et al. (2020) study determined the efficacy of soft robotic gloves vs electrical stimulation effects for hand rehabilitation. Comparable to the current study, the results showed that both interventions had a substantial improvement, although the soft robotic gloves group had a greater improvement (p value p < .001). QuickDASH was utilized as an assessment tool in the Proulx study.¹⁷

Current study suggested before the intervention, Group A (robotic glove) had a mean FMA upper extremity (UE) score of 21.111 ± 5.486 with a mean rank of 20.17, while Group B had a mean score of 19.333 ± 5.810 with a mean rank of 16.83 (P = .336). After the intervention, Group A's FMA UE score increased to 29.555 ± 5.271 with a mean rank of 23.22, while Group B had a lower post-intervention score of 24.055 ± 6.601 with a mean rank of 13.78 (Mann-Whitney U = 77.000, P = .006), indicating a significant improvement in Group A. These findings were consistent with a research by Nuckols et al. on 40 stroke survivors, which found that the use of robotic gloves had a negative impact on hand strength following a stroke. The study also used FMA to determine the upper extremity score after 4 weeks of therapy, and the results were P < 0.001 when compared to the control group.¹⁹ Group A's pre-intervention mean for the FMA

wrist scores was 5.555 ± 1.460 with a mean rank of 19.47, whereas Group B's mean was 5.444 ± 1.149 with a mean rank of 17.53 (Mann-Whitney $U = 144.500$, $P = .560$). Following the intervention, the wrist score of Group A increased to 7.444 ± 1.338 with a mean rank of 23.19, whereas the score of Group B was 6.277 ± 0.826 with a mean rank of 13.81 (Mann-Whitney $U = 77.500$, $P = .006$), indicating that Group A had once again improved significantly. These findings were in contrast to Cheng et al.'s study, which found that robotic gloves improved hand function and that the FMA wrist score was less than 0.05. However, that study took eight weeks to exhibit the same outcomes, whereas the current study required four weeks.²⁰

However, post-intervention comparisons demonstrated significant improvements in Group A compared to Group B across all FMA components, these findings suggest that the intervention in Group A was more effective in improving fine motor skills, wrist control, hand function, and overall motor performance as compared to the intervention in Group B. These findings were in accordance to McCabe et al. (2015) study conducted to evaluate the effects of functional electrical stimulation against robotics gloves with motor learning for upper-limb therapy in 30 subjects. Each group got a different kind of treatment for five days a week for five hours a day, or sixty sessions. The upper-limb FMA scale is used as a measurement tool. The FMA coordination treatment response demonstrated statistically and clinically significant improvements in robotic groups ($P \leq .009$).²¹

Group A exhibited greater improvements across all components, underscoring the superior efficacy of the intervention employed in this group these results were accordance to Zahra Jiryaei et al. (2024) a peer-reviewed research that examined the use of a soft robot glove as a functional assistive device.²²

Current research focuses on short-term outcomes of rehabilitation interventions. Future studies should include follow-up assessments at 6 months and 12 months post-intervention to determine the long-term effectiveness of soft robotic gloves and electrical muscle stimulation (EMS) on hand function and quality of life. This could provide valuable insights into sustained benefits or potential relapses. Stroke can present with different etiologies, including ischemic and hemorrhagic types, which may respond differently to rehabilitation techniques.

Future studies should explore whether the effectiveness of soft robotic gloves and EMS varies based on stroke type, lesion location, and the degree of initial hand dysfunction. Such analysis would allow for more targeted rehabilitation strategies.

5. LIMITATIONS

Lack of follow-up cooperation from the patients. The efficacy of soft robotic gloves and EMS may differ depending

6. CONCLUSIONS

This study highlights the effectiveness of robotic gloves and electrical muscle stimulation interventions in improving upper extremity function, as evidenced by significant improvements in Quick-DASH and Fugl-Meyer scores. However, the intervention used in Group A (robotic gloves) was found to be more effective as compared to EMS group B leading to greater reductions in disability and more significant improvements in motor function.

7. Data availability

The numerical data generated during this research is available with the authors.

8. Conflict of interest

All authors declare that there was no conflict of interest.

9. Funding

The study utilized the hospital resources only, and no external or industry funding was involved.

10. Authors' contribution

MY: Conceptualization, study design, and manuscript drafting

QK: Data collection, literature review, and methodology development

AH: Data analysis, interpretation, and critical review of the manuscript

JS, SA: Proofreading, reference management, and technical formatting

TM: Supervision, final approval of the version to be published, and correspondence

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