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Article

The Effect of Repetitive Facilitative Exercise Combined With Electromyography Biofeedback in Promoting Limb Function Rehabilitation in Patients With Post-Stroke Hemiplegia

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Abstract

Aims/Background: Hemiplegia is a common complication following a stroke, resulting in decreased motor function. Although various treatment options are available, there is currently insufficient evidence to determine the definitive superiority of any single treatment modality, and the effectiveness of using a single therapy remains limited. Therefore, this study aims to investigate the efficacy and safety of combining repetitive facilitative exercise (RFE) with electromyography (EMG) biofeedback in managing patients with post-stroke hemiplegia. **Methods**: This retrospective study included 106 patients with post-stroke hemiplegia who were treated at The Second Affiliated Hospital of Qiqihar Medical University, China, between January 2022 and January 2024. Patients who received RFE alone were included in the RFE group ($n = 51$), while those who received the combination of RFE and EMG biofeedback treatment were included in the RFE+EMG group ($n = 55$). Both groups were treated continuously for 12 weeks. The limb function (Fugl-Meyer Assessment [FMA]), balance ability (Berg Balance Scale [BBS], Timed Up and Go Test [TUGT], 10-Meter Walk Test [10MWT]), and quality of life (Stroke Specific Quality of Life Scale [SS-QOL]) were comparatively assessed between the two groups before treatment and 12 weeks after treatment. Additionally, the incidence of adverse events throughout the treatment period was recorded for both groups. **Results**: After treatment, the FMA scores showed significant improvements in both groups compared to their pre-treatment values ($p < 0.05$). Notably, the RFE+EMG group exhibited significantly higher improvements in upper extremity, lower extremity and overall scores compared to the RFE group after treatment ($p < 0.05$). Following the intervention, both groups demonstrated a substantial increase in the BBS score compared to their scores before treatment ($p < 0.05$). In contrast, the TUGT and 10MWT were significantly shortened in both groups compared to their times before treatment ($p < 0.05$). Notably, the RFE+EMG group exhibited significantly higher BBS scores ($p < 0.05$) and significantly shorter TUGT and 10MWT times compared to the RFE group after treatment ($p < 0.05$). After treatment, the SS-QOL scores increased significantly in both groups compared to their scores before treatment ($p < 0.05$). Notably, the RFE+EMG group exhibited significantly higher scores in energy, family roles, language, mobility, mood, personality, self-care, social roles, thinking, upper extremity function, vision and work/productivity compared to the RFE group after treatment ($p < 0.05$). **Conclusion**: The combination of RFE and EMG biofeedback shows promising effects in limb functional recovery, improving balance ability, and enhancing quality of life in patients with post-stroke hemiplegia, while also demonstrating a favourable safety profile, with no severe adverse events reported.

Keywords: exercise therapy; biofeedback; stroke; hemiplegia; recovery of function; postural balance; quality of life

1. Introduction

Stroke refers to varying degrees of functional impairment in brain tissue due to the sudden blockage or rupture of cerebral blood vessels, and is generally divided into ischemic stroke and hemorrhagic types [1,2,3]. In China, stroke is the leading cause of death, with a high incidence rate of 126.9 per 100,000 person-years, and is associated with a high mortality, recurrence, and disability rate [4,5]. Hemiplegia is one of the common complications following stroke, affecting approximately 65% of patients, and significantly impairs motor function and reduces the ability to perform activities of daily living [6]. This not only affects patients' quality of life but also poses significant emotional, physical, and financial burdens on families and society. Various therapeutic strategies to address post-motor dysfunction include pharmacological therapy, traditional Chinese medicine, exercise therapy, physical therapy, orthotic devices, and rehabilitation robotics [7,8,9,10,11]. However, there is currently insufficient evidence to determine the superiority of any single approach.

Repetitive facilitative exercise (RFE) is a novel post-stroke rehabilitation method developed by Professor Kawahira K. of Kagoshima University, Japan, designed to improve motor function recovery [12]. This strategy targets the strengthening of neural conduction pathways via high-frequency repetitive stimulation and a specific neural induction method, aiming to restore normal movement patterns [13]. A study by Kawahira and colleagues [12] revealed that repetitive stimulation therapy more effectively improved motor control, joint mobility, and functional recovery of the affected limb compared to a conventional re-

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habilitation program. In recent years, a combination of RFE with other therapeutic methods has been found to enhance its efficacy. For example, Ohnishi et al. [14] investigated the impact of RFE in combination with neuromuscular electrical stimulation (NMES) in patients with severe stroke-induced paresis and found that the combined strategy effectively activated paralysed muscles and promoted upper limb motor functional recovery.

Electromyography (EMG) biofeedback therapy, introduced into clinical practice in the 1980s, is a multifunctional neurorehabilitation physiotherapy method widely used in Western countries. This approach is widely recognised by its simplicity, safety, and efficacy. It facilitates the re-establishment of neural connections between the brain and paralysed muscles by enabling patients to actively participate in training, thereby promoting proprioceptive recovery and cognitive relearning [15,16]. EMG biofeedback has been proven to be effective in strengthening pelvic floor muscles [17], improving swallowing function [18], managing anal incontinence [19], and reducing pain [20]. Furthermore, recent evidence suggests that EMG biofeedback therapy is particularly effective in improving limb function in stroke patients, especially upper limb mobility [21]. Studies by Rayegani et al. [22] and Lirio-Romero et al. [23], which involved patients with post-stroke hemiplegia, have revealed that EMG biofeedback therapy significantly enhances hand function and upper limb motor performance.

The above studies have revealed the efficacy of RFE and EMG biofeedback in promoting limb function recovery in patients with post-stroke hemiplegia; however, no research has investigated the combined application of these two approaches for limb rehabilitation. Therefore, to address this gap, this study retrospectively analysed 106 cases of post-stroke hemiplegia undergoing rehabilitation at The Second Affiliated Hospital of Qiqihar Medical University. The aim is to assess the efficacy and safety of combining RFE with EMG biofeedback, thereby providing new insights and potential approaches for enhancing functional outcomes in patients with post-stroke hemiplegia.

2. Methods

2.1 Research Subjects

This retrospective study included 106 patients with post-stroke hemiplegia who were treated at The Second Affiliated Hospital of Qiqihar Medical University, China, between January 2022 and January 2024.

2.2 Inclusion and Exclusion Criteria

The inclusion criteria for patient selection were as follows: (1) patient diagnosis with the American Heart Association/American Stroke Association guidelines for stroke [24], confirmed by imaging examinations such as computed tomography (CT) or magnetic resonance imaging (MRI), with evidence of unilateral paralysis; (2) patient age 18 years and above, with intact consciousness and basic verbal communication ability; (3) patients with symptoms of limb motor dysfunction and the ability to stand and walk independently of at least 10 meters; and (4) those with stable medical conditions with controlled blood pressure and a disease course of $\leq$3 months.

However, exclusion criteria included (1) walking instability due to prior limb dysfunction or unrelated diseases; (2) significant vital organ dysfunction, such as heart, liver, and kidneys; (3) known cognitive conditions such as Parkinson's disease, Alzheimer's disease, or intellectual disability; (4) combined with vestibular dysfunction, unilateral neglect, hemianopsia, or similar neurological symptoms; (5) metal implants, such as cardiac pacemakers, or vascular stents; (6) a history of spondylolisthesis, spinal surgery, or severe osteoporosis, (7) diagnosis of malignant tumors; and (8) limb conditions such as severe arthritis or amputation. A flow chart of the patient selection and inclusion/exclusion criteria is presented in Fig. 1.

2.3 Sample Size Calculation

The sample size was determined using the following formula: $n1 = n2 = 2 \times (Z_{1-\alpha}/2 + Z_{1-\beta})^2 \times \sigma^2/\Delta^2$, where $Z_{1-\alpha}/2 = 1.96$ ($\alpha = 0.05$), $Z_{1-\beta} = 0.84$ ($\beta = 0.2$, power = 80%), $\Delta = 10.24$, and $\sigma = 6.57$ [25]. The calculation yielded a required sample size of 38 patients per group. To account for a potential 20% attrition rate, the minimum sample size was adjusted to 46 patients per group ($38 \times 1.2 = 45.6$, rounded up). This study successfully met this requirement, with at least 46 cases included in each group.

2.4 Patient Treatment Protocol

Patients were divided into two groups based on their treatment regimen: those who underwent RFE alone were included in the RFE group (n = 51), while those who received RFE in combination with EMG biofeedback were assigned to the RFE+EMG group (n = 55). Both groups received routine medical care and rehabilitation, which included adjustment of electrolyte imbalance, dehydration therapy to reduce cranial pressure, stabilization of blood pressure and blood glucose levels, improvement of blood lipemia, improvement of cerebral circulation, nutritional support of cranial nerves, and routine physical rehabilitation training (such as roll-over training, sitting and standing exercises, unassisted walking, and stair-climbing exercises to enhance motor recovery). All patients received health education outlining the purpose and procedures of the treatment, with a focus on the importance of active participation and independent training for optimal recovery.

Patients in the RFE group were positioned in a seated posture during treatment sessions. The therapist implemented a facilitative technique to stimulate the target muscle groups. One hand was used to deliver rapid stretch reflexes to promote neural pathway excitability, while the other hand administered percussion or brushing stimuli directly to the target muscle group. Patient followed the ther-

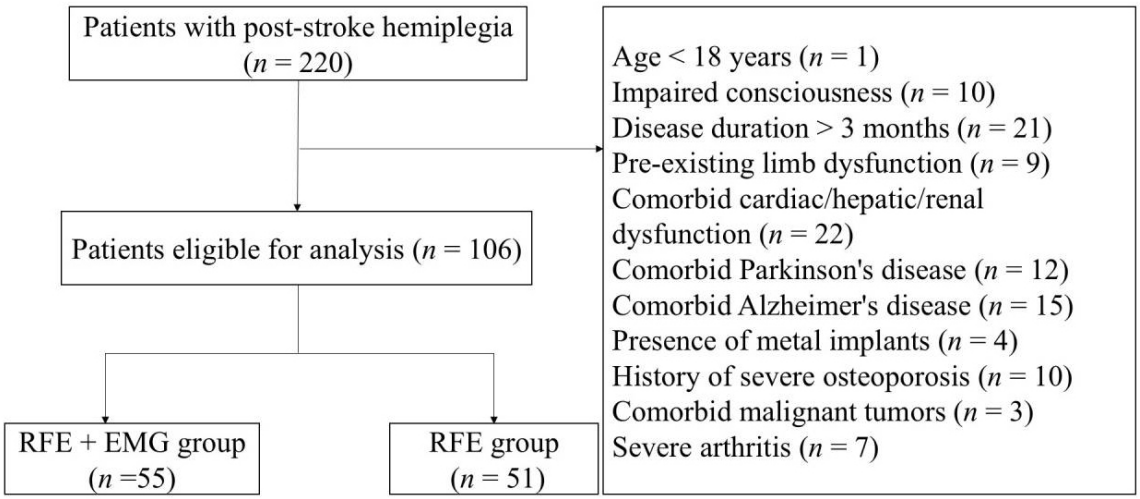


Fig. 1. A flowchart of patient inclusion and exclusion criteria. RFE, repetitive facilitative exercise; EMG, electromyography.

apist's verbal instructions to actively perform specific functional movements.

Target movements included upper limb, trunk, and lower limb exercises. The upper limb movements included shoulder and elbow flexion and extension, forearm pronation and supination, wrist dorsiflexion, finger flexion and extension, abduction, arch extension, and volar abduction of the thumb. Furthermore, trunk movement included rotation and lateral bending. Lower limb movement involved hip extension/abduction—flexion adduction, knee flexion/extension, seated lateral flexion, and ankle dorsiflexion.

Additionally, during training sessions, the patient was advised to focus on activating the target muscles while reducing compensatory or excessive contractions of non-target muscles. Each session involved selecting 4–6 groups of target movements every day, with each movement practised 50 to 100 times (divided into 2 sets with a short rest in the middle). The total training time was limited to $\leq$40 minutes per day, 6 days per week (Sunday as a rest day), over a treatment period of 4 weeks.

Patients in the RFE+EMG group (RFE combined with EMG biofeedback) received therapy using a myoelectric biofeedback instrument. Patients were seated in front of the monitor, the skin over the affected side (hemiplegic) was wiped with alcohol, and surface stimulation electrodes were applied sequentially to the hemiplegic side, starting with the upper limb (deltoid, wrist extensor, hand muscle), followed by the lower limb (anterior tibial muscle). After that, a ground electrode was placed between the two stimulation electrodes.

Furthermore, the device was set to either automatic or manual operation mode. Parameters included a square wave stimulation waveform at a frequency of 50 Hz, a pulse width of 200 µs, a stimulation time of 8 s, and an intermittent time of 10 s. The stimulation current intensity was adjusted based on the patient's tolerance and clinical situation.

During the treatment session, RFE was combined with closed-loop myoelectric training using the "stimulus-rest-strength-sustainment-relaxation" protocol. The instrument continuously monitored myoelectric signals, dynamically adjusting the output current. The signals were converted into auditory cues and displayed visually on the monitor, prompting the patient to follow the limb training to achieve functional positioning. The patient was asked to observe the EMG values on the screen and respond to the auditory prompt to facilitate active participation. The intensity of electrical stimulation was set according to the patient's tolerance levels. All treatment sessions were performed in a quiet, comfortable, and light-free treatment room. The treatment time and frequency were the same as the RFE group. Both groups received continuous treatment for a total duration of 12 weeks (three consecutive 4-week cycles).

2.5 Evaluation Indicators

Baseline characteristics were recorded for both groups. Outcome assessments included: limb motor function through Fugl-Meyer Assessment (FMA), balance ability through Berg Balance Scale (BBS), Timed Up and Go Test (TUGT), and 10-Meter Walk Test (10MWT), and quality of life using the Stroke Specific Quality of Life Scale (SS-QOL). All outcomes were evaluated at baseline and 12 weeks post-intervention. Adverse events occurring during the treatment period were systematically documented for both groups. To ensure assessment consistency and minimise bias, a single team of certified rehabilitation therapists (each with >3 years of clinical experience) conducted all measurements. The team received standardised training on assessment protocols and scoring criteria and remained blinded to group allocation throughout the study.

(1) Baseline Characteristics: baseline data, such as age, gender, education level, affected side, disease duration, and stroke type, were collected for all patients.

(2) Fugl-Meyer Assessment (FMA) [26]: this scale assesses motor function in both upper and lower limbs. The upper limb assessment includes the shoulder, elbow, forearm, wrist, hand, and coordination functions across 33 items. While the lower limb sections include 17 items, they evaluate reflex activity, coordinated extensor and flexor movement, isolated movement, hyperreflexia, coordination ability, and speed. Each item is scored on a 3-point scale, with 0 indicating an inability to perform the task, 1 indicating partially being able to perform the task, and 2 indicating being able to perform the task completely. The overall possible score is 100 points (66 for the upper limb, 34 for the lower limb), with higher scores indicating better motor function.

(3) Berg Balance Scale (BBS) [27]: this scale includes a total of 14 items assessing static and dynamic balance tasks, including sitting, standing, bed chair transferring, closed eye independent standing, bipedal independent standing, upper limb extension, picking up objects from the ground, turning from the shoulder to the back, turning at 360 degree, bipedal forward and backward standing, stepping, and single leg stance. Each item is scored from 0 to 4 (5-point scale), with a maximum score of 56. Higher scores indicate better balance performance.

(4) Timed Up and Go Test (TUGT): during this assessment, patients are allowed to use walking aids or assistive devices. The timer starts as the patient rises from the chair, turns around, walks 3 meters, returns, and sits down. The test is conducted 3 times, and the average score is recorded, with shorter times indicating better mobility.

(5) 10-Meter Walk Test (10MWT): the patients walk a distance of 15 meters at their fastest and most stable pace. The time taken from the 2nd to the 12th meter is documented using a stopwatch. The test is performed three times, and the average time is used for subsequent analysis.

(6) Stroke-Specific Quality of Life Scale (SS-QOL) [28]: this patient-reported measure assesses quality of life across 12 dimensions: energy, family roles, language, mobility, mood, personality, self-care, social roles, thinking, upper extremity function, vision, and work/productivity. It includes 49 items, each rated on a 5-point scale, yielding a total score of 49–245. Higher scores indicate a better quality of life.

(7) Adverse Reactions: during the treatment period, adverse events, such as severe muscle or joint pain, tendonitis, ligament sprain, dizziness, palpitations, skin rash, itching, or contact dermatitis, were monitored and compared between the two groups.

2.6 Quality Control

To ensure data quality, several quality control measures were implemented in this study. First, a structured and standardised data extraction protocol was used, involving dual independent data entry, cross-verification, and logical consistency checks to minimise errors. Second, study subjects were selected based on pre-defined strict inclusion and exclusion criteria, aimed at minimising selection bias. Furthermore, all assessment scales and methods applied were standardised and widely accepted in clinical practice, and the intervention protocols were described in detail to reduce potential bias due to inadequate procedural clarity. However, we acknowledge the inherent limitations associated with retrospective study design, and these are thoroughly addressed in the discussion section of the manuscript.

2.7 Statistical Analysis

Data were analysed using SPSS 21.0 software (International Business Machines Corporation, Armonk, NY, USA). Data were assessed for normality using the Kolmogorov-Smirnov test. Quantitative variables, such as age, disease duration, FMA score, BBS score, TUGT, 10MWT, and SS-QOL score, were found to follow a normal distribution and were presented as mean $\pm$ standard deviation (SD). Independent samples t-tests were used for between-group comparisons, while paired samples t-tests were employed for within-group comparisons. Categorical variables, including gender, education level, affected side, and stroke type, were presented as frequencies and percentages [n (%)] and compared using the Chi-squared test. A p-value less than 0.05 was considered statistically significant.

3. Results

3.1 Comparison of Baseline Characteristics Between the Two Groups

There were no significant differences between the RFE+EMG and RFE groups at baseline in terms of age, gender, education level, affected side, duration of disease, or stroke type ($p > 0.05$, Table 1).

3.2 Comparison of Limb Motor Function Between the Two Groups

There was no significant difference in FMA scores between the two groups before treatment ($p > 0.05$). However, after treatment, both groups demonstrated significant improvements in FMA scores compared to their baseline scores ($p < 0.05$). Notably, the RFE+EMG group exhibited significantly higher improvements in upper extremity, lower extremity, and total FMA scores compared to the RFE group after treatment ($p < 0.05$, Table 2).

3.3 Comparison of Balance Function Between the Two Groups

Prior to the intervention, no significant differences were observed between the two groups in BBS scores, TUGT, or 10MWT ($p > 0.05$). However, both groups demonstrated substantial improvements after treatment: the BBS score increased significantly ($p < 0.05$), while TUGT and 10MWT were significantly reduced ($p < 0.05$) com-

Table 1. Comparison of baseline characteristics between the two experimental groups.

Variable	RFE+EMG group (n = 55)	RFE group (n = 51)	χ^2/t	p-value
Age (mean ± SD, years old)	58.33 ± 7.09	58.63 ± 5.72	0.239	0.812
Gender [n (%)]			0.019	0.891
Male	32 (58.18)	29 (56.86)		
Female	23 (41.82)	22 (43.14)		
Education level [n (%)]			0.239	0.887
Junior high school and below	22 (40.00)	19 (37.25)		
High school/vocational school	18 (32.73)	19 (37.25)		
College degree or above	15 (27.27)	13 (25.49)		
Affected side [n (%)]			0.282	0.596
Left side	33 (60.00)	28 (54.90)		
Right side	22 (40.00)	23 (45.10)		
Duration of disease (mean ± SD, days)	52.04 ± 20.66	53.86 ± 24.12	0.420	0.676
Stroke type [n (%)]			0.004	0.947
Cerebral infarction	37 (67.27)	34 (66.67)		
Cerebral hemorrhage	18 (32.73)	17 (33.33)		

RFE, repetitive facilitative exercise; EMG, electromyography; SD, standard deviation.

Table 2. Comparison of FMA scores between the two groups before and after treatment ($\bar{x} \pm s$, points).

Experimental group	n	Upper extremity		Lower extremity		Total score	
		Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
RFE+EMG group	55	35.02 ± 4.50	48.49 ± 4.18*	18.13 ± 3.51	26.47 ± 3.14*	53.15 ± 5.85	74.96 ± 4.97*
RFE group	51	34.33 ± 4.74	44.18 ± 4.41*	17.45 ± 3.29	23.45 ± 3.34*	51.78 ± 5.47	67.63 ± 5.48*
t		0.763	5.169	1.020	4.801	1.235	7.227
p-value		0.447	<0.001	0.310	<0.001	0.220	<0.001

Notes: "*" indicated that a significant difference existed in the comparison of data before and after treatment in the same group ($p < 0.05$). FMA, Fugl-Meyer Assessment.

Table 3. Comparison of balance function between the two groups before and after treatment ($\bar{x} \pm s$).

Experimental group	n	BBS score (points)		TUGT (s)		10MWT (s)	
		Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
RFE+EMG group	55	27.80 ± 3.85	38.45 ± 4.21*	39.67 ± 3.66	31.49 ± 3.09*	40.49 ± 3.16	32.02 ± 3.45*
RFE group	51	26.51 ± 3.86	34.16 ± 4.01*	38.47 ± 3.04	33.10 ± 3.03*	40.08 ± 3.22	33.88 ± 3.38*
t		1.723	5.370	1.832	2.701	0.665	2.806
p-value		0.088	<0.001	0.070	0.008	0.508	0.006

Notes: "*" indicated that a significant difference existed in the comparison of data before and after treatment in the same group ($p < 0.05$). BBS, Berg Balance Scale; TUGT, Timed Up and Go Test; 10MWT, 10-Meter Walk Test.

pared to their respective pre-treatment values. Furthermore, after treatment, the RFE+EMG group exhibited significantly higher BBS scores ($p < 0.05$) and substantially shorter TUGT and 10MWT times compared to the RFE group after treatment ($p < 0.05$, Table 3).

3.4 Comparison of Quality of Life Between the Two Groups

Prior to the treatment, no significant difference was observed in SS-QOL scores between the two groups ($p > 0.05$). However, after treatment, both groups showed significant improvement in SS-QOL scores compared to their pre-treatment values ($p < 0.05$). Notably, following the intervention, the RFE+EMG group exhibited significantly higher scores in energy, family roles, language, mobility, mood, personality, self-care, social roles, thinking, upper extremity function, vision, and work/productivity scores compared to the RFE group ($p < 0.05$, Table 4).

3.5 Comparison of Safety Between the Two Groups

Interestingly, assessing the incidence of adverse events and safety of the procedure revealed that no severe adverse events were reported in either the RFE+EMG or RFE group throughout the treatment period.

Table 4. Comparison of SS-QOL scores between the two groups before and after treatment ($\bar{x} \pm s$, points).

Experimental group	n	Energy		Family roles		Language	
		Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
RFE+EMG group	55	8.36 ± 1.54	12.49 ± 1.65*	7.85 ± 1.41	12.15 ± 1.75*	14.89 ± 2.96	19.89 ± 2.53*
RFE group	51	8.04 ± 1.51	10.69 ± 1.63*	8.31 ± 1.49	10.76 ± 1.48*	15.39 ± 3.30	18.69 ± 2.44*
t		1.093	5.650	–1.632	4.376	–0.824	2.493
p-value		0.277	<0.001	0.106	<0.001	0.412	0.014
Experimental group	n	Mobility		Mood		Personality	
		Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
RFE+EMG group	55	18.18 ± 3.54	22.42 ± 2.39*	15.35 ± 2.98	19.85 ± 2.81*	7.93 ± 1.30	12.62 ± 1.81*
RFE group	51	18.43 ± 3.23	21.29 ± 2.71*	15.96 ± 3.38	18.59 ± 2.70*	7.98 ± 1.48	10.84 ± 1.69*
t		–0.378	2.268	–0.997	2.362	–0.197	5.208
p-value		0.706	0.025	0.321	0.020	0.844	<0.001
Experimental group	n	Self-care		Social roles		Thinking	
		Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
RFE+EMG group	55	14.33 ± 3.28	19.76 ± 2.49*	14.60 ± 3.38	20.20 ± 2.56*	8.29 ± 1.56	12.69 ± 1.84*
RFE group	51	15.16 ± 2.96	18.51 ± 2.39*	15.02 ± 3.20	18.25 ± 2.51*	7.84 ± 1.38	10.88 ± 1.66*
t		–1.365	2.636	–0.655	3.941	1.562	5.295
p-value		0.175	0.010	0.514	<0.001	0.121	<0.001
Experimental group	n	Upper extremity function		Vision		Work/Productivity	
		Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
RFE+EMG group	55	14.64 ± 2.86	20.20 ± 2.61*	8.33 ± 1.40	12.38 ± 1.76*	7.96 ± 1.49	12.47 ± 1.50*
RFE group	51	15.51 ± 3.38	18.78 ± 2.64*	8.04 ± 1.36	11.04 ± 1.41*	8.24 ± 1.48	11.22 ± 1.39*
t		–1.441	2.777	1.074	4.311	–0.942	4.463
p-value		0.153	0.007	0.285	<0.001	0.349	<0.001

Notes: "*" indicated that a significant difference existed in the comparison of data before and after treatment in the same group ($p < 0.05$). SS-QOL, Stroke Specific Quality of Life Scale.

4. Discussion

In this study, we retrospectively analysed 106 patients with post-stroke hemiplegia, dividing them into the RFE group (receiving RFE treatment alone) and the RFE+EMG group (receiving RFE combined with EMG biofeedback treatment) based on treatment methods. After 12 weeks of treatment, the RFE+EMG group showed substantially greater improvements in FMA scores, BBS scores, TUGT, 10MWT, and SS-QOL scores compared to the RFE group. These observations suggest that combining RFE with EMG biofeedback treatment further enhances motor function, balance mobility, and overall quality of life in patients with post-stroke hemiplegia, without increasing the risk of adverse events.

RFE combines multiple sensory stimuli with repeated, task-specific, and guided exercises, in which rehabilitation therapists assist patients in performing targeted motor tasks. In our study, both groups of patients showed significant improvement in functional outcomes after treatment, which can be attributed to the inherent plasticity of the brain. When brain tissue is damaged, the brain attempts to reroute neural signals through alternative conduction pathways. Repeated facilitative training and motor learning can activate and strengthen these nerve conduction pathways, leading to the reconstruction of new neural circuits. This mechanism improves limb motor function, balance of movement ability, and overall mobility on the affected side, ultimately improving the quality of life.

These observations are consistent with previous studies. For example, a study by Harris [29] revealed that RFE significantly enhanced upper limb function in patients with subacute stroke. Similarly, Etoh et al. [30] also suggested that RFE may promote upper limb functional recovery by reducing the excitability of spinal motor neurons.

Unlike these previous studies, which primarily investigated RFE intervention targeting only upper limb function, our study explored the combined effect of RFE and EMG biofeedback. Furthermore, our evaluation included both upper and lower limb motor function, balance ability, and quality of life, providing a more robust assessment of functional recovery.

EMG biofeedback is a behavioural therapy that has gradually emerged in recent years. Using visual and auditory feedback signals enables patients to self-monitor and adjust their motor responses, emphasising patients' active participation. This approach has demonstrated significant therapeutic efficacy in treating various diseases, including post-stroke hemiplegia [31,32]. Yan et al. [33] reported that

EMG biofeedback contributes to promoting limb function and daily living activities in patients with post-stroke motor dysfunction. Similarly, Feng et al. [34] recommended combining EMG biofeedback with traditional rehabilitation as an optimal approach for improving limb motor recovery and relieving post-stroke pain.

In our study, patients in the RFE+EMG group received a combination of RFE and EMG biofeedback treatment. We observed superior improvements across various functional indicators in the RFE+EMG group compared to RFE alone, suggesting that EMG biofeedback may further improve treatment outcomes. The speculated mechanism is that EMG biofeedback offers effective sensory input through surface stimulation of the affected skin, which, when combined with RFE and the patient's voluntary joint movements, provides continuous proprioceptive feedback. These sensory signals are transmitted to the central nervous system, inducing functional reorganisation within the motor cortex and promoting the generation of patterned voluntary movements, thereby enhancing functional recovery.

Given this speculation, Hoei et al. [35] team used a combination of RFE and neuromuscular electrical stimulation in patients with pure motor isolated hand palsy (PMIHP) and reported accelerated motor and improved hand function. Similarly, Fujimoto et al. [36] observed that the combination of continuous neuromuscular electrical stimulation and RFE significantly promoted upper limb motor function and enhanced patient satisfaction in post-stroke hemiplegia. Furthermore, Kutsuwa and Harada [37] highlighted the application of RFE combined with electrical stimulation in alleviating radiation-induced functional decline in patients with oropharyngeal cancer undergoing postoperative radiotherapy. Although these studies underscore the advantages of combining RFE with electrical stimulation approaches, they are generally restricted by relatively small sample sizes and lack specific investigation on their combination with EMG biofeedback therapy. This study addresses this gap, providing valuable insights that the combination of RFE and EMG biofeedback is a promising strategy for improving limb motor recovery in patients with post-stroke hemiplegia.

Additionally, no serious adverse reactions were observed in both groups throughout the intervention period, indicating that the combination of RFE and EMG biofeedback is not only effective but also safe, well-tolerated, and clinically applicable, demonstrating potential for practical implementation in rehabilitation settings.

Despite the promising outcomes, we acknowledge several limitations in this study. (1) This study used several internationally recognised assessment scales, including the FMA, BBS, and SS-QOL, as primary outcome measures. Although these scales are widely used in clinical rehabilitation and have established reliability and validity, they are inherently subjective assessment tools. Patient responses may be influenced by transient factors such as environmental conditions or emotional state at the time of assessment, potentially introducing bias. Future studies should include more objective indicators, such as serological or neurophysiological biomarkers, to enhance the precision of outcome assessments. (2) This study was based on a retrospective analysis of 106 hospitalised patients from a single rehabilitation department, restricting the generalizability of the findings. As a single-center study with a small sample size, the statistical power and external validity are also limited. Future investigations should include a larger sample size and a multicenter study design to enhance the applicability of the findings. (3) Although baseline characteristics showed no statistically significant differences between the two groups, the lack of multivariate statistical analysis to systematically adjust for potential confounding variables limits the strength of causal inferences. Without adjusting for these confounders, attributing the observed inter-group differences in treatment outcomes solely to the intervention may be premature.

However, the combination therapy group (RFE+EMG) demonstrated clinically significant improvements across multiple key functional domains with a favourable safety profile. These findings provide valuable evidence supporting the therapeutic potential of integrating RFE with EMG biofeedback. To establish a stronger causal association and validate clinical efficacy, well-designed prospective randomised controlled trials are required.

5. Conclusion

The combination of RFE and EMG biofeedback showed promising effects in promoting limb functional recovery, improving balance, and enhancing quality of life in patients with post-stroke hemiplegia, while also demonstrating a favourable safety profile. However, the underlying mechanisms of the synergistic effects of this combined treatment warrant further exploration. Further investigation and validation of this combined approach through rigorous clinical trials are required to support its broader implementations in rehabilitation practice.

Key Points

- RFE combined with EMG biofeedback therapy is beneficial for promoting limb function recovery in patients with post-stroke hemiplegia.
- RFE combined with EMG biofeedback therapy can effectively improve balance ability in post-stroke hemiplegic patients.
- RFE combined with EMG biofeedback therapy enhances the quality of life in patients with post-stroke hemiplegia.
- RFE combined with EMG biofeedback therapy does not increase the risk of adverse reactions in post-stroke hemiplegic patients.

Availability of Data and Materials

All data included in this study are available from the corresponding author upon reasonable request.

Author Contributions

BH and DJC designed the research study and wrote the first draft. BH and DJC performed the research. BH and DJC analysed the data. Both authors contributed to the important editorial changes in the manuscript. Both authors read and approved the final manuscript. Both authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study complies with the principles and ethical requirements of the World Medical Association Declaration of Helsinki, and has been approved by the Ethics Committee of The Second Affiliated Hospital of Qiqihar Medical University (No.2021-117). This study protects patients' personal information, with all questionnaires administered after obtaining written informed consent.

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Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Saini V, Guada L, Yavagal DR. Global Epidemiology of Stroke and Access to Acute Ischemic Stroke Interventions. Neurology. 2021; 97: S6–S16. https://doi.org/10.1212/WNL.0000000000012781

[2] Pohl M, Hesszenberger D, Kapus K, Meszaros J, Feher A, Varadi I, et al. Ischemic stroke mimics: A comprehensive review. Journal of Clinical Neuroscience. 2021; 93: 174–182. https://doi.org/10.1016/j.jocn.2021.09.025

[3] Murala S, Nagarajan E, Bollu PC. Infectious Causes of Stroke. Journal of Stroke and Cerebrovascular Diseases. 2022; 31: 106274. https://doi.org/10.1016/j.jstrokecerebrovasdis.2021.106274

[4] Tu WJ, Wang LD. China stroke surveillance report 2021. Military Medical Research. 2023; 10: 33. https://doi.org/10.1186/s40779-023-00463-x

[5] Markus HS, Leung T. Stroke in China. International Journal of Stroke. 2023; 18: 256–258. https://doi.org/10.1177/17474930231157479

[6] Zhang D, Zou W, Zhang B, Guo P. Scalp acupuncture for post-stroke spastic hemiparesis: A systematic review and meta-analysis. Medicine. 2024; 103: e37167. https://doi.org/10.1097/MD.0000000000037167

[7] Selves C, Stoquart G, Lejeune T. Gait rehabilitation after stroke: review of the evidence of predictors, clinical outcomes and timing for interventions. Acta Neurologica Belgica. 2020; 120: 783–790. https://doi.org/10.1007/s13760-020-01320-7

[8] Broderick P, Horgan F, Blake C, Ehrensberger M, Simpson D, Monaghan K. Mirror therapy for improving lower limb motor function and mobility after stroke: A systematic review and meta-analysis. Gait & Posture. 2018; 63: 208–220. https://doi.org/10.1016/j.gaitpost.2018.05.017

[9] Chien WT, Chong YY, Tse MK, Chien CW, Cheng HY. Robot-assisted therapy for upper-limb rehabilitation in subacute stroke patients: A systematic review and meta-analysis. Brain and Behavior. 2020; 10: e01742. https://doi.org/10.1002/brb3.1742

[10] Jesuthasan A, Maung M, Ajina S, Warburton E. Rehabilitation Guidelines in Stroke. British Journal of Hospital Medicine. 2025; 86: 1–23. https://doi.org/10.12968/hmed.2024.1040

[11] Liu T, Luo K, Zhou K, Hu Z, Ji Y, Feng W, et al. Analysis of electroencephalography characteristics during walking in stroke patients under different conditions: a cross-sectional study. British Journal of Hospital Medicine. 2024; 85: 1–11. https://doi.org/10.12968/hmed.2024.0237

[12] Kawahira K, Shimodozono M, Etoh S, Kamada K, Noma T, Tanaka N. Effects of intensive repetition of a new facilitation technique on motor functional recovery of the hemiplegic upper limb and hand. Brain Injury. 2010; 24: 1202–1213. https://doi.org/10.3109/02699052.2010.506855

[13] Zhang JZ, Chen J, Liu XL, Yan LB, Xu SM. Effectiveness of intelligent robotic-assisted training system combined with repetitive facilitative exercise on upper limb motor function after stroke: a randomized controlled trial. BMC Sports Science, Medicine & Rehabilitation. 2025; 17: 178. https://doi.org/10.1186/s13102-025-01234-y

[14] Ohnishi H, Miyasaka H, Shindo N, Ito K, Tsuji S, Sonoda S. Effectiveness of Repetitive Facilitative Exercise Combined with Electrical Stimulation Therapy to Improve Very Severe Paretic Upper Limbs in with Stroke Patients: A Randomized Controlled Trial. Occupational Therapy International. 2022; 2022: 4847363. https://doi.org/10.1155/2022/4847363

[15] Yassin MM, Saad MN, Khalifa AM, Said AM. Advancing clinical understanding of surface electromyography biofeedback: bridging research, teaching, and commercial applications. Expert Review of Medical Devices. 2024; 21: 709–726. https://doi.org/10.1080/17434440.2024.2376699

[16] Giggins OM, Persson UM, Caulfield B. Biofeedback in rehabilitation. Journal of Neuroengineering and Rehabilitation. 2013; 10: 60. https://doi.org/10.1186/1743-0003-10-60

[17] Piernicka M, Ossowski Z, Kortas J, Bojar D, Labun J, Szumilewicz A. Can We Improve the Technique of Pelvic Floor Muscle Exercises in Postmenopausal Women Using a Single Electromyography Biofeedback Session? An Experimental Study. Journal of Clinical Medicine. 2024; 13: 3062. https://doi.org/10.3390/jcm13113062

[18] Archer SK, Smith CH, Newham DJ. Surface Electromyographic Biofeedback and the Effortful Swallow Exercise for Stroke-Related Dysphagia and in Healthy Ageing. Dysphagia. 2021; 36: 281–292. https://doi.org/10.1007/s00455-020-10129-8

[19] Martín Prieto L, Pascual Migueláñez I, Fernández Cebrián JM, Martínez Puente MC, Varillas-Delgado D, Fernández Rodríguez M, et al. Targeted Electromyographic Biofeedback With Endoanal Electrostimulation for Anal Incontinence. Surgical Innovation. 2023; 30: 56–63. https://doi.org/10.1177/15533506221096885

[20] Wagner B, Steiner M, Huber DFX, Crevenna R. The effect of biofeedback interventions on pain, overall symptoms, quality of life and physiological parameters in patients with pelvic pain: A systematic review. Wiener Klinische Wochenschrift. 2022; 134: 11–48. https://doi.org/10.1007/s00508-021-01827-w

[21] Wang R, Zhang S, Zhang J, Tong Q, Ye X, Wang K, et al. Electromyographic biofeedback therapy for improving limb func-

tion after stroke: A systematic review and meta-analysis. PLoS One. 2024; 19: e0289572. https://doi.org/10.1371/journal.pone.0289572

[22] Rayegani SM, Raeissadat SA, Sedighipour L, Mohammad Rezazadeh I, Bahrami MH, Eliaspour D, et al. Effect of neurofeedback and electromyographic-biofeedback therapy on improving hand function in stroke patients. Topics in Stroke Rehabilitation. 2014; 21: 137–151. https://doi.org/10.1310/tsr2102-137

[23] Lirio-Romero C, Torres-Lacomba M, Gómez-Blanco A, Acero-Cortés A, Retana-Garrido A, de la Villa-Polo P, et al. Electromyographic biofeedback improves upper extremity function: a randomized, single-blinded, controlled trial. Physiotherapy. 2021; 110: 54–62. https://doi.org/10.1016/j.physio.2020.02.002

[24] Sacco RL, Kasner SE, Broderick JP, Caplan LR, Connors JJ, Culebras A, et al. An updated definition of stroke for the 21st century: a statement for healthcare professionals from the American Heart Association/American Stroke Association. Stroke. 2013; 44: 2064–2089. https://doi.org/10.1161/STR.0b013e318296aeca

[25] Duc Nguyen M, Van Tran T, Vinh Nguyen Q, Khac Nguyen N, Truong Vu S, Trong Nguyen L, et al. Effectiveness on post-stroke hemiplegia in patients: electroacupuncture plus cycling electroacupuncture alone. Journal of Traditional Chinese Medicine. 2023; 43: 352–358. https://doi.org/10.19852/j.cnki.jtcm.2023.02.006

[26] Fugl-Meyer AR, Jääskö L, Leyman I, Olsson S, Steglind S. The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. Scandinavian Journal of Rehabilitation Medicine. 1975; 7: 13–31.

[27] Berg KO, Wood-Dauphinee SL, Williams JI, Maki B. Measuring balance in the elderly: validation of an instrument. Canadian Journal of Public Health. 1992; 83: S7–S11.

[28] Williams LS, Weinberger M, Harris LE, Clark DO, Biller J. Development of a stroke-specific quality of life scale. Stroke. 1999; 30: 1362–1369. https://doi.org/10.1161/01.str.30.7.1362

[29] Harris JE. Repetitive facilitative exercise improves upper limb function in patients with subacute stroke. Journal of Physiotherapy. 2013; 59: 208. https://doi.org/10.1016/S1836-9553(13)70186-3

[30] Etoh S, Noma T, Miyata R, Shimodozono M. Effects of Repetitive Facilitative Exercise on Spasticity in the Upper Paretic Limb After Subacute Stroke. Journal of Stroke and Cerebrovascular Diseases. 2018; 27: 2863–2868. https://doi.org/10.1016/j.jstrokecerebrovasdis.2018.06.013

[31] Woodford H, Price C. EMG biofeedback for the recovery of motor function after stroke. Cochrane Database of Systematic Reviews. 2007; 2007: CD004585. https://doi.org/10.1002/14651858.CD004585.pub2

[32] Basmajian JV. Research foundations of EMG biofeedback in rehabilitation. Biofeedback and Self-regulation. 1988; 13: 275–298. https://doi.org/10.1007/BF00999085

[33] Yan F, Wu K, Wan Q, Zhang M, Zhang Y, Li N, et al. Assessing the effectiveness of biofeedback therapy in the rehabilitation of limb motor dysfunction after stroke and the influencing factors of disease-related shame. American Journal of Translational Research. 2023; 15: 6786–6796.

[34] Feng S, Tang M, Huang G, Wang J, He S, Liu D, et al. EMG biofeedback combined with rehabilitation training may be the best physical therapy for improving upper limb motor function and relieving pain in patients with the post-stroke shoulder-hand syndrome: A Bayesian network meta-analysis. Frontiers in Neurology. 2023; 13: 1056156. https://doi.org/10.3389/fneur.2022.1056156

[35] Hoei T, Kawahira K, Shimodozono M, Fukuda H, Shigenobu K, Ogura T, et al. Repetitive facilitative exercise under continuous electrical stimulation for recovery of pure motor isolated hand palsy after infarction of the “hand knob” area: A case report. Physiotherapy Theory and Practice. 2023; 39: 1545–1552. https://doi.org/10.1080/09593985.2022.2042633

[36] Fujimoto K, Ueno M, Etoh S, Shimodozono M. Combined repetitive facilitative exercise under continuous neuromuscular electrical stimulation and task-oriented training for hemiplegic upper extremity during convalescent phase after stroke: before-and-after feasibility trial. Frontiers in Neurology. 2024; 15: 1356732. https://doi.org/10.3389/fneur.2024.1356732

[37] Kutsuwa M, Harada H. A Patient with Oropharyngeal Cancer Who Developed Trapezius and Sternocleidomastoid Paralysis after Neck Dissection Showed Improvement by Applying Repetitive Facilitative Exercise with Electrical Stimulation-A Case Report. Gan To Kagaku Ryoho. Cancer & Chemotherapy. 2020; 47: 1481–1484.