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Original Article

Effects of contralateral controlled functional electrical stimulation combined with mirror therapy on motor recovery and negative mood in stroke patients

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Abstract: Objective: To investigate the effect of contralateral controlled functional electrical stimulation (CCFES) combined with mirror therapy on motor function and negative mood in stroke patients. Methods: Medical records of 94 stroke patients in Baoji Central Hospital admitted from April 2020 to October 2022 were retrospectively analyzed. Among them, 45 patients receiving routine rehabilitation training combined with mirror therapy were included in a control group, and 49 patients receiving CCFES combined with mirror therapy were in an observation group. Observation indexes included changes in Fugl-Meyer Assessment (FMA), Berg Balance Scale (BBS), Hamilton Anxiety Rating Scale (HAMA), Hamilton Depression Rating Scale (HAMD), Stroke Specific Quality of Life Scale (SS-QoL) score, and Barthel Index score before and after treatment. Patients with HAMA score >14 and HAMD score ≥20 after the treatment were included in a negative mood group, and logistics regression was used to analyze the risk factors for negative mood. Results: The observation group had a significantly higher overall response rate after treatment compared to the control group. In addition, the observation group exhibited significantly higher scores in the FMA and BBS after treatment, indicating better physical function ($P<0.001$). Furthermore, the observation group showed lower HAMA and HAMD scores after treatment, suggesting reduced anxiety and depression levels ($P<0.001$). The quality-of-life scores measured by the SS-QoL and the Barthel Index score were both increased in the observation group after treatment, indicating better overall well-being and functional independence ($P<0.001$). Logistic regression analysis revealed that age, post-treatment SS-QoL scores, and post-treatment Barthel Index were identified as influencing factors for the onset of adverse emotions in patients ($P<0.05$). Conclusion: CCFES plus mirror therapy can effectively ameliorate limb function and lessen anxiety and depression in stroke patients, exerting beneficial effects on rehabilitation.

Keywords: Contralateral controlled functional electrical stimulation, mirror therapy, stroke, limb function, negative emotions

Introduction

Stroke has emerged as a significant public health concern, posing a threat to human well-being. It is a leading cause of long-term disability worldwide, particularly in low- and middle-income countries [1]. In China, the incidence of stroke is on the rise, with an annual increase rate of 8.7%, and the age at which it occurs is decreasing [2]. According to the *2019 China Health and Wellness Statistics Summary*, cerebrovascular diseases account for over 20% of deaths among both urban and rural residents, implying that at least one in five deaths results from stroke [3]. Furthermore, out of the approximately 2 million new stroke cases reported each year, 75% of survivors experience various degrees of functional impairments, including motor dysfunction, sensory abnormalities, unilateral neglect, speech impairment, pain, and anxiety-depression. Motor dysfunction, in particular, is highly prevalent and significantly diminishes the quality of life and confidence of rehabilitation in patients [4, 5].

Even after undergoing standard rehabilitation and varying degrees of natural recovery, studies have shown that 30%-50% of stroke patients still experience walking impairments within 3 months post-stroke [6, 7]. Therefore, it is crucial to focus on early recovery of balance and walking ability, as these factors play a significant role in stroke patients' ability to perform independent daily activities. This aspect is considered top priority in most patients' rehabilitation needs [8]. Post-stroke disability not only has an irreversible prognosis and imposes immense psychological burden on the patients, but it also creates significant economic pressure on families and society. This can lead to the development of mental and psychological disorders in patients [5]. Statistics indicate that over 33% of stroke patients experience mental and psychological disorders, with over 25% experiencing anxiety and 35% to 65% suffering from depression [9, 10]. Hence, it is crucial to pay timely attention to the rehabilitation status of post-stroke patients and provide them with systematic and targeted rehabilitation treatment plans. This approach can help them reintegrate into normal life and society, improving their overall quality of life.

There are various clinical lower limb rehabilitation training methods available, such as weight-reduced gait and virtual reality technology. However, these methods can impose significant financial burdens, leading many patients to discontinue their use due to high costs. Therefore, it is important to choose an effective and economical rehabilitation approach for stroke patients [11]. One such method is mirror therapy, which is a simple adjunctive treatment for motor impairments after a stroke [12]. Another method is contralateral controlled functional electrical stimulation (CCFES), which involves using the movement of the healthy upper limb to control a functional electrical stimulation device. This device stimulates the muscles of the affected upper limb, aiming to achieve therapeutic goals [13]. In a meta-analysis conducted by Saavedra et al. [14], it was found that there is a lack of direct scientific evidence supporting the effectiveness of combining mirror therapy with electrical stimulation in improving upper limb motor function after a stroke. Therefore, further high-quality and well-designed research is needed.

This study analyzed the impact of CCFES combined with mirror therapy on the motor function and negative emotions of stroke patients, aiming at providing a reference for the selection of clinical rehabilitation plans.

Methods and materials

Ethics statement

This study was approved by the Medical Ethics Committee of Baoji Central Hospital (BZYL2021-14).

Sample source

In this study, we retrospectively analyzed the medical records of 134 stroke patients in Baoji Central Hospital admitted from April 2020 to October 2022.

Inclusion and exclusion criteria

Inclusion criteria: patients who had their first onset, met the diagnostic criteria for stroke [3], and confirmed by cranial CT or MRI; patients with unilateral onset, duration within 3 weeks of study; patients with lower limb dysfunction resulting from the stroke; patients who were conscious with stable vital signs; patients without obvious cognitive impairments; patients with complete clinical data available.

Exclusion criteria: patients with speech and cognitive impairments, unable to cooperate with treatment; patients with severe heart, lung, liver, or other organ diseases; patients with movement impairments due to other reasons; patients with cardiac pacemaker and conditions like skin damage that affect treatment; patients with malignant tumors.

Sample selection

A total of 134 patients were screened based on the inclusion and exclusion criteria, and 94 cases met the criteria. Of these, 45 patients who received routine rehabilitation training combined with mirror therapy were included in a control group, while the other 49 patients who underwent CCFES combined with mirror therapy were in an observation group.

Treatment plan

All patients received standard treatment (including thrombolysis intervention, antiplatelet therapy, lipid-lowering, plaque stabilization, etc.). After the patient's condition stabilized, rehabilitation training was carried out.

The study utilized mirror therapy, employing a professional mirror box to focus on the lower limbs of the patients. The patients were instructed to synchronize the movement of both feet with what they observed in the mirror, while actively moving the affected limb. This visual feedback from the mirror created an illusion of controlling both legs in the brain. The training sessions consisted of various movement tasks tailored to each patient's specific condition, such as knee joint flexion/extension, straight leg raises, deep squats, and ankle rotations. Each session lasted for 20-30 minutes and was conducted once a day, six days a week, with one rest day. The training program was carried out for a duration of four weeks.

Additional CCFES was employed in the observation group. The device's prescription included an output current frequency of 60 Hz, intensity ranging from 0 to 60 μA, pulse width of 200 μs, and a wave rise/fall ratio of 1 s/1 s. Electrodes were placed on the motor point of the target muscles on the affected side. The EMG values of the healthy side were initially calibrated using a three-point method, and the required current intensity for the affected side to generate a movement of the same amplitude as the healthy side was recorded. When the healthy side moved, the machine would automatically stimulate the target muscles on the affected side to contract. The strength of stimulation was proportional to the activity strength of the healthy side and was entirely triggered by the patient's healthy side. During functional movements of the patient's healthy hand, if the EMG value reached the level recorded during calibration, the set current would be applied to the affected upper limb, causing the target muscle to contract to the same extent as the healthy side. Each session lasted for 30 minutes and was conducted once a day, five days a week, for a total of four weeks.

Functional scoring

The Fugl-Meyer Assessment (FMA) is a tool used to evaluate motor function impairments. It has a maximum score of 34 points, with a higher score indicating better motor abilities of the tested limb [15]. The Berg Balance Scale (BBS) assesses balance capability through 14 daily life actions, such as standing, turning, and shifting. Each action has a detailed scoring criterion, ranging from 0 to 4 points. The total score ranges from 0 to 56 points, with a higher score indicating better balance capability [16]. The Hamilton Anxiety Rating Scale (HAMA) evaluates the severity of anxiety symptoms and consists of 14 items, including anxiety emotions, tension, fear, cognitive disturbances, palpitations, physiological symptoms, etc. Each item is scored from 0 to 4 points, resulting in a total score range of 0 to 56 points. A higher score indicates more severe anxiety symptoms, and a score of 14 suggests the presence of anxiety symptoms [17]. The Hamilton Depression Rating Scale (HAMD) assesses the severity of depressive symptoms using 17 items, such as mood, cognition, psychomotor retardation, sleep, and psychotic symptoms. Each item is scored between 0 and 4 points, with a total score range of 0 to 54 points. A higher score indicates more severe depression, and a score of 20 and above generally suggests the presence of depression [18]. The Stroke Specific Quality of Life Scale (SS-QoL) evaluates post-stroke quality of life across 12 domains with a total of 49 questions covering physical function, role function, mood, language communication, cognition, etc. Each question has five answer options, scored from 1 to 5 points. The total score ranges from 49 to 245 points, with a higher score indicating a better quality of life [19]. The Modified Barthel Index assesses a patient's daily living capability, with a perfect score being 100 points. A higher score indicates stronger self-care ability [20].

Clinical data collection

Patients' clinical data were collected through electronic medical records and outpatient review records. This included demographic information such as age, gender, body mass index (BMI), duration of illness, educational level, monthly household income, as well as details about the stroke including type, affected side, and history of hypertension, diabetes, smoking, and alcohol abuse. Functional scores, including FMA, BBS, HAMA, HAMD, SS-QOL, and Barthel Index, were also collected. The functional scores were measured before treatment and 4 weeks after treatment.

Observation indicators

The primary observation indicators focused on comparing the changes in FMA, BBS, HAMA, and HAMD scores before and after treatment.

Patients with HAMA scores above 14 and HAMD scores of 20 and above were included into a negative emotion group based on their post-treatment scores. Logistic regression was used to analyze the risk factors associated with negative emotions in the patients. The secondary observation indicators involved comparing the clinical data of both patient groups, as well as comparing the SS-QoL scores and Barthel Index changes in patients before and after treatment.

Statistical analysis

SPSS 26.0 statistical software was used for data analysis. Quantitative data were expressed as mean ± standard deviation (Mean ± Sd). Paired t-tests were used for within-group comparisons, while independent sample t-tests were used for between-group comparisons. Count data were presented as percentages or ratios (%) and were assessed using the Chi-square test. Logistic regression was used to analyze the risk factors influencing the patient's negative emotions. A *P*-value <0.05 was considered statistically significant.

Results

Comparison of clinical data

Comparison of clinical data between the two groups of patients showed no statistically significant differences in age, gender, BMI, disease duration, education level, monthly household income, type of stroke, affected side, history of hypertension, history of diabetes, smoking history, and history of alcohol consumption (P>0.05, **Table 1**).

Comparison of patients' motor function and balance

The FMA and BBS scores were compared before and after treatment in both groups of patients. There were no statistically significant differences in the pre-treatment FMA and BBS scores between the two groups (P>0.05, **Figure 1**). Both groups demonstrated significant improvements in their post-treatment FMA and BBS scores compared to their pre-treatment scores (P<0.0001, **Figure 1**). Additionally, the observation group exhibited significantly higher post-treatment FMA and BBS scores compared to the control group (P<0.0001, **Figure 1**).

Comparison of patients' anxiety and depression scores

The HAMA and HAMD scores were compared before and after treatment in both groups of patients. There were no statistically significant differences in the pre-treatment HAMA and HAMD scores between the two groups (P>0.05, **Figure 2**). Both groups exhibited significant reductions in their post-treatment HAMA and HAMD scores compared to their pre-treatment scores (P<0.0001, **Figure 2**). Additionally, the post-treatment HAMA and HAMD scores in the observation group were significantly lower than those in the control group (P<0.0001, **Figure 2**).

Comparison of patients' quality of life scores

The study compared the SS-QoL and Barthel Index scores before and after treatment in both groups of patients. There were no statistically significant differences in the pre-treatment SS-QoL and Barthel Index scores between the two groups (P>0.05, **Figure 3**). However, both groups showed significant improvements in their post-treatment SS-QoL and Barthel Index scores compared to their pre-treatment scores (P<0.0001, **Figure 3**). Additionally, the post-treatment SS-QoL and Barthel Index scores in the observation group were significantly higher than those in the control group (P<0.0001, **Figure 3**).

Analysis of risk factors associated with negative emotions

Statistical analysis was conducted on negative emotions in a sample of 94 patients. Among them, 33 patients had HAMA score higher than 14 after treatment, while 36 patients had HAMD score equal to or greater than 20. The analysis revealed that 33 patients belonged to the negative emotion group, while 61 patients were classified as emotionally stable. Subsequently, a comparison was made between the clinical data of these two patient groups. The results indicated that age, annual income, treatment plan, post-treatment SS-QoL scores, and post-treatment Barthel Index were significantly lower in the negative emotion group compared to the emotionally stable group (P<0.05, **Table 2**). Furthermore, significant indicators from the univariate analysis were assigned values (**Table 3**). Multivariate logistic

Table 1. Comparison of clinical data

Factors	Control Group (n = 45)	Observation Group (n = 49)	χ^2 Value	*P*-value
Age			0.310	0.577
≥60 years old	25	30		
<60 years old	20	19		
Gender			0.126	0.722
Male	25	29		
Female	20	20		
BMI			0.204	0.651
≥25 kg/m^2	11	14		
<25 kg/m^2	34	35		
Disease Duration			0.431	0.618
≥10 days	22	20		
<10 days	23	29		
Education Level			0.729	0.393
≥ Junior High School	26	24		
< Junior High School	19	25		
Monthly Household Income			0.007	0.935
≥5000 yuan	18	20		
<5000 yuan	27	29		
Stroke Type			0.126	0.722
Hemorrhagic	20	20		
Ischemic	25	29		
Affected Side			1.664	0.197
Left	17	25		
Right	28	24		
History of Hypertension			0.717	0.131
Yes	7	9		
No	38	40		
History of Diabetes			0.645	0.212
Yes	5	7		
No	40	42		
Smoking History			0.362	0.546
Yes	23	22		
No	22	27		
History of Alcohol Consumption			0.046	0.828
Yes	4	5		
No	41	44		

Note: BMI, Body mass index.

regression analysis demonstrated that age, post-treatment SS-QoL scores, and post-treatment Barthel Index were risk factors influencing the occurrence of negative emotions in patients (P<0.05, **Table 4**).

Discussion

Stroke is a debilitating brain injury that often results in damage to the cortical motor areas. It also leads to increased reverse inhibition from the healthy cortex to the affected one, as the callosal inhibition from the affected side to the healthy side is removed. This disruption of balanced inhibition between the two cerebral cortices can have a significant impact. Selecting appropriate rehabilitation treatments can greatly enhance limb function impairments and accelerate the rehabilitation process [21, 22].

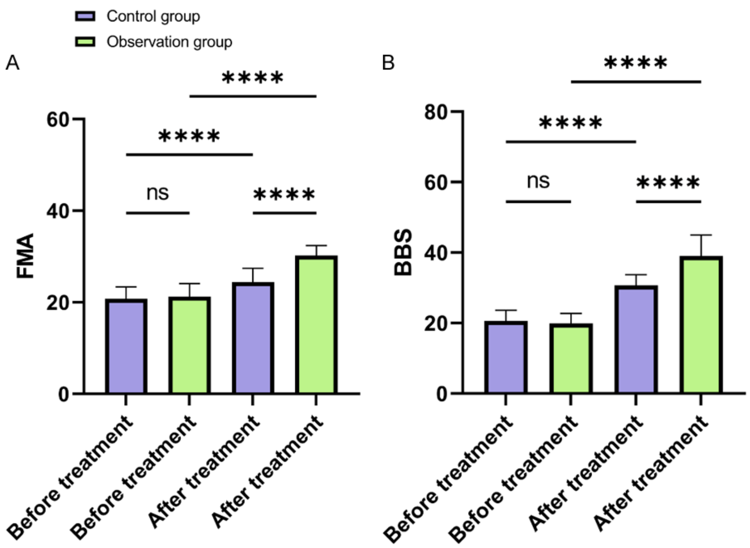

Figure 1. Changes in motor function and balance scores before and after treatment. A. Comparison of changes in FMA scores before and after treatment. B. Comparison of changes in BBS scores before and after treatment. Note: nsP>0.05, ****P<0.0001, FMA, Fugl-Meyer Assessment; BBS, Berg Balance Scale.

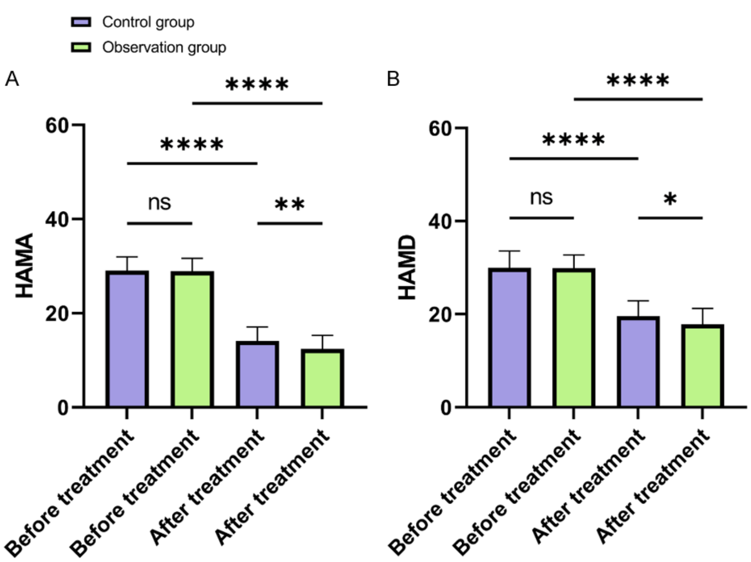

Figure 2. Changes in emotional score before and after treatment. A. Comparison of changes in HAMA scores before and after treatment. B. Comparison of changes in HAMD scores before and after treatment. Note: nsP>0.05, *P<0.05, **P<0.01, ****P<0.0001, HAMA, Hamilton Anxiety Rating Scale; HAMD, Hamilton Depression Rating Scale.

Once the condition of stroke patients with limb dysfunction stabilizes, they are generally given early passive or active limb training to promote functional recovery [23]. Rehabilitation treatment is widely used among stroke patients with limb dysfunction, and numerous studies have demonstrated its effectiveness [24, 25]. Mirror therapy, which was proposed in 1992 as a training method to alleviate phantom limb pain in amputees, has gradually been applied to motor function training after a stroke [26]. Mirror therapy involves processes such as action observation, motor imagery, and imitation learning, and has shown good efficacy in improving upper limb motor function in patients with limb dysfunction [27]. However, in daily life, the affected limb is often underused, which can lead to secondary cortical reconstruction and a decrease in the area of the affected cortical representation, making motor control recovery challenging. Contralateral controlled functional electrical stimulation is a rehabilitation technique that utilizes patient biofeedback to control the affected limb through functional electrical stimulation, based on the normal activity of the healthy limb [28]. By placing sensors on the healthy limb to detect electromyographic activity, the system automatically delivers current to the corresponding muscles of the affected side when the patient actively moves the healthy limb, following preset stimulation parameters, and enabling the performance of functional activities [29]. This therapy allows patients to actively participate, self-regulate therapy intensity, avoid passive dependency, and control the activity of the affected limb based on patient intent, thereby promoting central functional reorganization.

As previously discussed, mirror therapy, a simple rehabilitation training method, has shown some effectiveness in promoting the recovery

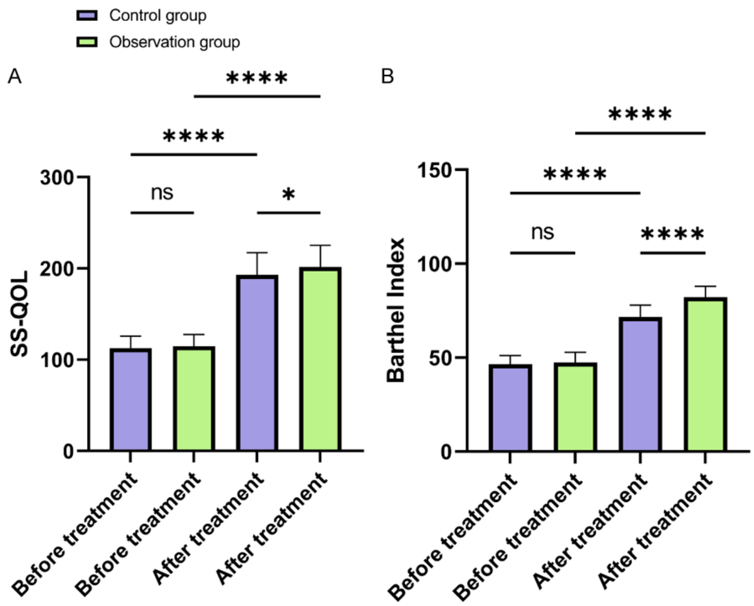

Figure 3. Changes in quality of life score before and after treatment. A. Comparison of changes in SS-QoL scores before and after treatment. B. Comparison of changes in Barthel Index scores before and after treatment. Note: nsP>0.05, *P<0.05, ****P<0.0001, SS-QoL, Stroke Specific Quality of Life Scale.

of limb function in stroke patients. However, relying solely on mirror therapy may lead to issues such as insufficient use of the affected limb, resulting in cortical reorganization dysfunction. To address this, researchers have considered combining mirror therapy with contralateral controlled functional electrical stimulation. This combination allows for the harnessing of the synergistic advantages of both treatments. Contralateral controlled functional electrical stimulation can activate the affected limb for functional practice through biofeedback, compensating for the limitations of relying solely on mirror therapy and preventing cortical dysfunction caused by prolonged non-use of the affected limb. In our study, we found that the combined therapy group showed significant improvements in limb motor function, balance, and quality of life scores compared to the control group that received mirror therapy only. Previous randomized controlled studies by Lee et al. [30] demonstrated that sensory electrical stimulation mirror therapy effectively improved muscle strength, gait, and balance in stroke hemiplegic survivors. Zhang et al.'s [31] study also found that combining mirror therapy with contralateral controlled functional electrical stimulation promoted motor function of the paralyzed wrist after a stroke, which is consistent with our findings. It is suggested that combined therapy may be superior to solo mirror therapy. In the combined treatment, contralateral controlled functional electrical stimulation provides an active rehabilitation mechanism through biofeedback, allowing patients to consciously control the activity of their affected limb, while mirror therapy provides visual input to activate cortical functional remodeling. Both mechanisms work together to promote the recovery of affected muscle and central control functions. Additionally, we observed significant improvements in anxiety and depression in the group that received the combined therapy, which we believe is directly related to the recovery of limb function. Improved limb function reduces the risk of falls and injuries, enhancing the patients' ability to carry out daily activities. The greater the patients' independence, the higher their quality of life, and the less their negative emotions. Furthermore, actively participating in the therapy itself may also boost patient confidence in treatment and generate positive psychological effects.

Negative emotional states, such as anxiety and depression, are commonly experienced by patients during the rehabilitation process of various diseases. These emotional states can have a detrimental impact on patient recovery. In this study, we investigated the risk factors that contribute to these negative emotions in the patients. Our analysis revealed that age and quality of life scores were independent risk factors for negative emotional states. As patients grow older, they may become more fearful about their illness and concerned about losing their ability to work. Elderly patients with mild cognitive decline may find it more challenging to adapt to the changes brought about by their illness. Previous logistic multivariate regression analysis by Tian et al. [32] found that age was an independent risk factor associated with poor prognosis. Moreover, Sever et al.

Table 2. Univariate analysis

Factor	Negative Emotion Group (n = 33)	Emotionally Stable Group (n = 61)	χ^2 Value	*P*-value
Age			6.231	0.012
≥60 years old	25	30		
<60 years old	8	31		
Gender			0.207	0.648
Male	20	34		
Female	13	27		
BMI			0.358	0.549
≥25 kg/m^2	10	15		
<25 kg/m^2	23	46		
Disease Duration			1.423	0.232
≥10 days	12	30		
<10 days	21	31		
Education Level			1.123	0.289
≥ Junior High School	20	30		
< Junior High School	13	31		
Monthly Household Income			7.795	0.005
≥5000 yuan	7	31		
<5000 yuan	26	30		
Stroke Type			0.207	0.648
Hemorrhagic	13	27		
Ischemic	20	34		
Affected Side			1.423	0.232
Left	12	30		
Right	21	31		
History of Hypertension			0.632	0.426
Yes	7	9		
No	26	52		
History of Diabetes			0.616	0.432
Yes	3	9		
No	30	52		
Smoking History			3.304	0.069
Yes	20	25		
No	13	36		
History of Alcohol Consumption			0.013	0.906
Yes	3	6		
No	30	55		
Treatment Plan			5.064	0.024
Control Group	21	24		
Observation Group	12	37		
Post-treatment FMA Score	27.00±3.56	27.69±4.05	0.819	0.414
Post-treatment BBS Score	33.73±6.23	35.75±6.29	1.497	0.137
Post-treatment SS-QoL Score	185±21.49	204.1±23.04	3.926	0.001
Post-treatment Barthel Index	72.36±6.24	79.8±7.59	4.815	<0.001

Note: BMI, Body mass index; FMA, Fugl-Meyer Assessment; BBS, Berg Balance Scale; SS-QoL, Stroke Specific Quality of Life Scale.

Table 3. Assignment table

Factor	Assigned Value
Age	≥60 years old = 1, <60 years old = 0
Monthly Household Income	≥5000 yuan = 0, <5000 yuan = 1
Post-treatment SS-QoL Score	≥210 = 0, <210 = 1
Post-treatment Barthel Index	≥80 = 0, <80 = 1
Grouping	Negative Emotion Group = 1, Emotionally Stable Group = 0

Note: SS-QOL, Stroke Specific Quality of Life Scale.

Table 4. Multivariate analysis

Factor	β	Standard Error	χ^2 Value	*P*-value	OR Value	95% CI
Age	1.386	0.598	5.379	0.020	4.000	1.24-12.906
Monthly Household Income	-0.047	0.014	12.243	<0.001	0.954	0.929-0.979
Post-treatment SS-QoL Score	-0.165	0.042	15.633	<0.001	0.848	0.782-0.920
Post-treatment Barthel Index	0.893	0.612	2.127	0.145	2.441	0.736-8.102
Treatment Plan	0.834	0.620	1.811	0.178	2.303	0.683-7.762

Note: SS-QoL, Stroke Specific Quality of Life Scale.

[33] identified age as a risk factor influencing depressive emotions in patients with cardiovascular diseases. Lower scores in post-treatment quality of life and daily living ability indicate significant obstacles in physical and mental functions, independence, and social integration for patients, hindering their return to a normal lifestyle and potentially leading to anxiety and depression. These lower scores suggest subpar rehabilitation outcomes, with patients struggling to regain a sense of autonomy and accomplishment, which may undermine their ability to cope. Therefore, these indicators of lower scores emphasize the need to optimize treatment plans and prioritize the psychological needs of different patients to achieve comprehensive rehabilitation outcomes.

In this study, we conducted a retrospective analysis to investigate the effects of combining contralateral controlled functional electrical stimulation with mirror therapy on limb function recovery in stroke patients and their emotional states. Our findings suggest that this combined approach can accelerate limb function recovery and improve negative emotional states. Additionally, we identified age and quality of life as independent risk factors that influence patient anxiety and depression. However, it is important to note that this study has certain limitations. Firstly, the research employed a retrospective design with a small sample size and lacked long-term follow-up. As a result, it is challenging to completely eliminate the influence of confounding factors and evaluate long-term therapeutic effects. To address these limitations, future research should consider using a prospective randomized controlled design, increasing the sample size and study duration, and incorporating long-term follow-up to enhance the reliability of the results.

In conclusion, our study highlights the effectiveness of combining contralateral controlled functional electrical stimulation with mirror therapy in improving limb function and reducing anxiety and depressive moods in stroke patients, thus positively impacting their rehabilitation.

Disclosure of conflict of interest

None.

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