ORIGINAL RESEARCH

Effect of MVF Combined with FES on Limb Function Recovery and Fine Function Rehabilitation of Hemiplegic Patients after ACI

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ABSTRACT

Background • This study assesses the efficacy of mirror visual feedback (MVF) combined with functional electrical stimulation (FES) in rehabilitating limb function and fine motor skills in hemiplegic patients after acute cerebral infarction (ACI). Given the limited research in this area, this study aims to provide insights into innovative rehabilitation techniques.

Methods • A randomized controlled trial was conducted on 106 post-ACI hemiplegic patients, split into two groups of 53 each. One group received conventional training plus FES, while the other group underwent MVF combined with FES. Key metrics like walking parameters, the modified Lindmark score, center of gravity movement speed, Fugl-Meyer Motor function (FMA) score, fall index, Berg score, and Time-Up-Go Time (TUGT) were measured to evaluate the effectiveness.

Results • In the study, significant improvements were observed in the observation group compared to the control group. The Modified Lindmark Scores for sensory function, motor coordination, and total scores in the observation group improved to 6.85±0.72, 15.77±2.25, and 22.62±2.78 respectively post-treatment, surpassing the control group's scores of 5.77±0.68, 13.92±1.87, and 19.69±2.45. In terms of FMA score, fall index, Berg score, and TUGT time, the observation group showed remarkable improvement: the FMA score increased from 43.69±4.51 to 67.25±7.04, the fall index decreased from 55.74±8.76 to 42.08±5.97, the Berg score rose from 31.03±6.28 to 43.11±6.71, and the TUGT time was reduced from 30.78±6.59s to 18.57±3.26s. These changes were significantly better than those in the control group, with all P = .000, indicating statistically significant improvements.

Conclusion • The results indicate that the combination of MVF and FES is more effective in improving limb function, hand fine movements, and balance in hemiplegic patients post-ACI compared to FES alone. This suggests that integrating MVF with FES may be a more beneficial approach in stroke rehabilitation. Future research is advised to explore larger sample sizes and long-term effects, offering guidance for developing more effective treatment and rehabilitation plans. This study suggests that integrating mirror visual feedback and functional electrical stimulation into stroke rehabilitation could significantly enhance recovery, potentially influencing clinical practices and rehabilitation policies. Future studies should explore the long-term effects, applicability to diverse patient groups, and cost-effectiveness of these combined therapies. (*Altern Ther Health Med.* [E-pub ahead of print.])

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INTRODUCTION

Acute cerebral infarction (ACI), commonly known as stroke, significantly impacts individuals, often leading to long-term disabilities. One of the most prevalent and debilitating outcomes of ACI is limb hemiparesis, particularly affecting the upper limbs. Hemiparesis, or partial paralysis, can severely impair a patient's ability to perform everyday tasks, especially those requiring fine motor skills.[1] Upper limb hemiparesis is particularly concerning because it directly impacts a patient's fine motor function. Activities that many take for granted, such as writing, dressing, or even eating, become challenging and sometimes unfeasible without assistance. This loss of function not only affects the physical capabilities of the patient but also has profound implications for their psychological well-being and quality of life. The inability to perform routine tasks independently can lead to feelings of helplessness, dependency, and a significant decline in self-esteem. Furthermore, the impact on fine motor skills means that patients with upper limb hemiparesis often struggle with precision and coordination, which are crucial for most occupational tasks. This limitation can hinder their ability to return to work or engage in social activities, further exacerbating the sense of isolation and loss of identity. Given these implications, addressing upper limb hemiparesis post-ACI is vital for rehabilitation and recovery. Effective interventions that can improve limb function and fine motor skills are essential not only for restoring physical abilities but also for enhancing the overall quality of life for these patients.[2]

Mirror Visual Feedback (MVF), also known as mirror therapy, is a therapeutic approach based on the concept of the mirror neuron system, which is fundamental to action observation, motor imagery, and imitative learning. This therapy involves the use of a mirror to create a reflective illusion of an affected limb, making it appear as if it is moving normally. The working principle of MVF revolves around the mirror neuron system in the brain. When a patient moves a healthy limb while watching its reflection superimposed over the affected limb in the mirror, it creates a visual illusion. This illusion tricks the brain into perceiving movement in the paralyzed limb, which can activate the mirror neurons. These neurons are believed to play a crucial role in motor control and learning by imitation. In practice, MVF treatment typically involves positioning a mirror in the median sagittal plane of the body. The patient moves the unaffected limb while watching its reflection, aligning with the position of the affected limb. This visual feedback can help in re-mapping the brain, aiding the recovery of motor function. Theoretically, MVF helps in enhancing awareness of the affected limb, reducing neglect, and can potentially alleviate pain and improve motor function in patients with limb hemiparesis or other similar conditions.[3] While there is existing literature on the individual benefits of MVF and FES in treating conditions like phantom limb pain, complex regional pain syndrome, and limb hemiparesis post-brain injury, studies exploring their synergistic effects are limited, particularly in the context of ACI. This study aims to evaluate the efficacy of combining mirror visual feedback (MVF) with functional electrical stimulation (FES) in the rehabilitation of patients with hemiplegia following acute cerebral infarction (ACI). Specifically, it seeks to investigate whether this combined intervention can improve limb function, enhance the recovery of hand fine movements and balance functions, and strengthen limb muscles in these patients. The underlying hypothesis is that MVF and FES together will yield significant improvements in these areas, contributing to better rehabilitation outcomes.

MATERIALS AND METHODS

Selection criteria of cases

Inclusion criteria: (1) meeting the criteria for cerebral infarction or cerebral hemorrhage in the Chinese Guidelines for the Prevention and Treatment of Cerebrovascular Disease[4] and confirmed by imaging; (2) age ≥40 years, ≤75 years: This age range is chosen as it represents the majority demographic of ACI patients. In this age group, the physiological response to stroke and potential for rehabilitation are relatively consistent, providing a more homogeneous sample for study; (3) first onset of the disease, duration of the disease of at least 2 weeks, and paralysis of one side of the limb: A minimum duration of 2 weeks ensures that the acute phase of stroke has passed. This criterion is set to focus on patients transitioning to the rehabilitation phase, where interventions like MVF and FES are more likely to be effective; (4) presence of unilateral hand fine motor impairment; (5) a score of at least 24 on the summary mental state examination (MMSE); (6) stable condition, voluntary participation in the study and signing a written protocol. This study was approved by the Ethics Committee of the Third Hospital of Xingtai(Approval number: 202008012-LL), and all subjects signed informed consent forms.

Exclusion criteria: (1) with heart, liver, kidney, and other vital organ diseases; (2) balance dysfunction due to skeletal muscle, brainstem, or vestibular diseases; (3) history of intracranial diseases or extracranial trauma; (4) with psychiatric diseases, malignant tumors; (5) with spinal cord diseases, lower limb fracture, and other diseases affecting the patient's walking function; (6) accompanied by serious systemic diseases unable to use rehabilitation exercise intervention.

Dropout criteria: (1) failure to receive rehabilitation exercise intervention on time and poor compliance; (2) withdrawal from the study due to aggravation of the disease or the patient's reasons.

Case data

106 patients with hemiplegia after ACI were admitted from August 2020 to February 2023 and were divided into two groups using the random number table method, with 53 cases in each group. This study was a single-blind experiment, so participants did not know whether they were receiving the actual treatment or a placebo. The control group shed 1 case due to poor adherence and finally completed 52 cases. The observation group shed 2 cases due to poor adherence, and 1 case withdrew from the study due to family reasons, and finally completed 50 cases. Comparing the general information of the two groups, the difference was not statistically significant (P > .05). See Table 1.

Table 1. Comparison of general information between the two groups

General information	Control group (n=52)	Observation group (n=50)	x^2/t	P value
Sex [n (%)]				
Male	28 (53.85)	24 (48.00)	0.349	.555
Female	24 (46.15)	26 (52.00)		
Age [(±s), yrs]	61.14±8.45	62.06±9.11	0.529	.598
BMI [(±s), kg/m²]	22.25±2.09	22.17±2.27	0.185	.853
MMSE score [(±s), points]	26.89±1.42	26.97±1.35	0.291	.771
Duration of disease [(±s), d]	45.85±10.12	44.27±12.39	0.707	.481
Type of stroke [n (%)]				
Ischaemic	32 (61.54)	29 (58.00)	0.133	.716
Haemorrhagic	20 (38.46)	21 (42.00)		
Side of hemiparesis [n (%)]				
Left side	28 (53.85)	26 (52.00)	0.035	.852
Right side	24 (46.15)	24 (48.00)		

Methods

Both groups were given conventional training interventions, and the control group was given FES interventions. 4 groups of FES surface electrodes were pasted on the quadriceps, hamstrings, gluteus maximus, and tibialis anterior muscles, respectively, to assess the maximum and minimum values of FES stimulation and obtain the optimal stimulation intensity. Training parameters: square wave, frequency 20 Hz, maximum pulse amplitude 127 mA, pulse width 300 μs. Training duration 20 min/times, 1 time/d, continuous training for 4 weeks.

The observation group was given MVF combined with FES intervention and rested for 10 minutes after the completion of FES before starting MVF treatment. The mirror box was placed on the treatment table, the patient was seated in front of the treatment table, a mirror (60 cm × 60 cm) was placed directly in front of the patient along the mid-sagittal plane, the healthy upper limb and trunk were located in front of the mirror, and the affected upper limb was placed at the back of the mirror. The patient was instructed to perform actions such as placing blocks, picking up a ball, holding a cup, pouring water, holding a cup, pouring water, and drinking water with both hands at the same time. The patient was asked to look at the mirror and complete the movement with the healthy hand. Through the feedback of the mirror combined with the therapist's verbal prompts, the patient imagined the healthy limb as the affected limb and imagined that the affected limb followed the upper limb in the mirror, as if it was the affected limb completing the movement. After that, the patients were instructed to look directly at the movement of the affected limb and complete the training with the affected upper limb as much as possible. The duration of MVF treatment was 30 min/times, 1 time/d, and the training was continuous for 4 weeks. The MVF exercises were selected based on their potential to activate the mirror neuron system and encourage motor relearning and neural plasticity. These exercises are tailored to mimic daily activities, thereby directly contributing to the rehabilitation goals of improving fine motor skills and functional use of the affected limb.

Detection methods

Walking parameters: Before treatment and after 4 weeks of treatment, the 3D gait analysis and training system of Zhanghe Electric Company was used to measure the grounding angle of the affected foot, the single-support phase of the affected/healthy side, the length of the healthy side's stride, and the frequency of the stride.

"Time-Up-Go Time (TUGT): TUGT was measured before and after 4 weeks of treatment. The patient was instructed to sit on a chair with armrests, with his/her back resting on the seat and both upper limbs relaxed, and the time taken for him/her to get up from the chair and walk forwards for 3m and then return and sit back down was recorded as the TUGT. TUGT is a simple test used to assess a person's mobility and requires both static and dynamic balance. It measures the time taken by an individual to stand up from a seated position, walk three meters, turn around, walk back, and sit down. In ACI patients, where mobility can be a major issue, TUGT provides a quick and effective assessment of functional mobility.

Centre of gravity movement speed: The center of gravity movement speed was measured before treatment and after 4 weeks of treatment using the Dutch STABLE 3D Balance Posture Control Training and Evaluation System in the postures of standing with eyes open, standing with eyes closed, standing with the feet forward and backward, and standing on one leg.

Efficacy Criteria

Cure: limb muscle strength returns to normal; obvious effect: muscle strength increases ≥2 grades; improvement: muscle strength increases I grade; ineffective: no increase or even decrease in muscle strength.

Scoring criteria

Modified Lindmark score:[5] divided into sensory function (4 items, total score of 8 points) and motor coordination (8 items, total score of 24 points), modified Lindmark total score of 32 points, the score is proportional to the degree of recovery of fine hand movements. This score evaluates the patient's ability to perform motor tasks, focusing particularly on limb function. In the context of ACI, where limb function impairment is a primary concern, the Modified Lindmark Score provides a direct measure of the patient's motor recovery, especially in the affected limb.

Simple Fugl-Meyer motor function (FMA) score:[6] divided into upper limb and lower limb function, corresponding to a full score of 66 and 34 points, with a total score of 100 points, proportional to the degree of recovery of limb motor function. The FMA score is a stroke-specific, performance-based impairment index. It is designed to assess motor functioning, balance, sensation, and joint functioning in patients with post-stroke hemiplegia. It's particularly relevant for evaluating the recovery of motor function, a key goal of the study.

Fall index: the Tetrax balance instrument was used to assess the fall index obtained by the patients in different postures, with a percentage scoring system, and the score was proportional to the risk of falling. The Fall Index measures the likelihood of falls, which is a significant risk in patients with impaired balance and motor function post-stroke. Improvements in the Fall Index would indicate enhanced balance and stability, which are critical for patient safety and independence.

Berg score: 14 items, with a full score of 56 points, and the score was proportional to the balance ability. This score assesses the patient's ability to safely balance during a series of predetermined tasks. In the context of ACI rehabilitation, where balance can be significantly compromised, the Berg Balance Score is crucial for tracking improvements in a patient's ability to maintain stability.

Table 2. Comparison of walking parameters between the two groups (±s)

Group	n	Grounding angle of the affected foot (°)		Single-support phase on the affected/healthy side		Healthy side step length (cm)		Step rate (steps/min)	
		Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
Control group	52	11.02±2.89	15.78±3.15[a]	0.75±0.11	0.84±0.13[a]	38.96±8.22	52.32±9.13[a]	13.02±2.41	20.25±4.78[a]
Observation group	50	10.86±3.03	18.95±3.24[a]	0.72±0.13	0.93±0.14[a]	39.14±7.49	61.02±8.52[a]	12.94±2.57	25.85±4.13[a]
t		0.273	5.010	1.260	3.366	0.115	4.971	0.162	6.320
P value		.785	.000	.211	.001	.908	.000	.871	.000

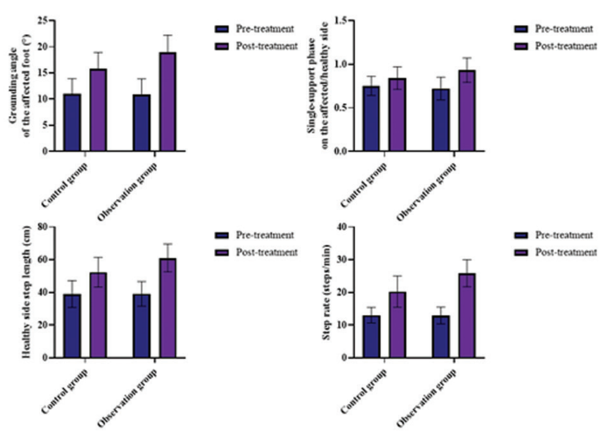
[a]Compared with pre-treatment, $P < .05$.

Table 3. Comparison of modified Lindmark scores between the two groups (±s)

Group	n	Sensory Function		Motor Coordination		Modified Lindmark Total Score	
		Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
Control group	52	3.84±0.54	5.77±0.68[a]	7.28±1.05	13.92±1.87[a]	11.12±1.85	19.69±2.45[a]
Observation group	50	3.79±0.61	6.85±0.72[a]	7.22±1.14	15.77±2.25[a]	11.01±1.96	22.62±2.78[a]
t		0.439	7.791	0.277	4.523	0.292	5.653
P value		.662	.000	.783	.000	.771	.000

[a]Compared with pre-treatment, $P < .05$.

Figure 1. Comparison of walking parameters between the two groups.



Statistical analysis

Statistic Package for Social Science (SPSS) 19.0 software (IBM, Armonk, NY, USA) was used to process, the Shapiro-Wilk method was used to measure and test whether the information conformed to the normal distribution, conforming to the normal distribution should be described by (±s), and the *t* test was used for comparison, the counting information should be described by percentage, the χ^2 test was used for comparison, and the $P < .05$ indicated that there was a statistically significant difference. A *P* value threshold of < .05 is used to determine statistical significance. This standard threshold is widely accepted in clinical research, balancing the risk of Type I and Type II errors.

RESULTS

Comparison of walking parameters between the two groups

Table 2 reveals significant post-treatment improvements in walking parameters for both the control and observation groups. The grounding angle of the affected foot increased in the observation group from 10.86±3.03 degrees to 18.95±3.24 degrees (t(100) = 5.010, $P < .001$), compared to the control group's increase from 11.02±2.89 to 15.78±3.15 degrees. The single-support phase ratio on the affected/healthy side improved significantly in the observation group (pre-treatment: 0.72±0.13, post-treatment: 0.93±0.14, t(100) = 3.366, $P = .001$), outperforming the control group's improvement. Additionally, the healthy side step length and step rate saw marked enhancements, particularly in the observation group, with step length increasing to 61.02±8.52 cm (t(100) = 4.971, $P < .001$) and step rate to 25.85±4.13 steps/min (t(100) = 6.320, $P < .001$). These results indicate that the intervention (presumably MVF, FES, or both) is effective in improving walking ability post-ACI. The increased grounding angle and prolonged single-support phase suggest better control and stability during gait, which are critical for safety and independence in ambulation. The enhancements in step length and rate not only demonstrate improved lower limb function but also suggest increased confidence and walking efficiency. Such improvements can have a profound impact on the quality of life and autonomy of ACI patients, potentially reducing the need for assistive devices and caregiver dependence. See Table 2, Figure 1.

Comparison of improved Lindmark scores between the two groups

Table 3 presents the comparison of Modified Lindmark scores between the control and observation groups, highlighting significant improvements post-treatment. In the observation group, the Sensory Function score improved from 3.79±0.61 to 6.85±0.72 (t(100) = 7.791, $P < .001$), the Motor Coordination score from 7.22±1.14 to 15.77±2.25 (t(100) = 4.523, $P < .001$), and the Modified Lindmark Total Score from 11.01±1.96 to 22.62±2.78 (t(100) = 5.653, $P < .001$). These improvements were significantly greater than those observed in the control group, which also showed improvements but to a lesser extent. The marked increase in Sensory Function and Motor Coordination scores in the observation group indicates that patients receiving the treatment experienced substantial gains in sensory awareness and motor skills, which are crucial for functional

Figure 2. Comparison of modified Lindmark scores between the two groups.

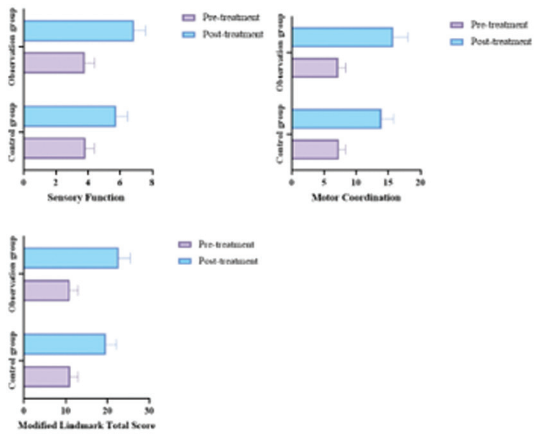


Figure 3. Comparison of FMA score, fall index, Berg score, TUGT time between two groups.

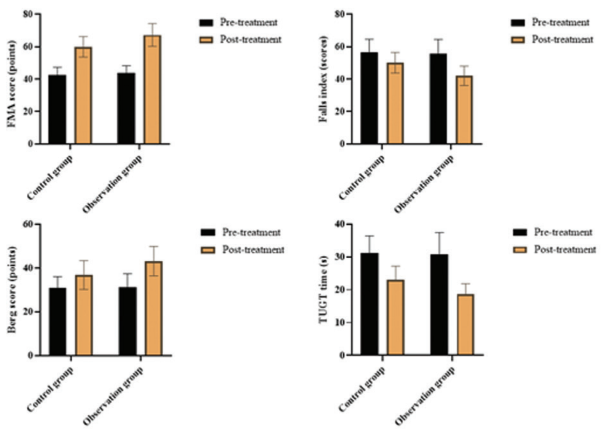


Table 4. Comparison of FMA score, fall index, Berg score, TUGT time between two groups (±s)

Group	n	FMA score (points)		Falls index (scores)		Berg score (points)		TUGT time (s)	
		Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
Control group	52	42.45±4.84	59.96±6.32[a]	56.52±8.12	50.12±6.36[a]	30.87±5.14	36.77±6.58[a]	31.12±5.26	23.12±4.05[a]
Observation group	50	43.69±4.51	67.25±7.04[a]	55.74±8.76	42.08±5.97[a]	31.03±6.28	43.11±6.71[a]	30.78±6.59	18.57±3.26[a]
t		1.337	5.508	0.467	6.577	0.141	4.818	0.289	6.235
P value		.184	.000	.642	.000	.888	.000	.774	.000

[a]Compared with pre-treatment, $P < .05$.

independence. The notable rise in the Modified Lindmark Total Score suggests a comprehensive enhancement of overall motor abilities. Clinically, these improvements mean patients may better perform everyday tasks and have a reduced risk of injury due to poor coordination or sensory deficits. This can lead to less dependency on care and an improved quality of life. See Table 3, Figure 2.

Comparison of FMA score, fall index, Berg score and TUGT time between two groups

Table 4 demonstrates significant post-treatment improvements in FMA scores, fall index, Berg balance scores, and TUGT times for both groups, with the observation group showing more substantial gains. The FMA scores increased from 43.69±4.51 to 67.25±7.04 points in the observation group ($t(100) = 5.508$, $P < .001$) compared to the control group's increase from 42.45±4.84 to 59.96±6.32 points. Fall index scores improved, decreasing from 55.74±8.76 to 42.08±5.97 in the observation group ($t(100) = 6.577$, $P < .001$), indicating a lower risk of falls. The Berg balance scores showed significant improvement, with the observation group increasing from 31.03±6.28 to 43.11±6.71 points ($t(100) = 4.818$, $P < .001$). Lastly, TUGT times decreased markedly in the observation group, from 30.78±6.59 seconds to 18.57±3.26 seconds ($t(100) = 6.235$, $P < .001$), suggesting faster and more efficient movement. These findings have important clinical implications. The increase in FMA scores for the observation group suggests better motor recovery and higher functional capabilities. The decrease in the fall index indicates a substantial reduction in the risk of falls, which is crucial for patient safety and autonomy. Improved Berg balance scores signify better static and dynamic balance abilities, essential for performing daily activities. The decrease in TUGT times reflects enhanced mobility and independence in basic ambulatory tasks. Overall, these results indicate that the intervention employed for the observation group could significantly improve functional outcomes and safety for hemiplegic patients post-ACI, which could have a profound impact on their rehabilitation process and quality of life. See Table 4, Figure 3.

Table 5. Comparison of limb muscle strength rehabilitation effect between the two groups

Group	n	Cured	Effective	Improvement	Ineffective	Total Effective Rate
Control group	52	9 (17.31)	17 (32.69)	14 (26.92)	12 (23.08)	40 (76.92)
Observation group	50	13 (26.00)	21 (42.00)	11 (22.00)	5 (10.00)	45 (90.00)
χ^2						3.139
P value						.076

Comparison of limb muscle strength rehabilitation effect between the two groups

Table 5 compares the rehabilitation effect on limb muscle strength between the control and observation groups. The observation group showed a higher total effective rate of 90.00%, with 13 patients (26.00%) being cured, 21 (42.00%) showing effective improvement, and 11 (22.00%) showing improvement. This compares favorably to the control group, which had a total effective rate of 76.92%, with 9 patients (17.31%) cured, 17 (32.69%) showing effective improvement, and 14 (26.92%) showing improvement. The chi-squared test showed a value of $\chi^2 = 3.139$ with $P = .076$. Although the p-value did not reach the conventional level of statistical significance ($P < .05$), the observation group demonstrated a higher rate of overall effectiveness in limb muscle strength

Table 6. Comparison of centre of gravity swing speed under different postures between the two groups [(±s), cm/s]

Group	n	Standing with eyes open		Standing with eyes closed		Standing on front and back legs		Standing on one leg	
		Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
Control group	52	5.02±0.77	4.51±0.63[a]	5.96±0.84	5.25±0.61[a]	7.45±0.38	6.20±0.35[a]	8.75±1.63	7.87±1.34[a]
Observation group	50	4.96±0.78	4.21±0.52[a]	6.01±0.79	4.67±0.52[a]	7.39±0.42	5.67±0.32[a]	8.80±1.57	7.12±1.19[a]
t		0.391	2.617	0.309	5.158	0.757	7.973	0.158	2.985
P value		.697	.010	.758	.000	.451	.000	.875	.004

[a]Compared with pre-treatment, $P < .05$.

rehabilitation. Clinically, this suggests that the treatment or intervention applied to the observation group could be more beneficial in achieving muscle strength recovery, which is a critical component of post-stroke rehabilitation. A total effective rate of 90.00% in the observation group indicates a strong potential for this approach to improve functional outcomes for patients with hemiplegia following ACI, possibly leading to greater independence and quality of life. These findings, while not statistically significant, indicate a trend that warrants further investigation with a larger sample size or additional studies to confirm the effectiveness. See Table 5.

Comparison of the center of gravity swinging speed in different postures of the two groups

Table 6 assesses the center of gravity swing speed under different postures between the control and observation groups. Both groups showed a decrease in swing speed post-treatment, indicating improved balance. Specifically, in the observation group, the swing speed while standing with eyes open decreased from 4.96±0.78 cm/s to 4.21±0.52 cm/s ($t(100) = 2.617$, $P = .010$), and with eyes closed from 6.01±0.79 cm/s to 4.67±0.52 cm/s ($t(100) = 5.158$, $P < .001$). Significant improvements were also seen in more challenging postures: while standing on front and back legs, the speed decreased from 7.39±0.42 cm/s to 5.67±0.32 cm/s ($t(100) = 7.973$, $P < .001$), and while standing on one leg from 8.80±1.57 cm/s to 7.12±1.19 cm/s ($t(100) = 2.985$, $P = .004$). Clinically, these results suggest that the interventions provided to both groups effectively enhanced static and dynamic balance, as indicated by the reduced center of gravity swing speed. Improved balance is crucial for reducing the risk of falls, enhancing mobility, and increasing confidence in daily activities. The greater improvements in the observation group, particularly with eyes closed and on unstable postures, imply that the treatment they received could be more beneficial for developing proprioceptive abilities and overall balance. This has significant implications for rehabilitation strategies, as it underscores the importance of balance training in enhancing functional independence for individuals recovering from ACI. See Table 6.

DISCUSSION

With the improvement of medical technology, the mortality rate caused by ACI has been greatly reduced, but its disability rate is still at a high level, and it is the leading cause of disability in adults.[8] Epidemiological investigations have found that about 75% or more of ACI patients are left with limb dysfunction. This is related to the decreased control over lower nerve centers caused by lesions of higher nerve centers in the brain and disruption of synaptic connections in ACI patients.[9] Patients with ACI tend to have pathological changes such as tendon reflex hyperreflexia, increased muscle tone, and decreased intermuscular coordination, sensation, and balance.[10]

FES is currently a commonly used clinical treatment for hemiparesis after ACI, and Shah et al.[11] found that FES can better improve the excitability of the motor cortex as well as lower limb motor function of patients with early stroke when applied in combination with transcranial direct current stimulation.

Basic research suggests that the mirror neuron system of the human brain includes the frontoparietal mirror system and the limbic mirror system, and the frontoparietal mirror system consists of Broca's area, the lower part of the precentral gyrus, the lateral aspect of the mouth of the sub parietal lobule, the ventral aspect of the premotor cortex, and the posterior part of the inferior frontal gyrus. The limbic mirror system consists of the insula, prefrontal cortex, amygdala, and other parts.[12] MVF method is a therapeutic technique based on the mirror neuron system, which promotes neural function reorganization, and has been studied more in the field of treatment of diseases such as complex localized pain syndrome, phantom limb pain after amputation, and rehabilitation of brain injury.[13] Takekawa et al.[14] applied mirror therapy in combination with gait-evoked functional electrical stimulation in the treatment of hemiplegia in stroke and found that it could increase the electromyographic integral value of hemiplegia patients with stroke and improve the limb motor function and the ability of daily life activities. In this study, it was found that the grounding angle of the affected foot, the single support phase of the affected/healthy side, the step length of the healthy side, and the step frequency were increased in both groups after treatment, and the observation group was higher than the control group. The modified Lindmark score and FMA score increased in both groups after treatment, and the observation group was higher than the control group; the TUGT time decreased in both groups after treatment, and the observation group was lower than the control group. The above results suggest that MVF combined with FES can improve the limb function of hemiplegic patients after ACI, and promote the recovery of fine hand movements and walking ability. This is due to the fact that, unlike conventional action memory therapy, the MVF method does not simply and mechanically repeat the actions of the training system, but activates the mirror neuron cells by observing the normal action images of the healthy limb, activates the limb proprioceptive-motor feedback loop, further deepens the intrinsic connection between limb sensation and movement, contributes to the restoration of neurons in the damaged brain region, and promote neural function reorganization, and then improve the hand fine movement and walking ability of the affected limb.[15]

Patients with hemiplegia after ACI have abnormal muscle activity status on the affected side, with decreased muscle strength and increased muscle tone, which is one of the important causes of poor posture and gait.[16] Weimar et al.[17] used multimodal mirror therapy to treat stroke patients and found that it could effectively improve patients' muscle strength. In this study, it was found that the total effective rate of limb muscle strength rehabilitation in the observation group was 90.00%, which was numerically higher than the 76.92% in the control group, but the difference was found to be not statistically significant by the χ^2 test. This result is not completely consistent with the conclusions of existing clinical studies. It is considered to be related to the resulting bias caused by the small sample size of this study (only more than fifty cases in each group). Whethermirror therapy has an advantage in improving muscle strength of hemiplegic patients after ACI should be further explored in future clinical work through large sample studies.

Improvements in motor function and balance profoundly impact patients' real-life scenarios. First, as limb function improves, patients may experience a significant increase in independence and autonomy in daily life. It may be easier for them to perform a series of daily activities, such as self-care, washing, eating, etc., which reduces their dependence on the assistance of others and improves their quality of life. Improving hand fine motor coordination is also critical for complex tasks such as pressing buttons, writing, and using everyday tools. This is critical to patients' occupational and social participation and may help them better adapt to work and social environments and improve the functionality of their lives. In a home environment, patients may adapt more easily to household activities such as cooking, cleaning, and caring for themselves. This enhances the patient's contribution to the family. It improves their sense of role and self-efficacy within the family. In addition, improved balance function can significantly reduce a patient's risk of falling, thereby reducing the likelihood of fractures and other fall-related complications. This is critical to maintaining the patient's long-term physical health and avoiding further medical intervention.

Centre of gravity instability is an important manifestation in patients with hemiplegia after ACI, which can cause an increased risk of falls and adversely affect the prognosis.[18] In this study, it was found that the speed of the center of gravity swing and fall index under standing with eyes open, standing with eyes closed, standing with feet in front and behind, and standing on one leg decreased in both groups after treatment, and the observation group was lower than the control group. Berg scores increased in both groups after treatment, and the observation group's scores were higher than the control group's. This result suggests that MVF combined with FES can improve the balance ability and correct the centre of gravity instability in hemiplegic patients after ACI. This is related to improving limb muscle strength and correcting poor gait in patients after treatment.[19,20]

A patient-centered approach is paramount in stroke rehabilitation, recognizing that each patient presents a unique set of challenges and goals. Personalized care is essential to address individual needs effectively, aiming not just to improve physical functioning but also to enhance quality of life. The integration of Mirror Visual Feedback (MVF) with Functional Electrical Stimulation (FES) exemplifies a tailored treatment strategy, as it can be adapted to the specific motor deficits and recovery stages of each patient. This bespoke approach allows for the modulation of therapy intensity and complexity, ensuring that rehabilitation is aligned with each patient's progress and preferences, which is crucial for maximizing engagement and outcomes.

The study's small sample size and short-term follow-up may limit the generalizability and understanding of the long-term efficacy of the interventions. Although randomization was used, the potential for unaccounted biases exists, which could influence the results. These factors suggest caution in broadly applying the findings without further research to confirm and extend these initial observations.

Future studies should expand on this work with larger, more diverse populations to confirm the findings and extend our understanding of their implications. Long-term studies are necessary to assess the sustainability of treatment benefits. Additionally, employing neuroimaging and other technologies could elucidate the underlying mechanisms of MVF and FES, offering deeper insight into stroke rehabilitation. Interdisciplinary collaboration in stroke rehabilitation can significantly amplify patient outcomes. By combining the expertise of physiotherapists, occupational therapists, neurologists, and other healthcare professionals, a comprehensive rehabilitation plan can be crafted that addresses all aspects of a patient's recovery. Physiotherapists can focus on restoring physical function and mobility, occupational therapists can assist patients in regaining the skills necessary for daily activities, while neurologists can manage the overall medical care and monitor the patient's neurological health. This team approach ensures that treatments like MVF and FES are integrated into a broader care plan, facilitating holistic recovery and enhancing the efficacy of each therapeutic intervention through a coordinated, synergistic approach.

In conclusion, MVF combined with FES can improve limb function in patients with hemiplegia after ACI, promote the recovery of fine hand movements and balance function, and improve limb muscle strength.

CONCLUSION

This study provides promising evidence for the use of combined MVF and FES interventions in enhancing limb function and balance in patients post-ACI. Significant improvements in functional scores and balance parameters suggest that these treatments can be beneficial additions to rehabilitation programs, potentially improving the quality of life for stroke survivors. While the findings are encouraging, they must be interpreted in light of the study's limitations, including its small sample size and the need for longer-term follow-up to confirm the sustainability of the treatment effects. Future research should aim to address these limitations and explore the mechanisms underlying the successful outcomes observed, paving the way for more effective and targeted rehabilitation strategies.

CONFLICT OF INTEREST

The authors have no potential conflicts of interest to report relevant to this article.

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AUTHOR CONTRIBUTIONS

PL and YL designed the study, HX and XZ collected the data, XL, LD and GW analyzed the data, PL and YL prepared the manuscript. All authors read and approved the final manuscript.

ETHICAL COMPLIANCE

The ethics committee of the Third Hospital of Xingtai approved this study. Signed written informed consent were obtained from the patients and/or guardians.

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