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Original Article

Improvement of upper limb function in post-stroke patients with motion feedback training-based combination therapy: a retrospective analysis of muscle activation and recovery dynamics

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Abstract: Objective: To evaluate the effectiveness of combination therapy based on motion feedback training in patients recovering from ischemic stroke. Methods: A retrospective analysis was conducted on 205 patients in the recovery phase of ischemic stroke admitted between June 2022 and June 2023. Patients were divided into two groups: the conventional treatment group (n=101), receiving standard care, and the combination therapy group (n=104), receiving additional motion feedback training for 30 days. Outcome measures included root mean square (RMS) and median frequency (MDF) of surface electromyography (sEMG) for upper limb muscles, biochemical indicators, active range of motion (AROM), Fugl-Meyer Assessment (FMA) scores, and Activities of Daily Living (ADL) scores. Results: Combination therapy significantly improved post-treatment RMS values in muscles such as the left Biceps brachii (BB) (P=0.008), right BB (P=0.003), and right Flexor pollicis brevis (FPB) (P=0.010). MDF values also improved significantly in the left BB (P=0.002) and left FPB (P=0.027). The combination therapy group showed higher post-treatment SOD levels compared to the conventional group (P=0.001). Significant improvements were observed in AROM (P<0.001), FMA (P<0.001), and ADL scores (P=0.010) in the combination therapy group. Logistic regression analysis revealed that combination therapy was associated with better outcomes (OR, 0.518; 95% CI, 0.291-0.923; P=0.026), while higher pre-treatment right FPB RMS values were linked to poorer prognosis (OR, 1.074; 95% CI, 1.004-1.149; P=0.039). Conclusion: Motion feedback training-based combination therapy significantly enhances muscle activation, antioxidant biochemical pathways, functional recovery, and daily living activities in post-stroke patients compared to conventional treatment alone.

Keywords: Ischemic stroke, upper limb dysfunction, combination therapy, motion feedback training, rehabilitation, surface electromyography

Introduction

Stroke remains a leading cause of disability worldwide, with ischemic stroke accounting for approximately 87% of all cases [1]. Among the various impairments caused by ischemic stroke, upper limb dysfunction is particularly common and significantly affects the quality of life and independence of survivors [2, 3]. Despite advancements in acute stroke management, recovery of upper limb function often remains incomplete, necessitating intensive post-stroke rehabilitation.

Ischemic stroke-induced upper limb dysfunction is characterized by motor weakness, spasticity, and loss of coordination, posing substantial challenges to functional recovery [4, 5]. Traditional rehabilitation primarily involves physical and occupational therapy focused on repetitive, task-specific exercises aimed at promoting neural plasticity and functional improvement [2, 6]. However, the efficacy of these interventions is variable, with many patients achieving only partial recovery. This has prompted growing interest in adjunctive therapies to enhance conventional rehabilitation outcomes [7, 8].

One promising approach is motion feedback training, which uses real-time feedback on muscle activity and movement accuracy to guide

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therapeutic exercises [9, 10]. This technique aligns with motor learning and neuroplasticity principles, reinforcing correct movement patterns and reducing maladaptive neural reorganization. Emerging evidence suggests that feedback-based therapies can significantly enhance motor function by promoting more precise and controlled movements [11, 12]. However, the mechanisms underlying the benefits of motion feedback training, as well as its optimal integration with conventional therapy, remain insufficiently explored.

Surface electromyography (sEMG) provides a non-invasive method to assess muscle activation and coordination, offering valuable insight into the neuromuscular changes associated with stroke recovery [13-15]. By quantifying measures such as root mean square (RMS) values and median frequency (MDF) of muscle activity, sEMG facilitates the objective evaluation of muscle function, informing and tailoring rehabilitation interventions [16]. Previous studies [17, 18] have highlighted the utility of sEMG in monitoring progress and adapting therapeutic strategies in real-time. However, its application in motion feedback training and stroke rehabilitation requires further exploration.

Identifying prognostic factors for poor upper limb recovery is essential for developing targeted, personalized rehabilitation plans [19]. Factors such as age, baseline motor function, spasticity severity, and comorbid conditions are associated with stroke recovery outcome. Understanding the influence of these and other factors can optimize clinical decision-making and resource allocation. Notably, pre-treatment muscle activation patterns measured by sEMG may serve as important predictors of rehabilitation outcome, but their prognostic utility remains underexplored [20].

This retrospective study aims to address two primary objectives. First, it seeks to identify key prognostic factors for poor upper limb recovery in ischemic stroke patients, with a particular focus on pre-treatment sEMG measurements. Second, it evaluates the effect of integrating motion feedback training with conventional therapy on rehabilitation outcome. By leveraging sEMG data, the study provides a detailed examination of muscle activation changes and their correlation with functional improvement. Through this dual focus, the research aims to advance stroke rehabilitation by supporting the development of more effective, individualized treatment protocols.

Materials and methods

Case selection

This retrospective case-control study, nested within a cohort, included 205 ischemic stroke patients in the recovery phase, admitted to Zhejiang Sian International Hospital between June 2022 and June 2023. The study was approved by the Ethics Committee of Zhejiang Sian International Hospital. Since the study used only de-identified patient data and posed no risk to patient care, the requirement for informed consent was waived.

Inclusion Criteria: Patients aged 18-70 years with a confirmed unilateral ischemic stroke [21], in the recovery phase, exhibiting mild to moderate upper limb motor impairment (baseline Fugl-Meyer Assessment score: 20-50), no history of mental illness, and sufficient cognitive ability to understand and follow simple instructions, as determined by a Mini-Mental State Examination (MMSE) score of ≥24. All patients were required to cooperate with treatment and evaluation.

Exclusion Criteria: 1. Patients with unstable vital signs, such as abnormal heart rate, body temperature, or blood pressure. 2. Those with severe cognitive impairment, visual/auditory dysfunction, or a history of mental illness, with an MMSE score <24. 3. Ischemic stroke caused by traumatic brain injury or brain tumor. 4. Patients with severe renal dysfunction. 5. Those with severe endocrine system disorders. 6. Patients with concurrent myocardial infarction.

Grouping and treatment methods

Patients were divided into two groups based on their treatment regimen: a conventional treatment group (n=101) and a combination therapy group (n=104). The conventional treatment group received standard western medical care, including intravenous infusion of 4 g olaxetan (Langtian Pharmaceutical, National Medical Standard H20153030, 5 mL:1 g), diluted in 100-250 mL of 5% glucose injection, administered once daily for 30 days. Dosages were

adjusted based on individual patient conditions.

In addition to conventional treatment, the combination therapy group underwent motion feedback training. To ensure patient and family compliance, the motion feedback system's purpose and usage were explained in detail. Upon enrollment, initial evaluations were recorded in an electronic rehabilitation training file. Researchers systematically guided patients through limb function and muscle strength training, progressing from upper to lower limbs, gross to fine motor skills, and small to large joints. After each training session, medical staff reviewed and verified the training programs. Metrics from patient activity were recorded and used to adjust training plans. This intervention was implemented consistently for 30 days, with each session lasting 50 minutes, conducted either in the department's treatment room or the patient's ward.

On the 30th day of treatment, patients were categorized based on prognostic outcome. Clinical spasticity assessment criteria commonly used in China were applied: a reduction in muscle tone of 0.5-2 grades classified patients into the good prognosis group (n=153), while no improvement in muscle tone categorized them into the poor prognosis group (n=52).

Primary outcome measure: The primary outcome was the change in upper limb motor function, quantified using the Fugl-Meyer Assessment (FMA) score for the upper extremity.

Secondary outcome measures: Secondary outcomes included assessments using the Modified Ashworth Scale (MAS), Range of Motion (ROM), Quality of Life (QoL) measures, and the Functional Independence Measure (FIM).

Blood testing

Fasting venous blood samples (5 mL) were collected from patients before 8 a.m. for laboratory analyses.

Hematological data: Red blood cells, white blood cells, neutrophils, lymphocytes, eosinophils, basophils, hemoglobin, and platelets were analyzed using the DxH800 hematology analyzer (Beckman Coulter, Inc., Brea, CA, USA).

C-Reactive Protein (CRP): CRP levels were measured using the BECKMAN Synchron LX20 automated biochemistry analyzer (Beckman Coulter, Inc., Brea, CA, USA) using the rate nephelometry method.

Erythrocyte Sedimentation Rate (ESR): ESR was determined using EDTA-anticoagulated whole blood with the TEST1 automated ESR analyzer (ALIFAX, Inc., Italy).

Serum Biomarkers: Serum samples were obtained by centrifuging blood at 3,000 rpm for 15 minutes. The following biomarkers were analyzed: Superoxide Dismutase (SOD), Nitric Oxide (NO), and Nitric Oxide Synthase (NOS): Levels were measured using a colorimetric method with a spectrophotometer (Longniko, Model 7200), following reagent kit instructions from Nanjing Jiancheng Bioengineering Institute. Neuron-Specific Enolase (NSE): NSE levels were quantified using an electrochemiluminescence immunoassay system (Roche Diagnostics, Switzerland). S100B and Myelin Basic Protein (MBP): S100B and MBP levels were determined using ELISA kits: S100B-ELISA (Physiology Department, Fourth Military Medical University) and MBP-ELISA (Nanjing Jiancheng Bioengineering Institute).

Serum Inflammatory Cytokines: Inflammatory cytokines, including procalcitonin (PCT), tumor necrosis factor-alpha (TNF-α), interleukin-6 (IL-6), and interleukin-8 (IL-8), were measured using enzyme-linked immunosorbent assays (ELISA) with the following kits: PCT (ab221828, Abcam, USA), TNF-α (ab181421, Abcam, USA), IL-6 (ab178013, Abcam, USA), and IL-8 (ab18-5986, Abcam, USA). All procedures were performed strictly according to the manufacturers' instructions.

Upper limb muscles

Surface electromyography (sEMG) data were collected and analyzed using the KEYPOINT Surface Electromyography System (Dantec, DK). Time-domain indicators, including root mean square (RMS) and median frequency (MDF), were selected for analysis. Patients were positioned either lying down or sitting during the examination. The skin at electrode placement sites was cleaned with 70% alcohol to reduce impedance. Disposable Ag/AgCl flexible electrocardiogram monitoring electrodes,

with a conductive area diameter of 10 mm, were used. Electrodes for differential measurement were placed 15 mm apart at the most prominent part of the muscle belly, with the line connecting the electrodes aligned parallel to the muscle fibers.

Before testing, participants were instructed to adopt a neutral posture and relax their upper limbs to ensure no visible sEMG signals were detected on the monitoring screen. Each participant performed maximum isometric voluntary contractions (MIVC) for the following muscle-specific actions: Biceps brachii (BB): Elbow flexion with a 90° isometric contraction for 3-5 seconds, repeated three times with 10-second intervals. Flexor pollicis brevis (FPB): Thumb flexion pressing against the ventral side of the thumb for a 3-second isometric contraction, repeated three times with 10-second breaks. First dorsal interosseous (FDI): Index finger abduction pressing against the side of the finger for a 3-5 second isometric contraction, repeated three times with 10-second intervals.

Scales and scores

Range of Motion (ROM): A joint range-of-motion protractor was used to measure anterior flexion, abduction, and lateral rotation of the affected shoulder joint.

National Institutes of Health Stroke Scale (NIHSS): This scale evaluates neurologic function, including consciousness, language, motor skills, sensation, coordination, eye movement, and visual fields. Scores range from 0 to 42, with higher scores indicating more severe neurologic impairment: scores ≤4 indicate mild stroke, while scores ≥21 denote severe stroke. Despite its utility, the NIHSS has limitations, including insensitivity to posterior circulation infarcts and exclusion of cognitive function and gait assessments. The reliability of the NIHSS, as measured by Cronbach's alpha, is 0.6885 [22].

Fugl-Meyer Assessment (FMA) for Upper Limb: This scale assesses upper limb motor function, with a maximum score of 66. Higher scores indicate better functionality. The FMA demonstrates excellent internal consistency, with a test-retest reliability alpha >0.9 [23].

Activities of Daily Living (ADL): This scale evaluates patient independence across six tasks. Each task is scored as 1 point if performed independently and 0 point if assistance is needed, with a maximum score of 6. Higher scores reflect greater independence, and the ADL scale has a high reliability coefficient of 0.99 [24].

Statistical methods

Continuous data were presented as mean ± standard deviation or median with interquartile range, depending on distribution normality. Categorical data were summarized as frequencies and percentages. Unpaired t-tests were used to compare continuous variables between groups. Univariate and multivariate logistic regression analyses were performed to calculate odds ratios (OR) and 95% confidence intervals (CI) for continuous parameters. A p-value <0.05 was considered statistically significant. Statistical analyses were performed using SPSS version 19 (SPSS Inc., Chicago, IL, USA) and R software version 3.0.2 (Free Software Foundation, Inc., Boston, MA, USA).

Results

Comparison of general information by prognosis

Patients in the good prognosis group were significantly older than those in the poor prognosis group (P=0.047) (**Table 1**). No significant differences were observed in other variables, such as BMI, education level, gender, or the prevalence of medical conditions, including hypertension and diabetes (all P>0.05). However, the proportion of patients receiving combination therapy was notably higher in the good prognosis group compared to the poor prognosis group (57.38% vs. 40.96%, P=0.021).

Comparison of blood test indicators before treatment

No significant differences were found between the good and poor prognosis groups in any pretreatment blood test indicator (all P>0.05) (**Table 2**). Parameters such as ESR, red and white blood cell counts, neutrophil counts, lymphocyte counts, eosinophil counts, and basophil counts were comparable across groups (all P>0.05). Similarly, hemoglobin, platelet levels, IL-6, IL-8, TNF-α, PCT, CRP, NSE, S100B, and MBP levels did not significantly differ (all P> 0.05).

Table 1. Comparison of general information of subjects grouped by prognosis

	Good prognosis group (n=153)	Poor prognosis group (n=52)	T	P
Age (years)	47.51 ± 15.35	43.27 ± 14.27	1.995	0.047
BMI (kg/m^2)	25.08 ± 3.14	24.57 ± 3.14	1.145	0.254
Education Level (years)	13.36 ± 2.97	13.31 ± 3.64	0.096	0.923
Gender [n (%)]			2.432	0.119
Male	63 (51.64%)	52 (62.65%)		
Female	59 (48.36%)	31 (37.35%)		
Hypertension [n (%)]			0.369	0.543
Yes	67 (54.92%)	42 (50.6%)		
No	55 (45.08%)	41 (49.4%)		
Valvular Heart Disease [n (%)]			0.242	0.623
Yes	56 (45.9%)	41 (49.4%)		
No	66 (54.1%)	42 (50.6%)		
Diabetes Mellitus [n (%)]			0.036	0.849
Yes	28 (22.95%)	20 (24.1%)		
No	94 (77.05%)	63 (75.9%)		
Smoking history [n (%)]	39 (31.97%)	35 (42.17%)	2.229	0.135
Drinking history [n (%)]	73 (59.84%)	48 (57.83%)	0.082	0.774
6-minute walk distance (m)	43 (35.25%)	35 (42.17%)	1.004	0.316
Chronic kidney failure [n (%)]	66 (54.1%)	39 (46.99%)	1.000	0.317
Congestive heart failure [n (%)]	62 (50.82%)	37 (44.58%)	0.771	0.380
Dementia [n (%)]	73 (59.84%)	43 (51.81%)	1.296	0.255
Previous stroke [n (%)]	73 (59.84%)	48 (57.83%)	0.082	0.774
NIHSS Score	12.28 ± 3.95	12.88 ± 4.4	1.004	0.317
Combination therapy	70 (57.38%)	34 (40.96%)	5.324	0.021

BMI: Body Mass Index.

Comparison of pre-treatment sEMG measurements, active range of motion (AROM), FMA, and ADL

Analysis of pre-treatment measurements showed no significant differences in levels of SOD (P=0.541), NO (P=0.224), or NOS (P=0.945) between groups (**Table 3**). Similarly, RMS values for most muscles, including the left and right BB, left FPB, and left and right FDI, were comparable between groups, except for the right FPB, which was significantly higher in the poor prognosis group (P=0.021). Muscle MDF values, pre-treatment AROM, FMA scores, and ADL scores, showed no significant differences between groups (all P>0.05).

Logistic regression analysis of prognostic factors for poor outcome

Logistic regression analysis (**Table 4**) identified key factors influencing upper limb function prognosis in post-stroke patients undergoing motion feedback training with combination therapy. In the univariate analysis, age significantly affected prognosis (P=0.049), with increasing age associated with poorer outcome. Pre-treatment RMS values of the right FPB muscle also demonstrated a significant negative impact on prognosis (P=0.023), suggesting that higher pre-treatment muscle activation may be detrimental. Additionally, combination therapy was associated with a significant reduction in the risk of poor prognosis (P= 0.022).

Multivariate regression confirmed the significance of pre-treatment RMS of the right FPB and combination therapy (P=0.026) as prognostic factors. However, the effect of age was no longer statistically significant in the multivariate model (P=0.073), although a potential clinical relevance was suggested by the observed trend.

Table 2. Comparison of blood test indicators before treatment

	Good prognosis group (n=153)	Poor prognosis group (n=52)	T	P
ESR (mm/h)	35.71 ± 5.09	34.66 ± 5.3	1.432	0.154
Red blood cell (1×10^6/μL)	5.45 ± 1.62	5.27 ± 1.65	0.755	0.451
White blood cell (1×10^3/μL)	7.38 ± 1.51	7.23 ± 1.82	5316.500	0.544
Neutrophil (1×10^3/μL)	4.35 ± 1.08	4.35 ± 1.06	0.047	0.963
Lymphocyte (1×10^3/μL)	2.08 ± 0.71	2.03 ± 0.67	0.554	0.580
Eosinophil (1×10^2/μL)	0.28 ± 0.03	0.28 ± 0.04	1.129	0.261
Basophil (1×10/μL)	0.09 ± 0.03	0.09 ± 0.03	0.625	0.533
Hemoglobin (g/L)	150.92 ± 23.88	147.66 ± 26.58	0.917	0.360
Platelet (1×10^3/μL)	216.3 ± 69.57	214.83 ± 73.51	0.145	0.885
IL-6 (ng/L)	28.28 ± 1.18	28.24 ± 1.06	0.211	0.833
IL-8 (μg/L)	36.36 ± 1.84	36.74 ± 1.85	1.444	0.150
TNF-α (pg/ml)	18.35 ± 1.7	18.12 ± 2	0.897	0.371
PCT (μg/L)	2.34 ± 0.71	2.45 ± 0.73	1.022	0.308
CRP (mg/L)	15.99 ± 3.62	15.91 ± 3.26	0.158	0.875
NSE	14.92 ± 5.04	15.52 ± 5.15	0.828	0.409
S100B	0.93 ± 0.28	0.87 ± 0.27	1.497	0.136
MBP	7.49 ± 2.32	6.93 ± 2.27	1.700	0.091

ESR: Sedimentation Rate; IL-6: interleukin-6; IL-8: interleukin-8; TNF-α: tumor necrosis factor-alpha; PCT: procalcitonin; CRP: C-reactive protein; NSE: Neuron-specific enolase; MBP: Myelin Basic Protein.

Table 3. The root mean square (RMS) and mean frequency (MDF) values of the respective muscles during maximum isometric contraction of elbow, thumb, and index finger abduction before treatment, and pre-treatment measurements of active range of motion (AROM), Fugl-Meyer Assessment (FMA), and Activities of Daily Living (ADL) scale

	Good prognosis group (n=153)	Poor prognosis group (n=52)	T	P
pre-SOD (μmol/L)	97.04 ± 6.32	98.05 ± 6.43	4807.500	0.541
pre-NO (U/mL)	59.17 ± 13.77	56.72 ± 14.59	1.221	0.224
pre-NOS (U/mL)	27.26 ± 2.12	27.28 ± 2.1	0.068	0.946
pre-RMS-left.BB	16.87 ± 5.14	17.56 ± 5	0.957	0.340
pre-RMS-right.BB	16.55 ± 4.63	16.54 ± 5.27	0.021	0.983
pre-RMS-left.FPB	14.57 ± 5.09	14.02 ± 4.32	0.806	0.421
pre-RMS-right.FPB	12.95 ± 4.48	14.4 ± 4.19	2.331	0.021
pre-RMS-left.FDI	18.16 ± 4.84	18.25 ± 3.9	0.148	0.883
pre-RMS-right.FDI	19.76 ± 3.7	20.08 ± 3.19	0.652	0.515
pre-MDF-left.BB	84.33 ± 14.49	82.64 ± 15.24	0.801	0.424
pre-MDF-right.BB	86.17 ± 13.76	84.56 ± 13.97	0.819	0.414
pre-MDF-left.FPB	100.54 ± 13.65	100.03 ± 11.65	0.282	0.778
pre-MDF-right.FPB	101.52 ± 11.81	100.02 ± 10.49	0.936	0.350
pre-MDF-left.FDI	106.06 ± 22.49	105.29 ± 20.98	0.245	0.807
pre-MDF-right.FDI	113.42 ± 22.73	107.76 ± 22.86	1.747	0.082
pre-AROM (°)	42.54 ± 7.54	43.09 ± 6.91	0.529	0.597
pre-FMA	28.77 ± 6.16	28.77 ± 5.96	0.004	0.997
pre-ADL	3.95 ± 1.12	3.81 ± 1.25	0.836	0.404

SOD: superoxide dismutase; NO: nitric oxide; NOS: nitric oxide synthase; RMS: root mean square; FDI: first dorsal interosseous; MDF: median frequency; BB: Biceps brachii; FPB: flexor pollicis brevis; AROM: active range of motion; FMA: Fugl-Meyer Assessment; ADL: Activities of Daily Living.

Table 4. Logistic regression analysis of influence factors and poor prognosis

	Coefficient	Std Error	Wald	*P* Value	OR	CI Lower	CI Upper
Univariate regression							
Age	-0.019	0.010	1.966	0.049	0.981	0.962	1.000
pre-RMS-right.FPB	0.077	0.034	2.281	0.023	1.080	1.012	1.155
Combination therapy	-0.663	0.289	2.296	0.022	0.515	0.291	0.904
Multivariate regression							
Age	-0.018	0.010	-1.795	0.073	0.982	0.963	1.002
pre-RMS-right.FPB	0.071	0.035	2.068	0.039	1.074	1.004	1.149
Combination therapy	-0.658	0.295	-2.232	0.026	0.518	0.291	0.923

RMS: root mean square; FPB: flexor pollicis brevis.

Table 5. General information of subjects grouped by treatment method

	Conventional treatment group (n=101)	Combination therapy group (n=104)	T	P
Age (years)	45.62 ± 15.12	45.96 ± 15.02	0.162	0.871
BMI (kg/m^2)	24.73 ± 3.30	25.02 ± 3.00	0.676	0.500
Education Level (years)	13.36 ± 3.62	13.32 ± 2.85	0.079	0.937
Gender [n (%)]			0.002	0.964
Male	56 (55.45%)	59 (56.73%)		
Female	45 (44.55%)	45 (43.27%)		
Hypertension [n (%)]			0.003	0.955
Yes	53 (52.48%)	56 (53.85%)		
No	48 (47.52%)	49 (46.15%)		
Valvular Heart Disease [n (%)]			0.007	0.935
Yes	47 (46.53%)	50 (48.08%)		
No	54 (53.47%)	54 (51.92%)		
Diabetes Mellitus [n (%)]			0.002	0.961
Yes	23 (22.77%)	25 (24.04%)		
No	78 (77.23%)	79 (75.96%)		
Smoking history [n (%)]	35 (34.65%)	38 (36.54%)	0.000	1.000
Drinking history [n (%)]	59 (58.16%)	62 (59.62%)	0.001	0.974
6-minute walk distance (m)	424.36 ± 30.74	423.68 ± 30.76	0.158	0.874
Chronic kidney failure [n (%)]	38 (37.62%)	40 (38.46%)	0.000	1.000
Congestive heart failure [n (%)]	51 (50.50%)	54 (51.92%)	0.004	0.948
Dementia [n (%)]	48 (47.52%)	51 (49.04%)	0.006	0.939
Previous stroke [n (%)]	56 (55.45%)	60 (57.69%)	0.034	0.854
NIHSS Score	12.36 ± 4.12	12.68 ± 4.16	0.544	0.587
Prognosis (Poor)	33	19	5.615	0.018

BMI: body mass index; NIHSS: National Institutes of Health Stroke Scale.

General information of subjects grouped by treatment method

A comparison of patients receiving conventional treatment (n=101) versus combination therapy (n=104) revealed no significant differences in baseline characteristics such as age, BMI, education level, gender, or prevalence of hypertension, heart disease, diabetes, smoking, or alcohol consumption (all P>0.05) (**Table 5**). Other clinical factors, including 6-minute walk distance, chronic kidney failure, heart failure, dementia, previous stroke, and NIHSS scores, were also similar. Notably, the combination therapy group had a significantly lower incidence of poor prognosis (P=0.018).

Table 6. Comparison of blood test indicators before treatment

	Conventional treatment group (n=101)	Combination therapy group (n=104)	T	P
ESR (mm/h)	35.83 ± 5.36	34.76 ± 4.98	1.474	0.142
Red blood cell (1×10^6/μL)	5.44 ± 1.59	5.32 ± 1.67	0.536	0.593
White blood cell (1×10^3/μL)	7.38 ± 1.62	7.26 ± 1.67	0.534	0.594
Neutrophil (1×10^3/μL)	4.32 ± 1.06	4.37 ± 1.08	0.351	0.726
Lymphocyte (1×10^3/μL)	2.03 ± 0.68	2.09 ± 0.71	0.617	0.538
Eosinophil (1×10^2/μL)	0.28 ± 0.03	0.28 ± 0.03	0.745	0.457
Basophil (1×10/μL)	0.09 ± 0.03	0.09 ± 0.03	0.226	0.821
Hemoglobin (g/L)	149.4 ± 24.8	149.8 ± 25.3	0.116	0.908
Platelet (1×10^3/μL)	215.8 ± 71.8	215.6 ± 70.6	0.020	0.984
IL-6 (ng/L)	28.28 ± 1.15	28.25 ± 1.12	0.186	0.853
IL-8 (μg/L)	36.51 ± 1.81	36.52 ± 1.89	0.039	0.969
TNF-α (pg/ml)	18.26 ± 1.88	18.25 ± 1.79	0.058	0.954
PCT (μg/L)	2.42 ± 0.73	2.35 ± 0.71	0.702	0.484
CRP (mg/L)	16.18 ± 3.14	15.74 ± 3.77	0.905	0.367
SE	15.36 ± 5.12	14.97 ± 5.06	0.549	0.584
S100B	0.87 ± 0.29	0.94 ± 0.27	1.853	0.065
MBP	7.35 ± 2.38	7.17 ± 2.26	0.561	0.575

ESR: Sedimentation Rate; IL-6: interleukin-6; IL-8: interleukin-8; TNF-α: tumor necrosis factor-alpha; PCT: procalcitonin; CRP: C-reactive protein; SE: specific enolase; MBP: Myelin Basic Protein.

Comparison of blood test indicators before treatment

Pre-treatment blood test indicators were compared between patients undergoing conventional treatment and those receiving combination therapy (**Table 6**). No significant differences were observed in ESR, red and white blood cell counts, neutrophil counts, lymphocytes, eosinophils, basophils, hemoglobin, platelets, IL-6, IL-8, TNF-α, PCT, or CRP levels (all P>0.05). Markers such as S100B and MBP were also comparable, although S100B was marginally higher in the combination therapy group (P= 0.065). Overall, pre-treatment blood test indicators were similar between the two groups.

Comparison of biochemical indicators before and after 30 days of treatment

Biochemical indicators were evaluated before and after 30 days of treatment in the conventional and combination therapy groups (**Figure 1**). At baseline, levels of SOD (P=0.878), NO (P=0.774), and NOS (P=0.838) were comparable between groups. After 30 days, the combination therapy group showed significant improvements, with higher post-treatment SOD (104.05 ± 6.72 μmol/L vs. 101.13 ± 6.18 μmol/L; P=0.001) and NOS levels (28.91 ± 1.53 U/mL vs. 28.32 ± 1.35 U/mL; P=0.004). Although post-treatment NO levels were higher in the combination therapy group (73.25 ± 15.42 U/mL vs. 69.36 ± 16.21 U/mL), the difference was not statistically significant (P= 0.08).

Comparison of pre- and post-treatment upper limb muscle RMS values

This study analyzed the RMS values of upper limb muscles in ischemic stroke patients before and after 30 days of treatment, comparing conventional and combination therapies (**Table 7**). At baseline, there were no significant differences in RMS values between the two groups for any muscle. After 30 days, the combination therapy group showed significant improvements in post-treatment RMS values for all muscles assessed: left BB (P=0.008), right BB (P=0.003), left FPB (P=0.008), right FPB (P=0.010), left FDI (P=0.008), and right FDI (P=0.001).

Comparison of pre- and post-treatment upper limb muscle median frequency (MDF) values

MDF values of upper limb muscles were evaluated in ischemic stroke patients over 30 days, comparing conventional and combination ther-

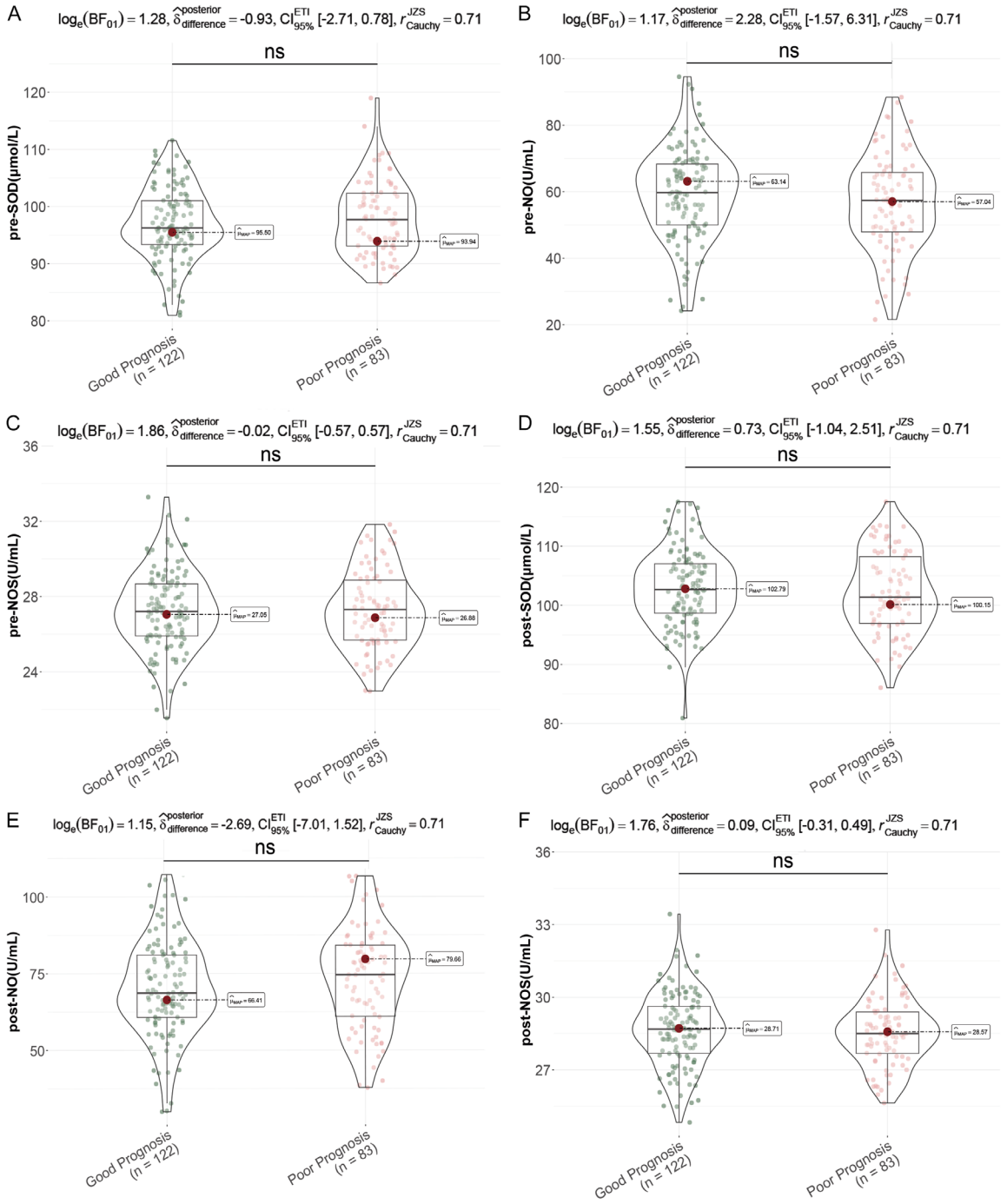

Figure 1. Comparison of biochemical indicators before and after 30 days of treatment. A. pre-SOD; B. pre-NO; C. pre-NOS; D. post-SOD; E. post-NO; F. post-NOS. SOD: superoxide dismutase; NO: nitric oxide; NOS: nitric oxide synthase. ns: no statistically significant difference.

apies (**Table 8**). At baseline, MDF values were similar between groups for all muscles. After 30 days, the combination therapy group exhibited significant improvement, with higher post-treatment MDF values for all muscles assessed: left biceps brachii (BB) (P=0.002), right BB (P=0.026), left flexor pollicis brevis (FPB) (P=0.027), right FPB (P=0.023), left first dorsal interosseous (FDI) (P=0.047), and right FDI (P=0.045).

Table 7. Comparison of first upper limb muscle RMS test results between the two groups of patients before and 30 days after treatment

	Conventional treatment group (n=101)	Combination therapy group (n=104)	T	P
pre-RMS-left.BB	17.52 ± 5.24	16.79 ± 4.92	1.026	0.306
pre-RMS-right.BB	16.68 ± 4.67	16.42 ± 5.11	0.381	0.704
pre-RMS-left.FPB	14.46 ± 4.88	14.23 ± 4.72	0.347	0.729
pre-RMS-right.FPB	13.74 ± 4.38	13.35 ± 4.45	0.635	0.526
pre-RMS-left.FDI	18.03 ± 4.32	18.36 ± 4.63	0.522	0.602
pre-RMS-right.FDI	19.92 ± 3.43	19.86 ± 3.57	0.119	0.906
post-RMS-left.BB	24.92 ± 4.91	26.67 ± 4.51	2.664	0.008
post-RMS-right.BB	24.38 ± 4.63	26.42 ± 5.06	3.013	0.003
post-RMS-left.FPB	25.46 ± 4.85	27.23 ± 4.58	2.689	0.008
post-RMS-right.FPB	26.74 ± 4.37	28.35 ± 4.49	2.603	0.010
post-RMS-left.FDI	26.03 ± 4.28	27.68.26 ± 4.61	2.668	0.008
post-RMS-right.FDI	27.92 ± 3.56	29.56 ± 3.57	3.297	0.001

MDF: median frequency; FPB: flexor pollicis brevis; RMS: root mean square; FDI: First dorsal interosseous.

Table 8. Comparison of first upper limb muscle MDF test results (Hz, $\bar{x} \pm s$) before and 30 days after treatment

	Conventional treatment group (n=101)	Combination therapy group (n=104)	T	P
pre-MDF-left.BB	83.70 ± 14.88	83.59 ± 14.76	0.053	0.957
pre-MDF-right.BB	85.63 ± 13.95	85.41 ± 13.78	0.112	0.911
pre-MDF-left.FPB	100.56 ± 12.89	100.12 ± 12.87	0.242	0.809
pre-MDF-right.FPB	101.10 ± 11.38	100.73 ± 11.26	0.232	0.817
pre-MDF-left.FDI	105.98 ± 21.94	105.53 ± 21.85	0.147	0.883
pre-MDF-right.FDI	111.30 ± 23.03	110.96 ± 22.87	0.108	0.914
post-MDF-left.BB	91.12 ± 9.78	95.42 ± 9.73	3.152	0.002
post-MDF-right.BB	90.23 ± 9.66	93.25 ± 9.58	2.243	0.026
post-MDF-left.FPB	120.43 ± 31.36	130.45 ± 33.12	2.224	0.027
post-MDF-right.FPB	119.96 ± 30.69	130.03 ± 32.15	2.294	0.023
post-MDF-left.FDI	145.98 ± 40.23	157.47 ± 41.90	2.002	0.047
post-MDF-right.FDI	145.13 ± 41.96	156.86 ± 41.42	2.013	0.045

MDF: median frequency; FPB: flexor pollicis brevis; FDI: First dorsal interosseous.

Comparison of AROM, FMA, and ADL scores

Upper limb function and daily living activities were assessed by comparing AROM, FMA scores, and ADL scores between the two groups over 30 days (**Figure 2**). At baseline, there were no significant differences in AROM, FMA, or ADL scores between groups (P>0.05). After 30 days, the combination therapy group demonstrated significantly greater improvement: AROM increased to 69.78° compared to 58.91° in the conventional group (P<0.001). FMA scores rose to 45.70 versus 35.47 (P<0.001); and ADL scores improved to 5.47 compared to 5.01 (P=0.010).

Discussion

The results of this study demonstrate that combination therapy significantly enhances muscle activation and functional recovery in post-stroke patients compared to conventional treatment alone. These findings align with those of Hyun et al. [25], who reported that integrating motion feedback therapy with standard rehabilitation improved upper limb motor function in stroke patients. The current study expands on this work by including a larger cohort and utilizing sEMG for objective assessment of muscle activation patterns.

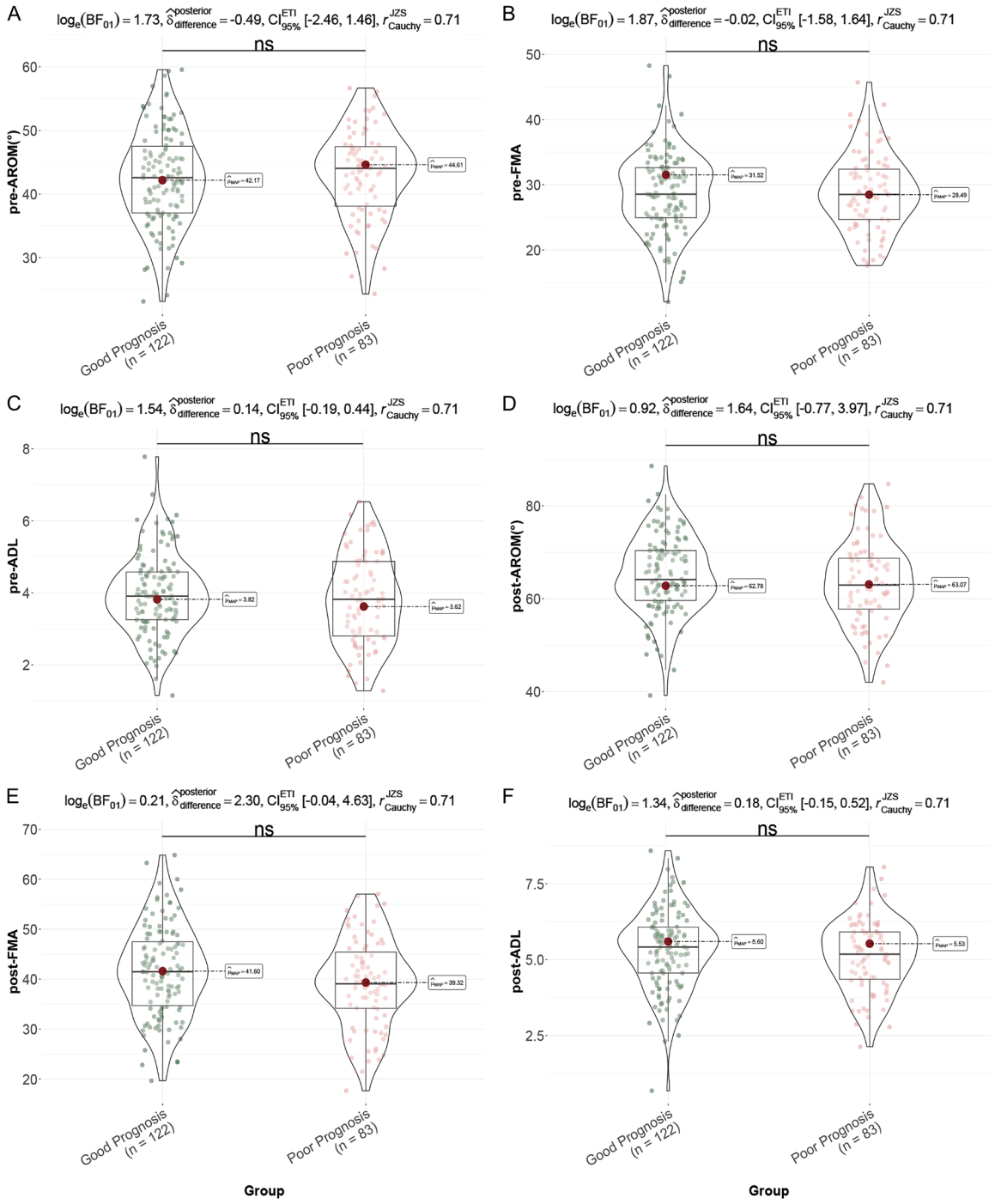

Figure 2. Comparison of AROM, FMA scores, and ADL scores before and after 30 days of treatment. A. pre-AROM; B. pre-FMA; C. pre-ADL; D. post-AROM; E. post-FMA; F. post-ADL. AROM: active range of motion; FMA: Fugl-Meyer Assessment; ADL: Activities of Daily Living. ns: no statistically significant difference.

A particularly notable finding was the predictive value of pre-treatment root mean square (RMS) values of the right FPB for poorer prognosis. This is consistent with the findings of Junata et al. [26], who associated high baseline muscle tone with reduced rehabilitation efficacy in stroke patients, suggesting that initial muscle activation patterns may reflect underlying neural dysfunction that hinders recovery. This observation highlights the importance of early detection and individualized interventions to address abnormal muscle activity. Identifying

patients with elevated pre-treatment RMS values can enable clinicians to implement targeted and personalized treatment strategies, improving rehabilitation outcome.

Motion feedback training likely contributes significantly to neuroplasticity and motor relearning. Neural plasticity, the brain's ability to reorganize synaptic connections in response to learning or injury, is a cornerstone of stroke recovery [27, 28]. By providing real-time feedback on movement accuracy and promoting repetitive, task-specific exercises, motion feedback training facilitates adaptive changes within the central nervous system [29]. This mechanism aligns with the principles of Hebbian plasticity [30], which asserts that "neurons that fire together, wire together". Moreover, studies [31-33] have shown that repetitive, precise movements enhanced by feedback training can aid in reorganizing the motor cortex. The deliberate practice of movements under feedback conditions strengthens synaptic connections essential for motor skill acquisition [34], possibly explaining the observed improvement in muscle activation patterns.

Comparison between the conventional treatment and combination therapy groups revealed that combination therapy was associated with significantly better prognostic outcome. Biochemical improvements, including elevated SOD levels and enhanced NO pathways, provide robust evidence that combination therapy not only improves muscle activation and functional recovery but also supports the molecular mechanisms underlying effective post-stroke rehabilitation.

Our study observed significant biochemical improvements post-therapy, notably enhanced antioxidant activity as indicated by increased SOD levels. These findings align with Perez-Marcos et al. [35], who emphasized the role of oxidative stress in functional recovery. The observed improvements in nitric oxide (NO) pathways further support the hypothesis that combination therapy ameliorates vascular function. This finding is consistent with Shin et al. [36], who highlighted NO's critical role in neural repair mechanisms.

SOD is a key antioxidant enzyme that mitigates the damage caused by reactive oxygen species [37]. Post-stroke, excessive ROS production exacerbates tissue damage and impairs recovery processes [38]. The increased SOD levels observed in our study suggest that combination therapy enhances the antioxidative defense system, protecting neurons from oxidative damage and facilitating recovery. Similarly, NO and NOS are vital for vascular regulation and neural communication [39]. NO acts as a signaling molecule to regulate blood flow, essential for delivering oxygen and nutrients to recovering neural tissues [40]. Enhanced NOS activity, leading to increased NO production, likely improves cerebral blood flow, supporting the metabolic demands of neuroplasticity and recovery.

The comparison between the conventional treatment group and the combination therapy group revealed significantly better prognostic outcomes in the latter. These biochemical improvements, including elevated SOD levels and improved NO pathways, strongly suggest that combination therapy not only enhances muscle activation and functional recovery but also underpins the molecular mechanisms essential for effective post-stroke rehabilitation.

To assess the effectiveness of combination therapy in improving upper limb function in post-stroke patients, we used functional measures such as AROM, FMA scores, and ADL scores. These assessments provided comprehensive evidence supporting the superiority of combination therapy over conventional treatment. The combination therapy group demonstrated significant improvements in all three measures.

The AROM improvements can be attributed to enhanced muscle activation patterns facilitated by motion feedback training [35]. By engaging patients in systematic, targeted upper limb movements, combination therapy promotes muscle strength and flexibility, leading to better joint mobility and overall function. The FMA, a widely validated motor function assessment for post-stroke patients [41], showed greater improvements in the combination therapy group, indicating enhanced muscle activation and more precise, coordinated movements. Furthermore, ADL scores, which reflect the practical impacts of therapy on daily living [42], underscored the real-world benefits of combination therapy. Patients in the combination therapy

group experienced greater independence and improved quality of life, highlighting the clinical significance of this approach.

The use of sEMG provided valuable insight into muscle activation patterns and their relationship with rehabilitation outcomes. sEMG is a crucial tool for objectively quantifying muscle activity, enabling targeted interventions tailored to individual muscle performance [43]. The finding that pre-treatment RMS values were indicative of prognosis highlights the importance of assessing and monitoring muscle activity throughout the rehabilitation process. This approach facilitates the development of personalized treatment plans to address specific dysfunctions, thereby optimizing recovery [44, 45].

While the results of this study are promising, several limitations must be acknowledged. First, as a retrospective study, it is inherently subject to selection bias and potential confounding variables that may not have been fully controlled. Second, the relatively small sample size, drawn from a single medical center, may limit the generalizability of the findings to broader populations. Third, the absence of long-term follow-up data restricts conclusions about the enduring efficacy of combination therapy. Future research should focus on evaluating long-term outcomes and exploring the potential of combination therapy to sustain functional improvements. Additionally, further investigation into the underlying molecular mechanisms, particularly oxidative stress and neuroplasticity, could enhance our understanding of and approaches to treating post-stroke dysfunctions.

In conclusion, this study identifies key factors influencing the prognosis of upper limb dysfunction in ischemic stroke patients and demonstrates the significant benefit of integrating motion feedback training with conventional treatment regimens. These findings advocate for a more holistic, personalized approach to rehabilitation, leveraging advanced methodologies such as sEMG to optimize treatment efficacy and improve patient outcome.

Disclosure of conflict of interest

None.

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